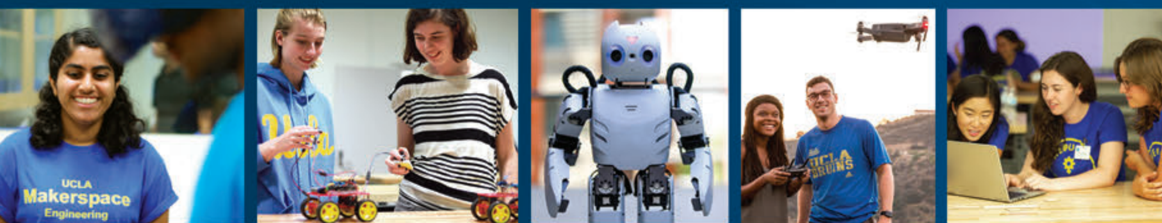
UCLA Samueli School of Engineering

UCLA 100 YEARS




2019 - 2020

# ANNOUNCEMENT

## UNIVERSITY OF CALIFORNIA, LOS ANGELES

October 1, 2019

Bioengineering

Chemical & Biomolecular

Civil & Environmental

Computer Science

Electrical & Computer

Materials Science

Mechanical & Aerospace

Master of Science in Enginering Online

# ANNOUNCEMENT 2019-20

## HENRY SAMUELI SCHOOL OF ENGINEERING AND APPLIED SCIENCE

UNIVERSITY OF CALIFORNIA, LOS ANGELES
OCTOBER 1, 2019

# Contents



## DISCLOSURE OF STUDENT RECORDS

**To all students:** Pursuant to the federal Family Educational Rights and Privacy Act (FERPA), the California Information Practices Act, and the *University of California Policies Applying to the Disclosure of Information from Student Records,* students at UCLA have the right to (1) inspect and review records pertaining to themselves in their capacity as students, except as the right may be waived or qualified under federal and state laws and University policies, (2) have withheld from disclosure, absent their prior written consent for release, personally identifiable information from their student records, except as provided by federal and state laws and University policies, (3) inspect records maintained by UCLA of disclosures of personally identifiable information from their student records, (4) seek correction of their student records through a request to amend the records or, if such request is denied, through a hearing, and (5) file complaints with the U.S. Department of Education regarding alleged violations of the rights accorded them by FERPA.

UCLA, in accordance with federal and state laws and University policies, has designated the following categories of personally identifiable information as public information that UCLA may release and publish without the student's prior consent: name, e-mail address, telephone numbers, major field of study, dates of attendance, number of course units in which enrolled, degrees and honors received, the most recent previous educational institution attended, participation in officially recognized activities (including intercollegiate athletics); and the name, weight, and height of participants on intercollegiate athletic teams.

As a matter of practice, UCLA does not publish student telephone numbers in the campus electronic directory unless released by the student. The term public information in this policy is synonymous with the term directory information in FERPA.

Students who do not wish certain items (i.e., name, e-mail address, telephone numbers, major field of study, dates of attendance, number of course units in which enrolled, and degrees and honors received) of this public information released and published may so indicate through MyUCLA at http://my.ucla.edu. To restrict the release and publication of the additional items in the category of public information, complete the UCLA FERPA Restriction Request form available from the Registrar's Office, 1113 Murphy Hall.

Student records that are the subject of federal and state laws and University policies may be maintained in a variety of UCLA offices, including the Registrar's Office, Office of Student Conduct, Career Center, Graduate Division, External Affairs Department, and the offices of a student's College or school and major department. Students are referred to the *UCLA Campus Directory* at http://directory.ucla.edu, which lists all the offices that may maintain student records, together with their campus address and telephone number. Students have the right to inspect their student records in any such office subject to the terms of federal and state laws and University policies. Inspection of student records maintained by the Registrar's Office is by appointment only and must be arranged three working days in advance. Call 310-825-1091, option 6; or inquire at the Registrar's Office, 1113 Murphy Hall.

A copy of the federal and state laws, University policies, and the print *UCLA Telephone Directory* may be inspected in the office of the Information Practices Coordinator, 500 UCLA Wilshire Center. Information concerning students' hearing rights may be obtained from that office and from the Office of Student Conduct, 1104 Murphy Hall.


Published by UCLA Academic Publications, Box 951429, Los Angeles, CA 90095-1429




**All announcements herein are subject to revision.** Every effort has been made to ensure the accuracy of the information presented in the *Announcement of the UCLA Henry Samueli School of Engineering and Applied Science*. However, all courses, course descriptions, instructor designations, curricular degree requirements, and fees described herein are subject to change or deletion without notice. Further details on graduate programs are available in various Graduate Division publications online at http://grad.ucla.edu.

**Cover:** Students create, build, discover, fly, connect, and develop inventions of all kinds in seven engineering departments and an online Master's degree program. They epitomize the growth and contributions of UCLA as it celebrates its centennial anniversary in 2019-20.

# A Message from the Dean

The UCLA Henry Samueli School of Engineering has a long legacy of excellence in education and research.

In the twenty-first century this includes designing sustainable and resilient communities, developing personalized medicine, advancing artificial intelligence, and unearthing insights from an unprecedented volume of data. We welcome a new generation of engineers to join us as we tackle these and many more compelling issues.

Our classes are taught by faculty members who are among the best in the world in their respective fields, and we are proud to instruct students of all backgrounds who are creative, motivated, and bring an exemplary work ethic to their studies.

The school offers a rigorous curriculum that pairs strong fundamentals with practical, hands-on experience. For our prospective students, let me offer three points beyond the curriculum that this dynamic school offers.

First, UCLA Samueli isn't just a great school standing in isolation. It is an integral part of one of the world's most innovative cities, and offers unparalleled access to sought-after internships and careers. Leading firms in aerospace, semiconductors, biotechnology, and other impactful areas are headquartered in Southern California. The region is also home to a major startup scene in which our engineers are involved; many founded their first startup while at UCLA.

Second, in addition to paving the way into industry, we offer unique research opportunities for our undergraduate students. Our faculty members are distinguished leaders in their fields and students have an active role in their research labs, with some research even earning course credit. Our students also often collaborate with the UCLA medical school, and other disciplines, as they pursue new approaches and breakthroughs.

Third, you will meet some extraordinary people in your fellow students. The talent, smarts, outside-the-box thinking, and collaborative can-do energy at UCLA are unparalleled. If you are interested in exploring fields outside your major, we have more than 44 engineering clubs focused on a wide range of activities. We also recently opened a 9,000-square-foot makerspace where you can work on personal projects, and hold group activities such as hack-a-thons.

UCLA Samueli is entering an extraordinary period of growth, with significant expansion in the number of research labs, faculty, and students. The school already is world-renowned, but we are reaching for new heights. This growth will offer extraordinary new opportunities for you to make a significant impact on our society and the world, and I invite you to be part of it.

**Jayathi Y. Murthy**
*Ronald and Valerie Sugar Dean of UCLA Engineering*

# Henry Samueli School of Engineering and Applied Science

## Officers of Administration

**Jayathi Y. Murthy**, Ph.D., Professor and Dean, Henry Samueli School of Engineering and Applied Science

**Scott J. Brandenberg**, Ph.D., Professor and Associate Dean, Diversity and Inclusion

**Jia-Ming Liu**, Ph.D., Professor and Associate Dean, Academic Personnel

**Harold G. Monbouquette**, Ph.D., Professor and Associate Dean, Research and Physical Resources

**Richard D. Wesel**, Ph.D., Professor and Associate Dean, Academic and Student Affairs

**Jenn-Ming Yang**, Ph.D., Professor and Associate Dean, International Initiatives and Online Education

**Panagiotis D. Christofides**, Ph.D., Professor and Chair, Chemical and Biomolecular Engineering Department

**Bruce S. Dunn**, Ph.D., Professor and Chair, Materials Science and Engineering Department

**Timothy S. Fisher**, Ph.D., Professor and Chair, Mechanical and Aerospace Engineering Department

**Richard E. Korf**, Ph.D., Professor and Interim Chair, Computer Science Department

**Song Li**, Ph.D., Professor and Chair, Bioengineering Department

**Gregory J. Pottie**, Ph.D., Professor and Chair, Electrical and Computer Engineering Department

**Ertugrul Taciroglu**, Ph.D., Professor and Chair, Civil and Environmental Engineering Department

## The Campus

UCLA is a large urban university situated between the city and the sea at the foot of the Santa Monica Mountains. Less than six miles from the Pacific Ocean, it is bordered by Sunset and Wilshire Boulevards. As the city has grown physically and culturally, so has the campus, whose students and faculty members mirror the cultural and racial diversity of today's Los Angeles. UCLA is one of the most widely respected and recognized universities in the world, and its impact on society can be felt into the far reaches of the globe. Students come from around the world to receive a UCLA education, and our alumni go on to become leaders in their fields, from visionary startup founders to heads of international corporations.

UCLA is recognized as the West's leading center for the arts, culture, and medical research. Each year, more than half a million people attend visual and performing arts programs on campus, while more than 300,000 patients from around the world come to the Ronald Reagan UCLA Medical Center for treatment. The University's 419-acre campus houses the College of Letters and Science and 12 professional schools. There are more than 46,000 students enrolled in 138 undergraduate programs, and more than 250 graduate degree programs.

UCLA is rated one of the best public research universities in the U.S. and among a handful of top U.S. research universities, public and private. The chief executive of UCLA is Chancellor Gene D. Block. He oversees all aspects of the UCLA three-part mission of education, research, and service.

Southern California has grown to become one of the nation's dominant industrial centers, and the UCLA Henry Samueli School of Engineering and Applied Science is uniquely situated as a hub of engineering research and professional training for this region.

## The School

The UCLA College of Engineering (as it was known then) was established in 1943 when California Governor Earl Warren signed a bill to provide instruction in engineering at the UCLA campus. It welcomed its first students in 1945 and was officially dedicated as the Henry Samueli School of Engineering and Applied Science in 2000.

Counted among the faculty are scores of National Academy of Engineering members, three Turing award winners, one National Medal of Science recipient, and one Nobel laureate. While no ranking can fully capture the mission as a leading public research university, the school is consistently ranked in the top 10 among U.S. public engineering schools, and the online master's program has consistently been ranked first or second nationally.

The goal of UCLA Samueli is to enable as much positive change as possible through the impact that engineers can have on society. As part of its academic spirit, the school focuses on research that targets today's greatest societal challenges, education that empowers students to become future change agents, access for the many to succeed in engineering careers, and innovation that helps bring great ideas to the market.

The school has identified six critical areas of research where it can have the greatest positive impact in the years and decades to come. These include robotics and cyber-physical systems; sustainable and resilient urban systems; engineering in medicine; big data, artificial intelligence, and machine learning; cybersecurity and future Internet; and advanced materials and manufacturing.

UCLA Samueli is well known for the research advances its laboratories and alumni have brought to the world. By defining these critical areas of research for the 21st century, the school is able to focus its resources and create a relevant educational structure for its students to galvanize the next generation of global leaders.

The school offers 40 academic and professional degree programs. The Bachelor of Science degree is offered in Aerospace Engineering, Bioengineering, Chemical Engineering, Civil Engineering, Computer Engineering, Computer Science, Computer Science and Engineering, Electrical Engineering, Materials Engineering, and Mechanical Engineering. The undergraduate curricula leading to these degrees offer students with a solid foundation in engineering and applied science and prepare graduates for immediate practice of the profession as well as advanced studies. In addition to engineering courses, students complete about one year of study in the humanities, social sciences, and/or fine arts.

Master of Science and Doctor of Philosophy degrees are offered in Aerospace Engineering, Bioengineering, Chemical Engineering, Civil Engineering, Computer Science, Electrical Engineering, Manufacturing Engineering (M.S. only), Materials Science and Engineering, and Mechanical Engineering. The schoolwide online Master of Science in Engineering degree program includes 11 individual degrees. The Engineer degree is more advanced than the master's, but does not require the research effort and orientation involved in a doctoral dissertation. For information on the Engineer degree, see Graduate Programs on page 26. A one-year program leading to a Certificate of Specialization is offered in various fields of engineering and applied science.

## Endowed Chairs

Endowed professorships or chairs, funded by gifts from individuals or corporations, support the research and educational activities of distinguished members of the faculty. The following endowed chairs have been established in the Henry Samueli School of Engineering and Applied Science.

L.M.K. Boelter Chair in Engineering

Vijay K. Dhir Chair in Engineering

Englekirk Presidential Endowed Chair in Structural Engineering

Traugott and Dorothea Frederking Endowed Chair in Cryogenics

Norman E. Friedmann Chair in Knowledge Sciences

Armond and Elena Hairapetian Chair in Engineering and Medicine

Leonard Kleinrock Chair in Computer Science

Evalyn Knight Chair in Engineering

Levi James Knight, Jr., Chair in Engineering

Richard G. Newman AECOM Endowed Chair in Civil Engineering

Nippon Sheet Glass Company Chair in Materials Science

Northrop Grumman Chair in Electrical Engineering

Northrop Grumman Chair in Electrical Engineering/Electromagnetics

Northrop Grumman Opto-Electronic Chair in Electrical Engineering

Ralph M. Parsons Foundation Chair in Chemical Engineering

Jonathan B. Postel Chair in Computer Systems

Jonathan B. Postel Chair in Networking

Raytheon Company Chair in Electrical Engineering

Raytheon Company Chair in Mechanical Engineering

Charles P. Reames Endowed Chair in Electrical Engineering

Ben Rich Lockheed Martin Chair in Aeronautics

Rockwell Collins Chair in Engineering

John P. and Claudia H. Schauerman Endowed Chair in Engineering

William Frederick Seyer Chair in Materials Electrochemistry

Ronald and Valerie Sugar Dean

Ronald and Valerie Sugar Endowed Chair in Engineering

Symantec Term Chair in Computer Science

Carol and Lawrence E. Tannas, Jr. Endowed Chair in Engineering

Carol and Lawrence E. Tannas, Jr. Endowed Term Chair in Engineering

William D. Van Vorst Chair in Chemical Engineering Education

Volgenau Chair for Engineering Excellence

Volgenau Chair for Engineering Innovation

Volgenau Endowed Chair in Engineering

Wintek Endowed Chair in Electrical Engineering

Neria and Manizheh Yomtoubian Endowed Chair in Cancer and Risk Sciences

# The Engineering Profession

The following describes the challenging types of work UCLA Samueli graduates might perform based on their program of study.

## Aerospace Engineering

Aerospace engineers conceive, design, develop, test, and supervise the construction of aerospace vehicle systems such as commercial and military aircraft, helicopters and other types of rotorcraft, and space vehicles and satellites, including launch systems. They are employed by aerospace companies, airframe and engine manufacturers, government agencies such as NASA and the military services, and research and development organizations.

Working in a high-technology industry, aerospace engineers are generally well versed in applied mathematics and the fundamental engineering sciences, particularly fluid mechanics and thermodynamics, dynamics and control, and structural and solid mechanics. Aerospace vehicles are complex systems. Proper design and construction involves the coordinated application of technical disciplines, including aerodynamics, structural analysis and design, stability and control, aeroelasticity, performance analysis, and propulsion systems technology.

Aerospace engineers use computer systems and programs extensively and should have at least an elementary understanding of modern electronics. They work in a challenging and highly technical atmosphere and are likely to operate at the forefront of scientific discoveries, often stimulating these discoveries and providing the inspiration for the creation of new scientific concepts.

The B.S. program in Aerospace Engineering emphasizes fundamental disciplines and therefore provides a solid base for professional career development in industry and graduate study in aerospace engineering. Graduate education prepares students for careers at the forefront of aerospace technology. The Ph.D. degree provides a strong background for employment by government laboratories, such as NASA, and industrial research laboratories supported by the major aerospace companies. It also provides the appropriate background for academic careers.

## Bioengineering

At the interface of engineering, medicine, and basic sciences, bioengineering has emerged and established itself internationally as an engineering discipline in its own right. Such an interdisciplinary education is necessary to develop a quantitative engineering approach to tackle complex medical and biological problems, as well as to invent and improve the ever-evolving experimental and computational tools that are required in this engineering approach. UCLA has a long history of fostering interdisciplinary training and is a superb environment for bioengineers. UCLA boasts the top hospital in the western U.S., nationally ranked medical and engineering schools, and numerous nationally recognized programs in the basic sciences. Rigorously trained bioengineers are in demand in research institutions, academia, and industry. Their careers may follow a bioengineering concentration, but the ability of bioengineers to cut across traditional boundaries will facilitate their innovation in new areas.

## Chemical and Biomolecular Engineering

Chemical and biomolecular engineers use their knowledge of mathematics, physics, chemistry, biology, and engineering to meet the needs of our technological society. They design, research, develop, operate, and manage within the biochemical and chemical industries and are leaders in the fields of energy and the environment, nanoengineering/nanotechnology, systems engineering, biotechnology and biomolecular engineering, and advanced materials processing. They are in charge of the chemical processes used by virtually all industries, including the pharmaceutical, biotechnology, biofuel, food, aerospace, automotive, water treatment, and semiconductor industries. Architectural, engineering, and construction firms employ chemical engineers for equipment and process design. It is also their mission to develop the clean and environmentally friendly technologies of the future.

Major areas of fundamental interest within chemical engineering are

1. *Applied chemical kinetics,* which involves the design of chemical and biochemical reactors and processes and the creation of catalysts that accelerate reaction kinetics and modeling,

2. *Transport phenomena,* which involves the exchange of momentum, heat, and mass in physical and biological systems and has applications to the separation of valuable materials from mixtures, or of pollutants from gas and liquid streams,
3. *Thermodynamics,* which is fundamental to physical, chemical, and biological processes, and
4. *Process design and synthesis,* which provide the overall framework and computing technology for integrating chemical engineering knowledge into industrial application and practice.

# Civil and Environmental Engineering

Civil engineers plan, design, construct, and manage a range of physical systems, such as buildings, bridges, dams and tunnels, transportation systems, water and wastewater treatment systems, coastal and ocean engineering facilities, and environmental engineering projects, related to public works and private enterprises. Thus, civil and environmental engineering embraces activities in traditional areas and in emerging problem areas associated with modern industrial and social development.

The civil engineering profession demands rigorous scientific training and a capacity for creativity and growth into developing fields. In Southern California, besides employment in civil engineering firms and governmental agencies for public works, civil engineering graduates often choose other industries for assignments based on their engineering background. Graduates are also qualified for positions outside engineering where their broad engineering education is a valuable asset.

The curriculum leading to a B.S. in Civil Engineering provides an excellent foundation for entry into professional practice, as well as for graduate study in civil engineering and other related fields.

# Computer Science and Engineering

Students specializing in the computer science and engineering undergraduate program are educated in a range of computer system concepts. As a result, students at the B.S. level are qualified for employment as applications programmers, systems programmers, digital system designers, digital system marketing engineers, and project engineers.

Undergraduate students can major in the computer science and engineering program, the computer science program, or the computer engineering program.

Graduate degree programs in computer science prepare students for leadership positions in the computer field. In addition, they prepare graduates to deal with the most difficult problems facing the computer science field. University or college teaching generally requires the graduate degree.

# Electrical and Computer Engineering

The electrical and computer engineering discipline is concerned with the useful applications of electromagnetic phenomena (light, magnetism, electricity). Courses and research at UCLA span the entire stack from basic physics, electronic and photonic devices, antennas, integrated circuits, signal processing and machine learning, control, communications systems, to vast networks such as the electrical grid and the Internet. These are the main automated tools used by our society to sense, make decisions, and take action in the world using the data collected according to the priorities established by people. The Electrical and Computer Engineering Department is a recognized leader in education and research related to these subjects.

# Manufacturing Engineering

Manufacturing engineering is an interdisciplinary field that integrates the basic knowledge of materials, design, processes, computers, and system analysis. The manufacturing engineering program is part of the Mechanical and Aerospace Engineering Department.

Specialized areas are generally classified as manufacturing processes, manufacturing planning and control, and computer-aided manufacturing.

Manufacturing engineering as an engineering specialty requires the education and experience necessary to understand, apply, and control engineering procedures in manufacturing processes and production methods of industrial commodities and products. It involves the generation of manufacturing systems, the development of novel and specialized equipment, research into the phenomena of fabricating technologies, and manufacturing feasibility of new products.

Coursework, independent studies, and research are offered in the manufacturing processes area, leading to an M.S. degree. This includes computer-aided design and computer-aided manufacturing, robotics, metal forming and metal cutting analysis, nondestructive evaluation, and design and optimization of manufacturing processes.

# Materials Engineering

Materials engineering is concerned with the structure and properties of materials used in modern technology. Advances in technology are often limited by available materials. Solutions to energy problems depend largely on new materials, such as solar cells or materials for batteries for electric cars.

Two programs within materials engineering are available at UCLA:

1. In the *materials engineering* program, students become acquainted with metals, ceramics, polymers, and composites. Such expertise is highly sought by the aerospace and manufacturing industries. Materials engineers are responsible for the selection and testing of materials for specific applications. Traditional fields of metallurgy and ceramics have been merged in industry, and this program reflects the change.
2. In the *electronic materials option* of the materials engineering program, students learn the basics of materials engineering with a concentration in electronic materials and processing. The optional program requires additional coursework which includes five to eight electrical and computer engineering courses.

In order to enter a career in research and development of new materials (such as new energy devices), an M.S. or Ph.D. degree is desirable.

# Mechanical Engineering

Mechanical engineering is a broad discipline finding application in virtually all industries and manufactured products. The mechanical engineer applies principles of mechanics, dynamics, and energy transfer to the design, analysis, testing, and manufacture of consumer and industrial products. A mechanical engineer usually has specialized knowledge in areas such as design, materials, fluid dynamics, solid mechanics, heat transfer, thermodynamics, dynamics, control systems, manufacturing methods, and human factors. Applications of mechanical engineering include design of machines used in the manufacturing and processing industries, mechanical components of electronic and data processing equipment, engines and power-generating equipment, components and vehicles for land, sea, air, and space, and artificial components for the human body. Mechanical engineers are employed throughout the engineering community as individual consultants in small firms providing specialized products or services, as designers and managers in large corporations, and as public officials in government agencies. Mechanical engineers apply their knowledge to a wealth of systems, products, and processes, including energy generation, utilization and conservation, power and propulsion systems (power plants, engines), and commercial products found in the automotive, aerospace, chemical, or electronics industries.

The B.S. program in Mechanical Engineering at UCLA provides excellent preparation for a career in mechanical engineering and a foundation for advanced graduate studies. Graduate studies in one of the specialized fields of mechanical engineering prepare students for a career at the forefront of technology. The Ph.D. degree provides a strong background for employment by government laboratories, industrial research laboratories, and academia.

# Correspondence Directory

## Henry Samueli School of Engineering and Applied Science

**https://samueli.ucla.edu**

**Office of Academic and Student Affairs**
6426 Boelter Hall
https://www.seasoasa.ucla.edu

**Bioengineering Department**
5121 Engineering V
https://www.bioeng.ucla.edu

**Chemical and Biomolecular Engineering Department**
5531 Boelter Hall
https://www.chemeng.ucla.edu

**Civil and Environmental Engineering Department**
5731 Boelter Hall
https://www.cee.ucla.edu

**Computer Science Department**
277 Engineering VI
https://www.cs.ucla.edu

**Electrical and Computer Engineering Department**
58-121 Engineering IV
https://www.ee.ucla.edu

**Materials Science and Engineering Department**
3111 Engineering V
https://www.mse.ucla.edu

**Mechanical and Aerospace Engineering Department**
48-121 Engineering IV
https://www.mae.ucla.edu

**Continuing Education in Engineering**
UCLA Extension
10960 Wilshire Boulevard, Suite 1600
https://www.uclaextension.edu/engineering

**Engineering and Science Career Services**
UCLA Career Center
501 Westwood Plaza, Strathmore Building
https://career.ucla.edu

**Master of Science in Engineering Online Program**
4732 Boelter Hall
https://www.msol.ucla.edu

## Academic Counselors

**Aerospace Engineering**
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**Bioengineering**
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**Chemical and Biomolecular Engineering**
Erkki Corpuz, 310-825-9442, erkki@seas.ucla.edu; Julietta Torres, 310-206-6397, juliet@seas.ucla.edu

**Civil Engineering**
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**Computer Science**
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## University of California, Los Angeles

Los Angeles, California 90095
**http://www.ucla.edu**

**Undergraduate Admission**
1147 Murphy Hall
http://www.admission.ucla.edu

**Graduate Diversity, Inclusion, and Admissions**
1248 Murphy Hall
https://grad.ucla.edu/gasaa/admissions/

**Financial Aid and Scholarships**
A129J Murphy Hall
https://www.financialaid.ucla.edu

**Registrar's Office**
1105 Murphy Hall
https://www.registrar.ucla.edu

**Dashew Center for International Students and Scholars**
106 Bradley Hall
https://www.internationalcenter.ucla.edu

**Summer Sessions**
1332 Murphy Hall
https://www.summer.ucla.edu

**University of California**
Systemwide Admissions
http://admission.universityofcalifornia.edu

# Calendars

## Academic Calendar

| | Fall 2019 | Winter 2020 | Spring 2020 |
|---|---|---|---|
| First day for continuing students to check MyUCLA at http://my.ucla.edu for assigned enrollment appointments | May 28 | October 28 | January 27 |
| MyUCLA enrollment appointments begin | June 17 | November 1 | February 1 |
| Registration fee payment deadline | September 20 | December 20 | March 20 |
| Quarter begins | September 23 | January 2, 2020 | March 25 |
| Instruction begins | September 26 | January 6 | March 30 |
| Last day for undergraduates to add courses with per-course fee through MyUCLA | October 18 | January 24 | April 17 |
| Last day for undergraduates to drop nonimpacted courses without a transcript notation (with per-transaction fee through MyUCLA) | October 25 | January 31 | April 24 |
| Last day for undergraduates to change grading basis (optional P/NP) with per-transaction fee through MyUCLA | November 8 | February 14 | May 8 |
| Instruction ends | December 6 | March 13 | June 5 |
| Final examinations | December 9–13 | March 16–20 | June 8–12 |
| Quarter ends | December 13 | March 20 | June 12 |
| Engineering Commencement | — | — | June 13 |
| Academic and administrative holidays | November 11<br>November 28-29<br>December 24-25<br>December 31, January 1 | January 20<br>February 17 | March 27<br>May 25 |
| Winter campus closure (tentative) | December TBD | | |

***Dates subject to change; see UCLA Registrar's Office website for most current information.***

## Admission Calendar

| | Fall 2019 | Winter 2020 | Spring 2020 |
|---|---|---|---|
| Filing period for undergraduate applications (file online at http://admission.universityofcalifornia.edu/how-to-apply/apply-online/index.html) | November 1–30, 2018 | — | — |
| Last day to file Application for Graduate Admission or readmission with complete credentials and application fee, online at https://app.applyyourself.com/AYApplicantLogin/fl_ApplicantConnectLogin.asp?id=ucla-grad or with Graduate Diversity, Inclusion, and Admissions (DIA), 1248 Murphy Hall, UCLA, Los Angeles, CA 90024-1419 | Consult department | Consult department | Consult department |
| Last day to file Undergraduate Readmission Application at 1113 Murphy Hall (late applicants pay a late fee) | August 15 | November 25 | February 25 |

# General Information

## Facilities and Services

Teaching and research facilities at UCLA Samueli are in Boelter Hall, Engineering IV, Engineering V, and Engineering VI, located in the southern part of the UCLA campus. Boelter Hall houses classrooms and laboratories for undergraduate and graduate instruction, the Office of Academic and Student Affairs (http://www.seasoasa.ucla.edu), the SEASnet computer facility (http://www.seasnet.ucla.edu), specialized libraries, offices of faculty and administration, Shop Services Center, and the Student and Faculty Shop. The California Nano-Systems Institute (CNSI) building hosts additional school collaborative research activities.

## Library Facilities

### University Library System

The UCLA Library, a campuswide network of libraries serving programs of study and re-search in many fields, is among the top 10 ranked research libraries in the U.S. Total collections number more than 12 million volumes, and over 112,000 serial titles are received regularly. Nearly 53,000 serials and databases are electronically available through the UCLA Library Catalog, which is linked to the library homepage at http://www.library.ucla.edu

### Science and Engineering Library

The combined Science and Engineering Library (SEL) collections contain more than half a million print volumes; subscriptions to nearly 5,400 print or electronic journals, many with full archival access; a large collection of online technical reports; and tens of thousands of e-books. The library offers access to online databases covering each discipline.

The SEL/Boelter location (formerly Engineering and Mathematical Sciences Collection), 8270 Boelter Hall, focuses on engineering, mathematics, statistics, astronomy, chemistry, physics, and atmospheric and oceanic sciences, and is the location of most librarian and staff offices. The library also offers laptop checkout, a group study room, two spaces for collaborative group work (the Learning Commons and the Research Commons), and quiet areas for study.

The SEL/Geology location, 4697 Geology Building, focuses on earth and space sciences with materials in geochemistry, geology, hydrology, tectonics, water resources, geophysics, and space physics. The William C. Putnam Map Room includes U.S. and international topographic and geologic maps.

The SEL website, http://www.library.ucla.edu/sel, is the access point to all of the above resources. The site also supplies information on course reserves, laptop lending, interlibrary loan, document delivery, news and events, and a staff directory. Librarians are available for consultations and to provide course-related instruction on using electronic and print resources including journal article databases, the UCLA Library catalog, Web search engines, research impact metrics, research data management and curation, scholarly communication, copyright, and open access publishing.

## Services

### Computing Resources

Nicodemus Wibowo, *SEASnet Director*

UCLA Samueli maintains an advanced computing facility and local-area network to support its education, research, and administrative activities. A total of 16 full-time positions and 10 lab consultants support the school's computing needs.

A network of over 158 enterprise servers supply a wide array of critical services. Eight Network Appliance NFS servers supply reliable storage for users' personal data and e-mail, and offer nearly instant recovery of deleted files through regular snapshots.

More than 100 Unix/Linux servers, including 20 virtual machines, supply both administrative and instructional support to ensure smooth operation of approximately 700 Linux and Windows workstations. The Unix servers handle back-end services such as DNS, authentication, virtualization, software licensing, web servers, interactive login, database, e-mail, class applications, and security monitoring.

Thirty Windows servers make up the backbone for all instructional computing labs, and allow students to work remotely with resource- and computationally intensive applications. There are four computer labs and one instructional computer lab with 200 Windows workstations.

A high-speed network that links the entire infrastructure ensures latency-free operation for users from UCLA and around the world. It consists of dual fiber uplinks to a Cisco core router, which feeds and routes 20 networks and over 100 switches. The network serves over 8,000 users across four buildings.

For backup and disaster recovery, large-capacity LTO tapes are used to back up servers and selected user workstations regularly, and incremental backups are done to online disk storage. Tapes are sent to off-site storage monthly.

The servers are protected by two high-capacity UPS units along with seven racked UPS for short-term power outages. Campus emergency power keeps critical equipment running during extended downtime.

Students and faculty have access to retail Microsoft software, through the Microsoft Azure Dev Tools for Teaching program; MathType software; and Abaqus, through a download service at no charge. Faculty and staff have access to Microsoft Office software at no charge through the same service and the Microsoft Consolidated Campus Agreement (MCCA). Adobe software is also available to tenure-track faculty and staff. Microsoft Azure Dev Tools for Teaching, Autodesk, and Ansys programs offer additional software at no charge to all UCLA engineering students.

The school's manufacturing engineering program operates a group of workstations dedicated to CAD/CAM instruction; and the Computer Science Department operates a network of SUN, Windows, and Macintosh workstations. The school is connected to the Internet through high-speed networks. Computing resources at the national supercomputer centers are also available.

### Shop Services Center

The Shop Services Center is available to faculty, staff, and students for projects.

### Continuing Education

**UCLA Extension**
10960 Wilshire Boulevard, Suite 1600
https://www.uclaextension.edu/engineering

*Department of Engineering*
Varaz Shahmirian, Ph.D., *Director*
Vivian Taslakian, M.B.A., *Program Director*

*Department of Digital Technology*
Bruce Huang, Ph.D., *Director*

The UCLA Extension Engineering and Digital Technology departments offer one of the nation's largest selections of continuing engineering education programs. A short-course program of 150 annual offerings draws participants from around the world for two- to four-day intensive programs. Many of these short courses are also offered on-site at companies and government agencies. The acclaimed Technical

Management Program has been offered for more than 60 years.

The Information Systems program offers over 200 courses annually in applications programming, database management, information systems security, Linux/Unix, operating systems, systems analysis, data science, and Web technology.

The engineering program offers over 250 courses annually, including 10 certificate programs in advanced plumbing systems design, biotechnology engineering, communication systems, construction management, contract management, information technology management, government cost estimating and pricing, medical device engineering, recycling and solid waste management, and supply chain management. In addition, the department offers EIT and PE review courses in mechanical engineering. Most engineering and technical management courses are offered evenings on the UCLA campus, or are available online.

## Career Services

**UCLA Career Center**
501 Westwood Plaza, Strathmore Building
310-206-1915
**https://career.ucla.edu**

The UCLA Career Center assists UCLA Samueli undergraduate and graduate students, and alumni, in exploring career possibilities, preparing for graduate and professional school, obtaining employment and internship leads, and developing skills for conducting a successful job search.

Services include individual career counseling, career assessments, workshops, industry-specific programming, employer information sessions, career fairs, and targeted networking opportunities. Annual engineering and technical fairs, held in fall and winter quarters, feature more than 100 top national and local employers. Using a Handshake account (**https://ucla.joinhandshake.com/login**), students can discover internship and job opportunities, schedule career counseling appointments, access career resources, and register for events.

Career Center drop-in hours (Tuesday through Thursday from 10 a.m. to 2 p.m.) offer support with résumés, cover letters, and the job/internship search process. The center is open Monday through Friday from 9 a.m. to 5 p.m. An engineering-specific pop-up event is held once per quarter in 6288 Boelter Hall.

## Health Services

**Ashe Student Health and Wellness Center**
221 Westwood Plaza
310-825-4073
**http://www.studenthealth.ucla.edu**

The Ashe Student Health and Wellness Center is a full-service medical clinic available to all registered UCLA students. Most services are subsidized by registration fees, and a current BruinCard is required for service. Its clinical staff of physicians, nurse practitioners, and nurses is board certified. It offers primary care, specialty clinics, and physical therapy. The center has its own laboratory and radiology sections. It operates the Bruin Health Pharmacy and U See LA Optometry in nearby Ackerman Union. Visits, core laboratory tests, Xrays, and preventive immunizations are all prepaid for students with the University of California Student Health Insurance Plan (UCSHIP).

The cost of services received outside the Ashe Center, such as emergency room services, is each student's financial responsibility. Students are required to purchase medical insurance either through UCLA-sponsored UCSHIP or other plans that provide adequate coverage. Adequate medical insurance is a condition of registration. Students who waive UCSHIP must ensure that they are enrolled in a plan qualified to cover expenses incurred outside of the Ashe Center, and are responsible for knowing the benefits of and local providers for their medical plan.

Contact the Ashe Center for specific information on its primary care, women's health, immunization, health clearance, optometry, travel medicine, and mind-body clinics, as well as dental care available to students at discounted rates. UCSHIP benefits tier structure and coverage information is available on the Ashe Center website

For emergency care when the Ashe Center is closed, students may obtain treatment at the Ronald Reagan UCLA Medical Center emergency room on a fee-for-service basis.

All incoming students must be vaccinated against or show immunity to multiple infectious diseases consistent with guidelines of the American College Health Association, California Department of Public Health, and U.S. Centers for Disease Control and Prevention (CDC). The Ashe Center website processes students' proof of immunity prior to enrollment.

The Ashe Center is open Monday through Friday during the academic year.

Nonregistered students (those who withdraw, or are on approved leave or planned academic leave) may have access to UCSHIP services under certain conditions.

## Services for Students with Disabilities

**Center for Accessible Education**
A255 Murphy Hall
voice 310-825-1501, TTY 310-206-6083
**https://www.cae.ucla.edu**

The Center for Accessible Education (CAE) offers academic support services to regularly enrolled students with documented permanent or temporary disabilities in compliance with Section 504 of the Rehabilitation Act of 1973, the Americans with Disabilitites Act (ADA) of 1990, and UC and UCLA policies. Services include campus orientation and accessibility, notetakers, reader service, sign-language interpreters, registration assistance, test-taking facilitation, special parking assistance, real-time captioning, assistive listening devices, on-campus transportation, adaptive equipment, support groups and workshops, tutorial referral, special materials, housing appeals, referral to the Disabilities and Computing Program, and processing of California Department of Rehabilitation authorizations.

There is no fee for any of these services. All contacts and assistance are handled confidentially.

**Disabilities and Computing Program**
4909 Math Sciences
voice 310-206-7133
**https://dcp.ucla.edu**

The Disabilities and Computing Program (DCP) supplies adaptive technology and information-access support and services to students, faculty, and staff with disabilities. Applications include voice input, Braille, large print, screen-reading software, and learning disability software. Consulting and training for individuals and departments are available. The program also offers Web accessibility evaluations andguidelines.

## International Student Services

**Dashew Center for International Students and Scholars**
106 Bradley Hall
**https://www.internationalcenter.ucla.edu**

The Dashew Center for International Students and Scholars assists students with questions about immigration, employment, government regulations, financial aid, academic and administrative procedures, cultural adjustment, and personal matters. The center seeks to improve student and community relationships; helps international students with language, housing, and personal concerns; and sponsors cultural, educational, and social programs. It also offers visa assistance for faculty members, researchers, and postdoctoral scholars.

# Fees and Financial Support

## Fees and Expenses

Annual UCLA student fees shown for 2019-20 are current as of publication. See the Registrar's Office fees web page for fees breakdown by term at **https://sa.ucla.edu/RO/Fees/Public/public-fees**.

Students who are not legal residents of California (out-of-state and international students) pay nonresident supplemental tuition. See the *UCLA General Catalog* appendix or the Registrar's website residence section at **https://www.registrar.ucla.edu/Fees-Residence/Residence-Requirements** for information on how to determine residence for tuition purposes. Inquiries may be directed to the Residence Deputy, UCLA Registrar's Office, 1113 Murphy Hall, Los Angeles, CA 90024-1429.

In addition to the fees shown, students should be prepared to pay living expenses for the academic period.

## Living Accommodations

**UCLA Housing Services**
360 De Neve Drive, Box 951383
Los Angeles, CA 90095-1383
310-206-7011
**https://housing.ucla.edu**

Housing in Los Angeles, both on and off campus, is in great demand. Students should make arrangements early. Newly admitted students should access the UCLA Housing website for information about costs, locations, and eligibility for both private and UCLA-sponsored housing.

Information about campus residence halls and suites, and applications for on-on-campus housing, are available from the UCLA Housing website.

## Financial Aid

**Financial Aid and Scholarships**
A129J Murphy Hall
310-206-0400
**https://www.financialaid.ucla.edu**

## Undergraduate Students

Financial aid at UCLA includes scholarships, grants, loans, and work-study programs. With the exception of certain scholarships, awards are based on need as determined by national financial aid criteria. California residents must file the Free Application for Federal Student Aid (FAFSA). Students who are not citizens or permanent residents but who are eligible for Assembly Bill 540 nonresident fee waivers may be eligible to qualify for scholarships, UCLA grant aid, and additional state aid if they complete a California Dream Act application. International students in their first year are ineligible for aid. Continuing undergraduate international students are asked to submit a separate Financial Aid Application for International Students.

Applications for each academic year are available in January. The priority application deadline for financial aid for the 2020-21 academic year is March 2, 2020.

### Scholarships

All UCLA undergraduate scholarship awards are made on a competitive basis, with consideration given to academic excellence, achievement, scholastic promise, and financial need. Scholarships are awarded to entering and continuing undergraduates. The term and amount of the award vary; students are expected to maintain academic excellence in their coursework.

**Regents Scholarships** are awarded to students with an outstanding academic record and a high degree of promise. Regents Scholars receive a yearly honorarium if they have no financial need. If financial need is established, other scholarships and/or grants are awarded to cover that need.

**UCLA Samueli Scholarships** are awarded to entering and continuing undergraduate students based on criteria including financial need, academic excellence, community service, extracurricular activities, and research achievement. The school works with alumni, industry, and individual donors to establish scholarships to benefit engineering students. In 2018-19, the school awarded 143 undergraduate scholarship awards totaling more than $583,500. The majority of these scholarships are publicized in the fall, with additional scholarships promoted throughout the academic year as applicable. For more information on all available scholarships, see **http://www.seasoasa.ucla.edu/scholarships-for-undergraduates**.

### Grants

**Cal Grants A and B** are awarded by the California Student Aid Commission to entering and continuing undergraduate students who are U.S. citizens or eligible noncitizens and California residents, based on financial need and academic achievement. Cal Grant A awards are applied toward tuition and fees. Cal Grant B awards help with living expenses, books, supplies, and transportation costs.

**Federal Pell Grants** are federal aid awards designed to provide financial assistance to U.S. citizens or eligible noncitizen undergraduates in exceptional need of funds to attend post-high school educational institutions. Students who file a FAFSA are automatically considered for a Pell Grant.

Detailed information on other grants for students with demonstrated need is available from Financial Aid and Scholarships.

### Federal Family Education Loan Program

**Student Loan Services and Collections**
A227 Murphy Hall
310-825-9864
**https://www.loans.ucla.edu**

**Federal loans** are available to undergraduate or graduate students who are U.S. citizens or eligible noncitizens and who carry at least a half-time academic workload. Information on loan programs is available from the Financial Aid Office.

All loan recipients must complete an exit interview with Loan Services Office before leaving UCLA for any reason. This interview helps students understand their loan agreement and plan for loan repayment. Failure to complete an exit interview results in a hold being placed on all university services and records. In addition, if the campus-based loans become delinquent following separation from UCLA, all university services and records will be withheld. For more information concerning loan repayment, contact Student Loan Services and Collections.

### Work-Study Programs

Under **Federal Work-Study**, the federal government pays a portion of the student's wage and the employer pays the balance. When possible, work is related to student educational objectives. Hourly pay rates comply with minimum wage laws and vary with the nature of the work, experience, and capabilities. Employment may be on or off campus. To be eligible, undergraduate and graduate students must demonstrate financial need and be a U.S. citizen or eligible noncitizen. Submission of the FAFSA is required.

Students must be enrolled at least half-time (6 units for undergraduates, 4 for graduate students) and not be appointed at more than 50 percent time while employed at UCLA. Students not meeting these requirements are subject to Social Security and Medicare taxation.

**Community Service** is a component of the Federal Work-Study program. Students who secure a community service position are eligible to petition for an increase in work-study funds up to a total of $5,000 while at the same time reducing their Perkins and/or Stafford loan by the amount of the increase. Most community service positions are located off campus.

## Graduate Students

A high percentage of UCLA Samueli graduate students receive departmental financial support.

### Merit-Based Support

Three major types of merit-based support are available in the school:

1. Fellowships from University, private, or corporate funds
2. Employment as a teaching assistant
3. Employment as a graduate student researcher

**Fellowships** usually supply stipends competitive with those of other major universities, plus tuition and nonresident supplemental tuition (where applicable). These stipends may be supplemented by a teaching assistantship or graduate student researcher appointment. The awards are generally reserved for new students.

**Teaching assistantships** are awarded to students on the basis of scholarship and promise as teachers. Appointees serve under the supervision of regular faculty members.

**Graduate student researcher** (GSR) appointments are awarded to students on the basis of scholastic achievement and promise as creative scholars. Appointees perform research under the supervision of a faculty member in research work. Full-time employment in summer and interterm breaks is possible, depending on the availability of research funds from contracts or grants.

Since a graduate student researcher appointment constitutes employment in the service of a particular faculty member who has a grant, students must take the initiative in obtaining desired positions.

GSR appointments are generally awarded after one year of study at UCLA.

Applicants for departmental financial support must be accepted for admission to UCLA Samueli in order to be considered in the 2019-20 competition. Applicants should check the deadline for submitting the UCLA Application for Graduate Admission and the Fellowship Application for Entering Graduate Students with their preferred department.

### Need-Based Aid

Unlike the awards above, which are based solely on merit and administered by the school, the University also offers work-study and low-interest loans based on financial need exclusively.

Need-based awards are administered by Financial Aid and Scholarships, A129J Murphy Hall. Financial aid applicants must file the Free Application for Federal Student Aid (FAFSA).

Continuing graduate students should contact Financial Aid and Scholarships in December 2019 for information on 2020-21 application procedures.

International graduate students are not eligible for need-based University financial aid or for long-term student loans.

**2019-20 ANNUAL UCLA UNDERGRADUATE AND GRADUATE STUDENT FEES**

***Fees are subject to revision without notice.***

| | Undergraduate Students | | Academic Master's Students | | Academic Doctoral Students | |
|---|---|---|---|---|---|---|
| | Resident | Nonresident | Resident | Nonresident | Resident | Nonresident |
| Tuition | $ 11,442.00 | $ 11,442.00 | $ 11,442.00 | $ 11,442.00 | $ 11,442.00 | $ 11,442.00 |
| Student Services Fee | 1,128.00 | 1,128.00 | 1,128.00 | 1,128.00 | 1,128.00 | 1,128.00 |
| Nonresident Supplemental Tuition (NRST)* | | 29,754.00 | | 15,102.00 | | 15,102.00 |
| Ackerman Student Union Fee | 66.00 | 66.00 | 66.00 | 66.00 | 66.00 | 66.00 |
| Ackerman/Kerckhoff Seismic Fee | 113.00 | 113.00 | 113.00 | 113.00 | 113.00 | 113.00 |
| Arts Restoring Community Fee | 5.17 | 5.17 | | | | |
| Bruin Bash Fee | 4.48 | 4.48 | | | | |
| Course Materials and Services Fee | varies, see course listings | | | | | |
| Graduate Students Association Fee | | | 38.25 | 38.25 | 38.25 | 38.25 |
| Graduate Writing Center Fee | | | 18.05 | 18.05 | 18.05 | 18.05 |
| Green Initiative Fee | 14.40 | 14.40 | | | | |
| Instructional Enhancement Initiative (IEI) Fee | 324.00 | 324.00 | | | | |
| PLEDGE Fee | 56.52 | 56.52 | | | | |
| Student Health Insurance Plan (UCSHIP) | 2,516.70 | 2,516.70 | 4,318.98 | 4,318.98 | 4,318.98 | 4,318.98 |
| Student Programs, Activities, and Resources Complex (SPARC) Fee | 114.00 | 114.00 | 114.00 | 114.00 | 114.00 | 114.00 |
| Undergraduate Students Association Fee | 262.28 | 262.28 | | | | |
| Wooden Center Fee | 34.00 | 34.00 | 34.00 | 34.00 | 34.00 | 34.00 |
| **Continuing student total mandatory fees** | **$ 16,080.55** | **$ 45,834.55** | **$ 17,272.28** | **$ 32,374.28** | **$ 17,272.28** | **$ 32,374.28** |
| Document Fee | 165.00 | 165.00 | 80.00 | 80.00 | 100.00 | 100.00 |
| **New student total mandatory fees** | **$ 16,245.55** | **$ 45,999.55** | **$ 17,352.28** | **$ 32,454.28** | **$ 17,372.28** | **$ 32,474.28** |

**Beginning with the first academic term following advancement to doctoral candidacy, nonresident supplemental tuition for graduate students is reduced by 100% for a maximum of three years including nonregistered time periods.*

### School of Engineering Fellowships

Fellowship packages offered by the school may include fellowship contributions from the following sources:

*Atlantic Richfield Company (ARCO) Fellowship*. Chemical and Biomolecular Engineering Department; supports study in chemical engineering

*Balu and Mohini Balakrishnan Endowed Fellowship*. Supports doctoral study in any engineering department

*William and Mary Beedle Fellowship*. Chemical and Biomolecular Engineering Department; supports study in chemical engineering

*Boeing Fellowship*. Supports graduate study in mechanical and aerospace engineering

*John J. and Clara C. Boelter Fellowship*. Supports study in engineering

*Broadcom Fellowship*. Electrical and Computer Engineering Department; supports doctoral students who have passed the preliminary examination and are doing research that explores new possibilities in state-of-the-art 22-nm CMOS technology

*Broadcom Foundation First Year Fellowship*. Supports first-year doctoral students in electrical engineering

*Leon and Alyne Camp Fellowship*. Supports graduate study in electrical and/or mechanical engineering, must be U.S. citizen

*Deutsch Company Fellowship*. Supports engineering research on problems that aid small business in Southern California

*Electrical Engineering Graduate Fellowship*. Supports master's or doctoral study in electrical engineering

*Venky Harinarayan Fellowship*. Supports doctoral study in computer science

*IBM Doctoral Fellowship*. Supports doctoral study in computer science

*Intel Fellowship*. Computer Science Department; supports doctoral study in selected areas of computer science

*The Kalosworks.org Fellowship*. Supports graduate students in electrical engineering who have a GPA of at least 3.0 and have demonstrated financial need

*Les Knesel Scholarship Fund*. Materials Science and Engineering Department; supports master's or doctoral study in ceramic engineering

*Guru Krupa Foundation Fellowships in Electrical Engineering*. Multiple fellowships to support graduate study with preference for those conducting research in integrated circuits and embedded systems or signals and systems, and who have an undergraduate degree in electrical engineering from the Indian Institutes of Technology (IIT) or the Indian Institute of Science, Bangalore

*T.H. Lin Graduate Fellowship*. Civil and Environmental Engineering Department; supports study by an international student in structural mechanics

*Living Rocks Electrical Engineering Fellowship*. Supports graduate study with preference for students conducting research in the areas of integrated circuits and embedded systems or signals and systems, and who have an undergraduate degree in electrical engineering from National Taiwan University, National Tsing Hua University, or National Chiao Tung University in Taiwan

*Living Spring Fellowship*. Electrical and Computer Engineering Department; supports graduate students with preference for those conducting research in integrated circuits and embedded systems or signals and systems, and who have an undergraduate degree in electrical engineering degrees from National Taiwan University, National Tsing Hua University, or National Chiao Tung University in Taiwan

*Microsoft Fellowship*. Supports doctoral study in computer science

*National Consortium for Graduate Degrees for Minorities in Engineering and Science (GEM) Fellowships*. Support study in engineering and science to highly qualified individuals from communities where human capital is virtually untapped

*Northrop Grumman Fellowship*. Supports graduate study in mechanical and aerospace engineering

*H.J. Orchard Memorial Fellowship*. Supports graduate study in electrical engineering

*Qualcomm Innovation Fellowship*. Supports doctoral students across a broad range of technical research areas based on Qualcomm core values of innovation, execution, and teamwork

*Raytheon Fellowship*. Supports graduate study in electrical engineering with preference for U.S. citizens

*Martin Rubin Scholarship*. Supports two undergraduate and/or graduate students pursuing degrees in civil engineering with an interest in transportation engineering

*Henry Samueli Fellowship*. Electrical and Computer Engineering Department; supports master's and doctoral students

*Henry Samueli Fellowship*. Mechanical and Aerospace Engineering Department; supports master's and doctoral students

*Texaco Scholarship*. Civil and Environmental Engineering Department; supports research in environmental engineering

*Dr. Robert K. Williamson Graduate Fellowship*. Supports graduate study in mechanical and aerospace engineering

Many other companies in the area also make arrangements for their employees to work part-time and to study at UCLA for advanced degrees in engineering or computer science. In addition, the Graduate Division offers other fellowship packages including the Dissertation Year, Eugene V. Cota-Robles, and Graduate Opportunity Fellowships.

# Special Programs, Activities, and Awards

## Center for Excellence in Engineering and Diversity (CEED)

The UCLA Samueli Center for Excellence in Engineering and Diversity (CEED) seeks to create a community of collaborative and sustainable partnerships that increase academic opportunities for urban, disadvantaged, and underrepresented students. CEED supports precollege students in science, engineering, mathematics, and technology curricula, and focuses on engineering and computer science at the undergraduate and graduate levels.

### Precollege Outreach Programs

*Summer Math and Science Honors Academy (SMASH)*. A rigorous and innovative education program, SMASH increases opportunities for educationally and financially disadvantaged urban school students to excel in the fields of science, technology, engineering, and math (STEM) at the college level for five weeks each summer. SMASH scholars also receive year-round academic support including SAT preparation, college counseling, financial aid workshops, and other activities to ensure continued academic success. Thirty new SMASH scholars are selected each year to attend the residential program each of three summers (after their 9th, 10th, and 11th grade years). A total of 103 students participated in SMASH during summer 2019.

*MESA Schools Program (MSP)*. Through CEED, UCLA Samueli partners with middle and high school principals to implement MSP services, which focus on outreach and student development in engineering, mathematics, science, and technology. At individual school sites, four mathematics and science teachers serve as MSP advisers and coordinate the activities and instruction for 1000 students. Advisers work as a team to deliver services that include SAT preparation. MSP prepares students for regional engineering and science competitions and provides an individual academic planning program, academic excellence workshops, CEED undergraduate mentors, field trips, and exposure to high-tech careers. The MSP goal is to increase the numbers of urban and educationally underserved students who are competitively eligible for UC admission, particularly in engineering and computer science.

Students are provided academic planning, SAT preparation, career exploration, and other services starting at the elementary school level through college. UCLA Samueli CEED currently serves 18 schools in the Los Angeles Unified School District and four schools in the Inglewood Unified School District.

## Undergraduate Programs

CEED currently supports some 330 underrepresented and educationally disadvantaged engineering students. Components of the undergraduate program include

*CEED Summer Bridge*. A two-week intensive residential summer program, CEED Summer Bridge provides advanced preparation and exposure for fall quarter classes in mathematics, chemistry, and computer science.

*Freshman Orientation Course*. Designed to give CEED freshmen exposure to the engineering profession, "Engineering 87—Introduction to Engineering Disciplines" also teaches the principles of effective study and team/community-building skills, and research experiences.

*Academic Excellence Workshops (AEW)*. Providing an intensive mathematics/science approach to achieving mastery through collaborative learning and facilitated study groups, workshops meet twice a week for two hours and are facilitated by a Ph.D. student.

*Bridge Review for Enhancing Engineering Students (BREES)*. Sponsored by the National Science Foundation (NSF). A 14-day intensive summer program designed to provide CEED students with the skills and knowledge to gain sufficient mastery, understanding, and problem solving skills in the core engineering courses. Current CEED students and incoming CEED transfer students take part in lectures and collaborative, problem-solving workshops facilitated by UCLA graduate students.

*Research Intensive Series in Engineering for Underrepresented Populations (RISE-UP)*. During the summer of 2005, UCLA CEED began its Research Intensive Series in Engineering for Underrepresented Populations (RISE-UP). The purpose of this program is to keep engineering and computing students, particularly from underrepresented groups, interested in the fun of learning through a process in which faculty participate. The ultimate goal of this program is to encourage these young scholars to go on to graduate school and perhaps the professoriate.

*Academic Advising and Counseling*. A CEED counselor assists in the selection of course combinations, professors, and course loads and meets regularly with students to assess progress and discuss individual concerns.

*Tutoring*. Review sessions and tutoring are provided for several upper division engineering courses.

*Career Development*. Presentations by corporate representatives and field trips to major company locations are offered. Other services include summer and full-time job placement and assistance.

*Cluster Systems*. Common class sections that team students, Cluster Systems facilitate group study and successful academic excellence workshops.

*Student Study Center:* A complex with a study area open 24 hours a day, the Student Study Center also houses a computer room and is used for tutoring, presentations, and engineering student organizations.

*Center for Translational Applications of Nanoscale Multiferroic Systems (TANMS)*. The Center for Translational Applications of Nanoscale Multiferroic Systems (TANMS) brings together critical expertise in physics, chemistry, materials science, and engineering to enable rapid advancement and application of multiferroic technologies to next-generation electromagnetic (EM) devices. Its goal is to create a synergistic environment that fosters fundamental studies on magnetism control through application of an electric field while providing a pathway to commercial endeavors. Its unique needs include diverse participant characteristics that encompass how we think, how we do things, and our humanity—including but not limited to age, color, culture, disability, diversity of thought, ethnicity, gender, geographic and national origin, language, life experience, perspective, race, religion, sexual identity, socioeconomic status, and technical expertise—aimed to increase creativity and innovation.

The center workforce is composed of researchers who span a wide range of disciplines from chemical to mechanical engineering, and an educational spectrum from K-12 and undergraduate students to postdoctoral scholars, including those who work with industries and national laboratories focused on multiferroic systems.

The TANMS vision is to move from diversity and inclusion advocate to active leader in the ERC community, and provide an educational pathway from cradle to career for the nation's best and brightest, fully representative and inclusive of the talents of every community. TANMS recognizes diversity as a national imperative to take specific actions by its leadership to source and include a complete talent pool, especially those critically underrepresented populations, and all its population segments and characteristics, in the TANMS academic leadership, technical workforce, and efforts to develop the next generation of engineers, scientists, and entrepreneurs in multiferroics systems.

***CEED students participate in a professional development workshop.***

TANMS is a multi-university partnership between lead institution UCLA and partners California State University Northridge, Cornell University, UC Berkeley, and the Edgenossische Technische Hochschule in Switzerland. CEED directs the TANMS program component, supports undergraduates placed in research laboratories, and coordinates recruitment of undergraduates from other universities. CEED brings teacher-student teams to UCLA to conduct summer research and gain exposure to entrepreneurship.

## Scholarships/Financial Aid

UCLA Samueli also participates in the NACME and GEM scholarships. The CEED Industry Advisory Board and support network provide significant contributions to program services and scholarships. Information may be obtained from the CEED director.

## Student Organizations

UCLA Samueli CEED supports student chapters of three engineering organizations: the American Indian Science and Engineering Society (AISES), the National Society of Black Engineers (NSBE), and the Society of Latino Engineers and Scientists (SOLES), the UCLA chapter of the Society of Hispanic Professional Engineers (SHPE). These organizations are vital elements of the program.

### American Indian Science and Engineering Society (AISES)

AISES encourages American Indians to pursue careers as scientists and engineers while preserving their cultural heritage. The goal of AISES is to promote unity and cooperation and to provide a basis for the advancement of American Indians while providing financial assistance and educational opportunities. AISES devotes most of its energy to its outreach program where members conduct monthly science academies with elementary and precollege students from Indian Reservations. Serving as mentors and role models for younger students enables UCLA AISES students to further develop professionalism and responsibility while maintaining a high level of academics and increasing cultural awareness.

### National Society of Black Engineers (NSBE)

http://nsbebruins.wixsite.com/nsbe/home

Chartered in 1980 to respond to the shortage of blacks in science and engineering fields and to promote academic excellence among black students in these disciplines, NSBE provides academic assistance, tutoring, and study groups while sponsoring ongoing activities such as guest speakers, company tours, and participation in UCLA events such as Career Day and Engineers Week. NSBE also assists students with employment. Through the various activities sponsored by NSBE, students develop leadership and interpersonal skills while enjoying the college experience. UCLA NSBE was recently named national chapter of the year for small chapters by the national organization.

### Society of Latino Engineers and Scientists (SOLES)

http://www.uclasoles.com

Recognized as the national chapter of the year five times over the past ten years by the Society of Hispanic Professional Engineers (SHPE), SOLES promotes engineering as a viable career option for Latino students. SOLES is committed to the advancement of Latinos in engineering and science through endeavors to stimulate intellectual pursuit through group studying, tutoring, and peer counseling for all members. This spirit is carried into the community with active recruitment of high school students into the field of engineering.

SOLES also strives to familiarize the UCLA community with the richness and diversity of the Latino culture and the scientific accomplishments of Latinos. SOLES organizes cultural events such as Latinos in Science, Cinco de Mayo, and co-sponsors the Women in Science and Engineering (WISE) Day with AISES and NSBE. By participating in campus events such as Career Day and Engineers Week, the organization's growing membership strives to fulfill the needs of the individual and the community.

## Women in Engineering

Women make up about 25 percent of the UCLA Samueli undergraduate enrollment and 22 percent of the graduate enrollment. Today's opportunities for women in engineering are excellent, as both employers and educators try to change the image of engineering as a males-only field. Women engineers are in great demand in all fields of engineering.

### Society of Women Engineers (SWE)

http://www.swe.ucla.edu

The Society of Women Engineers (SWE), recognizing that women in engineering are still a minority, has established a UCLA student chapter that sponsors field trips and engineering-related speakers (often professional women) to introduce the various options available to women engineers. The UCLA chapter of SWE, in conjunction with other Los Angeles schools, also publishes an annual résumé book to help women students find jobs, and presents a career day for women high school students.

## Student and Honorary Societies

Professionally related societies and activities at UCLA provide valuable experience in leadership, service, recreation, and personal satisfaction. The faculty of the school encourages students to participate in such societies and activities where they can learn more about the engineering profession in a more informal setting than the classroom. For more information, see **https://samueli.ucla.edu/student-clubs-organizations**.

| | |
|---|---|
| AAAEA | Arab American Association of Engineers and Architects |
| ACM | Association for Computing Machinery |
| ACM-W | Association for Computing Machinery–Women |
| AIAA | American Institute of Aeronautics and Astronautics |
| AIChE | American Institute of Chemical Engineers |
| AISES | American Indian Science and Engineering Society |
| ASCE | American Society of Civil Engineers |
| ASME | American Society of Mechanical Engineers/BattleBots |
| AWWA | American Water Works Association |
| BEAM | Building Engineers and Mentors |
| BMES | Biomedical Engineering Society |
| — | Blockchain at UCLA |
| — | Bruin Amateur Radio Club |
| — | Bruin Home Solutions |
| BruinKSEA | Korean-American Scientists and Engineers Association |
| — | Bruin Space Group |
| CalGeo | California Geotechnical Engineers Association |
| Chi Epsilon | Civil Engineering Honor Society |
| DBF | Design/Build/Fly at UCLA |
| — | Engineering Ambassador Program |
| EGSA | Engineering Graduate Students Association |
| ESUC | Engineering Society, University of California. Umbrella organization for all engineering and technical societies at UCLA |
| Eta Kappa Nu | Electrical engineering/computer science and engineering honor society |
| EWB | Engineers Without Borders |

| | |
|---|---|
| IEEE | Institute of Electrical and Electronic Engineers |
| ISPE | International Society for Pharmaceutical Engineering |
| ITE | Institute of Transportation Engineers |
| LUG | Linux Users Group |
| MRS | Materials Research Society |
| — | Mentor SEAS |
| NSBE | National Society of Black Engineers |
| Phi Sigma Rho | Engineering social sorority |
| PIE | Pilipinos in Engineering |
| QSTEM | Queers in STEM at UCLA |
| REA | Renewable Energy Association at UCLA |
| — | Robotics Club |
| — | Rocket/Space Project at UCLA |
| SAE | Society of Automotive Engineers |
| SASE | Society of Asian Scientists and Engineers |
| SMV | Supermileage Vehicle SAE |
| SOLES | Society of Latino Engineers and Scientists |
| SWE | Society of Women Engineers |
| Tau Beta Pi | Engineering honor society |
| Theta Tau | Professional engineering fraternity |
| Triangle | Social fraternity of engineers, architects, and scientists |
| — | UCLA 3D4E |
| — | UCLA DevX |
| Upsilon Pi Epsilon | International honor society for the computing and information disciplines |
| WATT | IEEE Women Advancing Technology through Teamwork |

## Student Representation

The student body takes an active part in shaping policies of the school through elected student representatives on the school Executive Committee.

# Prizes and Awards

Each year, outstanding students are recognized for their academic achievement and exemplary record of contributions to the school. Recipients are acknowledged in the UCLA Samueli annual commencement program as well as by campuswide announcement.

The *Russell R. O'Neill Distinguished Service Award* is presented annually to an upper-division student in good academic standing who has made outstanding contributions through service to the undergraduate student body, student organizations, the school, and to the advancement of the undergraduate engineering program, through service and participation in extracurricular activities.

The *Harry M. Showman Engineering Prize* is awarded to a UCLA engineering student or students who most effectively communicate the achievements, research results, or social significance of any aspect of engineering to a student audience, the engineering professions, or the general public.

The *Engineering Achievement Award for Student Welfare* is given to undergraduate and graduate engineering students who have made outstanding contributions to student welfare through participation in extracurricular activities and who have given outstanding service to the campus community.

Additional awards may be given to those degree candidates who have achieved academic excellence. Criteria may include such items as grade-point average, creativity, research, and community service.

# Departmental Scholar Program

The school may nominate exceptionally promising juniors and seniors as Departmental Scholars to pursue engineering bachelor's and master's degrees simultaneously.

Minimum qualifications include the completion of 24 courses (96 quarter units) at UCLA, or the equivalent at a similar institution, a minimum 3.7 grade-point average (GPA) in the major field upper-division courses and a minimum 3.7 cumulative GPA, and the requirements in preparation for the major. To obtain both the bachelor's and master's degrees, Departmental Scholars fulfill the requirements for each program. Students may not use any one course to fulfill requirements for both degrees.

For details, contact the Office of Academic and Student Affairs, 6426 Boelter Hall well in advance of application dates for admission to graduate standing.

# Exceptional Student Admissions Program

**http://www.seasoasa.ucla.edu/exceptional-student-admissions-program/**

UCLA Samueli has an Exceptional Student Admissions Program (ESAP) for its outstanding undergraduates who wish to enter the school graduate program upon completion of the B.S. degree. ESAP is an alternative to the Departmental Scholar Program. In contrast to that program, an ESAP-admitted student would be an enrolled graduate student and eligible for consideration of graduate fellowships and teaching assistant positions if available.

# Official Publications

This *Announcement of the Henry Samueli School of Engineering and Applied Science* contains detailed information about the school, areas of study, degree programs, and course listings. The *UCLA General Catalog* (**http://catalog.registrar.ucla.edu**), however, is the official and binding document for the guidance of students. UCLA students are responsible for complying with all rules, regulations, policies, and procedures described in the *Catalog*.

For rules and regulations on graduate study, see the Graduate Division website, **https://grad.ucla.edu**.

# Grades

## Grading Policy

Instructors should announce their complete grading policy in writing at the beginning of the term, along with the syllabus and other course information, and make that policy available on the course website. Once the policy is announced, it should be applied consistently for the entire term.

## Grade Disputes

A student who believes that a grade has been given unfairly should first discuss the issue with the instructor of the course. If the dispute cannot be resolved between the student and the instructor, the student may refer the issue to the Associate Dean for Academic and Student Affairs, 6426 Boelter Hall.

The associate dean may form an ad hoc committee to review the complaint. The ad hoc committee members are recommended by the appropriate department chair and the associate dean. The student receives a copy of the ad hoc committee report as well as a copy of the associate dean's recommendation. The student file will contain no reference to the dispute.

The associate dean informs the students of their rights with respect to complaints and appeals at UCLA.

# Nondiscrimination

The University of California, in accordance with applicable federal and state laws and University policies, does not discriminate on the basis of race, color, national origin, religion, sex, gender identity, pregnancy (including pregnancy, childbirth, and medical conditions related to pregnancy and childbirth), physical or mental disability, medical condition (cancer-related or genetic characteristics), ancestry, marital status, age, sexual orientation, citizenship, or service in the uniformed services (including membership, application for membership, performance of service, application for service, or obligation for service in the uniformed services). The University also prohibits sexual harassment and harassment on any of the above bases. This nondiscrimination policy covers admission, access, and treatment in University programs and activities.

Students may grieve any action that they believe discriminates against them on the ground of race, color, national or ethnic origin, alienage, sex, religion, age, sexual orientation, gender identity, marital status, veteran status, or perceived membership in any of these categories which results in injuries to the student by contacting the Office of the Dean of Students by e-mail at dean@saonet.ucla.edu, or in person at 1104 Murphy Hall. Refer to UCLA Procedure 230.1, available in 1104 Murphy Hall or at http://www.adminpolicies.ucla.edu/APP/Number/230.1, for more information and procedures.

Inquiries regarding University student-related nondiscrimination policies may be directed to the Office of the Dean of Students by e-mail at dean@saonet.ucla.edu, in person at 1104 Murphy Hall, or by phone at 310-825-3871. An assistant dean is available at this office to support students who need information or assistance in filing a discrimination complaint.

In accordance with applicable federal and state laws and University policy, including Title II of the Americans with Disabilities Act, Section 504 of the Rehabilitation Act of 1973, and University of California policy PACAOS-20 (Policy on Nondiscrimination), UCLA does not discriminate on the basis of physical or mental disability. Retaliation for participation in University procedures relating to complaints of discrimination is also prohibited. This nondiscrimination policy covers admission, access, and treatment in University programs and activities. UCLA is committed to prohibiting disability-based discrimination and harassment, and retaliation, performing a prompt and equitable investigation of complaints alleging discrimination, and properly remedying discrimination when it occurs. Examples of discrimination against students with disabilities include, but are not limited to: failure to engage with the student in a discussion of reasoning accommodations; failure to implement approved reasonable accommodations such as the provision of notes or extra time on tests; and exclusion of a qualified student from any course, course of study, or other educational program or activity because of the student's disability. Disability-based harassment is conduct which is sufficiently severe, pervasive, or persistent so as to interfere with or limit an individual's ability to participate in or benefit from the services, activities, or opportunities offered by the University.

UCLA has issued Procedure 230.2: Student Grievances Regarding Violations of Anti-Discrimination Laws or University Policies on Discrimination on Basis of Disability. See http://www.adminpolicies.ucla.edu/APP/Number/230.2. Students may grieve any action that they believe discriminates against them on the basis of disability by contacting the office of the dean of students by e-mail at dean@saonet.ucla.edu, or in person at 1104 Murphy Hall. Refer to procedure 230.2 for more information and procedures.

Title IX prohibits sex discrimination, including sexual harassment and sexual violence, in any education program or activity receiving federal financial assistance. Inquiries regarding the application of Title IX may be directed to the Title IX Director, 2255 Murphy Hall, 310-206-3417, titleix@conet.ucla.edu, or the U.S. Department of Education Office for Civil Rights at ocr@ed.gov.

# Harassment

## Sexual Harassment

The University of California is committed to creating and maintaining a community where all persons who participate in University programs and activities can work and learn together in an atmosphere free from all forms of harassment, exploitation, or intimidation. Every member of the University community should be aware that the University is strongly opposed to sexual harassment and that such behavior is prohibited both by law and by the *UC Policy on Sexual Violence and Sexual Harassment* (hereafter referred to as the *SVSH Policy*) at http://policy.ucop.edu/doc/4000385/SVSH (PDF). The University will respond promptly and effectively to reports of sexual harassment and will take appropriate action to prevent, correct and, if necessary, discipline behavior that violates the *SVSH Policy*. See the Title IX Office website at https://www.sexualharassment.ucla.edu.

### Definitions

For detailed definitions of sexual harassment, refer to the *SVSH Policy*.

### Complaint Resolution

An individual who believes that they have been sexually harassed may contact the Title IX Director Mohammed Cato, 2255 Murphy Hall, 310-206-3417, titleix@conet.ucla.edu. If a student reports sexual harassment or sexual violence to a responsible employee, as defined under the *SVSH Policy*, the responsible employee must report it to the Title IX Director. Responsible employees include academic personnel, faculty members, and most other employees who are not defined as a confidential resource under the *SVSH Policy*.

Title IX prohibits sex discrimination, including sexual harassment and sexual violence, in any education program or activity receiving federal financial assistance. Inquiries regarding Title IX may be directed to the Title IX Director, 2255 Murphy Hall, 310-206-3417, titleix@conet.ucla.edu, or the U.S. Department of Education Office for Civil Rights at ocr@ed.gov.

## Other Forms of Harassment

The University strives to create an environment that fosters the values of mutual respect and tolerance and is free from discrimination based on race, ethnicity, sex, religion, sexual orientation, disability, age, and other personal characteristics. Certainly harassment, in its many forms, works against those values and often corrodes a person's sense of worth and interferes with one's ability to participate in University programs or activities. While the University is committed to the free exchange of ideas and the full protection of free expression, the University also recognizes that words can be used in such a way that they no longer express an idea, but rather injure and intimidate, thus undermining the ability of individuals to participate in the University community. The *University of California Policies Applying to Campus Activities, Organizations, and Students* (hereafter referred to as *Policies*; https://www.ucop.edu/student-affairs/policies/student-life-policies/pacaos.html) presently prohibit a variety of conduct by students which, in certain contexts, may be regarded as harassment or intimidation.

For example, harassing expression which is accompanied by physical abuse, threats of violence, or conduct that threatens the health or safety of any person on University property or in connection with official University functions may subject an offending student to University discipline under the provisions of the *Policies*.

Similarly, harassing conduct, including symbolic expression, which also involves conduct resulting in damage to or destruction of any property of the University or property of others while on University premises may subject a student violator to University discipline under the provisions of Section 102.04 of the *Policies*.

Further, under specific circumstances described in Section 102.11 of the *Policies,* students may be subject to University discipline for misconduct which may consist solely of expression. Copies of these *Policies* are available in the Office of Student Conduct, 1104 Murphy Hall.

## Complaint Resolution

One of the necessary measures in our efforts to assure an atmosphere of civility and mutual respect is the establishment of procedures which provide effective informal and formal mechanisms for those who believe that they have been victims of any of the above misconduct.

Many incidents of harassment and intimidation can be effectively resolved through informal means. For example, an individual may wish to confront the alleged offender immediately and firmly. An individual who chooses not to confront the alleged offender and who wishes help, advice, or information is urged to contact the Office of Student Conduct.

In addition to providing support for those who believe they have been victims of harassment, the Office of Student Conduct can help students to consider which of the available options is the most useful for the particular circumstances.

With regard to the *Universitywide Student Conduct Harassment Policy,* complainants should be aware that not all conduct which is offensive may be regarded as a violation of this *Policy* and may, in fact, be protected expression. Thus, the application of formal institutional discipline to such protected expression may not be legally permissible. Nevertheless, the University is committed to reviewing any complaint of harassing or intimidating conduct by a student and intervening on behalf of the complainant to the extent possible.

# Undergraduate Programs

The Henry Samueli School of Engineering and Applied Science offers 10 four-year curricula listed below (see the departmental listings for complete descriptions of the programs), in addition to undergraduate minors in Bioinformatics and in Environmental Engineering:

1. Bachelor of Science in Aerospace Engineering
2. Bachelor of Science in Bioengineering
3. Bachelor of Science in Chemical Engineering
4. Bachelor of Science in Civil Engineering
5. Bachelor of Science in Computer Engineering
6. Bachelor of Science in Computer Science
7. Bachelor of Science in Computer Science and Engineering
8. Bachelor of Science in Electrical Engineering
9. Bachelor of Science in Materials Engineering
10. Bachelor of Science in Mechanical Engineering

The aerospace engineering, bioengineering, chemical engineering, civil engineering, computer science and engineering, electrical engineering, materials engineering, and mechanical engineering programs are accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The computer science and computer science and engineering curricula are accredited by the Computing Accreditation Commission of ABET, http://www.abet.org. The undergraduate program in computer engineering, established in fall 2017, will be submitted to ABET for accreditation during the next ABET visit in 2024.

## Admission

Applicants to UCLA Samueli must satisfy the general UC admission requirements. See the Undergraduate Admission website at http://www.admission.ucla.edu for details. Applicants must apply directly to the school by selecting one of the majors within the school or the undeclared engineering option. In the selection process many elements are considered, including grades, test scores, and academic preparation.

Students applying as freshmen or transfers must submit their applications during the November 1 through 30 filing period. In addition, it is essential that official test scores be received no later than the date in January when the December test scores are normally reported.

Applicants must submit scores from an approved core test of mathematics, language arts, and writing. This requirement may be satisfied by taking either the ACT with Writing tests, the SAT Reasoning Test (last administered January 2016), or the SAT with Essay test. Applicants to the school are strongly encouraged to also take the following SAT Subject Tests: Mathematics Level 2 and a laboratory science test (Biology E/M, Chemistry, or Physics) that is closely related to the intended major.

Fulfilling the admission requirements, however, does not assure admission to the school. Limits have had to be set for the enrollment of new undergraduate students. Thus, not every applicant who meets the minimum requirements can be admitted.

Although applicants may qualify for admission to UCLA Samueli in freshman standing, many students take their first two years in engineering at a community college and apply to the school at the junior level. Students who begin their college work at a California community college are expected to remain at the community college to complete the lower-division requirements in chemistry, computer programming, English composition, mathematics, physics, and the recommended engineering courses before transferring to UCLA.

## Admission as a Freshman

UC requirements specify a minimum of three years of mathematics, including the topics covered in elementary and advanced algebra and two- and three-dimensional geometry. Additional study in mathematics, concluding with calculus or precalculus in the senior year, is strongly recommended and typical for applicants to UCLA Samueli.

Freshman applicants must meet the UC subject, scholarship, and examination requirements described at http://www.admission.ucla.edu.

### Credit for Advanced Placement Examinations

Students may fulfill part of the school requirements with credit allowed at the time of admission for College Board Advanced Placement (AP) Examinations with scores of 3, 4, or 5. Students with AP Examination credit may exceed the 213-unit maximum by the amount of this credit. AP Examination credit for freshmen entering fall quarter 2019 fulfills UCLA Samueli requirements as indicated on the AP credit table.

Students who have completed 36 quarter units after high school graduation at the time of the examination receive no AP Examination credit.

## Admission as a Transfer Student

Admission as a junior-level transfer student is competitive. The University of California requires applicants to have completed a minimum of 60 transferable semester units (90 quarter units) and two transferable English courses prior to enrolling at UCLA. In addition, to be considered all applicants to UCLA Samueli majors must have at least a 3.4 grade-point average in their college work. Many of the majors in the school are impacted. Excellent grades, especially for courses in preparation for the major, are expected.

Completion of the required courses in preparation for the major is critical for admission. Articulation agreements between California community colleges and UCLA Samueli include college-specific course numbers for these requirements and can be found at http://www.assist.org. Applicants who are lacking two or more of the courses are unlikely to be admitted.

Required preparation for UCLA Samueli majors:

1. Mathematics, including calculus I and II, calculus III (multivariable), differential equations, and linear algebra. The Aerospace Engineering and Mechanical Engineering majors do not require differential equations, but it is recommended
2. Calculus-based physics courses in mechanics, electricity and magnetism, and waves, sound, heat, optics, and modern physics
3. Chemistry, including two terms of general chemistry. Bioengineering and Chemical Engineering majors are also required to complete two terms of organic chemistry. The Computer Science and Computer Science and Engineering majors do not require chemistry. Electrical Engineering majors must complete only one term of chemistry
4. Computer programming: applicants to the Computer Science, Computer Science and Engineering, and Electrical Engineering majors may take any C++, C, or Java course to meet the admission requirement, but to be competitive the applicant must take a C++ course equivalent to UCLA Computer Science 31. Applicants to Chemical Engineering may take any C++, C, Java, or MATLAB course to satisfy the admission requirement, but lack of a MATLAB course

# Henry Samueli School of Engineering and Applied Science
# Advanced Placement (AP) Examination Credit

All units and course equivalents to AP examinations are lower division. If an AP examination has been given UCLA course equivalency (e.g., Economics 2), it may not be repeated at UCLA for units or grade points.

| ADVANCED PLACEMENT SCORE-TO-CREDIT CONVERSION | | | |
|---|---|---|---|
| **AP EXAMINATION** | **SCORE** | **UCLA LOWER-DIVISION UNITS AND COURSE EQUIVALENTS** | **CREDIT ALLOWED FOR UNIVERSITY AND GE REQUIREMENTS** |
| Art History | 3, 4, or 5 | 8 excess units | No application |
| Art, Studio | | 8 units maximum for all tests | |
| Drawing Portfolio | 3, 4, or 5 | 8 excess units | No application |
| Two-Dimensional Design Portfolio | 3, 4, or 5 | 8 excess units | No application |
| Three-Dimensional Design Portfolio | 3, 4, or 5 | 8 excess units | No application |
| Biology | 3, 4, or 5 | 8 excess units | No application |
| Chemistry | 3 | 8 excess units | No application |
| | 4 or 5 | 4 units (may be applied toward Chemistry 20A) plus 4 excess units | No application |
| Computer Science | | | |
| Computer Science A Test | 3, 4, or 5 | 2 excess units | No application |
| Computer Science AB Test | 3, 4, or 5 | 4 excess units | No application |
| Computer Science Principles | 3, 4, or 5 | 8 excess units | No application |
| Economics | | | |
| Macroeconomics | 3 | 4 excess units | No application |
| | 4 or 5 | Economics 2 (4 excess units) | No application |
| Microeconomics | 3 | 4 excess units | No application |
| | 4 or 5 | Economics 1 (4 excess units) | No application |
| English | | 8 units maximum for both tests | |
| Language and Composition | 3 | 8 excess units | Satisfies Entry-Level Writing requirement |
| | 4 or 5 | English Composition 3 (5 units) plus 3 excess units | Satisfies Entry-Level Writing requirement |
| Literature and Composition | 3 | 8 excess units | Satisfies Entry-Level Writing requirement |
| | 4 or 5 | English Composition 3 (5 units) plus 3 excess units | Satisfies Entry-Level Writing requirement |
| Environmental Science | 3, 4, or 5 | 4 excess units | No application |
| Geography, Human | 3, 4, or 5 | 4 excess units | No application |
| Government and Politics | | | |
| Comparative | 3, 4, or 5 | 4 excess units | No application |
| United States | 3, 4, or 5 | 4 excess units | Satisfies American History and Institutions requirement |
| History | | | |
| European | 3 | 4 excess units | No application |
| | 4 or 5 | 8 excess units | No application |
| United States | 3, 4, or 5 | 8 excess units | Satisfies American History and Institutions requirement |
| World | 3, 4, or 5 | 8 excess units | No application |

| | | | |
|---|---|---|---|
| Languages and Literatures | | | |
| Chinese Language and Culture | 3, 4, or 5 | 8 excess units | No application |
| French Language | 3 | French 3 (4 units) plus 4 excess units | No application |
| | 4 | French 4 (4 units) plus 4 excess units | No application |
| | 5 | French 5 (4 units) plus 4 excess units | No application |
| French Literature | 3, 4, or 5 | 8 excess units | No application |
| German Language | 3 | German 3 (4 units) plus 4 excess units | No application |
| | 4 | German 4 (4 units) plus 4 excess units | No application |
| | 5 | German 5 (4 units) plus 4 excess units | No application |
| Japanese Language and Culture | 3, 4, or 5 | 8 excess units | No application |
| Latin | | 8 units maximum for both tests | |
| Latin Literature | 3 | Latin 1 (4 units) | No application |
| | 4 or 5 | Latin 3 (4 units) | No application |
| Vergil | 3 | Latin 1 (4 units) | No application |
| | 4 or 5 | Latin 3 (4 units) | No application |
| Spanish Language | 3 | Spanish 3 (4 units) plus 4 excess units | No application |
| | 4 | Spanish 4 (4 units) plus 4 excess units | No application |
| | 5 | Spanish 5 (4 units) plus 4 excess units | No application |
| Spanish Literature | 3, 4, or 5 | 8 excess units | No application |
| Mathematics | | 8 units maximum for both tests | |
| Mathematics AB Test: Calculus | 3 | 4 excess units | No application |
| | 4 | 4 excess units | No application |
| | 5 | 4 units | May be applied toward Mathematics 31A |
| Mathematics BC Test: Calculus | 3 | 8 excess units | No application |
| | 4 | 4 excess units plus 4 units | 4 units may be applied toward Mathematics 31A |
| | 5 | 8 units | Mathematics 31A plus 4 units that may be applied toward Mathematics 31B |
| Music Theory | 3, 4, or 5 | 8 excess units | No application |
| Physics | | 8 units maximum for all tests | |
| Physics 1 | 3, 4, or 5 | 8 excess units | No application |
| Physics 2 | 3, 4, or 5 | 8 excess units | No application |
| Physics B Test | 3, 4, or 5 | 8 excess units | No application |
| Physics C Test: Mechanics | 3 | 4 excess units | No application |
| | 4 or 5 | 4 units (may be applied toward Physics 1A) | No application |
| Physics C Test: Electricity and Magnetism | 3, 4, or 5 | 4 excess units | No application |
| Psychology | 3 | 4 excess units | No application |
| | 4 or 5 | Psychology 10 (4 excess units) | No application |
| Statistics | 3, 4, or 5 | 4 excess units | No application |

equivalent to UCLA Mechanical and Aerospace Engineering M20 or Civil and Environmental Engineering M20 will delay time to graduation. Applicants to all other engineering majors may take any C++, C, Java, or MATLAB course to satisfy the admission requirement, but the MATLAB course equivalent to Mechanical and Aerospace Engineering M20 or Civil and Environmental Engineering M20 is preferred

5. One year of biology for applicants to the Bioengineering major is recommended
6. English composition courses, including one course equivalent to English Composition 3 at UCLA and a second UC-transferable English composition course

Transfer applicants may complete courses in addition to those above that satisfy degree requirements. Engineering and computer science courses appropriate for each major may be found at http://www.assist.org.

### Lower-Division Courses in Other Departments

Chemistry and Biochemistry 20A. Chemical Structure (4 units)

Chemistry and Biochemistry 20B. Chemical Energetics and Change (4 units)

Chemistry and Biochemistry 20L. General Chemistry Laboratory (3 units)

English Composition 3. English Composition, Rhetoric, and Language (5 units)

Mathematics 31A. Differential and Integral Calculus (4 units)

Mathematics 31B. Integration and Infinite Series (4 units)

Mathematics 32A, 32B. Calculus of Several Variables (4 units each)

Mathematics 33A. Linear Algebra and Applications (4 units)

Mathematics 33B. Differential Equations (4 units)

Physics 1A. Physics for Scientists and Engineers: Mechanics (5 units)

Physics 1B. Physics for Scientists and Engineers: Oscillations, Waves, Electric and Magnetic Fields (5 units)

Physics 1C. Physics for Scientists and Engineers: Electrodynamics, Optics, and Special Relativity (5 units)

Physics 4AL. Physics Laboratory for Scientists and Engineers: Mechanics (2 units)

Physics 4BL. Physics Laboratory for Scientists and Engineers: Electricity and Magnetism (2 units)

The courses in chemistry, mathematics, and physics are those required as preparation for majors in these subjects. Transfer students should select equivalent courses required for engineering or physical sciences majors.

# Requirements for B.S. Degrees

The Henry Samueli School of Engineering and Applied Science awards B.S. degrees to students who have satisfactorily completed four-year programs in engineering studies.

Students must meet University requirements, school requirements, and department requirements for the Bachelor of Science degree.

## University Requirements

The University of California has two requirements that undergraduate students must satisfy in order to graduate: (1) Entry-Level Writing or English as a Second Language, and (2) American History and Institutions. These requirements are discussed in detail in the Undergraduate Study section of the *UCLA General Catalog*.

## School Requirements

The Henry Samueli School of Engineering and Applied Science has seven requirements that must be satisfied for the award of the degree: unit, scholarship, academic residence, writing, technical breadth, ethics, and general education.

### Unit Requirement

To receive a bachelor's degree in any UCLA Samueli major, students must complete a minimum of 180 units. The maximum allowed is 213 units.

After 213 quarter units, enrollment may not normally be continued in the school without special permission from the associate dean. This regulation does not apply to Departmental Scholars.

### Scholarship Requirement

In addition to the requirement of at least a 2.0 (C) grade-point average (GPA) in all courses taken at any UC campus, students must achieve at least a 2.0 GPA in all upper-division courses offered in satisfaction of the subject and elective requirements of the curriculum. A 2.0 minimum GPA in upper-division mathematics, upper-division core courses, and the major field is also required for graduation. Grade-point averages are not rounded up.

### Academic Residence Requirement

Of the last 48 units completed for the B.S. degree, 36 must be earned in residence at UCLA Samueli on this campus. No more than 16 of the 36 units may be completed in Summer sessions at UCLA.

### Writing Requirement

Students must complete the UC Entry-Level Writing or English as a Second Language (ESL) requirement prior to completing the school writing requirement.

Students admitted to the school are required to complete a two-term writing requirement—Writing I and engineering writing. Both courses must be taken for letter grades, and students must receive a grade of C or better in each (a C– grade is not acceptable).

#### Writing I

The Writing I requirement must be satisfied by completing English Composition 3, 3D, 3DS, 3E, or 3SL with a grade of C or better (a C– or Passed grade is not acceptable) by the end of the second year of enrollment.

The Writing I requirement may also be satisfied by (1) scoring 4 or 5 on one of the College Board Advanced Placement Examinations in English, (2) a combination of a score of 720 or better on the SAT Reasoning Test, Writing section (last administered in January 2016) and superior performance on the English Composition 3 Proficiency Examination, (3) completing a course equivalent to English Composition 3 with a grade of C or better (a C– or Passed grade is not acceptable) taken at another institution, or (4) scoring 5, 6, or 7 on an International Baccalaureate Higher Level Examination.

Students whose native language is not English may need to take English Composition 1A, 1B, and 2I before enrolling in a Writing I course. All courses in the sequence must be passed with a grade of C or better (a C– or Passed grade is not acceptable).

#### Engineering Writing

The engineering writing requirement is satisfied by selecting one approved engineering writing (EW) course from the school writing course list or by selecting one approved Writing II (W) course. The course must be completed with a grade of C or better (a C– or Passed grade is not acceptable). Writing courses are published in the Schedule of Classes at https://sa.ucla.edu/ro/public/soc.

Writing courses also approved for general education credit may be applied toward the relevant general education foundational area.

## Technical Breadth Requirement

The technical breadth requirement consists of a set of three courses providing sufficient breadth outside the student's core program. A list of school Faculty Executive Committee-approved technical breadth requirement courses is available in the Office of Academic and Student Affairs, and deviations from that list are subject to approval by the associate dean for Academic and Student Affairs. None of the technical breadth requirement courses selected by students can be used to satisfy other major course requirements.

## Ethics Requirement

The ethics and professionalism requirement is satisfied by completing one course from Engineering 181EW, 182EW, 183EW, or 185EW with a grade of C or better (a C– or Passed grade is not acceptable). The course may be applied toward the engineering writing requirement.

## General Education Requirements

General education (GE) is more than a checklist of required courses. It is a program of study that reveals to students the ways that research scholars in the arts, humanities, social sciences, and natural sciences create and evaluate new knowledge, introduces students to the important ideas and themes of human cultures, fosters appreciation for the many perspectives and the diverse voices that may be heard in a democratic society, and develops the intellectual skills that give students the dexterity they need to function in a rapidly changing world.

This entails the ability to make critical and logical assessments of information, both traditional and digital; deliver reasoned and persuasive arguments; and identify, acquire, and use the knowledge necessary to solve problems.

Students may take one GE course per term on a Passed/Not Passed basis if they are in good academic standing and are enrolled in at least three and one-half courses (14 units) for the term. For details on P/NP grading, see Grading in the Academic Policies chapter of the *UCLA General Catalog* or consult with the Office of Academic and Student Affairs.

GE courses used to satisfy the engineering writing and/or ethics requirements must be taken for a letter grade.

### Foundations of Knowledge

General education courses are grouped into three foundational areas: Foundations of the Arts and Humanities, Foundations of Society and Culture, and Foundations of Scientific Inquiry.

Five courses (24 units minimum) are required. Engineering writing requirement courses also approved for GE credit may be applied toward the relevant GE foundational areas.

Students must meet with a counselor in the Office of Academic and Student Affairs to determine the applicability of GE cluster courses toward the engineering writing or GE requirements.

Courses listed in more than one category can fulfill GE requirements in only one of the cross-listed categories.

#### Foundations of the Arts and Humanities

Two 5-unit courses selected from two different subgroups:

- Literary and Cultural Analysis
- Philosophical and Linguistic Analysis
- Visual and Performance Arts Analysis and Practice

Courses in this area provide perspectives and intellectual skills necessary to comprehend and think critically about our situation in the world as human beings. In particular, courses provide the basic means to appreciate and evaluate the ongoing efforts of humans to explain, translate, and transform their diverse experiences of the world through such media as language, literature, philosophical systems, images, sounds, and performances. The courses introduce students to the historical development and fundamental intellectual and ethical issues associated with the arts and humanities and may also investigate the complex relations between artistic and humanistic expression and other facets of society and culture.

#### Foundations of Society and Culture

Two 5-unit courses, one from each subgroup:

- Historical Analysis
- Social Analysis

Courses in this area introduce students to the ways in which humans organize, structure, rationalize, and govern their diverse societies and cultures over time. The courses focus on a particular historical question, societal problem, or topic of political and economic concern in an effort to demonstrate how issues are objectified for study, how data is collected and analyzed, and how new understandings of social phenomena are achieved and evaluated.

#### Foundations of Scientific Inquiry

One course (4 units minimum) from the Life Sciences subgroup or one course from Bioengineering CM145/Chemical Engineering CM145, Chemistry and Biochemistry 153A, or Civil and Environmental Engineering M166/Environmental Health Sciences M166:

- Life Sciences

This requirement is automatically satisfied for Bioengineering and Chemical Engineering majors. The requirement is satisfied for Civil Engineering majors by the natural science requirement.

Courses in this area ensure that students gain a fundamental understanding of how scientists formulate and answer questions about the operation of both the physical and biological world. Courses also deal with some of the most important issues, developments, and methodologies in contemporary science, addressing such topics as the origin of the universe, environmental degradation, and the decoding of the human genome. Through lectures, laboratory experiences, writing, and intensive discussions, students consider the important roles played by the laws of physics and chemistry in society, biology, Earth and environmental sciences, and astrophysics and cosmology.

#### Foundations Course Lists

Creating and maintaining a general education curriculum is a dynamic process; consequently, courses are frequently added to the list. For the most current list of approved courses that satisfy the Foundations of Knowledge GE plan, consult with an academic counselor or see **https://www.registrar.ucla.edu/Academics/GE-Requirement**.

### Intersegmental General Education Transfer Curriculum

Transfer students from California community colleges have the option to fulfill UCLA lower-division GE requirements by completing the Intersegmental General Education Transfer Curriculum (IGETC) prior to transfer. The curriculum consists of a series of subject areas and types of courses which have been agreed on by the University of California and the California community colleges. Although GE or transfer core courses are degree requirements rather than admission requirements, students are advised to fulfill them prior to transfer. The IGETC significantly eases the transfer process, as all UCLA GE requirements are fulfilled when students complete the IGETC courses. Students who select the IGETC must complete it entirely before enrolling at UCLA. Otherwise, they must fulfill UCLA Samueli GE requirements. The school does not accept partial IGETC.

# Department Requirements

UCLA Samueli departments generally set two types of requirements that must be satisfied for award of a degree: preparation for the major (lower-division courses) and the major (upper-division courses). Preparation for the major courses should be completed before beginning upper-division work.

## Preparation for the Major

A major requires completion of a set of courses known as preparation for the major. Each department sets its own preparation for the major requirements; see the Departments and Programs chapter of this announcement.

## The Major

Students must complete their major with a scholarship average of at least a 2.0 (C) in all courses in order to remain in the major. Each course in the major department must be taken for a letter grade. See the Departments and Programs chapter of this announcement for details on each major.

# Policies and Regulations

Degree requirements are subject to policies and regulations, including the following:

# Student Responsibility

Students should take advantage of academic support resources, but they are ultimately responsible for keeping informed of and complying with the rules, regulations, and policies affecting their academic standing.

# Study List

Study lists require approval of the dean of the school or a designated representative. It is the student's responsibility to present a study list that reflects satisfactory progress toward the Bachelor of Science degree, according to standards set by the faculty. Study lists or programs of study that do not comply with these standards may result in enforced withdrawal from UCLA or other academic action.

Undergraduate students in the school are expected to enroll in at least 12 units each term. Students enrolling in fewer than 12 units must obtain approval by petition to the dean before enrolling in classes. The normal program is 16 units per term. Students may not enroll in more than 21 units per term unless an Excess Unit Petition is approved in advance by the dean.

# Minimum Progress

Full-time UCLA Samueli undergraduate students must complete a minimum of 36 units in three consecutive terms in which they are registered.

# Credit Limitations

## Advanced Placement Examinations

Some portions of Advanced Placement (AP) Examination credit are evaluated by corresponding UCLA course number. If students take the equivalent UCLA course, a deduction of UCLA unit credit is made prior to graduation. See the AP credit table.

## College Level Examination Program

Credit earned through the College Level Examination Program (CLEP) may not be applied toward the bachelor's degree.

## Community College/ Lower Division Transfer Limitation

Effective for students admitted fall 2017 and later, after completing 105 lower-division quarter units toward the degree in all institutions attended, students are allowed no further unit credit for courses completed at a community college or for lower-division courses completed at any institution outside of the University of California. The University of California does not grant transfer credit for community college or lower-division courses beyond 105 quarter units, but students may still receive subject credit for this coursework to satisfy lower-division requirements. Units earned through Advanced Placement (AP), International Baccalaureate (IB), and/or A-Level examinations are not included in the limitation. Units earned at any UC campus (through extension, summer, cross-campus, UCEAP, Intercampus Visitor Program, and regular academic year enrollment) are not included in the limitation. To convert semester units into quarter units, multiply the semester units by 1.5; for example, 12 semester units x 1.5 = 18 quarter units. To convert quarter units into semester units, multiply the quarter units by .666; for example, 12 quarter units x .666 = 7.99 or 8 semester units.

## Foreign Language

No credit is granted toward the bachelor's degree for college foreign language courses equivalent to quarter levels one and two if the equivalent of level two of the same language was completed with satisfactory grades in high school.

## Repetition of Courses

For undergraduate students who repeat a total of 16 or fewer units, only the most recently earned letter grades and grade points are computed in the grade-point average (GPA). After repeating 16 units, the GPA is based on all letter grades assigned and total units attempted. The grade assigned each time a course is taken is permanently recorded on the transcript.

1. To improve the GPA, students may repeat only those courses in which they receive a grade of C– or lower; NP or U grades may be repeated to gain unit credit. Courses in which a letter grade is received may not be repeated on a P/NP or S/U basis. Courses originally taken on a P/NP or S/U basis may be repeated on the same basis or for a letter grade.
2. Repetition of a course more than once requires the approval of the College or school or the dean of the Graduate Division and is granted only under extraordinary circumstances.
3. Degree credit for a course is given only once, but the grade assigned each time the course is taken is permanently recorded on the transcript.
4. There is no guarantee that in a later term a course can be repeated (such as in cases when a course is deleted or no longer offered). In these cases, students should consult with their academic counselor to determine if there is an alternate course that can be taken to satisfy a requirement. The alternate course would not count as a repeat of the original course.

## Minors and Double Majors

UCLA Samueli students in good academic standing may be permitted to have a minor or double major. The minor or second major must be outside the school (e.g., Electrical Engineering major and Economics major). UCLA Samueli students are not permitted to have a double major with two school majors (e.g., Chemical Engineering and Civil Engineering). Students may file an Undergraduate Request to Double Major or Add Minor form at the Office of Academic and Student Affairs. The school determines final approval of a minor or double major request; review is done on a case-by-case basis, and filing the request does not guarantee approval. Students interested in a minor or double major should meet with their counselor in 6426 Boelter Hall.

While the school considers minor or double major requests, specializations are not considered.

## Advising

It is mandatory for all students entering undergraduate programs to have their course of study approved by an academic counselor. After the first term, curricular and career advising is accomplished on a formal basis. Freshman students are assigned a faculty adviser in their particular specialization.

In addition, all undergraduate students are assigned, by major, to an academic counselor in the Office of Academic and Student Affairs who provides them with advice regarding general requirements for degrees, and UC, UCLA, and school regulations and procedures. It is the student's responsibility to periodically meet with the academic counselor, as well as with the faculty adviser, to discuss curriculum requirements, programs of study, and any other academic matters of concern.

### Curricula Planning Procedure

Students normally follow the curricula in effect when they enter the school. California community college transfer students may also select the curriculum in the *UCLA General Catalog* in effect at the time they began their community college work in an engineering program, provided attendance has been continuous since that time.

Students admitted to UCLA in fall quarter 2012 and thereafter use the Degree Audit system, which can be accessed through MyUCLA at **http://my.ucla.edu**. Students should contact their academic counselor in 6426 Boelter Hall with any questions.

UCLA Samueli undergraduate students following a *Catalog* year prior to fall quarter 2012 should schedule an appointment with their academic counselor in 6426 Boelter Hall, or by calling 310-825-9580, to review course credit and degree requirements and for program planning.

The student's regular faculty adviser is available to assist in planning electives and for discussions regarding career objectives. Students should discuss their elective plan with the adviser and obtain the adviser's approval.

Students should also see any member or members of the faculty specially qualified in their major for advice in working out a program of major courses.

Students are assigned to advisers by majors and major fields of interest. A specific adviser, or an adviser in a particular engineering department, may be requested by logging in to MyEngineering (**https://my.engineering.ucla.edu**) and clicking on the My Advisors link.

Academic counselors in the Office of Academic and Student Affairs assist students with UCLA procedures and answer questions related to general requirements.

# Honors

## Dean's Honors List

Students following the engineering curricula are eligible to be named to the Dean's Honors List each term. Minimum requirements are a course load of at least 15 units (12 units of letter grade) with a grade-point average equal to or greater than 3.7. Students are not eligible for the Dean's Honors List if they receive an Incomplete (I) or Not Passed (NP) grade or repeat a course. Only courses applicable to an undergraduate degree are considered toward eligibility for Dean's Honors.

## Latin Honors

Students who have achieved scholastic distinction may be awarded the bachelor's degree with honors. Students eligible for 2019-20 honors at graduation must have completed 90 or more units for a letter grade at the University of California and must have attained a cumulative grade-point average at graduation that places them in the top five percent of the school (GPA of 3.899 or better) for summa cum laude, next five percent (GPA of 3.839 or better) for magna cum laude, and the next 10 percent (GPA of 3.715 or better) for cum laude. The minimum GPAs required are subject to change on an annual basis. Required GPAs in effect in the graduating year determine student eligibility.

Based on grades achieved in upper-division courses applied to a specific UCLA Samueli degree requirement, engineering students must also have a 3.899 grade-point average for summa cum laude, a 3.839 for magna cum laude, and a 3.715 for cum laude. For all designations of honors, students must have a minimum 3.25 GPA in their major field upper-division courses. Upper-division courses that are not applied to a specific school BS degree requirement are excluded from these upper-division averages.

# Graduate Programs

The Henry Samueli School of Engineering and Applied Science offers courses leading to the Master of Science and Doctor of Philosophy degrees, Master of Science in Engineering online degree, Master of Engineering degree, and Engineer degree. The school is divided into seven departments that encompass the major engineering disciplines: aerospace engineering, bioengineering, chemical engineering, civil engineering, computer science, electrical and computer engineering, manufacturing engineering, materials science and engineering, and mechanical engineering. Graduate students are not required to limit their studies to a particular department and are encouraged to consider related offerings in several departments.

Also, a one-year program leading to a Certificate of Specialization is offered in various fields of engineering and applied science.

Graduate degree information is updated annually in Program Requirements for UCLA Graduate Degrees at https://grad.ucla.edu.

## Master of Science Degrees

The Henry Samueli School of Engineering and Applied Science offers the M.S. degree in Aerospace Engineering, Bioengineering, Chemical Engineering, Civil Engineering, Computer Science, Electrical Engineering, Manufacturing Engineering, Materials Science and Engineering, and Mechanical Engineering. The thesis plan requires seven formal courses and a thesis, which may be written while the student is enrolled in two individual study courses. The comprehensive examination plan requires nine formal courses and a comprehensive examination. In some fields students may be allowed to use the Ph.D. major field examination to satisfy the M.S. comprehensive examination requirement. Full-time students complete M.S. programs in an average of five terms of study (about a year and a half). To remain in good academic standing, an M.S. student must obtain a 3.0 grade-point average overall and a 3.0 GPA in graduate courses.

## Concurrent Degree Program

A concurrent degree program between UCLA Samueli and the Anderson Graduate School of Management allows students to earn two master's degrees simultaneously: the M.B.A. and the M.S. in Computer Science. Contact the Office of Academic and Student Affairs for details.

## Master of Science in Engineering Online Degree

The primary purpose of the Master of Science in Engineering online self-supporting degree program is to enable employed engineers and computer scientists to augment their technical education beyond the Bachelor of Science degree and to enhance their value to the technical organizations in which they are employed. For more information, see https://www.msol.ucla.edu.

The individual degrees include:

Engineering (online M.S.)

Engineering—Aerospace (online M.S.)

Engineering—Computer Networking (online M.S.)

Engineering—Electrical (online M.S.)

Engineering—Electronic Materials (online M.S.)

Engineering—Integrated Circuits (online M.S.)

Engineering—Manufacturing and Design (online M.S.)

Engineering—Materials Science (online M.S.)

Engineering—Mechanical (online M.S.)

Engineering—Signal Processing and Communications (online M.S.)

Engineering—Structural Materials (online M.S.)

## Master of Engineering Degree

The Master of Engineering (M.Engr.) degree is granted to graduates of the Engineering Executive Program, a two-year work-study program consisting of graduate-level professional courses in the management of technological enterprises. For details, write to the UCLA Samueli Office of Academic and Student Affairs, 6426 Boelter Hall, UCLA, Box 951601, Los Angeles, CA 90095-1601, 310-825-2514.

## Engineer Degree

The Engineer (Engr.) degree is similar to the Ph.D. degree in that the program of study is built around a major and two minor fields, and the preliminary written and oral examinations are the same. However, a dissertation is not required. Unlike the Ph.D. degree, the Engineer degree does have a formal course requirement of a minimum of 15 (at least nine graduate) courses beyond the bachelor's degree, with at least six courses in the major field (minimum of four graduate courses) and at least three in each minor field (minimum of two graduate courses in each).

## Ph.D. Degrees

The Ph.D. programs prepare students for advanced study and research in the major areas of engineering and computer science. To complete the Ph.D. all candidates must fulfill the minimum requirements of the Graduate Division. Major and minor fields may have additional course and examination requirements. For further information, contact the individual departments. To remain in good academic standing, a Ph.D. student must obtain an overall grade-point average of 3.25.

## Established Fields of Study for the Ph.D.

Students may propose other fields of study when the established fields do not meet their educational objectives.

### Bioengineering Department

Biomedical instrumentation

Biomedical signal and image processing

Biosystems science and engineering

Medical imaging informatics

Molecular cellular tissue therapeutics

Neuroengineering

### Chemical and Biomolecular Engineering Department

Chemical engineering

### Civil and Environmental Engineering Department

Civil engineering materials

Environmental engineering

Geotechnical engineering

Hydrology and water resources engineering

Structures (structural mechanics and structural/earthquake engineering)

### Computer Science Department

Artificial intelligence

Computational systems biology

Computer network systems

Computer science theory

Computer system architecture

Data science computing

Graphics and vision

Software systems

## Electrical and Computer Engineering Department

Circuits and embedded systems

Physical and wave electronics

Signals and systems

## Materials Science and Engineering Department

Ceramics and ceramic processing

Electronic and optical materials

Structural materials

## Mechanical and Aerospace Engineering Department

Applied mathematics (established minor field only)

Applied plasma physics (minor field only)

Design, robotics, and manufacturing (DROM)

Dynamics

Fluid mechanics

Micro-nano engineering

Structural and solid mechanics

Systems and control

Thermal science and engineering

For more information on specific research areas, contact the individual faculty member in the field that most closely matches the area of interest.

# Admission

Applications for admission are invited from graduates of recognized colleges and universities. Selection is based on promise of success in the work proposed, which is judged largely on the previous college record.

Candidates whose engineering background is judged to be deficient may be required to take additional coursework that may not be applied toward the degree. The adviser helps plan a program to remedy any such deficiencies, after students arrive at UCLA.

Entering students normally are expected to have completed the B.S. degree requirements with at least a 3.0 grade-point average in all coursework taken in the junior and senior years.

Students entering the Engineer/Ph.D. program normally are expected to have completed the requirements for the master's degree with at least a 3.25 grade-point average, and to have demonstrated creative ability. Normally the M.S. degree is required for admission to the Ph.D. program. Exceptional students, however, can be admitted to the Ph.D. program without having an M.S. degree.

For information on the proficiency in English requirements for international graduate students, see Graduate Admission in the Graduate Study section of the *UCLA General Catalog*.

To submit a graduate application, see **https://www.seasoasa.ucla.edu/graduate-admissions-2/**. From there connect to the site of the preferred department or program and go to the online graduate application.

# Graduate Record Examination

Educational Testing Service
P.O. Box 6000, Princeton, NJ 08541-6000
**https://www.ets.org/gre/**

Applicants to UCLA Samueli graduate programs are required to take the General Test of the Graduate Record Examination (GRE). Specific information about the GRE may be obtained from the department of interest.

Obtain applications for the GRE by contacting Educational Testing Service.

# Departments and Programs of the School

## Bioengineering

5121 Engineering V
Box 951600
Los Angeles, CA 90095-1600

310-267-4985
**bioeng@hsseas.ucla.edu**
**https://www.bioeng.ucla.edu**

Song Li, Ph.D., *Chair*
Dino Di Carlo, Ph.D., *Graduate Vice Chair*
Jacob Schmidt, Ph.D., *Undergraduate Vice Chair*

### Professors

Denise R. Aberle, M.D.
Pei-Yu Chiou, Ph.D.
Mark S. Cohen, Ph.D., *in Residence*
Linda L. Demer, M.D., Ph.D
Timothy J. Deming, Ph.D.
Dino Di Carlo, Ph.D.
Robin L. Garrell, Ph.D.
Zhen Gu, Ph.D.
Tzung K. Hsiai, M.D., Ph.D., *in Residence*
Bahram Jalali, Ph.D.
Daniel T. Kamei, Ph.D.
Andrea M. Kasko, Ph.D.
H. Pirouz Kavehpour, Ph.D.
Alireza Khademhosseini, Ph.D. *(Levi James Knight, Jr. Professor of Engineering)*
Chang-Jin (CJ) Kim, Ph.D. *(Volgenau Endowed Professor of Engineering)*
Debiao Li, Ph.D., *in Residence*
Song Li, Ph.D. *(Chancellor's Professor)*
Wentai Liu, Ph.D.
Arash Naeim, M.D., Ph.D.
Aydogan Ozcan, Ph.D.
Jacob Rosen, Ph.D.
Jacob J. Schmidt, Ph.D.
Vivek Shetty, D.D.S., Dr.Med.Dent.
Kalyanam Shivkumar, M.D., Ph.D., *in Residence*
Maie St. John, M.D., Ph.D.
Ren Sun, Ph.D.
Yi Tang, Ph.D.
Michael A. Teitell, M.D., Ph.D.
Cun Yu Wang, D.D.S., Ph.D.
Paul S. Weiss, Ph.D. *(Presidential Professor of Chemistry)*
Gerard C.L. Wong, Ph.D.
Benjamin M. Wu, D.D.S., Ph.D.
Yang Yang, Ph.D.

### Professors Emeriti

Chih-Ming Ho, Ph.D. *(Ben Rich Lockheed Martin Professor Emeritus of Aeronautics)*
Edward R.B. McCabe, M.D., Ph.D. *(Mattel Executive Endowed Professor Emeritus of Pediatrics)*

### Associate Professors

Corey W. Arnold, Ph.D., *in Residence*
Elisa Franco, Ph.D.
William Hsu, Ph.D., *in Residence*
Dan Ruan, Ph.D., *in Residence*
Holden H. Wu, Ph.D., *in Residence*

### Assistant Professors

Jun Chen, Ph.D.
Liang Gao, Ph.D.
Aaron S. Meyer, Ph.D.
Stephanie K. Seidlits, Ph.D.

### Adjunct Associate Professors

Mehmet R. Dokmeci, Ph.D.
Sophia N. Sangiorgio, Ph.D.
Bill J. Tawil, M.B.A., Ph.D.

### Adjunct Assistant Professor

Chase Linsley, Ph.D.

### AFFILIATED FACULTY

### Professors

Peyman Benharash, M.D. *(Cardiothoracic Surgery)*
Marvin Bergsneider, M.D., *in Residence (Neurosurgery)*
Douglas L. Black, Ph.D. *(Microbiology, Immunology, and Molecular Genetics)*
Alex A.T. Bui, Ph.D. *(Radiological Sciences)*
Gregory P. Carman, Ph.D. *(Materials Science and Engineering, Mechanical and Aerospace Engineering)*
Yong Chen, Ph.D. *(Materials Science and Engineering, Mechanical and Aerospace Engineering)*
Thomas Chou, Ph.D. *(Biomathematics, Mathematics)*
Samson A. Chow, Ph.D. *(Molecular and Medical Pharmacology)*
Joseph L. Demer, M.D., Ph.D. *(Neurology, Ophthalmology)*
Katrina M. Dipple, M.D., Ph.D. *(Human Genetics, Pediatrics)*
Joseph J. DiStefano III, Ph.D. *(Computer Science, Medicine)*
Bruce S. Dunn, Ph.D. *(Materials Science and Engineering)*
Jeffrey D. Eldredge, Ph.D. *(Mechanical and Aerospace Engineering)*
Alan Garfinkel, Ph.D. *(Cardiology, Integrative Biology and Physiology)*
Christopher C. Giza, Ph.D., *in Residence (Neurosurgery, Surgery)*
Thomas G. Graeber, Ph.D. *(Molecular and Medical Pharmacology)*
Robert P. Gunsalus, Ph.D. *(Microbiology, Immunology, and Molecular Genetics)*
Vijay Gupta, Ph.D. *(Materials Science and Engineering, Mechanical and Aerospace Engineering)*
Y. Sungtaek Ju, Ph.D. *(Mechanical and Aerospace Engineering)*
H. Phillip Koeffler, M.D., *in Residence (Medicine)*
Jody E. Kreiman, Ph.D., *in Residence (Surgery)*
Elliot M. Landaw, M.D., Ph.D. *(Biomathematics)*
Min Lee, Ph.D. *(Dentistry)*
Karen M. Lyons, Ph.D. *(Molecular, Cell, and Developmental Biology, Orthopaedic Surgery)*
Dejan Markovic, Ph.D. *(Electrical and Computer Engineering)*
Thomas G. Mason, Ph.D. *(Chemistry and Biochemistry, Physics and Astronomy)*
Heather D. Maynard, Ph.D. *(Chemistry and Biochemistry)*
Istvan Mody, Ph.D. *(Neurology, Physiology)*
Harold G. Monbouquette, Ph.D. *(Chemical and Biomolecular Engineering)*
Samuel S. Murray, M.D., Ph.D., *in Residence (Medicine)*
Peter M. Narins, Ph.D. *(Ecology and Evolutionary Biology, Integrative Biology and Physiology)*
Ichiro Nishimura, D.D.S., D.M.Sc., D.M.D. *(Dentistry)*
Matteo Pellegrini, Ph.D. *(Human Genetics, Molecular, Cell, and Developmental Biology)*
Laurent Pilon, Ph.D. *(Mechanical and Aerospace Engineering)*
Zhilin Qu, Ph.D., *in Residence (Cardiology, Medicine)*
Dario L. Ringach, Ph.D. *(Neurobiology, Psychology)*
Ke Sheng, Ph.D. *(Radiation Oncology)*
Desmond Smith, Ph.D. *(Molecular and Medical Pharmacology)*
Michael V. Sofroniew, M.D., Ph.D. *(Neurobiology)*
Chia B. Soo, M.D. *(Plastic Surgery)*
Igor Spigelman, Ph.D. *(Dentistry)*
Ricky Taira, Ph.D, *in Residence (Radiological Sciences)*
Albert Thomas, Ph.D., *in Residence (Radiological Sciences)*
James G. Tidball, Ph.D. *(Integrative Biology and Physiology, Pathology and Laboratory Medicine)*
Kang Ting, D.M.D., D.M.Sc. *(Dentistry)*
Hsian-Rong Tseng, Ph.D. *(Molecular and Medical Pharmacology)*
Jack Van Horn, Ph.D. *(Neurology)*
David Wong, Ph.D. *(Dentistry)*
Lily Wu, Ph.D., M.D. *(Molecular and Medical Pharmacology, Urology)*
Xinshu Grace Xiao, Ph.D. *(Integrative Biology and Physiology)*
Z. Hong Zhou, Ph.D. *(Microbiology, Immunology, and Molecular Genetics)*

### Professors Emeriti

Tony F. Chan, Ph.D. *(Mathematics)*
V. Reggie Edgerton, Ph.D. *(Integrative Biology and Physiology)*

### Associate Professors

Aydin Babakhani, Ph.D. *(Electrical and Computer Engineering)*
James W. Bisley, Ph.D. *(Neurobiology, Psychology)*
Louis S. Bouchard, Ph.D. *(Chemistry and Biochemistry)*
Robert N. Candler, Ph.D. *(Electrical and Computer Engineering, Mechanical and Aerospace Engineering)*
Benjamin M. Ellingson, Ph.D. *(Radiology)*
Peng Hu, Ph.D. *(Radiology)*
Jean-Pierre Hubschman, M.D., *in Residence (Ophthalmology)*
Daniel S. Levi, Ph.D. *(Pediatrics)*
Zili Liu, Ph.D. *(Psychology)*
Nader Pouratian, Ph.D. *(Neurosurgery)*
Amy C. Rowat, Ph.D. *(Integrative Biology and Physiology)*
Veronica J. Santos, Ph.D. *(Mechanical and Aerospace Engineering)*
Ladan Shams, Ph.D. *(Psychology)*
Michael R. van Dam, Ph.D. *(Molecular and Medical Pharmacology)*
Zhaoyan Zhang, Ph.D., *in Residence (Head and Neck Surgery)*

### Assistant Professors

Sam Emaminejad, Ph.D. *(Electrical and Computer Engineering)*
Zhaoyang Fan, Ph.D. *(Medicine)*
Neema Jamshidi, P.hD. *(Radiological Sciences)*
Shantanu Joshi, Ph.D. *(Neurology)*
Sotiris C. Masmanidis, Ph.D. *(Neurobiology)*
Behzad Sharif, Ph.D. *(Medicine)*

Kyung Hyun Sung, Ph.D. *(Radiology)*
Nanthia Suthana, Ph.D. *(Psychiatry and Biobehavioral Sciences)*

## Scope and Objectives

The faculty members in the Department of Bioengineering have created state-of-the-art facilities for cutting-edge research and developed an innovative curriculum for the education of the next generation of bioengineers.

The bioengineering program offers forward-looking courses dedicated to producing graduates who are well grounded in the fundamental sciences and highly proficient in rigorous analytical engineering tools necessary for lifelong success in the wide range of possible bioengineering careers. Combined with a strong emphasis on research, the program provides a unique engineering educational experience that responds to the growing needs and demands of bioengineering.

## Department Mission

The mission of the Bioengineering Department is to perform cutting-edge research that benefits society and to train future leaders in the wide range of possible bioengineering careers by producing graduates who are well grounded in the fundamental sciences, adept at addressing open-ended problems, and highly proficient in rigorous analytical engineering tools necessary for lifelong success.

## Undergraduate Program Educational Objectives

The bioengineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

The goal of the bioengineering curriculum is to train future leaders by providing students with the fundamental scientific knowledge and engineering tools necessary for graduate study in engineering or scientific disciplines, continued education in professional schools, or employment in industry. There are five main program educational objectives: graduates (1) participate in graduate, professional, and continuing education activities that demonstrate an appreciation for lifelong learning, (2) demonstrate professional, ethical, societal, environmental, and economic responsibility (e.g., by active membership in professional organizations), (3) demonstrate the ability to identify, analyze, and solve complex, open-ended problems by creating and implementing appropriate designs, (4) work effectively in teams consisting of people of diverse disciplines and cultures, and (5) be effective written and oral communicators in their professions or graduate/professional schools.

## Undergraduate Study

The Bioengineering major is a designated capstone major. Utilizing knowledge from previous courses and new skills learned from the capstone courses, undergraduate students work in teams to apply advanced knowledge of mathematics, science, and engineering principles to address problems at the interface of biology and engineering and to develop innovative bioengineering solutions to meet specific sets of design criteria. Coursework entails construction of student designs, project updates, presentation of projects in written and oral format, and team competition.

## Bioengineering B.S.

***Capstone Major***

### Learning Outcomes

The Bioengineering major has the following learning outcomes:

- Application of advanced knowledge of mathematics, science, and engineering principles to address problems at the interface of biology and engineering
- Design of a system, component, or process to meet desired needs
- Function as a productive member of a multidisciplinary team
- Effective oral and written communication
- Identification, formulation, and solution of engineering problems

### Preparation for the Major

*Required:* Bioengineering 10; Chemistry and Biochemistry 20A, 20B, 20L, 30A, 30AL, 30B; Civil and Environmental Engineering M20 or Computer Science 31 or Mechanical and Aerospace Engineering M20; Life Sciences 2 (satisfies GE life sciences requirement) and 3, or 7A (satisfies GE life sciences requirement) and 7C; Mathematics 31A, 31B, 32A, 32B, 33A, 33B; Physics 1A, 1B, 1C, 4AL.

### The Major

Students must complete the following courses:

1. Bioengineering 100, 110, 120, 167L, 176, 180, Electrical and Computer Engineering 100, Engineering 183EW or 185EW; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; two capstone design courses (Bioengineering 177A, 177B)
2. Two major field elective courses (8 units) from Bioengineering C101, C106, C131, C155, M260 (a petition is required for M260)
3. Five additional major field elective courses (20 units) from Bioengineering C101 (unless taken under item 2), CM102, CM103, C104, C105, C106 (unless taken under item 2), C131 (unless taken under item 2), CM140, CM145, C147, M153, C155 (unless taken under item 2), C170, C171, CM178, C179, 180L, C183, C185, CM186, CM187, 199 (8 units maximum)

Three of the major field elective courses and the three technical breadth courses may also be selected from one of the following tracks. Bioengineering majors cannot take bioengineering technical breadth

*Bioengineering undergraduates seed cells to make 3D tissue constructs.*

courses to fulfill the technical breadth requirement.

*Biomaterials and Regenerative Medicine:* Bioengineering C104, C105, CM140, C147, C183, C185, 199 (8 units maximum), Materials Science and Engineering 104, 110, 111, 120, 130, 132, 143A, 150, 151, 160, 161. The above materials science and engineering courses may be used to satisfy the technical breadth requirement.

*Biomedical Devices:* Bioengineering C131, M153, C172, 199 (8 units maximum), Electrical and Computer Engineering 102, Mechanical and Aerospace Engineering C187L. The electrical and computer engineering or mechanical and aerospace engineering courses listed above may be used to satisfy the technical breadth requirement.

For Bioengineering 199 to fulfill a track requirement, the research project must fit within the scope of the track field, and the research report must be approved by the supervisor and vice chair.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

# Graduate Study

For information on graduate admission, see Graduate Programs on page 26.

The following introductory information is based on 2019-20 program requirements for UCLA graduate degrees. Complete program requirements are available at https://grad.ucla.edu/academics/graduate-study/program-requirements-for-ucla-graduate-degrees/. Students are subject to the detailed degree requirements as published in program requirements for the year in which they enter the program.

The Bioengineering Department offers Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees in Bioengineering.

# Bioengineering M.S.

## Course Requirements

A minimum of 13 courses (44 units) is required.

For the comprehensive plan, at least 11 courses must be from the 200 series, three of which must be Bioengineering 299 courses. Students must also take one 495 course. One 100-series course may be applied toward the total course and unit requirement. No units of 500-series courses may be applied toward the minimum course requirements except for the field of medical imaging informatics where 2 units of course 597A are required.

For the thesis plan, at least 10 of the 13 courses must be from the 200 series, three of which must be Bioengineering 299 courses. Students must also take two 598 courses involving work on the thesis and one 495 course.

To remain in good academic standing, M.S. students must maintain an overall grade-point average of 3.0 and a grade-point average of 3.0 in graduate courses.

## Comprehensive Examination Plan

The comprehensive examination plan is available in all fields, and requirements vary for each field. Specific details are available from the graduate adviser. Students who fail the examination may repeat it once only, subject to the approval of the faculty examination committee. Students who fail the examination twice are not permitted to submit a thesis and are subject to termination.

## Thesis Plan

Every master's degree thesis plan requires the completion of an approved thesis that demonstrates student ability to perform original independent research. New students who select this plan are expected to submit the name of the thesis adviser to the graduate adviser by the end of their first term in residence. The thesis adviser serves as chair of the thesis committee.

A research thesis (8 units of Bioengineering 598) is to be written on a bioengineering topic approved by the thesis adviser. The thesis committee consists of the thesis adviser and two other qualified faculty members who are selected from a current list of designated members for the graduate program.

# Bioengineering Ph.D.

## Course Requirements

To complete the Ph.D. degree, all students must fulfill minimum University requirements. Students must pass the University Oral Qualifying Examination and final oral examination, and complete the courses in Group I and Group II under Fields of Study below. Also see Course Requirements under Bioengineering M.S. Students must maintain a grade-point average of 3.25 or better in all courses.

## Written and Oral Qualifying Examinations

Academic Senate regulations require all doctoral students to complete and pass University written and oral qualifying examinations prior to doctoral advancement to candidacy. Under Senate regulations the University Oral Qualifying Examination is open only to students and appointed members of their doctoral committees. In addition to University requirements, some graduate programs have other precandidacy examination requirements. What follows are the requirements for this doctoral program.

To remain in good standing in the program, Ph.D. students are expected to take the University Oral Qualifying Examination within six academic quarters and two summer quarters (i.e., two years) following matriculation. The nature and content of the examination are at the discretion of the doctoral committee, but ordinarily include a broad inquiry into the student's preparation for research. The doctoral committee also reviews the prospectus of the dissertation, the written component of the qualifying examination, prior to the oral qualifying examination.

A doctoral committee consists of a minimum of four qualified UCLA faculty members.

A final oral examination (defense of the dissertation) is required of all students.

# Fields of Study

## Biomedical Instrumentation

The biomedical instrumentation (BMI) field is designed to train bioengineers interested in the applications and development of instrumentation used in medicine and biotechnology. Examples include the use of lasers in surgery and diagnostics, new microelectrical machines for surgery, sensors for detecting and monitoring of disease, microfluidic systems for cell-based diagnostics, new tool development for basic and applied life sciences research, and controlled drug delivery devices. The principles underlying each instrument and specific clinical or biological needs are emphasized. Graduates are targeted principally for employment in academia, government research laboratories, and the biotechnology, medical devices, and biomedical industries.

### Course Requirements

Students must select at least three courses from Group I: Core Bioengineering Courses, and at least six courses from Group II: Elective Courses. A course cannot be used to simultaneously satisfy Group I and Group II course requirements.

*Group I: Core Bioengineering Courses.* At least three courses selected from Bioengineering C201, CM202, CM203, C204 C205, C206, C207, M219, M229, C239A, C239B, CM245, C255, M260, C275, CM278, C283, C285, CM286, an approved topic of 298.

*Group II: Elective Courses*. At least three courses selected from Bioengineering C201, CM202, CM203, C204, C205, C206, C207, M214A, M215, M217, M219, 220, 221, 223A, 223B, 223C, 224A, 224B, M225, M226, M227, M228, M229, C231, M233A, M233B, C239A, C239B, CM240, CM245, C247, M248, M250B, M252, C255, M260, M263, C270, C271, C272, C275, CM278, C279, 282, C283, M284, C285, CM286, M296A, M296B, M296C, M296D, an approved topic of 298, Biomathematics, 201, M203, 206, 208A, M211, 213, 220, M230, M261, M270, M271, 296B, Biostatistics M238, Chemical and Biomolecular Engineering CM215, C216, CM225, Chemistry and Biochemistry 118, 153A, 153B, 156, M230B, C240, CM260A, CM260B, C265, 269A, 269D, 277, C281, Computer Science 161, CM224, 269, Electrical and Computer Engineering 100, 102, 110, 110L, 113, 121B, 128, 131A, 132A, 141, 142, 176, 210A, 211A, M214A, 216B, M217, 224, 225, 236A, 236B, 239AS, M240C, 241A, M242A, M250B, M252, 260A, 260B, 266, 273, 274, Materials Science 110, 111, 200, 201, Mathematics, 133, 134, 136, 151A, 151B, 155, 170A, 170B, 171, 270A, 270B, 270C, 270D, 270E, 270F, Mechanical and Aerospace Engineering 103, 107, 150A, C150G, M168, 171A, 250B, 250M, 263D, 281, M287, Microbiology, Immunology, and Molecular Genetics C134, C185A, Molecular and Medical Pharmacology M110A, 110B, 203, 211A, 211B, 288, Molecular, Cell, and Developmental Biology 100, M140, 144, 165A, 168, M175A, M175B, C222D, 224, M230B, M234, M272, Neuroscience M201, M202, 205, 207, Pathology M237, 294, Physics and Biology in Medicine 205, M209, 210, 217, 218, 222, 227, M230, M248, Physiological Science M135, 166, 200.

## Biomedical Signal and Image Processing

The biomedical signal and image processing (BSIP) field prepares students for careers in the acquisition and analysis of biomedical signals and enables students to apply quantitative methods to extract meaningful information for both clinical and research applications. The program is premised on the fact that a core set of mathematical and statistical methods are held in common across signal acquisition and imaging modalities and across data analyses regardless of their dimensionality. These include signal transduction, characterization and analysis of noise, transform analysis, feature extraction from time series or images, quantitative image processing, and imaging physics. Students have the opportunity to focus their work over a broad range of modalities, including electrophysiology, optical imaging methods, MRI, CT, PET, and other tomographic devices, and/or on the extraction of image features such as organ morphometry or neurofunctional signals, and detailed anatomic/functional feature extraction. Career opportunities for BSIP trainees include medical instrumentation, engineering positions in medical imaging, and research in the application of advanced engineering skills to the study of anatomy and function.

### Course Requirements

Students must select at least three courses from Group I: Core Bioengineering Courses, and at least six courses from Group II: Elective Courses. A course cannot be used to simultaneously satisfy Group I and Group II course requirements.

*Group I: Core Bioengineering Courses*. At least three courses selected from Bioengineering C201, CM202, CM203, C204 C205, C206, C207, M219, M229, C239A, C239B, CM245, C255, M260, C275, CM278, C283, C285, CM286, an approved topic of 298.

*Group II: Elective Courses*. At least three courses selected from Bioengineering C201, CM202, CM203, C204, C205, C206, C207, M214A, M215, M217, M219, 220, 221, 223A, 223B, 223C, 224A, 224B, M225, M226, M227, M228, M229, C231, M233A, M233B, C239A, C239B, CM240, CM245, C247, M248, M250B, M252, C255, M260, M263, C270, C271, C272, C275, CM278, C279, 282, C283, M284, C285, CM286, M296A, M296B, M296C, M296D, an approved topic of 298, Biomathematics, 201, M203, 206, 208A, M211, 213, 220, M230, M261, M270, M271, 296B, Biostatistics M238, Chemical and Biomolecular Engineering CM215, C216, CM225, Chemistry and Biochemistry 118, 153A, 153B, 156, M230B, C240, CM260A, CM260B, C265, 269A, 269D, 277, C281, Computer Science 161, CM224, 269, Electrical and Computer Engineering 100, 102, 110, 110L, 113, 121B, 128, 131A, 132A, 141, 142, 176, 210A, 211A, M214A, 216B, M217, 224, 225, 236A, 236B, 239AS, M240C, 241A, M242A, M250B, M252, 260A, 260B, 266, 273, 274, Materials Science 110, 111, 200, 201, Mathematics, 133, 134, 136, 151A, 151B, 155, 170A, 170B, 171, 270A, 270B, 270C, 270D, 270E, 270F, Mechanical and Aerospace Engineering 103, 107, 150A, C150G, M168, 171A, 250B, 250M, 263D, 281, M287, Microbiology, Immunology, and Molecular Genetics C134, C185A, Molecular and Medical Pharmacology M110A, 110B, 203, 211A, 211B, 288, Molecular, Cell, and Developmental Biology 100, M140, 144, 165A, 168, M175A, M175B, C222D, 224, M230B, M234, M272, Neuroscience M201, M202, 205, 207, Pathology M237, 294, Physics and Biology in Medicine 205, M209, 210, 217, 218, 222, 227, M230, M248, Physiological Science M135, 166, 200.

## Biosystems Science and Engineering

Graduate study in biosystems science and engineering (BSSE) emphasizes the systems aspects of living processes, as well as their component parts. It is intended for science and engineering students interested in understanding biocontrol, regulation, communication, and measurement or visualization of biomedical systems (of aggregate parts—whole systems), for basic or clinical applications. Dynamic systems engineering, mathematical, statistical, and multiscale computational modeling and optimization methods—applicable at all biosystems levels—form the theoretical underpinnings of the field. They are the paradigms for exploring the integrative and hierarchical dynamical properties of biomedical systems quantitatively—at molecular, cellular, organ, whole organism, or societal levels—and leveraging them in applications. The academic program provides directed interdisciplinary biosystems studies in these areas, as well as quantitative dynamic systems biomodeling methods—integrated with the biology for specialized life sciences domain studies of interest to the students.

Typical research areas include molecular and cellular systems physiology, organ systems physiology, and medical, pharmacological, and pharmacogenomic systems studies, neurosystems, imaging and remote sensing systems, robotics, learning and knowledge-based systems, visualization, and virtual clinical environments. The program fosters careers in research and teaching in systems biology/physiology, engineering, medicine, and/or the biomedical sciences, or research and development in the biomedical or pharmaceutical industry.

### Course Requirements

Students must select at least three courses from Group I: Core Bioengineering Courses, and at least six courses from Group II: Elective Courses. A course cannot be used to simultaneously satisfy Group I and Group II course requirements.

*Group I: Core Bioengineering Courses*. At least three courses selected from Bioengineering C201, CM202, CM203, C204 C205, C206, C207, M219, M229, C239A, C239B, CM245, C255, M260, C275, CM278, C283, C285, CM286, an approved topic of 298.

*Group II: Elective Courses*. At least three courses selected from Bioengineering C201, CM202, CM203, C204, C205, C206, C207, M214A, M215, M217, M219, 220, 221, 223A, 223B, 223C, 224A, 224B, M225, M226, M227, M228, M229, C231, M233A, M233B, C239A, C239B, CM240, CM245, C247, M248, M250B, M252, C255, M260, M263, C270, C271, C272, C275, CM278, C279, 282, C283, M284, C285, CM286, M296A, M296B, M296C, M296D, an approved topic of 298, Biomathematics, 201, M203, 206, 208A, M211, 213, 220, M230, M261, M270, M271, 296B, Biostatistics M238, Chemical and Biomolecular Engineering CM215, C216, CM225, Chemistry and Biochemistry 118, 153A, 153B, 156, M230B, C240, CM260A, CM260B, C265, 269A, 269D, 277, C281, Computer Science 161, CM224, 269, Electrical and Computer Engineering 100, 102, 110, 110L, 113, 121B, 128, 131A, 132A, 141, 142, 176, 210A, 211A, M214A, 216B, M217, 224, 225, 236A, 236B, 239AS, M240C, 241A, M242A, M250B, M252, 260A, 260B, 266, 273, 274, Materials Science 110, 111, 200, 201, Mathematics, 133, 134, 136, 151A, 151B, 155, 170A, 170B, 171, 270A, 270B, 270C, 270D, 270E, 270F, Mechanical and Aerospace Engineering 103, 107, 150A, C150G, M168, 171A, 250B, 250M, 263D, 281, M287, Microbiology, Immunology, and Molecular Genetics C134, C185A, Molecular and Medical Pharmacology M110A, 110B, 203, 211A, 211B, 288, Molecular, Cell, and Developmental Biology 100, M140, 144, 165A, 168, M175A, M175B, C222D, 224, M230B, M234, M272, Neuroscience M201, M202, 205, 207, Pathology M237, 294, Physics and Biology in Medicine 205, M209, 210, 217, 218, 222, 227, M230, M248, Physiological Science M135, 166, 200.

## Medical Imaging Informatics

Medical imaging informatics (MII) is the rapidly evolving field that combines biomedical informatics and imaging, developing and adapting core methods in informatics to improve the usage and application of imaging in healthcare. Graduate study encompasses principles from across engineering, computer science, information sciences, and biomedicine. Imaging informatics research concerns itself with the full spectrum of low-level concepts (e.g., image standardization and processing, image feature extraction) to higher-level abstractions (e.g., associating semantic meaning to a region in an image, visualization and fusion of images with other biomedical data) and ultimately, applications and the derivation of new knowledge from imaging. Medical imaging informatics ad-dresses not only the images themselves, but encompasses the associated (clinical) data to understand the context of the imaging study, to document observations, and to correlate and reach new conclusions about a disease and the course of a medical problem.

Research foci include distributed medical information architectures and systems, medical image understanding and applications of image processing, medical natural language processing, knowledge engineering and medical decision-support, and medical data visualization. Coursework is geared toward students with science and engineering backgrounds, introducing them to these areas in addition to providing exposure to fundamental biomedical informatics, imaging, and clinical issues. The area encourages interdisciplinary training with faculty members from multiple departments and emphasizes the practical translational development and evaluation of tools/applications to support clinical research and care.

### Course Requirements

Medical Imaging Informatics students must take the nine Group I: Core Courses on General Concepts, at least three courses from Group II: Subfield Specific Courses, and at least one course from Group III: Ethics Courses.

*Group I: Core Courses on General Concepts.* Bioengineering 220, 223A, 223B, 223C, 224A, 224B, M226, M227, M228.

*Group II: Subfield Specific Courses.* M.S. capstone students must take any three courses from across the four concentrations, and Ph.D. students must take six course, three each from two concentrations.

*Computer Understanding of Images:* Computer Science M266A, M266B, Electrical and Computer Engineering 211A, Physics in Biology and Medicine 210, 214, M219, M230.

*Computer Understanding of Text and Medical Information Retrieval:* Computer Science 263A, Information Studies 228, 245, 246, 260, Linguistics 218, 232, Statistics M231A.

*Information Networks and Data Access in Medical Environment:* Computer Science 240B, 241A, 244A, 246

*Probabilistic Modeling and Visualization of Medical Data:* Biostatistics M232, M234, M235, M236, Computer Science 241B, 262A, M262C, Epidemiology 212, Information Studies 272, 277

*Group III: Ethics Course.* One course selected from Bioengineering 165EW, Biomathematics M261, Microbiology, Immunology, and Molecular Genetics C134, or Neuroscience 207.

## Molecular Cellular Tissue Therapeutics

The molecular cellular tissue therapeutics (MCTT) field covers novel therapeutic development across all biological length scales from molecules to cells to tissues. At the molecular and cellular levels, this research area encompasses the engineering of biomaterials, ligands, enzymes, protein-protein interactions, intracellular trafficking, biological signal transduction, genetic regulation, cellular metabolism, drug delivery vehicles, and cell-cell interactions, as well as the development of chemical/biological tools to achieve this.

At the tissue level, the field encompasses two subfields—biomaterials and tissue engineering. The properties of bone, muscles, and tissues, the replacement of natural materials with artificial compatible and functional materials such as polymers, composites, ceramics, and metals, and the complex interactions between implants and the body are studied at the tissue level. The research emphasis is on the fundamental basis for diagnosis, disease treatment, and redesign of molecular, cellular, and tissue functions. In addition to quantitative experiments required to obtain spatial and temporal information, quantitative and integrative modeling approaches at the molecular, cellular, and tissue levels are also included within this field. Although some of the research remains exclusively at one length scale, research that bridges any two or all three length scales is also an integral part of this field. Graduates are targeted principally for employment in academia, government research laboratories, and the biotechnology, pharmaceutical, and biomedical industries.

### Course Requirements

Students must select at least three courses from Group I: Core Bioengineering Courses, and at least six courses from Group II: Elective Courses. A course cannot be used to simultaneously satisfy Group I and Group II course requirements.

*Group I: Core Bioengineering Courses.* At least three courses selected from Bioengineering C201, CM202, CM203, C204 C205, C206, C207, M219, M229, C239A, C239B, CM245, C255, M260, C275, CM278, C283, C285, CM286, an approved topic of 298.

*Group II: Elective Courses.* At least three courses selected from Bioengineering C201, CM202, CM203, C204, C205, C206, C207, M214A, M215, M217, M219, 220, 221, 223A, 223B, 223C, 224A, 224B, M225, M226, M227, M228, M229, C231, M233A, M233B, C239A, C239B, CM240, CM245, C247, M248, M250B, M252, C255, M260, M263, C270, C271, C272, C275, CM278, C279, 282, C283, M284, C285, CM286, M296A, M296B, M296C, M296D, an approved topic of 298, Biomathematics, 201, M203, 206, 208A, M211, 213, 220, M230, M261, M270, M271, 296B, Biostatistics M238, Chemical and Biomolecular Engineering CM215, C216, CM225, Chemistry and Biochemistry 118, 153A, 153B, 156, M230B, C240, CM260A, CM260B, C265, 269A, 269D, 277, C281, Computer Science 161, CM224, 269, Electrical and Computer Engineering 100, 102, 110, 110L, 113, 121B, 128, 131A, 132A, 141, 142, 176, 210A, 211A, M214A, 216B, M217, 224, 225, 236A, 236B, 239AS, M240C, 241A, M242A, M250B, M252, 260A, 260B, 266, 273, 274, Materials Science 110, 111, 200, 201, Mathematics, 133, 134, 136, 151A, 151B, 155, 170A, 170B, 171, 270A, 270B, 270C, 270D, 270E, 270F, Mechanical and Aerospace Engineering 103, 107, 150A, C150G, M168, 171A, 250B, 250M, 263D, 281, M287, Microbiology, Immunology, and Molecular Genetics C134, C185A, Molecular and Medical Pharmacology M110A, 110B, 203, 211A, 211B, 288, Molecular, Cell, and Developmental Biology 100, M140, 144, 165A, 168, M175A, M175B, C222D, 224, M230B, M234, M272, Neuroscience M201, M202, 205, 207, Pathology M237, 294, Physics and Biology in Medicine 205, M209, 210, 217, 218, 222, 227, M230, M248, Physiological Science M135, 166, 200.

## Neuroengineering

The neuroengineering (NE) field is designed to enable students with a background in biological sciences to develop and execute projects that make use of state-of-the-art technology, including microelectromechanical systems (MEMS), signal processing, and photonics. Students with a background in engineering develop and execute projects that address problems that have a neuro-scientific base, including locomotion and pattern generation, central control of movement, and the processing of sensory information. Trainees develop the capacity for the multidisciplinary teamwork, in intellectually and socially diverse settings, that is necessary for new scientific insights and dramatic technological progress in the twenty-first century. Students take a curriculum designed to encourage cross-fertilization of neuroscience and engineering. The goal is for neuroscientists and engineers to speak each others' language and move comfortably among the intellectual domains of the two fields.

### Course Requirements

Students must select at least three courses from Group I: Core Bioengineering Courses, and at least six courses from Group II: Elective Courses. A course cannot be used to simultaneously satisfy Group I and Group II course requirements.

*Group I: Core Bioengineering Courses*. At least three courses selected from Bioengineering C201, CM202, CM203, C204 C205, C206, C207, M219, M229, C239A, C239B, CM245, C255, M260, C275, CM278, C283, C285, CM286, an approved topic of 298.

*Group II: Elective Courses*. At least three courses selected from Bioengineering C201, CM202, CM203, C204, C205, C206, C207, M214A, M215, M217, M219, 220, 221, 223A, 223B, 223C, 224A, 224B, M225, M226, M227, M228, M229, C231, M233A, M233B, C239A, C239B, CM240, CM245, C247, M248, M250B, M252, C255, M260, M263, C270, C271, C272, C275, CM278, C279, 282, C283, M284, C285, CM286, M296A, M296B, M296C, M296D, an approved topic of 298, Biomathematics, 201, M203, 206, 208A, M211, 213, 220, M230, M261, M270, M271, 296B, Biostatistics M238, Chemical and Biomolecular Engineering CM215, C216, CM225, Chemistry and Biochemistry 118, 153A, 153B, 156, M230B, C240, CM260A, CM260B, C265, 269A, 269D, 277, C281, Computer Science 161, CM224, 269, Electrical and Computer Engineering 100, 102, 110, 110L, 113, 121B, 128, 131A, 132A, 141, 142, 176, 210A, 211A, M214A, 216B, M217, 224, 225, 236A, 236B, 239AS, M240C, 241A, M242A, M250B, M252, 260A, 260B, 266, 273, 274, Materials Science 110, 111, 200, 201, Mathematics, 133, 134, 136, 151A, 151B, 155, 170A, 170B, 171, 270A, 270B, 270C, 270D, 270E, 270F, Mechanical and Aerospace Engineering 103, 107, 150A, C150G, M168, 171A, 250B, 250M, 263D, 281, M287, Microbiology, Immunology, and Molecular Genetics C134, C185A, Molecular and Medical Pharmacology M110A, 110B, 203, 211A, 211B, 288, Molecular, Cell, and Developmental Biology 100, M140, 144, 165A, 168, M175A, M175B, C222D, 224, M230B, M234, M272, Neuroscience M201, M202, 205, 207, Pathology M237, 294, Physics and Biology in Medicine 205, M209, 210, 217, 218, 222, 227, M230, M248, Physiological Science M135, 166, 200.

# Faculty Areas of Thesis Guidance

### Professors

Denise R. Aberle, M.D. (U. Kansas, 1979)
*Medical imaging informatics: imaging-based clinical trials, medical data visualization*

Pei-Yu Chiou, Ph.D. (UC Berkeley, 2005)
*Optofluidics systems*

Mark S. Cohen, Ph.D. (Rockefeller, 1985)
*Rapid methods of MR imaging, fusion of electrophysiology and fMRI, advanced approaches to MR data analysis, ultra-low field MRI using SQUID detection, low energy focused ultrasound for neurostimulation*

Linda L. Demer, M.D., Ph.D. (Johns Hopkins, 1983)
*Vascular biology, biomineralization, vascular calcification, mesenchymal stem cells*

Timothy J. Deming, Ph.D. (UC Berkeley, 1993)
*Polymer synthesis, polymer processing, supramolecular materials, organometallic catalysis, biomimetic materials, polypeptides*

Dino Di Carlo, Ph.D. (UC Berkeley, 2006)
*Microfluidics, biomedical microdevices, cellular diagnostics, cell analysis and engineering*

Robin L. Garrell, Ph.D. (U. Michigan, 1984)
*Bioanalytical and surface chemistry with emphasis on fundamentals and applications of adhesion and wetting*

Zhen Gu, Ph.D. (UCLA, 2010)
*Drug delivery, biomaterials, cell therapy, micro- and nano-biotechnology*

Tzung K. Hsiai, M.D. (U. Chicago, 1993), Ph.D. (UCLA, 2001)
*Cardiovascular mechnotransduction, MEMS and nanosensors, vascular endothelial dynamics, molecular imaging of atherosclerotic lesions, reactive nitrogen species (RNS) and reactive oxygen species (ROS)*

Bahram Jalali, Ph.D. (Columbia, 1989)
*RF photonics, fiber-optic integrated circuits, integrated optics, microwave photonics*

Daniel T. Kamei, Ph.D. (MIT, 2001)
*Molecular cell bioengineering, rational design of molecular therapeutics, systems-level analyses of cellular processes, drug delivery, diagnostics*

Andrea M. Kasko, Ph.D. (U. Akron, 2004)
*Polymer synthesis, biomaterials, tissue engineering, cell-material interactions*

H. Pirouz Kavehpour, Ph.D. (MIT, 2003)
*Microscale fluid mechanics, transport phenomena in biological systems, physics of contact line phenomena, complex fluids, non-isothermal flows, micro- and nano-heat guides, microtribology*

Alireza Khademhosseini, Ph.D. (MIT, 2005)
*Biomaterials, tissue engineering, organ-on-a-chip, stem cell engineering, biofabrication, micro- and nano-technology, biomedical devices*

Chang-Jin (CJ) Kim, Ph.D. (UC Berkeley, 1991)
*Microelectromechanical systems: micro/nano fabrication technologies, structures, actuators, devices, and systems; microfluidics involving surface tension (especially droplets)*

Debiao Li, Ph.D. (U. Virginia, 1992)
*Development and clinical application of fast MR imaging techniques for the evaluation of the cardiovascular system*

Song Li, Ph.D. (UC San Diego, 1997)
*Stem cell engineering, tissue engineering and vascular remodeling, mechanobiology/mechanotransduction*

Wentai Liu, Ph.D. (U. Michigan, 1983)
*Neural engineering*

Arash Naeim, M.D. (UCLA, 1995), Ph.D. (RAND Graduate School, 2002)
*Remote monitoring, wearable sensors, big data analytics, clinical informatics, health care analytics*

Aydogan Ozcan, Ph.D. (Stanford, 2005)
*Photonics, nano- and bio-technology*

Jacob Rosen, Ph.D. (Tel Aviv U., Israel, 1997)
*Natural integration of a human arm/powered exoskeleton system*

Jacob J. Schmidt, Ph.D. (U. Minnesota, 1999)
*Bioengineering and biophysics at micro and nanoscales, membrane protein engineering, biological-inorganic hybrid devices*

Vivek Shetty, D.D.S., Dr.Med.Dent. (U. Regensburg, Germany, 1992)
*Mobile health, biosensors, salivary diagnostics, value-based health care*

Kalyanam Shivkumar, M.D. (U. Madras, India, 1990), Ph.D. (UCLA, 1999)
*Mechanisms of cardiac arrhythmias in humans, complex catheter ablation, medical technology for cardiovascular therapeutics*

Maie St. John, M.D., Ph.D. (Yale, 1999)
*Novel diagnostic and treatment modalities for head and neck cancer*

Ren Sun, Ph.D. (Yale, 1993)
*Integration of biology and nanotechnology to define underlying mechanism and develop new diagnostic and therapeutic approaches, with murine gammaherpesvirus 68 (MHV-68) as an in vivo model*

Yi Tang, Ph.D. (Caltech, 2002)
*Biosynthesis of proteins/polypeptides with unnatural amino acids, synthesis of novel antibiotics/antitumor products*

Michael A. Teitell, M.D. (UCLA, 1993), Ph.D. (UCLA, 1991)
*Immune system development and cancer; regulation of gene expression in development and malignancy; linking RNA processing with mitochondrial homeostasis, metabolism and proliferation; nanoscale evaluation of malignant transformation*

Cun Yu Wang, D.D.S. (Peking U., China, 1989), Ph.D. (U. North Carolina Chapel Hill, 1998)
*Molecular signaling (NF-KB and Wnt) tumor-invasive growth and metastasis, adult mesenchymal stem cells, dental stem cells and regenerative medicine, inflammation and innate immunity*

Paul S. Weiss, Ph.D. (UC Berkeley, 1986)
*Atomic-scale surface chemistry and physics, molecular devices, nanolithography, biophysics and neuroscience, nanometer-scale electronics and storage, surface interactions, surface motion, dynamics, and direct manipulation, extending capabilities of scanning tunneling microscope, molecular-scale control and measurement of composition and properties in membranes*

Gerald C.L. Wong, Ph.D. (UC Berkeley, 1994)
*Antimicrobials and antibiotic-resistant pathogens, bacterial communities, cystic fibrosis, apoptosis proteins and cancer therapeutics, disinfection and water purification, self-assembly in biology and biotechnology, physical chemistry of solvation, soft condensed matter physics, biophysics*

Benjamin M. Wu, D.D.S. (U. Pacific, 1987), Ph.D. (MIT, 1997)
*Biomaterials, cell-material interactions, materials processing, tissue engineering, prosthetic and regenerative dentistry*

Yang Yang, Ph.D. (U. Massachusetts Lowell, 1992)
*Conjugated polymers and applications in optoelectronic devices such as light-emitting diodes, photodiodes, and field-effect transistors*

### Professors Emeriti

Chih-Ming Ho, Ph.D. (Johns Hopkins, 1974)
*Molecular fluidic phenomena, microelectromechanical systems (MEMS), bionano technologies, biomolecular sensor arrays, control of cellular complex systems, rapid search of combinatorial medicine*

Edward R.B. McCabe, Ph.D. (USC, 1972), M.D. (USC, 1974)
*Stem cell identification, regenerative medicine, systems biology*

### Associate Professors

Corey W. Arnold, Ph.D. (UCLA, 2009)
*Machine learning, deep learning, medical imaging, radiology, pathology, electronic health records, mHealth*

Elisa Franco, Ph.D. (U. Trieste, Italy, 2007)
*Convergence of structural biology, dynamics and controls using specialized biomolecular frameworks*

William Hsu, Ph.D. (UCLA, 2009)
*Deep and reinforcement learning, data integration, clinical data science, imaging informatics*

Dan Ruan, Ph.D. (U. Michigan Ann Arbor, 2008)
*Signal and image processing, system modeling and optimization, time series, data science and informatics*

Holden H. Wu, Ph.D. (Stanford, 2009)
*Signal and image processing, magnetic resonance imaging, MRI-guided interventions, nanotheranostics*

### Assistant Professors

Jun Chen, Ph.D. (Georgia Tech, 2016)
*Biomaterials, biomedical devices, wearable bioelectronics, smart textiles, nanogenerator, body area network*

Liang Gao, Ph.D. (Rice, 2011)
*Biomedical optics, tissue imaging, ultra-fast optics, hyperspectral imaging*

Aaron S. Meyer, Ph.D. (MIT, 2014)
*Molecular cell bioengineering, systems-level cellular signaling analysis, model-driven analysis and design, cancer and innate immune signaling*

Stephanie K. Seidlits, Ph.D. (U. Texas Austin, 2010)
*Neural tissue engineering, spinal cord injury, gene therapy, hydrogels, cell-material interactions, high-throughput biological techniques, nervous system extracellular matrix, neural stem cells and development*

### Adjunct Associate Professors

Mehmet R. Dokmeci, Ph.D. (U. Michigan Ann Arbor, 2000)
*Micro-and nano-scale sensors and systems, biomedical devices, tissue engineering, implantable sensors*

Sophia N. Sangiorgio, Ph.D. (UCLA, 2006)
*Orthopedic biomechanics*

Bill J. Tawil, M.B.A. (California Lutheran, 2006), Ph.D. (McGill, 1992)
*Skin tissue engineering, bone tissue engineering, vascular tissue engineering, wound healing*

### Adjunct Assistant Professor

Chase Linsley, Ph.D. (UCLA, 2015)
*Biomaterials, tissue engineering, drug delivery, additive manufacturing*

### Affiliated Faculty

For areas of thesis guidance, see **http://www.bioeng.ucla.edu/about-your-faculty-adviser**.

## Lower-Division Courses

**10. Introduction to Bioengineering. (2)** Lecture, two hours; discussion, one hour; outside study, three hours. Preparation: high school biology, chemistry, mathematics, physics. Introduction to scientific and technological bases for established and emerging subfields of bioengineering, including biosensors, bioinstrumentation, and biosignal processing, biomechanics, biomaterials, tissue engineering, biotechnology, biological imaging, biomedical optics and lasers, neuroengineering, and biomolecular machines. Letter grading. Mr. Deming (F)

**19. Fiat Lux Freshman Seminars. (1)** Seminar, one hour. Discussion of and critical thinking about topics of current intellectual importance, taught by faculty members in their areas of expertise and illuminating many paths of discovery at UCLA. P/NP grading.

**99. Student Research Program. (1 to 2)** Tutorial (supervised research or other scholarly work), three hours per week per unit. Entry-level research for lower-division students under guidance of faculty mentor. Students must be in good academic standing and enrolled in minimum of 12 units (excluding this course). Individual contract required; consult Undergraduate Research Center. May be repeated. P/NP grading.

## Upper-Division Courses

**100. Bioengineering Fundamentals. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Mathematics 32A, Physics 1A. Fundamental basis for analysis and design of biological and biomedical devices and systems. Classical and statistical thermodynamic analysis of biological systems. Material, energy, charge, and force balances. Introduction to network analysis. Letter grading. Mr. Kamei (F)

**C101. Engineering Principles for Drug Delivery. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Mathematics 33B, Physics 1B. Application of engineering principles for designing and understanding delivery of therapeutics. Discussion of physics and mathematics required for understanding colloidal stability. Analysis of concepts related to both modeling and experimentation of endocytosis and intracellular trafficking mechanisms. Analysis of diffusion of drugs, coupled with computational and engineering mathematics approaches. Concurrently scheduled with course C201. Letter grading. Mr. Kamei (W)

**CM102. Human Physiological Systems for Bioengineering I. (4)** (Same as Physiological Science CM102.) Lecture, three hours; laboratory, two hours. Preparation: human molecular biology, biochemistry, and cell biology. Not open for credit to Physiological Science majors. Broad overview of basic biological activities and organization of human body in system (organ/tissue) to system basis, with particular emphasis on molecular basis. Modeling/simulation of functional aspect of biological system included. Actual demonstration of biomedical instruments, as well as visits to biomedical facilities. Concurrently scheduled with course CM202. Letter grading. Ms. Seidlits (Sp)

**CM103. Human Physiological Systems for Bioengineering II. (4)** (Same as Physiological Science CM103.) Lecture, three hours; laboratory, two hours. Preparation: human molecular biology, biochemistry, and cell biology. Not open for credit to Physiological Science majors. Molecular-level understanding of human anatomy and physiology in selected organ systems (digestive, skin, musculoskeletal, endocrine, immune, urinary, reproductive). System-specific modeling/simulations (immune regulation, wound healing, muscle mechanics and energetics, acid-base balance, excretion). Functional basis of biomedical instrumentation (dialysis, artificial skin, pathogen detectors, ultrasound, birth-control drug delivery). Concurrently scheduled with course CM203. Letter grading. Ms. Seidlits (Not offered 2019-20)

**C104. Physical Chemistry of Biomacromolecules. (4)** Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: Chemistry 20A, 20B, 30A, Life Sciences 2, 3. To understand biological materials and design synthetic replacements, it is imperative to understand their physical chemistry. Biomacromolecules such as protein or DNA can be analyzed and characterized by applying fundamentals of polymer physical chemistry. Investigation of polymer structure and conformation, bulk and solution thermodynamics and phase behavior, polymer networks, and viscoelasticity. Application of engineering principles to problems involving biomacromolecules such as protein conformation, solvation of charged species, and separation and characterization of biomacromolecules. Concurrently scheduled with course C204. Letter grading. Mr. Wong (F)

**C105. Engineering of Bioconjugates. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Chemistry 20A, 20B, 20L. Highly recommended: one organic chemistry course. Bioconjugate chemistry is science of coupling biomolecules for wide range of applications. Oligonucleotides may be coupled to one surface in gene chip, or one protein may be coupled to one polymer to enhance its stability in serum. Wide variety of bioconjugates are used in delivery of pharmaceuticals, in sensors, in medical diagnostics, and in tissue engineering. Basic concepts of chemical ligation, including choice and design of conjugate linkers depending on type of biomolecule and desired application, such as degradable versus nondegradable linkers. Presentation and discussion of design and synthesis of synthetic bioconjugates for some sample applications. Concurrently scheduled with course C205. Letter grading. Mr. Deming (F)

**C106. Topics in Bioelectricity for Bioengineers. (4)** Lecture, three hours; discussion, one hour; outside study, eight hours. Requisites: Chemistry 20B, Life Sciences 2, 3, Mathematics 33B, Physics 1C. Coverage in depth of physical processes associated with biological membranes and channel proteins, with specific emphasis on electrophysiology. Basic physical principles governing electrostatics in dielectric media, building on complexity to ultimately address action potentials and signal propagation in nerves. Topics include Nernst/Planck and Poisson/Boltzmann equations, Nernst potential, Donnan equilibrium, GHK equations, energy barriers in ion channels, cable equation, action potentials, Hodgkin/Huxley equations, impulse propagation, axon geometry and conduction, dendritic integration. Concurrently scheduled with course C206. Letter grading. Mr. Schmidt (F)

**C107. Polymer Chemistry for Bioengineers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course C104 or C105. Fundamental concepts of polymer synthesis, including step-growth, chain growth (ionic, radical, metal catalyzed), and ring-opening, with focus on factors that can be used to control chain length, chain length distribution, and chain-end functionality, chain copolymerization, and stereochemistry in polymerizations. Presentation of applications of use of different polymerization techniques. Concepts of step-growth, chain-growth, ring-opening, and coordination polymerization, and effects of synthesis route on polymer properties. Lectures include both theory and practical issues demonstrated through examples. Concurrently scheduled with course C207. Letter grading. Mr. Deming (W)

**110. Biotransport and Bioreaction Processes. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: course 100, Mathematics 33B. Introduction to analysis of fluid flow, heat transfer, mass transfer, binding events, and biochemical reactions in systems of interest to bioengineers, including cells, tissues, organs, human body, extracorporeal devices, tissue engineering systems, and bioartificial organs. Introduction to pharmacokinetic analysis. Letter grading. Mr. Kamei (Sp)

**120. Biomedical Transducers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Chemistry 30A, Electrical Engineering 100, Mathematics 32B, Physics 1C. Principles of transduction, design characteristics for different measurements, reliability and performance characteristics, and data processing and recording. Emphasis on silicon-based microfabricated and nanofabricated sensors. Novel materials, biocompatibility, biostability. Safety of electronic interfaces. Actuator design and interfacing control. Letter grading. Mr. Schmidt (W)

**C131. Nanopore Sensing. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: courses 100, 120, Life Sciences 2, 3, Physics 1A, 1B, 1C. Analysis of sensors based on measurements of fluctuating ionic conductance through artificial or protein nanopores. Physics of pore conductance. Applications to single molecule detection and DNA sequencing. Review of current literature and technological applications. History and instrumentation of resistive pulse sensing, theory and instrumentation of electrical measurements in electrolytes, nanopore fabrication, ionic conductance through pores and GHK equation, patch clamp and single channel measurements and instrumentation, noise issues, protein engineering, molecular sensing, DNA sequencing, membrane engineering, and future directions of field. Concurrently scheduled with course C231. Letter grading. Mr. Schmidt (Not offered 2019-20)

**C139A. Biomolecular Materials Science I. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Overview of chemical and physical foundations of biomolecular materials science that concern materials aspects of molecular biology, cell biology, and bioengineering. Understanding of different types of interactions that exist between biomolecules, such as van der Waals interactions, entropically modulated electrostatic interactions, hydrophobic interactions, hydration and solvation interactions, polymer-mediated interactions, depletion interactions, molecular recognition, and others. Illustration of these ideas using examples from bioengineering and biomedical engineering. Students should be able to make simple calculations and estimates that allow them to engage broad spectrum of bioengineering problems, such as those in drug and gene delivery and tissue engineering. May be taken independently for credit. Concurrently scheduled with course C239A. Letter grading. Mr. Wong (W)

**C139B. Biomolecular Materials Science II. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Course C139A is not requisite to C139B. Overview of chemical and physical foundations of biomolecular materials science that concern materials aspects of molecular biology, cell biology, and bioengineering. Understanding of different basic types of biomolecules, with emphasis on nucleic acids, proteins, and lipids. Study of how biological and biomimetic systems organize into their functional forms via self-assembly and how these structures impart biological function. Illustration of these ideas using examples from bioengineering and biomedical engineering. Case study on current topics, including drug delivery, gene therapy, cancer therapeutics, emerging pathogens, and relation of self-assembly to disease states. May be taken independently for credit. Concurrently scheduled with course C239B. Letter grading. Mr. Wong (Sp)

**CM140. Introduction to Biomechanics. (4)** (Same as Mechanical and Aerospace Engineering CM140.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: Mechanical and Aerospace Engineering 101, 102, and 156A or 166A. Introduction to mechanical functions of human body; skeletal adaptations to optimize load transfer, mobility, and function. Dynamics and kinematics. Fluid mechanics applications. Heat and mass transfer. Power generation. Laboratory simulations and tests. Concurrently scheduled with course CM240. Letter grading. Mr. Gupta (W)

**CM145. Molecular Biotechnology for Engineers. (4)** (Same as Chemical Engineering CM145.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: Chemical Engineering 45. Selected topics in molecular biology that form foundation of biotechnology and biomedical industry today. Topics include recombinant DNA technology, molecular research tools, manipulation of gene expression, directed mutagenesis and protein engineering, DNA-based diagnostics and DNA microarrays, antibody and protein-based diagnostics, genomics and bioinformatics, isolation of human genes, gene therapy, and tissue engineering. Concurrently scheduled with course CM245. Letter grading. Mr. Liao (F)

**C147. Applied Tissue Engineering: Clinical and Industrial Perspective. (4)** Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: course CM102, Chemistry 20A, 20B, 20L, Life Sciences 1 or 2. Overview of central topics of tissue engineering, with focus on how to build artificial tissues into regulated clinically viable products. Topics include biomaterials selection, cell source, delivery methods, FDA approval processes, and physical/chemical and biological testing. Case studies include skin and artificial skin, bone and cartilage, blood vessels, neurotissue engineering, and liver, kidney, and other organs. Clinical and industrial perspectives of tissue engineering products. Manufacturing constraints, clinical limitations, and regulatory challenges in design and development of tissue-engineering devices. Concurrently scheduled with course C247. Letter grading. Mr. Wu (Sp)

**M153. Introduction to Microscale and Nanoscale Manufacturing. (4)** (Same as Chemical Engineering M153, Electrical and Computer Engineering M153, and Mechanical and Aerospace Engineering M183B.) Lecture, three hours; laboratory, four hours; outside study, five hours. Enforced requisites: Chemistry 20A, Physics 1A, 1B, 1C, 4AL, 4BL. Introduction to general manufacturing methods, mechanisms, constrains, and microfabrication and nanofabrication. Focus on concepts, physics, and instruments of various microfabrication and nanofabrication techniques that have been broadly applied in industry and academia, including various photolithography technologies, physical and chemical deposition methods, and physical and chemical etching methods. Hands-on experience for fabricating microstructures and nanostructures in modern cleanroom environment. Letter grading. Mr. Chiou (F,Sp)

**C155. Fluid-Particle and Fluid-Structure Interactions in Microflows. (4)** Lecture, four hours; laboratory, one hour; outside study, seven hours. Enforced requisite: course 110. Introduction to Navier/Stokes equations, assumptions, and simplifications. Analytical framework for calculating simple flows and numerical methods to solve and gain intuition for complex flows. Forces on particles in Stokes flow and finite-inertia flows. Flows induced around particles with and without finite inertia and implications for particle-particle interactions. Secondary flows induced by structures and particles in confined flows. Particle separations by fluid dynamic forces: field-flow fractionation, inertial focusing, structure-induced separations. Application concepts in internal biological flows and separations for biotechnology. Helps students become sufficiently fluent with fluid mechanics vocabulary and techniques, design and model microfluidic systems to manipulate fluids, cells, and particles, and develop strong intuition for how fluid and particles behave in arbitrarily structured microchannels over range of Reynolds numbers. Concurrently scheduled with course C255. Letter grading. Mr. Di Carlo (W)

**165EW. Bioengineering Ethics. (4)** Lecture, four hours; discussion, three hours; outside study, five hours. All professions have ethical rules that derive from moral theory. Bioethics is well-established discipline that addresses ethical problems about life, such as when do fertilized eggs become people? Should ending of life ever be assisted? At what cost should it be maintained? Unlike physicians, bioengineers do not make these decisions in practice. Engineering ethics addresses ethical problems about producing devices from molecules to bridges, such as when do concerns about risk outweigh concerns about cost? When are weapons too dangerous to design? At what point does benefit of committing to building devices outweigh need to wait for more scientific confirmation of their effectiveness? Bioengineers must be aware of consequences of applying such devices to all living systems. Emphasis on research and writing within engineering environments. Satisfies engineering writing requirement. Letter grading. Mr. Wu (Not offered 2019-20)

**167L. Bioengineering Laboratory. (4)** Lecture, two hours; laboratory, six hours; outside study, four hours. Enforced requisite: Chemistry 20L. Laboratory experiments in fluorescence microscopy, bioconjugation, soft lithography, and cell culture culminate in design of engineered surface for cell growth. Introduction to techniques used in laboratories and their underlying physical or chemical properties. Case studies connect laboratory techniques to current biomedical engineering research and reinforce experimental design skills. Letter grading. Ms. Seidlits (F,Sp)

**C170. Energy-Tissue Interactions. (4)** Lecture, three hours; outside study, nine hours. Enforced requisites: Life Sciences 2, Physics 1C. Introduction to therapeutic and diagnostic use of energy delivery devices in medical and dental applications, with emphasis on understanding fundamental mechanisms underlying various types of energy-tissue interactions. Concurrently scheduled with course C270. Letter grading. (Not offered 2019-20)

**C170L. Introduction to Techniques in Studying Laser-Tissue Interaction. (2)** Laboratory, four hours; outside study, two hours. Corequisite: course C170. Introduction to simulation and experimental techniques used in studying laser-tissue interactions. Topics include computer simulations of light propagation in tissue, measuring absorption spectra of tissue/tissue phantoms, making tissue phantoms, determination of optical properties of different tissues, techniques of temperature distribution measurements. Concurrently scheduled with course C270L. Letter grading. (Not offered 2019-20)

**C171. Laser-Tissue Interaction II: Biologic Spectroscopy. (4)** Lecture, four hours; outside study, eight hours. Requisite: course C170. Designed for physical sciences, life sciences, and engineering majors. Introduction to optical spectroscopy principles, design of spectroscopic measurement devices, optical properties of tissues, and fluorescence spectroscopy biologic media. Concurrently scheduled with course C271. Letter grading. (Not offered 2019-20)

**C172. Design of Minimally Invasive Surgical Tools. (4)** Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: Chemistry 30B, Life Sciences 2, 3, Mathematics 32A. Introduction to design principles and engineering concepts used in design and manufacture of tools for minimally invasive surgery. Coverage of FDA regulatory policy and surgical procedures. Topics include optical devices, endoscopes and laparoscopes, biopsy devices, laparoscopic tools, cardiovascular and interventional radiology devices, orthopedic instrumentation, and integration of devices with therapy. Examination of complex process of tool design, fabrication, testing, and validation. Preparation of drawings and consideration of development of new and novel devices. Concurrently scheduled with course C272. Letter grading. (Not offered 2019-20)

**C175. Machine Learning and Data-Driven Modeling in Bioengineering. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Requisites: Civil Engineering M20 or Mechanical and Aerospace Engineering M20, Computer Science 31, Mathematics 32B, 33A. Overview of foundational data analysis and machine-learning methods in bioengineering, focusing on how these techniques can be applied to interpret experimental observations. Topics include probabilities, distributions, cross-validation, analysis of variance, reproducible computational workflows, dimensionality reduction, regression, hidden Markov models, and clustering. Students gain theoretical and practical knowledge of data analysis and machine-learning methods relevant to bioengineering. Application of these methods to experimental data from bioengineering studies. Students become sufficiently familiar with these techniques to design studies incorporating such analyses, execute analysis, and work in teams using similar approaches, and ensure correctness of their results. Concurrently scheduled with course C275. Letter grading. Mr. Meyer (Sp)

**176. Principles of Biocompatibility. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: course 100, Mathematics 33B, Physics 1C. Biocompatibility at systemic, tissue, cellular, and molecular levels. Biomechanical compatibility, stress/strain constitutive equations, cellular and molecular response to mechanical signals, biochemical and cellular compatibility, immune response. Letter grading. Mr. Wu (Sp)

**177A. Bioengineering Capstone Design I. (4)** Lecture, two hours; laboratory, six hours; outside study, four hours. Enforced requisites: courses 167L, 176. Lectures, seminars, and discussions on aspects of biomedical device and therapeutic design, including topics such as need finding, intellectual property, entrepreneurship, regulation, and project management. Working in teams, students develop innovative solutions to address current problems in medicine and biology. Sourcing and ordering of materials and supplies relevant to student projects. Exploration of different experimental and computational methods. Scientific presentation of progress. Letter grading. Mr. Di Carlo (F)

**177B. Bioengineering Capstone Design II. (4)** Lecture, two hours; laboratory, six hours; outside study, four hours. Enforced requisite: course 177A. Lectures, seminars, and discussions on aspects of biomedical device and therapeutic design, including meetings with scientific/clinical advisers and guest lectures from scientists in industry. Working in teams, students develop innovative solutions to address current problems in medicine and biology. Students conduct directed experiments and computational modeling, give oral presentations, write reports, and participate in bioengineering design competition. Letter grading. Mr. Di Carlo (W)

**CM178. Introduction to Biomaterials. (4)** (Same as Materials Science CM180.) Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: Chemistry 20A, 20B, and 20L, or Materials Science 104. Engineering materials used in medicine and dentistry for repair and/or restoration of damaged natural tissues. Topics include relationships between material properties, suitability to task, surface chemistry, processing and treatment methods, and biocompatibility. Concurrently scheduled with course CM278. Letter grading. Ms. Kasko (F)

**C179. Biomaterials-Tissue Interactions. (4)** Lecture, three hours; outside study, nine hours. Requisite: course CM178. In-depth exploration of host cellular response to biomaterials: vascular response, interface, and clotting, biocompatibility, animal models, inflammation, infection, extracellular matrix, cell adhesion, and role of mechanical forces. Concurrently scheduled with course C279. Letter grading. Mr. Wu (Not offered 2019-20)

**180. System Integration in Biology, Engineering, and Medicine I. (4)** Lecture, three hours; discussion, two hours; outside study, seven hours. Enforced requisites: courses 100, 110, 120, Life Sciences 3, Physics 1C. Corequisite: course 180L. Part I of two-part series. Molecular basis of normal physiology and pathophysiology, and engineering design principles of cardiovascular and pulmonary systems. Fundamental engineering principles of selected medical therapeutic devices. Letter grading. Mr. Dunn, Mr. Wu (W)

**180L. System Integration in Biology, Engineering, and Medicine I Laboratory. (4)** Lecture, one hour; laboratory, four hours; clinical visits, four hours; outside study, three hours. Corequisite: course 180. Hands-on experimentation and clinical applications of selected medical therapeutic devices associated with cardiovascular and pulmonary disorders. Letter grading. Mr. Dunn, Mr. Wu (Sp)

**M182. Systems Biomodeling and Simulation Basics. (4)** (Same as Computer Science M182.) Lecture, three hours; discussion, one hour; laboratory, two hours; outside study, six hours. Requisite: Mathematics 3B, 31B, or Life Sciences 30A. Recommended corequisite: Mathematics 3C, 32A, or Life Sciences 30B. Designed for undergraduate students in life sciences and engineering. Introduction to explicit modeling and simulation of dynamic biological systems. Presentation of how biology, biochemistry, and physiology underlying dynamic systems biomodeling are transformed into system diagrams and graphs for refining conceptual understanding of their form and function. Structural models, formulated from basic conservation and mass action laws and feedback concepts, are further transformed into first-order differential equations, and implemented in simulation diagrams for quantifying and exploring biosystem properties. Examples show how to use these explicit models to gain clarity on nature of biosystem phenomena, and frame questions and explore new ideas for research. Letter grading. (F)

**C183. Targeted Drug Delivery and Controlled Drug Release. (4)** Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: Chemistry 20A, 20B, 20L. New therapeutics require comprehensive understanding of modern biology, physiology, biomaterials, and engineering. Targeted delivery of genes and drugs and their controlled release are important in treatment of challenging diseases and relevant to tissue engineering and regenerative medicine. Drug pharmacodynamics and clinical pharmacokinetics. Application of engineering principles (diffusion, transport, kinetics) to problems in drug formulation and delivery to establish rationale for design and development of novel drug delivery systems that can provide spatial and temporal control of drug release. Introduction to biomaterials with specialized structural and interfacial properties. Exploration of both chemistry of materials and physical presentation of devices and compounds used in delivery and release. Concurrently scheduled with course C283. Letter grading. Ms. Kasko (Sp)

**M184. Introduction to Computational and Systems Biology. (2)** (Same as Computational and Systems Biology M184 and Computer Science M184.) Lecture, two hours; outside study, four hours. Enforced requisites: one course from Civil Engineering M20, Computer Science 31, Mechanical and Aerospace Engineering M20, or Program in Computing 10A, and Mathematics 3B or 31B. Survey course designed to introduce students to computational and systems modeling and computation in biology and medicine, providing motivation, flavor, culture, and cutting-edge contributions in computational biosciences and aiming for more informed basis for focused studies by students with computational and systems biology interests. Presentations by individual UCLA researchers discussing their active computational and systems biology research. P/NP grading. Mr. DiStefano (Not offered 2019-20)

**C185. Introduction to Tissue Engineering. (4)** Lecture, three hours; discussion, one hour; outside study, eight hours. Requisites: course CM102 or CM202, Chemistry 20A, 20B, 20L. Tissue engineering applies principles of biology and physical sciences with engineering approach to regenerate tissues and organs. Guiding principles for proper selection of three basic components for tissue engineering: cells, scaffolds, and molecular signals. Concurrently scheduled with course C285. Letter grading. Ms. Kasko (W)

**CM186. Computational Systems Biology: Modeling and Simulation of Biological Systems. (5)** (Same as Computational and Systems Biology M186, Computer Science CM186, and Ecology and Evolutionary Biology M178.) Lecture, four hours; laboratory, three hours; outside study, eight hours. Dynamic biosystems modeling and computer simulation methods for studying biological/biomedical processes and systems at multiple levels of organization. Control system, multicompartmental, predator-prey, pharmacokinetic (PK), pharmacodynamic (PD), and other structural modeling methods applied to life sciences problems at molecular, cellular (biochemical pathways/networks), organ, and organismic levels. Both theory- and data-driven modeling, with focus on translating biomodeling goals and data into mathematics models and implementing them for simulation and analysis. Basics of numerical simulation algorithms, with modeling software exercises in class and PC laboratory assignments. Concurrently scheduled with course CM286. Letter grading. Mr. DiStefano (W)

**CM187. Research Communication in Computational and Systems Biology. (4)** (Same as Computational and Systems Biology M187 and Computer Science CM187.) Lecture, four hours; outside study, eight hours. Requisite: course CM186. Closely directed, interactive, and real research experience in active quantitative systems biology research laboratory. Direction on how to focus on topics of current interest in scientific community, appropriate to student interests and capabilities. Critiques of oral presentations and written progress reports explain how to proceed with search for research results. Major emphasis on effective research reporting, both oral and written. Concurrently scheduled with course CM287. Letter grading. Mr. DiStefano (W,Sp)

**188. Special Courses in Bioengineering. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Special topics in bioengineering for undergraduate students taught on experimental or temporary basis, such as those taught by resident and visiting faculty members. May be repeated for credit with topic or instructor change. Letter grading. (F,W,Sp)

**194. Research Group Seminars: Bioengineering. (4)** Seminar, three hours. Limited to bioengineering undergraduate students who are part of research group. Study and analysis of current topics in bioengineering. Discussion of current research literature in research specialty of faculty member teaching course. Student presentation of projects in research specialty. May be repeated for credit. Letter grading.

**199. Directed Research in Bioengineering. (2 to 8)** Tutorial, to be arranged. Limited to juniors/seniors. Supervised individual research or investigation under guidance of faculty mentor. Culminating paper or project required. May be repeated for credit with school approval. Individual contract required; enrollment petitions available in Office of Academic and Student Affairs. Letter grading. (F,W,Sp)

## Graduate Courses

**C201. Engineering Principles for Drug Delivery. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Mathematics 33B, Physics 1B. Application of engineering principles for designing and understanding delivery of therapeutics. Discussion of physics and mathematics required for understanding colloidal stability. Analysis of concepts related to both modeling and experimentation of endocytosis and intracellular trafficking mechanisms. Analysis of diffusion of drugs, coupled with computational and engineering mathematics approaches. Concurrently scheduled with course C101. Letter grading. Mr. Kamei (F)

**CM202. Human Physiological Systems for Bioengineering I. (4)** (Same as Physiological Science CM204.) Lecture, three hours; laboratory, two hours. Preparation: human molecular biology, biochemistry, and cell biology. Not open for credit to Physiological Science majors. Broad overview of basic biological activities and organization of human body in system (organ/tissue) to system basis, with particular emphasis on molecular basis. Modeling/simulation of functional aspect of biological system included. Actual demonstration of biomedical instruments, as well as visits to biomedical facilities. Concurrently scheduled with course CM102. Letter grading. Ms. Seidlits (F)

**CM203. Human Physiological Systems for Bioengineering II. (4)** (Same as Physiological Science CM203.) Lecture, three hours; laboratory, two hours. Preparation: human molecular biology, biochemistry, and cell biology. Not open for credit to Physiological Science majors. Molecular-level understanding of human anatomy and physiology in selected organ systems (digestive, skin, musculoskeletal, endocrine, immune, urinary, reproductive). System-specific modeling/simulations (immune regulation, wound healing, muscle mechanics and energetics, acid-base balance, excretion). Functional basis of biomedical instrumentation (dialysis, artificial skin, pathogen detectors, ultrasound, birth-control drug delivery). Concurrently scheduled with course CM103. Letter grading. Ms. Seidlits (W)

**C204. Physical Chemistry of Biomacromolecules. (4)** Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: Chemistry 20A, 20B, 30A, Life Sciences 2, 3. To understand biological materials and design synthetic replacements, it is imperative to understand their physical chemistry. Biomacromolecules such as protein or DNA can be analyzed and characterized by applying fundamentals of polymer physical chemistry. Investigation of polymer structure and conformation, bulk and solution thermodynamics and phase behavior, polymer networks, and viscoelasticity. Application of engineering principles to problems involving biomacromolecules such as protein conformation, solvation of charged species, and separation and characterization of biomacromolecules. Concurrently scheduled with course C104. Letter grading. Mr. Wong (F)

**C205. Engineering of Bioconjugates. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Chemistry 20A, 20B, 20L. Highly recommended: one organic chemistry course. Bioconjugate chemistry is science of coupling biomolecules for wide range of applications. Oligonucleotides may be coupled to one surface in gene chip, or one protein may be coupled to one polymer to enhance its stability in serum. Wide variety of bioconjugates are used in delivery of pharmaceuticals, in sensors, in medical diagnostics, and in tissue engineering. Basic concepts of chemical ligation, including choice and design of conjugate linkers depending on type of biomolecule and desired application, such as degradable versus nondegradable linkers. Presentation and discussion of design and synthesis of synthetic bioconjugates for some sample applications. Concurrently scheduled with course C105. Letter grading. Mr. Deming (F)

**C206. Topics in Bioelectricity for Bioengineers. (4)** Lecture, three hours; discussion, one hour; outside study, eight hours. Requisites: Chemistry 20B, Life Sciences 2, 3, Mathematics 33B, Physics 1C. Coverage in depth of physical processes associated with biological membranes and channel proteins, with specific emphasis on electrophysiology. Basic physical principles governing electrostatics in dielectric media, building on complexity to ultimately address action potentials and signal propagation in nerves. Topics include Nernst/Planck and Poisson/Boltzmann equations, Nernst potential, Donnan equilibrium, GHK equations, energy barriers in ion channels, cable equation, action potentials, Hodgkin/Huxley equations, impulse propagation, axon geometry and conduction, dendritic integration. Concurrently scheduled with course C106. Letter grading. Mr. Schmidt (F)

**C207. Polymer Chemistry for Bioengineers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course C204 or C205. Fundamental concepts of polymer synthesis, including step-growth, chain growth (ionic, radical, metal catalyzed), and ring-opening, with focus on factors that can be used to control chain length, chain length distribution, and chain-end functionality, chain copolymerization, and stereochemistry in polymerizations. Presentation of applications of use of different polymerization techniques. Concepts of step-growth, chain-growth, ring-opening, and coordination polymerization, and effects of synthesis route on polymer properties. Lectures include both theory and practical issues demonstrated through examples. Concurrently scheduled with course C107. Letter grading. Mr. Deming (W)

**M214A. Digital Speech Processing. (4)** (Same as Electrical and Computer Engineering M214A.) Lecture, three hours; laboratory, two hours; outside study, seven hours. Requisite: Electrical and Computer Engineering 113. Theory and applications of digital processing of speech signals. Mathematical models of human speech production and perception mechanisms, speech analysis/synthesis. Techniques include linear prediction, filter-bank models, and homomorphic filtering. Applications to speech synthesis, automatic recognition, and hearing aids. Letter grading. Ms. Alwan (W)

**M215. Biochemical Reaction Engineering. (4)** (Same as Chemical Engineering CM215.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: Chemical Engineering 101C. Use of previously learned concepts of biophysical chemistry, thermodynamics, transport phenomena, and reaction kinetics to develop tools needed for technical design and economic analysis of biological reactors. Letter grading. Mr. Liao (Sp)

**M217. Biomedical Imaging. (4)** (Same as Electrical and Computer Engineering M217.) Lecture, three hours; discussion, one hour; outside study, eight hours. Requisite: Electrical and Computer Engineering 114 or 211A. Optical imaging modalities in biomedicine. Other nonoptical imaging modalities discussed briefly for comparison purposes. Letter grading.

**M219. Principles and Applications of Magnetic Resonance Imaging. (4)** (Same as Physics and Biology in Medicine M219.) Lecture, three hours; discussion, one hour. Basic principles of magnetic resonance (MR), physics, and image formation. Emphasis on hardware, Bloch equations, analytic expressions, image contrast mechanisms, spin and gradient echoes, Fourier transform imaging methods, structure of pulse sequences, and various scanning parameters. Introduction to advanced techniques in rapid imaging, quantitative imaging, and spectroscopy. Letter grading.

**220. Introduction to Medical Informatics. (2)** Lecture, two hours; outside study, four hours. Designed for graduate students. Introduction to research topics and issues in medical informatics for students new to field. Definition of this emerging field of study, current research efforts, and future directions in research. Key issues in medical informatics to expose students to different application domains, such as information system architectures, data and process modeling, information extraction and representations, information retrieval and visualization, health services research, telemedicine. Emphasis on current research endeavors and applications. S/U grading. Mr. Kangarloo (F)

**221. Human Anatomy and Physiology for Medical and Imaging Informatics. (4)** Lecture, four hours; outside study, eight hours. Designed for graduate students. Introduction to basic human anatomy and physiology, with particular emphasis on understanding and visualization of anatomy and physiology through medical images. Topics relevant to acquisition, representation, and dissemination of anatomical knowledge in computerized clinical applications. Topics include chest, cardiac, neurology, gastrointestinal/genitourinary, endocrine, and musculoskeletal systems. Introduction to basic imaging physics (magnetic resonance, computed tomography, ultrasound, computed radiography) to provide context for imaging modalities predominantly used to view human anatomy. Geared toward nonphysicians who require more formal understanding of human anatomy/physiology. Letter grading. Mr. El-Saden (F)

**223A-223B-223C. Programming Laboratories for Medical and Imaging Informatics I, II, III. (4-4-4)** Lecture, two hours; laboratory, two hours; outside study, eight hours. Designed for graduate students. Programming laboratories to support coursework in other medical and imaging informatics core curriculum courses. Exposure to programming concepts for medical applications, with focus on basic abstraction techniques used in image processing and medical information system infrastructures. Letter grading. **223A.** Requisites: Computer Science 31, 32, Program in Computing 20A, 20B. Course 223A is requisite to 223B, which is requisite to 223C. Integrated with topics presented in course M227 to reinforce concepts presented with practical experience. Projects focus on understanding medical networking issues and implementation of basic protocols for healthcare environment, with emphasis on use of DICOM. Introduction to basic tools and methods used within informatics. **223B.** Requisite: course 223A. Integrated with topics presented in courses 223A, M227, and M228 to reinforce concepts presented with practical experience. Projects focus on medical image manipulation and decision support systems. **223C.** Requisite: course 223B. Exposure to programming concepts for medical applications, with focus on basic abstraction techniques used to extract meaningful features from medical text and imaging data and visualize results. Integrated with topics presented in courses 224B and M226 to reinforce concepts presented with practical experience. Projects focus on medical information retrieval, knowledge representation, and visualization. Mr. Meng (F,W,Sp)

**224A. Physics and Informatics of Medical Imaging. (4)** Lecture, four hours; laboratory, eight hours. Requisites: Mathematics 33A, 33B. Designed for graduate students. Introduction to principles of medical imaging and imaging informatics for nonphysicists. Overview of core imaging modalities: X ray, computed tomography (CT), and magnetic resonance (MR). Topics include signal generation, localization, and quantization. Image representation and analysis techniques such as Markov random fields, spatial characterization (atlases), denoising, energy representations, and clinical imaging workstation design. Provides basic understanding of issues related to basic medical image acquisition and analysis. Current research efforts with focus on clinical applications and new types of information made available through these modalities. Letter grading. Mr. Morioka (W)

**224B. Advances in Imaging Informatics. (4)** Lecture, four hours; outside study, eight hours. Overview of informatics-based applications of medical imaging with focus on various advances in field, such as content-based image retrieval, computer-aided detection/diagnosis, and imaging genomics. Introduction to core concepts in information retrieval (IR), reviewing seminal papers on evaluating IR systems and their use in medicine (e.g., teaching files, case-based retrieval, etc.). Examination of specific techniques for image feature extraction and processing, feature representation, indexing and querying, and classification (machine/deep learning). Survey of clinical applications of these techniques and ongoing challenges. Letter grading. Mr. Morioka (Sp)

**M225. Bioseparations and Bioprocess Engineering. (4)** (Same as Chemical Engineering CM225.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced corequisite: Chemical Engineering 101C. Separation strategies, unit operations, and economic factors used to design processes for isolating and purifying materials like whole cells, enzymes, food additives, or pharmaceuticals that are products of biological reactors. Letter grading. Mr. Monbouquette (W)

**M226. Medical Knowledge Representation. (4)** (Same as Information Studies M253.) Seminar, four hours; outside study, eight hours. Designed for graduate students. Issues related to medical knowledge representation and its application in healthcare processes. Topics include data structures used for representing knowledge (conceptual graphs, frame-based models), different data models for representing spatio-temporal information, rule-based implementations, current statistical methods for discovery of knowledge (data mining, statistical classifiers, and hierarchical classification), and basic information retrieval. Review of work in constructing ontologies, with focus on problems in implementation and definition. Common medical ontologies, coding schemes, and standardized indices/terminologies (SNOMED, UMLS). Letter grading. Mr. Taira (Sp)

**M227. Medical Information Infrastructures and Internet Technologies. (4)** (Same as Information Studies M254.) Lecture, four hours; outside study, eight hours. Designed for graduate students. Introduction to networking, communications, and information infrastructures in medical environment. Exposure to basic concepts related to networking at several levels: low-level (TCP/IP, services), medium-level (network topologies), and high-level (distributed computing, Web-based services) implementations. Commonly used medical communication protocols (HL7, DICOM) and current medical information systems (HIS, RIS, PACS). Advances in networking, such as wireless health systems, peer-to-peer topologies, grid/cloud computing. Introduction to security and encryption in networked environments. Letter grading. Mr. Bui (F)

**M228. Medical Decision Making. (4)** (Same as Information Studies M255.) Lecture, four hours; outside study, eight hours. Designed for graduate students. Overview of issues related to medical decision making. Introduction to concept of evidence-based medicine and decision processes related to process of care and outcomes. Basic probability and statistics to understand research results and evaluations, and algorithmic methods for decision-making processes (Bayes theorem, decision trees). Study design, hypothesis testing, and estimation. Focus on technical advances in medical decision support systems and expert systems, with review of classic and current research. Introduction to common statistical and decision-making software packages to familiarize students with current tools. Letter grading. Mr. Kangarloo (W)

**M229. Advanced Topics in Magnetic Resonance Imaging. (4)** (Same as Physics and Biology in Medicine M229.) Lecture, four hours. Requisite: course M219. Designed for students interested in pursuing research related to development or translation of new magnetic resonance imaging (MRI) technique. Basic tools and understanding of recent MRI developments that have had high impact on field, involve novel pulse sequence design or image reconstructions, and enable imaging of anatomy or function in way that surpasses what is currently possible with any modality. Topics include in-depth sequence simulation, RF pulse design, rapid image acquisition, parallel imaging, compressed sensing, image reconstruction and processing, motion encoding and compensation, chemical-shift imaging and understanding, and understanding/avoiding artifacts. Programming exercises in MATLAB to provide hands-on experience. Letter grading.

**C231. Nanopore Sensing. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: courses 100, 120, Life Sciences 2, 3, Physics 1A, 1B, 1C. Analysis of sensors based on measurements of fluctuating ionic conductance through artificial or protein nanopores. Physics of pore conductance. Applications to single molecule detection and DNA sequencing. Review of current literature and technological applications. History and instrumentation of resistive pulse sensing, theory and instrumentation of electrical measurements in electrolytes, nanopore fabrication, ionic conductance through pores and GHK equation, patch clamp and single channel measurements and instrumentation, noise issues, protein engineering, molecular sensing, DNA sequencing, membrane engineering, and future directions of field. Concurrently scheduled with course C131. Letter grading. Mr. Schmidt (F)

**M233A. Medtech Innovation I: Entrepreneurial Opportunities in Medical Technology. (4)** (Same as Management M271A.) Lecture, three hours; outside study, nine hours. Designed for graduate and professional students in engineering, dentistry, design, law, management, and medicine. Focus on understanding how to identify unmet clinical needs, properly filtering through these needs using various acceptance criteria, and selecting promising needs for which potential medtech solutions are explored. Students work in groups to expedite traditional research and development processes to invent and implement new medtech devices that increase quality of clinical care and result in improved patient outcomes in hospital system. Introduction to intellectual property basics and various medtech business models. Letter grading. Mr. Liu, Mr. Shivkumar (W)

**M233B. Medtech Innovation II: Prototyping and New Venture Development. (4)** (Same as Management M271B.) Lecture, three hours; outside study, nine hours. Requisite: course M233A. Designed for graduate and professional students in engineering, dentistry, design, law, management, and medicine. Development of medtech solutions for unmet clinical needs previously identified in course M233A. Steps necessary to commercialize viable medtech solutions. Exploration of concept selection, business plan development, intellectual property filing, financing strategies, and device prototyping. Letter grading. Mr. Lieu, Mr. Shivkumar, Mr. Wu (Sp)

**C239A. Biomolecular Materials Science I. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Overview of chemical and physical foundations of biomolecular materials science that concern materials aspects of molecular biology, cell biology, and bioengineering. Understanding of different types of interactions that exist between biomolecules, such as van der Waals interactions, entropically modulated electrostatic interactions, hydrophobic interactions, hydration and solvation interactions, polymer-mediated interactions, depletion interactions, molecular recognition, and others. Illustration of these ideas using examples from bioengineering and biomedical engineering. Students should be able to make simple calculations and estimates that allow them to engage broad spectrum of bioengineering problems, such as those in drug and gene delivery and tissue engineering. May be taken independently for credit. Concurrently scheduled with course C139A. Letter grading. Mr. Wong (W)

**C239B. Biomolecular Materials Science II. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Course C239A is not requisite to C239B. Overview of chemical and physical foundations of biomolecular materials science that concern materials aspects of molecular biology, cell biology, and bioengineering. Understanding of different basic types of biomolecules, with emphasis on nucleic acids, proteins, and lipids. Study of how biological and biomimetic systems organize into their functional forms via self-assembly and how these structures impart biological function. Illustration of these ideas using examples from bioengineering and biomedical engineering. Case study on current topics, including drug delivery, gene therapy, cancer therapeutics, emerging pathogens, and relation of self-assembly to disease states. May be taken independently for credit. Concurrently scheduled with course C139B. Letter grading. Mr. Wong (Sp)

**CM240. Introduction to Biomechanics. (4)** (Same as Mechanical and Aerospace Engineering CM240.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: Mechanical and Aerospace Engineering 101, 102, and 156A or 166A. Introduction to mechanical functions of human body; skeletal adaptations to optimize load transfer, mobility, and function. Dynamics and kinematics. Fluid mechanics applications. Heat and mass transfer. Power generation. Laboratory simulations and tests. Concurrently scheduled with course CM140. Letter grading. Mr. Gupta (W)

**CM245. Molecular Biotechnology for Engineers. (4)** (Same as Chemical Engineering CM245.) Lecture, four hours; discussion, one hour; outside study, seven hours. Selected topics in molecular biology that form foundation of biotechnology and biomedical industry today. Topics include recombinant DNA technology, molecular research tools, manipulation of gene expression, directed mutagenesis and protein engineering, DNA-based diagnostics and DNA microarrays, antibody and protein-based diagnostics, genomics and bioinformatics, isolation of human genes, gene therapy, and tissue engineering. Concurrently scheduled with course CM145. Letter grading. Mr. Liao (F)

**C247. Applied Tissue Engineering: Clinical and Industrial Perspective. (4)** Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: course CM202, Chemistry 20A, 20B, 20L, Life Sciences 1 or 2. Overview of central topics of tissue engineering, with focus on how to build artificial tissues into regulated clinically viable products. Topics include biomaterials selection, cell source, delivery methods, FDA approval processes, and physical/chemical and biological testing. Case studies include skin and artificial skin, bone and cartilage, blood vessels, neurotissue engineering, and liver, kidney, and other organs. Clinical and industrial perspectives of tissue engineering products. Manufacturing constraints, clinical limitations, and regulatory challenges in design and development of tissue-engineering devices. Concurrently scheduled with course C147. Letter grading. Mr. Wu (Sp)

**M248. Introduction to Biological Imaging. (4)** (Same as Pharmacology M248 and Physics and Biology in Medicine M248.) Lecture, three hours; laboratory, one hour; outside study, seven hours. Exploration of role of biological imaging in modern biology and medicine, including imaging physics, instrumentation, image processing, and applications of imaging for range of modalities. Practical experience provided through series of imaging laboratories. Letter grading.

**M250B. Microelectromechanical Systems (MEMS) Fabrication. (4)** (Same as Electrical and Computer Engineering M250B and Mechanical and Aerospace Engineering M280B.) Lecture, three hours; discussion, one hour; outside study, eight hours. Enforced requisite: course M153. Advanced discussion of micromachining processes used to construct MEMS. Coverage of many lithographic, deposition, and etching processes, as well as their combination in process integration. Materials issues such as chemical resistance, corrosion, mechanical properties, and residual/intrinsic stress. Letter grading. Mr. Candler (Sp)

**M252. Microelectromechanical Systems (MEMS) Device Physics and Design. (4)** (Same as Electrical and Computer Engineering M252 and Mechanical and Aerospace Engineering M282.) Lecture, four hours; discussion, one hour; outside study, seven hours. Introduction to MEMS design. Design methods, design rules, sensing and actuation mechanisms, microsensors, and microactuators. Designing MEMS to be produced with both foundry and nonfoundry processes. Computer-aided design for MEMS. Design project required. Letter grading. Mr. Wu (Sp)

**C255. Fluid-Particle and Fluid-Structure Interactions in Microflows. (4)** Lecture, four hours; laboratory, one hour; outside study, seven hours. Enforced requisite: course 110. Introduction to Navier/Stokes equations, assumptions, and simplifications. Analytical framework for calculating simple flows and numerical methods to solve and gain intuition for complex flows. Forces on particles in Stokes flow and finite-inertia flows. Flows induced around particles with and without finite inertia and implications for particle-particle interactions. Secondary flows induced by structures and particles in confined flows. Particle separations by fluid dynamic forces: field-flow fractionation, inertial focusing, structure-induced separations. Application concepts in internal biological flows and separations for biotechnology. Helps students become sufficiently fluent with fluid mechanics vocabulary and techniques, design and model microfluidic systems to manipulate fluids, cells, and particles, and develop strong intuition for how fluid and particles behave in arbitrarily structured microchannels over range of Reynolds numbers. Concurrently scheduled with course C155. Letter grading. Mr. Di Carlo (Sp)

**M260. Neuroengineering. (4)** (Same as Electrical and Computer Engineering M255 and Neuroscience M206.) Lecture, four hours; laboratory, three hours; outside study, five hours. Requisites: Mathematics 32A, Physics 1B or 5C. Introduction to principles and technologies of bioelectricity and neural signal recording, processing, and stimulation. Topics include bioelectricity, electrophysiology (action potentials, local field potentials, EEG, ECOG), intracellular and extracellular recording, microelectrode technology, neural signal processing (neural signal frequency bands, filtering, spike detection, spike sorting, stimulation artifact removal), brain-computer interfaces, deep-brain stimulation, and prosthetics. Letter grading. Mr. Liu (F)

**M261A-M261B-M261C. Evaluation of Research Literature in Neuroengineering. (2–2-2)** (Same as Electrical and Computer Engineering M256A-M256B-M256C and Neuroscience M212A-M212B-M212C.) Discussion, two hours; outside study, four hours. Critical discussion and analysis of current literature related to neuroengineering research. S/U grading.

**M263. Anatomy of Central Nervous System. (4)** (Same as Neuroscience M203.) Lecture, 75 minutes; discussion/laboratory, two hours. Prior to first laboratory meeting, students must complete Bloodborne Pathogens training course through UCLA Environment, Health and Safety. Study of anatomical locations of and relationships between ascending and descending sensory and motor systems from spinal cord to cerebral cortex. Covers cranial nerves and brainstem anatomy along with anatomy of ventricular and vascular systems of brain. Subcortical forebrain areas covered in detail. Integrated anatomy laboratory includes brain dissections and overview of tools for MRI analysis. Letter grading.

**C270. Energy-Tissue Interactions. (4)** Lecture, three hours; outside study, nine hours. Enforced requisites: Life Sciences 2, Physics 1C. Introduction to therapeutic and diagnostic use of energy delivery devices in medical and dental applications, with emphasis on understanding fundamental mechanisms underlying various types of energy-tissue interactions. Concurrently scheduled with course C170. Letter grading. (F)

**C270L. Introduction to Techniques in Studying Laser-Tissue Interaction. (2)** Laboratory, four hours; outside study, two hours. Corequisite: course C270. Introduction to simulation and experimental techniques used in studying laser-tissue interactions. Topics include computer simulations of light propagation in tissue, measuring absorption spectra of tissue/tissue phantoms, making tissue phantoms, determination of optical properties of different tissues, techniques of temperature distribution measurements. Concurrently scheduled with course C170L. Letter grading.

**C271. Laser-Tissue Interaction II: Biologic Spectroscopy. (4)** Lecture, four hours; outside study, eight hours. Requisite: course C270. Designed for physical sciences, life sciences, and engineering majors. Introduction to optical spectroscopy principles, design of spectroscopic measurement devices, optical properties of tissues, and fluorescence spectroscopy biologic media. Concurrently scheduled with course C171. Letter grading. (W)

**C272. Design of Minimally Invasive Surgical Tools. (4)** Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: Chemistry 30B, Life Sciences 2, 3, Mathematics 32A. Introduction to design principles and engineering concepts used in design and manufacture of tools for minimally invasive surgery. Coverage of FDA regulatory policy and surgical procedures. Topics include optical devices, endoscopes and laparoscopes, biopsy devices, laparoscopic tools, cardiovascular and interventional radiology devices, orthopedic instrumentation, and integration of devices with therapy. Examination of complex process of tool design, fabrication, testing, and validation. Preparation of drawings and consideration of development of new and novel devices. Concurrently scheduled with course C172. Letter grading. (Sp)

**C275. Machine Learning and Data-Driven Modeling in Bioengineering. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Requisites: Civil Engineering M20 or Mechanical and Aerospace Engineering M20, Computer Science 31, Mathematics 32B, 33A. Overview of foundational data analysis and machine-learning methods in bioengineering, focusing on how these techniques can be applied to interpret experimental observations. Topics include probabilities, distributions, cross-validation, analysis of variance, reproducible computational workflows, dimensionality reduction, regression, hidden Markov models, and clustering. Students gain theoretical and practical knowledge of data analysis and machine-learning methods relevant to bioengineering. Application of these methods to experimental data from bioengineering studies. Students become sufficiently familiar with these techniques to design studies incorporating such analyses, execute analysis, and work in teams using similar approaches, and ensure correctness of their results. Concurrently scheduled with course C175. Letter grading.

**CM278. Introduction to Biomaterials. (4)** (Same as Materials Science CM280.) Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: Chemistry 20A, 20B, and 20L, or Materials Science 104. Engineering materials used in medicine and dentistry for repair and/or restoration of damaged natural tissues. Topics include relationships between material properties, suitability to task, surface chemistry, processing and treatment methods, and biocompatibility. Concurrently scheduled with course CM178. Letter grading. Ms. Kasko (F)

**C279. Biomaterials-Tissue Interactions. (4)** Lecture, three hours; outside study, nine hours. Requisite: course CM278. In-depth exploration of host cellular response to biomaterials: vascular response, interface, and clotting, biocompatibility, animal models, inflammation, infection, extracellular matrix, cell adhesion, and role of mechanical forces. Concurrently scheduled with course C179. Letter grading. Mr. Wu (Not offered 2019-20)

**282. Biomaterial Interfaces. (4)** Lecture, four hours; laboratory, eight hours. Requisite: course CM178 or CM278. Function, utility, and biocompatibility of biomaterials depend critically on their surface and interfacial properties. Discussion of morphology and composition of biomaterials and nanoscales, mesoscales, and macroscales, techniques for characterizing structure and properties of biomaterial interfaces, and methods for designing and fabricating biomaterials with prescribed structure and properties in vitro and in vivo. Letter grading. Ms. Maynard (W)

**C283. Targeted Drug Delivery and Controlled Drug Release. (4)** Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: Chemistry 20A, 20B, 20L. New therapeutics require comprehensive understanding of modern biology, physiology, biomaterials, and engineering. Targeted delivery of genes and drugs and their controlled release are important in treatment of challenging diseases and relevant to tissue engineering and regenerative medicine. Drug pharmacodynamics and clinical pharmacokinetics. Application of engineering principles (diffusion, transport, kinetics) to problems in drug formulation and delivery to establish rationale for design and development of novel drug delivery systems that can provide spatial and temporal control of drug release. Introduction to biomaterials with specialized structural and interfacial properties. Exploration of both chemistry of materials and physical presentation of devices and compounds used in delivery and release. Concurrently scheduled with course C183. Letter grading. Ms. Kasko (Sp)

**M284. Functional Neuroimaging: Techniques and Applications. (3)** (Same as Neuroscience M285, Physics and Biology in Medicine M285, Psychiatry M285, and Psychology M278.) Lecture, three hours. In-depth examination of activation imaging, including MRI and electrophysiological methods, data acquisition and analysis, experimental design, and results obtained thus far in human systems. Strong focus on understanding technologies, how to design activation imaging paradigms, and how to interpret results. Laboratory visits and design and implementation of functional MRI experiment. S/U or letter grading.

**C285. Introduction to Tissue Engineering. (4)** Lecture, three hours; discussion, one hour; outside study, eight hours. Requisites: course CM102 or CM202, Chemistry 20A, 20B, 20L. Tissue engineering applies principles of biology and physical sciences with engineering approach to regenerate tissues and organs. Guiding principles for proper selection of three basic components for tissue engineering: cells, scaffolds, and molecular signals. Concurrently scheduled with course C185. Letter grading. Ms. Kasko (W)

**CM286. Computational Systems Biology: Modeling and Simulation of Biological Systems. (5)** (Same as Computer Science CM286.) Lecture, four hours; laboratory, three hours; outside study, eight hours. Dynamic biosystems modeling and computer simulation methods for studying biological/biomedical processes and systems at multiple levels of organization. Control system, multicompartmental, predator-prey, pharmacokinetic (PK), pharmacodynamic (PD), and other structural modeling methods applied to life sciences problems at molecular, cellular (biochemical pathways/networks), organ, and organismic levels. Both theory- and data-driven modeling, with focus on translating biomodeling goals and data into mathematics models and implementing them for simulation and analysis. Basics of numerical simulation algorithms, with modeling software exercises in class and PC laboratory assignments. Concurrently scheduled with course CM186. Letter grading. Mr. DiStefano (F)

**CM287. Research Communication in Computational and Systems Biology. (4)** (Same as Computer Science CM287.) Lecture, four hours; outside study, eight hours. Requisite: course CM286. Closely directed, interactive, and real research experience in active quantitative systems biology research laboratory. Direction on how to focus on topics of current interest in scientific community, appropriate to student interests and capabilities. Critiques of oral presentations and written progress reports explain how to proceed with search for research results. Major emphasis on effective research reporting, both oral and written. Concurrently scheduled with course CM187. Letter grading. Mr. DiStefano (Sp)

**295A-295Z. Seminars: Research Topics in Bioengineering. (2 each)** Seminar, two hours; outside study, four hours. Limited to bioengineering graduate students. Advanced study and analysis of current topics in bioengineering. Discussion of current research and literature in research specialty of faculty member teaching course. Student presentation of projects in research specialty. May be repeated for credit. S/U grading. **295A.** Biomaterial Research. **295B.** Biomaterials and Tissue Engineering Research. **295C.** Minimally Invasive and Laser Research. **295D.** Hybrid Device Research. **295E.** Molecular Cell Bioengineering Research. **295F.** Biopolymer Materials and Chemistry. **295G.** Biomicrofluidics and Bionanotechnology Research. **295H.** Biomimetic System Research. **295J.** Neural Tissue Engineering and Regenerative Medicine.

**M296A. Advanced Modeling Methodology for Dynamic Biomedical Systems. (4)** (Same as Computer Science M296A and Medicine M270C.) Lecture, four hours; outside study, eight hours. Requisite: Electrical Engineering 141 or 142 or Mathematics 115A or Mechanical and Aerospace Engineering 171A. Development of dynamic systems modeling methodology for physiological, biomedical, pharmacological, chemical, and related systems. Control system, multicompartmental, noncompartmental, and input/output models, linear and nonlinear. Emphasis on model applications, limitations, and relevance in biomedical sciences and other limited data environments. Problem solving in PC laboratory. Letter grading. Mr. DiStefano (F)

**M296B. Optimal Parameter Estimation and Experiment Design for Biomedical Systems. (4)** (Same as Biomathematics M270, Computer Science M296B, and Medicine M270D.) Lecture, four hours; outside study, eight hours. Requisite: course CM286 or M296A or Biomathematics 220. Estimation methodology and model parameter estimation algorithms for fitting dynamic system models to biomedical data. Model discrimination methods. Theory and algorithms for designing optimal experiments for developing and quantifying models, with special focus on optimal sampling schedule design for kinetic models. Exploration of PC software for model building and optimal experiment design via applications in physiology and pharmacology. Letter grading. Mr. DiStefano (W)

**M296C. Advanced Topics and Research in Biomedical Systems Modeling and Computing. (4)** (Same as Computer Science M296C and Medicine M270E.) Lecture, four hours; outside study, eight hours. Requisite: course M296B. Research techniques and experience on special topics involving models, modeling methods, and model/computing in biological and medical sciences. Review and critique of literature. Research problem searching and formulation. Approaches to solutions. Individual MS- and PhD-level project training. Letter grading. Mr. DiStefano (Sp)

**M296D. Introduction to Computational Cardiology. (4)** (Same as Computer Science M296D.) Lecture, four hours; outside study, eight hours. Requisite: course CM186. Introduction to mathematical modeling and computer simulation of cardiac electrophysiological process. Ionic models of action potential (AP). Theory of AP propagation in one-dimensional and two-dimensional cardiac tissue. Simulation on sequential and parallel supercomputers, choice of numerical algorithms, to optimize accuracy and to provide computational stability. Letter grading. Mr. Kogan (F,Sp)

**298. Special Studies in Bioengineering. (4)** Lecture, four hours; outside study, eight hours. Study of selected topics in bioengineering taught by resident and visiting faculty members. May be repeated for credit. Letter grading.

**299. Seminar: Bioengineering Topics. (2)** Seminar, two hours; outside study, four hours. Designed for graduate bioengineering students. Seminar by leading academic and industrial bioengineers from UCLA, other universities, and bioengineering companies such as Baxter, Amgen, Medtronics, and Guidant on development and application of recent technological advances in discipline. Exploration of cutting-edge developments and challenges in wound healing models, stem cell biology, angiogenesis, signal transduction, gene therapy, cDNA microarray technology, bioartificial cultivation, nano- and micro-hybrid devices, scaffold engineering, and bioinformatics. S/U grading. Mr. Wu (F,W,Sp)

**375. Teaching Apprentice Practicum. (1 to 4)** Seminar, to be arranged. Preparation: apprentice personnel employment as teaching assistant, associate, or fellow. Teaching apprenticeship under active guidance and supervision of regular faculty member responsible for curriculum and instruction at UCLA. May be repeated for credit. S/U grading.

**495. Teaching Assistant Training Seminar. (2)** Seminar, two hours; outside study, four hours. Limited to graduate bioengineering students. Required of all departmental teaching assistants. May be taken concurrently while holding TA appointment. Seminar on communicating bioengineering and biomedical engineering principles, concepts, and methods; teaching assistant preparation, organization, and presentation of material, including use of visual aids, grading, advising, and rapport with students. S/U grading. Mr. Kamei (F)

**596. Directed Individual or Tutorial Studies. (2 to 8)** Tutorial, to be arranged. Limited to graduate bioengineering students. Petition forms to request enrollment may be obtained from program office. Supervised investigation of advanced technical problems. S/U grading.

**597A. Preparation for MS Comprehensive Examination. (2 to 12)** Tutorial, to be arranged. Limited to graduate bioengineering students. Reading and preparation for MS comprehensive examination. S/U grading.

**597B. Preparation for PhD Preliminary Examinations. (2 to 16)** Tutorial, to be arranged. Limited to graduate bioengineering students. S/U grading.

**597C. Preparation for PhD Oral Qualifying Examination. (2 to 16)** Tutorial, to be arranged. Limited to graduate bioengineering students. Preparation for oral qualifying examination, including preliminary research on dissertation. S/U grading.

**598. Research for and Preparation of MS Thesis. (2 to 12)** Tutorial, to be arranged. Limited to graduate bioengineering students. Supervised independent research for MS candidates, including thesis prospectus. S/U grading.

**599. Research for and Preparation of PhD Dissertation. (2 to 16)** Tutorial, to be arranged. Limited to graduate bioengineering students. Usually taken after students have been advanced to candidacy. S/U grading.

# Chemical and Biomolecular Engineering

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Los Angeles, CA 90095-1592

310-825-2046
**chemeng@ucla.edu**
**https://www.chemeng.ucla.edu**

Panagiotis D. Christofides, Ph.D., *Chair*
Philippe Sautet, Ph.D., *Vice Chair*

## Professors

Emily A. Carter, Ph.D. *(Executive Vice Chancellor, Provost)*
Jane P. Chang, Ph.D. *(William Frederick Seyer Professor of Materials Electrochemistry)*
Panagiotis D. Christofides, Ph.D. *(William D. Van Vorst Professor of Chemical Engineering Education)*
Yoram Cohen, Ph.D.
James F. Davis, Ph.D., *Vice Provost*
Vijay K. Dhir, Ph.D.
Alireza Khademhosseini, Ph.D.
Yunfeng Lu, Ph.D.
Vasilios I. Manousiouthakis, Ph.D.
Harold G. Monbouquette, Ph.D.
Stanley J. Osher, Ph.D.
Philippe Sautet, Ph.D.
Yi Tang, Ph.D. (*Chancellor's Professor)*

## Professors Emeriti

Robert F. Hicks, Ph.D.
Kendall N. Houk, Ph.D. *(Saul Winstein Professor Emeritus of Organic Chemistry)*
Louis J. Ignarro, Ph.D. *(Nobel laureate, Jerome J. Belzer Professor Emeritus of Medical Research)*
Eldon L. Knuth, Ph.D.
James C. Liao, Ph.D. *(Ralph M. Parsons Foundation Professor Emeritus of Chemical Engineering)*
Selim M. Senkan, Ph.D.
Vincent L. Vilker, Ph.D.
A.R. Frank Wazzan, Ph.D., *Dean Emeritus*

## Associate Professors

Irene A. Chen, Ph.D.
Yvonne Y. Chen, Ph.D.

## Assistant Professors

Nasim Annabi, Ph.D.
Carissa N. Eisler, Ph.D.
Carlos G. Morales-Guio, Ph.D.
Junyoung O. Park, Ph.D.
Dante A. Simonetti, Ph.D.
Samanvaya Srivastava, Ph.D.

# Scope and Objectives

The Department of Chemical and Biomolecular Engineering conducts undergraduate and graduate programs of teaching and research that focus on the areas of biomolecular engineering, systems engineering, and advanced materials processing and span the general themes of energy/environment and nanoengineering. Aside from the fundamentals of chemical engineering (thermodynamics, transport phenomena, kinetics, reactor engineering and separations), particular emphasis is given to metabolic engineering, protein engineering, synthetic biology, bio-nano-technology, biomaterials, air pollution, environmental modeling, pollution prevention, molecular simulation, process systems engineering, membrane science, semiconductor processing, chemical vapor deposition, plasma processing, and polymer engineering.

Students are trained in the fundamental principles of these fields while acquiring sensitivity to society's needs—a crucial combination needed to address the challenge of continued industrial growth and innovation in an era of economic, environmental, and energy constraints.

The undergraduate curriculum leads to a B.S. in Chemical Engineering and includes the standard core curriculum, as well as biomedical engineering, biomolecular engineering, environmental engineering, and semiconductor manufacturing engineering options. The department also offers graduate courses and research leading to M.S. and Ph.D. degrees. Both graduate and undergraduate programs closely relate teaching and research to important industrial problems.

## Undergraduate Program Educational Objectives

The chemical engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

The mission of the undergraduate program is to educate future leaders in chemical and biomolecular engineering who effectively combine their broad knowledge of physics, chemistry, biology, and mathematics with their engineering analysis and design skills for the creative solution of problems in chemical and biological technology and for the synthesis of innovative (bio)chemical processes and products. This goal is achieved by producing chemical and biomolecular engineering alumni who (1) draw readily on a rigorous education in mathematics, physics, chemistry, and biology in addition to the fundamentals of chemical engineering to creatively solve problems in chemical and biological technology, (2) incorporate social, ethical, environmental, and economical considerations, including the concept of sustainable development, into chemical and biomolecular engineering practice, (3) lead or participate successfully on multidisciplinary teams assembled to tackle complex multifaceted problems that may require implementation of both experimental and computational approaches and a broad array of analytical tools, and (4) pursue graduate study and achieve an M.S. or Ph.D. degree in the sciences and engineering and/or achieve success as professionals in chemical and biomolecular engineering as well as related fields, including business, medicine, and environmental protection.

# Undergraduate Study

The Chemical Engineering major is a designated capstone major. The capstone project requires students to first work individually and learn how to integrate chemical engineering fundamentals taught in prior required courses; they then work in groups to produce a paper design of a realistic chemical process using appropriate software tools. Graduates should be able to design a chemical or biological system, component, or process that meets technical and economical design objectives, with consideration of environmental, social, and ethical issues, as well as sustainable development goals. In addition, they should be able to apply their knowledge of mathematics, physics, chemistry, biology, and chemical and biological engineering to analysis and design of chemical and biochemical processes and products; function on multidisciplinary teams; identify, formulate, and solve complex chemical and biological engineering problems; and communicate effectively, both orally and in writing.

# Chemical Engineering B.S.

***Capstone Major***

The chemical engineering curricula provide a high quality, professionally oriented education in modern chemical engineering. The biomedical engineering, biomolecular engineering, environmental engineering, and semiconductor manufacturing engineering options provide students an opportunity for exposure to a subfield of chemical and biomolecular engineering. In all cases, balance is sought between engineering science and practice.

## Learning Outcomes

The Chemical Engineering major has the following learning outcomes:

- Application of knowledge of mathematics, physics, chemistry, biology, and chemical and biological engineering, especially to integration of molecular- to micro-scale information into macro-scale analysis and design of chemical and biochemical processes and products
- Design of a chemical or biological system, component, or process that meets technical and economical design objectives with consideration of environmental, social, and ethical issues, as well as sustainable development goals
- Identification, formulation, and solution of complex chemical and biological engineering problems
- Function as a productive member of a multidisciplinary team
- Effective oral and written communication

## Chemical Engineering Core Option

### Preparation for the Major

*Required:* Chemical Engineering 10; Chemistry and Biochemistry 20A, 20B, 20L, 30A, 30AL, 30B; Civil and Environmental Engineering M20 or Mechanical and Aerospace Engineering M20; Mathematics 31A, 31B, 32A, 32B, 33A, 33B; Physics 1A, 1B, 1C, 4AL.

### The Major

*Required:* Chemical Engineering 45, 100, 101A, 101B, 101C, 102A, 102B, 103, 104A, 104B, 106, 107, 109; three technical breadth

*Chemical and biomolecular engineering assistant professor Dante A. Simonetti sets up a packed bed reactor.*

courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; two capstone analysis and design courses (Chemical Engineering 108A, 108B); and two elective courses (8 units) from Chemical Engineering 110, C111, C112, 113, CM114, C115, C116, C118, C119, C121, C125, C128, C135, C140.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

## Biomedical Engineering Option

### Preparation for the Major

*Required:* Chemical Engineering 10; Chemistry and Biochemistry 20A, 20B, 20L, 30A, 30AL, 30B; Civil and Environmental Engineering M20 or Mechanical and Aerospace Engineering M20; Mathematics 31A, 31B, 32A, 32B, 33A, 33B; Physics 1A, 1B, 1C, 4AL.

### The Major

*Required:* Chemical Engineering 45, 100, 101A, 101B, 101C, 102A, 102B, 103, 104A, 104B, 106, 107, 109, CM145; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; two capstone analysis and design courses (Chemical Engineering 108A, 108B); and one biomedical elective course (4 units) from Bioengineering C105, C183, Chemical Engineering C112, Chemistry and Biochemistry C105, 153A, or C159 (another chemical engineering elective may be substituted for one of these with approval of the faculty adviser).

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

## Biomolecular Engineering Option

### Preparation for the Major

*Required:* Chemical Engineering 10; Chemistry and Biochemistry 20A, 20B, 20L, 30A, 30AL, 30B; Civil and Environmental Engineering M20 or Mechanical and Aerospace Engineering M20; Mathematics 31A, 31B, 32A, 32B, 33A, 33B; Physics 1A, 1B, 1C, 4AL.

### The Major

*Required:* Chemical Engineering 45, 100, 101A, 101B, 101C, 102A, 102B, 104A, 104D, 107, 109, C115, C125, CM145; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; two capstone analysis and design courses (Chemical Engineering 108A, 108B); and one biomolecular elective course (4 units) from Bioengineering C105, C183, Chemical Engineering C112, Chemistry and Biochemistry C105, 153A, or C159 (another chemical engineering elective may be substituted with approval of the faculty adviser).

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

## Environmental Engineering Option

### Preparation for the Major

*Required:* Chemical Engineering 10; Chemistry and Biochemistry 20A, 20B, 20L, 30A, 30AL, 30B; Civil and Environmental Engineering M20 or Mechanical and Aerospace Engineering M20; Mathematics 31A, 31B, 32A, 32B, 33A, 33B; Physics 1A, 1B, 1C, 4AL.

### The Major

*Required:* Chemical Engineering 45, 100, 101A, 101B, 101C, 102A, 102B, 103, 104A, 104B, 106, 107, 109; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; two capstone analysis and design courses (Chemical Engineering 108A, 108B); and two elective courses (8 units) from Chemical Engineering 113, C118, C119, C121, C128, C135, C140 (another chemical engineering elective may be substituted with approval of the faculty adviser).

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

## Semiconductor Manufacturing Engineering Option

### Preparation for the Major

*Required:* Chemical Engineering 10; Chemistry and Biochemistry 20A, 20B, 20L, 30A, 30AL, 30B; Civil and Environmental Engineering M20 or Mechanical and Aerospace Engineering M20; Mathematics 31A, 31B, 32A, 32B, 33A, 33B; Physics 1A, 1B, 1C, 4AL.

### The Major

*Required:* Chemical Engineering 45, 100, 101A, 101B, 101C, 102A, 102B, 103, 104A, 104C, 104CL, 106, 107, 109, C116; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; two capstone analysis and design courses (Chemical Engineering 108A, 108B); and one elective course (4 units) from chemical engineering or from Materials Science and Engineering 104, 120, 121, 122, or 150.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

# Graduate Study

For information on graduate admission, see Graduate Programs on page 26.

For additional information regarding the B.S., M.S., and Ph.D. in Chemical Engineering, refer to the Chemical and Biomolecular Engineering Department brochure.

The following introductory information is based on 2019-20 program requirements for UCLA graduate degrees. Complete program requirements are available at https://grad.ucla.edu/academics/graduate-study/program-requirements-for-ucla-graduate-degrees/. Students are subject to the detailed degree requirements as published in program requirements for the year in which they enter the program.

The Department of Chemical and Biomolecular Engineering offers Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees in Chemical Engineering.

# Chemical Engineering M.S.

### Areas of Study

The semiconductor manufacturing specialization requires that students have advanced knowledge, assessed in a comprehensive examination, of processing semiconductor devices on the nanoscale.

### Course Requirements

The requirements for the MS degree are a thesis, nine courses (36 units), and a minimum 3.0 grade-point average in the graduate courses. Chemical Engineering 200, 210, and 220 are required. Two other courses must be taken from regular offerings in the department, while two Chemical Engineering 598 courses involving work on the thesis may also be selected. The remaining two courses may be taken from those offered by the department or any other field in life sciences, physical sciences, mathematics, or engineering. At least 24 units must be in letter-graded 200-level courses.

All M.S. degree candidates are required to enroll in Chemical Engineering 299 during each term in residence.

*Undergraduate Courses.* No lower-division courses may be applied toward graduate degrees. In addition, the following upper-division courses are not applicable toward graduate degrees: Chemical Engineering 102A, 199, Civil and Environmental Engineering 108, 199, Computer Science M152A, 152B, 199, Electrical and Computer Engineering 100, 101A, 102, 110L, M116L, 133A, 199, Materials Science and Engineering 110, 120, 130, 131, 131L, 132, 150, 160, 161L, 199, Mechanical and Aerospace Engineering 102, 103, 105A, 105D, 199.

### Semiconductor Manufacturing Specialization

Students are required to complete 10 courses (44 units) with a minimum 3.0 grade-point average overall and in the graduate courses. A minimum of five 200-series courses (20 units) are required, including Chemical Engineering 270 and 270R. Students also are required to take courses 104C, 104CL, Electrical and Computer Engineering 123A, and Materials Science and Engineering 121. In addition, two departmental elective courses and two electrical and computer engineering or materials science and engineering electives must be selected, with a minimum of two at the 200 level. Approved elective courses include Chemical Engineering CM214, C218, C219, 223, C240, Electrical and Computer Engineering 221A, 221B, 223, 224, Materials Science and Engineering 210, 223.

Students in the specialization who have been undergraduates at or graduates of UCLA and who have already taken some of the required courses may substitute electives for those courses. However, courses taken by students not enrolled in the specialization may not be applied toward the 10-course requirement for the degree. A program of study that encompasses the course requirements must be submitted to the research adviser for approval before the end of the first term in residence and to the departmental Student Affairs Office for approval by Graduate Division before the end of the second term in residence.

*Field Experience.* Students are required to take Chemical Engineering 270R (directed research course) in the field, working at an industrial semiconductor fabrication facility. The proposed research must be approved by the graduate adviser for semiconductor manufacturing and the industrial sponsor of the research.

### Comprehensive Examination Plan

The comprehensive examination plan is only for students in the semiconductor manufacturing specialization.

Students take Chemical Engineering 597A to prepare for the comprehensive examination, which tests for knowledge of the engineering principles of semiconductor manufacturing. In case of failure, the examination may be repeated once within one term with the consent of the graduate adviser. A second failure leads to a recommendation to the Graduate Division for termination of graduate study.

### Thesis Plan

The thesis plan is for all MS degree students who are not in the semiconductor manufacturing specialization. Students must complete a thesis and should consult the research adviser for details. Students nominate a three-member thesis committee that must meet University requirements and be approved by the Graduate Division.

## Chemical Engineering Ph.D.

### Major Fields or Subdisciplines

Consult the department.

### Course Requirements

All Ph.D. students are required to take six letter graded, 200-level courses (24 units). They can select three chemical engineering core courses from 200, 210, 220, CM245, and a graduate engineering mathematics course. Two additional courses must be taken from those offered by the department. The final course can be selected from offerings in life sciences, physical sciences, mathematics, or engineering. Students are encouraged to take more courses in their field of specialization. The minor field courses should be selected in consultation with the research adviser. A minimum 3.33 grade-point average in graduate courses is required. A program of study to fulfill the course requirements must be submitted for approval to the departmental Student Affairs Office no later than one term after successful completion of the preliminary oral examination.

All Ph.D. students are required to enroll in Chemical Engineering 299 during each term in residence.

### Written and Oral Qualifying Examinations

Academic Senate regulations require all doctoral students to complete and pass University written and oral qualifying examinations prior to doctoral advancement to candidacy. Under Senate regulations the University Oral Qualifying Examination is open only to students and appointed members of their doctoral committees.

In addition to University requirements, some graduate programs have other precandidacy examination requirements. What follows are the requirements for this doctoral program.

All Ph.D. students are required to pass the preliminary written examination (PWE) to demonstrate proficiency in at least three of the five core areas as follows.

Students must select the transport phenomena core area and either the thermodynamics core area or reaction engineering core area or both. If they select only one of thermodynamics or reaction engineering, they must also select either the biomolecular engineering or engineering mathematics core area. The PWE is offered at the end of winter quarter of each academic year and is graded by a faculty committee. Students must take the PWE in their first year. If they fail the PWE on the first attempt, they can retake it for a second time the following spring quarter. Students who fail both attempts are not allowed to continue in the Ph.D. program.

After completion of the required courses for the degree and passing of the PWE, students must pass the written and oral qualifying examinations. These examinations focus on the dissertation research and are conducted by a doctoral committee consisting of at least four faculty members nominated by the department in accordance with University regulations. Three members, including the chair, are inside members and must hold faculty appointments in the department. The outside member must be a UCLA faculty member in another department. Students are required to have a minimum 3.33 grade-point average in graduate coursework to be eligible to take these examinations.

The written qualifying examination consists of a dissertation research proposal that provides a clear description of the problem(s) considered, a literature review of the current state of the art, and a detailed explanation of the research plan that is to be followed to solve the problem(s). Students normally submit their dissertation research proposals to their doctoral committees before the end of Winter quarter of the second year in academic residence.

The University Oral Qualifying Examination consists of an oral defense of the dissertation research proposal and is administered by the doctoral committee. The written research proposal must be submitted to the committee at least two weeks prior to the oral examination to allow the members sufficient time to evaluate the work.

## Facilities

### Biomolecular Engineering Laboratories

The laboratories are equipped for cutting-edge genetic, biomolecular, and cellular engineering teaching and research. Facilities and equipment include bioreactors, fluorescence microscopy, real-time PCR thermocycler, UV-visible and fluorescence spectrophotometers, HPLC and LC-mass spectrometer, aerobic and anaerobic bioreactors from bench top to 100-liter pilot scale, protein purification facility, potentiostat/galvanostat and impedance analyzer for electroenzymology, membrane extruder and multiangle laser light scattering for production and characterization of biological and semi-synthetic colloids such as micelles and vesicles, and phosphoimager for biochemical assays involving radiolabeled compounds.

Microbial cells are genetically and metabolically engineered to produce compounds that are used as fuel, chemicals, drugs, and food additives. Novel gene-metabolic circuits are designed and constructed in microbial cells to perform complex and non-native cellular behavior. These designer cells are cultured in bioreactors, and intracellular states are monitored. Such investigations are coupled with genomic and proteomic efforts, and mathematical modeling, to achieve system-wide understanding of the cell.

Protein engineering is being used to generate completely novel compounds that have important pharmaceutical value. Bacteria are being custom-designed to synthesize important therapeutic compounds that have anticancer, cholesterol-lowering, and/or antibiotic activities. Biosensors are being micromachined for detecting neurotransmitters in vivo. New biosensing schemes also are being invented for the detection of endocrine disrupting chemicals in the environment and for the high-throughput screening of drug candidates. Naturally occurring protein nanocapsules are being redesigned at the genetic level for applications in drug delivery and materials synthesis. Finally, the enzymology of extremely thermophilic microbes is being explored for applications in specialty chemical synthesis.

## Chemical Kinetics, Catalysis, and Reaction Engineering Laboratory

The laboratory is equipped with advanced research tools for experimental and computational studies of chemical kinetics, reaction engineering, and catalytic and adsorptive materials. Analytical instruments include a quadrupole mass spectrometer (QMS) system to sample reactive systems with electron impact and photoionization capabilities; several fully computerized gas chromatograph/mass spectrometer (GC/MS) systems for gas analysis; a computerized gas chromatograph/sulfur chemiluminescence detector (GC/SCD) system for gas analysis of sulfur-containing compounds; and fully computerized array channel microreactors and plug-flow reactors for catalyst discovery and optimization.

The laboratory also presents a strong expertise in computational catalysis and surface chemistry. It is equipped with state-of-the-art atomic-scale modeling software used to understand the properties of solids and the catalytic reactivity of surfaces, nanoparticles, and clusters. Codes include VASP, CP2K, and SIESTA. Applications domains are linked with chemistry and energy challenges and range from heterogeneous catalysis to photocatalysis, electrocatalysis, depollution, and electricity storage. Original simulation methods, developed by the researchers, are available for the modeling of electrocatalysis. A high-performance cluster is available for research and teaching. Campuswide computers are also available to laboratory researchers.

## Electrochemical Engineering and Catalysis Laboratories

With instrumentation such as rotating ring-disk electrodes, electrochemical packed-bed flow reactors, gas chromatographs, potentiostats, and function generators, the laboratories are used to study metal, alloy, and semiconductor corrosion processes, electro-deposition and electroless deposition of metals, alloys, and semiconductors for GMR and MEMS applications, electrochemical energy conversion (fuel cells) and storage (batteries), and bioelectrochemical processes and biomedical systems.

The electroorganic synthesis facility is for the development of electrochemical processes to transform biomass-derived organic compounds into useful chemicals, fuels, and pharmaceuticals. The catalysis facility is equipped to support various types of catalysis projects, including catalytic hydrocarbon oxidation, selective catalytic reduction of NOx, and Fischer-Tropsch synthesis.

## Electronic Materials Processing Laboratory

The laboratory focuses on the synthesis and patterning of mutlifunctional complex oxide films and nanostructures with tailored electronic, chemical, thermal, mechanical, and biological properties. Experimental and theoretical studies are combined to understand the process chemistry and surface kinetics in atomic layer deposition, plasma etching and deposition processes, gas-phase surface functionalization, and solution phase synthesis. Novel devices including advanced microelectronics, optoelectronics, chemical sensors, and energy storage devices are realized at nano-dimensions as the technologies become more enabling based on these fundamental studies.

The laboratory is equipped with a state-of-the-art advanced rapid thermal processing facility with in-situ vapor phase processing and atomic layer deposition capabilities; advanced plasma processing tools including thin film deposition and etching; and diagnostics including optical emissions spectroscopy, Langmuir probe, and quadruple mass spectrometry; a surface analytical facility including X-ray photoelectron spectroscopy, Auger electron spectroscopy, ultra-violet photoelectron spectroscopy, reflection high energy electron diffraction, spectroscopic ellipsometry, photoluminescence, and infrared spectroscopy; and a complete set of processing tools available for microelectronics and MEMS fabrication in the Nanoelectronic Research Facility. With the combined material characterization and electronic device fabrication, the reaction kinetics including composition and morphology, and the electrical property of these materials can be realized for applications in the next generation electronic devices and chemical or biological MEMS.

## Materials and Plasma Chemistry Laboratory

The laboratory is equipped with state-of-the-art instruments for studying the molecular processes that occur during chemical vapor deposition (CVD) and plasma processing. CVD is a key technology for synthesizing advanced electronic and optical devices, including solid-state lasers, infrared, visible, and ultraviolet detectors and emitters, solar cells, heterojunction bipolar transistors, and high-electron mobility transistors. The laboratory houses a commercial CVD reactor for the synthesis of III-V compound semiconductors. This tool is interfaced to an ultrahigh vacuum system equipped with scanning tunneling microscopy, low-energy electron diffraction; infrared spectroscopy and X-ray photoelectron spectroscopy. This apparatus characterizes the atomic structure of compound semiconductor heterojunction interfaces and determines the kinetics of CVD reactions on these surfaces.

The atmospheric plasma laboratory is equipped with multiple plasma sources and state-of-the-art diagnostic tools. The plasmas generate, at low temperature, beams of atoms and radicals well-suited for surface treatment, cleaning, etching, deposition, and sterilization. Applications are in the biomedical, electronics, and aerospace fields. The laboratory is unique in that it characterizes the reactive species generated in atmospheric plasmas and their chemical interactions with surfaces.

## Nanoparticle Technology and Air Quality Engineering Laboratory

Modern particle technology focuses on particles in the nanometer (nm) size range with applications to air pollution control and commercial production of fine particles. Particles with diameters between 1 and 100 nm are of interest both as individual particles and in the form of aggregate structures. The laboratory is equipped with instrumentation for online measurement of aerosols, including optical particle counters, electrical aerosol analyzers, and condensation particle counters. A novel low-pressure impactor designed in the laboratory is used to fractionate particles for morphological analysis in size ranges down to 50 nm (0.05 micron). Also available is a high-volumetric flow rate impactor suitable for collecting particulate matter for chemical analysis. Several types of specially designed aerosol generators are also available, including a laser ablation chamber, tube furnaces, and a specially designed aerosol microreactor.

Concern with nanoscale phenomena requires the use of advanced systems for particle observation and manipulation. Students have direct access to modern facilities for transmission and scanning electron microscopy. Located near the laboratory, the Electron Microscopy facilities staff provide instruction and assistance in the use of these instruments. Advanced electron microscopy has recently been used in the laboratory to make the first systematic studies of atmospheric nanoparticle chain aggregates. Such aggregate structures have been linked to public health effects and to the absorption of solar radiation. A novel nanostructure manipulation device, designed and built in the laboratory, makes it possible to probe the behavior of nanoparticle chain aggregates of a type produced commercially for use in nanocomposite materials; these aggregates are also released by sources of pollution such as diesel engines and incinerators.

## Polymer and Separations Research Laboratory

The laboratory is equipped for research on membranes, water desalination, adsorption, chemical sensors, polymerization kinetics, surface engineering with polymers and the behavior of polymeric fluids in confined geometries. Instrumentation includes a high resolution multiprobe atomic force microscope (AFM) and a quartz crystal microbalance system for membrane and sensor development work. An atmospheric plasma surface structuring system is available for nano-structuring ceramic and polymeric surfaces for a variety of applications that include membrane performance enhancement and chemical sensor arrays. Analytical equipment for polymer characterization includes several high-pressure liquid chromatographs for size exclusion chromatography equipped with different detectors, including refractive index, UV photodiode array, conductivity, and a photodiode array laser light scattering detector. The laboratory has a research-grade FTIR with a TGA interface, a thermogravimetric analysis system, and a dual column gas chromatograph. Equipment for viscometric analysis includes high- and low-pressure capillary viscometer, narrow gap cylindrical couette viscometer, cone-and-plate viscometer, intrinsic viscosity viscometer system and associated equipment. Flow equipment is also available for studying fluid flow through channels of different geometries (e.g., capillary, slit, porous media). The evaluation of polymeric and novel ceramic-polymer membranes, developed in the laboratory, is made possible with reverse osmosis, pervaporation, and cross-flow ultrafiltration systems equipped with online detectors. Studies of high recovery membrane desalination are carried out in a membrane concentrator/crystallizer system. Resin sorption and regeneration studies can be carried out with a fully automated system.

## Process Systems Engineering Laboratory

The laboratory is equipped with state-of-the-art computer hardware and software used for the simulation, design, optimization, control, and integration of chemical processes. Several personal computers and workstations, as well as an 8-node dual-processor cluster, are available for teaching and research. SEASnet and campuswide computational facilities are also available to the laboratory's members. Software for simulation and optimization of general systems includes MINOS, GAMS, MATLAB, CPLEX, and LINDO. Software for simulation of chemical engineering systems includes HYSYS for process simulation and CACHE-FUJITSU for molecular calculations. UCLA-developed software for heat/power integration and reactor network attainable region construction are also available.

# Faculty Areas of Thesis Guidance

### Professors

Jane P. Chang, Ph.D. (MIT, 1998)
*Materials processing, gas-phase and surface reaction, plasma enhanced chemistries, atomic layer deposition, chemical microelectromechanical systems, and computational surface chemistry*

Panagiotis D. Christofides, Ph.D. (U. Minnesota, 1996)
*Process modeling, dynamics and control, computational and applied mathematics*

Yoram Cohen, Ph.D. (U. Delaware, 1981)
*Water treatment and desalination, separation processes, membrane science and technology, surface nanostructuring, pollutant transport nanomaterials and exposure assessment*

James F. Davis, Ph.D. (Northwestern U., 1981)
*Intelligent systems in process, control operations and design, decision support, management of abnormal situations, data interpretation, knowledge databases, pattern recognition*

Vijay K. Dhir, Ph.D. (U. Kentucky, 1972)
*Two-phase heat transfer, boiling and condensation, thermal hydraulics of nuclear reactors, microgravity heat transfer, soil remediation, high-power density electronic cooling*

Alireza Khademhosseini, Ph.D. (MIT, 2005)
*Biomaterials, tissue engineering, organ-on-a-chip, stem cell engineering, biofabrication, micro- and nano-technology, biomedical devices*

Yunfeng Lu, Ph.D. (U. New Mexico, 1998)
*Semiconductor manufacturing and nanotechnology*

Vasilios I. Manousiouthakis, Ph.D. (Rensselaer, 1986)
*Process systems engineering: modeling, simulation, design, optimization, and control*

Harold G. Monbouquette, Ph.D. (North Carolina State, 1987)
*Biochemical engineering, biosensors, nanotechnology*

Stanley J. Osher, Ph.D. (New York U., 1966)
*Computational science, image processing, information science*

Philippe Sautet, Ph.D. (U. Paris XI Orsay, France, 1989)
*First principles atomic scale simulations; quantum chemistry; applications to heterogeneous catalysis: active sites and reaction mechanisms, nanomaterials for depollution and energy transformation, molecules at surfaces*

Yi Tang, Ph.D. (Caltech, 2002)
*Biosynthesis of proteins/polypeptides with unnatural amino acids, synthesis of novel antibiotics/antitumor products*

### Professors Emeriti

Robert F. Hicks, Ph.D. (UC Berkeley, 1984)
*Chemical vapor deposition and atmospheric plasma processing*

Kendall N. Houk, Ph.D. (Harvard, 1968)
*Computational chemistry, enzyme design, investigation of reaction mechanisms, design of materials and processes*

Louis J. Ignarro, Ph.D. (U. Minnesota, 1966)
*Regulation and modulation of NO production*

Eldon L. Knuth, Ph.D. (Caltech, 1953)
*Molecular dynamics, thermodynamics, combustion, applications to air pollution control and combustion efficiency*

James C. Liao, Ph.D. (U. Wisconsin-Madison, 1987)
*Metabolic engineering, synthetic biology, bioenergy*

Selim M. Senkan, Ph.D. (MIT, 1977)
*Reaction engineering, combinatorial catalysis, combustion, laser photoionization, real-time detection, quantum chemistry*

A.R. Frank Wazzan, Ph.D. (UC Berkeley, 1963)
*Fast reactors, nuclear fuel element modeling, stability and transition of boundary layers, heat transfer*

### Associate Professors

Irene A. Chen, Ph.D. (Harvard, 2007)
*Synthetic living systems, in vitro evolution, molecular biophysics, phage nanotechnology, microbiome*

Yvonne Y. Chen, Ph.D. (Caltech, 2011)
*Synthetic biology, gene-circuit engineering, cell-based therapy, T-cell engineering*

### Assistant Professors

Nasim Annabi, Ph.D. (U. Sydney, Australia, 2010)
*Biomaterials, tissue engineering, 3D bioprinting, microfabrication, nanocomposite hydrogels for drug/gene delivery, surgical sealants/ adhesives/glues, conductive hydrogels for heart tissue regeneration*

Carissa N. Eisler, Ph.D. (Caltech, 2016)
*Light and energy transport in nanomaterials, nanophotonics, renewable energy*

Carlos G. Morales-Guio, Ph.D. (École Polytechnique Fédérale de Lausanne [EPFL], Switzerland, 2016)
*Electrochemistry, renewable energy storage, nanotechnology, advanced energy materials catalysis, $CO_2$ utilization, process design, mass transport coupled to chemical transformations*

Junyoung O. Park, Ph.D. (Princeton, 2016)
*Cancer metabolism, metabolic engineering, bioenergy, systems biology, metabolomics*

Dante A. Simonetti, Ph.D. (U. Wisconsin-Madison, 2008)
*Heterogeneous catalysis and adsorption, catalytic reaction engineering and kinetics, design of reactive materials, materials characterization*

Samanvaya Srivastava, Ph.D. (Cornell, 2014)
*Soft materials, self-assembly, polymer chemistry and polymer physics, scattering rheology*

## Lower-Division Courses

**2. Technology and Environment. (4)** Lecture, four hours; outside study, eight hours. Natural and anthropogenic flows of materials at global and regional scales. Case studies of natural cycles include global warming ($CO_2$ cycles), stratospheric ozone depletion (chlorine and ozone cycles), and global nitrogen cycles. Flow of materials in industrial economies compared and contrasted with natural flows; presentation of lifecycle methods for evaluating environmental impact of processes and products. P/NP or letter grading. Mr. Manousiouthakis (Not offered 2019-20)

**10. Introduction to Chemical and Biomolecular Engineering. (1)** Lecture, one hour; outside study, two hours. General introduction to field of chemical and biomolecular engineering. Description of how chemical and biomolecular engineering analysis and design skills are applied for creative solution of current technological problems in production of microelectronic devices, design of chemical plants for minimum environmental impact, application of nanotechnology to chemical sensing, and genetic-level design of recombinant microbes for chemical synthesis. Letter grading. Mr. Tang (F)

**19. Fiat Lux Freshman Seminars. (1)** Seminar, one hour. Discussion of and critical thinking about topics of current intellectual importance, taught by faculty members in their areas of expertise and illuminating many paths of discovery at UCLA. P/NP grading.

**45. Biomolecular Engineering Fundamentals. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Recommended requisites: Chemistry 20A, 20L, 30A, 30L. Intended for those students who have not taken Life Sciences 2, 3, and Chemistry 153A. Fundamentals of modern biomolecular engineering. Topics include structure and function of biomolecules, central dogma of molecular biology, cellular information and energy processing, and experimental methods, with strong emphasis on applications in medicine, industry, and bioenergy. Letter grading. Mr. Tang (W)

**99. Student Research Program. (1 to 2)** Tutorial (supervised research or other scholarly work), three hours per week per unit. Entry-level research for lower-division students under guidance of faculty mentor. Students must be in good academic standing and enrolled in minimum of 12 units (excluding this course). Individual contract required; consult Undergraduate Research Center. May be repeated. P/NP grading.

## Upper-Division Courses

**100. Fundamentals of Chemical and Biomolecular Engineering. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Chemistry 20B, 20L (not enforced), Mathematics 32B (may be taken concurrently), Physics 1A. Introduction to analysis and design of industrial chemical processes. Material and energy balances. Introduction to programming in MATLAB. Letter grading. Mr. Rahardianto (F)

**101A. Transport Phenomena I. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Mathematics 33A, 33B. Enforced corequisite: course 109. Introduction to analysis of fluid flow in chemical, biological, materials, and molecular processes. Fundamentals of momentum transport, Newton law of viscosity, mass and momentum conservation in laminar flow, Navier/ Stokes equations, and engineering analysis of flow systems. Letter grading. Ms. Eisler (F)

**101B. Transport Phenomena II: Heat Transfer. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 101A. Introduction to analysis of heat transfer in chemical, biological, materials, and molecular processes. Fundamentals of thermal energy transport, molecular-level heat transfer in gases, liquids, and solids, forced and free convection, radiation, and engineering analysis of heat transfer in process systems. Letter grading. Ms. Chang (W)

**101C. Mass Transfer. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 101B. Introduction to analysis of mass transfer in systems of interest to chemical engineering practice. Fundamentals of mass species transport, Fick law of diffusion, diffusion in chemically reacting flows, interphase mass transfer, multicomponent systems. Letter grading. Mr. Srivastava (Sp)

**102A. Thermodynamics I. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Introduction to thermodynamics of chemical and biological processes. Work, energy, heat, and first law of thermodynamics. Second law, extremum principles, entropy, and free energy. Ideal and real gases, property evaluation. Thermodynamics of flow systems. Applications of first and second laws in biological processes and living organisms. Letter grading. Mr. Manousiouthakis (W)

**102B. Thermodynamics II. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 102A. Fundamentals of classical and statistical thermodynamics in chemical and biological sciences. Phase equilibria in single and multicomponent systems. Thermodynamics of ideal and nonideal solutions. Chemical reaction equilibria. Statistical ensembles and partition functions. Statistical thermodynamics of ideal gases. Intermolecular interactions and liquid state. Thermodynamics of polymers and biological macromolecules. Letter grading. Mr. Sautet (Sp)

**103. Separation Processes. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 100, 101B. Application of principles of heat, mass, and momentum transport to design and operation of separation processes such as distillation, gas absorption, filtration, and reverse osmosis. Letter grading. Mr. Monbouquette (Sp)

**104A. Chemical and Biomolecular Engineering Laboratory I. (4)** Lecture, two hours; laboratory, six hours; outside study, four hours. Enforced requisite: course 100. Enforced corequisite: course 101B. Recommended: course 102B. Investigation of basic transport phenomena in 10 predetermined experiments, collection of data for statistical analysis and individually written technical reports and group presentations. Design and performance of one original experimental study involving transport, separation, or another aspect of chemical and biomolecular engineering. Basic statistics: mean, standard deviation, confidence limits, comparison of two means and of multiple means, single and multiple variable linear regression, and brief introduction to factorial design of experiments. Oral and poster presentations. Technical writing of sections of technical reports and their contents; writing clearly, concisely, and consistently; importance of word choices and punctuation in multicultural engineering environment and of following required formatting. Letter grading. Ms. Eisler, Mr. Lu, Mr. Simonetti (W,Sp)

**104B. Chemical and Biomolecular Engineering Laboratory II. (6)** Lecture, four hours; laboratory, eight hours; outside study, four hours; other, two hours. Enforced requisites: courses 101C, 103, 104A. Course consists of four experiments in chemical engineering unit operations, each of two weeks duration. Students present their results both written and orally. Written report includes sections on theory, experimental procedures, scaleup and process design, and error analysis. Letter grading. Mr. Simonetti, Mr. Srivastava (F,Sp)

**104C. Semiconductor Processing. (3)** Lecture, four hours; outside study, five hours. Enforced requisite: course 101C. Enforced corequisite: course 104CL. Basic engineering principles of semiconductor unit operations, including fabrication and characterization of semiconductor devices. Investigation of processing steps used to make CMOS devices, including wafer cleaning, oxidation, diffusion, lithography, chemical vapor deposition, plasma etching, metallization, and statistical design of experiments and error analysis. Presentation of student results in both written and oral form. Letter grading. Ms. Chang (Sp)

**104CL. Semiconductor Processing Laboratory. (3)** Laboratory, four hours; outside study, five hours. Enforced requisite: course 101C. Enforced corequisite: course 104C. Series of experiments that emphasize basic engineering principles of semiconductor unit operations, including fabrication and characterization of semiconductor devices. Investigation of processing steps used to make CMOS devices, including wafer cleaning, oxidation, diffusion, lithography, chemical vapor deposition, plasma etching, and metallization. Hands-on device testing includes transistors, diodes, and capacitors. Letter grading. Ms. Chang (Sp)

**104D. Molecular Biotechnology Laboratory: From Gene to Product. (6)** Lecture, two hours; laboratory, eight hours; outside study, eight hours. Enforced requisites: courses 101C, C125. Integration of molecular and engineering techniques in modern biotechnology. Cloning of protein-coding gene into plasmid, transformation of construct into *E. coli,* production of gene product in bioreactor, downstream processing of bioreactor broth to purify recombinant protein, and characterization of purified protein. Letter grading. Mr. Park, Mr. Tang (W,Sp)

**106. Chemical Reaction Engineering. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 100, 101C, 102B. Fundamentals of chemical kinetics and catalysis. Introduction to analysis and design of homogeneous and heterogeneous chemical reactors. Letter grading. Mr. Lu (F)

**107. Process Dynamics and Control. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 101C, 103 (or C125), 106 (or C115). Principles of dynamics modeling and start-up behavior of chemical engineering processes. Chemical process control ele-

ments. Design and applications of chemical process computer control. Letter grading.
Mr. Christofides (W)

**108A. Process Economics and Analysis. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 103 (or C125), 104A, 106 (or C115). Integration of chemical engineering fundamentals such as transport phenomena, thermodynamics, separation operations, and reaction engineering and simple economic principles for purpose of designing chemical processes and evaluating alternatives. Letter grading.
Mr. Morales Guio (W)

**108B. Chemical Process Computer-Aided Design and Analysis. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 103 (or C125), 106 (or C115), 108A, Civil and Environmental Engineering M20 (or Mechanical and Aerospace Engineering M20). Introduction to application of some mathematical and computing methods to chemical engineering design problems; use of simulation programs as automated method of performing steady state material and energy balance calculations. Letter grading.
Mr. Morales Guio (Sp)

**109. Numerical and Mathematical Methods in Chemical and Biological Engineering. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: Civil and Environmental Engineering M20 or Mechanical and Aerospace Engineering M20. Enforced corequisite: course 101A. Numerical methods for computation of solution of systems or linear and nonlinear algebraic equations, ordinary differential equations, and partial equations. Chemical and biomolecular engineering examples used throughout to illustrate application of these methods. Use of MATLAB as platform (programming environment) to write programs based on numerical methods to solve various problems arising in chemical engineering. Letter grading.
Mr. Christofides (F)

**110. Intermediate Engineering Thermodynamics. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 102B. Principles and engineering applications of statistical and phenomenological thermodynamics. Determination of partition function in terms of simple molecular models and spectroscopic data; nonideal gases; phase transitions and adsorption; nonequilibrium thermodynamics and coupled transport processes. Letter grading. (Not offered 2019-20)

**C111. Cryogenics and Low-Temperature Processes. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 102A, 102B (or Materials Science 130). Fundamentals of cryogenics and cryoengineering science pertaining to industrial low-temperature processes. Basic approaches to analysis of cryofluids and envelopes needed for operation of cryogenic systems; low-temperature behavior of matter, optimization of cryosystems and other special conditions. Concurrently scheduled with course C211. Letter grading.
(Not offered 2019-20)

**C112. Polymer Processes. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 101A, Chemistry 30A. Formation of polymers, criteria for selecting reaction scheme, polymerization techniques, polymer characterization. Mechanical properties. Rheology of macromolecules, polymer process engineering. Diffusion in polymeric systems. Polymers in biomedical applications and in microelectronics. Concurrently scheduled with course C212. Letter grading. Mr. Cohen (W)

**113. Air Pollution Engineering. (4)** Lecture, four hours; preparation, two hours; outside study, six hours. Enforced requisites: courses 101C, 102B. Integrated approach to air pollution, including concentrations of atmospheric pollutants, air pollution standards, air pollution sources and control technology, and relationship of air quality to emission sources. Links air pollution to multimedia environmental assessment. Letter grading. (Not offered 2019-20)

**CM114. Electrochemical Processes. (4)** (Formerly numbered C114.) (Same as Materials Science CM163.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 102B, Mechanical and Aerospace Engineering 105A (or Materials Science 130). Fundamentals of electrochemistry and engineering applications to industrial electrochemical processes. Primary emphasis on fundamental approach to analyze electrochemical processes. Specific topics include electrochemical reactions on metal and semiconductor surfaces, electrodeposition, electroless deposition, electrosynthesis, fuel cells, aqueous and non-aqueous batteries, solid-state electrochemistry. May be concurrently scheduled with course CM214. Letter grading.
Ms. Chang (Not offered 2019-20)

**C115. Biochemical Reaction Engineering. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 101C. Use of previously learned concepts of biophysical chemistry, thermodynamics, transport phenomena, and reaction kinetics to develop tools needed for technical design and economic analysis of biological reactors. May be concurrently scheduled with course CM215. Letter grading. Ms. Annabi (F)

**C116. Surface and Interface Engineering. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Introduction to surfaces and interfaces of engineering materials, particularly catalytic surface and thin films for solid-state electronic devices. Topics include classification of crystals and surfaces, analysis of structure and composition of crystals and their surfaces and interfaces. Examination of engineering applications, including catalytic surfaces, interfaces in microelectronics, and solid-state laser. May be concurrently scheduled with course C216. Letter grading. Mr. Lu (Sp)

**C118. Multimedia Environmental Assessment. (4)** Lecture, four hours; discussion, one hour; preparation, two hours; outside study, five hours. Recommended requisites: courses 101C, 102B. Pollutant sources, estimation of source releases, waste minimization, transport and fate of chemical pollutants in environment, intermedia transfers of pollutants, multimedia modeling of chemical partitioning in environment, exposure assessment and fundamentals of risk assessment, risk reduction strategies. Concurrently scheduled with course C218. Letter grading.
Mr. Cohen (Not offered 2019-20)

**C119. Pollution Prevention for Chemical Processes. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 108A. Systematic methods for design of environment-friendly processes. Development of methods at molecular, unit-operation, and network levels. Synthesis of mass exchange, heat exchange, and reactor networks. Concurrently scheduled with course C219. Letter grading.
Mr. Manousiouthakis (Not offered 2019-20)

**C121. Membrane Science and Technology. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 101A, 101C, 103. Fundamentals of membrane science and technology, with emphasis on separations at micro, nano, and molecular/angstrom scale with membranes. Relationship between structure/morphology of dense and porous membranes and their separation characteristics. Use of nanotechnology for design of selective membranes and models of membrane transport (flux and selectivity). Examples provided from various fields/applications, including biotechnology, microelectronics, chemical processes, sensors, and biomedical devices. Concurrently scheduled with course C221. Letter grading.
Mr. Cohen (Sp)

**C124. Cell Material Interactions. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: Life Sciences 2, 3, 23L. Introduction to design and synthesis of biomaterials for regenerative medicine, in vitro cell culture, and drug delivery. Biological principles of cellular microenvironment and design of extracellular matrix analogs using biological and engineering principles. Biomaterials for growth factor, and DNA and siRNA delivery as therapeutics and to facilitate tissue regeneration. Use of stem cells in tissue engineering. Concurrently scheduled with course C224. Letter grading.
Ms. Annabi (W)

**C125. Bioseparations and Bioprocess Engineering. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced corequisite: course 101C. Separation strategies, unit operations, and economic factors used to design processes for isolating and purifying materials like whole cells, enzymes, food additives, or pharmaceuticals that are products of biological reactors. Concurrently scheduled with course CM225. Letter grading.
Ms. Annabi (Sp)

**CM127. Synthetic Biology for Biofuels. (4)** (Same as Chemistry CM127.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: Chemistry 153A. Engineering microorganisms for complex phenotype is common goal of metabolic engineering and synthetic biology. Production of advanced biofuels involves designing and constructing novel metabolic networks in cells. Such efforts require profound understanding of biochemistry, protein structure, and biological regulations and are aided by tools in bioinformatics, systems biology, and molecular biology. Fundamentals of metabolic biochemistry, protein structure and function, and bioinformatics. Use of systems modeling for metabolic networks to design microorganisms for energy applications. Concurrently scheduled with course CM227. Letter grading. (Not offered 2019-20)

**C128. Hydrogen. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: Chemistry 20A. Electronic, physical, and chemical properties of hydrogen. Various methods of production, including production through methane steam reforming, electrolysis, and thermochemical cycles. Description in depth of several uses of hydrogen, including hydrogen combustion and hydrogen fuel cells. Concurrently scheduled with course C228. Letter grading.
Mr. Manousiouthakis (Sp)

**C135. Advanced Process Control. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 107. Introduction to advanced process control. Topics include (1) Lyapunov stability for autonomous nonlinear systems including converse theorems, (2) input to state stability, interconnected systems, and small gain theorems, (3) design of nonlinear and robust controllers for various classes of nonlinear systems, (4) model predictive control of linear and nonlinear systems, (5) advanced methods for tuning of classical controllers, and (6) introduction to control of distributed parameter systems. Concurrently scheduled with course C235. Letter grading. (Not offered 2019-20)

**C140. Fundamentals of Aerosol Technology. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 101C. Technology of particle/gas systems with applications to gas cleaning, commercial production of fine particles, and catalysis. Particle transport and deposition, optical properties, experimental methods, dynamics and control of particle formation processes. Concurrently scheduled with course C240. Letter grading.
(Not offered 2019-20)

**CM145. Molecular Biotechnology for Engineers. (4)** (Same as Bioengineering CM145.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 45. Selected topics in molecular biology that form foundation of biotechnology and biomedical industry today. Topics include recombinant DNA technology, molecular research tools, manipulation of gene expression, directed mutagenesis and protein engineering, DNA-based diagnostics and DNA microarrays, antibody and protein-based diagnostics, genomics and bioinformatics, isolation of human genes, gene therapy, and tissue engineering. Concurrently scheduled with course CM245. Letter grading. Mr. Park (F)

**M153. Introduction to Microscale and Nanoscale Manufacturing. (4)** (Same as Bioengineering M153, Electrical and Computer Engineering M153, and Mechanical and Aerospace Engineering M183B.) Lecture, three hours; laboratory, four hours; outside study, five hours. Enforced requisites: Chemistry 20A, Physics 1A, 1B, 1C, 4AL, 4BL. Introduction to general manufacturing methods, mechanisms, constrains, and microfabrication and nanofabrication. Focus on concepts, physics, and instruments of various microfabrication and nanofabrication techniques that have been broadly applied in industry and academia, including various photolithography technologies, physical and chemical deposition methods, and physical and chemical etching methods. Hands-on experience for fabricating microstructures and nanostructures in modern cleanroom environment. Letter grading. Mr. Chiou (F, Sp)

**188. Special Courses in Chemical Engineering. (4)** Seminar, four hours; outside study, eight hours. Special topics in chemical engineering for undergraduate students taught on experimental or temporary basis, such as those taught by resident and visiting faculty members. May be repeated once for credit with topic or instructor change. Letter grading.

**194. Research Group Seminars: Chemical Engineering. (4)** Seminar, four hours; outside study, eight hours. Designed for undergraduate students who are part of research group. Discussion of research methods and current literature in field. May be repeated for credit. Letter grading.

**199. Directed Research in Chemical Engineering. (2 to 8)** Tutorial, to be arranged. Limited to juniors/seniors. Supervised individual research or investigation of selected topic under guidance of faculty mentor. Culminating paper or project required. May be repeated for credit with school approval. Individual contract required; enrollment petitions available in Office of Academic and Student Affairs. Letter grading. (F,W,Sp)

# Graduate Courses

**200. Advanced Engineering Thermodynamics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 102B. Phenomenological and statistical thermodynamics of chemical and physical systems with engineering applications. Presentation of role of atomic and molecular spectra and intermolecular forces in interpretation of thermodynamic properties of gases, liquids, solids, and plasmas. Letter grading. Mr. Park (F)

**201. Methods of Molecular Simulation. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 200 or Chemistry C223A or Physics 215A. Modern simulation techniques for classical molecular systems. Monte Carlo and molecular dynamics in various ensembles. Applications to liquids, solids, and polymers. Letter grading. Mr. Sautet (W)

**210. Advanced Chemical Reaction Engineering. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 101C, 106. Principles of chemical reactor analysis and design. Particular emphasis on simultaneous effects of chemical reaction and mass transfer on noncatalytic and catalytic reactions in fixed and fluidized beds. Letter grading. Mr. Simonetti (W)

**C211. Cryogenics and Low-Temperature Processes. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Fundamentals of cryogenics and cryoengineering science pertaining to industrial low-temperature processes. Basic approaches to analysis of cryofluids and envelopes needed for operation of cryogenic systems; low-temperature behavior of matter, optimization of cryosystems and other special conditions. Concurrently scheduled with course C111. Letter grading. (Not offered 2019-20)

**C212. Polymer Processes. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 101A, Chemistry 30A. Formation of polymers, criteria for selecting reaction scheme, polymerization techniques, polymer characterization. Mechanical properties. Rheology of macromolecules, polymer process engineering. Diffusion in polymeric systems. Polymers in biomedical applications and in microelectronics. Concurrently scheduled with course C112. Letter grading. Mr. Cohen (W)

**CM214. Electrochemical Processes. (4)** (Formerly numbered C214.) (Same as Materials Science CM263.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 102B, Mechanical and Aerospace Engineering 105A (or Materials Science 130). Fundamentals of electrochemistry and engineering applications to industrial electrochemical processes. Primary emphasis on fundamental approach to analyze electrochemical processes. Specific topics include electrochemical reactions on metal and semiconductor surfaces, electrodeposition, electroless deposition, electrosynthesis, fuel cells, aqueous and non-aqueous batteries, solid-state electrochemistry. May be concurrently scheduled with course CM114. Letter grading. Ms. Chang (Not offered 2019-20)

**CM215. Biochemical Reaction Engineering. (4)** (Same as Bioengineering M215.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 101C. Use of previously learned concepts of biophysical chemistry, thermodynamics, transport phenomena, and reaction kinetics to develop tools needed for technical design and economic analysis of biological reactors. May be concurrently scheduled with course C115. Letter grading. Ms. Annabi (F)

**C216. Surface and Interface Engineering. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Introduction to surfaces and interfaces of engineering materials, particularly catalytic surface and thin films for solid-state electronic devices. Topics include classification of crystals and surfaces, analysis of structure and composition of crystals and their surfaces and interfaces. Examination of engineering applications, including catalytic surfaces, interfaces in microelectronics, and solid-state laser. May be concurrently scheduled with course C116. Letter grading. Mr. Lu (Sp)

**217. Electrochemical Engineering. (4)** Lecture, four hours; outside study, eight hours. Requisite: course C114. Transport phenomena in electrochemical systems; relationships between molecular transport, convection, and electrode kinetics, along with applications to industrial electrochemistry, fuel cell design, and modern battery technology. Letter grading. (Not offered 2019-20)

**C218. Multimedia Environmental Assessment. (4)** Lecture, four hours; discussion, one hour; preparation, two hours; outside study, five hours. Recommended requisites: courses 101C, 102B. Pollutant sources, estimation of source releases, waste minimization, transport and fate of chemical pollutants in environment, intermedia transfers of pollutants, multimedia modeling of chemical partitioning in environment, exposure assessment and fundamentals of risk assessment, risk reduction strategies. Concurrently scheduled with course C118. Letter grading. Mr. Cohen (Not offered 2019-20)

**C219. Pollution Prevention for Chemical Processes. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 108A. Systematic methods for design of environment-friendly processes. Development of methods at molecular, unit-operation, and network levels. Synthesis of mass exchange, heat exchange, and reactor networks. Concurrently scheduled with course C119. Letter grading. Mr. Manousiouthakis (Not offered 2019-20)

**220. Advanced Mass Transfer. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 101C. Advanced treatment of mass transfer, with applications to industrial separation processes, gas cleaning, pulmonary bioengineering, controlled release systems, and reactor design; molecular and constitutive theories of diffusion, interfacial transport, membrane transport, convective mass transfer, concentration boundary layers, turbulent transport. Letter grading. Mr. Srivastava (W)

**C221. Membrane Science and Technology. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 101A, 101C, 103. Fundamentals of membrane science and technology, with emphasis on separations at micro, nano, and molecular/angstrom scale with membranes. Relationship between structure/morphology of dense and porous membranes and their separation characteristics. Use of nanotechnology for design of selective membranes and models of membrane transport (flux and selectivity). Examples provided from various fields/applications, including biotechnology, microelectronics, chemical processes, sensors, and biomedical devices. Concurrently scheduled with course C121. Letter grading. Mr. Cohen (Sp)

**222A. Stochastic Modeling and Simulation of Chemical Processes. (4)** Lecture, four hours; outside study, eight hours. Introduction, definition, rationale of stochastic processes. Distribution, moments, correlation. Mean square calculus. Wiener process, white noise, Poisson process. Generalized functions. Linear systems with stochastic inputs, ergodicity. Application to chemical process modeling and simulation. Markov chains and processes. Ito integrals, stochastic difference, and differential equations. S/U or letter grading. Mr. Manousiouthakis (Not offered 2019-20)

**222B. Stochastic Optimization and Control. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 222A. Introduction to linear and nonlinear systems theory and estimation theory. Prediction, Kalman filter, smoothing of discrete and continuous systems. Stochastic control, systems with multiplicative noise. Applications to control of chemical processes. Stochastic optimization, stochastic linear and dynamic programming. S/U or letter grading. Mr. Manousiouthakis (Not offered 2019-20)

**223. Design for Environment. (4)** Lecture, four hours; outside study, eight hours. Limited to graduate chemical engineering, materials science and engineering, or Master of Engineering program students. Design of products for meeting environmental objectives; lifecycle inventories; lifecycle impact assessment; design for energy efficiency; design for waste minimization, computer-aided design tools, materials selection methods. Letter grading. (Not offered 2019-20)

**C224. Cell Material Interactions. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: Life Sciences 2, 3, 23L. Introduction to design and synthesis of biomaterials for regenerative medicine, in vitro cell culture, and drug delivery. Biological principles of cellular microenvironment and design of extracellular matrix analogs using biological and engineering principles. Biomaterials for growth factor, and DNA and siRNA delivery as therapeutics and to facilitate tissue regeneration. Use of stem cells in tissue engineering. Concurrently scheduled with course C124. Letter grading. Ms. Annabi (W)

**CM225. Bioseparations and Bioprocess Engineering. (4)** (Same as Bioengineering M225.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced corequisite: course 101C. Separation strategies, unit operations, and economic factors used to design processes for isolating and purifying materials like whole cells, enzymes, food additives, or pharmaceuticals that are products of biological reactors. Concurrently scheduled with course C125. Letter grading. Ms. Annabi (Sp)

**CM227. Synthetic Biology for Biofuels. (4)** (Same as Chemistry CM227.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: Chemistry 153A. Engineering microorganisms for complex phenotype is common goal of metabolic engineering and synthetic biology. Production of advanced biofuels involves designing and constructing novel metabolic networks in cells. Such efforts require profound understanding of biochemistry, protein structure, and biological regulations and are aided by tools in bioinformatics, systems biology, and molecular biology. Fundamentals of metabolic biochemistry, protein structureC224 and function, and bioinformatics. Use of systems modeling for metabolic networks to design microorganisms for energy applications. Concurrently scheduled with course CM127. S/U or letter grading. (Not offered 2019-20)

**C228. Hydrogen. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: Chemistry 20A. Electronic, physical, and chemical properties of hydrogen. Various methods of production, including production through methane steam reforming, electrolysis, and thermochemical cycles. Description in depth of several uses of hydrogen, including hydrogen combustion and hydrogen fuel cells. Concurrently scheduled with course C128. Letter grading.
Mr. Manousiouthakis (Sp)

**230. Reaction Kinetics. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 106, 200. Macroscopic descriptions: reaction rates, relaxation times, thermodynamic correlations of reaction rate constants. Molecular descriptions: kinetic theory of gases, models of elementary processes. Applications: absorption and dispersion measurements, unimolecular reactions, photochemical reactions, hydrocarbon pyrolysis and oxidation, explosions, polymerization. Letter grading. (Not offered 2019-20)

**231. Molecular Dynamics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 106 or 110. Analysis and design of molecular-beam systems. Molecular-beam sampling of reactive mixtures in combustion chambers or gas jets. Molecular-beam studies of gas-surface interactions, including energy accommodations and heterogeneous reactions. Applications to air pollution control and to catalysis. Letter grading. (Not offered 2019-20)

**232. Combustion Processes. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 106, 200, or Mechanical and Aerospace Engineering C132A. Fundamentals: change equations for multicomponent reactive mixtures, rate laws. Applications: combustion, including burning of (1) premixed gases or (2) condensed fuels. Detonation. Sound absorption and dispersion. Letter grading.
(Not offered 2019-20)

**233. Frontiers in Biotechnology. (2)** Lecture, one hour. Requisite: Life Sciences 3. Integration of science and business in biotechnology. Academic research leading to licensing and founding of companies that turn research breakthroughs into marketable products. Invited lecturers from academia and industry cover emerging areas of biotechnology from combination of science, engineering, and business points of view. S/U or letter grading.
(Not offered 2019-20)

**234. Plasma Chemistry and Engineering. (4)** Lecture, four hours; outside study, eight hours. Designed for graduate chemistry or engineering students. Application of chemistry, physics, and engineering principles to design and operation of plasma and ion-beam reactors used in etching, deposition, oxidation, and cleaning of materials. Examination of atomic, molecular, and ionic phenomena involved in plasma and ion-beam processing of semiconductors, etc. Letter grading. Ms. Chang (Not offered 2019-20)

**C235. Advanced Process Control. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 107. Introduction to advanced process control. Topics include (1) Lyapunov stability for autonomous nonlinear systems including converse theorems, (2) input to state stability, interconnected systems, and small gain theorems, (3) design of nonlinear and robust controllers for various classes of nonlinear systems, (4) model predictive control of linear and nonlinear systems, (5) advanced methods for tuning of classical controllers, and (6) introduction to control of distributed parameter systems. Concurrently scheduled with course C135. Letter grading. (Sp)

**236. Chemical Vapor Deposition. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 210, C216. Chemical vapor deposition is widely used to deposit thin films that comprise microelectronic devices. Topics include reactor design, transport phenomena, gas and surface chemical kinetics, structure and composition of deposited films, and relationship between process conditions and film properties. Letter grading. (Not offered 2019-20)

**C240. Fundamentals of Aerosol Technology. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 101C. Technology of particle/gas systems with applications to gas cleaning, commercial production of fine particles, and catalysis. Particle transport and deposition, optical properties, experimental methods, dynamics and control of particle formation processes. Concurrently scheduled with course C140. Letter grading.
(Not offered 2019-20)

**CM245. Molecular Biotechnology for Engineers. (4)** (Same as Bioengineering CM245.) Lecture, four hours; discussion, one hour; outside study, seven hours. Selected topics in molecular biology that form foundation of biotechnology and biomedical industry today. Topics include recombinant DNA technology, molecular research tools, manipulation of gene expression, directed mutagenesis and protein engineering, DNA-based diagnostics and DNA microarrays, antibody and protein-based diagnostics, genomics and bioinformatics, isolation of human genes, gene therapy, and tissue engineering. Concurrently scheduled with course CM145. Letter grading.
Mr. Park (F)

**246. Systems Biology: Intracellular Network Identification and Analysis. (4)** Lecture, four hours; outside study, eight hours. Requisites: course CM245, Life Sciences 1, 2, 3, 4, 23L, Mathematics 31A, 31B, 32A, 33B. Systems approach to intracellular network identification and analysis. Transcriptional regulatory networks, protein networks, and metabolic networks. Data from genome sequencing, large-scale expression analysis, and other high-throughput techniques provide bases for systems identification and analysis. Discussion of gene-metabolic network synthesis. Letter grading. (Not offered 2019-20)

**250. Computer-Aided Chemical Process Design. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 108B. Application of optimization methods in chemical process design; computer aids in process engineering; process modeling; systematic flowsheet invention; process synthesis; optimal design and operation of large-scale chemical processing systems. Letter grading.
Mr. Manousiouthakis (Not offered 2019-20)

**259. Theory of Applied Mathematics for Chemical Engineers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Recommended preparation: multivariable calculus. Review of functional analysis concepts. Vector spaces, norms, convexity, convergence, continuity, Banach/Hilbert/Sobolev spaces. Linear functionals. Orthonormal sets, linear operators and their spectrum. Minimum distance problems, least squares. Lagrange multipliers, nonlinear duality, variational methods. Finite difference and finite element approximation of partial differential equations (PDEs). Letter grading.
Mr. Manousiouthakis (Not offered 2019-20)

**260. Non-Newtonian Fluid Mechanics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 102A. Principles of non-Newtonian fluid mechanics. Stress constitutive equations. Rheology of polymeric liquids and dispersed systems. Applications in viscometry, polymer processing, biorheology, oil recovery, and drag reduction. Letter grading.
Mr. Cohen (Not offered 2019-20)

**270. Principles of Reaction and Transport Phenomena. (4)** Lecture, four hours; laboratory, eight hours. Fundamentals in transport phenomena, chemical reaction kinetics, and thermodynamics at molecular level. Topics include Boltzmann equation, microscopic chemical kinetics, transition state theory, and statistical analysis. Examination of engineering applications related to state-of-art research areas in chemical engineering. Letter grading. Ms. Chang

**270R. Advanced Research in Semiconductor Manufacturing. (6)** Laboratory, nine hours; outside study, nine hours. Limited to graduate chemical engineering students in MS semiconductor manufacturing option. Supervised research in processing semiconductor materials and devices. Letter grading.

**M280A. Linear Dynamic Systems. (4)** (Same as Electrical and Computer Engineering M240A and Mechanical and Aerospace Engineering M270A.) Lecture, four hours; outside study, eight hours. Requisite: Electrical and Computer Engineering 141 or Mechanical and Aerospace Engineering 171A. State-space description of linear time-invariant (LTI) and time-varying (LTV) systems in continuous and discrete time. Linear algebra concepts such as eigenvalues and eigenvectors, singular values, Cayley/Hamilton theorem, Jordan form; solution of state equations; stability, controllability, observability, realizability, and minimality. Stabilization design via state feedback and observers; separation principle. Connections with transfer function techniques. Letter grading.

**M280C. Optimal Control. (4)** (Same as Electrical and Computer Engineering M240C and Mechanical and Aerospace Engineering M270C.) Lecture, four hours; outside study, eight hours. Requisite: Electrical and Computer Engineering 240B or Mechanical and Aerospace Engineering 270B. Applications of variational methods, Pontryagin maximum principle, Hamilton/Jacobi/Bellman equation (dynamic programming) to optimal control of dynamic systems modeled by nonlinear ordinary differential equations. Letter grading.

**M282A. Nonlinear Dynamic Systems. (4)** (Same as Electrical and Computer Engineering M242A and Mechanical and Aerospace Engineering M272A.) Lecture, four hours; outside study, eight hours. Requisite: course M280A or Electrical and Computer Engineering M240A or Mechanical and Aerospace Engineering M270A. State-space techniques for studying solutions of time-invariant and time-varying nonlinear dynamic systems with emphasis on stability. Lyapunov theory (including converse theorems), invariance, center manifold theorem, input-to-state stability and small-gain theorem. Letter grading.

**283C. Analysis and Control of Infinite Dimensional Systems. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses M280A, M282A. Designed for graduate students. Introduction to advanced dynamical analysis and controller synthesis methods for nonlinear infinite dimensional systems. Topics include (1) linear operator and stability theory (basic results on Banach and Hilbert spaces, semigroup theory, convergence theory in function spaces), (2) nonlinear model reduction (linear and nonlinear Galerkin method, proper orthogonal decomposition), (3) nonlinear and robust control of nonlinear hyperbolic and parabolic partial differential equations (PDEs), (4) applications to transport-reaction processes. Letter grading. Mr. Christofides (Not offered 2019-20)

**284A. Optimization in Vector Spaces. (4)** Lecture, four hours; outside study, eight hours. Requisites: Electrical Engineering 236A, 236B. Review of functional analysis concepts. Convexity, convergence, continuity. Minimum distance problems for Hilbert and Banach spaces. Lagrange multiplier theorem in Banach spaces. Nonlinear duality theory. Letter grading. Mr. Manousiouthakis (Not offered 2019-20)

**290. Special Topics. (2 to 4)** Seminar, four hours. Requisites for each offering announced in advance by department. Advanced and current study of one or more aspects of chemical engineering, such as chemical process dynamics and control, fuel cells and batteries, membrane transport, advanced chemical engineering analysis, polymers, optimization in chemical process design. May be repeated for credit with topic change. Letter grading.

**M297. Seminar: Systems, Dynamics, and Control Topics. (2)** (Same as Electrical and Computer Engineering M248S and Mechanical and Aerospace Engineering M299A.) Seminar, two hours; outside study, six hours. Limited to graduate engineering students. Presentations of research topics by leading academic researchers from fields of systems, dynamics, and control. Students who work in these fields present their papers and results. S/U grading.

**298A-298Z. Research Seminars. (2 to 4 each)** Seminar, to be arranged. Requisites for each offering announced in advance by department. Lectures, discussions, student presentations, and projects in areas of current interest. May be repeated for credit. S/U grading. (F,W,Sp)

**299. Departmental Seminar. (2)** Seminar, two hours. Limited to graduate chemical engineering students. Seminars by leading academic and industrial chemical engineers on development or application of recent technological advances in discipline. May be repeated for credit. S/U grading. (F,W,Sp)

**375. Teaching Apprentice Practicum. (1 to 4)** Seminar, to be arranged. Preparation: apprentice personnel employment as teaching assistant, associate, or fellow. Teaching apprenticeship under active guidance and supervision of regular faculty member responsible for curriculum and instruction at UCLA. May be repeated for credit. S/U grading. (F,W,Sp)

**495A. Teaching Assistant Training Seminar. (2)** Seminar, two hours; outside study, four hours; one-day intensive training at beginning of Fall Quarter. Limited to graduate chemical engineering students. Required of all new teaching assistants. Special seminar on communicating chemical engineering principles, concepts, and methods; teaching assistant preparation, organization, and presentation of material, including use of grading, advising, and rapport with students. S/U grading. (F)

**495B. Teaching with Technology for Teaching Assistants. (2)** Seminar, two hours; outside study, four hours. Limited to graduate chemical engineering students. Designed for teaching assistants interested in learning more about effective use of technology and ways to incorporate that technology into their classrooms for benefit of student learning. S/U grading. (W)

**596. Directed Individual or Tutorial Studies. (2 to 8)** Tutorial, to be arranged. Limited to graduate chemical engineering students. Petition forms to request enrollment may be obtained from assistant dean, Graduate Studies. Supervised investigation of advanced technical problems. S/U grading.

**597A. Preparation for MS Comprehensive Examination. (2 to 12)** Tutorial, to be arranged. Limited to graduate chemical engineering students in MS semiconductor manufacturing option. Reading and preparation for MS comprehensive examination. S/U grading.

**597B. Preparation for PhD Preliminary Examinations. (2 to 16)** Seminar, to be arranged. Limited to graduate chemical engineering students. S/U grading.

**597C. Preparation for PhD Oral Qualifying Examination. (2 to 16)** Tutorial, to be arranged. Limited to graduate chemical engineering students. Preparation for oral qualifying examination, including preliminary research on dissertation. S/U grading.

**598. Research for and Preparation of MS Thesis. (2 to 12)** Tutorial, to be arranged. Limited to graduate chemical engineering students. Supervised independent research for MS candidates, including thesis prospectus. S/U grading.

**599. Research for and Preparation of PhD Dissertation. (2 to 16)** Tutorial, to be arranged. Limited to graduate chemical engineering students. Usually taken after students have been advanced to candidacy. S/U grading.

# Civil and Environmental Engineering

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Ertugrul Taciroglu, Ph.D., *Chair*
Jennifer A. Jay, Ph.D., *Vice Chair*
Jian Zhang, Ph.D., *Vice Chair*

### Professors

Yousef Bozorgnia, Ph.D., P.E.
Scott J. Brandenberg, Ph.D., P.E.
J.R. DeShazo, Ph.D.
Eric M.V. Hoek, Ph.D.
Jennifer A. Jay, Ph.D.
Jiann-Wen (Woody) Ju, Ph.D., P.E.
Dennis P. Lettenmaier, Ph.D., NAE
Shaily Mahendra, Ph.D. *(Henry Samueli Fellow)*
Steven A. Margulis, Ph.D.
Ali Mosleh, Ph.D., NAE *(Evalyn Knight Professor of Engineering)*
Gaurav N. Sant, Ph.D. *(Henry Samueli Fellow)*
Michael K. Stenstrom, Ph.D., P.E.
Jonathan P. Stewart, Ph.D., P.E.
Ertugrul Taciroglu, Ph.D.
John W. Wallace, Ph.D., P.E.
William W-G. Yeh, Ph.D., NAE *(Richard G. Newman AECOM Endowed Professor of Civil Engineering)*

### Professors Emeriti

Stanley B. Dong, Ph.D., P.E.
Lewis P. Felton, Ph.D.
Michael E. Fourney, Ph.D., P.E.
Poul V. Lade, Ph.D.
Richard L. Perrine, Ph.D.
Moshe F. Rubinstein, Ph.D.
Lawrence G. Selna, Ph.D., S.E.
Keith D. Stolzenbach, Ph.D., P.E.
Mladen Vucetic, Ph.D.

### Associate Professors

Mekonnen Gebremichael, Ph.D.
David Jassby, Ph.D.
Jian Zhang, Ph.D.

### Assistant Professors

Mathieu Bauchy, Ph.D.
Henry V. Burton, Ph.D., S.E. *(Englekirk Presidential Endowed Professor of Structural Engineering)*
Timu W. Gallien, Ph.D.
Sanjay Mohanty, Ph.D.

### Adjunct Professors

Robert E. Kayen, Ph.D., P.E.
Michael J. McGuire, Ph.D., P.E., NAE
George Mylonakis, Ph.D., P.E.
Thomas Sabol, Ph.D., S.E.

### Adjunct Associate Professors

Donald R. Kendall, Ph.D., P.E.
Issam Najm, Ph.D., P.E.

## Scope and Objectives

The Department of Civil and Environmental Engineering programs at UCLA include civil engineering materials, earthquake engineering, environmental engineering, geotechnical engineering, hydrology and water resources engineering, structural engineering, and structural mechanics.

The civil engineering undergraduate curriculum leads to a B.S. in Civil Engineering, a broad-based education in environmental engineering, geotechnical engineering, hydrology and water resources engineering, and structural engineering and mechanics. This program is an excellent foundation for entry into professional practice in civil engineering or for more advanced study. The department also offers the undergraduate Environmental Engineering minor.

At the graduate level, M.S. and Ph.D. degree programs are offered in the areas of civil engineering materials, environmental engineering, geotechnical engineering, hydrology and water resources engineering, and structures (including structural/earthquake engineering and structural mechanics). In these areas, research is being done on a variety of problems ranging from basic physics and mechanics problems to critical problems in earthquake engineering and in the development of new technologies for pollution control and water distribution and treatment.

## Department Mission

The Civil and Environmental Engineering Department seeks to exploit its subfield teaching and research strengths as well as to engage in multidisciplinary collaboration. This occurs within the context of a central guiding theme: engineering sustainable infrastructure for the future. Under this theme the department is educating future engineering leaders, most of whom will work in multidisciplinary environments and confront a host of twenty-first-century challenges. With an infrastructure-based vision motivating its teaching and research enterprise, the department conceptualizes and orients its activity toward broadening and deepening fundamental knowledge of the interrelationships among the built environment, natural systems, and human agency.

## Undergraduate Program Educational Objectives

The civil engineering program is accredited by the Engineering Accreditation Commission of ABET, **http://www.abet.org**.

The objectives of the civil engineering curriculum at UCLA are to (1) provide graduates with a solid foundation in basic mathematics, science, and humanities, as well as fundamental knowledge of relevant engineering principles, (2) provide students with the capability for critical thinking, engineering reasoning, problem solving, experimentation, and teamwork, (3) prepare graduates for advanced study and/or professional employment within a wide array of industries or governmental agencies, (4) produce graduates who understand ethical issues associated with their profession and who are able to apply their acquired knowledge and skills to the betterment of society, and (5) foster in students a respect for the educational process that is manifest by a lifelong pursuit of learning.

***Structural/earthquake engineering graduate students visit tower three of the Metropolis project in downtown Los Angeles, with professors Henry Burton and John Wallace.***

# Undergraduate Study

The Civil Engineering major is a designated capstone major. In each of the major field design courses, students work individually and in groups to complete design projects. To do so, they draw on their prior coursework, research the needed materials and possible approaches to creating their device or system, and come up with creative solutions. This process enables them to integrate many of the principles they have learned previously and apply them to real systems. In completing their projects, students are also expected to demonstrate effective oral and written communication skills, as well as their ability to work productively with others as part of a team.

# Civil Engineering B.S.

***Capstone Major***

## Learning Outcomes

The Civil Engineering major has the following learning outcomes:

- Understanding of, and ability to apply, basic mathematical and scientific concepts that underlie the field
- Ability to contribute meaningfully to design projects
- Critical thinking skills, problem-solving abilities, and familiarity with computational procedures essential to the field
- Ability to work productively as a member of a team
- Effective oral and written communication skills

## Preparation for the Major

*Required:* Chemistry and Biochemistry 20A, 20B, 20L; Civil and Environmental Engineering 1, M20 (or Computer Science 31); Mathematics 31A, 31B, 32A, 32B, 33A, 33B (or Mechanical and Aerospace Engineering 82); Physics 1A, 1B, 1C, 4AL; one natural science course selected from Civil and Environmental Engineering 58SL, Earth, Planetary, and Space Sciences 3, 15, 16, 17, 20, Environment 12, Life Sciences 1, 2, 7A, Microbiology, Immunology, and Molecular Genetics 5, 6, or Neuroscience 10.

## The Major

Required: Chemical Engineering 102A or Mechanical and Aerospace Engineering 105A, Civil and Environmental Engineering 91, 102, 103, C104 (or Materials Science and Engineering 104), 108, 110, 120, 135A, 150, 153, Mechanical and Aerospace Engineering 103; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; and at least eight major field elective courses (32 units) from the lists below with at least two design courses, one of which must be a capstone design course and two of which must be laboratory courses. The laboratory courses must be taken from two distinct areas. Courses applied toward the required course requirement may not also be applied toward the major field elective requirement.

Civil Engineering Materials: Civil and Environmental Engineering C104, C105, C182; laboratory course: 108L.

Environmental Engineering: Civil and Environmental Engineering 154, 155, 164, M165, M166; laboratory courses: 156A, 156B; capstone design courses: 157B, 157C.

Geotechnical Engineering: Civil and Environmental Engineering 125; laboratory courses: 128L, 129L; design courses: 121, 123 (capstone).

Hydrology and Water Resources Engineering: Civil and Environmental Engineering 157A; laboratory course: 157L; design courses: 151, 152 (capstone).

Structural Engineering and Mechanics: Civil and Environmental Engineering 125, 130, 135B, M135C, C137, 142; laboratory courses: 108L, 135L, 140L; design courses: 141, 143, 144 (capstone), 147 (capstone).

Transportation Engineering: Civil and Environmental Engineering 180, 181, C182.

Additional Elective Options: Courses selected from an approved list available in the UCLA Samueli Office of Academic and Student Affairs. Note: both 128L and 129L may be taken to satisfy the two-laboratory-course requirement.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or **https://www.registrar.ucla.edu/Academics/GE-Requirement**.

# Environmental Engineering Minor

The Environmental Engineering minor is designed for students who wish to augment their major program of study with courses addressing issues central to the application of environmental engineering to important environmental problems facing modern society in developed and developing countries. The minor provides students with a greater depth of experience and understanding of the role that environmental engineering can play in dealing with environmental issues.

To enter the minor, students must be in good academic standing (2.0 grade-point average or better) and file a petition in the Office of Academic and Student Affairs, 6426 Boelter Hall.

*Required Lower-Division Course (4 units):* Mathematics 3C or 32A.

*Required Upper-Division Courses (24 units minimum):* Civil and Environmental Engineering 153 and five courses from 154, 155, 156A, M165, M166, Chemical Engineering C118, Environment 159, 166, Environmental Health Sciences C125, C164.

A minimum of 20 units applied toward the minor requirements must be in addition to units applied toward major requirements or another minor, and at least 16 units applied toward the minor must be taken in residence at UCLA. Transfer credit for any of the above is subject to departmental approval; consult with the undergraduate counselors before enrolling in any courses for the minor.

Each minor course must be taken for a letter grade, and students must have a minimum grade of C (2.0) in each and an overall grade-point average of 2.0 or better in the minor. Successful completion of the minor is indicated on the transcript and diploma.

# Graduate Study

For information on graduate admission, see Graduate Programs on page 26.

The following introductory information is based on 2019-20 program requirements for UCLA graduate degrees. Complete program requirements are available at **https://grad.ucla.edu/academics/graduate-study/program-requirements-for-ucla-graduate-degrees/**. Students are subject to the detailed degree requirements as published in program requirements for the year in which they enter the program.

The Department of Civil and Environmental Engineering offers Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees in Civil Engineering.

# Civil Engineering M.S.

## Course Requirements

There are two plans of study that lead to the M.S. degree: the capstone plan (also known as comprehensive examination) and the thesis plan. At least nine courses (36 units) are required, a majority of which must be in the Civil and Environmental Engineering Department. At least five of the courses must be at the 200 level. In the thesis plan, seven of the nine must be formal 100- or 200-series courses. The remaining two may be 598 courses involving work on the thesis. In the capstone (comprehensive examination) plan, 500-series courses may not be applied toward the nine-course requirement. Courses completed outside of the department must be equal in rigor and related to the civil and environmental engineering program of study and are recommended to be quantitative in nature. In addition, M.S. students must attend the Civil and Environmental Engineering 200 seminar each quarter. Graduate students must meet two grade-point average requirements to graduate—a minimum 3.0 GPA in all coursework and a minimum 3.0 GPA in all 200-level coursework applied toward the degree. All courses counting toward the nine-course requirement, except for 598, must be taken for a letter grade.

Each major field has a set of required preparatory courses which are normally completed during undergraduate studies. Equivalent courses taken at other institutions can satisfy the preparatory course requirements. The preparatory courses cannot be used to satisfy course requirements for the M.S. degree; courses must be selected in accordance with the lists of required graduate and elective courses for each major field. Courses not listed below may be completed toward the course requirement if pre-approved by the faculty adviser and student affairs officer.

*Undergraduate Courses*. No lower-division courses (1-99) may be applied toward graduate degrees.

The M.S. degree offers six fields of specialization that have specific course requirements.

## Civil Engineering Materials

*Required Preparatory Courses*. General chemistry and physics with laboratory exercises, multivariate calculus, linear algebra, and differential equations, introductory thermodynamics. Other undergraduate preparation could include Civil and Environmental Engineering C104, 120, 121, 135A, 140L, 142, and Materials Science and Engineering 104.

*Required Graduate Courses*. Two courses must be selected from Civil and Environmental Engineering C204, C205, 226, 253, 258A, 261B, M262A, 263A, 266, 267.

*Other Elective Courses*. Remaining courses (at least two) must be selected from Chemical Engineering 102A, 102B, 200, C219, 223, 230, 270, Chemistry and Biochemistry 103, 110A, 110B, 113A, C213B, C215A, C215B, C215C, C223A, C223B, C226A, C275, 276B, 277, Civil and Environmental Engineering 110, M135C, 153, 154, 155, 157B, 157C, M166, 220, 224, 226, M230A, M230B, M230C, 235A, 235B, 235C, 243A, 243B, 254A, 258A, 261, Conservation of Archaeological and Ethnographic Materials M210, M215, M216, M250, Environmental Health Sciences 410A, Materials Science and Engineering 110, 111, 130, 131, 200, 201, 210, 211, 270, Mechanical and Aerospace Engineering 105A, 133A, 156A, 256F, 261A, 261B, C296A, M297B, Statistics 201A.

## Environmental and Water Resources Engineering

*Required Preparatory Courses*. Chemistry and Biochemistry 20A, 20B, 20L; Civil and Environmental Engineering 151 or 153; Mathematics 32A, 32B, 33B (or Mechanical and Aerospace Engineering 82); Mechanical and Aerospace Engineering 103; Physics 1A, 1B, 4AL.

*Environmental and Water Resources Engineering Option*. Required: Two courses from Civil and Environmental Engineering 250A through 250D; two courses from 254A, 255A, 255B, 266. Select the remaining courses (nine total for the capstone [comprehensive examination] option and seven total for the thesis option) from the approved elective list or obtain approval for other electives.

*Environmental Engineering Option*. Required: Civil and Environmental Engineering 254A, 255A, 255B, 266; one course from 250A through 250D. Select the remaining courses (nine total for the capstone [comprehensive examination] option and seven total for the thesis option) from the approved elective list or obtain approval for other electives.

*Hydrology and Water Resources Engineering Option*. Required: Civil and Environmental Engineering 250A through 250D; one course from 254A, 255A, 255B, or 266. Select the remaining courses (nine total for the capstone [comprehensive examination] option and seven total for the thesis option) from the approved elective list or obtain approval for other electives.

*Approved Elective Courses*. Civil and Environmental Engineering 110, 151, 152, 154, 155, 157A, 157B, 157C, 157L, M165, 226, 250A through 250D, 251C, 251D, 252, 253, 254A, 255A, 255B, 258A, 260, 261B, M262A, 263A, 263B, 266, or other elective courses approved by the academic adviser and graduate adviser. Electives in the fields of biostatistics/statistics, chemical engineering, chemistry and biochemistry, computer science, Earth and space sciences, electrical and computer engineering, and environmental health sciences are commonly approved to satisfy course requirements. No more than two courses may be applied outside of Civil and Environmental Engineering unless pre-approved for exceptional circumstances. No more than two undergraduate courses may be applied toward the nine-course requirement unless pre-approved for exceptional circumstances.

## Geotechnical Engineering

*Required Preparatory Courses*. Civil and Environmental Engineering 108, 120, 121.

*Required Graduate Courses*. Civil and Environmental Engineering 220, 221, 223, 224.

*Major Field Elective Courses*. Civil and Environmental Engineering 225, 226, 227, 228, C239, 245.

*Other Elective Courses*. Other elective courses may be taken with prior approval from the faculty adviser.

## Structural/Earthquake Engineering

*Required Preparatory Courses*. Civil and Environmental Engineering 135A, 135B, and 141 (or 142).

*Required Graduate Courses*. Civil and Environmental Engineering 235A, C239, 246, and at least three courses from 235B, 241, 243A, 243B, 244, 245, 247.

*Elective Courses*. Undergraduate—no more than two courses from Civil and Environmental Engineering M135C, C137, 143, and either 141 or 142 (whichever was not used as a requisite for graduate courses); geotechnical area—Civil and Environmental Engineering 220, 221, 222, 223, 225, 227; general graduate—Civil and Environmental Engineering M230A, M230B, M230C, 232, 233, 235B, 235C, 236, M237A, 238, 241, 243A, 243B, 244, 245, 247, Mechanical and Aerospace Engineering 269B.

Civil and Environmental Engineering 125 may not be applied toward elective courses.

## Structural Mechanics

*Required Preparatory Courses*. Civil and Environmental Engineering 130, 135A, 135B.

*Required Graduate Courses*. Civil and Environmental Engineering M230A, 232, 235A, 235B, M237A.

*Elective Courses*. Undergraduate—maximum of two courses from Civil and Environmental Engineering M135C, C137, 137L; graduate—Civil and Environmental Engineering M230B, M230C, 233, 235C, 238, 244, 246, 247, Mechanical and Aerospace Engineering 269B.

## Structures and Civil Engineering Materials

*Required Preparatory Courses*. General chemistry and physics with laboratory exercises, multivariate calculus, linear algebra, and differential equations, introductory thermodynamics, structural analysis (Civil and Environmental Engineering 135A, 135B), steel or concrete design (course 141 or 142). Other undergraduate preparation could include Civil and Environmental Engineering C104, 120, 121, 140L, and Materials Science and Engineering 104.

*Required Graduate Courses*. Civil and Environmental Engineering C204, M230A (or 243A), 235A, C282.

*Elective Courses*. At least one course from civil engineering materials (Civil and Environmental Engineering 226, 253, 258A, 261B, M262A, 266, or 267) and if M230A is selected, one course from structural mechanics (M230B, M230C, 232, 236, or M237A) or if 243A is selected, one course from structural/earthquake engineering (241, 243B, 244, 245, 246, or 247).

*Other Elective Courses*. Remaining courses must be selected from the following with no more than two undergraduate courses allowed: Chemical Engineering 102A, 102B, 200, C219, 223, 230, 270, Chemistry and Biochemistry 103, 110A, 110B, 113A, C213B, C215A, C215B, C215C, C223A, C223B, C226A, C275, 276B, 277, Civil and Environmental Engineering 110, M135C, C137, 141 or 142 (whichever was not used as a requisite for graduate courses), 143, 153, 154, 155, 157B, 157C, M166, 220 through 227, M230A, M230B, M230C, 232, 235A, 235B, 235C, 236, M237A, 243A through 247, 254A, 258A, 261, Conservation of Archaeological and Ethnographic Materials M210, M215, M216, M250, Environmental Health Sciences 410A, Materials Science and Engineering 110, 111, 130, 131, 200, 201, 210, 211, 270, Mechanical and Aerospace Engineering 105A, 133A, 156A, 256F, 261A, 261B, C296A, 296B, Statistics 201A.

## Comprehensive Examination Capstone Plan

In addition to the course requirements, a comprehensive examination (capstone) is administered that covers the subject matter contained in the program of study. The examination may be offered in one of the following formats: (1) a portion of the doctoral written preliminary examination, (2) examination questions offered separately on final examinations of common department courses to be selected by the comprehensive examination committee, or (3) a written and/or oral examination administered by the committee. Committees for the capstone plan consist of at least three faculty members. In case of failure, the examination may be repeated once with the consent of the graduate adviser.

## Thesis Plan

In addition to the course requirements, under this plan students are required to write a thesis on a research topic in civil and environmental engineering supervised by the thesis adviser. An M.S. thesis committee reviews and approves the thesis. No oral examination is required.

The normative duration for full-time students in the M.S. programs is three quarters. The maximum time allowed for completing the M.S. degree is three years from the time of admission to the M.S. program in the School. Each quarter, students must make satisfactory progress toward their degree. Quarters taken on an approved leave of absence do not count toward the three year time limit.

# Civil Engineering Ph.D.

## Major Fields or Subdisciplines

Civil engineering materials, environmental engineering, geotechnical engineering, hydrology and water resources engineering, structural/earthquake engineering, and structural mechanics.

## Course Requirements

There is no formal course requirement for the Ph.D. degree, and students may theoretically substitute coursework by examinations. However, students normally take courses to acquire the knowledge needed for the required written preliminary examination. The basic program of study for the Ph.D. degree is built around one major field and one super-minor field or two minor fields. A super-minor field is comprised of a body of knowledge equivalent to five courses, at least three of which are at the graduate level. When two minor fields are selected, each minor field normally embraces a body of knowledge equivalent to three courses from the selected field, at least two of which are graduate courses. The minimum acceptable grade-point average for the minor field is 3.25. If students fail to satisfy the minor field requirements through coursework, a minor field examination may be taken (once only). The minor fields are selected to support the major field and are usually subsets of other major fields. A minimum 3.25 grade-point average is required in all coursework. In addition, Ph.D. students must attend the Civil and Environmental Engineering 200 seminar each quarter until they advance to candidacy.

Students who have completed graduate-level coursework prior to entering a UCLA doctorate program may apply coursework toward one of the following: Ph.D. major field, one minor, or super-minor. At least 50 percent of coursework applied toward the Ph.D. program must be completed at UCLA, unless a petition has been approved by the department.

## Written and Oral Qualifying Examinations

After mastering the body of knowledge defined in the major field, students take a written preliminary examination that should be completed within the first two years of full-time enrollment in the Ph.D. program. Students may not take the examination more than twice.

After completing the written preliminary examination and/or starting the second year of the Ph.D. program, all Ph.D. students are required to make a public presentation once per year (summer through spring) each year of the program. The presentation may be delivered to various audiences (research group, Civil and Environmental Engineering Department, conference) and must be publicized to the Civil and Environmental Engineering Department in advance of the presentation date. Students will provide documentation of presentations annually to the Student Affairs Office. The qualifying oral examination (prospectus), final oral examination (defense), and poster presentations are eligible to fulfill the annual presentation requirement.

After passing the written preliminary examination and substantially completing all minor field coursework, students take the University Oral Qualifying Examination. The nature and content of the examination are at the discretion of the doctoral committee, but ordinarily include a broad inquiry into the student's preparation for research. The doctoral committee also reviews the prospectus of the dissertation at the oral qualifying examination. The student must confirm with the committee the expectations of deliverables for the prospectus including, but not limited to, written documents and an oral presentation.

Students nominate a doctoral committee prior to taking the University Oral Qualifying Examination. Students are required to meet with committee members once per year (summer through spring) after advancement to candidacy until graduation. Meetings may be one on one or as a group and members may participate remotely. Students will provide documentation of meetings annually to the Office of Academic and Student Affairs.

*Note: Doctoral Committees*. A doctoral committee consists of a minimum of four members. Two members, including the chair, must hold full-time faculty appointments in the department. For a full list of doctoral committee regulations, see the Graduate Division Standards and Procedures for Graduate Study at UCLA.

## Advancement to Candidacy

Students are advanced to candidacy upon successful completion of the written preliminary and oral qualifying examinations.

## Doctoral Dissertation

Every doctoral degree program requires the completion of an approved dissertation that demonstrates the student's ability to perform original, independent research and constitutes a distinct contribution to knowledge in the principal field of study.

## Final Oral Examination

A final oral examination, or defense of dissertation, is required for all students in the program.

## Time-to-Degree

The normative duration for full-time students in the Ph.D. program, after completing a M.S. degree, is 12 quarters. The maximum time allowed for completing the Ph.D. degree, after completing the M.S. degree, is 24 quarters. Each quarter, students must maintain satisfactory academic progress toward their degree. Quarters taken on an approved leave of absence do not count toward the time limit.

# Fields of Study

## Civil Engineering Materials

Ongoing research is focused on inorganic, random porous materials and incorporates expertise at the interface of chemistry and materials science to develop the next generation of sustainable construction materials. The work incorporates aspects of first principles and continuum scale simulations and integrated experiments, ranging from nano-to-macro scales. Special efforts are devoted toward developing low-clinker factor cements and concretes, reducing the carbon footprint of construction materials, and increasing the service life of civil engineering infrastructure.

## Environmental Engineering

Research in environmental engineering focuses on the understanding and management of physical, chemical, and biological processes in the environment and in engineering systems. Areas of research include process development for water and wastewater treatment systems and the investigation of the fate and transport as well as treatment technologies of contaminants in the environment.

## Geotechnical Engineering

Research in geotechnical engineering focuses on understanding and advancing the state of knowledge on the effects that soils and soil deposits have on the performance, stability, and safety of civil engineering structures. Areas of research include laboratory investigations of soil behavior under static and dynamic loads, constitutive modeling of soil behavior, behavior of structural foundations under static and dynamic loads, soil improvement techniques, response of soil deposits and earth structures to earthquake loads, and the investigation of geotechnical aspects of environmental engineering.

## Hydrology and Water Resources Engineering

Ongoing research in hydrology and water resources deals with surface and groundwater processes, hydrometeorology and hydroclimatology, watershed response to disturbance, remote sensing, data assimilation, hydrologic modeling and parameter estimation, multiobjective resources planning and management, numerical modeling of solute transport in groundwater, and optimization of conjunctive use of surface water and groundwater.

## Structures (Structural Mechanics and Earthquake Engineering)

Research in structural mechanics is directed toward improving the ability of engineers to understand and interpret structural behavior through experiments and computer analyses. Areas of special interest include computer analysis using finite-element techniques, computational mechanics, structural dynamics, nonlinear behavior, plasticity, micromechanics of composites, damage and fracture mechanics, structural optimization, probabilistic static and dynamic analysis of structures, and experimental stress analysis.

Designing structural systems capable of surviving major earthquakes is the goal of experimental studies on the strength of full-scale reinforced concrete structures, computer analysis of soils/structural systems, design of earthquake resistant masonry, and design of seismic-resistant buildings and bridges.

Teaching and research areas in structural/earthquake engineering involve assessing the performance of new and existing structures subjected to earthquake ground motions. Specific interests include assessing the behavior of reinforced concrete buildings and bridges, as well as structural steel, masonry, and timber structures. Integration of analytical studies with laboratory and field experiments is emphasized to assist in the development of robust analysis and design tools, as well as design recommendations. Reliability-based design and performance assessment methodologies are also an important field of study.

# Facilities

The Civil and Environmental Engineering Department has a number of laboratories to support its teaching and research.

## Instructional Laboratories

### Engineering Geomatics Laboratory

This field laboratory teaches basic and advanced geomatics techniques including light detection and range (LIDAR) imaging, geo-referencing using total station and differential global positioning system (GPS) equipment, and integration of measurements with LIDAR mapping software and Google Earth. Experiments are conducted on campus.

### Environmental Engineering Laboratories

The laboratories are used for the study of basic laboratory techniques for characterizing water and wastewaters. Selected experiments include measurement of biochemical oxygen demand, suspended solids, dissolved oxygen hardness, and other parameters used in water quality control.

### Experimental Fracture Mechanics Laboratory

The laboratory is used for preparing and testing specimens using modern dynamic testing machines to develop an understanding of fracture mechanics and to become familiar with experimental techniques available to study crack tip stress fields, strain energy release rate, surface flaws, and crack growth in laboratory samples.

### Hydrology Laboratory

The laboratory is used for studying basic surface water processes and characterizing a range of geochemical parameters. Basic experiments include measurements of suspended solids, turbidity, dissolved oxygen, sediment distributions, and other basic water quality constituents. The laboratory also includes an extensive suite of equipment for measuring surface water processes in situ, including precipitation, stage height, discharge, channel geomorphology, and other physical parameters.

### Mechanical Vibrations Laboratory

The laboratory is used for conducting free and forced vibration and earthquake response experiments on small model structures such as a three-story building, a portal frame, and a water intake/outlet tower for a reservoir. Two electromagnetic exciters, each with a 30-pound dynamic force rating, are available for generating steady state forced vibrations. A number of accelerometers, LVDTs (displacement transducers), and potentiometers are available for measuring the motions of the structure. A laboratory view-based computer-controlled dynamic data acquisition system, an oscilloscope, and a spectrum analyzer are used to visualize and record the motion of the model structures.

Two small electromagnetic and servohydraulic shaking tables (1.5 ft. x 1.5 ft. and 2 ft. x 4 ft.) are available to simulate the dynamic response of structures to base excitation such as earthquake ground motions.

### Reinforced Concrete Laboratory

The laboratory is available for students to conduct monotonic and cyclic loading to verify analysis and design methods for moderate-scale reinforced concrete slabs, beams, columns, and joints, which are tested to failure.

### Soil Mechanics Laboratory

The laboratory is used for performing experiments to establish data required for soil classification, soil compaction, shear strength of soils, soil settlement, and consolidation characteristics of soils. Students enrolled in the Advanced Soil Mechanics Laboratory course see demonstrations of cyclic soil testing techniques including triaxial and direct simple shear, and advanced data acquisition and processing.

### Structural Design and Testing Laboratory

The laboratory is used for the design/optimization, construction, instrumentation, and testing of small-scale structural models to compare theoretical and observed behavior. Projects provide integrated design/laboratory experience involving synthesis of structural systems and procedures for measuring and analyzing response under load.

## Research Laboratories

### Building Earthquake Instrumentation Network

The network consists of more than 100 earthquake strong motion instruments in two campus buildings to measure the response of actual buildings during earthquakes. When combined with over 50 instruments placed in Century City high-rises and other nearby buildings, this network, which is maintained by the U.S. Geological Survey (USGS) and the California Geological Survey's Strong Instrumentation Motion Program, represents one of the most detailed building instrumentation networks in the world. The goal of the research conducted using the response of these buildings is to improve computer modeling methods and the ability of structural engineers to predict the performance of buildings during earthquakes.

### Environmental Engineering Laboratories

The laboratories are used for conducting water and waste-water analysis, including instrumental techniques such as microscopy, PCR, qPCR, GC, GC/MS, HPLC, TOC, IC, and particle counting instruments. A wide range of wet chemical analysis can be made in this facility with 6,000 square feet of laboratory space and an accompanying 4,000-square-foot rooftop facility where large pilot scale experiments can be conducted. Additionally, electron microscopy is available in another laboratory.

Recently studies have been conducted on oxygen transfer; storm water toxicity; transport and remediation of pollutants in soil; membrane fouling; toxicity assessment and removal of contaminants from drinking, ground, storm, and waste water; and computer simulation of a variety of environmental processes.

### Experimental Mechanics Laboratory

The laboratory supports two major laboratories: the Optical Metrology Laboratory and the Experimental Fracture Mechanics Laboratory.

In the Optical Metrology Laboratory, tools of modern optics are applied to engineering problems. Such techniques as holography, speckle-interferometry, Moiré analysis, and fluorescence-photo mechanics are used for obtaining displacement, stress, strain, or velocity fields in either solids or liquids. Recently, real-time video digital processors have been combined with these modern optical technical techniques, allowing direct interfacing with computer-based systems such as computer-aided testing or robotic manufacturing.

The Experimental Fracture Mechanics Laboratory is currently involved in computer-aided testing (CAT) of the fatigue fracture mechanics of ductile material. An online dedicated computer controls the experiment as well as records and manipulates data.

### Laboratory for the Chemistry of Construction Materials (LC$^2$)

Laboratory research efforts are directed toward development and design of sustainable, low-carbon-dioxide-footprint materials for infrastructure construction applications. To this end, its research group develops fundamental constituent chemistry-microstructure-engineering performance descriptors of cementitious materials to correlate and unify the fundamental variables that describe the overall response of the material.

These efforts are directed toward addressing the practical needs of the wider construction community and developing "new concretes" for the next generation of infrastructure construction applications. The overall research theme aims to rationalize use of natural resources in construction, promote environmental protection, and advance the cause of ecological responsibility in the concrete construction industry.

### Laboratory for the Physics of Amorphous and Inorganic Soils (PARISlab)

PARISlab research focuses on improving materials of engineering and industrial relevance. Its goal is to understand composition-nano- and micro-structure property relationships in materials at a fundamental level. To this end, it uses a computational physical/material science approach supported by experiments.

In strong collaboration with the Laboratory for the Chemistry of Construction Materials ($LC^2$), PARISlab works to establish a new paradigm in civil engineering by tackling the sustainability of infrastructure materials at different scales, from atoms to structures.

### Large-Scale Structure Test Facility

The facility allows investigation of the behavior of large-scale structural components and systems subjected to gravity and earthquake loadings. The facility consists of a high-bay area with a 20 ft. x 50 ft. strong floor with anchor points at 3 ft. on center. Actuators with servohydraulic controllers are used to apply monotonic or cyclic loads. The area is serviced by two cranes. The facilities are capable of testing large-scale structural components under a variety of axial and lateral loadings.

Associated with the laboratory is an electrohydraulic universal testing machine with force capacity of 100 tons. The machine is used mainly to apply tensile and compressive loads to specimens so that the properties of the materials from which the specimens are made can be determined. It can also be used in fatigue testing of small components.

### Soil Mechanics Laboratory

The laboratory is used for standard experiments and advanced research in geotechnical engineering, with equipment for static and dynamic triaxial and simple shear testing. Modem computer-controlled servohydraulic closed-loop system supports triaxial and simple shear devices. The system is connected to state-of-the-art data acquisition equipment. The laboratory also includes special simple shear apparatuses for small-strain static and cyclic testing and for one-dimensional or two-dimensional cyclic loading across a wide range of frequencies. A humidity room is available for storing soil samples.

## Faculty Areas of Thesis Guidance

### Professors

Yousef Bozorgnia, Ph.D., P.E. (UC Berkeley, 1981)
*Structural engineering, earthquake engineering, engineering seismology*

Scott J. Brandenberg, Ph.D., P.E. (UC Davis, 2005)
*Geotechnical earthquake engineering, soil-structure interaction, liquefaction, data acquisition and processing, numerical analysis*

J.R. DeShazo, Ph.D. (Harvard, 1997)
*Regulatory policy, institutional design, environmental economics, energy economics, electric vehicles*

Eric M.V. Hoek, Ph.D. (Yale, 2001)
*Physical and chemical environmental processes, colloidal and interfacial phenomena, environmental membrane separations, bioadhesion and bio-fouling*

Jennifer A. Jay, Ph.D. (MIT, 1999)
*Aquatic chemistry, environmental microbiology*

Jiann-Wen (Woody) Ju, Ph.D., P.E. (UC Berkeley, 1986)
*Damage mechanics, mechanics of composite materials, computational plasticity, micromechanics, concrete modeling and durability, computational mechanics*

Dennis P. Lettenmaier, Ph.D., NAE (U. Washington, 1975)
*Hydrologic modeling and prediction, hydrology-climate interactions, hydrologic change*

Shaily Mahendra, Ph.D. (UC Berkeley, 2007)
*Environmental microbiology, biodegradation of groundwater contaminants, microbial-nanomaterial interactions, nanotoxicology, applications of molecular biological and isotopic tools in environmental engineering*

Steven A. Margulis, Ph.D. (MIT, 2002)
*Surface hydrology, hydrometeorology, remote sensing, data assimilation*

Ali Mosleh, Ph.D., NAE (UCLA, 1981)
*Reliability engineering, physics of failure modeling and system life prediction, resilient systems design, prognostics and health monitoring, hybrid systems simulation, theories and techniques for risk and safety analysis*

Gaurav N. Sant, Ph.D. (Purdue, 2009)
*Cementitious materials and porous media with focus on chemistry-structure-property relationships and interfacial thermodynamics of materials*

Michael K. Stenstrom, Ph.D., P.E. (Clemson, 1976)
*Process development and control for water and wastewater treatment plants*

Jonathan P. Stewart, Ph.D., P.E. (UC Berkeley, 1996)
*Geotechnical engineering, earthquake engineering, engineering seismology*

Ertugrul Taciroglu, Ph.D. (U. Illinois Urbana-Champaign, 1998)
*Computational structural and solid mechanics, constitutive modeling of materials, structural health monitoring, performance-based earthquake engineering, soil-structure interaction*

John W. Wallace, Ph.D., P.E. (UC Berkeley, 1988)
*Earthquake engineering, design methodologies, seismic evaluation and retrofit, large-scale testing laboratory and field testing*

William W-G. Yeh, Ph.D., NAE (Stanford, 1967)
*Hydrology and optimization of water resources systems*

### Professors Emeriti

Stanley B. Dong, Ph.D., P.E. (UC Berkeley, 1962)
*Structural mechanics, structural dynamics, finite element methods, numerical methods and mechanics of composite materials*

Lewis P. Felton, Ph.D. (Carnegie Institute of Technology, 1964)
*Structural analysis, structural mechanics, automated optimum structural design, including reliability-based design*

Michael E. Fourney, Ph.D., P.E. (Caltech, 1963)
*Experimental mechanics, special emphasis on application of modern optical techniques*

Poul V. Lade, Ph.D. (UC Berkeley, 1972)
*Soil mechanics, stress-strain and strength characteristics of soils, deformation and stability analyses of foundation engineering problems*

Richard L. Perrine, Ph.D. (Stanford, 1953)
*Resource and environmental problems—chemical, petroleum, or hydrological; physics of flow through porous media; transport phenomena; kinetics*

Moshe F. Rubinstein, Ph.D. (UCLA, 1961)
*Systems analysis and design, problem-solving and decision-making models*

Lawrence G. Selna, Ph.D., S.E. (UC Berkeley, 1967)
*Reinforced concrete, earthquake engineering*

Keith D. Stolzenbach, Ph.D., P.E. (MIT, 1971)
*Environmental fluid mechanics, fate and transport of pollutants, dynamics of particles*

Mladen Vucetic, Ph.D. (Rensselaer, 1986)
*Geotechnical engineering, soil dynamics, geotechnical earthquake engineering, experimental studies of static and cyclic soil properties*

### Associate Professors

Mekonnen Gebremichael, Ph.D. (U. Iowa, 2004)
*Remote sensing of hydrology, watershed hydrologic modeling, hydrometeorology, stochastic processes and scaling*

David Jassby, Ph.D. (Duke, 2011)
*Water treatment and desalination, membrane separation processes, membrane material fabrication, electrochemistry, environmental applications of nanotechnology*

Jian Zhang, Ph.D. (UC Berkeley, 2002)
*Earthquake engineering, structural dynamics and mechanics, seismic protective devices and strategies, soil-structure interaction, and bridge engineering*

### Assistant Professors

Mathieu Bauchy, Ph.D. (U. Pierre et Marie Curie, France, 2012)
*Development of high-performance and sustainable glasses and cementitious materials for infrastructure and handled devices applications; multi-scale simulations of materials*

Henry V. Burton, Ph.D., S.E. (Stanford, 2014)
*Performance-based earthquake engineering, seismic design, evaluation and retrofit, enhanced seismic performance systems, building community resilience*

Timu W. Gallien, Ph.D. (UC Irvine, 2012)
*Urban coastal flood prediction, wave runup and overstopping, coastal hazards, sea level rise, flood control infrastructure and mitigation methods, nearshore remote sensing and observation*

Sanjay Mohanty, Ph.D. (U. Colorado Boulder, 2011)
*Effect of water change on water quality and quantity; sustainable urban development at the water-energy nexus; transport of contaminants and colloids in the subsurface and groundwater; stormwater capture, treatment, and re-use; bioremediation*

## Adjunct Professors

Robert E. Kayen, Ph.D., P.E. (UC Berkeley, 1993)
*Geomatics and terrestrial laser-topographic modeling, geotechnical earthquake engineering, engineering geology, applied geophysics*

Michael J. McGuire, Ph.D., P.E., NAE (Drexel, 1977)
*Control of trace organics in water treatment including activated carbon*

George Mylonakis, Ph.D., P.E. (SUNY Buffalo, 2005)
*Soil mechanics and dynamics, earthquake engineering, geomechanics, stress wave propagation, foundation engineering*

Thomas Sabol, Ph.D., S.E. (UCLA, 1985)
*Seismic performance and structural design issues for steel and concrete seismic force resisting systems; application of probabilistic methods to earthquake damage quantification*

## Adjunct Associate Professors

Donald R. Kendall, Ph.D., P.E. (UCLA, 1989)
*Hydraulics, groundwater hydrology, advanced engineering economics, stochastic processes*

Issam Najm, Ph.D., P.E. (U. Illinois Urbana-Champaign, 1990)
*Water chemistry; physical and chemical processes in drinking water treatment*

# Lower-Division Courses

**1. Civil Engineering and Infrastructure. (2)** Lecture, two hours; outside study, four hours. Examples of infrastructure, its importance, and manner by which it is designed and constructed. Role of civil engineers in infrastructure development and preservation. P/NP grading. Mr. Taciroglu (F)

**19. Fiat Lux Freshman Seminars. (1)** Seminar, one hour. Discussion of and critical thinking about topics of current intellectual importance, taught by faculty members in their areas of expertise and illuminating many paths of discovery at UCLA. P/NP grading.

**M20. Introduction to Computer Programming with MATLAB. (4)** (Same as Mechanical and Aerospace Engineering M20.) Lecture, two hours; discussion, two hours; laboratory, two hours; outside study, six hours. Requisite: Mathematics 33A. Fundamentals of computer programming taught in context of MATLAB computing environment. Basic data types and control structures. Input/output. Functions. Data visualization. MATLAB-based data structures. Development of efficient codes. Introduction to object-oriented programming. Examples and exercises from engineering, mathematics, and physical sciences. Letter grading. Mr. Eldredge, Mr. Taciroglu (F,W,Sp)

**58SL. Climate Change, Water Quality, and Ecosystem Functioning. (5)** Lecture, four hours; service learning, two hours; outside study, nine hours. Science related to climate change, water quality, and ecosystem health. Topics include carbon and nutrient cycling, hydrologic cycle, ecosystem structure and services, biodiversity, basic aquatic chemistry, and impacts of climate change on ecosystem functioning and water quality. Participation in series of science education projects to elementary or middle school audience. Letter grading. Ms. Jay (Not offered 2019-20)

**91. Statics. (4)** (Formerly numbered 101.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: Mathematics 31A, 31B, Physics 1A. Newtonian mechanics, vector representation, and resultant forces and moments. Free-body diagrams and equilibrium, internal loads and equilibrium in trusses, frames, and beams. Planar and nonplanar systems, distributed forces, determinate and indeterminate force systems, shear and moment diagrams, and axial force diagrams. Letter grading. Mr. Sant (F)

**97. Variable Topics in Civil and Environmental Engineering. (2 to 4)** Seminar, two hours. Current topics and research methods in civil and environmental engineering. May be repeated for credit. Letter grading.

**99. Student Research Program. (1 to 2)** Tutorial (supervised research or other scholarly work), three hours per week per unit. Entry-level research for lower-division students under guidance of faculty mentor. Students must be in good academic standing and enrolled in minimum of 12 units (excluding this course). Individual contract required; consult Undergraduate Research Center. May be repeated. P/NP grading.

# Upper-Division Courses

**102. Dynamics of Particles and Bodies. (2)** Lecture, two hours; discussion, two hours; outside study, two hours. Requisites: course 91, Physics 1B. Introduction to fundamentals of dynamics of single particles, system of particles, and rigid bodies. Topics include kinematics and kinetics of particles, work and energy, impulse and momentum, multiparticles systems, kinematics and kinetics of rigid bodies in two- and three-dimensional motions. Letter grading. Mr. Bauchy (W)

**103. Applied Numerical Computing and Modeling in Civil and Environmental Engineering. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course M20 (or Computer Science 31), Mathematics 33B or Mechanical and Aerospace Engineering 82 (either may be taken concurrently). Introduction to numerical computing with specific applications in civil and environmental engineering. Topics include error and computer arithmetic, root finding, curve fitting, numerical integration and differentiation, solution of systems of linear and nonlinear equations, numerical solution of ordinary and partial differential equations. Letter grading. Mr. Margulis, Mr. Taciroglu (Sp)

**C104. Structure, Processing, and Properties of Civil Engineering Materials. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course 91, Chemistry 20A, 20B, Mathematics 31A, 31B, 32B, Physics 1A, 1B, 1C. Corequisite: course 108. Discussion of aspects of cement and concrete materials, including manufacture of cement and production of concrete. Aspects of cement composition and basic chemical reactions, microstructure, properties of plastic and hardened concrete, chemical admixtures, and quality control and acceptance testing. Development and testing of fundamentals for complete understanding of overall response of all civil engineering materials. By end of term, successful utilization of fundamental materials science concepts to understand, explain, analyze, and describe engineering performance of civil engineering materials. Concurrently scheduled with course C204. Letter grading. Mr. Sant (W)

**C105. Structure and Properties of Amorphous Civil Engineering Materials. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course 101, Chemistry 20A, 20B, Mathematics 31A, 31B, 32B, Physics 1A, 1B, 1C. Corequisite: course 108. Nature and properties of amorphous civil engineering materials in fields of infrastructure and technology. Special attention to composition-structure-properties relationships and design and selection with respect to targeted civil engineering applications. Concurrently scheduled with course C205. Letter grading. Mr. Bauchy (Sp)

**108. Introduction to Mechanics of Deformable Solids. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course 91, Mathematics 32B, Physics 1A. Review of equilibrium principles; forces and moments transmitted by slender members. Concepts of stress and strain. Stress-strain relations with focus on linear elasticity. Transformation of stress and strain. Deformations and stresses caused by tension, compression, bending, shear, and torsion of slender members. Structural applications to trusses, beams, shafts, and columns. Introduction to virtual work principle. Letter grading. Mr. Bauchy, Ms. Zhang (W,Sp)

**108L. Experimental Structural Mechanics. (4)** (Formerly numbered 130L.) Lecture, two hours; laboratory, six hours; outside study, four hours. Requisite or corequisite: course 108. Lectures and laboratory experiments in various structural mechanics testing of metals (steel, aluminum, brass), high-strength plastics, and concrete (cylinders, beams). Direct tension. Direct compression. Ultrasonic nondestructive evaluation. Elastic buckling of columns. Fracture mechanics testing and fracture toughness. Splitting tension and flexural tension. Elastic, plastic, and fracture behavior. ASTM and RILEM. Cyclic loading. Microstructures of concrete. Size effects. Letter grading. Mr. Ju (W)

**110. Introduction to Probability and Statistics for Engineers. (4)** Lecture, four hours; discussion, one hour (when scheduled); outside study, seven hours. Requisites: Mathematics 32A, 33A. Recommended: course M20. Introduction to fundamental concepts and applications of probability and statistics in civil engineering, with focus on how these concepts are used in experimental design and sampling, data analysis, risk and reliability analysis, and project design under uncertainty. Topics include basic probability concepts, random variables and analytical probability distributions, functions of random variables, estimating parameters from observational data, regression, hypothesis testing, and Bayesian concepts. Letter grading. Ms. Jay (Sp)

**120. Principles of Soil Mechanics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 108. Soil as foundation for structures and as material of construction. Soil formation, classification, physical and mechanical properties, soil compaction, earth pressures, consolidation, and shear strength. Letter grading. Mr. Brandenberg (F)

**121. Design of Foundations and Earth Structures. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 120. Design methods for foundations and earth structures. Site investigation, including evaluation of soil properties for design. Design of footings and piles, including stability and settlement calculations. Design of slopes and earth retaining structures. Letter grading. Mr. Stewart (W)

**123. Advanced Geotechnical Design. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 121. Analysis and design of earth dams, including seepage, piping, and slope stability analyses. Case history studies involving landslides, settlement, and expansive soil problems, and design of repair methodologies for those problems. Within context of above technical problems, emphasis on preparation of professional engineering documents such as proposals, work acknowledgements, figures, plans, and reports. Letter grading. Mr. Brandenberg (Sp)

**125. Fundamentals of Earthquake Engineering. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 135A. Overview of engineering seismology, including plate tectonics, faults, wave propagation, and earthquake strong ground motion. Development and selection of design ground motions using both probabilistic seismic hazard analysis and code-based methods. Overview of seismic design regulation and California PE examination's seismic component. Code-based seismic design for new buildings using current International Building Code seismic code provisions. Overview of seismic design of bridges, dams, and other non-building structures. Letter grading. Mr. Stewart (Sp)

**128L. Soil Mechanics Laboratory. (4)** Lecture, one hour; laboratory, six hours; outside study, five hours. Requisite or corequisite: course 120. Laboratory experiments to be performed by students to obtain soil parameters required for assigned design problems. Soil classification, grain size distribution, Atterberg limits, specific gravity, compaction, expansion index, consolidation, shear strength determination. Design problems, laboratory report writing. Letter grading. Mr. Brandenberg (W)

**129L. Engineering Geomatics. (4)** Lecture, two hours; laboratory, four hours; outside study, six hours. Collection, processing, and analysis of geospatial data. Ellipsoid and geoid models of shape of Earth. Sea level, height, and geopotential surfaces. Elements and usage of topographic data and maps. Advanced global positioning systems (GPS) for high-precision mapping. Advanced laser-based light detection and ranging (LIDAR) mapping. Quantitative terrain analysis and change detection. Hydrogeomatics: seafloor mapping. Letter grading. Mr. Stewart (Sp)

**130. Elementary Structural Mechanics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 108. Analysis of stress and strain, phenomenological material behavior, extension, bending, and transverse shear stresses in beams with general cross-sections, shear center, deflection of beams, torsion of beams, warping, column instability and failure. Letter grading. Mr. Ju (Sp)

**135A. Elementary Structural Analysis. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: courses M20 (or Computer Science 31), 108. Introduction to structural analysis; classification of structural elements; analysis of statically determinate trusses, beams, and frames; deflections in elementary structures; virtual work; analysis of indeterminate structures using force method; introduction to displacement method and energy concepts. Letter grading. Mr. Ju (F)

**135B. Intermediate Structural Analysis. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 135A. Analysis of truss and frame structures using matrix methods; matrix force methods; matrix displacement method; analysis concepts based on theorem of virtual work; moment distribution. Letter grading. Mr. Taciroglu, Mr. Wallace (W)

**M135C. Introduction to Finite Element Methods. (4)** (Same as Mechanical and Aerospace Engineering M168.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 130 or Mechanical and Aerospace Engineering 156A or 166A. Introduction to basic concepts of finite element methods (FEM) and applications to structural and solid mechanics and heat transfer. Direct matrix structural analysis; weighted residual, least squares, and Ritz approximation methods; shape functions; convergence properties; isoparametric formulation of multidimensional heat flow and elasticity; numerical integration. Practical use of FEM software; geometric and analytical modeling; preprocessing and postprocessing techniques; term projects with computers. Letter grading. Mr. Taciroglu (Sp)

**135L. Structural Design and Testing Laboratory. (4)** Lecture, two hours; laboratory, five hours; outside study, five hours. Requisites: courses M20, 135A. Limited enrollment. Computer-aided optimum design, construction, instrumentation, and test of small-scale model structure. Use of computer-based data acquisition and interpretation systems for comparison of experimental and theoretically predicted behavior. Letter grading. Mr. Burton, Mr. Wallace (F,Sp)

**C137. Elementary Structural Dynamics. (4)** (Formerly numbered 137.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 135B. Basic structural dynamics course for civil engineering students. Elastic free and forced vibrations of single degree of freedom systems, introduction to response history and response spectrum analysis approaches for single and multidegree of freedom systems. Axial, bending, and torsional vibration of beams. Concurrently scheduled with course C239. Letter grading. Mr. Taciroglu (F)

**137L. Structural Dynamics Laboratory. (4)** Lecture, two hours; laboratory, six hours; outside study, four hours. Requisite or corequisite: course 137. Calibration of instrumentation for dynamic measurements. Determination of natural frequencies and damping factors from free vibrations. Determination of natural frequencies, mode shapes, and damping factors from forced vibrations. Dynamic similitude. Letter grading. Mr. Wallace (Not offered 2019-20)

**140L. Structural Components and Systems Testing Laboratory. (4)** Lecture, two hours; laboratory, six hours; outside study, four hours. Enforced requisite: course 142. Comparison of experimental results with analytical results and code requirements to assess accuracies and limitations of calculation procedures used in structural design. Tests include quasi-static tests of structural elements (beams, columns) and systems (slab-column, beam-column) and dynamic tests of simple building systems. Quasi-static tests focus on assessment of element or subsystem stiffness, strength, and deformation capacity, whereas dynamic tests focus on assessment of periods, mode shapes, and damping. Development of communication skills through preparation of laboratory reports and oral presentations. Letter grading. Mr. Wallace (Sp)

**141. Steel Structures. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 135A. Introduction to building codes. Fundamentals of load and resistance factor design of steel elements. Design of tension and compression members. Design of beams and beam columns. Simple connection design. Introduction to computer modeling methods and design process. Letter grading. Mr. Wallace (F)

**142. Design of Reinforced Concrete Structures. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 135A. Beams, columns, and slabs in reinforced concrete structures. Properties of reinforced concrete materials. Design of beams and slabs for flexure, shear, anchorage of reinforcement, and deflection. Design of columns for axial force, bending, and shear. Ultimate strength design methods. Letter grading. Ms. Zhang (W)

**142L. Reinforced Concrete Structural Laboratory. (4)** Lecture, two hours; laboratory, six hours; outside study, four hours. Requisites: courses 135B, 142. Limited enrollment. Design considerations used for reinforced concrete beams, columns, slabs, and joints evaluated using analysis and experiments. Links between theory, building codes, and experimental results. Students demonstrate accuracies and limitations of calculation procedures used in design of reinforced concrete structures. Development of skills for written and oral presentations. Letter grading. Mr. Wallace (Not offered 2019-20)

**143. Design of Prestressed Concrete Structures. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 135A, 142. Equivalent loads and allowable flexural stresses in determinate and indeterminate systems. Flexural and shear strength design, including secondary effects in indeterminate systems. Design of indeterminate post-tensioned beam using both hand calculations and commercially available computer program. Discussion of external post-tensioning, one- and two-way slab systems. Letter grading. Mr. Wallace (Sp)

**144. Structural Systems Design. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 141 or 142. Design course for civil engineering students, with focus on design and performance of complete building structural systems. International Building Code (IBC) and ASCE 7 dead, live, wind, and earthquake loads. Design of reinforced concrete and structural steel buildings. Computer modeling, analysis, and performance assessment of buildings. Letter grading. Mr. Wallace (Sp)

**147. Design and Construction of Tall Buildings. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 135B, 141. Role of structural engineer, architect, and other design professions in design process. Development of architectural design of tall buildings. Influence of building code, zoning, and finance. Advantages and limitations of different structural systems. Development of structural system design and computer model for architectural design. Letter grading. Mr. Sabol (W)

**148. Wood and Timber Design. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Recommended requisites: courses 108, 135A. Properties and behavior of wood and wood products, analysis and design of wood and timber structural members subjected to flexural, shear, and axial stresses; connections, fasteners, and detailing; and light-framed wood shear walls and diaphragms. Letter grading. Mr. Ahlberg (W)

**150. Introduction to Hydrology. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: course M20 (or Computer Science 31), Mechanical and Aerospace Engineering 103. Study of hydrologic cycle and relevant atmospheric processes, water and energy balance, radiation, precipitation formation, infiltration, evaporation, vegetation transpiration, groundwater flow, storm runoff, and flood processes. Letter grading. Mr. Margulis (F)

**151. Introduction to Water Resources Engineering. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: course 150, Mechanical and Aerospace Engineering 103. Recommended: courses 103, 110. Principles of hydraulics, flow of water in open channels and pressure conduits, reservoirs and dams, hydraulic machinery, hydroelectric power. Introduction to system analysis and design applied to water resources engineering. Letter grading. Ms. Gallien (W)

**152. Hydraulic and Hydrologic Design. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: courses 150, 151. Analysis and design of hydraulic and hydrologic systems, including stormwater management systems, potable and recycled water distribution systems, wastewater collection systems, and constructed wetlands. Emphasis on practical design components, including reading/interpreting professional drawings and documents, environmental impact reports, permitting, agency coordination, and engineering ethics. Project-based course includes analysis of alternative designs, use of engineering economics, and preparation of written engineering reports. Letter grading. Mr. Margulis (Sp)

**153. Introduction to Environmental Engineering Science. (4)** Lecture, four hours; discussion, one hour (when scheduled); outside study, seven hours. Recommended requisite: Mechanical and Aerospace Engineering 103. Water, air, and soil pollution: sources, transformations, effects, and processes for removal of contaminants. Water quality, water and wastewater treatment, waste disposal, air pollution, global environmental problems. Field trip. Letter grading. Mr. Mohanty (F)

**154. Chemical Fate and Transport in Aquatic Environments. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Recommended requisite: course 153. Fundamental physical, chemical, and biological principles governing movement and fate of chemicals in surface waters and groundwater. Topics include physical transport in various aquatic environments, air-water exchange, acid-base equilibria, oxidation-reduction chemistry, chemical sorption, biodegradation, and bioaccumulation. Practical quantitative problems solved considering both reaction and transport of chemicals in environment. Letter grading. Ms. Jay (W)

**155. Unit Operations and Processes for Water and Wastewater Treatment. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 153. Biological, chemical, and physical methods used to modify water quality. Fundamentals of phenomena governing design of engineered systems for water and wastewater treatment systems. Field trip. Letter grading. Mr. Hoek (F)

**156A. Environmental Chemistry Laboratory. (4)** Lecture, four hours; laboratory, four hours; outside study, four hours. Requisites: course 153 (may be taken concurrently), Chemistry 20A, 20B. Basic laboratory techniques in analytical chemistry related to water and wastewater analysis. Selected experiments include gravimetric analysis, titrimetry spectrophotometry, redox systems, pH and electrical conductivity. Concepts to be applied to analysis of real water samples in course 156B. Letter grading. Mr. Stenstrom (F,Sp)

**156B. Environmental Engineering Unit Operations and Processes Laboratory. (4)** Lecture, two hours; laboratory, six hours; outside study, four hours. Requisites: Chemistry 20A, 20B. Characterization and analysis of typical natural waters and wastewaters for inorganic and organic constituents. Selected experiments include analysis of solids, nitrogen species, oxygen demand, and chlorine residual, that are used in unit operation experiments that include reactor dynamics, aeration, gas stripping, coagulation/flocculation, and membrane separation. Letter grading. Mr. Stenstrom (W)

**157A. Hydrologic Modeling. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 150 or 151. Introduction to hydrologic modeling. Topics selected from areas of (1) open-channel flow, including one-dimensional steady flow and unsteady flow, (2) pipe flow and water distribution systems, (3) rainfall-runoff modeling, and (4) groundwater flow and contaminant transport modeling, with focus on use of industry and/or research standard models with locally relevant applications. Letter grading. Ms. Gallien (Not offered 2019-20)

**157B. Design of Water Treatment Plants. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 155. Water quality standards and regulations, overview of water treatment plants, design of unit operations, predesign of water treatment plants, hydraulics of plants, process control, and cost estimation. Letter grading. Mr. Stenstrom (W)

**157C. Design of Wastewater Treatment Plants. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 155. Process design of wastewater treatment plants, including primary and secondary treatment, detailed design review of existing plants, process control, and economics. Letter grading. Mr. Stenstrom (Sp)

**157L. Hydrologic Analysis. (4)** Lecture, two hours; laboratory, five hours; outside study, five hours. Requisite: course 150. Collection, compilation, and interpretation of data for quantification of components of hydrologic cycle, including precipitation, evaporation, infiltration, and runoff. Use of hydrologic variables and parameters for development, construction, and application of analytical models for selected problems in hydrology and water resources. Letter grading. Mr. Gebremichael (W)

**C159. Green Infrastructure. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 150, 153. Overview of fundamental science, engineering, and ecological principles to designing green infrastructure for stormwater management. Students design green infrastructure based on current practices, perform engineering calculations to calculate its performance, and develop critical thinking skills needed to design innovative or futuristic green infrastructures that would not only mitigate adverse impact of climate change, but also remain resilient under extreme weather conditions expected during climate change. Concurrently scheduled with course C259. Letter grading.

**164. Hazardous Waste Site Investigation and Remediation. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 150, 153, Mechanical and Aerospace Engineering 103. Overview of hazardous waste types and potential sources. Techniques in measuring and modeling subsurface flow and contaminant transport in subsurface. Design project illustrating remedial investigation and feasibility study. Letter grading. Mr. Mohanty (W)

**M165. Environmental Nanotechnology: Implications and Applications. (4)** (Same as Engineering M103.) Lecture, four hours; discussion, two hours; outside study, six hours. Recommended requisite: Engineering M101. Introduction to potential implications of nanotechnology to environmental systems as well as potential application of nanotechnology to environmental protection. Technical contents include three multidisciplinary areas: (1) physical, chemical, and biological properties of nanomaterials, (2) transport, reactivity, and toxicity of nanoscale materials in natural environmental systems, and (3) use of nanotechnology for energy and water production, plus environmental protection, monitoring, and remediation. Letter grading. Ms. Mahendra (Sp)

**M166. Environmental Microbiology. (4)** (Same as Environmental Health Sciences M166.) Lecture, four hours; discussion, two hours; outside study, six hours. Recommended requisite: course 153. Microbial cell and its metabolic capabilities, microbial genetics and its potentials, growth of microbes and kinetics of growth, microbial ecology and diversity, microbiology of wastewater treatment, probing of microbes, public health microbiology, pathogen control. Letter grading. Ms. Mahendra (W)

**M166L. Environmental Microbiology and Biotechnology Laboratory. (1)** (Same as Environmental Health Sciences M166L.) Laboratory, two hours; outside study, two hours. Corequisite: course M166. General laboratory practice within environmental microbiology, sampling of environmental samples, classical and modern molecular techniques for enumeration of microbes from environmental samples, techniques for determination of microbial activity in environmental samples, laboratory setups for studying environmental biotechnology. Letter grading. Ms. Mahendra (Not offered 2019-20)

**170. Introduction to Construction Management. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Introduction to construction engineering theory, management, and techniques. Implementation of exercises from academic texts and real project case studies. Discussion of building systems, building components, project delivery methods, document control, critical path method scheduling, labor management, quality management, estimating, sustainability, and cost controls. Letter grading. Mr. Sant (W)

**180. Introduction to Transportation Engineering. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Designed for juniors/senior Civil Engineering students and Public Affairs graduate students. General characteristics of transportation systems, including streets and highways, rail, transit, air, and water. Capacity considerations, including planning, design, and operations. Components of roadway design, including horizontal and vertical alignment, cross sections, and pavements. Letter grading. Mr. Brandenberg (Sp)

**181. Traffic Engineering Systems: Operations and Control. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Designed for juniors/seniors and public affairs graduate students. Applications of traffic safety improvements, highway capacity analyses, signal design and timing, Intelligent Transportation Systems concepts, and traffic interface with railroads, urban transit, bicyclists, and pedestrians. Students analyze local roadway and present recommended improvements to public agency officials. Letter grading. Mr. Brandenberg (F)

**C182. Rigid and Flexible Pavements: Design, Materials, and Serviceability. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Recommended requisites: courses C104, 108, 120, Materials Science 104. Correlation, analysis, and metrication of aspects of pavement design, including materials selection and traffic loading and volume. Special attention to aspects of pavement distress/serviceability and factoring of these into metrics of pavement performance. Discussion of potential choices of pavement materials (i.e., asphalt and concrete) and their specific strengths and weaknesses in paving applications. Unification and correlation of different variables that influence pavement performance and highlight their relevance in pavement design. Concurrently scheduled with course C282. Letter grading. Mr. Sant (Not offered 2019-20)

**188. Special Courses in Civil and Environmental Engineering. (4)** Lecture, to be arranged; discussion, to be arranged (when scheduled); outside study, to be arranged. Special topics in civil engineering for undergraduate students taught on experimental or temporary basis, such as those taught by resident and visiting faculty members. May be repeated for credit with topic or instructor change. Letter grading. (Sp)

**194. Research Group Seminars: Civil and Environmental Engineering. (2 to 8)** Seminar, two to eight hours; outside study, four to 16 hours. Designed for undergraduate students who are part of research group. Discussion of research methods and current literature in field or of research of faculty members or students. May be repeated for credit. Letter grading. (W,Sp)

**199. Directed Research in Civil and Environmental Engineering. (2 to 8)** Tutorial, to be arranged. Limited to juniors/seniors. Supervised individual research or investigation under guidance of faculty mentor. Culminating paper or project required. May be repeated for credit with school approval. Individual contract required; enrollment petitions available in Office of Academic and Student Affairs. Letter grading. (F,W,Sp)

## Graduate Courses

**200. Civil and Environmental Engineering Graduate Seminar. (2)** Seminar, four hours; outside study, two hours. Various topics in civil and environmental engineering that may include earthquake engineering, environmental engineering, geotechnical engineering, hydrology and water resources engineering, materials engineering, structural engineering, and structural mechanics. May be repeated for credit. S/U grading. (F,W,Sp)

**C204. Structure, Processing, and Properties of Civil Engineering Materials. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Discussion of aspects of cement and concrete materials, including manufacture of cement and production of concrete. Aspects of cement composition and basic chemical reactions, microstructure, properties of plastic and hardened concrete, chemical admixtures, and quality control and acceptance testing. Development and testing of fundamentals for complete understanding of overall response of all civil engineering materials. By end of term, successful utilization of fundamental materials science concepts to understand, explain, analyze, and describe engineering performance of civil engineering materials. Concurrently scheduled with course C104. Letter grading. Mr. Sant (W)

**C205. Structure and Properties of Amorphous Civil Engineering Materials. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course 101, Chemistry 20A, 20B, Mathematics 31A, 31B, 32B, Physics 1A, 1B, 1C. Corequisite: course 108. Nature and properties of amorphous civil engineering materials in fields of infrastructure and technology. Special attention to composition-structure-properties relationships and design and selection with respect to targeted civil engineering applications. Concurrently scheduled with course C105. Letter grading. Mr. Bauchy (Sp)

**206. Modeling and Simulation of Civil Engineering Materials. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: Chemistry 20A, 20B, Mathematics 31A, 31B, 32B, Physics 1A, 1B, 1C. Fundamental examination of modeling and numerical simulations for civil engineering materials, with focus on practical examples and applications so students can independently run simulations at scale relevant to targeted problems. Letter grading. Mr. Bauchy (F)

**220. Advanced Soil Mechanics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 120. State of stress. Consolidation and settlement analysis. Shear strength of granular and cohesive soils. In situ and laboratory methods for soil property evaluation. Letter grading. Mr. Stewart (F)

**221. Advanced Foundation Engineering. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 121, 220. Stress distribution. Bearing capacity and settlement of shallow foundations, including spread footings and mats. Performance of driven pile and drilled shaft foundations under vertical and lateral loading. Construction considerations. Letter grading. Mr. Brandenberg (Sp)

**222. Introduction to Soil Dynamics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 120. Review of engineering problems involving soil dynamics. Fundamentals of theoretical soil dynamics: response of sliding block-on-plane to cyclic earthquake loads, application of theories of single degree-of-freedom (DOF) system, multiple DOF system and one-dimensional wave propagation. Fundamentals of cyclic soil behavior: stress-strain-pore water pressure behavior, shear moduli and damping, cyclic settlement and concept of volumetric cyclic threshold shear strain. Introduction to modeling of cyclic soil behavior. Letter grading. Mr. Brandenberg (Not offered 2019-20)

**223. Slope Stability and Earth Retention Systems. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 120, 121, 220. Basic concepts of stability of earth slopes, including shear strength, design charts, limit equilibrium analysis, seepage analysis, staged construction, and rapid drawdown. Theory of earth pressures behind retaining structures, with special application to design of retaining walls, sheet piles, mechanically stabilized earth, soil nails, and anchored and braced excavation. Letter grading. Mr. Brandenberg (W)

**224. Advanced Cyclic and Monotonic Soil Behavior. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 120. In-depth study of soil behavior under cyclic and monotonic loads. Relationships between stress, strain, pore water pressure, and volume change in range of very small and large strains. Concept of normalized static and cyclic soil behavior. Cyclic degradation and liquefaction of saturated soils. Cyclic settlement of partially saturated and dry soils. Concept of volumetric cyclic threshold shear strain. Factors affecting shear moduli and damping during cyclic loading. Postcyclic behavior under monotonic loads. Critical review of laboratory, field, and modeling testing techniques. Letter grading. Mr. Vucetic (W)

**225. Geotechnical Earthquake Engineering. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 220, 245 (may be taken concurrently). Analysis of earthquake-induced ground failure, including soil liquefaction, cyclic softening of clays, seismic compression, surface fault rupture, and seismic slope stability. Ground response effects on earthquake ground motions. Soil-structure interaction, including inertial and kinematic interaction and foundation deformations under seismic loading. Letter grading. Mr. Stewart (Sp)

**226. Geoenvironmental Engineering. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 120. Field of geoenvironmental engineering involves application of geotechnical principles to environmental problems. Topics include environmental regulations, waste characterization, geosynthetics, solid waste landfills, subsurface barrier walls, and disposal of high water content materials. Letter grading. Mr. Stewart (Sp)

**227. Numerical Methods in Geotechnical Engineering. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 220. Introduction to basic concepts of computer modeling of soils using finite element method, and to constitutive modeling based on elasticity and plasticity theories. Special emphasis on numerical applications and identification of modeling concerns such as instability, bifurcation, nonexistence, and nonuniqueness of solutions. Letter grading. Mr. Stewart (Not offered 2019-20)

**228. Engineering Geology: Geologic Principles for Engineers. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 120. Engineering geology involves interpretation, evaluation, analysis, and application of geologic information and data to civil works. Topics include geologic characterization and classification of soil and rock units. Relationships developed between landforms, active, past, and ancient geologic processes, ground and surface water, and properties of soil and rock. Landform changes occur in response to dynamic processes, including changes in climate, slope formation, fluvial (river) dynamics, coastal dynamics, and deep-seated processes like volcanism, seismicity, and tectonics. Evaluation and analysis of effects of geologic processes to predict their potential effect on land use, development, public health, and public safety. Letter grading. Mr. Stewart (F)

**M230A. Linear Elasticity. (4)** (Same as Mechanical and Aerospace Engineering M256A.) Lecture, four hours; outside study, eight hours. Requisite: Mechanical and Aerospace Engineering 156A or 166A. Linear elastostatics. Cartesian tensors; infinitesimal strain tensor; Cauchy stress tensor; strain energy; equilibrium equations; linear constitutive relations; plane elastostatic problems, holes, corners, inclusions, cracks; three-dimensional problems of Kelvin, Boussinesq, and Cerruti. Introduction to boundary integral equation method. Letter grading. Mr. Ju, Mr. Mal (F)

**M230B. Nonlinear Elasticity. (4)** (Same as Mechanical and Aerospace Engineering M256B.) Lecture, four hours; outside study, eight hours. Requisite: course M230A. Kinematics of deformation, material and spatial coordinates, deformation gradient tensor, nonlinear and linear strain tensors, strain displacement relations; balance laws, Cauchy and Piola stresses, Cauchy equations of motion, balance of energy, stored energy; constitutive relations, elasticity, hyperelasticity, thermoelasticity; linearization of field equations; solution of selected problems. Letter grading. Mr. Ju, Mr. Mal (W)

**M230C. Plasticity. (4)** (Same as Mechanical and Aerospace Engineering M256C.) Lecture, four hours; outside study, eight hours. Requisites: courses M230A, M230B. Classical rate-independent plasticity theory, yield functions, flow rules and thermodynamics. Classical rate-dependent viscoplasticity, Perzyna and Duvant/Lions types of viscoplasticity. Thermoplasticity and creep. Return mapping algorithms for plasticity and viscoplasticity. Finite element implementations. Letter grading. Mr. Ju, Mr. Mal (Sp)

**232. Theory of Plates and Shells. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 130. Small and large deformation theories of thin plates; energy methods; free vibrations; membrane theory of shells; axisymmetric deformations of cylindrical and spherical shells, including bending. Letter grading. Ms. Zhang (F)

**233. Mechanics of Composite Material Structures. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses M230B, 232. Elastic, anisotropic stress-strain-temperature relations. Analysis of prismatic beams by three-dimensional elasticity. Analysis of laminated anisotropic plates and shells based on classical and first-order shear deformation theories. Elastodynamic behavior of laminated plates and cylinders. Letter grading. Mr. Taciroglu (Not offered 2019-20)

**235A. Advanced Structural Analysis. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 135A. Recommended: course 135B. Review of matrix force and displacement methods of structural analysis; virtual work theorem, virtual forces, and displacements; theorems on stationary value of total and complementary potential energy, minimum total potential energy, Maxwell/Betti theorems, effects of approximations, introduction to finite element analysis. Letter grading. Mr. Burton (F)

**235B. Finite Element Analysis of Structures. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 130, 235A. Direct energy formulations for deformable systems; solution methods for linear equations; analysis of structural systems with one-dimensional elements; introduction to variational calculus; discrete element displacement, force, and mixed methods for membrane, plate, shell structures; instability effects. Letter grading. Mr. Taciroglu (W)

**235C. Nonlinear Structural Analysis. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 235B. Classification of nonlinear effects; material nonlinearities; conservative, nonconservative material behavior; geometric nonlinearities, Lagrangian, Eulerian description of motion; finite element methods in geometrically nonlinear problems; postbuckling behavior of structures; solution of nonlinear equations; incremental, iterative, programming methods. Letter grading. Mr. Taciroglu (Sp)

**236. Stability of Structures I. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 130 or 135B. Elastic buckling of bars. Different approaches to stability problems. Inelastic buckling of columns and beam columns. Columns and beam columns with linear, nonlinear creep. Combined torsional and flexural buckling of columns. Buckling of plates. Letter grading. Mr. Ju (Not offered 2019-20)

**M237A. Dynamics of Structures. (4)** (Same as Mechanical and Aerospace Engineering M269A.) Lecture, four hours; outside study, eight hours. Requisite: course 137. Principles of dynamics. Determination of normal modes and frequencies by differential and integral equation solutions. Transient and steady state response. Emphasis on derivation and solution of governing equations using matrix formulation. Letter grading. Mr. Bendiksen, Mr. Ju, Mr. Taciroglu (W)

**238. Computational Solid Mechanics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 235B. Advanced finite element and meshfree methods for computational solid mechanics. Stability and consistency in temporal discretization of parabolic and hyperbolic systems. Analysis of numerical dissipation and dispersion. Multifield variational principles for constrained problems. Meshfree methods: approximation theories, Galerkin meshfree methods, collocation meshfree methods, imposition of boundary conditions, domain integration, stability. Letter grading. Mr. Wallace (Not offered 2019-20)

**C239. Elementary Structural Dynamics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Recommended requisite: course 135B. Basic structural dynamics course for civil engineering students. Elastic free and forced vibrations of single degree of freedom systems, introduction to response history and response spectrum analysis approaches for single and multidegree of freedom systems. Axial, bending, and torsional vibration of beams. Concurrently scheduled with course C137. Letter grading. Mr. Taciroglu (F)

**241. Advanced Steel Structures. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses C137, 141, 235A. Performance characterization of steel structures for static and earthquake loads. Behavior state analysis and building code provisions for special moment resisting, braced, and eccentric braced frames. Composite steel-concrete structures. Letter grading. Mr. Sabol, Mr. Wallace (Sp)

**243A. Behavior and Design of Reinforced Concrete Structural Elements. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 142. Advanced topics on design of reinforced concrete structures, including stress-strain relationships for plain and confined concrete, moment-curvature analysis of sections, and design for shear. Design of slender and low-rise walls, as well as design of beam-column joints. Introduction to displacement-based design and applications of strut-and-tie models. Letter grading. Mr. Wallace (F)

**243B. Response and Design of Reinforced Concrete Structural Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 243A, 246. Information on response and behavior of reinforced concrete buildings to earthquake ground motions. Topics include use of elastic and inelastic response spectra, role of strength, stiffness, and ductility in design, use of prescriptive versus performance-based design methodologies, and application of elastic and inelastic analysis techniques for new and existing construction. Letter grading. Mr. Wallace (Sp)

**244. Structural Reliability. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Introduction to concepts and applications of structural reliability. Topics include computing first- and second-order estimates of failure probabilities of engineered systems, computing sensitivities of failure probabili-

ties to assumed parameter values, measuring relative importance of random variables associated with systems, identifying relative advantages and disadvantages of various analytical reliability methods, using reliability tools to calibrate simplified building codes, and performing reliability calculations related to performance-based engineering. Letter grading.
Mr. Burton (W)

**245. Earthquake Ground Motion Characterization. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Corequisite: course C137 or 246. Earthquake fundamentals, including plate tectonics, fault types, seismic waves, and magnitude scales. Characterization of earthquake source, including magnitude range and rate of future earthquakes. Ground motion prediction equations and site effects on ground motion. Seismic hazard analysis. Ground motion selection and modification for response history analysis. Letter grading.
Mr. Bozorgnia (W)

**246. Structural Response to Ground Motions. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses C137, 141, 142, 235A. Spectral analysis of ground motions: response, time, and Fourier spectra. Response of structures to ground motions due to earthquakes. Computational methods to evaluate structural response. Response analysis, including evaluation of contemporary design standards. Limitations due to idealizations. Letter grading. Mr. Taciroglu, Mr. Wallace (W)

**247. Earthquake Hazard Mitigation. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 130, and M237A or 246. Concept of seismic isolation, linear theory of base isolation, visco-elastic and hysteretic behavior, elastomeric bearings under compression and bending, buckling of bearings, sliding bearings, passive energy dissipation devices, response of structures with isolation and passive energy dissipation devices, static and dynamic analysis procedures, code provisions and design methods for seismically isolated structures. Letter grading. Ms. Zhang (Sp)

**250A. Surface Water Hydrology. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 150. In-depth study of surface water hydrology, including discussion and interrelationship of major topics such as rainfall and evaporation, soils and infiltration properties, runoff and snowmelt processes. Introduction to rainfall-runoff modeling, floods, and policy issues involved in water resource engineering and management. Letter grading. Mr. Gebremichael (F)

**250B. Groundwater Hydrology. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 150. Theory of movement and occurrence of water in subterranean aquifers. Steady flow in confined and unconfined aquifers. Mechanics of wells; steady and unsteady radial flows in confined and unconfined aquifers. Theory of leaky aquifers. Parameter estimation. Seawater intrusion. Numerical methods. Applications. Letter grading.
Mr. Yeh (W)

**250C. Hydrometeorology. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 250A. In-depth study of hydrometeorological processes. Role of hydrology in climate system, precipitation and evaporation processes, atmospheric radiation, exchange of mass, heat, and momentum between soil and vegetation surface and overlying atmosphere, flux and transport in turbulent boundary layer, basic remote sensing principles. Letter grading.
Mr. Margulis (W)

**250D. Water Resources Systems Engineering. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 151. Application of mathematical programming techniques to water resources systems. Topics include reservoir management and operation; optimal timing, sequencing and sizing of water resources projects; and multiobjective planning and conjunctive use of surface water and groundwater. Emphasis on management of water quantity. Letter grading. Mr. Yeh (Sp)

**251A. Rainfall-Runoff Modeling. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 250A, 251B. Introduction to hydrologic modeling concepts, including rainfall-runoff analysis, input data, uncertainty analysis, lumped and distributed modeling, parameter estimation and sensitivity analysis, and application of models for flood forecasting and prediction of streamflows in water resource applications. Letter grading.
Mr. Margulis (Not offered 2019-20)

**251B. Contaminant Transport in Groundwater. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 250B, 253. Phenomena and mechanisms of hydrodynamic dispersion, governing equations of mass transport in porous media, various analytical and numerical solutions, determination of dispersion parameters by laboratory and field experiments, biological and reactive transport in multiphase flow, remediation design, software packages and applications. Letter grading.
Mr. Yeh (Not offered 2019-20)

**251C. Remote Sensing with Hydrologic Applications. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 250A, 250C. Introduction to basic physical concepts of remote sensing as they relate to surface and atmospheric hydrologic processes. Applications include radiative transfer modeling and retrieval of hydrologically relevant parameters like topography, soil moisture, snow properties, vegetation, and precipitation. Letter grading.
Mr. Gebremichael (Sp)

**251D. Hydrologic Data Assimilation. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 250A, 250C. Introduction to basic concepts of classical and Bayesian estimation theory for purposes of hydrologic data assimilation. Applications geared toward assimilating disparate observations into dynamic models of hydrologic systems. Letter grading. Mr. Margulis (Sp)

**252. Engineering Economic Analysis of Water and Environmental Planning. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: Engineering 110, one or more courses from Economics 1, 2, 11, 101. Economic theory and applications in analysis and management of water and environmental problems; application of price theory to water resource management and renewable resources; benefit-cost analysis with applications to water resources and environmental planning. Letter grading. Mr. Yeh (Not offered 2019-20)

**253. Mathematical Models for Water Quality Management. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 153. Development of mathematical models for simulating environmental engineering problems. Emphasis on numerical techniques to solve nonlinear partial differential equations and their application to environmental engineering problems. Letter grading. Mr. Stenstrom (F)

**254A. Environmental Aquatic Inorganic Chemistry. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: Chemistry 20B, Mathematics 31A, 31B, Physics 1A, 1B. Equilibrium and kinetic descriptions of chemical behavior of metals and inorganic ions in natural fresh/marine surface waters and in water treatment. Processes include acid-base chemistry and alkalinity (carbonate system), complexation, precipitation/dissolution, absorption oxidation/reduction, and photochemistry. Letter grading. Ms. Jay (F)

**255A. Physical and Chemical Processes for Water and Wastewater Treatment. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 155, 254A. Review of momentum and mass transfer, chemical reaction engineering, coagulation and flocculation, granular filtrations, sedimentation, carbon adsorption, gas transfer, disinfection, oxidation, and membrane processes. Letter grading. Mr. Jassby (W)

**255B. Biological Processes for Water and Wastewater Treatment. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 254A, 255A. Fundamentals of environmental engineering microbiology; kinetics of microbial growth and biological oxidation; applications for activated sludge, gas transfer, fixed-film processes, aerobic and anaerobic digestion, sludge disposal, and biological nutrient removal. Letter grading.
Mr. Stenstrom (W)

**258A. Membrane Separations in Aquatic Systems. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 254A. Applications of membrane separations to desalination, water reclamation, brine disposal, and ultrapure water systems. Discussion of reverse osmosis, ultrafiltration, electrodialysis, and ion exchange technologies from both practical and theoretical standpoints. Letter grading.
Mr. Jassby (Sp)

**C259. Green Infrastructure. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 150, 153. Overview of fundamental science, engineering, and ecological principles to designing green infrastructure for stormwater management. Students design green infrastructure based on current practices, perform engineering calculations to calculate its performance, and develop critical thinking skills needed to design innovative or futuristic green infrastructures that would not only mitigate adverse impact of climate change, but also remain resilient under extreme weather conditions expected during climate change. Concurrently scheduled with course C159. Letter grading.

**260. Advanced Topics in Hydrology and Water Resources. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 250A, 250B, 250D. Current research topics in inverse problem of parameter estimation, experimental design, conjunctive use of surface and groundwater, multiobjective water resources planning, and optimization of water resource systems. Topics may vary from term to term. Letter grading. Mr. Yeh (Not offered 2019-20)

**261. Colloidal Phenomena in Aquatic Systems. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 254A, 255A. Colloidal interactions, colloidal stability, colloidal hydrodynamics, surface chemistry, adsorption of pollutants on colloidal surfaces, transport of colloids in porous media, coagulation, and particle deposition. Consideration of applications to colloidal processes in aquatic environments. Letter grading.
Mr. Hoek (Not offered 2019-20)

**261B. Advanced Biological Processes for Water and Wastewater Treatment. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 255B. In-depth treatment of selected topics related to biological treatment of waters and wastewaters, such as biodegradation of xenobiotics, pharmaceuticals, emerging pollutants, toxicity, and nutrients. Discussion of theoretical aspects, experimental observations, and recent literature. Application to important and emerging environmental problems. Letter grading. Mr. Stenstrom (Sp)

**M262A. Introduction to Atmospheric Chemistry. (4)** (Same as Atmospheric and Oceanic Sciences M203A.) Lecture, three hours. Requisite for undergraduates: Chemistry 20B. Principles of chemical kinetics, thermochemistry, spectroscopy, and photochemistry; chemical composition and history of Earth's atmosphere; biogeochemical cycles of key atmospheric constituents; basic photochemistry of troposphere and stratosphere, upper atmosphere chemical processes; air pollution; chemistry and climate. S/U or letter grading. (F)

**M262B. Atmospheric Diffusion and Air Pollution. (4)** (Same as Atmospheric and Oceanic Sciences M224B.) Lecture, three hours. Nature and sources of atmospheric pollution; diffusion from point, line, and area sources; pollution dispersion in urban complexes; meteorological factors and air pollution potential; meteorological aspects of air pollution. S/U or letter grading. (Not offered 2019-20)

**263A. Physics of Environmental Transport. (4)** Lecture, four hours; outside study, eight hours. Designed for graduate students. Transport processes in surface water, groundwater, and atmosphere. Emphasis on exchanges across phase boundaries: sediment/water interface; air/water gas exchange; parti-

cles, droplets, and bubbles; small-scale dispersion and mixing; effect of reactions on transport; linkages between physical, chemical, and biological processes. Letter grading.
Mr. Mohanty (Not offered 2019-20)

**263B. Advanced Topics in Transport at Environmental Interfaces. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 263A. In-depth treatment of selected topics involving transport phenomena at environmental interfaces between solid, fluid, and gas phases, such as aquatic sediments, porous aggregates, and vegetative canopies. Discussion of theoretical models and experimental observations. Application to important environmental engineering problems. Letter grading.
Ms. Jay (Not offered 2019-20)

**266. Environmental Biotechnology. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 153, 254A. Environmental biotechnology—concept and potential, biotechnology of pollutional control, bioremediation, biomass conversion: composting, biogas and bioethanol production. Letter grading. Ms. Mahendra (F)

**267. Environmental Applications of Geochemical Modeling. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 254A. Geochemical modeling is important tool for predicting environmental impacts of contamination. Hands-on experience in modeling using geochemical software packages commonly found in environmental consulting industry to gain better understanding of governing geochemical principles pertaining to movement and transformation of contaminants. Types of modeling include speciation, mineral solubility, surface complexation, reaction path, inverse mass balance, and reactive transport modeling. Case studies involve acid mine drainage, nuclear waste disposal, bioavailability and risk assessment, mine tailings and mining waste, deep well injection, landfill leachate, and microbial respiration. Research/modeling project required. Letter grading. Ms. Jay (Not offered 2019-20)

**C282. Rigid and Flexible Pavements: Design, Materials, and Serviceability. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Correlation, analysis, and metrication of aspects of pavement design, including materials selection and traffic loading and volume. Special attention to aspects of pavement distress/serviceability and factoring of these into metrics of pavement performance. Discussion of potential choices of pavement materials (i.e., asphalt and concrete) and their specific strengths and weaknesses in paving applications. Unification and correlation of different variables that influence pavement performance and highlight their relevance in pavement design. Concurrently scheduled with course C182. Letter grading.
Mr. Sant (Not offered 2019-20)

**296. Advanced Topics in Civil Engineering. (2 to 4)** Seminar, to be arranged. Discussion of current research and literature in research specialty of faculty member teaching course. S/U grading. (F,W,Sp)

**298. Seminar: Engineering. (2 to 4)** Seminar, to be arranged. Limited to graduate civil engineering students. Seminars may be organized in advanced technical fields. If appropriate, field trips may be arranged. May be repeated with topic change. Letter grading. (F,W,Sp)

**375. Teaching Apprentice Practicum. (1 to 4)** Seminar, to be arranged. Preparation: apprentice personnel employment as teaching assistant, associate, or fellow. Teaching apprenticeship under active guidance and supervision of regular faculty member responsible for curriculum and instruction at UCLA. May be repeated for credit. S/U grading. (F,W,Sp)

**495. Teaching Assistant Training Seminar. (2)** Seminar, two hours. Preparation: appointment as teaching assistant in Civil and Environmental Engineering Department. Seminar on communication of civil engineering principles, concepts, and methods; teaching assistant preparation, organization, and presentation of material, including use of visual aids; grading, advising, and rapport with students. S/U grading. (F)

**596. Directed Individual or Tutorial Studies. (2 to 8)** Tutorial, to be arranged. Limited to graduate civil engineering students. Petition forms to request enrollment may be obtained from assistant dean, Graduate Studies. Supervised investigation of advanced technical problems. S/U grading.

**597A. Preparation for MS Comprehensive Examination. (2 to 12)** Tutorial, to be arranged. Limited to graduate civil engineering students. Reading and preparation for MS comprehensive examination. S/U grading.

**597B. Preparation for PhD Preliminary Examinations. (2 to 16)** Tutorial, to be arranged. Limited to graduate civil engineering students. S/U grading.

**597C. Preparation for PhD Oral Qualifying Examination. (2 to 16)** Tutorial, to be arranged. Limited to graduate civil engineering students. Preparation for oral qualifying examination, including preliminary research on dissertation. S/U grading.

**598. Research for and Preparation of MS Thesis. (2 to 12)** Tutorial, to be arranged. Limited to graduate civil engineering students. Supervised independent research for MS candidates, including thesis prospectus. S/U grading.

**599. Research for and Preparation of PhD Dissertation. (2 to 16)** Tutorial, to be arranged. Limited to graduate civil engineering students. Usually taken after students have been advanced to candidacy. S/U grading.

# Computer Science

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**https://www.cs.ucla.edu**

Richard E. Korf, Ph.D., *Interim Chair*
Glenn D. Reinman, Ph.D., *Vice Chair*

## Professors

Junghoo (John) Cho, Ph.D.
Jason (Jingsheng) Cong, Ph.D. *(Chancellor's Professor)*
Adnan Y. Darwiche, Ph.D.
Joseph J. DiStefano III, Ph.D.
Milos D. Ercegovac, Ph.D.
Eleazar Eskin, Ph.D.
Eliezer M. Gafni, Ph.D.
Eran Halperin, Ph.D.
Miryung Kim, Ph.D.
Richard E. Korf, Ph.D.
Christopher J. Lee, Ph.D.
Songwu Lu, Ph.D.
Todd D. Millstein, Ph.D.
Stanley J. Osher, Ph.D.
Rafail Ostrovsky, Ph.D.
Jens Palsberg, Ph.D.
Miodrag Potkonjak, Ph.D.
Glenn D. Reinman, Ph.D.
Amit Sahai, Ph.D.
Majid Sarrafzadeh, Ph.D.
Stefano Soatto, Ph.D.
Mani B. Srivastava, Ph.D.
Demetri Terzopoulos, Ph.D. *(Chancellor's Professor)*
Mihaela van der Schaar, Ph.D.
George Varghese, Ph.D. *(Chancellor's Professor)*
Wei Wang, Ph.D. *(Leonard Kleinrock Term Professor of Computer Science)*
Carlo A. Zaniolo, Ph.D. *(Norman E. Friedmann Professor of Knowledge Sciences)*
Lixia Zhang, Ph.D. *(Jonathan B. Postel Professor of Computer Systems)*
Song-Chun Zhu, Ph.D.

## Professors Emeriti

Algirdas A. Avizienis, Ph.D.
Rajive L. Bagrodia, Ph.D.
Alfonso F. Cardenas, Ph.D.
Jack W. Carlyle, Ph.D.
Wesley W. Chu, Ph.D.
Michael G. Dyer, Ph.D.
Sheila A. Greibach, Ph.D.
Leonard Kleinrock, Ph.D.
Allen Klinger, Ph.D.
Lawrence P. McNamee, Ph.D.
Richard R. Muntz, Ph.D.
D. Stott Parker, Jr., Ph.D.
Judea Pearl, Ph.D. *(Chancellor's Professor Emeritus)*
David A. Rennels, Ph.D.

## Associate Professors

Raghu Meka, Ph.D.
Alexander Sherstov, Ph.D.
Yizhou Sun, Ph.D.
Yuval Tamir, Ph.D.
Guoqing (Harry) Xu, Ph.D.

## Assistant Professors

Kai-Wei Chang, Ph.D.
Jason Ernst, Ph.D.

Alyson K. Fletcher, Ph.D.
Quanquan Gu, Ph.D.
Cho-Jui Hsieh, Ph.D.
Ravi Netravali, Ph.D.
Anthony J. Nowatzki, Ph.D.
Sriram Sankararaman, Ph.D.
Fabien Scalzo, Ph.D., *in Residence*
Guy Van den Broeck, Ph.D.

### Senior Lecturers S.O.E.

Paul R. Eggert, Ph.D.
David A. Smallberg, M.S.

### Adjunct Professors

David E. Heckerman, Ph.D.
Van Jacobson, M.S.
Alan C. Kay, Ph.D.
Peter L. Reiher, Ph.D.

### Adjunct Associate Professors

Carey S. Nachenberg, M.S.
Giovanni Pau, Ph.D.

### Adjunct Assistant Professors

Alexander Afanasyev, Ph.D.
Ramin Ramezani, Ph.D.
Ameet S. Talwalkar, Ph.D.

## Scope and Objectives

Computer science is concerned with the design, modeling, analysis, and applications of computer systems. Its study at UCLA provides education at the undergraduate and graduate levels necessary to understand, design, implement, and use the software and hardware of digital computers and digital systems. The programs provide comprehensive and integrated studies of subjects in computer system architecture, computer networks, programming languages and software systems, information and data management, artificial intelligence, computer science theory, computational systems biology and bioinformatics, and computer vision and graphics.

The undergraduate and graduate studies and research projects in the Department of Computer Science are supported by significant computing resources. In addition to the departmental computing facility, there are over a dozen research laboratories specializing in areas such as distributed systems, multimedia computer communications, distributed sensor networks, VLSI systems, VLSI CAD, embedded and reconfigurable systems, computer graphics, bioinformatics, and artificial intelligence. Also, the Cognitive Systems Laboratory is engaged in studying computer systems that emulate or support human reasoning. The Biocybernetics Laboratory is devoted to multidisciplinary research involving the application of engineering and computer science methods to problems in biology and medicine.

The B.S. degree may be attained through the Computer Science and Engineering major, the Computer Science major, or the Computer Engineering major described below.

In addition, UCLA Samueli offers M.S. and Ph.D. degrees in Computer Science, as well as minor fields for graduate students seeking engineering degrees. In cooperation with the John E. Anderson Graduate School of Management, the Computer Science Department offers a concurrent degree program that enables students to obtain the M.S. in Computer Science and the M.B.A. (Master of Business Administration).

## Department Mission

The Computer Science Department strives for excellence in creating, applying, and imparting knowledge in computer science and engineering through comprehensive educational programs, research in collaboration with industry and government, dissemination through scholarly publications, and service to professional societies, the community, state, and nation.

## Computer Science and Engineering Undergraduate Program Educational Objectives

The computer science and engineering program is accredited by the Engineering Accreditation Commission and the Computing Accreditation Commission of ABET, http://www.abet.org.

The computer science and engineering undergraduate program educational objectives are that our alumni (1) make valuable technical contributions to design, development, and production in their practice of computer science and computer engineering, in related engineering or application areas, and at the interface of computers and physical systems, (2) demonstrate strong communication skills and the ability to function effectively as part of a team, (3) demonstrate a sense of societal and ethical responsibility in their professional endeavors, and (4) engage in professional development or postgraduate education to pursue flexible career paths amid future technological changes.

## Computer Science Undergraduate Program Educational Objectives

The computer science program is accredited by the Computing Accreditation Commission of ABET, http://www.abet.org.

The computer science undergraduate program educational objectives are that our alumni (1) make valuable technical contributions to design, development, and production in their practice of computer science and related engineering or application areas, particularly in software systems and algorithmic methods, (2) demonstrate strong communication skills and the ability to function effectively as part of a team, (3) demonstrate a sense of societal and ethical responsibility in their professional endeavors, and (4) engage in professional development or postgraduate education to pursue flexible career paths amid future technological changes.

## Computer Engineering Undergraduate Program Educational Objectives

The undergraduate computer engineering program prepares students to be able to (1) understand fundamental computing concepts and make valuable contributions to the practice of computer engineering; (2) design, analyze, and implement complex computer systems for a variety of application areas and cyberphysical domains; (3) demonstrate the ability to work effectively in a team and communicate their ideas; (4) continue to learn as part of a graduate program or otherwise in the world of constantly evolving technology.

## Undergraduate Study

The Computer Science and Engineering, Computer Engineering, and Computer Science majors are designated capstone majors. Computer Science and Engineering students complete a major product design course, while Computer Science students complete either a software engineering or a major product design course. Computer Engineering majors complete a design course in which they integrate their knowledge of the discipline and engage in creative design within realistic and professional constraints. Graduates are expected to apply the basic mathematical and scientific concepts that underlie modern computer science and engineering; design a software or digital hardware system, component, or process to meet desired needs within realistic constraints; function productively with others as part of a team; identify, formulate, and solve computer software- and hardware-related engineering problems; and demonstrate effective communication skills.

The Computer Engineering major is a designated capstone major that is jointly administered by the Computer Science and Electrical and Computer Engineering departments. Undergraduate students complete a design course in which they integrate their knowledge of the discipline and engage in creative design within realistic and professional constraints. Students apply their knowledge and expertise gained


*Distinguished Professor of Computer Science Leonard Kleinrock with the Interface Message Processor, the backbone of the Arpanet.*

in previous mathematics, science, and engineering coursework. Students identify, formulate, and solve engineering problems and present their projects to the class.

## Computer Science and Engineering B.S.

***Capstone Major***

The computer science and engineering curriculum at UCLA provides the education and training necessary to design, implement, test, and utilize the hardware and software of digital computers and digital systems. The curriculum has components spanning both the Computer Science and Electrical and Computer Engineering Departments. Within the curriculum students study all aspects of computer systems from electronic design through logic design, MSI, LSI, and VLSI concepts and device utilization, machine language design, implementation and programming, operating system concepts, systems programming, networking fundamentals, higher-level language skills, and application of these to systems. Students are prepared for employment in a wide spectrum of high-technology industries.

### Learning Outcomes

The Computer Science and Engineering major has the following learning outcomes:

- Application of basic mathematical and scientific concepts that underlie the modern field
- Design of a software or digital hardware system, component, or process to meet desired needs within realistic constraints
- Function productively with others on a team, including those with different specialties within the field
- Identification, formulation, and solution of computer software- and hardware-related engineering problems
- Effective communication

### Preparation for the Major

*Required:* Computer Science 1, 31, 32, 33, 35L, M51A; Electrical and Computer Engineering 3; Mathematics 31A, 31B, 32A, 32B, 33A, 33B, 61; Physics 1A, 1B, 1C, and 4AL or 4BL.

### The Major

*Required:* Computer Science 111, 118, 131, M151B, M152A, 180, 181, Electrical and Computer Engineering 100, 102, 115C; one course from Civil and Environmental Engineering 110, Electrical and Computer Engineering 131A, Mathematics 170A, or Statistics 100A; one capstone design course (Computer Science 152B); a minimum of 4 units of at least one elective course selected from Electrical and Computer Engineering 101A through M185; a minimum of 12 units of at least three elective courses selected from Computer Science 111 through CM187; and 12 units of technical breadth courses selected from an approved list available in the Office of Academic and Student Affairs.

Students who want to deepen their knowledge of electrical engineering are encouraged to select that discipline as their technical breadth area.

Credit is not allowed for both Computer Science 170A and Electrical and Computer Engineering 133A unless at least one of them is applied as part of the technical breadth area. Electrical and Computer Engineering 110, 131A, and CM182 may not satisfy elective credit. A petition may be submitted to consider four units of Computer Science 194 or 199 for an elective. Credit is not guaranteed and subject to vice chair review.

A multiple-listed (M) course offered in another department may be used instead of the same computer science course (e.g., Electrical and Computer Engineering M116C may be taken instead of Computer Science M151B). Credit is applied automatically.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or **https://www.registrar.ucla.edu/Academics/GE-Requirement**.

## Computer Science B.S.

***Capstone Major***

The computer science curriculum is designed to accommodate students who want professional preparation in computer science but do not necessarily have a strong interest in computer systems hardware. The curriculum consists of components in computer science, a minor or technical support area, and a core of courses from the social sciences, life sciences, and humanities. Within the curriculum, students study subject matter in software engineering, principles of programming languages, data structures, computer architecture, theory of computation and formal languages, operating systems, distributed systems, computer modeling, computer networks, compiler construction, and artificial intelligence. Majors are prepared for employment in a wide range of industrial and business environments.

### Learning Outcomes

The Computer Science major has the following learning outcomes:

- Application of basic mathematical and scientific concepts that underlie the modern field
- Design of a software or digital hardware system, component, or process to meet desired needs within realistic constraints
- Function productively with others on a team, including those with different specialties within the field
- Identification, formulation, and solution of computer software- and hardware-related engineering problems
- Effective communication

## Preparation for the Major

*Required:* Computer Science 1, 31, 32, 33, 35L, M51A; Mathematics 31A, 31B, 32A, 32B, 33A, 33B, 61; Physics 1A, 1B, 1C, and 4AL or 4BL.

## The Major

*Required:* Computer Science 111, 118, 131, M151B, M152A, 180, 181; one course from Civil and Environmental Engineering 110, Electrical and Computer Engineering 131A, Mathematics 170A, or Statistics 100A; one capstone software engineering or design course from Computer Science 130 or 152B; a minimum of 20 units of at least five elective courses selected from Computer Science 111 through CM187; a minimum of 12 units of at least three science and technology courses (not used to satisfy other requirements) that may include 12 units of upper-division computer science courses or 12 units of courses selected from an approved list available in the Office of Academic and Student Affairs.

Students must take at least one course from Computer Science 130 or 132. Computer Science 130 or 152B may be applied as an elective only if it is not taken as the capstone course. Credit is not allowed for both Computer Science 170A and Electrical and Computer Engineering 133A unless at least one of them is applied as part of the science and technology requirement or as part of the technical breadth area. A petition may be submitted to consider four units of Computer Science 194 or 199 for an elective. Credit is not guaranteed and subject to vice chair review.

A multiple-listed (M) course offered in another department may be used instead of the same computer science course (e.g., Electrical and Computer Engineering M116C may be taken instead of Computer Science M151B). Credit is applied automatically.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or **https://www.registrar.ucla.edu/Academics/GE-Requirement**.

# Computer Engineering B.S.

***Capstone Major***

The undergraduate curriculum provides all computer engineering students with preparation in the mathematical and scientific disciplines that lead to a set of courses that span the fundamentals of the discipline in the major areas of data science and embedded networked systems. These collectively provide an understanding of many inventions of importance to our society, such as the Internet of things, human-cyber-physical systems, mobile/wearable/implantable systems, robotic systems, and more generally smart systems at all scales in diverse spheres. The design of hardware, software, and algorithmic elements of such systems represents an already dominant and rapidly growing part of the computer engineering profession. Students are encouraged to make use of their computer science and electrical and computer engineering electives and a two-quarter capstone design course to pursue deeper knowledge within one of these areas according to their interests, whether for graduate study or preparation for employment.

## Learning Outcomes

The Computer Engineering major has the following learning outcomes:

- Application of mathematical, scientific, and engineering knowledge
- Design of a software or hardware system, component, or process to meet desired needs within realistic economic, environmental, social, ethical, health, safety, security, reliability, manufacturability, and sustainability constraints
- Function productively on a team with others
- Identification, formulation, and solution of computer engineering problems
- Effective communication

## Preparation for the Major

*Required:* Computer Science 1 (or Electrical and Computer Engineering 1), 31, 32, 33, 35L, M51A (or Electrical and Computer Engineering M16); Electrical and Computer Engineering 3; Engineering 96C; Mathematics 31A, 31B, 32A, 32B, 33A, 33B, 61; Physics 1A, 1B, 1C, and 4AL or 4BL.

## The Major

*Required:* Computer Science 111, 118 (or Electrical and Computer Engineering 132B), M151B (or Electrical and Computer Engineering M116C), M152A (or Electrical and Computer Engineering M116L), 180; Electrical and Computer Engineering 100, 102, 113, 115C; one course from Civil and Environmental Engineering 110, Electrical and Computer Engineering 131A, Mathematics 170A, Statistics 100A; 8 units of computer science and 8 units of electrical and computer engineering upper-division electives; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; 8 units capstone design from either Electrical and Computer Engineering 180DA/180DB or 183DA/183DB.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or **https://www.registrar.ucla.edu/Academics/GE-Requirement**.

## Suggested Tracks

*Networked Embedded Systems:* This track targets two related trends that have been a significant driver of computing, namely stand-alone embedded devices becoming networked and coupled to physical systems, and the Internet evolving toward a network of things (the IoT). These may broadly be classified as cyber physical systems, and includes a broad category of systems such as smart buildings, autonomous vehicles, and robots, which interact with each other and other systems. This trend in turn is driving innovation both in the network technologies (new low-power wireless networks for connecting things, and new high-speed networks and computing infrastructure to accommodate the transport and processing needs of the deluge of data resulting from continual sensing), and in embedded computing (new hardware and software stack catering to requirements such as ultra-low power operation, and embedded machine learning).

Students pursuing this track are strongly encouraged to take Electrical and Computer Engineering M119 or Computer Science M119 in junior year, and to choose three electives from courses such as Computer Science 117, 130, 131, 132, 133, 136, 181, 188, Electrical and Computer Engineering 2, 115A, 115B, 115C, 132A, 133A, 141, 142, 188.

Students who pursue a technical breadth area in either electrical and computer engineering or computer science can choose an additional three courses from this list.

*Data Science:* This track targets the trend toward the disruptive impact on computing systems, both at the edge and in the cloud, of massive amounts of sensory data being collected, shared, processed, and used for decision making and control. Application domains such as health, transportation, energy, etc. are being transformed by the abilities of inference-making and decision-making from sensory data that is pervasive, continual, and rich. This track will expose students to the entire data-to-decision pathway spanning the entire stack from hardware and software to algorithms, applications, and user experience.

Students pursing this track are strongly advised to take Computer Science 143 and M146 or Electrical and Computer Engineering M146, and to additionally choose two electives from courses such as Computer Science CM121, 136, 144, 145, 161, 188, Electrical and Computer Engineering 114, 133A, 133B, 134, 188.

Students who pursue a technical breadth area in either electrical and computer engineering or computer science can choose an additional three courses from this list.

Students are also free to design ad hoc tracks. The technical breadth area requirement provides an opportunity to combine elective courses in electrical and computer engineering and computer science with those from another UCLA Samueli major to produce a specialization in an interdisciplinary domain. As noted above, students can also select a technical breadth area in either Electrical and Computer Engineering or Computer Science to deepen their knowledge in either discipline.

# Bioinformatics Minor

The Bioinformatics minor introduces undergraduate students to the emerging interdisciplinary field of bioinformatics, an active area of research at UCLA combining elements of the computational sciences with the biological sciences. The minor organizes the many course offerings in different UCLA departments into a coherent course plan providing students with significant training in bioinformatics in addition to the training they obtain from their major. Students who complete the minor will be strong candidates for admission to Ph.D. programs in bioinformatics as well as have the relevant training to obtain jobs in the biotechnology industry.

Students complete a core curriculum and an elective course and are strongly encouraged to participate in undergraduate research as early as possible in one of the many groups offering research opportunities in bioinformatics.

To enter the minor, students must be (1) in good academic standing (2.0 grade point av-erage or better), (2) have completed at least two of the lower-division requirements with minimum grades of C, and (3) file a petition in the Office of Academic and Student Affairs of the Henry Samueli School of Engineering and Applied Science, 6426 Boelter Hall.

*Required Lower-Division Courses (17 units minimum):* Computer Science 32 or Program in Computing 10C, Life Sciences 3 or 7A, Mathematics 33A, 61.

*Required Upper-Division Courses (18 units minimum):* Computer Science 180 (or Mathematics 182), M184, two courses selected from Computer Science CM121, CM122, and CM124, and one course selected from Chemistry and Biochemistry C100, 153B, Civil and Environmental Engineering 110, Computer Science CM121, CM122, CM124, 170A, CM186, CM187, Ecology and Evolutionary Biology C135, Electrical and Computer Engineering 102, 131A, 141, Human Genetics C144, Mathematics 170A, Microbiology, Immunology, and Molecular Genetics 132, Molecular, Cell, and Developmental Biology 144, 187AL, Physiological Science 125, Statistics 100A, 100B. Eight units of either Bioinformatics 199 or Computer Science 194 or 199 may be applied as an elective by petition.Students are strongly encouraged to take Computer Science M184 as early as possible to obtain an overview of computational biology.

If students apply any of Civil and Environmental Engineering 110, Electrical and Computer Engineering 131A, Mathematics 170A, or Statistics 100A toward major requirements or another minor, then no other course from that set may be applied toward the minor requirements.

A minimum of 20 units applied toward the minor requirements must be in addition to units applied toward major requirements or another minor.

All minor courses must be taken for a letter grade (unless not offered on that grading basis), and students must have a minimum grade of C– in each and an overall C (2.0) grade-point average in all courses taken for the minor. Successful completion of the minor is indicated on the transcript and diploma.

# Graduate Study

For information on graduate admission, see Graduate Programs on page 26.

The following introductory information is based on 2019-20 program requirements for UCLA graduate degrees. Complete program requirements are available at **https://grad.ucla.edu/academics/graduate-study/program-requirements-for-ucla-graduate-degrees/**. Students are subject to the detailed degree requirements as published in program requirements for the year in which they enter the program.

The Department of Computer Science offers Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees in Computer Science and participates in a concurrent degree program (Computer Science M.S./Management M.B.A.) with the John E. Anderson Graduate School of Management.

# Computer Science M.S.

## Course Requirements

*Course Requirement*. A total of nine courses is required for the M.S. degree, including a minimum of five graduate courses. No specific courses are required, but a majority of both the total number of formal courses and the total number of graduate courses must consist of courses offered by the Computer Science Department.

*Undergraduate Courses*. No lower-division courses may be applied toward graduate degrees. In addition, the following upper-division courses are not applicable toward graduate degrees: Chemical Engineering 102A, 199, Civil and Environmental Engineering 108, 199, Computer Science M152A, 152B, 199, Electrical and Computer Engineering 100, 101A, 102, 110L, M116L, 199, Materials Science and Engineering 110, 120, 130, 131, 131L, 132, 141L, 150, 160, 161L, 199, Mechanical and Aerospace Engineering 102, 103, 105A, 105D, 199.

*Breadth Requirement*. M.S. degree students must satisfy the computer science breadth requirement by the end of the third term in graduate residence at UCLA. The requirement is satisfied by mastering the contents of five undergraduate courses or equivalent: Computer Science 180, two courses from 111, 118, and M151B, one course from 130, 131, or 132, and one course from 143, 161, or 174A. A UCLA undergraduate course taken by graduate students cannot be used to satisfy graduate degree requirements if students have already received a grade of B– or better for a course taken elsewhere that covers substantially the same material.

For the MS degree, students must also complete at least three terms of Computer Science 201 with grades of Satisfactory.

Competence in any or all courses in breadth requirements may be demonstrated in one of three ways:

1. Satisfactory completion of the course at UCLA with a grade of B– or better
2. Satisfactory completion of an equivalent course at another university with a grade of B– or better
3. Satisfactory completion of a final examination in the course at UCLA

## Comprehensive Examination Plan

In the comprehensive examination plan, at least five of the nine courses must be 200-series courses. The remaining four courses may be either 200-series or upper-division courses. No units of 500-series courses may be applied toward the comprehensive examination plan requirements.

## Thesis Plan

In the thesis plan, seven of the nine courses must be formal courses, including at least four from the 200 series. The remaining two courses may be 598 courses involving work on the thesis.

The thesis is a report on the results of student investigation of a problem in the major field of study under the supervision of the thesis committee, which approves the subject and plan of the thesis and reads and approves the complete manuscript. While the problem may be one of only limited scope, the thesis must exhibit a satisfactory style, organization, and depth of understanding of the subject. Students should normally start to plan the thesis at least one year before the award of the M.S. degree is expected. There is no examination under the thesis plan.

## Computer Science M.S./ Management M.B.A.

The Department of Computer Science and the John E. Anderson Graduate School of Management offer a concurrent degree program that enables students to complete the requirements for the M.S. in Computer Science and the M.B.A. (Master of Business Administration) in three academic years. Students should request application materials from both the M.B.A. Admissions Office, John E. Anderson Graduate School of Management, and the Department of Computer Science.

## Computer Science Ph.D.

### Major Fields or Subdisciplines

Artificial intelligence; computational systems biology; computer networks; computer science theory; computer system architecture; graphics and vision; data science computing; and software systems.

### Course Requirements

Normally, students take courses to acquire the knowledge needed to prepare for the written and oral examinations and for conducting Ph.D. research. The basic program of study for the Ph.D. degree is built around the major field requirement and two minor fields. The major field and at least one minor field must be in computer science.

The fundamental examination is common for all Ph.D. candidates in the department and is also known as the written qualifying examination.

To satisfy the major field requirement, students are expected to attain a body of knowledge contained in five courses, as well as the current literature in the area of specialization. In particular, students are required to take a minimum of three graduate courses in the major field of Ph.D. research, selecting these courses in accordance with guidelines specific to the major field. Guidelines for course selection in each major field are available from the departmental Student Affairs Office. Grades of B– or better, with a grade-point average of at least 3.33 in all courses used to satisfy the major field requirement, are required. Students are required to satisfy the major field requirement within the first nine terms after enrolling in the graduate program.

Each minor field normally embraces a body of knowledge equivalent to two courses, at least one of which is a graduate course. Grades of B– or better, with a grade-point average of at least 3.33 in all courses included in the minor field, are required. By petition and administrative approval, a minor field may be satisfied by examination.

*Breadth Requirement*. Ph.D. degree students must satisfy the computer science breadth requirement by the end of the third term in graduate residence at UCLA. The requirement is satisfied by mastering the contents of five undergraduate courses or equivalent: Computer Science 180, two courses from 111, 118, and M151B, one course from 130, 131, or 132, and one course from 143, 161, or 174A. A UCLA undergraduate course taken by graduate students cannot be used to satisfy graduate degree requirements if students have already received a grade of B– or better for a course taken elsewhere that covers substantially the same material.

For the Ph.D. degree, students must also complete at least three terms of Computer Science 201 with grades of Satisfactory (in addition to the three terms of 201 that may have been completed for the M.S. degree).

Competence in any or all courses may be demonstrated in one of three ways:

1. Satisfactory completion of the course at UCLA with a grade of B– or better
2. Satisfactory completion of an equivalent course at another university with a grade of B– or better
3. Satisfactory completion of a final examination in the course at UCLA

For requirements for the Graduate Certificate of Specialization, see Engineering Schoolwide Programs.

## Written and Oral Qualifying Examinations

The written qualifying examination consists of a high-quality paper, solely authored by the student. The paper can be either a research paper containing an original contribution or a focused critical survey paper. The paper should demonstrate that the student understands and can integrate and communicate ideas clearly and concisely. It should be approximately 10 pages single-spaced, and the style should be suitable for submission to a first-rate technical conference or journal. The paper must represent work that the student did as a graduate student at UCLA. Any contributions that are not the student's own, including those of the student's adviser, must be explicitly acknowledged in detail. Prior to submission, the paper must by reviewed by the student's adviser on a cover page with the adviser's signature indicating review. After submission, the paper must be reviewed and approved by at least two other members of the faculty. There are two deadlines a year for submission of papers.

After passing the preliminary examination and coursework for the major and minor fields, the student should form a doctoral committee and prepare to take the University Oral Qualifying Examination. A doctoral committee consists of a minimum of four members. Three members, including the chair, must hold appointments in the department. The remaining member must be a UCLA faculty member in another department. The nature and content of the oral qualifying examination are at the discretion of the doctoral committee but ordinarily include a broad inquiry into the student's preparation for research. The doctoral committee also reviews the prospectus of the dissertation at the oral qualifying examination.

## Fields of Study

### Artificial Intelligence

Artificial intelligence (AI) is the study of intelligent behavior. While other fields such as philosophy, psychology, neuroscience, and linguistics are also concerned with the study of intelligence, the distinguishing feature of AI is that it deals primarily with information processing models. Thus the central scientific question of artificial intelligence is how intelligent behavior can be reduced to information processing. Since even the simplest computer is a completely general information processing device, the test of whether some behavior can be explained by information processing mechanisms is whether a computer can be programmed to produce the same behavior. Just as human intelligence involves gathering sensory input and producing physical action in the world, in addition to purely mental activity, the computer for AI purposes is extended to include sense organs such as cameras and microphones, and output devices such as wheels, robotic arms, and speakers.

The predominant research paradigm in artificial intelligence is to select some behavior that seems to require intelligence on the part of humans, to theorize about how the behavior might be accounted for, and to implement the theory in a computer program to produce the same behavior. If successful, such an experiment lends support to the claim that the selected behavior is reducible to information processing terms, and may suggest the program's architecture as a candidate explanation of the corresponding human process.

The UCLA Computer Science Department has active research in the following major subfields of artificial intelligence:

1. *Problem Solving*. Analysis of tasks, such as playing chess or proving theorems, that require reasoning about relatively long sequences of primitive actions, deduc-

tions, or inferences

2. *Knowledge representation and qualitative reasoning*. Analysis of tasks such as common-sense reasoning and qualitative physics. Here the deductive chains are short, but the amount of knowledge that potentially may be brought to bear is very large
3. *Expert systems*. Study of large amounts of specialized or highly technical knowledge that is often probabilistic in nature. Typical domains include medical diagnosis and engineering design
4. *Natural language processing*. Symbolic, statistical, and artificial neural network approaches to text comprehension and generation
5. *Computer vision*. Processing of images, as from a TV camera, to infer spatial properties of the objects in the scene (three-dimensional shape), their dynamics (motion), their photometry (material and light), and their identity (recognition)
6. *Robotics*. Translation of a high-level command, such as picking up a particular object, into a sequence of low-level control signals that might move the joints of a robotic arm/hand combination to accomplish the task; often this involves using a computer vision system to locate objects and provide feedback
7. *Machine learning*. Study of the means by which a computer can automatically improve its performance on a task by acquiring knowledge about the domain
8. *Parallel architecture*. Design and programming of a machine with thousands or even millions of simple processing elements to produce intelligent behavior; the human brain is an example of such a machine

## Computational Systems Biology

The computational systems biology (CSB) field can be selected as a major or minor field for the Ph.D. or as a specialization area for the M.S. degree in Computer Science.

Graduate studies and research in the CSB field are focused on computational modeling and analysis of biological systems and biological data.

Core coursework is concerned with the methods and tools development for computational, algorithmic, and dynamic systems network modeling of biological systems at molecular, cellular, organ, whole organism, or population levels—and leveraging them in biosystem and bioinformatics applications. Methodological studies include bioinformatics and systems biology modeling, with focus on genomics, proteomics, metabolomics, and higher levels of biological/physiological organization, as well as multiscale approaches integrating the parts.

Typical research areas with a systems focus include molecular and cellular systems biology, organ systems physiology, medical, pharmacological, pharmacokinetic (PK), pharmacodynamic (PD), toxicokinetic (TK), physiologically based PBPK-PD, PBTK, and pharmacogenomic system studies; neurosystems, imaging and remote sensing systems, robotics, learning and knowledge-based systems, visualization, and virtual clinical environments. Typical research areas with a bioinformatics focus include development of computational methods for analysis of high-throughput molecular data, including genomic sequences, gene expression data, protein-protein interaction, and genetic variation. These computational methods leverage techniques from both statistics and algorithms.

## Computer Networks

The computer networks field involves the study of computer networks of different types, in different media (wired, wireless), and for different applications. Besides the study of network architectures and protocols, this field also emphasizes distributed algorithms, distributed systems, and the ability to evaluate system performance at various levels of granularity (but principally at the systems level). In order to understand and predict systems behavior, mathematical models are pursued that lead to the evaluation of system throughput, response time, utilization of devices, flow of jobs and messages, bottlenecks, speedup, power, etc. In addition, students are taught to design and implement computer networks using formal design methodologies subject to appropriate cost and objective functions. The tools required to carry out this design include probability theory, queueing theory, distributed systems theory, mathematical programming, control theory, operating systems design, simulation methods, measurement tools, and heuristic design procedures. The outcome of these studies provides the following:

1. An appropriate model of the computer system under study
2. An adequate (exact or approximate) analysis of the behavior of the model
3. The validation of the model as compared to simulation and/or measurement of the system
4. Interpretation of the analytical results in order to obtain behavioral patterns and key parameters of the system
5. Design methodology

## Resource Allocation

A central problem in the design and evaluation of computer networks deals with the allocation of resources among competing demands (e.g., wireless channel bandwidth allocation to backlogged stations). In fact, resource allocation is a significant element in most of the technical (and nontechnical) problems we face today.

Most of our resource allocation problems arise from the unpredictability of the demand for the use of these resources, as well as from the fact that the resources are geographically distributed (as in computer networks). The computer networks field encounters such resource allocation problems in many forms and in many different computer system configurations. Our goal is to find allocation schemes that permit suitable concurrency in the use of devices (resources) so as to achieve efficiency and equitable allocation. A very popular approach in distributed systems is allocation on demand, as opposed to pre-scheduled allocation. On-demand allocation is found to be effective, since it takes advantage of statistical averaging effects. It comes in many forms in computer networks and is known by names such as asynchronous time division multiplexing, packet switching, frame relay, random access, and so forth.

## Computer Science Theory

Computer science is in large measure concerned with information processing systems, their applications, and the corresponding problems of representation, transformation, and communication. The computer science fields are concerned with different aspects of such systems, and each has its own theoretical component with appropriate models for description and analysis, algorithms for solving the related problems, and mathematical tools. Thus in a certain sense computer science theory involves all of computer science and participates in all disciplines.

The term theoretical computer science has come to be applied nationally and intentionally to a certain body of knowledge emphasizing the interweaving themes of *computability* and *algorithms*, interpreted in the broadest sense. Under computability, one includes questions concerning which tasks can and cannot be performed by information systems of different types restricted in various ways, as well as the mathematical analysis of such systems, their computations, and the languages for communication with them. Under algorithms, one includes questions concerning (1) how a task can be performed efficiently under reasonable assumptions on available resources (e.g., time, storage, type of processor), (2) how efficiently a proposed system performs a task in terms of resources used, and (3) the limits on how efficiently a task can be performed. These questions are often addressed by first developing models of the relevant parts of an information processing system (e.g., the processors, their interconnections, their rules of operation, the means by which instructions are conveyed to the system, or the way the data is handled) or of the input/output behavior of the system as a whole. The properties of such models are studied both for their own interest and as tools for understanding the system and improving its performance or applications.

### Emphasis of Computer Science Theory

Computer science theory emphasizes

- Design and analysis of algorithms
- Distributed and parallel algorithms
- Models for parallel and concurrent computation
- Online and randomized algorithms
- Computational complexity
- Automata and formal languages
- Cryptography and interactive proofs

## Computer System Architecture

Computer system architecture deals with the design, implementation, and evaluation of computer systems and their building blocks. It deals with general-purpose systems as well as embedded special-purpose systems. The field also encompasses the development of tools to enable system designers to describe, model, fabricate, and test highly complex computer systems from single-chip to computing clouds.

Computer systems are implemented as a combination of hardware and software. Hence, research in the field of computer architecture often involves both hardware and software issues. The requirements of application software and operating systems, together with the capabilities of compilers, play a critical role in determining the features implemented in hardware. At the same time, the computer architect must also take into account the capabilities and limitations of the underlying implementation technology as well as of the design tools.

The goal of research in computer architecture is to develop building blocks, system organizations, design techniques, and design tools that lead to improved performance and reliability as well as reduced power consumption and cost.

Corresponding to the richness and diversity of computer systems architecture research at UCLA, a comprehensive set of courses is offered in the areas of advanced processor architecture, arithmetic processor systems. parallel and distributed architectures, fault-tolerant systems, reconfigurable systems, embedded systems, and computer-aided design of VLSI circuits and systems.

1. *Novel architectures* encompass the study of computations that are performed in ways that are quite different than those used by conventional machines. Examples include various domain-specific architectures characterized by high computational rates, low power, and reconfigurable hardwares used in a wide range of computing devices from smart phones to data centers.
2. The study of *high-performance processing algorithms* deals with algorithms for very high-performance numerical processing. Techniques such as redundant-digit representations of number systems, fast arithmetic, and the use of highly parallel arrays of processing elements are studied with the goal of providing the extremely high processing speeds required in a number of upcoming computer applications.
3. The study of *computational algorithms and structures* deals with the relationship between computational algorithms and the physical structures that can be employed to carry them out. It includes the study of interconnection networks, and the way that algorithms can be formulated for efficient implementation where regularity of structure and simplicity of interconnections are required.
4. *Computer-aided design of VLSI circuits and systems* is an active research area that develops techniques for the automated synthesis and analysis of large-scale systems. Topics include high-level and logic-level synthesis, technology mapping, physical design, interconnect modeling, and optimization of various VLSI technologies such as full-custom designs, standard cells, programmable logic devices (PLDs), multichip modules (MCMs), system-on-a-chip (SoCs) that are used in a wide range of applications from IoTs to data centers.
5. *VLSI architectures and implementation* is an area of current interest and collaboration between the Electrical and Computer Engineering and Computer Science departments that addresses the impact of large-scale integration on the issues of computer architecture. Application of these systems in medicine and healthcare, multimedia, and finance is being studied in collaboration with other schools on campus.

## Data Science Computing

The data science computing field focuses on basic problems of modeling and managing data and knowledge, and their relation with other fundamental areas of computer science, such as operating systems and networking, programming languages, and human-computer interface design.

A data management system embodies a collection of data, devices in which the data are stored, and logic or programs used to manipulate that data. Information management is a generalization of data management in which the data being stored are permitted to be arbitrarily complex data structures, such as rules and trees. In addition, information management goes beyond simple data manipulation and query and includes inference mechanisms, explanation facilities, and support for distributed and web-based access.

The need for rapid, accurate information is pervasive in all aspects of modern life. Modern systems are based on the coordination and integration of multiple levels of data representation, from characteristics of storage devices to conceptual and abstract levels. As human enterprises have become more complex, involving more complicated decisions and trade-offs among decisions, the need for sophisticated information and data management has become essential.

## Graphics and Vision

The graphics and vision field focuses on the synthesis and analysis of image and video data by computer. Graphics includes the topics of rendering, modeling, animation, visualization, and interactive techniques, among others, and it is broadly applicable in the entertainment industry (motion pictures and games) and elsewhere. Vision includes image/video representation and registration, feature extraction, three-dimensional reconstruction, object recognition, and image-based modeling, among others, with application to real-time vision/control for robots and autonomous vehicles, medical imaging, visual sensor networks and surveillance, and more. Several of the projects undertaken by our researchers in this field unify graphics and vision through mathematical modeling, wherein graphics is considered a models-to-images synthesis problem and vision the converse images-to-models analysis problem.

## Software Systems

The programming languages and systems field is concerned with the study of theory and practice in the development of software systems. Well-engineered systems require appreciation of both principles and architectural trade-offs. Principles provide abstractions and rigor that lead to clean designs, while systems-level understanding is essential for effective design.

Principles here encompass the use of programming systems to achieve specified goals, the identification of useful programming abstractions or paradigms, the development of comprehensive models of software systems, and so forth. The thrust is to identify and clarify concepts that apply in many programming contexts.

Development of software systems requires an understanding of many methodological and architectural issues. The complex systems developed today rely on concepts and lessons that have been extracted from years of research on programming languages, operating systems, database systems, knowledge-based systems, real-time systems, and distributed and parallel systems.

# Facilities

Departmental laboratories and centers for instruction and research include:

## Artificial Intelligence Laboratories

### Automated Reasoning Group

Adnan Y. Darwiche, *Director*
http://reasoning.cs.ucla.edu

The group focuses on research in automated reasoning (logical and probabilistic) and machine learning, including their application to problems in science and engineering. On the theoretical side, the group focuses on tractable circuit representations and models that combine logic and probability, in addition to new models for machine learning that can integrate background knowledge. On the practical side, the group builds scalable reasoning and learning systems that can scale to real-world problems.

### Cognitive Systems Laboratory

Judea Pearl, *Director*
http://singapore.cs.ucla.edu/cogsys.html

The laboratory targets research areas concerned with evidential reasoning, the distributed interpretation of multisource data in networks of partial beliefs; learning, the structuring and parameterizing of links in belief networks to form a representation consistent with a stream of observations; constraint processing, including intelligent backtracking, learning while searching, temporal reasoning, etc.; graphoids, the characterization of informational dependencies and their graph representations; and default reasoning, use of qualitative probabilistic reasoning to draw plausible and defeasible conclusions from incomplete information.

### Statistical and Relational Artificial Intelligence Laboratory (StarAI)

Guy Van den Broeck, *Director*
http://starai.cs.ucla.edu

The laboratory performs research on machine learning (statistical relational learning, tractable learning), knowledge representation and reasoning (graphical models, lifted probabilistic inference, knowledge compilation), applications of probabilistic reasoning and learning (probabilistic programming, probabilistic databases), and artificial intelligence in general.

### Statistical Machine Learning Laboratory

Quanquan Gu, *Director*
http://web.cs.ucla.edu/~qgu/uclaml

The laboratory conducts research on machine learning, optimization, and high-dimensional statistical inference. Its focus is on development and analysis of nonconvex optimization algorithms for machine learning to understand large-scale, dynamic, complex, and heterogeneous data; and on building the theoretical foundations of deep learning and deep reinforcement learning.

## Computational Systems Biology Laboratories

### Big Data and Genomics Laboratory

Eran Halperin, *Director*
https://www.eranhalperingenomics.com

The laboratory aims to improve understanding and treatment of human disease by analysis of big data collected in relation to diseases. The main focus of the laboratory has been development of methods for analysis of genomic data—including genetics, epigenetics, RNA, and microbiome data; as well as medical records, images, and waveforms of UCLA Health medical center patients. The methods developed are typically standalone tools, often used by other researchers for analysis of specific diseases. The methodology involves a combination of machine learning, optimization algorithms, combinatorial optimization, and classical and Bayesian statistics.

### Biocybernetics Laboratory

Joseph J. DiStefano III, *Director*
http://biocyb.cs.ucla.edu/wp/

This interdisciplinary research typically involves integration of theory with real laboratory data, using biomodeling, computational, and biosystems approaches. Problem domains are physiological systems, disease processes, pharmacology, and some post-genomic bioinformatics. Laboratory pedagogy involves development and exploitation of the synergistic and methodologic interface between structural and computational biomodeling with laboratory data, or computational systems biology, with a focus on integrated approaches for solving complex biosystem problems from sparse biodata e.g., in physiology, medicine, and pharmacology), as well as voluminous biodata (e.g., from genomic libraries and DNA array data).

### Computational Genetics Laboratory

Eleazar Eskin, *Director*
http://zarlab.cs.ucla.edu/about/

The laboratory is comprised of a computational genetics group affiliated with both the Computer Science and Human Genetics departments. Research interests are in computational genetics, bioinformatics, computer science, and statistics. The laboratory focuses on developing techniques for solving the challenging computational problems that arise in attempting to understand the genetic basis of human disease.

### Machine Learning and Genomics Laboratory

Sriram Sankararman, *Director*
https://sriramlab.dgsom.ucla.edu/pages/

This interdisciplinary research group is affiliated with UCLA departments of Computer Science, Human Genetics, and Biomathematics. The laboratory is broadly interested in questions at the intersection of computer science, statistics, and biomedicine. It develops statistical and computational methods to make sense of complex, high-dimensional datasets generated in the fields of genomics and medicine, to answer questions ranging from how humans have evolved, to what the biological underpinnings of diseases are, to how we can improve the diagnosis and treatment of disease. A major focus of this research is understanding and interpreting human genomes. The biological questions of interest center around understanding how evolution shapes human genes, and how they modulate complex traits that include common diseases. The laboratory develops and extends tools from a diverse set of disciplines including machine learning, algorithms, optimization, high-dimensional statistics, and information theory. It also applies these tools to high-dimensional genomic and medical datasets that are publicly available or being generated by laboratory collaborators.

## Computer Systems Architecture Laboratories

### Architecture Specialization Laboratory (PolyArch)

Anthony J. Nowatzki, *Director*
http://web.cs.ucla.edu/~tjn/01-research/

The laboratory studies how to redesign computer architectures and accelerators to continue improving performance and energy efficiency, even while technology scaling reaches its physical limits. Broadly, its approach is to consider how to reform traditional hardware/software abstractions to convey rich information that can make building efficient micro-architectures possible. These changes necessitate codesign of ISAs, architecture, execution models, and compilers.

### Concurrent Systems Laboratory

Yuval Tamir, *Director*
http://web.cs.ucla.edu/csl/

The laboratory conducts research on the design, implementation, and evaluation of computer systems that use state-of-the-art technology to achieve high performance and high reliability. Projects involve both software and hardware, and often focus on parallel and distributed systems in the context of general-purpose as well as embedded applications.

### Digital Arithmetic and Reconfigurable Architecture Laboratory

Milos D. Ercegovac, *Director*
http://arith.cs.ucla.edu

The laboratory is used for fast digital arithmetic (theory, algorithms, and design) and numerically intensive computing on reconfigurable hardware. Research includes floating-point arithmetic, online arithmetic, application-specific architectures, and design tools.

### eHealth Research Laboratory (ER Lab)

Majid Sarrafzadeh, *Director*
http://er.cs.ucla.edu

The ER Lab goal is to use technology in health care to reduce the cost of providing high-quality care to the chronically ill, estimated (by Milken Institute Center for Health Care Economics) to be over $1 trillion per year. The laboratory strives to improve global and local public health surveillance, with a resultant reduction in epidemics, increased control over infectious disease, and improved drug safety. Other goals are diminished rate of medical errors; ongoing preventive health, with attendant reductions in morbidity, mortality, and cost of care; and consumer engagement in health and self-management.

### VAST Laboratory

Jason Cong, *Director*
http://vast.cs.ucla.edu

The laboratory investigates cutting-edge research topics at the intersection of VLSI technologies, design automation, architecture, and compiler optimization at multiple scales, from micro-architecture building blocks to heterogeneous compute nodes and scalable data centers. Currently, the laboratory is focused on architecture and design automation for emerging technologies; and customizable domain-specific computing with applications to multiple domains such as imaging processing, bioinformatics, data mining, and machine learning.

## Graphics and Vision Laboratories

### Center for Vision, Cognition, Learning, and Art

Song-Chun Zhu, *Director*
http://vcla.stat.ucla.edu

The laboratory is affiliated with the Computer Science and Statistics departments. Research begins with computer vision and expands to other disciplines. The objective is to pursue a unified framework for representation, learning, inference, and reasoning; and to build intelligent computer systems for real-world applications. Its projects span four directions: vision (object, scene, events, etc.); cognition (intentions, roles causality, etc.); learning (information projection, stochastic grammars, etc.); and art (abstraction, expression, aesthetics, etc.).

### Computer Graphics and Vision Laboratory (GraViLab)

Demetri Terzopoulos, *Director*
http://gravilab.cs.ucla.edu

The laboratory engages in a broad spectrum of visual computing research unifying computer graphics (image synthesis), computer vision (image analysis), and related fields; with emphasis on geometric, physics-based, learning-driven, and artificial intelligence/life modeling and simulation. Major research interests include biomimetic simulation of humans and other animals, from biomechanics to sensorimotor control to intelligence; and image/video analysis combining (deep) learning and modeling paradigms, especially for application to medicine and health care.

### UCLA Collective on Vision and Image Sciences

http://visciences.ucla.edu

The collective brings together researchers from multiple departments at UCLA, including Mathematics, Statistics, Computer Science, Brain Mapping, Computational Biology, Neuroimaging, Image Informatics, Psychology, and Radiology.

### UCLA Vision Laboratory

Stefano Soatto, *Director*
http://vision.ucla.edu

Researchers investigate how images—i.e., measurements of light—can be used to infer properties of the physical world such as shape, motion, location, and material properties of objects. This is key to developing engineering systems that can “see” and interact intelligently with the world around them. For example, images captured by a car-mounted video camera can be processed by computers to infer a model of the car’s surroundings, e.g., other vehicles, pedestrians, etc. This technology can also be used to analyze images captured in the environment to understand the effects of climate change by monitoring the behavior of animals and plants. Analysis of images of the human body can be used both for diagnostic purposes and for planning interventions.

## Information and Data Management Laboratories

### Information and Data Management Group

(Multiple Faculty)
http://www.cs.ucla.edu/idm/

The group is a collaboration of all UCLA faculty from the information and data management field. It is interested in multiple research areas including big data, archival information systems, knowledge discovery and data mining, Earth Science Partners’ private network, genomics graph database development, multimedia information stream system technology, Smart Space middleware architecture, and technologically based assessment of language and literacy, to name just a few.

### Natural Language Processing Group

Kai-Wei Chang, *Director*

The group focuses on developing reliable machine learning solutions for processing natural languages. Specifically, it targets design of models, algorithms, and learning mechanisms to improve the generalization ability of natural-language processing models such that they can generalize across unseen tasks, unseen inputs, and low-resource languages.

### Web Information Systems Laboratory

Carlo A. Zaniolo, *Director*
http://wis.cs.ucla.edu/wis/

This research group investigates Web-based information systems and seeks to develop enabling technology for such systems by integrating the Web with database systems. Current research efforts include the DeAL system, a next-generation datalog system; SemScape, an NLP-based framework for mining unstructured or free text; EARL (Early Accurate Result Library) for Hadoop; Panta Rei, a study of support for schema evolution in the context of snapshot databases and transaction-time databases; Stream Mill, a complete data stream management system; and ArchIS, a powerful archival information system.

## Network Systems Laboratories

### Internet Research Laboratory (IRL)

Lixia Zhang, *Principal Investigator*
http://irl.cs.ucla.edu

The laboratory mission is to help the Internet grow. Its research efforts focus on design and development of network architecture and protocols, and the challenges in building secure networks and systems. Its past work has turned to Internet standards and successful startups. Since 2010, the laboratory has been working on design and development of named data networking (NDN), a new Internet architecture.

### Network Design Automation Laboratory

George Varghese, *Director*
http://nda.cs.ucla.edu

The laboratory focuses on research in network design automation, an effort to build a comprehensive set of design tools for networks inspired by electronic design automation for chips. A major focus is analysis and synthesis of router configuration files to avoid major outages that frequently cripple major service providers. This work involves development of new tools inspired by other fields such as programming languages, hardware design, and data mining; but targeted to incorporate the special structure and challenges of networks. It involves collaboration with multiple disciplines such as programming languages, systems, and network debugging; and includes other UCLA faculty.

### Networked and Application Systems Group (NAS)

Ravi Netravali, *Director*

The group is focused on building practical systems to improve the performance and ease of debugging large-scale distributed applications. Such applications include web pages, mobile apps, video streaming and analytics systems, data analytics platforms, and more. The group uses a cross-layer methodology that aims to understand the impact of decisions at different layers in the end-to-end system; and designs solutions that incorporate fundamental principles at the network, operating system, and application vantage points.

### UCLA Connection Laboratory

Leonard Kleinrock, *Director*
http://www.connectionlab.cs.ucla.edu

The laboratory offers an environment to support advanced research in technologies at the forefront of all things regarding networking and connectivity, and will deliver the benefits of that research to society globally. The laboratory's broad-based agenda enables faculty, students, and visitors to pursue research challenges of their own choosing, without externally imposed constraints on scope or risk. It draws inspiration from the foundational role of UCLA as the birthplace of the Internet. With its open inclusive structure, the laboratory will help to realize the vision of creating high-leverage technologies, as was accomplished years ago with the Internet.

### Wireless Networking Group (WiNG)

Songwu Lu, *Director*
http://metro.cs.ucla.edu

The laboratory's research areas include wireless networking, mobile systems, and cloud computing. Its focus is on design, implementation, and experimentation of protocols, algorithms, and systems for wireless data networks. The goal is to build high-performance and dependable networking solutions for the wireless Internet.

## Software Systems Laboratories

### Compilers Laboratory

http://compilers.cs.ucla.edu

The laboratory is used for research into compilers, embedded systems, and programming languages.

### Large-Scale Systems Group

Harry Xu, *Director*
http://systems.cs.ucla.edu

The group builds systems to improve the efficiency, scalability, reliability, and security of modern applications and workloads. These include graph analytics, video analytics, machine learning, smart contracts, etc. The group's solutions cross multiple layers of the compute stack, spanning the areas of programming languages, compilers, operating systems, runtime systems, distributed systems, networking, and computer architecture.

### Software Engineering and Analysis Laboratory (SEAL)

Miryung Kim, *Director*
http://web.cs.ucla.edu/~miryung/research.html

The laboratory conducts research in software engineering, in particular debugging and testing for big data systems and automated tools for data science and ML-based systems. Its overall goal is to improve software engineering productivity and correctness. To achieve it, the laboratory designs scalable software systems, software analysis algorithms, and automated development tools. It also conducts user studies with software engineers, and carries out statistical analysis of open-source project data to allow data-driven decisions for designing novel software engineering tools. With expertise in software evolution, the laboratory is known for its research on code clones—code duplication detection, management, and removal solutions. The laboratory is a leader in creation and definition of the emerging area where software engineering and data science intersect. It has conducted the most comprehensive study of industry data scientists, and developed automated debugging and testing technologies for widely-used big data systems such as Apache Spark. Through tech-transfer, several companies have used SEAL research on interactive code clone search and big data analytics debugging technologies.

### Software Systems Group

(Multiple Faculty)
http://compilers.cs.ucla.edu/ss/

The group is a collaboration of faculty from the software systems and network systems fields. It conducts research on the design, implementation, and evaluation of operating systems, networked systems, programming languages, and software engineering tools.

## Computer Science Centers

### Center for Autonomous Intelligent Networked Systems (CAINS)

http://www.cains.cs.ucla.edu

The center was established in 2001 with researchers from several laboratories in the Computer Science, and Electrical and

Computer Engineering, departments. It serves as a forum for intelligent-agent researchers and visionaries from academia, industry, and government, with an interdisciplinary focus on fields such as engineering, medicine, biology, and social sciences. Information and technology are exchanged through symposia, seminars, short courses, and collaboration in joint research projects sponsored by government and industry.

Research projects include use of unmanned autonomous vehicles, coordination of vehicles into computing clouds, and integration of body sensors and smart phones into m-health systems. Ongoing research encompasses personal and body networks, cognitive radios, ad hoc multihop networking, vehicular networks, dynamic unmanned backbone, underwater unmanned vehicles, mobile sensor platforms, and network coding.

## Center for Domain-Specific Computing (CDSC)

Jason Cong, *Director*
http://www.cdsc.ucla.edu

The center looks beyond parallelization and focuses on domain-specific customization as a disruptive technology to bring orders-of-magnitude power-performance efficiency improvement to application domains. CDSC develops a general methodology for creating novel, customizable computing platforms, and associated compilation tools and runtime management environment to support domain-specific computing. Its recent focus is on design and implementation of accelerator-rich architectures, from single chips to data centers. It also includes highly automated compilation tools and runtime management software for customizable heterogeneous platforms, including multi-core CPUs, many-core GPUs, and FPGAs; and a general, reusable methodology for customizable computing applicable across domains. By combining these capabilities, the goal is to deliver a supercomputer-in-a-box or -in-a-cluster, customizable to an application domain to enable disruptive innovations therein. This approach has been successful in medical image processing, precision medicine, and machine learning. Originally funded by a $10 million National Science Foundation (NSF) Expeditions in Computing award, in 2014 CDSC received $3 million from Intel Corporation with matching NSF InTrans program support. CDSC research is also supported by SRC JUMP and several industrial partners.

## Center for Encrypted Functionalities

Amit Sahai, *Director*
http://web.cs.ucla.edu/cef/

The center was established in 2014 through an NSF Secure and Trustworthy Cyberspace (SaTC) Frontier Award. The center tackles the deep and far-reaching problem of general-purpose software obfuscation. The goal of obfuscation is to enable software that can keep secrets: software that makes use of secrets, but such that they remain hidden even if an adversary can examine the software code in its entirety and analyze its behavior as it runs. The center is headquartered at UCLA with partners at Columbia, Johns Hopkins, and Stanford universities, and University of Texas at Austin.

## Center for Information and Computation Security (CICS)

Rafail Ostrovsky, *Director*
http://www.cs.ucla.edu/security/

CICS was established in 2003 to promote all aspects of research and education in cryptography and computer security. It explores novel techniques for securing national and private-sector information infrastructures across various network-based and wireless platforms as well as wide-area networks. The inherent challenge is to provide guarantees of privacy and survivability under malicious and coordinated attacks.

The center has raised federal, state, and private-sector funding, including collaboration with Israel through multiple U.S.–Israel Binational Science Foundation grants. It has also attracted multiple international visiting scholars. CICS explores and develops state-of-the-art cryptographic algorithms, definitions, and proofs of security; novel cryptographic applications such as new electronic voting protocols and identification, data-rights management schemes, and privacy-preserving data mining; security mechanisms underlying a clean-slate design for a next-generation secure Internet; biometric-based models and tools, such as encryption and identification schemes based on fingerprint scans; and the interplay of cryptography and security with other fields such as bioinformatics, machine learning, complexity theory, etc.

## Scalable Analytics Institute (ScAI)

The institute was established in 2013 with a focus on the continuing growth of data and demand for smart analytics to mine that data. Such analytics are creating major transformative opportunities in science and industry. To fully capitalize on these opportunities, computing technology must solve the three-pronged challenge created by the exploding size of big data, the growing complexity of big data, and the increased sophistication of analytics that can be used to extract patterns and trends from the data.

## Wireless Health Institute (WHI)

Benjamin M. Wu, D.D.S, Ph.D. (Bioengineering), *Director*; Bruce Dobkin, M.D. (Medicine/Neurology), William Kaiser, Ph.D. (Electrical and Computer Engineering), Gregory J. Pottie, Ph.D. (Electrical and Computer Engineering), *Co-Directors*

WHI is leading initiatives in health care solutions in the fields of disease diagnosis, neurological rehabilitation, optimization of clinical outcomes for many disease conditions, geriatric care, and many others. WHI also promotes this new field in the international community through the founding and organization of the leading Wireless Health conference series.

WHI technology always serves the clinician community through jointly developed innovations and clinical trial validation. Each WHI program is focused on large-scale product delivery in cooperation with manufacturing partners. WHI collaborators include the UCLA schools of Medicine, Nursing, and Engineering and Applied Sciences; Clinical Translational Science Institute for medical research; Ronald Reagan UCLA Medical Center; and faculty from many departments across UCLA. WHI education programs span high school, undergraduate, and graduate students, and provide training in end-to-end product development and delivery for WHI program managers.

WHI develops innovative, wearable biomedical monitoring systems that collect, integrate, process, analyze, communicate, and present information so that individuals become engaged and empowered in their own health care, improve their quality of life, and reduce burdens on caregivers. WHI products appear in diverse areas including motion sensing, wound care, orthopaedics, digestive health and process monitoring, advancing athletic performance, and many others. Clinical trials validating WHI technology are underway at 10 institutions. WHI products developed by the UCLA team are now in the marketplace in the U.S. and Europe. Physicians, nurses, therapists, other providers, and families can apply these technologies in hospital and community practices. Academic and industry groups can leverage the organization of WHI to rapidly develop products in complete-care programs, and validate in trials. WHI welcomes new team members, and continuously forms new collaborations with colleagues and organizations in medical science and health care delivery.

# Computing Resources

In summarizing the resources now available to conduct experimentally based research in the UCLA Computer Science Department, it is useful to identify the major components of the research environment: the departmental computing facility, other hardware and software systems, administrative structure, and technical support staff.

## Hardware

Computing facilities range from large campus-operated supercomputers to a major local network of servers and workstations that are administered by the department computing facilities (DCF) or school network (SEASnet).

The departmental research network includes Oracle servers and shared workstations, on the school ethernet TCP/IP local network. A wide variety of peripheral equipment is also part of the facility, and many more research-group workstations share the network; the total number of machines exceeds 1000, the majority running the Linux operating system. The network consists of switched 10/100/1000 ethernet to the desktop with a gigabit backbone connection. The department LAN is connected to the campus gigabit backbone. An 802.11n wireless network is also available to faculty, staff, and graduate students.

## Administrative Structure

The central facilities and wide-area networking are operated by the campuswide Information Technology Services. Access to the departmental and SEASnet machines is controlled so as to maximize the usefulness of these computers for education and research, but no direct charges are involved.

## Technical Support Staff

The support staff consists of hardware and software specialists. The hardware laboratory supports network connections, configures routers, switches, and network monitoring tools. The software group administers the department UNIX servers, providing storage space and backup for department users.

# Faculty Areas of Thesis Guidance

### Professors

Junghoo (John) Cho, Ph.D. (Stanford, 2002)
*Databases, web technologies, information discovery and integration*

Jason (Jingsheng) Cong, Ph.D. (U. Illinois, 1990)
*Computer-aided design of VLSI circuits, fault-tolerant design of VLSI systems, design and analysis of algorithms, computer architecture, reconfigurable computing, design for nanotechnologies*

Adnan Y. Darwiche, Ph.D. (Stanford, 1993)
*Knowledge representation and automated reasoning (symbolic and probabilistic), applications to diagnosis, prediction, planning, and verification*

*Joseph J. DiStefano III, Ph.D. (UCLA, 1966)
*Biocybernetics; computational systems biology; dynamic biosystems modeling, simulation, clinical therapy and experiment design optimization methodologies; pharmacokinetic (PK), pharmacodynamic (PD), and physiologically-based PK (PKPD) modeling; knowledge-based (expert) systems for life science research*

Milos D. Ercegovac, Ph.D. (U. Illinois, 1975)
*Application-specific architectures, digital computer arithmetic, digital design, low-power systems, reconfigurable systems*

Eleazar Eskin, Ph.D. (Columbia, 2002)
*Bioinformatics, genetics, genomics, machine learning*

Eliezer M. Gafni, Ph.D. (MIT, 1982)
*Computer communication, networks, mathematical programming algorithms*

Eran Halperin, Ph.D. (Tel Aviv U., Israel, 2000)
*Computational biology, population genetics, statistical genetics and epigenetics, machine learning, algorithms*

Miryung Kim, Ph.D. (U. Washington, 2008)
*Software engineering specifically on software evolution*

Richard E. Korf, Ph.D. (Carnegie Mellon, 1983)
*Problem solving, heuristic search, planning in artificial intelligence*

Christopher J. Lee, Ph.D. (Stanford, 1993)
*Bioinformatics and information theory of experiment planning, inference, and evolution*

Songwu Lu, Ph.D. (U. Illinois, 1999)
*Integrated-service support over heterogeneous networks, e.g., mobile computing environments, Internet and Activenet: networking and computing, wireless communications and networks, computer communication networks, dynamic game theory, dynamic systems, neural networks, and information economics*

Todd D. Millstein, Ph.D. (U. Washington, 2003)
*Programming language design, static type systems, formal methods, software model checking, compilers*

Stanley J. Osher, Ph.D. (New York U., 1966)
*Scientific computing and applied mathematics*

†Rafail Ostrovsky, Ph.D. (MIT, 1992)
*Theoretical computer science algorithms, cryptography, complexity theory, randomization, network protocols, geometric algorithms, data mining*

Jens Palsberg, Ph.D. (Aarhus U., Denmark, 1992)
*Compilers, embedded systems, programming languages*

Miodrag Potkonjak, Ph.D. (UC Berkeley, 1991)
*Computer-aided analysis and synthesis of system level designs, behavioral synthesis, and interaction between high-performance application-specific computations and communications*

Glenn D. Reinman, Ph.D. (UC San Diego, 2001)
*Microprocessor architecture, exploitation of instruction/thread/memory-level parallelism, power-efficient design, hardware/software co-design, multicore and multiprocessor design*

Amit Sahai, Ph.D. (MIT, 2000)
*Theoretical computer science, cryptology, computer security, algorithms, error-correcting codes and learning theory*

* Also Professor of Medicine
† Also Professor of Mathematics

Majid Sarrafzadeh, Ph.D. (U. Illinois, 1987)
*Computer engineering, embedded systems, VLSI CAD, algorithms*

Stefano Soatto, Ph.D. (Caltech, 1996)
*Computer vision; shape analysis, motion analysis, texture analysis, 3-D reconstruction, vision-based control; computer graphics: image-based modeling and rendering; medical imaging: registration, segmentation, statistical shape analysis; autonomous systems: sensor-based control, planning non-linear filtering; human-computer interaction: vision-based interfaces, visibility, visualization*

Mani B. Srivastava, Ph.D. (UC Berkeley, 1992)
*Energy aware networking and computing, embedded networked sensing, embedded software, low-power wireless systems and applications of wireless and embedded technology*

Demetri Terzopoulos, Ph.D. (MIT, 1984)
*Computer graphics, computer vision, medical image analysis, computer-aided design, artificial life/intelligence*

Mihaela van der Schaar, Ph.D. (Eindhoven U. Technology, Netherlands, 2001)
*Multimedia processing and compression, multimedia networking, multimedia communications, multimedia architectures, enterprise multimedia streaming, mobile and ubiquitous computing*

George Varghese, Ph.D. (MIT, 1993)
*Computer networks*

Wei Wang, Ph.D. (UCLA, 1999)
*Data mining, bioinformatics and computational biology, databases*

Carlo A. Zaniolo, Ph.D. (UCLA, 1976)
*Knowledge bases and deductive databases, parallel execution of PROLOG programs, formal software specifications, distributed systems, big data, artificial intelligence, and computational biology*

Lixia Zhang, Ph.D. (MIT, 1989)
*Computer network, Internet architecture, protocol designs, security and resiliency of large-scale systems*

Song-Chun Zhu, Ph.D. (Harvard, 1996)
*Computer vision, statistical modeling and computing, vision and visual arts, machine learning*

### Professors Emeriti

Algirdas A. Avizienis, Ph.D. (U. Illinois, 1960)
*Digital computer architecture and design, fault-tolerant computing, digital arithmetic*

Rajive L. Bagrodia, Ph.D. (U. Texas, 1987)
*Wireless networks, nomadic computing, parallel programming, performance evaluation of computer and communication systems*

Alfonso F. Cardenas, Ph.D. (UCLA, 1969)
*Database management, distributed heterogeneous and multimedia (text, image/picture, video, voice) systems, information systems planning and development methodologies, software engineering, medical informatics, legal and intellectual property issues*

Jack W. Carlyle, Ph.D. (UC Berkeley, 1961)
*Communication, computation theory and practice, algorithms and complexity, discrete system theory, developmental and probabilistic systems*

Wesley W. Chu, Ph.D. (Stanford, 1966)
*Distributed computing, distributed database, memory management, computer communications, performance measurement and evaluation for distributed systems and multiaccess packet-switched systems*

Michael G. Dyer, Ph.D. (Yale, 1982)
*Artificial intelligence; natural language processing; connectionist, cognitive, and animat-based modeling*

Sheila A. Greibach, Ph.D. (Harvard, 1963)
*Theoretical computer science, computational complexity, program schemes and semantics, formal languages, automata, computability*

Leonard Kleinrock, Ph.D. (MIT, 1963)
*Computer networks, computer-communication systems, resource sharing and allocation, computer systems modeling analysis and design, queueing systems theory and applications, performance evaluation of congestion-prone systems, performance evaluation and design of distributed multiaccess packet-switching systems, wireless networks, mobile computing, nomadic computing, and distributed and parallel processing systems*

Allen Klinger, Ph.D. (UC Berkeley, 1966)
*Pattern recognition, picture processing, biomedical applications, mathematical modeling*

Lawrence P. McNamee, Ph.D. (U. Pittsburgh, 1964)
*Computer graphics, discrete simulation, digital filtering, computer-aided design, LSI fabrication techniques, printed circuit board design*

Richard R. Muntz, Ph.D. (Princeton, 1969)
*Multimedia systems, database systems, data mining*

D. Stott Parker, Jr., Ph.D. (U. Illinois, 1978)
*Data mining, information modeling, scientific computing, bioinformatics, database and knowledge-based systems*

Judea Pearl, Ph.D. (Polytechnic Institute of Brooklyn, 1965)
*Artificial intelligence, philosophy of science, reasoning under uncertainty, causal inference, causal and counterfactual analysis*

David A. Rennels, Ph.D. (UCLA, 1973)
*Digital computer architecture and design, fault-tolerant computing, digital arithmetic*

### Associate Professors

Raghu Meka, Ph.D. (U. Texas Austin, 2011)
*Complexity theory, pseudorandomness, algorithms, learning probability and data mining*

Alexander Sherstov, Ph.D. (U. Texas Austin, 2009)
*Complexity theory with a focus on communication and circuit complexity, computational learning theory, quantum computing*

Yizhou Sun, Ph.D. (U. Illinois Urbana-Champaign, 2012)
*Information and social network analysis, data mining, database systems, statistics, information retrieval, machine learning and network science*

Yuval Tamir, Ph.D. (UC Berkeley, 1985)
*Computer systems, computer architecture, software systems, parallel and distributed systems, dependable systems, cluster computing, reliable network services, interconnection networks and switches, multi-core architectures, reconfigurable systems*

Guoqing (Harry) Xu (Ohio State, 2011)
*Programming languages, compilers, runtime systems, distributed systems, big data systems and analytics, software engineering*

### Assistant Professors

Kai-Wei Chang, Ph.D. (U. Illinois Urbana-Champaign, 2015)
*Tractable machine learning methods for complex and big data, statistical approaches to natural language processing*

Jason Ernst, Ph.D. (UCLA, 2008)
*Computational biology, bioinformatics, machine learning*

Alyson K. Fletcher, Ph.D. (UC Berkeley, 2006)
*Applied mathematics including inverse problems, statistical physics, dynamical systems, machine learning, information theory*

Quanquan Gu, Ph.D. (U. Illinois Urbana-Champaign, 2014)
*Maching learning, high-dimensional statistical inference, optimization, data mining*

Cho-Jui Hsieh, Ph.D. (U. Texas Austin, 2015)
*Fast and scalable algorithms for large-scale machine learning (deep learning), fast prediction and model compression for big ML models, low-rank models for recommender systems, theoretical analysis of optimization algorithms, security for machine learing*

Ravi Netravali, Ph.D. (MIT, 2018)
*Computer systems, computer networks, distributed systems, cloud computing*

Anthony J. Nowatzki, Ph.D. (U. Wisconsin Madison, 2016)
*Hardware/software co-design, modeling, and optimization*

Sriram Sankararaman, Ph.D. (UC Berkeley, 2010)
*Computational biology, computational/statistical genomics, statistical machine learning probabilistic graphical models, Bayesian statistics*

Fabien Scalzo, Ph.D. (U. Liège, Belgium, 2008)
*Stroke and traumatic brain injuries (TBI) using brain mapping of imaging and biosignals (MR, CT, X-ray angiography, TCD, and ICP); development of machine learning and computer vision algorithms to improve neurocritical care and bring understanding of neurological disorders*

Guy Van den Broeck, Ph.D. (Katholieke U. Leuven, Belgium, 2013)
*Machine learning (statistical relational learning), knowledge representation and reasoning (graphical models, lifted probabilistic inference), applications of probabilistic reasoning and learning (probabilistic programming, probabilistic databases), artificial intelligence*

### Senior Lecturers S.O.E.

Paul R. Eggert, Ph.D. (UCLA, 1980)
*Programming languages, operating systems principles, compilers, Internet*

David A. Smallberg, M.S. (UCLA, 1978)
*Programming languages, software development*

### Adjunct Professors

David E. Heckerman, Ph.D. (UCLA, 1979)
*Models and methods used for statistics and data analysis, machine learning, probability theory, decision theory, design of HIV vaccines, and genome-wide association studies*

Van Jacobson, M.S. (U. Arizona, 1972)
*Named data network (NDA), content-centric networking*

Alan Kay, Ph.D. (U. Utah, 1969)
*Object-oriented programming, personal computing, graphical user interfaces*

Peter L. Reiher, Ph.D. (UCLA, 1987)
*Computer and network security, ubiquitous computing, file systems, distributed systems*

### Adjunct Associate Professor

Carey S. Nachenberg, M.S. (UCLA, 1995)
*Anti-virus and intrusion detection technology*

Giovanni Pau, Ph.D. (U. Bologna, Italy, 1998)
*Protocol design implementation and evaluation for QOS support in wired/wireless networks and vertical handover protocols and architectures*

### Adjunct Assistant Professors

Alexander Afanasyev, Ph.D. (UCLA, 2013)
*Named data networking (NDN), information-centric networking (ICN)*

Ramin Ramezani, Ph.D. (Imperial College, London, England, 2014)
*Logic and AI, inductive logic programming, constraint solving, machine learning, combined reasoning, signal processing*

Ameet S. Talwalkar, Ph.D. (New York U., 2010)
*Statistical machine learning, scalable data analytics, computational genomics*

# Bioinformatics

## Lower-Division Courses

**19. Fiat Lux Freshman Seminars. (1)** Seminar, one hour. Discussion of and critical thinking about topics of current intellectual importance, taught by faculty members in their areas of expertise and illuminating many paths of discovery at UCLA. P/NP grading.

**99. Student Research Program. (1 to 2)** Tutorial (supervised research or other scholarly work), three hours per week per unit. Entry-level research for lower-division students under guidance of faculty mentor. Students must be in good academic standing and enrolled in minimum of 12 units (excluding this course). Individual contract required; consult Undergraduate Research Center. May be repeated. P/NP grading.

## Upper-Division Course

**199. Directed Research in Bioinformatics. (2 to 4)** Tutorial, six to 12 hours. Limited to juniors/seniors. Supervised individual research under guidance of faculty mentor. Culminating paper required. May be repeated for credit. Individual contract required. Letter grading.

# Computer Science

## Lower-Division Courses

**1. Freshman Computer Science Seminar. (1)** Seminar, one hour; discussion, one hour. Introduction to department resources and principal topics and key ideas in computer science and computer engineering. Assignments given to bolster independent study and writing skills. Letter grading.
Mr. Darwiche (F)

**19. Fiat Lux Freshman Seminars. (1)** Seminar, one hour. Discussion of and critical thinking about topics of current intellectual importance, taught by faculty members in their areas of expertise and illuminating many paths of discovery at UCLA. P/NP grading.

**30. Principles and Practices of Computing. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Designed for students in computer science and related majors who do not have prior programming experience. Precursor course to introductory computer science sequence (courses 31, 32, 33). Teaches students how to use computers as tool for problem solving, creativity, and exploration through design and implementation of computer programs. Key topics are data types including integers, strings, and lists; control structures, including conditionals and loops; and functional decomposition. Letter grading. Mr. Millstein (F)

**31. Introduction to Computer Science I. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Introduction to computer science via theory, applications, and programming. Basic data types, operators and control structures. Input/output. Procedural and data abstraction. Introduction to object-oriented software development. Functions, recursion. Arrays, strings, pointers. Abstract data types, object-oriented programming. Examples and exercises from computer science theory and applications. Letter grading.
Mr. Palsberg, Mr. Smallberg (F,W,Sp)

**32. Introduction to Computer Science II. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 31. Object-oriented software development. Abstract data type definition and use. Overloading, inheritance, polymorphism. Object-oriented view of data structures: stacks, queues, lists. Algorithm analysis. Trees, graphs, and associated algorithms. Searching and sorting. Case studies and exercises from computer science applications. Letter grading.
Mr. Nachenberg, Mr. Smallberg (W,Sp)

**33. Introduction to Computer Organization. (5)** Lecture, four hours; discussion, two hours; outside study, nine hours. Enforced requisite: course 32. Introductory course on computer architecture, assembly language, and operating systems fundamentals. Number systems, machine language, and assembly language. Procedure calls, stacks, interrupts, and traps. Assemblers, linkers, and loaders. Operating systems concepts: processes and process management, input/output (I/O) programming, memory management, file systems. Letter grading.
Mr. Nowatzki, Mr. Reinman (F,W,Sp)

**35L. Software Construction Laboratory. (3)** Laboratory, four hours; outside study, five hours. Requisite: course 31. Fundamentals of commonly used software tools and environments, particularly open-source tools to be used in upper-division computer science courses. Letter grading. Mr. Eggert (F,W,Sp)

**M51A. Logic Design of Digital Systems. (4)** (Same as Electrical and Computer Engineering M16.) Lecture, four hours; discussion, two hours; outside study, six hours. Introduction to digital systems. Specification and implementation of combinational and sequential systems. Standard logic modules and programmable logic arrays. Specification and implementation of algorithmic systems: data and control sections. Number systems and arithmetic algorithms. Error control codes for digital information. Letter grading. Mr. Ercegovac, Mr. Potkonjak (F,W,Sp)

**97. Variable Topics in Computer Science. (1 to 4)** Lecture, one to four hours; discussion, zero to two hours. Designed for freshmen/sophomores. Variable topics in computer science not covered in regular computer science courses. May be repeated once for credit with topic or instructor change. Letter grading.
Mr. Korf

**99. Student Research Program. (1 to 2)** Tutorial (supervised research or other scholarly work), three hours per week per unit. Entry-level research for lower-division students under guidance of faculty mentor. Students must be in good academic standing and enrolled in minimum of 12 units (excluding this course). Individual contract required; consult Undergraduate Research Center. May be repeated. P/NP grading.

# Upper-Division Courses

**111. Operating Systems Principles. (5)** Lecture, four hours; laboratory, two hours; outside study, nine hours. Enforced requisites: courses 32, 33, 35L. Introduction to operating systems design and evaluation. Computer software systems performance, robustness, and functionality. Kernel structure, bootstrapping, input/output (I/O) devices and interrupts. Processes and threads; address spaces, memory management, and virtual memory. Scheduling, synchronization. File systems: layout, performance, robustness. Distributed systems: networking, remote procedure call (RPC), asynchronous RPC, distributed file systems, transactions. Protection and security. Exercises involving applications using, and internals of, real-world operating systems. Letter grading.
Mr. Kampe, Mr. Reiher (F,W,Sp)

**112. Modeling Uncertainty in Information Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: course 111 and one course from Civil Engineering 110, Electrical Engineering 131A, Mathematics 170A, or Statistics 100A. Designed for juniors/seniors. Probability and stochastic process models as applied in computer science. Basic methodological tools include random variables, conditional probability, expectation and higher moments, Bayes theorem, Markov chains. Applications include probabilistic algorithms, evidential reasoning, analysis of algorithms and data structures, reliability, communication protocol and queueing models. Letter grading.
Mr. Sanadidi, Mr. Soatto (Not offered 2019-20)

**117. Computer Networks: Physical Layer. (4)** (Formerly numbered M117.) Lecture, two hours; discussion, two hours; laboratory, two hours; outside study, six hours. Not open to students with credit for course M171L. Introduction to fundamental computer communication concepts underlying and supporting modern networks, with focus on wireless communications and media access layers of network protocol stack. Systems include wireless LANs (IEEE802.11) and ad hoc wireless and personal area networks (e.g., Bluetooth, ZigBee). Experimental project based on mobile radio-equipped devices (smart phones, tablets, etc.) as sensor platforms for personal applications such as wireless health, positioning, and environment awareness, and experimental laboratory sessions included. Letter grading.
Mr. Dzhanidze (Not offered 2019-20)

**118. Computer Network Fundamentals. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 111. Designed for juniors/seniors. Introduction to design and performance evaluation of computer networks, including such topics as what protocols are, layered network architecture, Internet protocol architecture, network applications, transport protocols, routing algorithms and protocols, internetworking, congestion control, and link layer protocols including Ethernet and wireless channels. Letter grading.
Mr. Varghese, Ms. Zhang (F,W,Sp)

**M119. Fundamentals of Embedded Networked Systems. (4)** (Same as Electrical and Computer Engineering M119.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: Civil and Environmental Engineering 110 or Electrical and Computer Engineering 131A or Mathematics 170A or Statistics 100A, course 118 or Electrical and Computer Engineering 132B, course 33. Design trade-offs and principles of operation of cyber physical systems such as devices and systems constituting Internet of Things. Topics include signal propagation and modeling, sensing, node architecture and operation, and applications. Letter grading. Mr. Srivastava (Sp)

**CM121. Introduction to Bioinformatics. (4)** (Same as Chemistry CM160A.) Lecture, four hours; discussion, two hours. Requisites: course 32 or Program in Computing 10C with grade of C– or better, and one course from Biostatistics 100A, Civil Engineering 110, Electrical Engineering 131A, Mathematics 170A, or Statistics 100A. Prior knowledge of biology not required. Designed for engineering students as well as students from biological sciences and medical school. Introduction to bioinformatics and methodologies, with emphasis on concepts and inventing new computational and statistical techniques to analyze biological data. Focus on sequence analysis and alignment algorithms. Concurrently scheduled with course CM221. P/NP or letter grading. Mr. Lee (F)

**CM122. Algorithms in Bioinformatics. (4)** (Same as Chemistry CM160B.) Lecture, four hours; discussion, two hours. Requisites: course 32 or Program in Computing 10C with grade of C– or better, and one course from Biostatistics 100A, Civil Engineering 110, Electrical Engineering 131A, Mathematics 170A, or Statistics 100A. Course CM121 is not requisite to CM122. Designed for engineering students as well as students from biological sciences and medical school. Development and application of computational approaches to biological questions, with focus on formulating interdisciplinary problems as computational problems and then solving these problems using algorithmic techniques. Computational techniques include those from statistics and computer science. Concurrently scheduled with course CM222. Letter grading. Mr. Eskin (Sp)

**CM124. Computational Genetics. (4)** (Same as Human Genetics CM124.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course 32 or Program in Computing 10C with grade of C– or better, Mathematics 33A, and one course from Civil Engineering 110, Electrical and Computer Engineering 131A, Mathematics 170A, or Statistics 100A. Designed for engineering students as well as students from biological sciences and medical school. Introduction to computational analysis of genetic variation and computational interdisciplinary research in genetics. Topics include introduction to genetics, identification of genes involved in disease, inferring human population history, technologies for obtaining genetic information, and genetic sequencing. Focus on formulating interdisciplinary problems as computational problems and then solving those problems using computational techniques from statistics and computer science. Concurrently scheduled with course CM224. Letter grading. Mr. Halperin, Mr. Sankararaman (W)

**130. Software Engineering. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Requisites: courses 111, 131. Recommended requisite: Engineering 183EW or 185EW. Structured programming, program specification, program proving, modularity, abstract data types, composite design, software tools, software control systems, program testing, team programming. Letter grading.
Mr. Eggert, Ms. Kim (F,W,Sp)

**131. Programming Languages. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Enforced requisites: courses 33, 35L. Basic concepts in design and use of programming languages, including abstraction, modularity, control mechanisms, types, declarations, syntax, and semantics. Study of several different language paradigms, including functional, object-oriented, and logic programming. Letter grading. Mr. Eggert, Mr. Millstein (F,W,Sp)

**132. Compiler Construction. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 131. Compiler structure; lexical and syntactic analysis; semantic analysis and code generation; theory of parsing. Letter grading.
Mr. Palsberg (F)

**133. Parallel and Distributed Computing. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: courses 131, M151B. Distributed memory and shared memory parallel architectures; asynchronous parallel languages: MPI, Maisie; primitives for parallel computation: specification of parallelism, interprocess communication and synchronization; design of parallel programs for scientific computation and distributed systems. Letter grading. Mr. Cong (W)

**136. Introduction to Computer Security. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 118. Introduction to basic concepts of information security necessary for students to understand risks and mitigations associated with protection of systems and data. Topics include security models and architectures, security threats and risk analysis, access control and authentication/authorization, cryptography, network security, secure application design, and ethics and law. Letter grading. Mr. Reiher (F)

**C137A. Prototyping Programming Languages. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 131. How different programming language paradigms provide dramatically different ways of thinking about computation and offer trade-offs on many dimensions, such as modularity, extensibility, expressiveness, and safety. Concrete exploration of three major programming paradigms—functional, object-oriented, and logic programming—by prototyping implementations of languages in each. Analysis of prototypes to shed light on design and structural properties of each language and paradigm and to allow easy comparison against one another. Hands-on experience implementing new abstractions, both as stand-alone languages and as libraries in existing languages. Concurrently scheduled with course C237A. Letter grading. Mr. Millstein (Not offered 2019-20)

**C137B. Programming Language Design. (4)** Seminar, four hours; outside study, eight hours. Enforced requisite: course C137A. Study of various programming language designs, from computing history and research literature, that attempt to address problems of software systems that are bloated, buggy, and difficult to maintain and extend despite trend in computing toward ever higher levels of abstraction for programming. Hands-on experience designing, prototyping, and evaluating new languages, language abstractions, and/or programming environments. Concurrently scheduled with course C237B. Letter grading. Mr. Millstein (Not offered 2019-20)

**143. Database Systems. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Enforced requisite: course 111. Information systems and database systems in enterprises. File organization and secondary storage structures. Relational model and relational database systems. Network, hierarchical, and other models. Query languages. Database design principles. Transactions, concurrency, and recovery. Integrity and authorization. Letter grading. Mr. Cho, Mr. Zaniolo (W,Sp)

**144. Web Applications. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 143. Important concepts and theory for building effective and safe Web applications and first-hand experience with basic tools. Topics include basic Web architecture and protocol, XML and XML query language, mapping between XML and relational models, information retrieval model and theory, security and user model, Web services and distributed transactions. Letter grading. Mr. Cho (Sp)

**145. Introduction to Data Mining. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 180. Introductory survey of data mining (process of automatic discovery of patterns, changes, associations, and anomalies in massive databases), knowledge engineering, and wide spectrum of data mining application areas such as bioinformatics, e-commerce, environmental studies, financial markets, multimedia data processing, network monitoring, and social service analysis. Letter grading. Ms. Sun (F)

**M146. Introduction to Machine Learning. (4)** (Same as Electrical and Computer Engineering M146.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: Civil and Environmental Engineering 110 or Electrical and Computer Engineering 131A or Mathematics 170A or Statistics 100A, course 33. Introduction to breadth of data science. Foundations for modeling data sources, principles of operation of common tools for data analysis, and application of tools and models to data gathering and analysis. Topics include statistical foundations, regression, classification, kernel methods, clustering, expectation maximization, principal component analysis, decision theory, reinforcement learning and deep learning. Letter grading. Mr. Chang, Mr. Sankararaman (F,W,Sp)

**M151B. Computer Systems Architecture. (4)** (Same as Electrical and Computer Engineering M116C.) Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: courses 33, and M51A or Electrical and Computer Engineering M16. Recommended: courses 111, and M152A or Electrical and Computer Engineering M116L. Computer system organization and design, implementation of CPU datapath and control, instruction set design, memory hierarchy (caches, main memory, virtual memory) organization and management, input/output subsystems (bus structures, interrupts, DMA), performance evaluation, pipelined processors. Letter grading. Mr. Reinman, Mr. Tamir (F,W,Sp)

**M152A. Introductory Digital Design Laboratory. (2)** (Same as Electrical and Computer Engineering M116L.) Laboratory, four hours; outside study, two hours. Enforced requisite: course M51A or Electrical and Computer Engineering M16. Hands-on design, implementation, and debugging of digital logic circuits, use of computer-aided design tools for schematic capture and simulation, implementation of complex circuits using programmed array logic, design projects. Letter grading. Mr. Potkonjak (F,W,Sp)

**152B. Digital Design Project Laboratory. (4)** Laboratory, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course M151B or Electrical Engineering M116C. Recommended: Engineering 183EW or 185EW. Limited to seniors. Design and implementation of complex digital subsystems using field-programmable gate arrays (e.g., processors, special-purpose processors, device controllers, and input/output interfaces). Students work in teams to develop and implement designs and to document and give oral presentations of their work. Letter grading. Mr. Sarrafzadeh (F,W,Sp)

**161. Fundamentals of Artificial Intelligence. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Enforced requisite: course 180. Introduction to fundamental problem solving and knowledge representation paradigms of artificial intelligence. Introduction to Lisp with regular programming assignments. State-space and problem reduction methods, brute-force and heuristic search, planning techniques, two-player games. Knowledge structures including predicate logic, production systems, semantic nets and primitives, frames, scripts. Special topics in natural language processing, expert systems, vision, and parallel architectures. Letter grading. Mr. Darwiche, Mr. Korf, Mr. Van den Broeck (F,W,Sp)

**168. Computational Methods for Medical Imaging. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course 32 or Program in Computing 10C with grade of C– or better, Mathematics 33A, one course from Civil and Environmental Engineering 110, Electrical and Computer Engineering 131A, Mathematics 170A, or Statistics 100A. Theory and practice of image acquisition including angiography, computed tomography (CT), and magnetic resonance (MR). Project-based course covers applied topics in medical imaging including image processing, atlasing, predictive modeling, personalized medicine, data driven and machine learning methods. Letter grading. Mr. Scalzo (Sp)

**170A. Mathematical Modeling and Methods for Computer Science. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Enforced requisites: course 180, Mathematics 33B. Introduction to methods for modeling and simulation using interactive computing environments. Extensive coverage of methods for numeric and symbolic computation, matrix algebra, statistics, floating point, optimization, and spectral analysis. Emphasis on applications in simulation of physical systems. Letter grading. Mr. Parker (Not offered 2019-20)

**M171L. Data Communication Systems Laboratory. (2 to 4)** (Same as Electrical and Computer Engineering M171L.) Laboratory, four to eight hours; outside study, two to four hours. Recommended preparation: course M152A. Limited to seniors. Not open to students with credit for course M117. Interpretation of analog-signaling aspects of digital systems and data communications through experience in using contemporary test instruments to generate and display signals in relevant laboratory setups. Use of oscilloscopes, pulse and function generators, baseband spectrum analyzers, desktop computers, terminals, modems, PCs, and workstations in experiments on pulse transmission impairments, waveforms and their spectra, modem and terminal characteristics, and interfaces. Letter grading. Mr. Gerla (Not offered 2019-20)

**172. Real-Time Three-Dimensional Animation. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 32. Introduction to handling of geometry, appearance, and motion specifically for real-time virtual environments, both on theoretical and practical levels. Completion of one quality real-time three-dimensional animation by following through from preproduction to postproduction. End products expected to be game demonstrations, storytelling games, or machinima (use of real-time graphics engines to create cinematic productions). Focus on achieving highest quality productions to qualify and submit products to Student Academy Awards competition. Use of Unity Game Engine to make technical decisions to adapt stories to games. Introduction to interaction concepts, enabling students to create low-fidelity real-time three-dimensional animation and to concepts in artificial intelligence, enabling them to refine their interactions to create high-fidelity real-time three-dimensional animation. Letter grading. Ms. Ford (Not offered 2019-20)

**174A. Introduction to Computer Graphics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 32. Basic principles behind modern two- and three-dimensional computer graphics systems, including complete set of steps that modern graphics pipelines use to create realistic images in real time. How to position and manipulate objects in scene using geometric and camera transformations. How to create final image using perspective and orthographic transformations. Basics of modeling primitives such as polygonal models and implicit and parametric surfaces. Basic ideas behind color spaces, illumination models, shading, and texture mapping. Letter grading. Mr. Terzopoulos (F,W,Sp)

**174B. Introduction to Computer Graphics: Three-Dimensional Photography and Rendering. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 174A. State of art in three-dimensional photography and image-based rendering. How to use cameras and light to capture shape and appearance of real objects and scenes. Process provides simple way to acquire three-dimensional models of unparalleled detail and realism. Applications of techniques from entertainment (reverse engineering and postprocessing of movies, generation of realistic synthetic objects and characters) to medicine (modeling of biological structures from imaging data), mixed reality (augmentation of video), and security (visual surveillance). Fundamental analytical tools for modeling and inferring geometric (shape) and photometric (reflectance, illumination) properties of objects and scenes, and for rendering and manipulating novel views. Letter grading. Mr. Soatto (Not offered 2019-20)

**C174C. Computer Animation. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 174A. Designed for juniors/seniors. Introduction to computer animation, including basic principles of character modeling, forward and inverse kinematics, forward and inverse dynamics, motion capture animation techniques, physics-based animation of particles and systems, and motor control. Concurrently scheduled with course C274C. Letter grading. Mr. Terzopoulos (Sp)

**180. Introduction to Algorithms and Complexity. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: course 32, Mathematics 61. Designed for junior/senior Computer Science majors. Introduction to design and analysis of algorithms. Design techniques: divide-and-conquer, greedy method, dynamic programming; selection of prototypical algorithms; choice of data structures and representations; complexity measures: time, space, upper, lower bounds, asymptotic complexity; NP-completeness. Letter grading. Mr. Gafni, Mr. Ostrovsky, Mr. Sarrafzadeh (F,W,Sp)

**181. Introduction to Formal Languages and Automata Theory. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 180. Designed for junior/senior Computer Science majors. Grammars, automata, and languages. Finite-state languages and finite-state automata. Context-free languages and pushdown story automata. Unrestricted rewriting systems, recursively enumerable and recursive languages, and Turing machines. Closure properties, pumping lemmas, and decision algorithms. Introduction to computability. Letter grading. Mr. Sahai, Mr. Sherstov (F,W,Sp)

**M182. Dynamic Biosystem Modeling and Simulation Methodology. (4)** (Same as Bioengineering M182.) Lecture, four hours; discussion, one hour; laboratory, two hours; outside study, five hours. Requisites: Life Sciences 30A and 30B, or Mathematics 3A and 3B, or 31A and 31B. Recommended requisite or corequisite: Mathematics 3C, 32A, or 32T. For undergraduate students in life, computational, engineering, and mathematical sciences. Active learning approach. Introduction to explicit modeling and simulation of dynamic biological systems. Basic methodology for transforming biology, biochemistry, and physiology into system diagrams, graphs, and mathematical expressions for studying their behavior. Structural models, formulated from basic conservation and mass action laws and feedback concepts, are further transformed into first-order differential equations, and implemented in simulation diagrams for quantifying and exploring biosystem properties. Examples show how to use these explicit models to gain clarity on nature of biosystem phenomena, and frame questions and explore new ideas for research. Letter grading. Mr. DiStefano (F,Sp)

**183. Introduction to Cryptography. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Preparation: knowledge of basic probability theory. Enforced requisite: course 180. Introduction to cryptography, computer security, and basic concepts and techniques. Topics include notions of hardness, one-way functions, hard-core bits, pseudorandom generators, pseudorandom functions and pseudorandom permutations, semantic security, public-key and private-key encryption, key-agreement, homomorphic encryption, private information retrieval and voting protocols, message authentication, digital signatures, interactive proofs, zero-knowledge proofs, collision-resistant hash functions, commitment protocols, and two-party secure computation with static security. Letter grading. Mr. Ostrovsky (Sp)

**M184. Introduction to Computational and Systems Biology. (2)** (Same as Bioengineering M184 and Computational and Systems Biology M184.) Lecture, two hours; outside study, four hours. Enforced requisites: one course from 31, Civil Engineering M20, Mechanical and Aerospace Engineering M20, or Program in Computing 10A, and Mathematics 3B or 31B. Survey course designed to introduce students to computational and systems modeling and computation in biology and medicine, providing motivation, flavor, culture, and cutting-edge contributions in computational biosciences and aiming for more informed basis for focused studies by students with computational and systems biology interests. Presentations by individual UCLA researchers discussing their active computational and systems biology research. P/NP grading. Mr. DiStefano, Mr. Eskin (F)

**M185. Research Opportunities in Computational and Systems Biology. (4)** (Same as Computational and Systems Biology M185.) Lecture, two hours; discussion, two hours. Requisites: course M184, Mathematics 32B, 33A, 33B, Life Sciences 4. Introduction to interdisciplinary laboratory research methods and research opportunities in computational and systems biology to prepare and initiate students for active engagement in research. Presentation of potential projects by faculty members and student visits to individual laboratories and participation in ongoing projects. P/NP or letter grading. Mr. DiStefano (Not offered 2019-20)

**CM186. Computational Systems Biology: Modeling and Simulation of Biological Systems. (5)** (Same as Bioengineering CM186, Computational and Systems Biology M186, and Ecology and Evolutionary Biology M178.) Lecture, four hours; laboratory, three hours; outside study, eight hours. Dynamic biosystems modeling and computer simulation methods for studying biological/biomedical processes and systems at multiple levels of organization. Control system, multicompartmental, predator-prey, pharmacokinetic (PK), pharmacodynamic (PD), and other structural modeling methods applied to life sciences problems at molecular, cellular (biochemical pathways/networks), organ, and organismic levels. Both theory- and data-driven modeling, with focus on translating biomodeling goals and data into mathematics models and implementing them for simulation and analysis. Basics of numerical simulation algorithms, with modeling software exercises in class and PC laboratory assignments. Concurrently scheduled with course CM286. Letter grading. Mr. DiStefano (W)

**CM187. Research Communication in Computational and Systems Biology. (4)** (Same as Bioengineering CM187 and Computational and Systems Biology M187.) Lecture, four hours; outside study, eight hours. Requisite: course CM186. Closely directed, interactive, and real research experience in active quantitative systems biology research laboratory. Direction on how to focus on topics of current interest in scientific community, appropriate to student interests and capabilities. Critiques of oral presentations and written progress reports explain how to proceed with search for research results. Major emphasis on effective research reporting, both oral and written. Concurrently scheduled with course CM287. Letter grading. Mr. DiStefano (Not offered 2019-20)

**188. Special Courses in Computer Science. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Special topics in computer science for undergraduate students taught on experimental or temporary basis, such as those taught by resident and visiting faculty members. May be repeated for credit with topic or instructor change. Letter grading. (F,W,Sp)

**192. Methods and Application of Collaborative Learning Theory in Life Sciences. (2)** Seminar, two hours; clinic, four hours. Requisites: course 192A or Life Sciences 192A (may be taken concurrently), and at least one term of prior experience in same course in which collaborative learning theory is practiced and refined under supervision of instructors. With instructor guidance, students apply pedagogical principles based on current education research, assist with development of innovative instructional materials, and receive frequent feedback on their progress. May be repeated four times for credit. Letter grading.

**192A. Introduction to Collaborative Learning Theory and Practice. (1)** Seminar, one hour; outside study, two hours. Training seminar for undergraduate students who are selected for learning assistants (LA) program. Exploration of current topics in pedagogy and education research focused on methods of learning and their practical application in small-group settings. Students practice communication skills with constant assessment of and feedback on progress. Letter grading. (F,W,Sp)

**194. Research Group Seminars: Computer Science. (4)** Seminar, four hours; outside study, eight hours. Designed for undergraduate students who are part of research group. Discussion of research methods and current literature in field or of research of faculty members or students. May be repeated for credit. Letter grading. (F,W,Sp)

**199. Directed Research in Computer Science. (2 to 8)** Tutorial, to be arranged. Limited to juniors/seniors. Supervised individual research or investigation under guidance of faculty mentor. Culminating paper or project required. May be repeated for credit with school approval. Individual contract required; enrollment petitions available in Office of Academic and Student Affairs. Letter grading. (F,W,Sp)

# Graduate Courses

**201. Computer Science Seminar. (2)** Seminar, four hours; outside study, two hours. Designed for graduate computer science students. Seminars on current research topics in computer science. May be repeated for credit. S/U grading. (F,W,Sp)

**202. Advanced Computer Science Seminar. (4)** Seminar, four hours; outside study, eight hours. Preparation: completion of major field examination in computer science. Current computer science research into theory of, analysis and synthesis of, and applications of information processing systems. Each member completes one tutorial and one or more original pieces of work in one specialized area. May be repeated for credit. Letter grading.

**205. Health Analytics. (4)** Lecture, four hours; outside study, eight hours. Enforced requisites: courses 31, 180. Recommended: statistics and probability, numerical methods, knowledge in programming languages. Applied data analytics course, with focus on healthcare applications. How to properly generate and analyze health data. Project-based course to learn about best practices in health data collection and validation. Exploration of various machine learning and data analytic tools to learn underlying structure of datasets to solve healthcare problems. Different machine learning concepts and algorithms, statistical models, and building of data-driven models. Big data analytics and tools for handling structured, unstructured, and semistructured datasets. Letter grading. Mr. Sarrafzadeh

**211. Network Protocol and Systems Software Design for Wireless and Mobile Internet. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 118. Designed for graduate students. In-depth study of network protocol and systems software design in area of wireless and mobile Internet. Topics include (1) networking fundamentals: design philosophy of TCP/IP, end-to-end arguments, and protocol design principles, (2) networking protocols: 802.11 MAC standard, packet scheduling, mobile IP, ad hoc routing, and wireless TCP, (3) mobile computing systems software: middleware, file system, services, and applications, and (4) topical studies: energy-efficient design, security, location management, and quality of service. Letter grading. Mr. Lu (F)

**212A. Queueing Systems Theory. (4)** Lecture, four hours; outside study, eight hours. Requisites: course 112, Electrical Engineering 131A. Resource sharing issues and theory of queueing (waiting-line) systems. Review of Markov chains and baby queueing theory. Method of stages. $M/E_r/1$. $E_r/M/1$. Bulk arrival and bulk service systems. Series-parallel stages. Fundamentals of open and closed queueing networks. Intermediate queueing theory: M/G/1; G/M/m. Collective marks. Advanced queueing theory: G/G/1; Lindley integral equation; spectral solution. Inequalities, bounds, approximations. Letter grading. Mr. Gerla

**M213A. Embedded Systems. (4)** (Same as Electrical and Computer Engineering M202A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Designed for graduate computer science and electrical engineering students. Methodologies and technologies for design of embedded systems. Topics include hardware and software platforms for embedded systems, techniques for modeling and specification of system behavior, software organization, real-time operating system scheduling, real-time communication and packet scheduling, low-power battery and energy-aware system design, timing synchronization, fault tolerance and debugging, and techniques for hardware and software architecture optimization. Theoretical foundations as well as practical design methods. Letter grading. Mr. Potkonjak, Mr. Srivistava

**M213B. Energy-Aware Computing and Cyber-Physical Systems. (4)** (Same as Electrical and Computer Engineering M202B.) Lecture, four hours; outside study, eight hours. Requisite: course M51A or Electrical and Computer Engineering M16. Recommended: courses 111, and M151B or Electrical and Computer Engineering M116C. System-level management and cross-layer methods for power and energy consumption in computing and communication at various scales ranging across embedded, mobile, personal, enterprise, and data-center scale. Computing, networking, sensing, and control technologies and algorithms for improving energy sustainability in human-cyber-physical systems. Topics include modeling of energy consumption, energy sources, and energy storage; dynamic power management; power-performance scaling and energy proportionality; duty-cycling; power-aware scheduling; low-power protocols; battery modeling and management; thermal management; sensing of power consumption. Letter grading. Mr. Srivistava

**216. Network Algorithmics. (4)** Lecture, four hours; outside study, eight hours. Recommended preparation: one course on networks. Requisite: course 211.

Introduction to algorithms for routers and servers. Models of network devices and hardware design. Principles for efficient implementation. Lookup algorithms (exact match, prefix lookups, advanced cardiac life support), fair queuing implementations, crossbar and scalable switches, with examples from well-known networking devices. Advanced topics include traffic measurement and network security. Letter grading.

**217A. Internet Architecture and Protocols. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 118. Focus on mastering existing core set of Internet protocols, including IP, core transport protocols, routing protocols, DNS, NTP, and security protocols such as DNSSEC, to understand principles behind design of these protocols, appreciate their design tradeoffs, and learn lessons from their operations. Letter grading. Ms. Zhang (Not offered 2019-20)

**217B. Advanced Topics in Internet Research. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 217A. Designed for graduate students. Overview of Internet development history and fundamental principles underlying TCP/IP protocol design. Discussion of current Internet research topics, including latest research results in routing protocols, transport protocols, network measurements, network security protocols, and clean-slate approach to network architecture design. Fundamental issues in network protocol design and implementations. Letter grading. Ms. Zhang (Not offered 2019-20)

**218. Advanced Computer Networks. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 112, 118. Review of seven-layer ISO-OSI model. High-speed networks: LANs, MANs, ATM. Flow and congestion control; bandwidth allocation. Internetting. Letter grading. Mr. Gerla (F)

**219. Current Topics in Computer System Modeling Analysis. (4)** Lecture, eight hours; outside study, four hours. Review of current literature in area of computer system modeling analysis in which instructor has developed special proficiency as consequence of research interests. Students report on selected topics. May be repeated for credit with consent of instructor. Letter grading. Mr. Lu (Sp)

**CM221. Introduction to Bioinformatics. (4)** (Same as Bioinformatics M221, Chemistry CM260A, and Human Genetics M260A.) Lecture, four hours; discussion, two hours. Requisites: course 32 or Program in Computing 10C with grade of C– or better, and one course from Biostatistics 100A, Civil Engineering 110, Electrical Engineering 131A, Mathematics 170A, or Statistics 100A. Prior knowledge of biology not required. Designed for engineering students as well as students from biological sciences and medical school. Introduction to bioinformatics and methodologies, with emphasis on concepts and inventing new computational and statistical techniques to analyze biological data. Focus on sequence analysis and alignment algorithms. Concurrently scheduled with course CM121. S/U or letter grading. Mr. Lee (F)

**CM222. Algorithms in Bioinformatics. (4)** (Same as Bioinformatics M222 and Chemistry CM260B.) Lecture, four hours; discussion, two hours. Requisites: course 32 or Program in Computing 10C with grade of C– or better, and one course from Biostatistics 100A, Civil Engineering 110, Electrical Engineering 131A, Mathematics 170A, or Statistics 100A. Course CM221 is not requisite to CM222. Designed for engineering students as well as students from biological sciences and medical school. Development and application of computational approaches to biological questions, with focus on formulating interdisciplinary problems as computational problems and then solving these problems using algorithmic techniques. Computational techniques include those from statistics and computer science. Concurrently scheduled with course CM122. Letter grading. Mr. Eskin (W)

**CM224. Computational Genetics. (4)** (Same as Bioinformatics M224 and Human Genetics CM224.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course 32 or Program in Computing 10C with grade of C– or better, Mathematics 33A, and one course from Civil Engineering 110, Electrical and Computer Engineering 131A, Mathematics 170A, or Statistics 100A. Designed for engineering students as well as students from biological sciences and medical school. Introduction to computational analysis of genetic variation and computational interdisciplinary research in genetics. Topics include introduction to genetics, identification of genes involved in disease, inferring human population history, technologies for obtaining genetic information, and genetic sequencing. Focus on formulating interdisciplinary problems as computational problems and then solving those problems using computational techniques from statistics and computer science. Concurrently scheduled with course CM124. Letter grading. Mr. Sankararaman (Sp)

**M225. Computational Methods in Genomics. (4)** (Same as Bioinformatics M225 and Human Genetics M265.) Lecture, two and one half hours; discussion, two and one half hours; outside study, seven hours. Introduction to computational approaches in bioinformatics, genomics, and computational genetics and preparation for computational interdisciplinary research in genetics and genomics. Topics include genome analysis, regulatory genomics, association analysis, association study design, isolated and admixed populations, population substructure, human structural variation, model organisms, and genomic technologies. Computational techniques and methods include those from statistics and computer science. Letter grading. Mr. Eskin (Not offered 2019-20)

**M226. Machine Learning in Bioinformatics. (4)** (Same as Bioinformatics M226 and Human Genetics M226.) Lecture, four hours; outside study, eight hours. Enforced requisite: course 32 or Program in Computing 10C with grade of C– or better. Recommended: one course from Biostatistics 100A, 110A, Civil Engineering 110, Electrical Engineering 131A, Mathematics 170A, or Statistics 100A. Familiarity with probability, statistics, linear algebra, and algorithms expected. Designed for engineering students as well as students from biological sciences and medical school. Biology has become data-intensive science. Bottleneck in being able to make sense of biological processes has shifted from data generation to statistical models and inference algorithms that can analyze these datasets. Statistical machine learning provides important toolkit in this endeavor. Biological datasets offer new challenges to field of machine learning. Examination of statistical and computational aspects of machine learning techniques and their application to key biological questions. Letter grading. Mr. Sankararaman (F)

**M229S. Seminar: Current Topics in Bioinformatics. (4)** (Same as Biological Chemistry M229S and Human Genetics M229S.) Seminar, four hours; outside study, eight hours. Designed for graduate engineering students as well as students from biological sciences and medical school. Introduction to current topics in bioinformatics, genomics, and computational genetics and preparation for computational interdisciplinary research in genetics and genomics. Topics include genome analysis, regulatory genomics, association analysis, association study design, isolated and admixed populations, population substructure, human structural variation, model organisms, and genomic technologies. Computational techniques include those from statistics and computer science. May be repeated for credit with topic change. Letter grading. Mr. Eskin (Not offered 2019-20)

**230. Software Engineering. (4)** Lecture, four hours; discussion, two hours. Recommended preparation for undergraduate students: prior software engineering course. Required preparation for graduate students: undergraduate-level knowledge of data structures and object-oriented program languages. As software systems become increasingly large and complex, automated software engineering analysis and development tools play important role in various software engineering tasks, such as design, construction, evolution, and testing and debugging of software systems. Introduction to foundations, techniques, tools, and applications of automated software engineering technology. Development, extension, and evaluation of mini automated software engineering analysis tool and assessment of how tool fits into software development process. Introduction to current research topics in automated software engineering. S/U or letter grading. Ms. Kim (Sp)

**231. Types and Programming Languages. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 131. Introduction to static type systems and their usage in programming language design and software reliability. Operational semantics, simply-typed lambda calculus, type soundness proofs, types for mutable references, types for exceptions. Parametric polymorphism, let-bound polymorphism, polymorphic type inference. Types for objects, subtyping, combining parametric polymorphism and subtyping. Types for modules, parameterized modules. Formal specification and implementation of variety of type systems, as well as readings from recent research literature on modern applications of type systems. Letter grading. Mr. Millstein (F)

**232. Static Program Analysis. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 132. Introduction to static analysis of object-oriented programs and its usage for optimization and bug finding. Class hierarchy analysis, rapid type analysis, equality-based analysis, subset-based analysis, flow-insensitive and flow-sensitive analysis, context-insensitive and context-sensitive analysis. Soundness proofs for static analyses. Efficient data structures for static analysis information such as directed graphs and binary decision diagrams. Flow-directed method inlining, type-safe method inlining, synchronization optimization, deadlock detection, security vulnerability detection. Formal specification and implementation of variety of static analyses, as well as readings from recent research literature on modern applications of static analysis. Letter grading. Mr. Palsberg

**233A. Parallel Programming. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 111, 131. Mutual exclusion and resource allocation in distributed systems; primitives for parallel computation: specification of parallelism, interprocess communication and synchronization, atomic actions, binary and multiway rendezvous; synchronous and asynchronous languages: CSP, Ada, Linda, Maisie, UC, and others; introduction to parallel program verification. Letter grading. Mr. Cong

**233B. Verification of Concurrent Programs. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 233A. Formal techniques for verification of concurrent programs. Topics include safety, liveness, program and state assertion-based techniques, weakest precondition semantics, Hoare logic, temporal logic, UNITY, and axiomatic semantics for selected parallel languages. Letter grading. Mr. Bagrodia

**234. Computer-Aided Verification. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 181. Introduction to theory and practice of formal methods for design and analysis of concurrent and embedded systems, with focus on algorithmic techniques for checking logical properties of hardware and software systems. Topics include semantics of reactive systems, invariant verification, temporal logic model checking, theory of omega automata, state-space reduction techniques, compositional and hierarchical reasoning. Letter grading. Mr. Majumdar

**235. Advanced Operating Systems. (4)** Lecture, four hours. Preparation: C or C++ programming experience. Requisite: course 111. In-depth investigation of operating systems issues through guided construction of research operating system for PC machines and consideration of recent literature. Memory management and protection, interrupts and traps, processes, interprocess communication, preemptive multitasking, file systems. Virtualization, networking, profiling, research operating systems. Series of laboratory projects, including extra challenge work. Letter grading. Mr. Eggert

**236. Computer Security. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 111, 118. Basic and research material on computer security. Topics include basic principles and goals of computer security, common security tools, use of cryptographic protocols for security, security tools (firewalls, virtual private networks, honeypots), virus and worm protection, security assurance and testing, design of secure programs, privacy, applying security principles to realistic problems, and new and emerging threats and security tools. Letter grading. Mr. Palsberg, Mr. Reiher

**C237A. Prototyping Programming Languages. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 131. How different programming language paradigms provide dramatically different ways of thinking about computation and offer trade-offs on many dimensions, such as modularity, extensibility, expressiveness, and safety. Concrete exploration of three major programming paradigms—functional, object-oriented, and logic programming—by prototyping implementations of languages in each. Analysis of prototypes to shed light on design and structural properties of each language and paradigm and to allow easy comparison against one another. Hands-on experience implementing new abstractions, both as stand-alone languages and as libraries in existing languages. Concurrently scheduled with course C137A. Letter grading. Mr. Millstein

**C237B. Programming Language Design. (4)** Seminar, four hours; outside study, eight hours. Enforced requisite: course C237A. Study of various programming language designs, from computing history and research literature, that attempt to address problems of software systems that are bloated, buggy, and difficult to maintain and extend despite trend in computing toward ever higher levels of abstraction for programming. Hands-on experience designing, prototyping, and evaluating new languages, language abstractions, and/or programming environments. Concurrently scheduled with course C137B. Letter grading. Mr. Millstein

**239. Current Topics in Computer Science: Programming Languages and Systems. (2 to 12)** Lecture, four hours; outside study, eight hours. Review of current literature in area of computer science programming languages and systems in which instructor has developed special proficiency as consequence of research interests. May be repeated for credit with topic change. Letter grading. Mr. Millstein

**240A. Databases and Knowledge Bases. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 143. Theoretical and technological foundation of Intelligent Database Systems, that merge database technology, knowledge-based systems, and advanced programming environments. Rule-based knowledge representation, spatio-temporal reasoning, and logic-based declarative querying/programming are salient features of this technology. Other topics include object-relational systems and data mining techniques. Letter grading. Mr. Zaniolo (F)

**240B. Advanced Data and Knowledge Bases. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 143, 240A. Logical models for data and knowledge representations. Rule-based languages and nonmonotonic reasoning. Temporal queries, spatial queries, and uncertainty in deductive databases and object relational databases (ORDBs). Abstract data types and user-defined column functions in ORDBs. Data mining algorithms. Semistructured information. Letter grading.
Mr. Parker, Mr. Zaniolo (Not offered 2019-20)

**241B. Pictorial and Multimedia Database Management. (4)** Lecture, three and one half hours; discussion, 30 minutes; laboratory, one hour; outside study, seven hours. Requisite: course 143. Multimedia data: alphanumeric, long text, images/pictures, video, and voice. Multimedia information systems requirements. Data models. Searching and accessing databases and across Internet by alphanumeric, image, video, and audio content. Querying, visual languages, and communication. Database design and organization, logical and physical. Indexing methods. Internet multimedia streaming. Other topics at discretion of instructor. Letter grading. Mr. Cardenas

**244A. Distributed Database Systems. (4)** Lecture, four hours; outside study, eight hours. File allocation, intelligent directory design, transaction management, deadlock, strong and weak concurrency control, commit protocols, semantic query answering, multidatabase systems, fault recovery techniques, network partitioning, examples, trade-offs, and design experiences. Letter grading.

**245. Big Data Analytics. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 143 or 180 or equivalent. With unprecedented rate at which data is being collected today in almost all fields of human endeavor, there is emerging economic and scientific need to extract useful information from it. Data analytics is process of automatic discovery of patterns, changes, associations, and anomalies in massive databases, and is highly inter-disciplinary field representing confluence of several disciplines, including database systems, data warehousing, data mining, machine learning, statistics, algorithms, data visualization, and cloud computing. Survey of main topics in big data analytics and latest advances, as well as wide spectrum of applications such as bioinformatics, E-commerce, environmental study, financial market study, multimedia data processing, network monitoring, social media analysis. Letter grading.

**246. Web Information Management. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 112, 143, 180, 181. Designed for graduate students. Scale of Web data requires novel algorithms and principles for their management and retrieval. Study of Web characteristics and new management techniques needed to build computer systems suitable for Web environment. Topics include Web measuring techniques, large-scale data mining algorithms, efficient page refresh techniques, Web-search ranking algorithms, and query processing techniques on independent data sources. Letter grading. Mr. Cho (Sp)

**247. Advanced Data Mining. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 145 or M146 or equivalent. Introduction of concepts, algorithms, and techniques of data mining on different types of datasets, covering basic data mining algorithms, advanced topics on text mining, recommender systems, and graph/network mining. Team-based project involving hands-on practice of mining useful knowledge from large data sets is required. Letter grading.

**249. Current Topics in Data Structures. (2 to 12)** Lecture, four hours; outside study, eight hours. Review of current literature in area of data structures in which instructor has developed special proficiency as consequence of research interests. Students report on selected topics. May be repeated for credit with consent of instructor. Letter grading.

**251A. Advanced Computer Architecture. (4)** Lecture, four hours; outside study, eight hours. Requisite: course M151B. Recommended: course 111. Design and implementation of high-performance systems, advanced memory hierarchy techniques, static and dynamic pipelining, superscalar and VLIW processors, branch prediction, speculative execution, software support for instruction-level parallelism, simulation-based performance analysis and evaluation, state-of-art design examples, introduction to parallel architectures. Letter grading.
Mr. Ercegovac, Mr. Tamir (F)

**251B. Parallel Computer Architectures. (4)** Lecture, four hours; outside study, eight hours. Requisite: course M151B. Recommended: course 251A. SIMD and MIMD systems, symmetric multiprocessors, distributed-shared-memory systems, messages-passing systems, multicore chips, clusters, interconnection networks, host-network interfaces, switching element design, communication primitives, cache coherency, memory consistency models, synchronization primitives, state-of-art design examples. Letter grading.
Mr. Ercegovac, Mr. Tamir (Not offered 2019-20)

**252A. Arithmetic Algorithms and Processors. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 251A. Number systems: conventional, redundant, signed-digit, and residue. Types of algorithms and implementations. Complexity measures. Fast algorithms and implementations for two-operand addition, multioperand addition, multiplication, division, and square root. Online arithmetic. Evaluation of transcendental functions. Floating-point arithmetic and numerical error control. Arithmetic error codes. Residue arithmetic. Examples of contemporary arithmetic ICs and processors. Letter grading.
Mr. Ercegovac (Not offered 2019-20)

**256A. Advanced Scalable Architectures. (4)** Lecture, four hours; outside study, eight hours. Requisite: course M151B. Recommended: course 251A. State-of-art scalable multiprocessors. Interdependency among implementation technology, chip microarchitecture, and system architecture. High-performance building blocks, such as chip multiprocessors (CMPs). On-chip and off-chip communication. Mechanisms for exploiting parallelism at multiple levels. Current research areas. Examples of chips and systems. Letter grading. Mr. Tamir (Not offered 2019-20)

**M258A. Design of VLSI Circuits and Systems. (4)** (Same as Electrical and Computer Engineering M216A.) Lecture, four hours; discussion, two hours; laboratory, four hours; outside study, two hours. Requisites: course M51A or Electrical and Computer Engineering M16, and Electrical and Computer Engineering 115A. Recommended: Electrical and Computer Engineering 115C. LSI/VLSI design and application in computer systems. Fundamental design techniques that can be used to implement complex integrated systems on chips. Letter grading.

**M258C. LSI in Computer System Design. (4)** (Same as Electrical and Computer Engineering M216C.) Lecture, four hours; laboratory, four hours; outside study, four hours. Requisite: course M258A. LSI/VLSI design and application in computer systems. In-depth studies of VLSI architectures and VLSI design tools. Letter grading.

**258F. Physical Design Automation of VLSI Systems. (4)** Lecture, four hours; outside study, eight hours. Detailed study of various physical design automation problems of VLSI circuits, including logic partitioning, floorplanning, placement, global routing, channel and switchbox routing, planar routing and via minimization, compaction and performance-driven layout. Discussion of applications of number of important optimization techniques, such as network flows, Steiner trees, simulated annealing, and generic algorithms. Letter grading. Mr. Cong

**258G. Logic Synthesis of Digital Systems. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses M51A, 180. Detailed study of various problems in logic-level synthesis of VLSI digital systems, including two-level Boolean network optimization; multilevel Boolean network optimization; technology mapping for standard cell designs and field-programmable gate-array (FPGA) designs; retiming for sequential circuits; and applications of binary decision diagrams (BDDS). Letter grading. Mr. Cong

**258H. Analysis and Design of High-Speed VLSI Interconnects. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses M258A, 258F. Detailed study of various problems in analysis and design of high-speed VLSI interconnects at both integrated circuit (IC) and packing levels, including interconnect capacitance and resistance, lossless and lossy transmission lines, cross-talk and power distribution noise, delay models and power dissipation models, interconnect topology and geometry optimization, and clocking for high-speed systems. Letter grading. Mr. Cong

**259. Current Topics in Computer Science: System Design/Architecture. (2 to 12)** Lecture, four hours; outside study, eight hours. Review of current literature in area of computer science system design in which instructor has developed special proficiency as consequence of research interests. Students report on selected topics. May be repeated for credit with topic change. Letter grading. (F,W,Sp)

**260. Machine Learning Algorithms. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Recommended requisite: course 180. Problems of identifying patterns in data. Machine learning allows computers to learn potentially complex patterns from data and to make decisions based on these patterns. Introduction to fundamentals of this discipline to provide both conceptual grounding and practical experience with several learning algorithms. Techniques and examples used in areas such as healthcare, financial systems, commerce, and social networking. Letter grading. Mr. Sha (F)

**261A. Problem Solving and Search. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 180. In-depth treatment of systematic problem-solving search algorithms in artificial intelligence, including problem spaces, brute-force search, heuristic search, linear-space algorithms, real-time search, heuristic evaluation functions, two-player games, and constraint-satisfaction problems. Letter grading. Mr. Korf (Not offered 2019-20)

**262A. Learning and Reasoning with Bayesian Networks. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 112 or Electrical Engineering 131A. Review of several formalisms for representing and managing uncertainty in reasoning systems; presentation of comprehensive description of Bayesian inference using belief networks representation. Letter grading. Mr. Darwiche (Not offered 2019-20)

**M262C. Current Topics in Causal Modeling, Inference, and Reasoning. (4)** (Same as Statistics M241.) Lecture, four hours; outside study, eight hours. Requisite: one graduate probability or statistics course such as course 262A, Statistics 200B, or 202B. Review of Bayesian networks, causal Bayesian networks, and structural equations. Learning causal structures from data. Identifying causal effects. Covariate selection and instrumental variables in linear and nonparametric models. Simpson paradox and confounding control. Logic and algorithmization of counterfactuals. Probabilities of counterfactuals. Direct and indirect effects. Probabilities of causation. Identifying causes of events. Letter grading. Mr. Pearl

**262Z. Current Topics in Cognitive Systems. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 262A. Additional requisites for each offering announced in advance by department. Theory and implementation of systems that emulate or support human reasoning. Current literature and individual studies in artificial intelligence, knowledge-based systems, decision support systems, computational psychology, and heuristic programming theory. May be repeated for credit with topic change. Letter grading. Mr. Pearl

**263A. Language and Thought. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 130 or 131 or 161. Introduction to natural language processing (NLP), with emphasis on semantics. Presentation of process models for variety of tasks, including question answering, paraphrasing, machine translation, word-sense disambiguation, narrative and editorial comprehension. Examination of both symbolic and statistical approaches to language processing and acquisition. Letter grading. Mr. Dyer (Not offered 2019-20)

**263C. Animats-Based Modeling. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 130 or 131 or 161. Animats are mobile/sensing animal-like software agents embedded in simulated dynamic environments. Emphasis on modeling: goal-oriented behavior via neurocontrollers, adaptation via reinforcement learning, evolutionary programming. Animat-based tasks include foraging, mate finding, predation, navigation, predator avoidance, cooperative nest construction, communication, and parenting. Letter grading. Mr. Dyer (F)

**264A. Automated Reasoning: Theory and Applications. (4)** Lecture, four hours; laboratory, four hours; outside study, four hours. Requisite: course 161. Introduction to theory and practice of automated reasoning using propositional and first-order logic. Topics include syntax and semantics of formal logic; algorithms for logical reasoning, including satisfiability and entailment; syntactic and semantic restrictions on knowledge bases; effect of these restrictions on expressiveness, compactness, and computational tractability; applications of automated reasoning to diagnosis, planning, design, formal verification, and reliability analysis. Letter grading. Mr. Darwiche (Not offered 2019-20)

**265A. Machine Learning. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 263A, 264A. Introduction to machine learning. Learning by analogy, inductive learning, modeling creativity, learning by experience, role of episodic memory organization in learning. Examination of BACON, AM, Eurisko, HACKER, teachable production systems. Failure-driven learning. Letter grading.

**M266A. Statistical Modeling and Learning in Vision and Cognition. (4)** (Same as Statistics M232A.) Lecture, three hours. Preparation: basic statistics, linear algebra (matrix analysis), computer vision. Computer vision and pattern recognition. Study of four types of statistical models for modeling visual patterns: descriptive, causal Markov, generative (hidden Markov), and discriminative. Comparison of principles and algorithms for these models; presentation of unifying picture. Introduction of minimax entropy and EM-type and stochastic algorithms for learning. S/U or letter grading.

**M266B. Statistical Computing and Inference in Vision and Cognition. (4)** (Same as Statistics M232B.) Lecture, three hours. Preparation: basic statistics, linear algebra (matrix analysis), computer vision. Introduction to broad range of algorithms for statistical inference and learning that could be used in vision, pattern recognition, speech, bioinformatics, data mining. Topics include Markov chain Monte Carlo computing, sequential Monte Carlo methods, belief propagation, partial differential equations. S/U or letter grading.

**267A. Probabilistic Programming and Relational Learning. (4)** Lecture, four hours; outside study, eight hours. Introduction to computational models of probability and statistical models of relational data. Study of relational representations such as probabilistic databases, relational graphical models, and Markov logic networks, as well as various probabilistic programming languages. Covers their syntax and semantics, probabilistic inference problems, parameter, and structure learning algorithms, and theoretical properties of representation and inference. Expressive statistical modeling, how to formalize and reason about complex statistical assumptions and encode knowledge in machine learning models. Survey of key applications in natural language processing, graph mining, computer vision, and computational biology. Letter grading.

**M268. Machine Perception. (4)** (Same as Electrical and Computer Engineering M206.) Lecture, four hours; discussion, two hours; outside study, six hours. Designed for graduate students. Computational aspects of processing visual and other sensory information. Unified treatment of early vision in man and machine. Integration of symbolic and iconic representations in process of image segmentation. Computing multimodal sensory information by neural-net architectures. Letter grading. Mr. Soatto (F)

**268S. Seminar: Computational Neuroscience. (2)** Seminar, two hours; outside study, four hours. Designed for students undertaking thesis research. Discussion of advanced topics and current research in computational neuroscience. Neural networks and connectionism as paradigm for parallel and concurrent computation in application to problems of perception, vision, multimodal sensory integration, and robotics. May be repeated for credit. S/U grading.

**269. Seminar: Current Topics in Artificial Intelligence. (4)** Seminar, to be arranged. Review of current literature and research practicum in area of artificial intelligence in which instructor has developed special proficiency as consequence of research interests. Students report on selected topics. May be repeated for credit with topic change. Letter grading. Mr. Terzopoulos (F)

**C274C. Computer Animation. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 174A. Introduction to computer animation, including basic principles of character modeling, forward and inverse kinematics, forward and inverse dynamics, motion capture animation techniques, physics-based animation of particles and systems, and motor control. Concurrently scheduled with course C174C. Letter grading. Mr. Terzopoulos (Not offered 2019-20)

**275. Artificial Life for Computer Graphics and Vision. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 174A. Recommended: course 161. Investigation of important role that concepts from artificial life, emerging discipline that spans computational and biological sciences, can play in construction of advanced computer graphics and vision models for virtual reality, animation, interactive games, active vision, visual sensor networks, medical image analysis, etc. Focus on comprehensive models that can realistically emulate variety of living things (plants and animals) from lower animals to humans. Exposure to effective computational modeling of natural phenomena of life and their incorporation into sophisticated, self-animating graphical entities. Specific topics include modeling plants using L-systems, biomechanical simulation and control, behavioral animation, reinforcement and neural-network learning of locomotion, cognitive modeling, artificial animals and humans, human facial animation, and artificial evolution. Letter grading. Mr. Terzopoulos (Not offered 2019-20)

**M276A. Pattern Recognition and Machine Learning. (4)** (Same as Statistics M231A.) Lecture, three hours; discussion, one hour. Designed for graduate students. Fundamental concepts, theories, and algorithms for pattern recognition and machine learning that are used in computer vision, image processing, speech recognition, data mining, statistics, and computational biology. Topics include Bayesian decision theory, parametric and nonparametric learning, clustering, complexity (VC-dimension, MDL, AIC), PCA/ICA/TCA, MDS, SVM, boosting. S/U or letter grading. Mr. Zhu

**280A-280ZZ. Algorithms. (4 each)** Lecture, four hours; outside study, eight hours. Requisite: course 180. Additional requisites for each offering announced in advance by department. Selections from design, analysis, optimization, and implementation of algorithms; computational complexity and general theory of algorithms; algorithms for particular application areas. Subtitles of some current sections: Principles of Design and Analysis (280A); Distributed Algorithms (280D); Graphs and Networks (280G). May be repeated for credit with consent of instructor and topic change. Letter grading:

**280AP.** Approximation Algorithms. (4) Lecture, four hours; outside study, eight hours. Requisite: course 180. Background in discrete mathematics helpful. Theoretically sound techniques for dealing with NP-Hard problems. Inability to solve these problems efficiently means algorithmic techniques are based on approximation—finding solution that is near to best possible in efficient running time. Coverage of approximation techniques for number of different problems, with algorithm design techniques that include primal-dual method, linear program rounding, greedy algorithms, and local search. Letter grading.

**281A. Computability and Complexity. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 181 or compatible background. Concepts fundamental to study of discrete information systems and theory of computing, with emphasis on regular sets of strings, Turing-recognizable (recursively enumerable) sets, closure properties, machine characterizations, nondeterminisms, decidability, unsolvable problems, "easy" and "hard" problems, PTIME/NPTIME. Letter grading. Mr. Ostrovsky (Not offered 2019-20)

**M282A. Cryptography. (4)** (Same as Mathematics M209A.) Lecture, four hours; outside study, eight hours. Introduction to theory of cryptography, stressing rigorous definitions and proofs of security. Topics include notions of hardness, one-way functions, hard-core bits, pseudorandom generators, pseudorandom functions and pseudorandom permutations, semantic security, public-key and private-key encryption, secret-sharing, message authentication, digital signatures, interactive proofs, zero-knowledge proofs, collision-resistant hash functions, commitment protocols, key-agreement, contract signing, and two-party secure computation with static security. Letter grading. Mr. Ostrovsky (F)

**M282B. Cryptographic Protocols. (4)** (Same as Mathematics M209B.) Lecture, four hours; outside study, eight hours. Requisite: course M282A. Consideration of advanced cryptographic protocol design and analysis. Topics include noninteractive zero-knowledge proofs; zero-knowledge arguments; concurrent and non-black-box zero-knowledge; IP=PSPACE proof, stronger notions of security for public-key encryption, including chosen-ciphertext security; secure multiparty computation; dealing with dynamic adversary; nonmalleability and composability of secure protocols; software protection; threshold cryptography; identity-based cryptography; private information retrieval; protection against man-in-middle attacks; voting protocols; identification protocols; digital cash schemes; lower bounds on use of cryptographic primitives, software obfuscation. May be repeated for credit with topic change. Letter grading. Mr. Ostrovsky (Sp)

**M283A-M283B. Topics in Applied Number Theory. (4–4)** (Same as Mathematics M208A-M208B.) Lecture, three hours. Basic number theory, including congruences and prime numbers. Cryptography: public-key and discrete log cryptosystems. Attacks on cryptosystems. Primality testing and factorization methods. Elliptic curve methods. Topics from coding theory: Hamming codes, cyclic codes, Gilbert/Varshamov bounds, Shannon theorem. S/U or letter grading.

**284A-284ZZ. Topics in Automata and Languages. (4 each)** Lecture, four hours; outside study, eight hours. Requisite: course 181. Additional requisites for each offering announced in advance by department. Selections from families of formal languages, grammars, machines, operators; pushdown automata, context-free languages and their generalizations, parsing; multidimensional grammars, developmental systems; machine-based complexity. Subtitles of some current and planned sections: Context-Free Languages (284A), Parsing Algorithms (284P). May be repeated for credit with consent of instructor and topic change. Letter grading.
Mr. Sahai (Not offered 2019-20)

**CM286. Computational Systems Biology: Modeling and Simulation of Biological Systems. (5)** (Same as Bioengineering CM286.) Lecture, four hours; laboratory, three hours; outside study, eight hours. Dynamic biosystems modeling and computer simulation methods for studying biological/biomedical processes and systems at multiple levels of organization. Control system, multicompartmental, predator-prey, pharmacokinetic (PK), pharmacodynamic (PD), and other structural modeling methods applied to life sciences problems at molecular, cellular (biochemical pathways/networks), organ, and organismic levels. Both theory- and data-driven modeling, with focus on translating biomodeling goals and data into mathematics models and implementing them for simulation and analysis. Basics of numerical simulation algorithms, with modeling software exercises in class and PC laboratory assignments. Concurrently scheduled with course CM186. Letter grading.
Mr. DiStefano (Not offered 2019-20)

**CM287. Research Communication in Computational and Systems Biology. (4)** (Same as Bioengineering CM287.) Lecture, four hours; outside study, eight hours. Requisite: course CM286. Closely directed, interactive, and real research experience in active quantitative systems biology research laboratory. Direction on how to focus on topics of current interest in scientific community, appropriate to student interests and capabilities. Critiques of oral presentations and written progress reports explain how to proceed with search for research results. Major emphasis on effective research reporting, both oral and written. Concurrently scheduled with course CM187. Letter grading. Mr. DiStefano (Not offered 2019-20)

**288S. Seminar: Theoretical Computer Science. (2)** Seminar, two hours; outside study, six hours. Requisites: courses 280A, 281A. Intended for students undertaking thesis research. Discussion of advanced topics and current research in such areas as algorithms and complexity models for parallel and concurrent computation, and formal language and automata theory. May be repeated for credit. S/U grading.

**289A-289ZZ. Current Topics in Computer Theory. (2 to 12 each)** Lecture, four hours; outside study, eight hours. Review of current literature in area of computer theory in which instructor has developed special proficiency as consequence of research interests. Students report on selected topics. Letter grading:

**289CO.** Complexity Theory. (4). Lecture, four hours; outside study, eight hours. Diagonalization, polynomial-time hierarchy, PCP theorem, randomness and de-randomization, circuit complexity, attempts and limitations to proving P does not equal NP, average-case complexity, one-way functions, hardness amplification. Problem sets and presentation of previous and original research related to course topics. Letter grading. Mr. Sahai (F)

**289OA.** Online Algorithms. (4) Lecture, four hours; outside study, eight hours. Requisite: course 180. Introduction to decision making under uncertainty and competitive analysis. Review of current research in online algorithms for problems arising in many areas, such as data and memory management, searching and navigating in unknown terrains, and server systems. Letter grading.

**289RA.** Randomized Algorithms. (4) Lecture, four hours; outside study, eight hours. Basic concepts and design techniques for randomized algorithms, such as probability theory, Markov chains, random walks, and probabilistic method. Applications to randomized algorithms in data structures, graph theory, computational geometry, number theory, and parallel and distributed systems. Letter grading.

**M296A. Advanced Modeling Methodology for Dynamic Biomedical Systems. (4)** (Same as Bioengineering M296A and Medicine M270C.) Lecture, four hours; outside study, eight hours. Requisite: Electrical Engineering 141 or 142 or Mathematics 115A or Mechanical and Aerospace Engineering 171A. Development of dynamic systems modeling methodology for physiological, biomedical, pharmacological, chemical, and related systems. Control system, multicompartmental, noncompartmental, and input/output models, linear and nonlinear. Emphasis on model applications, limitations, and relevance in biomedical sciences and other limited data environments. Problem solving in PC laboratory. Letter grading. Mr. DiStefano

**M296B. Optimal Parameter Estimation and Experiment Design for Biomedical Systems. (4)** (Same as Bioengineering M296B, Biomathematics M270, and Medicine M270D.) Lecture, four hours; outside study, eight hours. Requisite: course CM286 or M296A or Biomathematics 220. Estimation methodology and model parameter estimation algorithms for fitting dynamic system models to biomedical data. Model discrimination methods. Theory and algorithms for designing optimal experiments for developing and quantifying models, with special focus on optimal sampling schedule design for kinetic models. Exploration of PC software for model building and optimal experiment design via applications in physiology and pharmacology. Letter grading. Mr. DiStefano

**M296C. Advanced Topics and Research in Biomedical Systems Modeling and Computing. (4)** (Same as Bioengineering M296C and Medicine M270E.) Lecture, four hours; outside study, eight hours. Requisite: course M296B. Research techniques and experience on special topics involving models, modeling methods, and model/computing in biological and medical sciences. Review and critique of literature. Research problem searching and formulation. Approaches to solutions. Individual MS- and PhD-level project training. Letter grading. Mr. DiStefano

**M296D. Introduction to Computational Cardiology. (4)** (Same as Bioengineering M296D.) Lecture, four hours; outside study, eight hours. Requisite: course CM186. Introduction to mathematical modeling and computer simulation of cardiac electrophysiological process. Ionic models of action potential (AP). Theory of AP propagation in one-dimensional and two-dimensional cardiac tissue. Simulation on sequential and parallel supercomputers, choice of numerical algorithms, to optimize accuracy and to provide computational stability. Letter grading. Mr. DiStefano

**298. Research Seminar: Computer Science. (2 to 4)** Seminar, two to four hours; outside study, four to eight hours. Designed for graduate computer science students. Discussion of advanced topics and current research in algorithmic processes that describe and transform information: theory, analysis, design, efficiency, implementation, and application. May be repeated for credit. S/U grading. (F,W,Sp)

**375. Teaching Apprentice Practicum. (1 to 4)** Seminar, to be arranged. Preparation: apprentice personnel employment as teaching assistant, associate, or fellow. Teaching apprenticeship under active guidance and supervision of regular faculty member responsible for curriculum and instruction at UCLA. May be repeated for credit. S/U grading. (F,W,Sp)

**495. Teaching Assistant Training Seminar. (2)** Seminar, four hours; outside study, two hours. Limited to graduate Computer Science Department students. Seminar on being effective teaching assistant, including preparation, classroom presentation, encouraging interactive discussion, active learning, office hours, review sessions, making up and grading assignments and exam questions, proctoring exams, and grading. S/U grading. Mr. Korf (F)

**495B. Teaching with Technology. (2)** Seminar, two hours; outside study, four hours. Limited to graduate Computer Science Department teaching assistants. Seminar for teaching assistants covering how technology can be used to aid instruction in and out of classroom. S/U grading.
Mr. Korf (Not offered 2019-20)

**497D-497E. Field Projects in Computer Science. (4–4)** Fieldwork, to be arranged. Students are divided into teams led by instructor; each team is assigned one external company or organization that they investigate as candidate for possible computerization, submitting team report of their findings and recommendations. In Progress (497D) and S/U or letter (497E) grading.

**596. Directed Individual or Tutorial Studies. (1 to 8)** Tutorial, to be arranged. Limited to graduate computer science students. Petition forms to request enrollment may be obtained from assistant dean, Graduate Studies. Supervised investigation of advanced technical problems. S/U grading.

**597A. Preparation for MS Comprehensive Examination. (2 to 12)** Tutorial, to be arranged. Limited to graduate computer science students. Reading and preparation for MS comprehensive examination. S/U grading.

**597B. Preparation for PhD Preliminary Examinations. (2 to 16)** Tutorial, to be arranged. Limited to graduate computer science students. Preparation for PhD preliminary examinations. S/U grading.

**597C. Preparation for PhD Oral Qualifying Examination. (2 to 16)** Tutorial, to be arranged. Limited to graduate computer science students. Preparation for oral qualifying examination, including preliminary research on dissertation. S/U grading.

**598. Research for and Preparation of MS Thesis. (2 to 12)** Tutorial, to be arranged. Limited to graduate computer science students. Supervised independent research for MS candidates, including thesis prospectus. S/U grading.

**599. Research for and Preparation of PhD Dissertation. (2 to 16)** Tutorial, to be arranged. Limited to graduate computer science students. Petition forms to request enrollment may be obtained from assistant dean, Graduate Studies. S/U grading.

# Electrical and Computer Engineering

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### Professors

Asad A. Abidi, Ph.D. *(Chancellor's Professor)*
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Katsushi Arisaka, Ph.D.
Danijela Cabric, Ph.D.
Robert N. Candler, Ph.D.
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William J. Kaiser, Ph.D.
Kuo-Nan Liou, Ph.D.
Jia-Ming Liu, Ph.D. *(Associate Dean)*
Dejan Markovic, Ph.D.
Warren B. Mori, Ph.D.
Stanley J. Osher, Ph.D.
Aydogan Ozcan, Ph.D. *(Chancellor's Professor)*
Sudhakar Pamarti, Ph.D.
Gregory J. Pottie, Ph.D.
Yahya Rahmat-Samii, Ph.D., *(Northrop Grumman Professor of Electrical Engineering/ Electromagnetics)*
Behzad Razavi, Ph.D. *(Chancellor's Professor)*
Vwani P. Roychowdhury, Ph.D.
Henry Samueli, Ph.D.
Ali H. Sayed, Ph.D.
Stefano Soatto, Ph.D.
Jason L. Speyer, Ph.D.
Mani B. Srivastava, Ph.D.
Paulo Tabuada, Ph.D. *(Vijay K. Dhir Professor of Engineering)*
Lieven Vandenberghe, Ph.D.
Mihaela van der Schaar, Ph.D. *(Chancellor's Professor)*
John D. Villasenor, Ph.D.
Kang L. Wang, Ph.D. *(Raytheon Company Professor of Electrical Engineering)*
Yuanxun Ethan Wang, Ph.D.
Richard D. Wesel, Ph.D., *Associate Dean*
Benjamin S. Williams, Ph.D.
Chee Wei Wong, Sc.D.
Jason C.S. Woo, Ph.D.
C.-K. Ken Yang, Ph.D.

### Professors Emeriti

Frederick G. Allen, Ph.D.
Francis F. Chen, Ph.D.
Harold R. Fetterman, Ph.D.
Stephen E. Jacobsen, Ph.D.
Rajeev Jain, Ph.D.
Alan J. Laub, Ph.D.
Nhan N. Levan, Ph.D.
Dee-Son Pan, Ph.D.
Izhak Rubin, Ph.D.
Frederick W. Schott, Ph.D.
Oscar M. Stafsudd, Ph.D.
Gabor C. Temes, Ph.D.
Donald M. Wiberg, Ph.D.
Alan N. Willson, Jr., Ph.D. *(Charles P. Reames Endowed Professor Emeritus of Electrical Engineering)*
Kung Yao, Ph.D.

### Associate Professor

Aydin Babakhani, Ph.D.

### Assistant Professors

Clarice D. Aiello, Ph.D.
Xiang Anthony Chen, Ph.D.
Sam Emaminejad, Ph.D.
Achuta Kadambi, Ph.D.
Jonathan C. Kao, Ph.D.
Ankur Mehta, Ph.D.
Lin F. Yang, Ph.D.

### Adjunct Professors

Dariush Divsalar, Ph.D.
Dan M. Goebel, Ph.D.
Diana L. Huffaker, Ph.D.
Asad M. Madni, Ph.D.
Ingrid M. Verbauwhede, Ph.D.
Eli Yablonovitch, Ph.D.

### Adjunct Associate Professor

Chi On Chui, Ph.D.

### Adjunct Assistant Professors

Shervin Moloudi, Ph.D.
Zachary Taylor, Ph.D.

## Scope and Objectives

Electrical and computer engineers are responsible for inventions that have revolutionized our society, such as the electrical grid, telecommunications, and automated computing and control. The profession continues to make vital contributions in many domains, such as the infusion of information technology into all aspects of daily life. To further these ends, the Department of Electrical and Computer Engineering fosters a dynamic academic environment that is committed to a tradition of excellence in teaching, research, and service and has state-of-the-art research programs and facilities in a variety of fields. Departmental faculty members are engaged in research efforts across several disciplines in order to serve the needs of industry, government, society, and the scientific community. Interactions with other disciplines are strong. Faculty members regularly conduct collaborative research projects with colleagues in the Geffen School of Medicine; Graduate School of Education and Information Studies; School of Theater, Film, and Television; and College of Letters and Science.

There are three primary research areas in the department: circuits and embedded systems, physical and wave electronics, and signals and systems. These areas cover a broad spectrum of specializations in, for example, communications and telecom-

*Professor Mona Jarrahi and her group work on a terahertz spectroscopy setup.*

munications, control systems, signal processing, data science, electromagnetics, embedded computing systems, engineering optimization, integrated circuits and systems, microelectromechanical systems (MEMS), nanotechnology, photonics and optoelectronics, plasma electronics, and solid-state electronics.

The program grants two undergraduate degrees (Bachelor of Science in Electrical Engineering and Bachelor of Science in Computer Engineering) and two graduate degrees (Master of Science and Doctor of Philosophy in Electrical and Computer Engineering). The graduate program provides students with an opportunity to pursue advanced coursework, in-depth training, and research investigations in several fields.

## Department Mission

The education and research activities in the Electrical and Computer Engineering Department are aligned with its mission statement. In partnership with its constituents, consisting of students, alumni, industry, and faculty members, the mission of the department is to (1) produce highly qualified, well-rounded, and motivated students with fundamental knowledge of electrical engineering who can provide leadership and service to California, the nation, and the world, (2) pursue creative research and new technologies in electrical engineering and across disciplines in order to serve the needs of industry, government, society, and the scientific community, (3) develop partnerships with industrial and government agencies, (4) achieve visibility by active participation in conferences and technical and community activities, and (5) publish enduring scientific articles and books.

## Electrical Engineering Undergraduate Program Educational Objectives

The electrical engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

The electrical engineering curriculum provides an excellent background for either graduate study or employment. Undergraduate education in the department provides students with (1) fundamental knowledge in mathematics, physical sciences, and electrical engineering, (2) the opportunity to specialize in specific areas of interest or career aspiration, (3) intensive training in problem solving, laboratory skills, and design skills, and (4) a well-rounded education that includes communication skills, the ability to function well on a team, an appreciation for ethical behavior, and the ability to engage in lifelong learning. This education is meant to prepare students to thrive and to lead. It also prepares them to achieve the following two program educational objectives: (1) that graduates of the program have successful technical or professional careers and (2) that graduates of the program continue to learn and to adapt in a world of constantly evolving technology.

## Computer Engineering Undergraduate Program Educational Objectives

The undergraduate computer engineering program prepares students to be able to (1) understand fundamental computing concepts and make valuable contributions to the practice of computer engineering; (2) design, analyze, and implement complex computer systems for a variety of application areas and cyberphysical domains; (3) demonstrate the ability to work effectively in a team and communicate their ideas; (4) continue to learn as part of a graduate program or otherwise in the world of constantly evolving technology.

## Undergraduate Study

The Electrical Engineering major is a designated capstone major. Undergraduate students complete a design course in which they integrate their knowledge of the discipline and engage in creative design within realistic and professional constraints. Students apply their knowledge and expertise gained in previous mathematics, science, and engineering coursework. Within a multidisciplinary team structure, students identify, formulate, and solve engineering problems and present their projects to the class.

The Computer Engineering major is a designated capstone major that is jointly administered by the Computer Science and Electrical and Computer Engineering departments. Undergraduate students complete a design course in which they integrate their knowledge of the discipline and engage in creative design within realistic and professional constraints. Students apply their knowledge and expertise gained in previous mathematics, science, and engineering coursework. Students identify, formulate, and solve engineering problems and present their projects to the class.

## Electrical Engineering B.S.

***Capstone Major***

The undergraduate curriculum provides all Electrical Engineering majors with preparation in the mathematical and scientific disciplines that lead to a set of courses that span the fundamentals of the three major departmental areas of signals and systems, circuits and embedded systems, and physical wave electronics. These collectively provide an understanding of inventions of importance to society, such as integrated circuits, embedded systems, photonic devices, automatic computation and control, and telecommunication devices and systems.

Students are encouraged to make use of their electrical and computer engineering electives and a two-term capstone design course to pursue deeper knowledge within one of these areas according to their interests, whether for graduate study or preparation for employment. See the elective examples and suggested tracks below.

### Learning Outcomes

The Electrical Engineering major has the following learning outcomes:

- Application of knowledge of mathematics, science, and engineering
- Design of a system, component, or process to meet desired needs within realistic constraints
- Function as a productive member of a multidisciplinary team
- Effective communication
- Identification, formulation, and solution of electrical engineering problems

### Preparation for the Major

*Required:* Chemistry and Biochemistry 20A; Computer Science 31, 32; Electrical and Computer Engineering 2, 3, 10, 11L, M16 (or Computer Science M51A); Mathematics 31A, 31B, 32A, 32B, 33A, 33B; Physics 1A, 1B, 1C, 4AL, 4BL.

### The Major

*Required:* Electrical and Computer Engineering 101A, 102, 110, 111L, 113, 131A; six core courses selected from Computer Science 33, Electrical and Computer Engineering 101B, 115A, 121B, 132A, 133A, 141, 170A; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; 12 units of major field elective courses, at least 8 of which must be upper-division electrical and computer engineering courses—the remaining 4 units may be from upper-division electrical and computer engineering courses or from another UCLA Samueli department; and one two-term electrical and computer engineering capstone design course (8 units).

Electrical and Computer Engineering 100 and CM182 may not satisfy elective credit.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

## Elective Examples

*Communications Systems:* Studies range from basic wave propagation to point-to-point links up to large-scale networks for both wired and wireless applications. Students might take 12 units selected from Electrical and Computer Engineering 132A, 132B, 133A, 134, and M171L, and 8 capstone design units from 113DA/113DB or 180DA/180DB.

*Control Systems and Optimization:* The study of how to control a variety of systems ranging from a single physical system to continental networks, such as the electrical grid. Students might take 12 units selected from Electrical and Computer Engineering 112, 133A, 133B, 134, 141, and 142 and 8 capstone design units from 113DA/113DB or 184DA/184DB.

*Electromagnetic Systems:* Topics include the fundamentals of electromagnetic wave propagation in guided systems and free space, antennas, and radio systems. Students might take 12 units selected from Electrical and Computer Engineering 101B, 162A, 163A, and 163C and 8 capstone design units from 163DA/163DB or 164DA/164DB.

*Embedded Computing:* The study of compact systems that include collections of integrated circuits that interact with the physical world for purposes such as sensing and control in applications as diverse as appliances, automobiles, and medicine. Students might take 12 units selected from Electrical and Computer Engineering 115A, 115C, M116C, M116L, M119, and 142 and 8 capstone design units from 180DA/180DB or 183DA/183DB.

*Integrated Circuits:* The study of how to achieve large-scale integration of thousands to billions of computational, memory, and sensing elements in single or multichip modules. Students might take 12 units selected from Electrical and Computer Engineering 115A, 115AL, 115B, 115C, and 115E and 8 capstone design units from 164DA/164DB or 183DA/183DB.

*Photonics and Plasma Electronics:* The study of how to manipulate light and plasmas to create devices such as those that enable high-speed optical communication systems. Students might take 12 units selected from Electrical and Computer Engineering 170A, 170B, 170C, and M185 and 8 capstone design units from 173DA/173DB.

*Signal Processing:* The study of how to derive meaningful inferences from measured data, such as speech, images, or other data, after conversion from analog to digital form. Students might take 12 units selected from Electrical and Computer Engineering 114, 133A, 133B, 134, and M146 and 8 capstone design units from 113DA/113DB.

*Simulation and Data Analysis:* Studies focus on applications related to the processing of big data for both analog/multimedia and digital sources. Students might take 12 units selected from Electrical and Computer Engineering 114, 132A, 133A, 133B, 134, and M146 and 8 capstone design units from 113DA/113DB or 180DA/180DB.

*Solid-State and Microelectromechanical Systems (MEMS) Devices:* The study of the nanoscale and microscale devices that are the base of modern computation and sensing systems. Students might take 12 units selected from Electrical and Computer Engineering 121B, 123A, 123B, 128, and M153 and 8 capstone design units from 121DA/121DB.

## Suggested Tracks

The technical breadth area requirement provides an opportunity to combine elective courses in the Electrical Engineering major with those from another UCLA Samueli major to produce a specialization in an interdisciplinary domain. Students are free to design a specialization in consultation with a faculty adviser.

*Bioengineering and Informatics (BI)* refers to the design of biomedical devices and the analysis of data derived from such devices and instruments. Students might take Chemistry and Biochemistry 20B and two courses from Bioengineering 100, C101, CM102, and 110 and/or 12 units from Computer Science CM121, Electrical and Computer Engineering 114, 133B, 134, and 176 and 8 capstone design units from 180DA/180DB.

*Computer Engineering (CE)* concentrates on the part of the hardware/software stack related to the design of new processors and the operation of embedded systems. Students might take a 12-unit technical breadth area in computer science such as Computer Science 111, 117, 130, and 180 and/or 12 units of electives from Electrical and Computer Engineering 115C, M116C, M116L, M119, 132B, and M146 and 8 capstone design units from 113DA/113DB or 180DA/180DB or 183DA/183DB.

*Cyber Physical Systems (CPS)* refer to networked systems that include sensors and actuators that interact with the physical world. They blend embedded systems with networking and control and include, for example, robotic systems and the Internet of things (IoT). Students might take a 12-unit technical breadth area in computer science such as Computer Science 111, 117, and 180 and/or 12 units of electives from Electrical and Computer Engineering M116C, 132B, and 142 and 8 capstone design units from 183DA/183DB.

# Computer Engineering B.S.

***Capstone Major***

The undergraduate curriculum provides all computer engineering students with preparation in the mathematical and scientific disciplines that lead to a set of courses that span the fundamentals of the discipline in the major areas of data science and embedded networked systems. These collectively provide an understanding of many inventions of importance to our society, such as the Internet of things, human-cyber-physical systems, mobile/wearable/implantable systems, robotic systems, and more generally smart systems at all scales in diverse spheres. The design of hardware, software, and algorithmic elements of such systems represents an already dominant and rapidly growing part of the computer engineering profession. Students are encouraged to make use of their computer science and electrical and computer engineering electives and a two-quarter capstone design course to pursue deeper knowledge within one of these areas according to their interests, whether for graduate study or preparation for employment.

## Learning Outcomes

The Computer Engineering major has the following learning outcomes:

- Application of mathematical, scientific, and engineering knowledge
- Design of a software or hardware system, component, or process to meet desired needs within realistic economic, environmental, social, ethical, health, safety, security, reliability, manufacturability, and sustainability constraints
- Function productively on a team with others
- Identification, formulation, and solution of computer engineering problems
- Effective communication

## Preparation for the Major

*Required:* Computer Science 1 (or Electrical and Computer Engineering 1), 31, 32, 33, 35L, M51A (or Electrical and Computer Engineering M16); Electrical and Computer Engineering 3; Engineering 96C; Mathematics 31A, 31B, 32A, 32B, 33A, 33B, 61; Physics 1A, 1B, 1C, and 4AL or 4BL.

## The Major

*Required:* Computer Science 111, 118 (or Electrical and Computer Engineering 132B), M151B (or Electrical and Computer Engineering M116C), M152A (or Electrical and Computer Engineering M116L), 180; Electrical and Computer Engineering 100, 102, 113, 115C; one course from Civil and Environmental Engineering 110, Electrical and Computer Engineering 131A, Mathematics 170A, Statistics 100A; 8 units of computer science and 8 units of electrical and computer engineering upper-division electives; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; 8 units capstone design from either Electrical and Computer Engineering 180DA/180DB or 183DA/183DB.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

## Suggested Tracks

*Networked Embedded Systems:* This track targets two related trends that have been a significant driver of computing, namely stand-alone embedded devices becoming networked and coupled to physical systems, and the Internet evolving toward a network of things (the IoT). These may broadly be classified as cyber physical systems, and includes a broad category of systems such as smart buildings, autonomous vehicles, and robots, which interact with each other and other systems. This trend in turn is driving innovation both in the network technologies (new low-power wireless networks for connecting things, and new high-speed networks and computing infrastructure to accommodate the transport and processing needs of the deluge of data resulting from continual sensing), and in embedded computing (new hardware and software stack catering to requirements such as ultra-low power operation, and embedded machine learning).

Students pursuing this track are strongly encouraged to take Electrical and Computer Engineering M119 or Computer Science M119 in junior year, and to choose three electives from courses such as Computer Science 117, 130, 131, 132, 133, 136, 181, 188, Electrical and Computer Engineering 2, 115A, 115B, 132A, 133A, 141, 142, 188.

Students who pursue a technical breadth area in either electrical and computer engineering or computer science can choose an additional three courses from this list.

*Data Science:* This track targets the trend toward the disruptive impact on computing systems, both at the edge and in the cloud, of massive amounts of sensory data being collected, shared, processed, and used for decision making and control. Application domains such as health, transportation, energy, etc. are being transformed by the abilities of inference-making and decision-making from sensory data that is pervasive, continual, and rich. This track will expose students to the entire data-to-decision pathway spanning the entire stack from hardware and software to algorithms, applications, and user experience.

Students pursing this track are strongly advised to take Computer Science 143 and M146 or Electrical and Computer Engineering M146, and to additionally choose two electives from courses such as Computer Science CM121, 136, 144, 145, 161, 188, Electrical and Computer Engineering 114, 133A, 133B, 134, 188.

Students who pursue a technical breadth area in either electrical and computer engineering or computer science can choose an additional three courses from this list.

Students are also free to design ad hoc tracks. The technical breadth area requirement provides an opportunity to combine elective courses in electrical and computer engineering and computer science with those from another UCLA Samueli major to produce a specialization in an interdisciplinary domain. As noted above, students can also select a technical breadth area in either Electrical and Computer Engineering or Computer Science to deepen their knowledge in either discipline.

# Graduate Study

For information on graduate admission see Graduate Programs on page 26.

The following introductory information is based on 2019-20 program requirements for UCLA graduate degrees. Complete program requirements are available at https://grad.ucla.edu/academics/graduate-study/program-requirements-for-ucla-graduate-degrees/. Students are subject to the detailed degree requirements as published in program requirements for the year in which they enter the program.

The Department of Electrical and Computer Engineering offers Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees in Electrical and Computer Engineering.

# Electrical Engineering M.S.

## Areas of Study

Students may pursue specialization across three major areas of study: (1) circuits and embedded systems, (2) physical and wave electronics, and (3) signals and systems. These areas cover a broad spectrum of specializations in, for example, communications and telecommunications, control systems, electromagnetics, embedded computing systems, engineering optimization, integrated circuits and systems, microelectromechanical systems (MEMS), nanotechnology, photonics and optoelectronics, plasma electronics, signal processing, and solid-state electronics. Students must select a number of formal graduate courses to serve as their major and minor fields of study according to the requirements listed below for the thesis (seven courses) and non-thesis (eight courses) options. The selected courses must be approved by the faculty adviser.

## Course Requirements

Students may select either the thesis plan or the non-thesis (comprehensive examination) plan. The selection of courses is tailored to the professional objectives of the students and must meet the requirements stated below. The courses should be selected and approved in consultation with the faculty adviser. Departures from the stated requirements are considered only in exceptional cases and must be approved by the departmental graduate adviser.

The minimum requirements for the M.S. degree are as follows:

1. *Requisite*. B.S. degree in Electrical Engineering or a related field
2. All M.S. program requirements should be completed within two academic years from admission into the M.S. graduate program in the Henry Samueli School of Engineering and Applied Science
3. Students must maintain a minimum cumulative grade-point average of 3.0 every term and 3.0 in all graduate courses
4. *Thesis Option*. Students selecting the thesis option must complete at least the following requirements: (a) five formal graduate courses to serve as the major field of study, (b) two formal graduate courses to serve as the minor field of study, (c) Electrical and Computer Engineering 297, (d) two Electrical and Computer Engineering 598 courses involving work on the M.S. thesis, (e) no other 500-level courses, other seminar courses, nor Electrical and Computer Engineering 296 or 375 may be applied toward the course requirements, and (f) an M.S. thesis completed under the direction of the faculty adviser to a standard that is approved by a committee comprised of three faculty members. The thesis research must be conducted concurrently with the coursework
5. *Non-Thesis Option*. Students selecting the non-thesis option must complete at least the following requirements: (a) six formal graduate courses to serve as the major field of study, (b) two formal graduate courses to serve as the minor field of study, (c) Electrical and Computer Engineering 297, (d) Electrical and Computer Engineering 299 to serve as the M.S. comprehensive examination, which is evaluated by a committee of three faculty members appointed by the department. In case of failure, students may be re-examined only once with consent of the departmental graduate adviser, and (e) no 500-level courses, other seminar courses, nor Electrical and Computer Engineering

296 or 375 may be applied toward the course requirements

6. Students must select a number of formal graduate courses to serve as their major and minor fields of study according to the requirements listed above for the thesis (seven courses) and non-thesis (eight courses) options. The selection of the major and minor sequences of courses must be from different established tracks, or approved ad hoc tracks, or combinations thereof. The selected courses must be approved by the faculty adviser
7. For the thesis option at least four, and for the non-thesis option five, of the formal graduate courses used to satisfy the M.S. program requirements listed above must be in the Electrical and Computer Engineering Department
8. A formal graduate course is defined as any 200-level course, excluding seminar or tutorial courses
9. At most one upper-division undergraduate course is allowed to replace one of the formal graduate courses covering the major and minor fields of study provided that (a) the undergraduate course is not required of undergraduate students in the Electrical and Computer Engineering Department and (b) the undergraduate course is approved by the faculty adviser
10. A track is a coherent set of courses in some general field of study. The department suggests lists of established tracks as a means to assist students in selecting their courses. Students are not required to adhere to the suggested courses in any specific track

## Circuits and Embedded Systems Area Tracks

1. *Embedded Computing Track*. Courses deal with the engineering of computer systems as may be applied to embedded devices used for communications, multimedia, or other such restricted purposes. Courses include Computer Science 251A, Electrical and Computer Engineering 201A, 201C, M202A, M202B, M216A
2. *Integrated Circuits Track*. Courses deal with the analysis and design of analog and digital integrated circuits; architecture and integrated circuit implementations of large-scale digital processors for communications and signal processing; hardware-software codesign; and computer-aided design methodologies. Courses include Computer Science 251A, 252A, Electrical and Computer Engineering 215A through 215E, M216A, 221A, 221B

## Physical and Wave Electronics Area Tracks

1. *Electromagnetics Track*. Courses deal with electromagnetic theory; propagation and scattering; antenna theory and design; microwave and millimeter wave circuits; printed circuit antennas; integrated and fiber optics; microwave-optical interaction, antenna measurement, and diagnostics; numerical and asymptotic techniques; satellite and personal communication antennas; periodic structures; genetic algorithms; and optimization techniques. Courses include Electrical and Computer Engineering 221C, 260A, 260B, 261, 262, 263, 266, 270
2. *Photonics and Plasma Electronics Track*. Courses deal with laser physics, optical amplification, electro-optics, acousto-optics, magneto-optics, nonlinear optics, photonic switching and modulation, ultrafast phenomena, optical fibers, integrated waveguides, photodetection, optoelectronic integrated circuits, optical microelectromechanical systems (MEMS), analog and digital signal transmission, photonics sensors, lasers in biomedicine, fundamental plasma waves and instability; interaction of microwaves and laser radiation with plasmas; plasma diagnostics; and controlled nuclear fusion. Courses include Electrical and Computer Engineering 270, 271, 272, 273, 274, 285A, 285B, M287
3. *Solid-State and Microelectromechanical Systems (MEMS) Devices Track*. Courses deal with solid-state physical electronics, semiconductor device physics and design, and microelectromechanical systems (MEMS) design and fabrication. Courses include Electrical and Computer Engineering 221A, 221B, 221C, 222, 223, 225, M250B, Mechanical and Aerospace Engineering 281, 284, C287L

## Signals and Systems Area Tracks

1. *Communications Systems Track*. Courses deal with communication and telecommunication principles and engineering applications; channel and source coding; spread spectrum communication; cryptography; estimation and detection; algorithms and processing in communication and radar; satellite communication systems; stochastic modeling in telecommunication engineering; mobile radio engineering; and telecommunication switching, queuing system, communication networks, local-area, metropolitan-area, and wide-area computer communication networks. Courses include Electrical and Computer Engineering 205A, 210A, 230A through 230D, 231A, 231E, 232A through 232E, 238, 241A
2. *Control Systems and Optimization Track*. Courses deal with state-space theory of linear systems; optimal control of deterministic linear and nonlinear systems; stochastic control; Kalman filtering; stability theory of linear and nonlinear feedback control systems; computer-aided design of control systems; optimization theory, including linear and nonlinear programming; convex optimization and engineering applications; numerical methods; nonconvex programming; associated network flow and graph problems; renewal theory; Markov chains; stochastic dynamic programming; and queuing theory. Courses include Electrical and Computer Engineering 205A, M208B, M208C, 210B, 236A, 236B, 236C, M237, M240A, M240C, 241A, M242A
3. *Signal Processing Track*. Courses deal with digital signal processing theory, statistical signal processing, analysis and design of digital filters, digital speech processing, digital image processing, multirate digital signal processing, adaptive filtering, estimation theory, neural networks, and communications signal processing. Courses include Electrical and Computer Engineering 205A, 210A, 210B, 211A, 212A, M214A, 214B, M217, 238

## Ad Hoc Tracks

In consultation with their faculty advisers, students may petition for an ad hoc track tailored to their professional objectives. This may comprise graduate courses from established tracks, from across areas, and even from outside electrical and computer engineering. The petition must justify how the selection of courses in the ad hoc track forms a coherent set of courses, and how the proposed ad hoc track serves the professional objectives. The petition must be approved by the faculty adviser and the departmental graduate adviser.

## Comprehensive Examination Plan

The M.S. comprehensive examination requirement is satisfied either (1) by solving a comprehensive examination problem in the final project, or equivalent, of every formal graduate electrical and computer engineering course taken. A grade-point average of at least 3.0 in the comprehensive examination problems is required for graduation. The M.S. individual study program is administered by the academic adviser, the director of the area to which the students belong, and the vice chair of Graduate Affairs or (2) through completion of an individual study course (Electrical and Computer Engineering 299) under the direction of a faculty member. Students are assigned a topic of individual study by the faculty member. The study culminates with a written report and an oral presentation. The M.S. individual study program is administered by the faculty member directing the course, the director of the area to which the students belong, and the vice chair of Graduate Affairs. Students who fail the examination may be reexamined once with consent of the vice chair of Graduate Affairs.

# Electrical Engineering Ph.D.

## Areas of Study

Students may pursue specialization across three major areas of study: (1) circuits and embedded systems, (2) physical and wave electronics, and (3) signals and systems. These areas cover a broad spectrum of specializations in, for example, communications and telecommunications, control systems, electromagnetics, embedded computing systems, engineering optimization, integrated circuits and systems, microelectromechanical systems (MEMS), nanotechnology, photonics and optoelectronics, plasma electronics, signal processing, and solid-state electronics.

## Course Requirements

The selection of courses for the Ph.D. program is tailored to the professional objectives of the students and must meet the requirements stated below. The courses should be selected and approved in consultation with the faculty adviser. Departures from the stated requirements are considered only in exceptional cases and must be approved by the departmental graduate adviser. Normally, students take additional courses to acquire deeper and broader knowledge in preparation for the dissertation research.

The minimum requirements for the Ph.D. degree are as follows:

1. *Requisite*. M.S. degree in Electrical Engineering or a related field granted by UCLA or by an institution recognized by the UCLA Graduate Division
2. All Ph.D. program requirements should be completed within five academic years from admission into the Ph.D. graduate program in the Henry Samueli School of Engineering and Applied Science
3. Students must maintain a minimum cumulative grade-point average of 3.5 in the Ph.D. program
4. Students must complete at least the following requirements: (a) four formal graduate courses selected in consultation with the faculty adviser, (b) Electrical and Computer Engineering 297, (c) one technical communications course such as Electrical and Computer Engineering 295, (d) no 500-level courses, other seminar courses, nor Electrical and Computer Engineering 296 or 375 may be applied toward the course requirements, (e) pass the Ph.D. preliminary examination which is administered by the department and takes place once every year. In case of failure, students may be reexamined only once with consent of the departmental graduate adviser, (f) pass the University Oral Qualifying Examination which is administered by the doctoral committee, (g) complete a Ph.D. dissertation under the direction of the faculty adviser, and (h) defend the Ph.D. dissertation in a public seminar with the doctoral committee
5. A formal graduate course is defined as any 200-level course, excluding seminar or tutorial courses. Formal graduate courses taken to meet the M.S. degree requirements may not be applied toward the Ph.D. course requirements
6. At least two of the formal graduate courses must be in electrical and computer engineering
7. Within two academic years from admission into the Ph.D. program, all courses should be completed and the Ph.D. preliminary examination should be passed. It is strongly recommended that students take the Ph.D. preliminary examination during their first academic year in the program
8. The University Oral Qualifying Examination must be taken when all required courses are complete, and within one year after passing the Ph.D. preliminary examination
9. Students admitted originally to the M.S. program in the Electrical and Computer Engineering Department must complete all M.S. program requirements with a grade-point average of at least 3.5 to be considered for admission into the Ph.D. program. Only after admission into the program can students take the Ph.D. preliminary examination
10. Students must nominate a doctoral committee prior to taking the University Oral Qualifying Examination. A doctoral committee consists of a minimum of four members. Three members, including the chair, are inside members and must hold appointments in the department. The outside member must be a UCLA faculty member in another department. By petition, one of the four members may be a faculty member from another UC campus

## Written and Oral Qualifying Examinations

The written qualifying examination is known as the Ph.D. preliminary examination in the department. The purpose of the examination is to assess student competency in the discipline, knowledge of the fundamentals, and potential for independent research. Students admitted originally to the M.S. program in the Electrical and Computer Engineering Department must complete all M.S. program requirements with a grade-point average of at least 3.5 to be considered for admission into the Ph.D. program. Only after admission into the program can students take the Ph.D. preliminary examination, which is held once every year. Students are examined independently by a group of faculty members in their general area of study. The examination by each faculty member typically includes both oral and written components, and students pass the entire Ph.D. preliminary examination and not in parts. Students who fail the examination may repeat it once only with consent of the departmental graduate adviser. The preliminary examination, together with the course requirements for the Ph.D. program, should be completed within two years from admission into the program.

After passing the written qualifying examination described above, students are ready to take the University Oral Qualifying Examination. The nature and content of the examination are at the discretion of the doctoral committee, but ordinarily include a broad inquiry into the preparation for research. The doctoral committee also reviews the prospectus of the dissertation at the oral qualifying examination.

Students must nominate a doctoral committee prior to taking the University Oral Qualifying Examination. A doctoral committee consists of a minimum of four members. Three members, including the chair, are inside members and must hold appointments in the department. The outside member must be a UCLA faculty member in another department. By petition, one of the four members may be a faculty member from another UC campus.

# Facilities and Programs

## Computing Resources

The department maintains a server room with several racks of computer and storage servers in addition to computing resources within individual faculty labs. The network infrastructure supports a variety of Windows, UNIX, and Linux servers, workstations, and laptops. The school also offers access to a computing cluster primarily used for undergraduate and graduate teaching purposes. The campus supplies free access to a large-scale computing cluster (Hoffman2) with over 13,000 computing cores on over 1200 server nodes. Archival-class backup storage is also available through the campus.

# Research Centers and Laboratories

## Center for Development of Emerging Storage Systems (CoDESS)

CoDESS has a dual mission: to push the frontiers of modern data storage systems through an integrated research program and to create a highly-trained workforce of graduate students. Current research thrusts include information and coding theory for ultra-reliable data storage systems, data reduction algorithms and communication methods for cloud storage, enabling technologies for future recording paradigms and storage devices, and resource-efficient signal processing techniques and architecture optimization.

## Center for Engineering Economics, Learning, and Networks

The center will develop a new wave of ideas, technologies, networks, and systems that change the ways in which people (and devices) interact, communicate, collaborate, learn, teach, and discover. The center brings together an interdisciplinary group of researchers from diverse disciplines—including computer science, electrical engineering, economics, and mathematics—with diverse interests spanning microeconomics, machine learning, multiagent systems, artificial intelligence, optimization, and physical and social networks, all sharing a common passion: developing rigorous theoretical foundations to shape the design of future generations of networks and systems for interaction.

## Center for Heterogeneous Integration and Performance Scaling (CHIPS)

CHIPS addresses emerging technologies, design, and architectures to achieve a more holistic Moore's Law for the overall system. The center's core activities include advanced heterogeneous hardware integration technologies; methodologies and tools relying on fine-pitch interconnects on both rigid and flexible substrates; wafer-scale integration; active and passive components for advanced systems; and large-scale systems especially for cognitive, memory, and medical engineering applications.

CHIPS is multidisciplinary, integrating specialties and students in diverse areas including electrical engineering, materials science and engineering, mechanical engineering, computer science and engineering, and biosciences, with strong industry participation. The center has extensive fabrication facilities to support these activities.

## Center for High-Frequency Electronics

The center was established with support from several governmental agencies and contributions from local industries, beginning with a $10 million grant from Hewlett-Packard.

The first major goal of the center is to combine, in a synergistic manner, five areas of research. These include (1) solid-state millimeter wave devices, (2) millimeter systems for imaging and communications, (3) millimeter wave high-power sources (gyrotrons), (4) GaAs gigabit logic systems, and (5) VLSI and LSI based on new materials and structures. The center supports work in these areas by providing the necessary advanced equipment and facilities and allows the University to play a major role in initiating and generating investigations into new electronic devices. Students, both graduate and under-graduate, receive training and instruction in a unique facility.

The second major goal of the center is to bring together the manpower and skills necessary to synthesize new areas of activity by stimulating interactions between different interdependent fields. The Electrical and Computer Engineering Department, other departments within UCLA, and local universities (such as Caltech and USC) have begun to combine and correlate certain research programs as a result of the formation of the center.

## Clean Energy Research Center–Los Angeles (CERC–LA)

Lei He, *Director*

CERC–LA was created by UCLA to tackle many of the grand challenges related to generation, transmission, storage, and management of energy. As many energy challenges are global in nature, this center engages the participation of a multidisciplinary group of researchers from many nations. CERC–LA leads a U.S.-China clean energy and climate change research consortium. CERC–LA, together with the China National Center for Climate Change Strategy and International Cooperation (NCSC), Peking University (PKU), and Fudan University, was selected by the U.S. Department of State and the China National Development and Reform Commission as a U.S.-China EcoPartner. CERC–LA plans to have satellite offices in other cities including Shanghai and Beijing.

## Circuits Laboratories

The laboratories are equipped for measurements on high-speed analog and digital circuits and are used for the experimental study of communication, signal processing, and instrumentation systems. A hybrid integrated circuit facility is available for rapid mounting, testing, and revision of miniature circuits. These include both discrete components and integrated circuit chips. The laboratory is available to advanced undergraduate and graduate students through faculty sponsorship on thesis topics, research grants, or special studies.

## Electromagnetics Laboratories

The laboratories involve the disciplines of microwaves, millimeter waves, wireless electronics, and electromechanics. Students enrolled in microwave laboratory courses, such as Electrical and Computer Engineering 163DA and 164DB, special projects classes such as Electrical and Computer Engineering 199, and/or research projects, have the opportunity to obtain experimental and design experience in the following technology areas: integrated microwave circuits and antennas, integrated millimeter wave circuits and antennas, numerical visualization of electromagnetic waves, electromagnetic scattering and radar cross-section measurements, and antenna near field and diagnostics measurements.

## Koç UCLA Translational Research Center

Aydogan Ozcan, *Director*

The center is a world-leading research nexus for new imaging, sensing, and diagnostics technologies to use in creating a massively scalable suite of ubiquitous computational laboratories, which will significantly improve the tool set for probing micro- and nano-scale objects and processes. Its focus on simplified and cost-effective designs for these analysis tools ensures they are especially suitable for point-of-care and home use, and for professional needs in resource-constrained settings. Through these next-generation technologies, the laboratory will create integrated self-learning systems and networks, specifically for sensing and diagnosis, that aim to impact measurement challenges in application focus areas—such as point-of-care medicine, mobile health, telemedicine, and environmental monitoring—with highly sensitive, specific, and yet remarkably cost-effective and massively scalable technological solutions.

## Nanoelectronics Research Facility (Nanolab)

http://www.nanolab.ucla.edu

Nanolab is a state-of-the-art, 20,000-square-foot, class 10/10011000 clean-room facility that supports graduate research and teaching. The space includes the Microlab, an undergraduate teaching laboratory for device fabrication (CMOS, MEMS, and optoelectronics). With a full complement of utilities (high-purity deionized water, high-purity nitrogen, exhaust scrubbers) and the latest technologies in vibration isolation and electromagnetic shielding, the Nanolab offers advanced processing equipment for fabrication and analysis. In BSL2-capable biosuites, researchers can leverage standard semiconductor process techniques with evolving biomedical, nanometer-scale fabrication to study fundamental quantum size effects; and explore novel nanometer-scale device concepts. Nanolab staff has deep knowledge of fabrication techniques and process development to support both academic and commercial research and development projects.

## Photonics and Optoelectronics Laboratories

Students in the Laser Laboratory study the properties of lasers and gain an understanding of the application of this modern tech-nology to optics, communication, and holography.

The photonics and optoelectronics laboratories include facilities for research in all of the basic areas of quantum electronics. Specific areas of experimental investigation include high-powered lasers, nonlinear optical processes, ultrafast lasers, parametric frequency conversion, electro-optics, infrared detection, and semiconductor lasers and detectors. Operating lasers include mode-locked and Q-switched Nd:YAG and Nd:YLF lasers, Ti:Al2O3 lasers, ultraviolet and visible wavelength argon lasers, wavelength-tunable dye lasers, as well as gallium arsenide, helium-neon, excimer, and high-powered continuous and pulsed carbon dioxide laser systems. Also available are equipment and facilities for research on semiconductor lasers, fiber optics, nonlinear optics, and ultrashort laser pulses. These laboratories are open to undergraduate and graduate students who have faculty sponsorship for their thesis projects or special studies.

## Plasma Electronics Facilities

Two laboratories are dedicated to the study of the effects of intense laser radiation on matter in the plasma state. One houses a state-of-the-art, table-top terawatt (T3) 400fs laser system that can be operated in either a single or dual frequency mode for laser-plasma interaction studies. Diagnostic equipment includes a ruby laser scattering system, a streak camera, and optical spectrographs and multichannel analyzer. Parametric instabilities such as stimulated Raman scattering have been studied, as well as the resonant excitation of plasma waves by optical mixing. The second laboratory, located in Boelter Hall, houses the MARS laser, currently the largest on-campus university $CO_2$ laser in the U.S. It can produce 200J, 170ps pulses of $CO_2$ radiation, focusable to 1016 W/cm2. The laser is used for testing new ideas for laser-driven particle accelerators and free-electron lasers. Several high-pressure, short-pulse drivers can be used on the MARS; other equipment includes a theta-pinch plasma generator, an electron linac injector, and electron detectors and analyzers.

A second group of laboratories is dedicated to basic research in plasma sources for basic experiments, plasma processing, and plasma heating.

There is also a large computing cluster called DAWSON 2 that is dedicated to the study of plasma-based acceleration, inertial fusion energy, and high energy density plasma science. DAWSON 2 consists of 96 HP L390 nodes each with 12 Intel X5650 CPUs and 48 GB of RAM, and three Nvidia M2070s GPUs and 18 GB of Global Memory (for a total of 1152 CPUs and 288 GPUs) connected by a non-blocking QDR Infiniband network with 160TB of parallel storage from Panasas. Peak system performance is approximately 300TF/150TF (single/double precision) with a measured linpack performance of 68.1TF (double precision). DAWSON 2 is housed within the UCLA Institute for Digital Research Engineering data center.

## Solid-State Electronics Facilities

Solid-state electronics equipment and facilities include a modern integrated semiconductor device processing laboratory, complete new Si and III-V compound molecular beam epitaxy systems, CAD and mask-making facilities, lasers for beam crystallization study, thin film and characterization equipment, deep-level transient spectroscopy instruments, computerized capacitance-voltage and other characterization equipment, including doping density profiling systems, low-temperature facilities for material and device physics studies in cryogenic temperatures, optical equipment, including many different types of lasers for optical characterization of superlattice and quantum well devices, and characterization equipment for high-speed devices, including high magnetic field facilities for magnetotransport measurement of heterostructures. The laboratory facilities are available to faculty, staff, and graduate students for their research.

## Wireless Health Institute (WHI)

Benjamin M. Wu, D.D.S, Ph.D. (Bioengineering), *Director*; Bruce Dobkin, M.D. (Medicine/Neurology), William Kaiser, Ph.D. (Electrical and Computer Engineering), Gregory J. Pottie, Ph.D. (Electrical and Computer Engineering), *Co-Directors*

WHI is leading initiatives in health care solutions in the fields of disease diagnosis, neurological rehabilitation, optimization of clinical outcomes for many disease conditions, geriatric care, and many others. WHI also promotes this new field in the international community through the founding and organization of the leading Wireless Health conference series.

WHI technology always serves the clinician community through jointly developed innovations and clinical trial validation. Each WHI program is focused on large-scale product delivery in cooperation with manufacturing partners. WHI collaborators include the UCLA schools of Medicine, Nursing, and Engineering and Applied Sciences; Clinical Translational Science Institute for medical research; Ronald Reagan UCLA Medical Center; and faculty from many departments across UCLA. WHI education programs span high school, undergraduate, and graduate students, and provide training in end-to-end product development and delivery for WHI program managers.

WHI develops innovative, wearable biomedical monitoring systems that collect, integrate, process, analyze, communicate, and present information so that individuals become engaged and empowered in their own health care, improve their quality of life, and reduce burdens on caregivers. WHI products appear in diverse areas including motion sensing, wound care, orthopaedics, digestive health and process monitoring, advancing athletic performance, and many others. Clinical trials validating WHI technology are underway at 10 institutions. WHI products developed by the UCLA team are now in the marketplace in the U.S. and Europe. Physicians, nurses, therapists, other providers, and families can apply these technologies in hospital and community practices. Academic and industry groups can leverage the organization of WHI to rapidly develop products in complete-care programs, and validate in trials. WHI welcomes new team members, and continuously forms new collaborations with colleagues and organizations in medical science and health care delivery.

# Multidisciplinary Research Facilities

The department is also associated with several multidisciplinary research centers including

- California NanoSystems Institute (CNSI)
- Center for Heterogeneous Integration and Performance Scaling (CHIPS)
- Center for High-Frequency Electronics (CHFE)
- Center for Nanoscience Innovation for Defense (CNID)
- Center of Excellence in Green Nanotechnology (CEGN)
- Functional Engineered Nano Architectonics Focus Center (FENA)
- Plasma Science and Technology Institute
- Translational Applications of Nanoscale Multiferroic Systems (TANMS)
- WIN Institute of Neurotronics (WINs)

## Faculty Groups and Laboratories

Department faculty members also lead a broad range of research groups and laboratories that cover a wide spectrum of specialties, including

- Actuated Sensing and Coordinated Embedded Networked Technologies (ASCENT) Laboratory *(Kaiser)*
- Adaptive Systems Laboratory *(Sayed)*
- Algorithmic Research in Network Information Laboratory *(Fragouli)*
- Antenna Research, Analysis, and Measurement Laboratory *(Rahmat-Samii)*
- Autonomous Intelligent Networked Systems *(Rubin)*
- BioPhotonics Laboratory *(Ozcan)*
- CAD for VLSI Design and Manufacturing, Machine Learning Systems in Emerging Technologies *(Gupta)*
- CMOS Research Laboratory *(Woo)*
- Communication Circuits Laboratory *(Razavi)*
- Complex Networks Group *(Roychowdhury)*
- Cyber-Physical Systems Laboratory *(Tabuada)*
- Device Research Laboratory *(K. Wang)*
- Digital Microwave Laboratory *(E. Wang)*
- Energy and Electronic Design Automation Laboratory *(He)*
- High-Performance Mixed Mode Circuit Design Group *(Yang)*
- High-Speed Electronics Laboratory *(Chang)*
- Image Communications Laboratory *(Villasenor)*
- Information Theory and Systems Laboratory *(Diggavi)*
- Integrated Circuits and Systems Laboratory *(Abidi)*
- Interconnected and Integrated Biolelectronics Laboratory (I2BL) *(Emaminejad)*
- Laboratory for Embedded Machines and Ubiquitous Robotics *(Mehta)*
- Laser-Plasma Group *(Joshi)*
- MedAdvance: Machine Learning and Artificial Intelligence for Medicine *(van der Schaar)*
- Mesoscopic Optics and Quantum Electronics Laboratory *(Wong)*
- Microwave Electronics Laboratory *(Itoh)*
- Nanoelectronics Research Center *(Candler)*
- Nanostructure Devices and Technology Laboratory *(Chui)*
- Networked and Embedded Systems Laboratory *(Srivastava)*
- Neural Computation and Engineering Laboratory *(Kao)*
- Neuroengineering Group *(Markovic)*
- Optoelectronics Circuits and Systems Laboratory *(Jalali)*
- Optoelectronics Group *(Yablonovitch)*
- Public Safety Network Systems Laboratory *(Yao, Rubin)*
- Quantum Biology Tech (QuBiT) *(Aiello)*
- Quantum Electronics Laboratory *(Stafsudd)*
- Robust Information Systems Laboratory *(Dolecek)*
- Sensors and Technology Laboratory *(Candler)*
- Signal Processing and Circuit Electronics Group *(Pamarti)*
- Speech Processing and Auditory Perception Laboratory *(Alwan)*
- Terahertz Devices and Intersubband Nanostructures Group *(Williams)*
- Terahertz Electronics Laboratory *(Jarrahi)*
- Visual Machines Group (Kadambi)
- Wireless Integrated Systems Research Group *(Daneshrad)*

## Faculty Areas of Thesis Guidance

### Professors

Asad A. Abidi, Ph.D. (UC Berkeley, 1981)
*High-performance analog electronics, device modeling*

Abeer A.H. Alwan, Ph.D. (MIT, 1992)
*Speech processing, acoustic properties of speech sounds with applications to speech synthesis, recognition by machine and coding, hearing-aid design, and digital signal processing*

Katsushi Arisaka, Ph.D. (U. Tokyo, Japan, 1985)
*High energy and astroparticle experiments*

Danijela Cabric, Ph.D. (UC Berkeley, 2007)
*Wireless communications system design, cognitive radio networks, VLSI architectures of signal processing and digital communication algorithms, performance analysis and experiments on embedded system platforms*

Robert N. Candler, Ph.D. (Stanford, 2006)
*MEMS/NEMS for compact free-electron lasers, miniature medical devices, nanoscale magnetic structures and devices, additive manufacturing, fundamental limits of micro- and nano-scale devices*

M.-C. Frank Chang, Ph.D. (National Chiao-Tung U., Taiwan, 1979)
*High-speed semiconductor (GaAs, InP, and Si) devices and integrated circuits for digital, analog, microwave, and optoelectronic integrated circuit applications*

Panagiotis D. Christofides, Ph.D. (U. Minnesota, 1996)
*Process modeling, dynamics and control, computational and applied mathematics*

Jason (Jingsheng) Cong, Ph.D. (U. Illinois, 1990)
*Computer-aided design of VLSI circuits, fault-tolerant design of VLSI systems, design and analysis of algorithms, computer architecture, reconfigurable computing, design for nanotechnologies*

Babak Daneshrad, Ph.D. (UCLA, 1993)
*Digital VLSI circuits: wireless communication systems, high-performance communications integrated circuits for wireless applications*

Suhas Diggavi, Ph.D. (Stanford, 1999)
*Wireless communication, information theory, wireless networks, data compression, signal processing*

Lara Dolecek, Ph.D. (UC Berkeley, 2007)
*Information and coding theory, graphical models, statistical algorithms and computational methods with applications to large-scale and complex systems for data processing, communication and storage*

Christina Fragouli, Ph.D. (UCLA, 2000)
*Network coding, algorithms for networking, wireless networks and network security*

Warren S. Grundfest, M.D., FACS (Columbia, 1980)
*Development of lasers for medical applications, minimally invasive surgery, magnetic resonance-guided interventional procedures, laser lithotripsy, microendoscopy, spectroscopy, photodynamic therapy (PDT), optical technology, biologic feedback control mechanisms*

Puneet Gupta, Ph.D. (UC San Diego, 2007)
*CAD for VLSI design and manufacturing, physical design, manufacturing-aware circuits and layouts, design-aware manufacturing*

Lei He, Ph.D. (UCLA, 1999)
*Artificial intelligence (AI) and Internet of things (IoT) for education, health, transportation, and power and water sustainability; programmable logic (FPGA), re-configurable computing, AI-on-a-chip, neuromorphic computing, and quantum computing; modeling, simulation-end validation, and computer-aided design of VLSI circuits, software, and IoT systems.*

Tatsuo Itoh, Ph.D. (U. Illinois Urbana, 1969)
*Microwave and millimeter wave electronics; guided wave structures; low-power wireless electronics; integrated passive components and antennas; photonic bandgap structures and meta materials applications; active integrated antennas, smart antennas; RF technologies for reconfigurable front-ends; sensors and transponders*

Subramanian S. Iyer, Ph.D. (UCLA, 1981)
*Heterogeneous system integration and scaling, advanced packaging and 3D integration, technologies and techniques for memory subsystem integration and neuromorphic computing*

Bahram Jalali, Ph.D. (Columbia, 1989)
*RF photonics, integrated optics, fiber optic integrated circuits*

Mona Jarrahi, Ph.D. (Stanford, 2007)
*Radio frequency (RF), microwave, millimeter-wave, and terahertz circuits, high-frequency devices and circuits, integrated photonics and optoelectronics*

Chandrashekhar J. Joshi, Ph.D. (Hull U., England, 1978)
*Laser fusion, laser acceleration of particles, nonlinear optics, high-power lasers, plasma physics*

William J. Kaiser, Ph.D. (Wayne State, 1983)
*Research and development of new microsensor and microinstrument technology for industry, science, and biomedical applications; development and applications of new atomic-resolution scanning probe microscopy methods for microelectronic device research*

Kuo-Nan Liou, Ph.D. (New York U., 1971)
*Radiative transfer, remote sensing of clouds and aerosols and climate/clouds-aerosols research*

Jia-Ming Liu, Ph.D. (Harvard, 1982)
*Nonlinear optics, ultrafast optics, laser chaos, semiconductor lasers, optoelectronics, photonics, nonlinear and ultrafast processes*

Dejan Markovic, Ph.D. (UC Berkeley, 2006)
*Implantable neuromodulation devices, domain-specific hardware accelerators, embedded systems, design methodologies*

Warren B. Mori, Ph.D. (UCLA, 1987)
*Laser and charged particle beam-plasma interactions, advanced accelerator concepts, advanced light sources, laser-fusion, high-energy density science, high-performance computing, plasma physics*

Stanley J. Osher, Ph.D. (New York U., 1966)
*Scientific computing, applied mathematics*

Aydogan Ozcan, Ph.D. (Stanford, 2005)
*Bioimaging, nanophotonics, nonlinear optics*

Sudhakar Pamarti, Ph.D. (UC San Diego, 2003)
*Analog, mixed-signal, and RF-integrated circuit design; signal processing techniques to improve circuit design*

Gregory J. Pottie, Ph.D. (McMaster U., Canada, 1988)
*Communication systems and theory with applications to wireless sensor networks*

Yahya Rahmat-Samii, Ph.D. (U. Illinois, 1975)
*Satellite communications antennas, personal communication antennas including human interactions, antennas for remote sensing and radio astronomy applications, advanced numerical and genetic optimization techniques in electromagnetics, frequency selective surfaces and photonic band gap structures, novel integrated and fractal antennas, near-field antenna measurements and diagnostic techniques, electromagnetic theory*

Behzad Razavi, Ph.D. (Stanford, 1992)
*Analog, RF, and mixed-signal integrated circuit design, dual-standard RF transceivers, phase-locked systems and frequency synthesizers, A/D and D/A converters, high-speed data communication circuits*

Vwani P. Roychowdhury, Ph.D. (Stanford, 1989)
*Models of computation including parallel and distributed processing systems, quantum computation and information processing, circuits and computing paradigms for nanoelectronics and molecular electronics, adaptive and learning algorithms, nonparametric methods and algorithms for large-scale information processing, combinatorics and complexity, and information theory*

Henry Samueli, Ph.D. (UCLA, 1980)
*VLSI implementation of signal processing and digital communication systems, high-speed digital integrated circuits, digital filter design*

Ali H. Sayed, Ph.D. (Stanford, 1992)
*Adaptive systems, statistical and digital signal processing, estimation theory, signal processing for communications, linear system theory, interplays between signal processing and control methodologies, fast algorithms for large-scale problems*

Stefano Soatto, Ph.D. (Caltech, 1996)
*Computer vision, systems and control theory, detection and estimation, robotics, system identification, shape analysis, motion analysis, image processing, video processing, autonomous systems*

Jason L. Speyer, Ph.D. (Harvard, 1968)
*Stochastic and deterministic optimal control and estimation with application to aerospace systems; guidance, flight control, and flight mechanics*

Mani B. Srivastava, Ph.D. (UC Berkeley, 1992)
*Wireless networking, embedded computing, networked embedded systems, sensor networks, mobile and ubiquitous computing, low-power and power-aware systems*

Paulo Tabuada, Ph.D. (Technical U. Lisbon, Portugal, 2002)
*Real-time, networked, embedded control systems; mathematical systems theory including discrete-event, timed, and hybrid systems; geometric nonlinear control; algebraic/categorical methods*

Lieven Vandenberghe, Ph.D. (Katholieke U. Leuven, Belgium, 1992)
*Optimization in engineering and applications in systems and control, circuit design, and signal processing*

Mihaela van der Schaar, Ph.D. (Eindhoven U. Technology, Netherlands, 2001)
*Multimedia processing and compression, multimedia networking, multimedia communications, multimedia architectures, enterprise multimedia streaming, mobile and ubiquitous computing*

John D. Villasenor, Ph.D. (Stanford, 1989)
*Communications, signal and image processing, configurable computing systems, and design environments*

Kang L. Wang, Ph.D. (MIT, 1970)
*Nanoelectronics and optoelectronics, nano and molecular devices, MBE and superlattices, microwave and millimeter electronics, quantum information*

Yuanxun Ethan Wang, Ph.D. (U. Texas Austin, 1999)
*Smart antennas, RF and microwave power amplifiers, numerical techniques, DSP techniques for microwave systems, phased arrays, wireless and radar systems, microwave integrated circuits*

Richard D. Wesel, Ph.D. (Stanford, 1996)
*Communication theory and signal processing with particular interests in channel coding, including turbo codes and trellis codes, joint algorithms for distributed communication and detection*

Benjamin Williams, Ph.D. (MIT, 2003)
*Development of terahertz quantum cascade lasers*

Chee Wei Wong, Sc.D. (MIT, 2003)
*Ultrafast and nonlinear optics, quantum communications and computing, chip-scale optoelectronics, precision measurements and sensing*

Jason C.S. Woo, Ph.D. (Stanford, 1987)
*Solid-state technology, CMOS and bipolar device/circuit optimization, novel device design, modeling of integrated circuits, VLSI fabrication*

C.-K. Ken Yang, Ph.D. (Stanford, 1998)
*High-performance VLSI design, digital and mixed-signal circuit design*

## Professors Emeriti

Frederick G. Allen, Ph.D. (Harvard, 1956)
*Semiconductor physics, solid-state devices, surface physics*

Francis F. Chen, Ph.D. (Harvard, 1954)
*Radio frequency plasma sources and diagnostics for semiconductor processing*

Harold R. Fetterman, Ph.D. (Cornell, 1968)
*Optical millimeter wave interactions, high-frequency optical polymer modulators and applications, solid-state millimeter wave structures and systems, biomedical applications of lasers*

Stephen E. Jacobsen, Ph.D. (UC Berkeley, 1968)
*Operations research, mathematical programming, nonconvex programming, applications of mathematical programming to engineering and engineering/economic systems*

Rajeev Jain, Ph.D. (Katholieke U. Leuven, Belgium, 1985)
*Design of digital communications and digital signal processing circuits and systems*

Alan Laub, Ph.D. (U. Minnesota, 1974)
*Numerical linear algebra, numerical analysis, condition estimation, computer-aided control system design, high-performance computing*

Nhan N. Levan, Ph.D. (Monash U., Australia, 1966)
*Control systems, stability and stabilizability, errors in dynamic systems, signal analysis, wavelets, theory and applications*

Dee-Son Pan, Ph.D. (Caltech, 1977)
*New semiconductor devices for millimeter and RF power generation and amplification, transport in small geometry semiconductor devices, generic device modeling*

Izhak Rubin, Ph.D. (Princeton, 1970)
*Telecommunications and computer communications systems and networks, mobile wireless networks, multimedia IP networks, UAV/UGV-aided networks, integrated system and network management, C4ISR systems and networks, optical networks, network simulations and analysis, traffic modeling and engineering*

Frederick W. Schott, Ph.D. (Stanford, 1949)
*Electromagnetics, applied electromagnetics*

Oscar M. Stafsudd, Ph.D. (UCLA, 1967)
*Quantum electronics: IR lasers and nonlinear optics; solid-state: IR detectors*

Gabor C. Temes, Ph.D. (U. Ottawa, Canada, 1961)
*Analog MOS integrated circuits, signal processing, analog and digital filters*

Chand R. Viswanathan, Ph.D. (UCLA, 1964)
*Semiconductor electronics: VLSI devices and technology, thin oxides; reliability and failure physics of MOS devices; process-induced damage, low-frequency noise*

*Donald M. Wiberg, Ph.D. (Caltech, 1965)
*Identification and control, especially of aerospace, biomedical, mechanical, and nuclear processes, modeling and simulation of respiratory and cardiovascular systems*

Alan N. Willson, Jr., Ph.D. (Syracuse, 1967)
*Theory and application of digital signal processing including VLSI implementations, digital filter design, nonlinear circuit theory*

Kung Yao, Ph.D. (Princeton, 1965)
*Communication theory, signal and array processing, sensor system, wireless communication systems, VLSI and systolic algorithms*

## Associate Professor

Aydin Babakhani, Ph.D. (Caltech, 2008)
*Millimeter-wave/terahertz integrated circuits, wirelessly powered single-chip circuits*

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* Also Professor Emeritus of Anesthesiology

### Assistant Professors

Clarice D. Aiello, Ph.D. (MIT, 2014)
*Experimental quantum sensing and control, experimental quantum biology, nanobioelectromagnetics*

Xiang Anthony Chen, Ph.D. (Carnegie Mellon, 2017)
*Human-computer interaction, sensing and interaction techniques, intelligent interactive systems, computational design and fabrication*

Sam Emaminejad, Ph.D. (Stanford, 2014)
*Biological and chemical sensors, wearable and flexible electronics, MEMS and NEMS fabrication microfluidics, internet of things devices, technology development for personalized/precision medicine*

Achuta Kadambi, Ph.D. (MIT, 2018)
*Computational imaging, computer vision, robotics, medical devices*

Jonathan C. Kao, Ph.D. (Stanford, 2016)
*Computational neuroscience, neural engineering, machine learning*

Ankur Mehta, Ph.D. (UC Berkeley, 2012)
*Robotics and electromechanical systems design, fabrication, and control; wireless sensor networks hardware and applications; systems integration*

Lin F. Yang, Ph.D. (Johns Hopkins, 2017)
*Foundations for AI, machine learning theories and applications, reinforcement learning, statistical learning, big data algorithms, optimization control*

### Adjunct Professors

Ezio Biglieri, Dr. Ing. (Politecnico di Torino, Italy, 1967)
*Digital communication, wireless channels, modulation, error-control coding, signal processing in telecommunications*

Dariush Divsalar, Ph.D. (UCLA, 1978)
*Information theory, communication theory, bandwidth-efficient combined coding modulation techniques, spread spectrum systems and mutual user interference cancellation for CDMA, turbo codes, binary and nonbinary LDPC codes, iterative decoding*

Dan M. Goebel, Ph.D. (UCLA, 1981)
*Electric propulsion, high-efficiency ion and Hall thrusters, cathodes, high-voltage engineering, microwave devices and microwave communications, pulsed power*

Diana L. Huffaker, Ph.D. (U. Texas Austin, 1995)
*Solid-state nanotechnology, MWIR optoelectronic devices, solar cells, Si photonics, novel materials*

Asad M. Madni, Ph.D. (California Coast U., 1987)
*Development and commercialization of intelligent sensors and systems, RF and microwave instrumentation, signal processing*

Yi-Chi Shih, Ph.D. (U. Texas Austin, 1982)
*Microwave/millimeter-wave active and passive devices, characterization and modeling, integrated circuits, components and subsystems for sensors and communications applications*

Ingrid M. Verbauwhede, Ph.D. (Katholieke U. Leuven, Belgium, 1991)
*Embedded systems, VLSI, architecture and circuit design and design methodologies for applications in security, wireless communications and signal processing*

Eli Yablonovitch, Ph.D. (Harvard, 1972)
*Optoelectronics, high-speed optical communications, photonic integrated circuits, photonic crystals, plasmonic optics and plasmonic circuits, quantum computing and communication*

### Adjunct Associate Professor

Chi On Chui, Ph.D. (Stanford, 2004)
*Nanoelectronic and optoelectronic devices and technology, heterostructure semiconductor devices, monolithic integration of heterogeneous technology, exploratory nanotechnology*

### Adjunct Assistant Professors

Shervin Moloudi, Ph.D. (UCLA, 2008)
*Telecommunication analog and high-frequency circuit design*

Zachary Taylor, Ph.D. (UC Santa Barbara, 2009)
*Biomedical optics, imaging system design, novel contrast-generation mechanisms*

## Lower-Division Courses

**1. Undergraduate Seminar. (1)** (Formerly numbered Electrical Engineering 1.) Seminar, one hour; outside study, two hours. Introduction by faculty members and industry lecturers to electrical engineering disciplines through current and emerging applications of autonomous systems and vehicles, biomedical devices, aerospace electronic systems, consumer products, data science, and entertainment products (amusement rides, etc.), as well as energy generation, storage, and transmission. P/NP grading. Ms. Alwan (F)

**2. Physics for Electrical Engineers. (4)** (Formerly numbered Electrical Engineering 2.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: Physics 1C. Introduction to concepts of modern physics necessary to understand solid-state devices, including elementary quantum theory, Fermi energies, and concepts of electrons in solids. Discussion of electrical properties of semiconductors leading to operation of junction devices. Letter grading. Mr. Jalali, Mr. Williams (F,Sp)

**2H. Physics for Electrical Engineers (Honors). (4)** (Formerly numbered Electrical Engineering 2H.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: Physics 1C. Honors course parallel to course 2. Letter grading. Mr. Williams (W)

**3. Introduction to Electrical Engineering. (4)** (Formerly numbered Electrical Engineering 3.) Lecture, two hours; laboratory, two hours; outside study, eight hours. Introduction to field of electrical engineering. Basic circuits techniques with application to explanation of electrical engineering inventions such as telecommunications, electrical grid, automatic computing and control, and enabling device technology. Research frontiers of electrical engineering. Introduction to measurement and design of electrical circuits. Letter grading. Mr. Pottie (F,Sp)

**10. Circuit Theory I. (4)** (Formerly numbered Electrical Engineering 10.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 3 (or Computer Science 1 or Materials Science 10), Mathematics 33A, Physics 1B. Corequisites: course 11L (enforced only for Computer Science and Engineering and Electrical Engineering majors), Mathematics 33B. Introduction to linear circuit analysis. Resistive circuits, capacitors, inductors and ideal transformers, Kirchhoff laws, node and loop analysis, first-order circuits, second-order circuits, Thevenin and Norton theorem, sinusoidal steady state. Letter grading. Mr. Pamarti (W)

**10H. Circuit Theory I (Honors). (4)** (Formerly numbered Electrical Engineering 10H.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 3 (or Computer Science 1 or Materials Science 10), Mathematics 33A, Physics 1B. Corequisites: course 11L (enforced only for Computer Science and Engineering and Electrical Engineering majors), Mathematics 33B. Honors course parallel to course 10. Letter grading. Mr. Abidi (F)

**11L. Circuits Laboratory I. (1)** (Formerly numbered Electrical Engineering 11L.) Lecture, one hour; laboratory, one hour; outside study, one hour. Enforced corequisite: course 10. Experiments with basic circuits containing resistors, capacitors, inductors, and transformers. Ohm's law voltage and current division, Thevenin and Norton equivalent circuits, superposition, transient and steady state analysis. Letter grading. Mr. Abidi, Mr. Pamarti (F,W)

**M16. Logic Design of Digital Systems. (4)** (Formerly numbered Electrical Engineering M16.) (Same as Computer Science M51A.) Lecture, four hours; discussion, two hours; outside study, six hours. Introduction to digital systems. Specification and implementation of combinational and sequential systems. Standard logic modules and programmable logic arrays. Specification and implementation of algorithmic systems: data and control sections. Number systems and arithmetic algorithms. Error control codes for digital information. Letter grading. Mr. Srivastava (F,W,Sp)

**19. Fiat Lux Freshman Seminars. (1)** Seminar, one hour. Discussion of and critical thinking about topics of current intellectual importance, taught by faculty members in their areas of expertise and illuminating many paths of discovery at UCLA. P/NP grading.

**89. Honors Seminars. (1)** Seminar, three hours. Limited to 20 students. Designed as adjunct to lower-division lecture course. Exploration of topics in greater depth through supplemental readings, papers, or other activities and led by lecture course instructor. May be applied toward honors credit for eligible students. Honors content noted on transcript. P/NP or letter grading. Mr. Pottie

**99. Student Research Program. (1 to 2)** Tutorial (supervised research or other scholarly work), three hours per week per unit. Entry-level research for lower-division students under guidance of faculty mentor. Students must be in good academic standing and enrolled in minimum of 12 units (excluding this course). Individual contract required; consult Undergraduate Research Center. May be repeated. P/NP grading.

## Upper-Division Courses

**100. Electrical and Electronic Circuits. (4)** (Formerly numbered Electrical Engineering 100.) Lecture, three hours; discussion, one hour; outside study, eight hours. Requisites: Mathematics 33A, 33B or Mechanical and Aerospace Engineering 82, Physics 1C. Not open for credit to students with credit for course 110. Electrical quantities, linear circuit elements, circuit principles, signal waveforms, transient and steady state circuit behavior, semiconductor diodes and transistors, small signal models, and operational amplifiers. Letter grading. Mr. Razavi (F,W,Sp)

**101A. Engineering Electromagnetics. (4)** (Formerly numbered Electrical Engineering 101A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: Mathematics 32A and 32B, or 33A and 33B, Physics 1C. Electromagnetic field concepts, waves and phasors, transmission lines and Smith chart, transient responses, vector analysis, introduction to Maxwell equations, static and quasistatic electric and magnetic fields. Letter grading. Mr. Joshi, Mr. Williams (F,W)

**101B. Electromagnetic Waves. (4)** (Formerly numbered Electrical Engineering 101B.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 101A. Time-varying fields and Maxwell equations, plane wave propagation and interaction with media, energy flow and Poynting vector, guided waves in waveguides, phase and group velocity, radiation and antennas. Letter grading. Mr. Y.E. Wang (W,Sp)

**102. Systems and Signals. (4)** (Formerly numbered Electrical Engineering 102.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: Mathematics 33A. Corequisite: Mathematics 33B. Elements of differential equations, first- and second-order equations, variation of parameters method and method of undetermined coefficients, existence and uniqueness. Systems: input/output description, linearity, time-invariance, and causality. Impulse response functions, superposition and convolution integrals. Laplace transforms and system functions. Fourier series and transforms. Frequency

responses, responses of systems to periodic signals. Sampling theorem. Letter grading.
Ms. Fragouli (F,W,Sp)

**110. Circuit Theory II. (4)** (Formerly numbered Electrical Engineering 110.) Lecture, three hours; discussion, one hour; outside study, eight hours. Enforced requisites: courses 10, M16 (or Computer Science M51A), 102. Corequisite: course 111L (enforced only for Computer Science and Engineering and Electrical Engineering majors). Sinusoidal excitation and phasors, AC steady state analysis, AC steady state power, network functions, poles and zeros, frequency response, mutual inductance, ideal transformer, application of Laplace transforms to circuit analysis. Letter grading. Mr. Abidi (Sp)

**110H. Circuit Theory II (Honors). (4)** (Formerly numbered Electrical Engineering 110H.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: courses 10, M16 (or Computer Science M51A), 102. Corequisite: course 111L. Sinusoidal excitation and phasors, AC steady state analysis, AC steady state power, network functions, poles and zeros, frequency response, mutual inductance, ideal transformer, application of Laplace transforms to circuit analysis. Letter grading.
Mr. Abidi, Mr. Pamarti (W)

**110L. Circuit Measurements Laboratory. (2)** (Formerly numbered Electrical Engineering 110L.) Laboratory, four hours; outside study, two hours. Requisite: course 100 or 110. Experiments with basic circuits containing resistors, capacitors, inductors, and op-amps. Ohm's law voltage and current division, Thevenin and Norton equivalent circuits, superposition, transient and steady state analysis, and frequency response principles. Letter grading.
Mr. Razavi (F,W,Sp)

**111L. Circuits Laboratory II. (1)** (Formerly numbered Electrical Engineering 111L.) Lecture, one hour; laboratory, one hour; outside study, one hour. Enforced requisites: courses 10, 11L. Enforced corequisite: course 110. Experiments with electrical circuits containing resistors, capacitors, inductors, transformers, and op-amps. Steady state power analysis, frequency response principles, op-amp-based circuit synthesis, and two-port network principles. Letter grading. Mr. Pamarti (W,Sp)

**112. Introduction to Power Systems. (4)** (Formerly numbered Electrical Engineering 112.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 110. Complete overview of organization and operation of interconnected power systems. Development of appropriate models for interconnected power systems and learning how to perform power flow, economic dispatch, and short circuit analysis. Introduction to power system transient dynamics. Letter grading.
Mr. Tabuada (Not offered 2019-20)

**113. Digital Signal Processing. (4)** (Formerly numbered Electrical Engineering 113.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 102. Relationship between continuous-time and discrete-time signals. Z-transform. Discrete Fourier transform. Fast Fourier transform. Structures for digital filtering. Introduction to digital filter design techniques. Letter grading.
Ms. Fragouli, Ms. van der Schaar (F,Sp)

**113DA-113DB. Digital Signal Processing Design. (4–4)** (Formerly numbered Electrical Engineering 113DA-113DB.) Real-time implementation of digital signal processing algorithms on digital processor chips. Experiments involving A/D and D/A conversion, aliasing, digital filtering, sinusoidal oscillators, Fourier transforms, and finite wordlength effects. Course project involving original design and implementation of signal processing systems for communications, speech, audio, or video using DSP chip. **113DA.** Lecture, two hours; laboratory, four hours; outside study, six hours. Enforced requisite: course 113. In progress grading (credit to be given only on completion of course 113DB). **113DB.** Laboratory, four hours; outside study, eight hours. Enforced requisites: courses 113, 113DA. Completion of projects begun in course 113DA. Letter grading.
Mr. Daneshrad (113DA in F,W; 113DB in W,Sp)

**114. Speech and Image Processing Systems Design. (4)** (Formerly numbered Electrical Engineering 114.) Lecture, three hours; discussion, one hour; laboratory, two hours; outside study, six hours. Enforced requisite: course 113. Design principles of speech and image processing systems. Speech production, analysis, and modeling in first half of course; design techniques for image enhancement, filtering, and transformation in second half. Lectures supplemented by laboratory implementation of speech and image processing tasks. Letter grading.
Ms. Alwan, Mr. Villasenor (F)

**115A. Analog Electronic Circuits I. (4)** (Formerly numbered Electrical Engineering 115A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 110. Review of physics and operation of diodes and bipolar and MOS transistors. Equivalent circuits and models of semiconductor devices. Analysis and design of single-stage amplifiers. DC biasing circuits. Small-signal analysis. Operational amplifier systems. Letter grading. Mr. Abidi, Mr. Daneshrad (F,Sp)

**115AL. Analog Electronics Laboratory I. (2)** (Formerly numbered Electrical Engineering 115AL.) Laboratory, four hours; outside study, two hours. Enforced requisites: courses 110L or 111L, 115A. Experimental determination of device characteristics, resistive diode circuits, single-stage amplifiers, compound transistor stages, effect of feedback on single-stage amplifiers, operational amplifiers, and operational amplifier circuits. Introduction to hands-on design experience based on individual student hardware design and implementation platforms. Letter grading.
Mr. Abidi (F,Sp)

**115B. Analog Electronic Circuits II. (4)** (Formerly numbered Electrical Engineering 115B.) Lecture, four hours; discussion, one hour; outside study, eight hours. Enforced requisite: course 115A. Analysis and design of differential amplifiers in bipolar and CMOS technologies. Current mirrors and active loads. Frequency response of amplifiers. Feedback and its properties. Stability issues and frequency compensation. Letter grading. Mr. Abidi (W)

**115C. Digital Electronic Circuits. (4)** (Formerly numbered Electrical Engineering 115C.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 100 or 115A, and Computer Science M51A. Transistor-level digital circuit analysis and design. Modern logic families (static CMOS, pass-transistor, dynamic logic), integrated circuit (IC) layout, digital circuits (logic gates, flipflops/latches, counters, etc.), computer-aided simulation of digital circuits. Letter grading. Mr. Markovic (W,Sp)

**115E. Design Studies in Electronic Circuits. (4)** (Formerly numbered Electrical Engineering 115E.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 115B. Description of process of circuit design through lectures to complement other laboratory-based design courses. Topics vary by instructor and include communication circuits, power electronics, and instrumentation and measurement and may entail simulation-based design projects. Emphasis throughout on design-oriented analysis and rigorous approach to practical circuit design. Letter grading. Mr. Abidi (Sp)

**M116C. Computer Systems Architecture. (4)** (Formerly numbered Electrical Engineering M116C.) (Same as Computer Science M151B.) Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: course M16 or Computer Science M51A, Computer Science 33. Recommended: course M116L or Computer Science M152A, Computer Science 111. Computer system organization and design, implementation of CPU datapath and control, instruction set design, memory hierarchy (caches, main memory, virtual memory) organization and management, input/output subsystems (bus structures, interrupts, DMA), performance evaluation, pipelined processors. Letter grading.
Mr. Gupta (F,W,Sp)

**M116L. Introductory Digital Design Laboratory. (2)** (Formerly numbered Electrical Engineering M116L.) (Same as Computer Science M152A.) Laboratory, four hours; outside study, two hours. Enforced requisite: course M16 or Computer Science M51A. Hands-on design, implementation, and debugging of digital logic circuits, use of computer-aided design tools for schematic capture and simulation, implementation of complex circuits using programmed array logic, design projects. Letter grading.
Mr. He (F,W,Sp)

**M119. Fundamentals of Embedded Networked Systems. (4)** (Formerly numbered Electrical Engineering M119.) (Same as Computer Science M119.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 131A or Civil and Environmental Engineering 110 or Mathematics 170A or Statistics 100A, course 132B or Computer Science 118, Computer Science 33. Design trade-offs and principles of operation of cyber physical systems such as devices and systems constituting Internet of Things. Topics include signal propagation and modeling, sensing, node architecture and operation, and applications. Letter grading.
Mr. Srivastava (Sp)

**121B. Principles of Semiconductor Device Design. (4)** (Formerly numbered Electrical Engineering 121B.) Lecture, three hours; discussion, one hour; outside study, eight hours. Enforced requisite: course 2. Introduction to principles of operation of bipolar and MOS transistors, equivalent circuits, high-frequency behavior, voltage limitations. Letter grading.
Mr. Woo (F,W)

**121DA-121DB. Semiconductor Processing and Device Design. (4–4)** (Formerly numbered Electrical Engineering 121DA-121DB.) Design fabrication and characterization of p-n junction and transistors. Students perform various processing tasks such as wafer preparation, oxidation, diffusion, metallization, and photolithography. Introduction to CAD tools used in integrated circuit processing and device design. Device structure optimization tool based on MEDICI; process integration tool based on SUPREM. Course familiarizes students with those tools. Using CAD tools, CMOS process integration to be designed. **121DA.** Lecture, four hours; laboratory, four hours; outside study, four hours. Enforced requisite or corequisite: course 121B. In progress grading (credit to be given only on completion of course 121DB). **121DB.** Lecture, two hours; laboratory, four hours; outside study, six hours. Enforced requisites: courses 121B, 121DA. Letter grading.
Mr. Woo (Not offered 2019-20)

**123A. Fundamentals of Solid-State I. (4)** (Formerly numbered Electrical Engineering 123A.) Lecture, three hours; discussion, one hour; outside study, eight hours. Requisite: course 2 or Physics 1C. Limited to junior/senior engineering majors. Fundamentals of solid-state, introduction to quantum mechanics and quantum statistics applied to solid-state. Crystal structure, energy levels in solids, and band theory and semiconductor properties. Letter grading.
Mr. K.L. Wang (F)

**123B. Fundamentals of Solid-State II. (4)** (Formerly numbered Electrical Engineering 123B.) Lecture, four hours; outside study, eight hours. Enforced requisite: course 123A. Discussion of solid-state properties, lattice vibrations, thermal properties, dielectric, magnetic, and superconducting properties. Letter grading. Mr. K.L. Wang (Not offered 2019-20)

**128. Principles of Nanoelectronics. (4)** (Formerly numbered Electrical Engineering 128.) Lecture, four hours; discussion, four hours; outside study, four hours. Requisite: Physics 1C. Introduction to fundamentals of nanoscience for electronics nanosystems. Principles of fundamental quantities: electron charge, effective mass, Bohr magneton, and spin, as well as theoretical approaches. From these nanoscale components, discussion of basic behaviors of nanosystems such as analysis of dynamics, variability, and noise, contrasted with those of scaled CMOS. Incorporation of design project in which students are challenged to design electronics nanosystems. Letter grading. Mr. K.L. Wang (W)

**131A. Probability and Statistics. (4)** (Formerly numbered Electrical Engineering 131A.) Lecture, four hours; discussion, one hour; outside study, 10 hours. Requisites: course 102 (enforced), Mathematics 32B, 33B. Introduction to basic concepts of probability, including random variables and vectors, distributions and densities, moments, characteristic functions, and limit theorems. Applications to communication, control, and signal processing. Introduction to computer simulation and generation of random events. Letter grading. Mr. Roychowdhury (F,W)

**132A. Introduction to Communication Systems. (4)** (Formerly numbered Electrical Engineering 132A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 102, 113, 131A. Review of basic probability, basics of hypothesis testing, sufficient statistics and waveform communication, signal-design tradeoffs for digital communications, basics of error control coding, intersymbol interference channels and orthogonal frequency division multiplexing (OFDM), basics of wireless communications. Letter grading. Mr. Diggavi (W,Sp)

**132B. Data Communications and Telecommunication Networks. (4)** (Formerly numbered Electrical Engineering 132B.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 131A. Layered communications architectures. Queueing system modeling and analysis. Error control, flow and congestion control. Packet switching, circuit switching, and routing. Network performance analysis and design. Multiple-access communications: TDMA, FDMA, polling, random access. Local, metropolitan, wide area, integrated services networks. Letter grading. Mr. Rubin (F)

**133A. Applied Numerical Computing. (4)** (Formerly numbered Electrical Engineering 133A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: course 131A, and Civil Engineering M20 or Computer Science 31 or Mechanical and Aerospace Engineering M20. Introduction to numerical computing/analysis; analytic formulations versus numerical solutions; floating-point representations and rounding errors. Review of MATLAB; mathematical software. Linear equations; LU factorization; bounds on error; iterative methods for solving linear equations; conditioning and stability; complexity. Interpolation and approximation; splines. Zeros and roots of nonlinear equations. Linear least squares and orthogonal (QR) factorization; statistical interpretation. Numerical optimization; Newton method; nonlinear least squares. Numerical quadrature. Solving ordinary differential equations. Eigenvalues and singular values; QR algorithm; statistical applications. Letter grading. Mr. Vandenberghe (F,W)

**133B. Simulation, Optimization, and Data Analysis. (4)** (Formerly numbered Electrical Engineering 133B.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 133A. Simulation of dynamical systems. Algorithms for ordinary differential and difference equations. Fourier analysis; fast Fourier transforms. Random number generators. Simulation of stochastic systems, Monte Carlo methods. Constrained optimization; applications of optimization to engineering design, modeling, and data analysis. Introduction to data mining and machine learning. Algorithms and complexity. Integration of mathematical software in applications. Letter grading. Mr. Vandenberghe (Sp)

**134. Graph Theory in Engineering. (4)** (Formerly numbered Electrical Engineering 134.) Lecture, four hours; discussion, one hour; outside study, seven hours. Basics of graph theory, including trees, bipartite graphs and matching, vertex and edge coloring, planar graphs and networks. Emphasis on reducing real-world engineering problems to graph theory formulations. Letter grading. Ms. Fragouli (W)

**141. Principles of Feedback Control. (4)** (Formerly numbered Electrical Engineering 141.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 102. Mathematical modeling of physical control systems in form of differential equations and transfer functions. Design problems, system performance indices of feedback control systems via classical techniques, root-locus and frequency-domain methods. Computer-aided solution of design problems from real world. Letter grading. Mr. Tabuada (W,Sp)

**142. Linear Systems: State-Space Approach. (4)** (Formerly numbered Electrical Engineering 142.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 102. State-space methods of linear system analysis and synthesis, with application to problems in networks, control, and system modeling. Letter grading. Mr. Tabuada (Not offered 2019-20)

**C143A. Neural Signal Processing. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 131A, Mathematics 33A. Topics include fundamental properties of electrical activity in neurons; technology for measuring neural activity; spiking statistics and Poisson processes; generative models and classification; regression and Kalman filtering; principal components analysis, factor analysis, and expectation maximization. Concurrently scheduled with course C243A. Letter grading. Mr. Kao (Sp)

**M146. Introduction to Machine Learning. (4)** (Formerly numbered Electrical Engineering M146.) (Same as Computer Science M146.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 131A or Civil and Environmental Engineering 110 or Mathematics 170A or Statistics 100A, Computer Science 33. Introduction to breadth of data science. Foundations for modeling data sources, principles of operation of common tools for data analysis, and application of tools and models to data gathering and analysis. Topics include statistical foundations, regression, classification, kernel methods, clustering, expectation maximization, principal component analysis, decision theory, reinforcement learning and deep learning. Letter grading. Ms. Dolecek (F,W,Sp)

**C147. Neural Networks and Deep Learning. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 131A, 133A or 205A, and M146, or equivalent. Review of machine learning concepts; maximum likelihood; supervised classification; neural network architectures; backpropagation; regularization for training neural networks; optimization for training neural networks; convolutional neural networks; practical CNN architectures; deep learning libraries in Python; recurrent neural networks, backpropagation through time, long short-term memory and gated recurrent units; variational autoencoders; generative adversarial networks; adversarial examples and training. Concurrently scheduled with course C247. Letter grading. Mr. Kao (W)

**M153. Introduction to Microscale and Nanoscale Manufacturing. (4)** (Formerly numbered Electrical Engineering M153.) (Same as Bioengineering M153, Chemical Engineering M153, and Mechanical and Aerospace Engineering M183B.) Lecture, three hours; laboratory, four hours; outside study, five hours. Enforced requisites: Chemistry 20A, Physics 1A, 1B, 1C, 4AL, 4BL. Introduction to general manufacturing methods, mechanisms, constrains, and microfabrication and nanofabrication. Focus on concepts, physics, and instruments of various microfabrication and nanofabrication techniques that have been broadly applied in industry and academia, including various photolithography technologies, physical and chemical deposition methods, and physical and chemical etching methods. Hands-on experience for fabricating microstructures and nanostructures in modern cleanroom environment. Letter grading. Mr. Chiou (F,Sp)

**162A. Wireless Communication Links and Antennas. (4)** (Formerly numbered Electrical Engineering 162A.) Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 101B. Basic properties of transmitting and receiving antennas and antenna arrays. Array synthesis. Adaptive arrays. Friis transmission formula, radar equations. Cell-site and mobile antennas, bandwidth budget. Noise in communication systems (transmission lines, antennas, atmospheric, etc.). Cell-site and mobile antennas, cell coverage for signal and traffic, interference, multipath fading, ray bending, and other propagation phenomena. Letter grading. Mr. Rahmat-Samii (Sp)

**163A. Introductory Microwave Circuits. (4)** (Formerly numbered Electrical Engineering 163A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 101B. Transmission lines description of waveguides, impedance matching techniques, power dividers, directional couplers, active devices, transistor amplifier design. Letter grading. Mr. Itoh (F)

**163C. Introduction to Microwave Systems. (4)** (Formerly numbered Electrical Engineering 163C.) Lecture, four hours; outside study, eight hours. Enforced requisite: course 101B. Theory and design of modern microwave systems such as satellite communication systems, radar systems, wireless sensors, and biological applications of microwaves. Letter grading. Mr. Itoh, Mr. Jalali (W)

**163DA. Microwave and Wireless Design I. (4)** (Formerly numbered Electrical Engineering 163DA.) Lecture, one hour; laboratory, three hours; outside study, eight hours. Enforced requisites: courses 101A, 101B. Course 163DA is enforced requisite to 163DB. Limited to senior Electrical Engineering majors. Capstone design course, with emphasis on transmission line-based circuits and components to address need in industry and research community for students with microwave and wireless circuit design experiences. Standard design procedure for waveguide and transmission line-based microwave circuits and systems to gain experience in using Microwave CAD software such as Agilent ADS or HFSS. How to fabricate and test these designs, In Progress grading (credit to be given only on completion of course 163DB). Mr. Y.E. Wang (W)

**163DB. Microwave and Wireless Design II. (4)** (Formerly numbered Electrical Engineering 163DB.) Lecture, one hour; laboratory, three hours; outside study, eight hours. Enforced requisites: courses 101A, 101B, 163DA. Limited to senior Electrical Engineering majors. Design of radio frequency circuits and systems, with emphasis on both theoretical foundations and hands-on experience. Design of radio frequency transceivers and their building blocks according to given specifications or in form of open-ended problems. Introduction to advanced topics related to projects through lecture and laboratories. Creation by students of end-to-end systems in application context, managing trade-offs across subsystems while meeting constraints and optimizing metrics related to cost, performance, ease of use, manufacturability, testing, and other real-world issues. Oral and written presentations of project results required. Letter grading. Mr. Y.E. Wang (Sp)

**164DA-164DB. Radio Frequency Design Project I, II. (4–4)** (Formerly numbered Electrical Engineering 164DA-164DB.) Lecture, one hour; laboratory, three hours; outside study, eight hours. Enforced requisite: course 115B. Course 164DA is enforced requisite to 164DB. Limited to senior Electrical Engineering majors. Design of radio frequency circuits and systems, with emphasis on both theoretical foundations and hands-on experience. Design of radio frequency transceivers and their building blocks according to given specifications or in form of open-ended problems. Introduction to advanced topics related to projects through lecture and laboratories. Creation by students of end-to-end systems in application context, managing trade-offs across subsystems while meeting constraints and optimizing metrics related to cost, performance, ease of use, manufacturability, testing, and other real-world issues. Oral and written presentations of project results required. In Progress (164DA) and letter (164DB) grading.
Mr. Chang, Mr. Itoh, Mr. Razavi (Not offered 2019-20)

**170A. Principles of Photonics. (4)** (Formerly numbered Electrical Engineering 170A.) Lecture, four hours; recitation, one hour; outside study, seven hours. Enforced requisites: courses 2, 101A. Development of solid foundation on essential principles of photonics from ground up with minimum prior knowledge on this subject. Topics include optical properties of materials, optical wave propagation and modes, optical interferometers and resonators, optical coupling and modulation, optical absorption and emission, principles of lasers and light-emitting diodes, and optical detection. Letter grading. Mr. Liu (F,W)

**170B. Photonic Devices and Circuits. (4)** (Formerly numbered Electrical Engineering 170B.) Lecture, four hours; recitation, one hour; outside study, seven hours. Enforced requisite: course 170A. Coverage of core knowledge of practical photonic devices and circuits. Topics include optical waveguides, optical fibers, optical couplers, optical modulators, lasers and light-emitting diodes, optical detectors, and integrated photonic devices and circuits. Letter grading. Mr. Liu (W)

**170C. Photonic Sensors and Solar Cells. (4)** (Formerly numbered Electrical Engineering 170C.) Lecture, four hours; recitation, one hour; outside study, seven hours. Enforced requisite: course 101A. Recommended: courses 2, 170A. Fundamentals of detection of light for communication and sensing, as well as conversion of light to electrical energy in solar cells. Introduction to radiometry, semiconductor photodetectors, noise processes and figures of merit, thermal detectors, and photovoltaic solar cells of various types and materials. Letter grading. Mr. Williams (Sp)

**M171L. Data Communication Systems Laboratory. (2 to 4)** (Formerly numbered Electrical Engineering M171L.) (Same as Computer Science M171L.) Laboratory, four to eight hours; outside study, two to four hours. Recommended preparation: course M116L. Limited to seniors. Not open to students with credit for course M117. Interpretation of analog-signaling aspects of digital systems and data communications through experience in using contemporary test instruments to generate and display signals in relevant laboratory setups. Use of oscilloscopes, pulse and function generators, baseband spectrum analyzers, desktop computers, terminals, modems, PCs, and workstations in experiments on pulse transmission impairments, waveforms and their spectra, modem and terminal characteristics, and interfaces. Letter grading. Mr. Jalali (Not offered 2019-20)

**173DA-173DB. Photonics and Communication Design. (4–4)** (Formerly numbered Electrical Engineering 173DA-173DB.) Lecture, one hour; laboratory, three hours; outside study, eight hours. Introduction to measurement of basic photonic devices, including LEDs, lasers, detectors, and amplifiers; fiber-optic fundamentals and measurement of fiber systems. Modulation techniques, including AM, FM, phase and suppressed carrier methods. Possible projects include lasers, optical communication, and biomedical imaging and sensing. **173DA.** Enforced requisite: course 101A. Recommended: course 170A or Bioengineering C170. Choice of project preliminary design. In Progress grading (credit to be given only on completion of course 173DB). **173DB.** Enforced requisites: courses 101A, 173DA. Finalization of design and testing of projects begun in course 173DA. Letter grading.
Mr. Stafsudd (173DA in F; 173DB in W)

**176. Photonics in Biomedical Applications. (4)** (Formerly numbered Electrical Engineering 176.) Lecture, three hours; discussion, one hour; outside study, eight hours. Enforced requisite: course 101A. Study of different types of optical systems and their physics background. Examination of their roles in current and projected biomedical applications. Specific capabilities of photonics to be related to each example. Letter grading. Mr. Ozcan (Sp)

**180DA-180DB. Systems Design. (4–4)** (Formerly numbered Electrical Engineering 180DA-180DB.) Limited to senior Electrical Engineering majors. Advanced systems design integrating communications, control, and signal processing subsystems. Introduction to advanced topics related to projects through lecture and laboratories. Open-ended projects vary each offering. Student teams create high-performance designs that manage trade-offs among subsystem components, including cost, performance, ease of use, and other real-world constraints. Oral and written presentation of project results. **180DA.** Lecture, two hours; laboratory, four hours; outside study, six hours. In Progress grading (credit to be given only on completion of course 180DB). **180DB.** Laboratory, four hours; outside study, eight hours. Enforced requisite: course 180DA. Completion of projects begun in course 180DA. Letter grading.
Mr. Kaiser, Mr. Pottie (180DA in F; 180DB in W)

**CM182. Science, Technology, and Public Policy. (4)** (Formerly numbered Electrical Engineering CM182.) (Same as Public Affairs M164 and Public Policy CM182.) Lecture, three hours. Recent and continuing advances in science and technology are raising profoundly important public policy issues. Consideration of selection of critical policy issues, each of which has substantial ethical, social, economic, political, scientific, and technological aspects. Concurrently scheduled with course CM282. Letter grading. Mr. Villasenor (W)

**183DA. Design of Robotic Systems I. (4)** (Formerly numbered Electrical Engineering 183DA.) Lecture, four hours; laboratory, two hours; outside study, six hours. Requisite: course 102. Recommended: courses 141, 142. Course 183DA is requisite to 183DB. Limited to senior Electrical Engineering majors. Topics in robotic design include integrated electromechanical design, design for manufacturing (DFM), design software, and design automation. Topics in robotic manufacturing include materials, sensors and actuators, programming, and rapid prototyping. Topics in control include manipulation, motion and path planning, learning and adaptation, and human-robot interaction. Additional topics may include distributed and multi-robot systems, bio-inspired robotics, project management, and societal implications. Open-ended projects vary annually. Student teams create and analyze robotic systems for various applications. Oral and written presentation of project results. In Progress grading (credit to be given only on completion of course 183DB). Mr. Mehta (W)

**183DB. Design of Robotic Systems II. (4)** (Formerly numbered Electrical Engineering 183DB.) Laboratory, four hours; outside study, eight hours. Requisite: course 183DA. Recommended: courses 141, 142. Limited to senior Electrical Engineering majors. Topics in robotic design include integrated electromechanical design, design for manufacturing (DFM), design software, and design automation. Topics in robotic manufacturing include materials, sensors and actuators, programming, and rapid prototyping. Topics in control include manipulation, motion and path planning, learning and adaptation, and human-robot interaction. Additional topics may include distributed and multi-robot systems, bio-inspired robotics, project management, and societal implications. Open-ended projects vary annually. Student teams create and analyze robotic systems for various applications. Oral and written presentation of project results. Letter grading. Mr. Mehta (Sp)

**184DA-184DB. Independent Group Project Design. (2–2)** (Formerly numbered Electrical Engineering 184DA-184DB.) Laboratory, five hours; discussion, one hour. Enforced requisites: courses M16, 110, 110L. Course 184DA is enforced requisite to 184DB. Courses centered on group project that runs year long to give students intensive experience on hardware design, microcontroller programming, and project coordination. Several projects based on autonomous robots that traverse small mazes and courses offered yearly and target regional competitions. Students may submit proposals that are evaluated and approved by faculty members. Topics include sensing circuits and amplifier-based design, microcontroller programming, feedback control, actuation, and motor control. In Progress (184DA) and letter (184DB) grading.
Mr. Briggs (Not offered 2019-20)

**M185. Introduction to Plasma Electronics. (4)** (Formerly numbered Electrical Engineering M185.) (Same as Physics M122.) Lecture, three hours; discussion, one hour; outside study, eight hours. Requisite: course 101A or Physics 110A. Senior-level introductory course on electrodynamics of ionized gases and applications to materials processing, generation of coherent radiation and particle beams, and renewable energy sources. Letter grading. Mr. Mori (F)

**188. Special Courses in Electrical Engineering. (4)** (Formerly numbered Electrical Engineering 188.) Seminar, four hours; outside study, eight hours. Special topics in electrical engineering for undergraduate students taught on experimental or temporary basis, such as those taught by resident and visiting faculty members. May be repeated once for credit with topic or instructor change. Letter grading. (F)

**189. Advanced Honors Seminars. (1)** Seminar, three hours. Limited to 20 students. Designed as adjunct to undergraduate lecture course. Exploration of topics in greater depth through supplemental readings, papers, or other activities and led by lecture course instructor. May be applied toward honors credit for eligible students. Honors content noted on transcript. P/NP or letter grading. (F,W,Sp)

**194. Research Group Seminars: Electrical Engineering. (2 to 4)** (Formerly numbered Electrical Engineering 194.) Seminar, four hours; outside study, eight hours. Designed for undergraduate students who are part of research group. Discussion of research methods and current literature in field. May be repeated for credit. Letter grading. (F,W,Sp)

**199. Directed Research in Electrical Engineering. (2 to 8)** (Formerly numbered Electrical Engineering 199.) Tutorial, to be arranged. Limited to juniors/seniors. Supervised individual research or investigation under guidance of faculty mentor. Culminating paper or project required. May be repeated for credit with school approval. Individual contract required; enrollment petitions available in Office of Academic and Student Affairs. Letter grading. (F,W,Sp)

## Graduate Courses

**201A. VLSI Design Automation. (4)** (Formerly numbered Electrical Engineering 201A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 115C. Fundamentals of design automation of VLSI circuits and systems, including introduction to circuit and system platforms such as field programmable gate arrays and multicore systems; high-level synthesis, logic synthesis, and technology mapping; physical design; and testing and verification. Letter grading. Mr. Gupta (Sp)

**201C. Modeling of VLSI Circuits and Systems. (4)** (Formerly numbered Electrical Engineering 201C.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 115C. Detailed study of VLSI circuit and system models considering performance, signal integrity, power and thermal effects, reliability, and manufacturability. Discussion of principles of modeling and optimization codevelopment. Letter grading. Mr. He (W)

**201D. Design in Nanoscale Technologies. (4)** (Formerly numbered Electrical Engineering 201D.) Lecture, four hours; outside study, eight hours. Enforced requisite: course 115C. Challenges of digital circuit design and layout in deeply scaled technologies, with focus on design-manufacturing interactions. Summary of large-scale digital design flow; basic manufacturing flow; lithographic patterning, resolution enhancement, and mask preparation; yield and variation modeling; circuit reliability and aging issues; design rules and their origins; layout design for manufacturing; test structures and process control; circuit ans architecture methods for variability mitigation. Letter grading. Mr. Gupta (Not offered 2019-20)

**M202A. Embedded Systems. (4)** (Formerly numbered Electrical Engineering M202A.) (Same as Computer Science M213A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Designed for graduate computer science and electrical engineering students. Methodologies and technologies for design of embedded systems. Topics include hardware and software platforms for embedded systems, techniques for modeling and specification of system behavior, software organization, real-time operating system scheduling, real-time communication and packet scheduling, low-power battery and energy-aware system design, timing synchronization, fault tolerance and debugging, and techniques for hardware and software architecture optimization. Theoretical foundations as well as practical design methods. Letter grading. Mr. Srivastava (F)

**M202B. Energy-Aware Computing and Cyber-Physical Systems. (4)** (Formerly numbered Electrical Engineering M202B.) (Same as Computer Science M213B.) Lecture, four hours; outside study, eight hours. Requisite: course M16 or Computer Science M51A. Recommended: course M116C or Computer Science M151B, and Computer Science 111. System-level management and cross-layer methods for power and energy consumption in computing and communication at various scales ranging across embedded, mobile, personal, enterprise, and datacenter scale. Computing, networking, sensing, and control technologies and algorithms for improving energy sustainability in human-cyber-physical systems. Topics include modeling of energy consumption, energy sources, and energy storage; dynamic power management; power-performance scaling and energy proportionality; duty-cycling; power-aware scheduling; low-power protocols; battery modeling and management; thermal management; sensing of power consumption. Letter grading.
Mr. Srivastava (Not offered 2019-20)

**202C. Networked Embedded Systems Design. (4)** (Formerly numbered Electrical Engineering 202C.) Lecture, four hours; laboratory, four hours; outside study, four hours. Designed for graduate computer science and electrical engineering students. Training in combination of networked embedded systems design combining embedded hardware platform, embedded operating system, and hardware/software interface. Essential graduate student background for research and industry career paths in wireless devices for applications ranging from conventional wireless mobile devices to new area of wireless health. Laboratory design modules and course projects based on state-of-art embedded hardware platform. Letter grading. Mr. Kaiser (Not offered 2019-20)

**205A. Matrix Analysis for Scientists and Engineers. (4)** (Formerly numbered Electrical Engineering 205A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Preparation: one undergraduate linear algebra course. Designed for first-year graduate students in all branches of engineering, science, and related disciplines. Introduction to matrix theory and linear algebra, language in which virtually all of modern science and engineering is conducted. Review of matrices taught in undergraduate courses and introduction to graduate-level topics. Letter grading. Mr. Vandenberghe (F)

**M206. Machine Perception. (4)** (Formerly numbered Electrical Engineering M206.) (Same as Computer Science M268.) Lecture, four hours; discussion, two hours; outside study, six hours. Designed for graduate students. Computational aspects of processing visual and other sensory information. Unified treatment of early vision in man and machine. Integration of symbolic and iconic representations in process of image segmentation. Computing multimodal sensory information by neural-net architectures. Letter grading. Mr. Soatto (Not offered 2019-20)

**M208B. Functional Analysis for Applied Mathematics and Engineering. (4)** (Formerly numbered Electrical Engineering M208B.) (Same as Mathematics M268A.) Lecture, four hours; outside study, eight hours. Requisites: course 208A (or Mathematics 115A and 115B), Mathematics 131A, 131B, 132. Topics may include L^{p} spaces, Hilbert, Banach, and separable spaces; Fourier transforms; linear functionals. Riesz representation theory, linear operators and their adjoints; self-adjoint and compact operators. Spectral theory. Differential operators such as Laplacian and eigenvalue problems. Resolvent distributions and Green's functions. Semigroups. Applications. S/U or letter grading. (Not offered 2019-20)

**M208C. Topics in Functional Analysis for Applied Mathematics and Engineering. (4)** (Formerly numbered Electrical Engineering M208C.) (Same as Mathematics M268B.) Lecture, four hours; outside study, eight hours. Requisite: course M208B. Semigroups of linear operators over Hilbert spaces; generator and resolvent, generation theorems, Laplace inversion formula. Dissipative operators and contraction semigroups. Analytic semigroups and spectral representation. Semigroups with compact resolvents. Parabolic and hyperbolic systems. Controllability and stabilizability. Spectral theory of differential operators, PDEs, generalized functions. S/U or letter grading.
(Not offered 2019-20)

**209AS. Special Topics in Circuits and Embedded Systems. (4)** (Formerly numbered Electrical Engineering 209AS.) Lecture, four hours; discussion, one hour; outside study, seven hours. Special topics in one or more aspects of circuits and embedded systems, such as digital, analog, mixed-signal, and radio frequency integrated circuits (RF ICs); electronic design automation; wireless communication circuits and systems; embedded processor architectures; embedded software; distributed sensor and actuator networks; robotics; and embedded security. May be repeated for credit with topic change. S/U or letter grading. Mr. Pamarti (F,W)

**209BS. Seminar: Circuits and Embedded Systems. (2 to 4)** (Formerly numbered Electrical Engineering 209BS.) Seminar, two to four hours; outside study, four to eight hours. Seminars and discussions on current and advanced topics in one or more aspects of circuits and embedded systems, such as digital, analog, mixed-signal, and radio frequency integrated circuits (RF ICs); electronic design automation; wireless communication circuits and systems; embedded processor architectures; embedded software; distributed sensor and actuator networks; robotics; and embedded security. May be repeated for credit with topic change. S/U grading.
Mr. Pamarti (Not offered 2019-20)

**210A. Adaptation and Learning. (4)** (Formerly numbered Electrical Engineering 210A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Preparation: prior training in probability theory, random processes, and linear algebra. Recommended requisites: courses 205A, 241A. Mean-square-error estimation and filters, least-squares estimation and filters, steepest-descent algorithms, stochastic-gradient algorithms, convergence, stability, tracking, and performance, algorithms for adaptation and learning, adaptive filters, learning and classification, optimization. Letter grading.
Mr. Sayed (Sp)

**210B. Inference over Networks. (4)** (Formerly numbered Electrical Engineering 210B.) Lecture, four hours; outside study, eight hours. Preparation: prior training in probability theory, random processes, linear algebra, and adaptation. Enforced requisite: course 210A. Adaptation, learning, estimation, and detection over networks. Steepest-descent algorithms, stochastic-gradient algorithms, convergence, stability, tracking, and performance analyses. Distributed optimization. Online and distributed adaptation and learning. Synchronous and asynchronous network behavior. Incremental, consensus, diffusion, and gossip strategies. Letter grading.
Mr. Sayed (Not offered 2019-20)

**211A. Digital Image Processing I. (4)** (Formerly numbered Electrical Engineering 211A.) Lecture, three hours; discussion, one hour; laboratory, four hours; outside study, four hours. Preparation: computer programming experience. Requisite: course 113. Fundamentals of digital image processing theory and techniques. Topics include two-dimensional linear system theory, image transforms, and enhancement. Concepts covered in lecture applied in computer laboratory assignments. Letter grading.
Mr. Kadambi, Mr. Villasenor (W)

**212A. Theory and Design of Digital Filters. (4)** (Formerly numbered Electrical Engineering 212A.) Lecture, three hours; discussion, one hour; outside study, eight hours. Requisite: course 113. Approximation of filter specifications. Use of design charts. Structures for recursive digital filters. FIR filter design techniques. Comparison of IIR and FIR structures. Implementation of digital filters. Limit cycles. Overflow oscillations. Discrete random signals. Wave digital filters. Letter grading.
Mr. Pamarti (Not offered 2019-20)

**M214A. Digital Speech Processing. (4)** (Formerly numbered Electrical Engineering 214A.) (Same as Bioengineering M214A.) Lecture, three hours; laboratory, two hours; outside study, seven hours. Requisite: course 113. Theory and applications of digital processing of speech signals. Mathematical models of human speech production and perception mechanisms, speech analysis/synthesis. Techniques include linear prediction, filter-bank models, and homomorphic filtering. Applications to speech synthesis, automatic recognition, and hearing aids. Letter grading. Ms. Alwan (W)

**214B. Advanced Topics in Speech Processing. (4)** (Formerly numbered Electrical Engineering 214B.) Lecture, three hours; discussion, one hour; computer assignments, two hours; outside study, six hours. Requisite: course M214A. Advanced techniques used in various speech-processing applications, with focus on speech recognition by humans and machine. Physiology and psychoacoustics of human perception. Dynamic Time Warping (DTW) and Hidden Markov Models (HMM) for automatic speech recognition systems, pattern classification, and search algorithms. Aids for hearing impaired. Letter grading. Ms. Alwan (Sp)

**215A. Analog Integrated Circuit Design. (4)** (Formerly numbered Electrical Engineering 215A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 115B. Analysis and design of analog integrated circuits. MOS and bipolar device structures and models, single-stage and differential amplifiers, noise, feedback, operational amplifiers, offset and distortion, sampling devices and discrete-time circuits, bandgap references. Letter grading. Mr. Abidi, Mr. Razavi (F)

**215B. Advanced Digital Integrated Circuits. (4)** (Formerly numbered Electrical Engineering 215B.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: courses 115C, M216A. Analysis and comparison of modern logic families. VLSI memories (SRAM, DRAM, and ROMs). Accuracy of various simulation models and simulation methods for digital circuits. Letter grading.
Mr. Yang (W)

**215C. Analysis and Design of RF Circuits and Systems. (4)** (Formerly numbered Electrical Engineering 215C.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 215A. Principles of RF circuit and system design, with emphasis on monolithic implementation in VLSI technologies. Basic concepts, communications background, transceiver architectures, low-noise amplifiers and mixers, oscillators, frequency synthesizers, power amplifiers. Letter grading. Mr. Abidi, Mr. Razavi (W)

**215D. Analog Microsystem Design. (4)** (Formerly numbered Electrical Engineering 215D.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 215A. Analysis and design of data conversion interfaces and filters. Sampling circuits and architectures, D/A conversion techniques, A/D converter architectures, building blocks, precision techniques, discrete- and continuous-time filters. Letter grading. Mr. Abidi, Mr. Razavi (Sp)

**215E. Signaling and Synchronization. (4)** (Formerly numbered Electrical Engineering 215E.) Lecture, four hours; outside study, eight hours. Requisites: courses 215A, M216A. Analysis and design of circuits for synchronization and communication for VLSI systems. Use of both digital and analog design techniques to improve data rate of electronics between functional blocks, chips, and systems. Advanced clocking methodologies, phase-locked loop design for clock generation, and high-performance wire-line transmitters, receivers, and timing recovery circuits. Letter grading. Mr. Pamarti (Sp)

**M216A. Design of VLSI Circuits and Systems. (4)** (Formerly numbered Electrical Engineering M216A.) (Same as Computer Science M258A.) Lecture, four hours; discussion, two hours; laboratory, four hours; outside study, two hours. Requisites: courses M16 or Computer Science M51A, and 115A. Recommended: course 115C. LSI/VLSI design and application in computer systems. Fundamental design techniques that can be used to implement complex integrated systems on chips. Letter grading. Mr. Markovic (F)

**216B. VLSI Signal Processing. (4)** (Formerly numbered Electrical Engineering 216B.) Lecture, four hours; outside study, eight hours. Advanced concepts in VLSI signal processing, with emphasis on architecture design and optimization within block-based description that can be mapped to hardware. Fundamental concepts from digital signal processing (DSP) theory, architecture, and circuit design applied to complex DSP algorithms in emerging applications for personal communications and healthcare. Letter grading. Mr. Markovic (Not offered 2019-20)

**M216C. LSI in Computer System Design. (4)** (Formerly numbered Electrical Engineering M216C.) (Same as Computer Science M258C.) Lecture, four hours; laboratory, four hours; outside study, four hours. Requisite: course M216A. LSI/VLSI design and application in computer systems. In-depth studies of VLSI architectures and VLSI design tools. Letter grading. (Not offered 2019-20)

**M217. Biomedical Imaging. (4)** (Formerly numbered Electrical Engineering M217.) (Same as Bioengineering M217.) Lecture, three hours; discussion, one hour; outside study, eight hours. Requisite: course 114 or 211A. Optical imaging modalities in biomedicine. Other nonoptical imaging modalities discussed briefly for comparison purposes. Letter grading. Mr. Ozcan (W)

**218. Network Economics and Game Theory. (4)** (Formerly numbered Electrical Engineering 218.) Lecture, four hours; discussion, one hour; outside study, seven hours. Discussion of how different cooperative and noncooperative games among agents can be constructed to model, analyze, optimize, and shape emerging interactions among users in different networks and system settings. How strategic agents can successfully compete with each other for limited and time-varying resources by optimizing their decision process and learning from their past interaction with other agents. To determine their optimal actions in these distributed, informationally decentralized environments, agents need to learn and model directly or implicitly other agents' responses to their actions. Discussion of existing multiagent learning techniques and learning in games, including adjustment processes for learning equilibria, fictitious play, regret-learning, and more. Letter grading.
Ms. van der Schaar (Not offered 2019-20)

**219. Large-Scale Data Mining: Models and Algorithms. (4)** (Formerly numbered Electrical Engineering 219.) Lecture, four hours; discussion, one hour; outside study, seven hours. Introduction of variety of scalable data modeling tools, both predictive and causal, from different disciplines. Topics include supervised and unsupervised data modeling tools from machine learning, such as support vector machines, different regression engines, different types of regularization and kernel techniques, deep learning, and Bayesian graphical models. Emphasis on techniques to evaluate relative performance of different methods and their applicability. Includes computer projects that explore entire data analysis and modeling cycle: collecting and cleaning large-scale data, deriving predictive and causal models, and evaluating performance of different models. Letter grading.
Mr. Roychowdhury (W)

**221A. Physics of Semiconductor Devices I. (4)** (Formerly numbered Electrical Engineering 221A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Physical principles and design considerations of junction devices. Letter grading.
Mr. K.L. Wang, Mr. Woo (W)

**221B. Physics of Semiconductor Devices II. (4)** (Formerly numbered Electrical Engineering 221B.) Lecture, four hours; outside study, eight hours. Principles and design considerations of field effect devices and charge-coupled devices. Letter grading.
Mr. Woo (Sp)

**221C. Microwave Semiconductor Devices. (4)** (Formerly numbered Electrical Engineering 221C.) Lecture, four hours; discussion, one hour; outside study, seven hours. Physical principles and design considerations of microwave solid-state devices: Schottky barrier mixer diodes, IMPATT diodes, transferred electron devices, tunnel diodes, microwave transistors. Letter grading.
Mr. K.L. Wang, Mr. Woo (Not offered 2019-20)

**222. Integrated Circuits Fabrication Processes. (4)** (Formerly numbered Electrical Engineering 222.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 2. Principles of integrated circuits fabrication processes. Technological limitations of integrated circuits design. Topics include bulk crystal and epitaxial growth, thermal oxidation, diffusion, ion-implantation, chemical vapor deposition, dry etching, lithography, and metallization. Introduction of advanced process simulation tools. Letter grading. Mr. Woo (Sp)

**223. Solid-State Electronics I. (4)** (Formerly numbered Electrical Engineering 223.) Lecture, four hours; discussion, one hour; outside study, seven hours. Recommended requisite: course 270. Energy band theory, electronic band structure of various elementary, compound, and alloy semiconductors, defects in semiconductors. Recombination mechanisms, transport properties. Letter grading.
Mr. Wong (F)

**224. Solid-State Electronics II. (4)** (Formerly numbered Electrical Engineering 224.) Lecture, four hours; outside study, eight hours. Requisite: course 223. Techniques to solve Boltzmann transport equation, various scattering mechanisms in semiconductors, high field transport properties in semiconductors, Monte Carlo method in transport. Optical properties. Letter grading. Mr. K.L. Wang (W)

**225. Physics of Semiconductor Nanostructures and Devices. (4)** (Formerly numbered Electrical Engineering 225.) Lecture, four hours; outside study, eight hours. Requisite: course 223. Theoretical methods for circulating electronics and optical properties of semiconductor structures. Quantum size effects and low-dimensional systems. Application to semiconductor nanometer scale devices, including negative resistance diodes, transistors, and detectors. Letter grading. Mr. K.L. Wang (Sp, alternate years)

**229. Seminar: Advanced Topics in Solid-State Electronics. (4)** (Formerly numbered Electrical Engineering 229.) Seminar, four hours; outside study, eight hours. Requisites: courses 223, 224. Current research areas, such as radiation effects in semiconductor devices, diffusion in semiconductors, optical and microwave semiconductor devices, nonlinear optics, and electron emission. Letter grading.
(Not offered 2019-20)

**229S. Advanced Electrical Engineering Seminar. (2)** (Formerly numbered Electrical Engineering 229S.) Seminar, two hours; outside study, six hours. Preparation: successful completion of PhD major field examination. Seminar on current research topics in solid-state and quantum electronics (Section 1) or in electronic circuit theory and applications (Section 2). Students report on tutorial topic and on research topic in their dissertation area. May be repeated for credit. S/U grading. (Not offered 2019-20)

**230A. Detection and Estimation in Communication. (4)** (Formerly numbered Electrical Engineering 230A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 131A. Applications of estimation and detection concepts in communication and signal processing; random signal and noise characterizations by analysis and simulations; mean square (MS) and maximum likelihood (ML) estimations and algorithms; detection under ML, Bayes, and Neyman/Pearson (NP) criteria; signal-to-noise ratio (SNR) and error probability evaluations. Introduction to Monte Carlo simulations. Letter grading. Mr. Yao (F)

**230B. Digital Communication Systems. (4)** (Formerly numbered Electrical Engineering 230B.) Lecture, four hours; outside study, eight hours. Requisites: courses 132A, 230A. Principles and practical techniques for communication at physical and multiple access layers. Review of communications over Gaussian channel. Synchronization and adaptive equalization. Nonlinear impairments in radio transceivers. Wireless channel models, diversity techniques, and link budgets. Modulations for wireless channels. Multi-antenna methods. Wireless multiple access and resource allocation techniques. Scalable approaches to meeting wireless data rate demand. Letter grading. Mr. Pottie (Not offered 2019-20)

**230C. Signal Processing in Communications. (4)** (Formerly numbered Electrical Engineering 230C.) Lecture, four hours; outside study, eight hours. Requisites: courses 131A, 230A. Concepts and implementations of signal processing in communication and signal processing systems. Spectral analysis using Fourier transform and windowing, parametric modeling, eigen-decomposition methods, time-frequency analysis, wavelet transform, and sub-band processing. Array processing using beamforming for SNIR enhancement, smart antenna, and source separation and localization. Introduction to compressive sampling and applications. Letter grading.
Mr. Yao (Not offered 2019-20)

**230D. Algorithms and Processing in Communication Systems. (4)** (Formerly numbered Electrical Engineering 230D.) Lecture, four hours; outside study, eight hours. Requisites: courses 131A, 230A. Review of computational linear algebra methods on QRD, eigen- and singular-value decompositions, and LS estimation with applications to estimation and detection in communication, radar, speech, image, and array processing systems. Systolic and parallel algorithms and VLSI architectures for high performance and high throughput real-time estimation, detection, decoding, and beamforming applications. Letter grading. Mr. Yao (Not offered 2019-20)

**231A. Information Theory: Channel and Source Coding. (4)** (Formerly numbered Electrical Engineering 231A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 131A. Fundamentals information compression, transmission, processing, and learning. Topics include limits and algorithms for lossless data compression, connections to model estimation and learning, channel capacity, rate versus distortion in lossy compression, and basics of information theory for networks. Letter grading. Mr. Diggavi (Sp)

**231B. Network Information Theory. (4)** (Formerly numbered Electrical Engineering 231B.) Lecture, four hours; outside study, eight hours. Enforced requisite: course 231A. Point-to-point multiple-input, multiple-output (MIMO) wireless channels: capacity and outage; single-hop networks: multiple access, broadcast, interference, and relay channels; channels and sources with side-information; basics of multiterminal lossy data compression; basics of network information flow over general noisy networks. Letter grading.
Mr. Diggavi (Not offered 2019-20)

**231E. Channel Coding Theory. (4)** (Formerly numbered Electrical Engineering 231E.) Lecture, four hours; outside study, eight hours. Requisite: course 131A. Fundamentals of error control codes and decoding algorithms. Topics include block codes, convolutional codes, trellis codes, and turbo codes. Letter grading. Mr. Wesel (Not offered 2019-20)

**232A. Stochastic Modeling with Applications to Telecommunication Systems. (4)** (Formerly numbered Electrical Engineering 232A.) Lecture, four hours; outside study, eight hours. Requisite: course 131A. Stochastic processes as applied to study of telecommunication systems, traffic engineering, business, and management. Discrete-time and continuous-time Markov chain processes. Renewal processes, regenerative processes, Markov-renewal, semi-Markov and semiregenerative stochastic processes. Decision and reward processes. Applications to traffic and queueing analysis of basic telecommunications and computer communication networks, Internet, and management systems. Letter grading.
Mr. Rubin (Not offered 2019-20)

**232B. Queuing Systems and Intelligent Transportation Networks. (4)** (Formerly numbered Electrical Engineering 232B.) Lecture, four hours; outside study, eight hours. Requisite: course 131A or equivalent. Modeling, analysis, and design of queuing systems; traffic management and design of intelligent transportation systems, communications networks, autonomous vehicular networks, business and management systems. Markovian and non-Markovian queuing systems and networks. Applications to traffic engineering, transportation and autonomous vehicular systems; computer communications, management and business systems. Letter grading.
Mr. Rubin (W)

**232D. Communications Networking and Traffic Management for Autonomous Mobile Systems. (4)** (Formerly numbered Electrical Engineering 232D.) Lecture, four hours; outside study, eight hours. Requisite: course 131A or equivalent. Analysis, design, and traffic management of autonomous mobile systems. Telecommunication networks, mobile wireless networks, and multiple-access communication systems. Networking architectures, multiple-access communications under adaptive quality-of-service metrics. Switching, routing, networking protocols, and Internet. Autonomous mobile networked systems. Cellular wireless networks, WiFi mesh networks, peer-to-peer mobile ad hoc wireless networks. Autonomous transportation networked systems. Traffic management architectures in support of self-driving cars. Smart grid networks. Adaptive multimedia streaming over mobile wireless networks. Embedded sensor networks. Energy and pollution aware sustainable networking. Security mechanisms. Letter grading. Mr. Rubin (Sp)

**232E. Large-Scale Social and Complex Networks: Design and Algorithms. (4)** (Formerly numbered Electrical Engineering 232E.) Lecture, four hours; recitation, one hour; outside study, seven hours. Modeling and design of large-scale complex networks, including social networks, peer-to-peer file-sharing networks, World Wide Web, and gene networks. Modeling of characteristic topological features of complex networks, such as power laws and percolation threshold. Mining topology to design algorithms for various applications, such as e-mail spam detection, friendship recommendations, viral popularity, and epidemics. Introduction to network algorithms, computational complexity, and nondeterministic, polynomial-time completeness. Letter grading.
Mr. Roychowdhury (Sp)

**233. Wireless Communications System Design, Modeling, and Implementation. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 113. Covers algorithms, architectures, and implementation for radio transceivers, physical, and network layer functionalities. Topics include wireless channel modeling, single-carrier and multi-carrier systems, multiple antenna systems, radio impairments and their correction, architectures and circuits design trade-offs, wideband spectrum sensing, wideband signaling, cognitive radio, massive multiple-input, multiple-output (MIMO) systems, and applications in 5G and Internet of things (IoT) communication. Letter grading.
Ms. Cabric (Sp)

**234A. Network Coding Theory and Applications. (4)** (Formerly numbered Electrical Engineering 234A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Algebraic approach and main theorem in network coding, combinatorial approach and alphabet size, linear programming approach and throughput benefits, network code design algorithms, secure network coding, network coding for wireless, other applications. Letter grading.
Ms. Fragouli (Not offered 2019-20)

**235A. Mathematical Foundations of Data Storage Systems. (4)** (Formerly numbered Electrical Engineering 235A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 131A or equivalent. Research developments in new mathematical techniques for emerging large-scale, ultra-reliable, fast, and affordable data storage systems. Topics include, but are not limited to, graph-based codes and algebraic codes and decoders for modern storage devices (e.g., Flash), rank modulation, rewriting codes, algorithms for data deduplication and synchronization, and redundant array of independent disks (RAID) systems. Letter grading.
Ms. Dolecek (Not offered 2019-20)

**236A. Linear Programming. (4)** (Formerly numbered Electrical Engineering 236A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: Mathematics 115A or equivalent knowledge of linear algebra. Basic graduate course in linear optimization. Geometry of linear programming. Duality. Simplex method. Interior-point methods. Decomposition and large-scale linear programming. Quadratic programming and complementary pivot theory. Engineering applications. Introduction to integer linear programming and computational complexity theory. Letter grading.
Ms. Fragouli, Mr. Vandenberghe (F)

**236B. Convex Optimization. (4)** (Formerly numbered Electrical Engineering 236B.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 236A. Introduction to convex optimization and its applications. Convex sets, functions, and basics of convex analysis. Convex optimization problems (linear and quadratic programming, second-order cone and semidefinite programming, geometric programming). Lagrange duality and optimality conditions. Applications of convex optimization. Unconstrained minimization methods. Interior-point and cutting-plane algorithms. Introduction to nonlinear programming. Letter grading. Mr. Vandenberghe (W)

**236C. Optimization Methods for Large-Scale Systems. (4)** (Formerly numbered Electrical Engineering 236C.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 236B. First-order algorithms for convex optimization: subgradient method, conjugate gradient method, proximal gradient and accelerated proximal gradient methods, block coordinate descent. Decomposition of large-scale optimization problems. Augmented Lagrangian method and alternating direction method of multipliers. Monotone operators and operator-splitting algorithms. Second-order algorithms: inexact Newton methods, interior-point algorithms for conic optimization. Letter grading. Mr. Vandenberghe (Sp)

**M237. Dynamic Programming. (4)** (Formerly numbered Electrical Engineering M237.) (Same as Mechanical and Aerospace Engineering M276.) Lecture, four hours; outside study, eight hours. Recommended requisite: course 232A or 236A or 236B. Introduction to mathematical analysis of sequential decision processes. Finite horizon model in both deterministic and stochastic cases. Finite-state infinite horizon model. Methods of solution. Examples from inventory theory, finance, optimal control and estimation, Markov decision processes, combinatorial optimization, communications. Letter grading.
Mr. Vandenberghe (Not offered 2019-20)

**238. Multimedia Communications and Processing. (4)** (Formerly numbered Electrical Engineering 238.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 131A. Key concepts, principles, and algorithms of online learning and learning how to make decisions under uncertainty in broad context, including Markov decision processes, optimal stopping, reinforcement learning, structural results for online learning, multi-armed bandits learning, multiagent learning, multiagent deep learning. Letter grading.
Ms. van der Schaar (Sp)

**239AS. Special Topics in Signals and Systems. (4)** (Formerly numbered Electrical Engineering 239AS.) Lecture, four hours; discussion, one hour; outside study, seven hours. Special topics in one or more aspects of signals and systems, such as communications, control, image processing, information theory, multimedia, computer networking, optimization, speech processing, telecommunications, and VLSI signal processing. May be repeated for credit with topic change. S/U or letter grading.
Ms. Fragouli (F,W)

**239BS. Seminar: Signals and Systems. (2 to 4)** (Formerly numbered Electrical Engineering 239BS.) Seminar, two to four hours; outside study, four to eight hours. Seminars and discussions on current and advanced topics in one or more aspects of signals and systems, such as communications, control, image processing, information theory, multimedia, computer networking, optimization, speech processing, telecommunications, and VLSI signal processing. May be repeated for credit with topic change. S/U grading.
Ms. Fragouli (Not offered 2019-20)

**M240A. Linear Dynamic Systems. (4)** (Formerly numbered Electrical Engineering M240A.) (Same as Chemical Engineering M280A and Mechanical and Aerospace Engineering M270A.) Lecture, four hours; outside study, eight hours. Requisite: course 141 or Mechanical and Aerospace Engineering 171A. State-space description of linear time-invariant (LTI) and time-varying (LTV) systems in continuous and discrete time. Linear algebra concepts such as eigenvalues and eigenvectors, singular values, Cayley/Hamilton theorem, Jordan form; solution of state equations; stability, controllability, observability, realizability, and minimality. Stabilization design via state feedback and observers; separation principle. Connections with transfer function techniques. Letter grading. Mr. Tabuada (F)

**M240C. Optimal Control. (4)** (Formerly numbered Electrical Engineering M240C.) (Same as Chemical Engineering M280C and Mechanical and Aerospace Engineering M270C.) Lecture, four hours; outside study, eight hours. Requisite: course 240B. Applications of variational methods, Pontryagin maximum principle, Hamilton/Jacobi/Bellman equation (dynamic programming) to optimal control of dynamic systems modeled by nonlinear ordinary differential equations. Letter grading. Mr. Tabuada (F)

**241A. Stochastic Processes. (4)** (Formerly numbered Electrical Engineering 241A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 131A. Review of basic probability, axiomatic development, expectation, convergence of random processes: stationarity, power spectral density. Response of linear systems to random inputs. Basics of estimation. Special random processes, Markov processes, martingales, etc. Letter grading. Mr. Diggavi (F)

**M242A. Nonlinear Dynamic Systems. (4)** (Formerly numbered Electrical Engineering M242A.) (Same as Chemical Engineering M282A and Mechanical and Aerospace Engineering M272A.) Lecture, four hours; outside study, eight hours. Requisite: course M240A or Chemical Engineering M280A or Mechanical and Aerospace Engineering M270A. State-space techniques for studying solutions of time-invariant and time-varying nonlinear dynamic systems with emphasis on stability. Lyapunov theory (including converse theorems), invariance, center manifold theorem, input-to-state stability and small-gain theorem. Letter grading. Mr. Tabuada (W)

**C243A. Neural Signal Processing. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 131A, Mathematics 33A. Topics include fundamental properties of electrical activity in neurons; technology for measuring neural activity; spiking statistics and Poisson processes; generative models and classification; regression and Kalman filtering; principal components analysis, factor analysis, and expectation maximization. Concurrently scheduled with course C143A. Letter grading. Mr. Kao (Sp)

**C247. Neural Networks and Deep Learning. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 131A, 133A or 205A, and M146, or equivalent. Review of machine learning concepts; maximum likelihood; supervised classification; neural network architectures; backpropagation; regularization for training neural networks; optimization for training neural networks; convolutional neural networks; practical CNN architectures; deep learning libraries in Python; recurrent neural networks, backpropagation through time, long short-term memory and gated recurrent units; varia-

tional autoencoders; generative adversarial networks; adversarial examples and training. Concurrently scheduled with course C147. Letter grading.
Mr. Kao (W)

**M248S. Seminar: Systems, Dynamics, and Control Topics. (2)** (Formerly numbered Electrical Engineering M248S.) (Same as Chemical Engineering M297 and Mechanical and Aerospace Engineering M299A.) Seminar, two hours; outside study, six hours. Limited to graduate engineering students. Presentations of research topics by leading academic researchers from fields of systems, dynamics, and control. Students who work in these fields present their papers and results. S/U grading.
Mr. Tabuada (Not offered 2019-20)

**M250B. Microelectromechanical Systems (MEMS) Fabrication. (4)** (Formerly numbered Electrical Engineering M250B.) (Same as Bioengineering M250B and Mechanical and Aerospace Engineering M280B.) Lecture, three hours; discussion, one hour; outside study, eight hours. Enforced requisite: course M153. Advanced discussion of micromachining processes used to construct MEMS. Coverage of many lithographic, deposition, and etching processes, as well as their combination in process integration. Materials issues such as chemical resistance, corrosion, mechanical properties, and residual/intrinsic stress. Letter grading. Mr. Candler (Not offered 2019-20)

**M252. Microelectromechanical Systems (MEMS) Device Physics and Design. (4)** (Formerly numbered Electrical Engineering M252.) (Same as Bioengineering M252 and Mechanical and Aerospace Engineering M282.) Lecture, four hours; discussion, one hour; outside study, seven hours. Introduction to MEMS design. Design methods, design rules, sensing and actuation mechanisms, microsensors, and microactuators. Designing MEMS to be produced with both foundry and nonfoundry processes. Computer-aided design for MEMS. Design project required. Letter grading. Mr. Candler (Sp)

**M255. Neuroengineering. (4)** (Formerly numbered Electrical Engineering M255.) (Same as Bioengineering M260 and Neuroscience M206.) Lecture, four hours; laboratory, three hours; outside study, five hours. Requisites: Mathematics 32A, Physics 1B or 5C. Introduction to principles and technologies of bioelectricity and neural signal recording, processing, and stimulation. Topics include bioelectricity, electrophysiology (action potentials, local field potentials, EEG, ECOG), intracellular and extracellular recording, microelectrode technology, neural signal processing (neural signal frequency bands, filtering, spike detection, spike sorting, stimulation artifact removal), brain-computer interfaces, deep-brain stimulation, and prosthetics. Letter grading. Mr. Markovic (F)

**M256A-M256B-M256C. Evaluation of Research Literature in Neuroengineering. (2–2-2)** (Formerly numbered Electrical Engineering M256A-M256B-M256C.) (Same as Bioengineering M261A-M261B-M261C and Neuroscience M212A-M212B-M212C.) Discussion, two hours; outside study, four hours. Critical discussion and analysis of current literature related to neuroengineering research. S/U grading.
Mr. Markovic (W)

**M257. Nanoscience and Technology. (4)** (Formerly numbered Electrical Engineering M257.) (Same as Mechanical and Aerospace Engineering M287.) Lecture, four hours; outside study, eight hours. Introduction to fundamentals of nanoscale science and technology. Basic physical principles, quantum mechanics, chemical bonding and nanostructures, top-down and bottom-up (self-assembly) nanofabrication; nanocharacterization; nanomaterials, nanoelectronics, and nanobiodetection technology. Introduction to new knowledge and techniques in nano areas to understand scientific principles behind nanotechnology and inspire students to create new ideas in multidisciplinary nano areas. Letter grading.
Mr. Chen (Not offered 2019-20)

**260A. Advanced Engineering Electrodynamics. (4)** (Formerly numbered Electrical Engineering 260A.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: courses 101B, 162A. Advanced treatment of concepts in electrodynamics and their applications to modern engineering problems. Vector calculus in generalized coordinate system. Solutions of wave equation and special functions. Reflection, transmission, and polarization. Vector potential, duality, reciprocity, and equivalence theorems. Scattering from cylinder, half-plane, wedge, and sphere, including radar cross-section characterization. Green's functions in electromagnetics and dyadic calculus. Letter grading.
Mr. Rahmat-Samii (F)

**260B. Advanced Engineering Electrodynamics. (4)** (Formerly numbered Electrical Engineering 260B.) Lecture, four hours; outside study, eight hours. Requisites: courses 101B, 162A, 260A. Advanced treatment of concepts and numerical techniques in electrodynamics and their applications to modern engineering problems. Differential geometry of curves and surfaces. Geometrical optics and geometrical theory of diffraction. Physical optics techniques. Asymptotic techniques and uniform theories. Integral equations in electromagnetics. Numerical techniques based on method of moments. Letter grading.
Mr. Rahmat-Samii (Not offered 2019-20)

**261. Microwave and Millimeter Wave Circuits. (4)** (Formerly numbered Electrical Engineering 261.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 163A. Rectangular and circular waveguides, microstrip, stripline, finline, and dielectric waveguide distributed circuits, with applications in microwave and millimeter wave integrated circuits. Substrate materials, surface wave phenomena. Analytical methods for discontinuity effects. Design of passive microwave and millimeter wave circuits. Letter grading. Mr. Itoh (W)

**262. Antenna Theory and Design. (4)** (Formerly numbered Electrical Engineering 262.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 162A. Antenna patterns. Sum and difference patterns. Optimum designs for rectangular and circular apertures. Arbitrary side lobe topography. Discrete arrays. Mutual coupling. Design of feeding networks. Letter grading.
Mr. Rahmat-Samii (F)

**263. Reflector Antennas Synthesis, Analysis, and Measurement. (4)** (Formerly numbered Electrical Engineering 263.) Lecture, four hours; outside study, eight hours. Requisites: courses 260A, 260B. Reflector pattern analysis techniques. Single and multi-reflector antenna configurations. Reflector synthesis techniques. Reflector feeds. Reflector tolerance studies, including systematic and random errors. Array-fed reflector antennas. Near-field measurement techniques. Compact range concepts. Microwave diagnostic techniques. Modern satellite and ground antenna applications. Letter grading.
Mr. Rahmat-Samii (Not offered 2019-20)

**266. Computational Methods for Electromagnetics. (4)** (Formerly numbered Electrical Engineering 266.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: courses 162A, 163A. Computational techniques for partial differential and integral equations: finite-difference, finite-element, method of moments. Applications include transmission lines, resonators, integrated circuits, solid-state device modeling, electromagnetic scattering, and antennas. Letter grading.
Mr. Itoh (Not offered 2019-20)

**270. Applied Quantum Mechanics. (4)** (Formerly numbered Electrical Engineering 270.) Lecture, four hours; discussion, one hour; outside study, seven hours. Preparation: modern physics (or course 123A), linear algebra, and ordinary differential equations courses. Principles of quantum mechanics for applications in lasers, solid-state physics, and nonlinear optics. Topics include eigenfunction expansions, observables, Schrödinger equation, uncertainty principle, central force problems, Hilbert spaces, WKB approximation, matrix mechanics, density matrix formalism, and radiation theory. Letter grading.
Mr. Stafsudd (F)

**271. Classical Laser Theory. (4)** (Formerly numbered Electrical Engineering 271.) Lecture, four hours; outside study, eight hours. Enforced requisite: course 170A. Microscopic and macroscopic laser phenomena and propagation of optical pulses using classical formalism. Letter grading. Mr. Joshi (W)

**272. Dynamics of Lasers. (4)** (Formerly numbered Electrical Engineering 272.) Lecture, four hours; outside study, eight hours. Requisite: course 271. Ultrashort laser pulse characteristics, generation, and measurement. Gain switching, Q switching, cavity dumping, active and passive mode locking. Pulse compression and soliton pulse formation. Nonlinear pulse generation: soliton laser, additive-pulse mode locking, and parametric oscillators. Pulse measurement techniques. Letter grading.
Mr. Liu (Not offered 2019-20)

**273. Nonlinear Photonics. (4)** (Formerly numbered Electrical Engineering 273.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 170A. Recommended: course 271. Nonlinear optical susceptibilities. Coupled-wave and coupled-mode theories. Crystal optics, electro-optics, and magneto-optics. Nonlinear optical interactions, sum- and difference-frequency generation, harmonic and parametric generation, stimulated Raman and Brillouin scattering, field-induced index changes and self-phase modulation. Nonlinear photonic devices. Nonlinear guided-wave photonics and devices. Letter grading. Mr. Liu (W)

**274. Optical Communication and Sensing Design. (4)** (Formerly numbered Electrical Engineering 274.) Lecture, three hours; outside study, nine hours. Requisites: courses 170A and 170B or equivalent. Top-down introduction to physical layer design in fiber optic communication systems, including Telecom, Datacom, and CATV. Fundamentals of digital and analog optical communication systems, fiber transmission characteristics, and optical modulation techniques, including direct and external modulation and computer-aided design. Architectural-level design of fiber optic transceiver circuits, including preamplifier, quantizer, clock and data recovery, laser driver, and predistortion circuits. Letter grading. Mr. Jalali (Sp)

**279AS. Special Topics in Physical and Wave Electronics. (4)** (Formerly numbered Electrical Engineering 279AS.) Lecture, four hours; discussion, on hour; outside study, seven hours. Special topics in one or more aspects of physical and wave electronics, such as electromagnetics, microwave and millimeter wave circuits, photonics and optoelectronics, plasma electronics, microelectromechanical systems, solid state, and nanotechnology. May be repeated for credit with topic change. S/U or letter grading. Mr. Y. Wang (W,Sp)

**279BS. Seminar: Physical and Wave Electronics. (2 to 4)** (Formerly numbered Electrical Engineering 279BS.) Seminar, two to four hours; outside study, four to eight hours. Seminars and discussions on current and advanced topics in one or more aspects of physical and wave electronics, such as electromagnetics, microwave and millimeter wave circuits, photonics and optoelectronics, plasma electronics, microelectromechanical systems, solid state, and nanotechnology. May be repeated for credit with topic change. S/U grading.
Mr. Y. Wang (Not offered 2019-20)

**279CS. Clean Green IGERT Brown-Bag Seminar. (1)** (Formerly numbered Electrical Engineering 279CS.) Seminar, one hour. Required of students in Clean Energy for Green Industry (IGERT) Research. Literature seminar presented by graduate students and experts from around country who conduct research in energy harvest, storage, and conservation. S/U grading. Mr. Y. Wang (Not offered 2019-20)

**CM282. Science, Technology, and Public Policy. (4)** (Formerly numbered Electrical Engineering CM282.) (Same as Public Policy CM282.) Lecture, three hours. Recent and continuing advances in science and technology are raising profoundly important public policy issues. Consideration of selection of critical policy issues, each of which has substantial ethical, social, economic, political, scientific, and technological aspects. Concurrently scheduled with course CM182. Letter grading. Mr. Villasenor (Not offered 2019-20)

**285A. Plasma Waves and Instabilities. (4)** (Formerly numbered Electrical Engineering 285A.) Lecture, four hours; outside study, eight hours. Requisites: courses 101A, and M185 or Physics M122. Wave phenomena in plasmas described by macroscopic fluid equations. Microwave propagation, plasma oscillations, ion acoustic waves, cyclotron waves, hydromagnetic waves, drift waves. Rayleigh/Taylor, Kelvin/Helmholtz, universal, and streaming instabilities. Application to experiments in fully and partially ionized gases. Letter grading. Mr. Mori (Not offered 2019-20)

**285B. Advanced Plasma Waves and Instabilities. (4)** (Formerly numbered Electrical Engineering 285B.) Lecture, four hours; outside study, eight hours. Requisites: courses M185, and 285A or Physics 222A. Interaction of intense electromagnetic waves with plasmas: waves in inhomogeneous and bounded plasmas, nonlinear wave coupling and damping, parametric instabilities, anomalous resistivity, shock waves, echoes, laser heating. Emphasis on experimental considerations and techniques. Letter grading. Mr. Joshi (Not offered 2019-20)

**M287. Fusion Plasma Physics and Analysis. (4)** (Formerly numbered Electrical Engineering M287.) (Same as Mechanical and Aerospace Engineering M237B.) Lecture, four hours; outside study, eight hours. Fundamentals of plasmas at thermonuclear burning conditions. Fokker/Planck equation and applications to heating by neutral beams, RF, and fusion reaction products. Bremsstrahlung, synchrotron, and atomic radiation processes. Plasma surface interactions. Fluid description of burning plasma. Dynamics, stability, and control. Applications in tokamaks, tandem mirrors, and alternate concepts. Letter grading. Mr. Chen, Mr. Joshi (Not offered 2019-20)

**M293. Intellectual Property for Technology Entrepreneurs and Managers. (2)** (Formerly numbered Electrical Engineering M293.) (Same as Management M247.) Seminar, two hours; outside study, four hours. Introduction to intellectual property (IP) in context of technology products and markets. Topics include best practices to put in place before product development starts, how to develop high-value patent portfolios, patent licensing, offensive and defensive IP litigation considerations, trade secrets, opportunities and pitfalls of open source software, trademarks, managing copyright in increasingly complex content ecosystems, and adopting IP strategies to globalized marketplaces. Includes case studies inspired by complex IP questions facing technology companies today. S/U or letter grading. Mr. Villasenor (Sp)

**295. Academic Technical Writing for Electrical Engineers. (3)** (Formerly numbered Electrical Engineering 295.) Seminar, three hours. Designed for electrical engineering PhD students who have completed preliminary examinations. Students read models of good writing and learn to make rhetorical observations and writing decisions, improve their academic and technical writing skills by writing and revising conference and journal papers, and practice writing for and speaking to various audiences, including potential students, engineers outside their specific fields, and nonengineers (colleagues outside field, policymakers, etc.). Students write in variety of genres, all related to their professional development as electrical engineers. Emphasis on writing as vital way to communicate precise technical and professional information in distinct contexts, directly resulting in specific outcomes. S/U grading. (W,Sp)

**296. Seminar: Research Topics in Electrical Engineering. (2)** (Formerly numbered Electrical Engineering 296.) Seminar, two hours; outside study, four hours. Advanced study and analysis of current topics in electrical engineering. Discussion of current research and literature in research specialty of faculty member teaching course. May be repeated for credit. S/U grading.

**297. Seminar Series: Electrical Engineering. (1)** (Formerly numbered Electrical Engineering 297.) Seminar, 90 minutes; outside study, 90 minutes. Limited to graduate electrical engineering students. Weekly seminars and discussion by invited speakers on research topics of heightened interest. S/U grading. (F,Sp)

**298. Seminar: Engineering. (2 to 4)** (Formerly numbered Electrical Engineering 298.) Seminar, to be arranged. Limited to graduate electrical engineering students. Seminars may be organized in advanced technical fields. If appropriate, field trips may be arranged. May be repeated with topic change. S/U or letter grading. (Not offered 2019-20)

**299. MS Project Seminar. (4)** (Formerly numbered Electrical Engineering 299.) Seminar, to be arranged. Required of all MS students not in thesis option. Supervised research in small groups or individually under guidance of faculty mentor. Regular meetings, culminating report, and presentation required. Individual contract required; enrollment petitions available in Office of Graduate Student Affairs. S/U grading. Ms. Jarrahi (F,W,Sp)

**375. Teaching Apprentice Practicum. (1 to 4)** (Formerly numbered Electrical Engineering 375.) Seminar, to be arranged. Preparation: apprentice personnel employment as teaching assistant, associate, or fellow. Teaching apprenticeship under active guidance and supervision of regular faculty member responsible for curriculum and instruction at UCLA. May be repeated for credit. S/U grading. (F,W,Sp)

**M495. Teaching Preparation Seminar: Teaching and Writing Pedagogies for Electrical Engineers. (2)** (Formerly numbered Electrical Engineering M495.) (Same as English Composition M495K). Seminar, two hours. Limited to graduate electrical engineering students. Required of all departmental teaching assistants (TAs). May be taken concurrently while holding a TA appointment. Seminar on pedagogy and logistics of being a TA with emphasis on student-centered teaching, clear communication, and multimodal teaching and learning. S/U grading. Ms. Alwan (F)

**596. Directed Individual or Tutorial Studies. (2 to 8)** (Formerly numbered Electrical Engineering 596.) Tutorial, to be arranged. Limited to graduate electrical engineering students. Petition forms to request enrollment may be obtained from assistant dean, Graduate Studies. Supervised investigation of advanced technical problems. S/U grading.

**597A. Preparation for MS Comprehensive Examination. (2 to 12)** (Formerly numbered Electrical Engineering 597A.) Tutorial, to be arranged. Limited to graduate electrical engineering students. Reading and preparation for MS comprehensive examination. S/U grading.

**597B. Preparation for PhD Preliminary Examinations. (2 to 16)** (Formerly numbered Electrical Engineering 597B.) Tutorial, to be arranged. Limited to graduate electrical engineering students. S/U grading.

**597C. Preparation for PhD Oral Qualifying Examination. (2 to 16)** (Formerly numbered Electrical Engineering 597C.) Tutorial, to be arranged. Limited to graduate electrical engineering students. Preparation for oral qualifying examination, including preliminary research on dissertation. S/U grading.

**598. Research for and Preparation of MS Thesis. (2 to 12)** (Formerly numbered Electrical Engineering 598.) Tutorial, to be arranged. Limited to graduate electrical engineering students. Supervised independent research for MS candidates, including thesis prospectus. S/U grading.

**599. Research for and Preparation of PhD Dissertation. (2 to 16)** (Formerly numbered Electrical Engineering 599.) Tutorial, to be arranged. Limited to graduate electrical engineering students. Usually taken after students have been advanced to candidacy. S/U grading.

# Materials Science and Engineering

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Los Angeles, CA 90095-1595

310-825-5534
**https://www.mse.ucla.edu**

Bruce S. Dunn, Ph.D., *Chair*
Yu Huang, Ph.D., *Vice Chair*
Ya-Hong Xie, Ph.D., *Vice Chair*

## Professors

Gregory P. Carman, Ph.D.
Jane P. Chang, Ph.D. *(William Frederick Seyer Professor of Materials Electrochemistry)*
Yong Chen, Ph.D.
Bruce S. Dunn, Ph.D. *(Nippon Sheet Glass Company Professor of Materials Science)*
Nasr M. Ghoniem, Ph.D.
Mark S. Goorsky, Ph.D.
Vijay Gupta, Ph.D.
Yu Huang, Ph.D.
Subramanian S. Iyer, Ph.D.
Ioanna Kakoulli, D.Phil.
Richard B. Kaner, Ph.D.
Suneel Kodambaka, Ph.D.
Xiaochun Li, Ph.D.
Ali Mosleh, Ph.D., NAE *(Evalyn Knight Professor of Engineering)*
Qibing Pei, Ph.D.
Gaurav N. Sant, Ph.D. *(Henry Samueli Fellow)*
Dwight C. Streit, Ph.D.
Sarah H. Tolbert, Ph.D.
Kang L. Wang, Ph.D. *(Raytheon Company Professor of Electrical Engineering)*
Paul S. Weiss, Ph.D. *(Presidential Professor of Chemistry)*
Benjamin M. Wu, D.D.S., Ph.D.
Ya-Hong Xie, Ph.D.
Jenn-Ming Yang, Ph.D.
Yang Yang, Ph.D. *(Carol and Lawrence E. Tannas, Jr., Endowed Professor of Engineering)*

## Professors Emeriti

Alan J. Ardell, Ph.D.
David L. Douglass, Ph.D.
John D. Mackenzie, Ph.D. *(Nippon Sheet Glass Company Professor Emeritus of Materials Science)*
Kanji Ono, Ph.D.
King-Ning Tu, Ph.D

## Associate Professor

Jaime Marian, Ph.D.

## Assistant Professors

Amartya Banerjee, Ph.D.
Ximin He, Ph.D.
Aaswath P. Raman, Ph.D.

## Adjunct Associate Professors

Eric P. Bescher, Ph.D.
Sergey Prikhodko, Ph.D.

## Adjunct Assistant Professors

Magdalena Balonis-Sant, Ph.D.
Marta Pozuelo, Ph.D.

## Scope and Objectives

At the heart of materials science and engineering is the understanding and control of the microstructure of solids. Microstructure is used broadly in reference to electronic and atomic structure of solids—and defects within them—at size scales ranging from atomic bond lengths to airplane wings. The structure of solids over this wide range dictates their structural, electrical, biological, and chemical properties. The phenomenological and mechanistic relationships between microstructure and the macroscopic properties of solids are, in essence, what materials science is all about.

Materials engineering builds on the foundation of materials science and is concerned with the design, fabrication, and optimal selection of engineering materials that must simultaneously fulfill dimensional, property, quality control, and economic requirements.

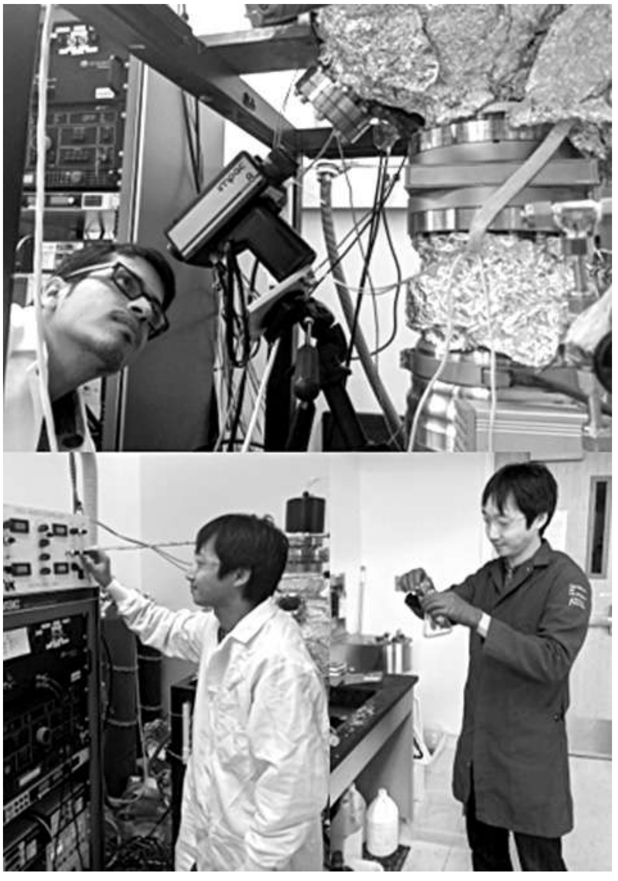
The undergraduate program in the Department of Materials Science and Engineering leads to the B.S. degree in Materials Engineering. Students are introduced to the basic principles of metallurgy and ceramic and polymer science as part of the department's Materials Engineering major. A joint major field, Chemistry/Materials Science, is offered to students enrolled in the Department of Chemistry and Biochemistry (College of Letters and Science).

The department also has a program in electronic materials that provides a broad-based background in materials science, with opportunity to specialize in the study of those materials used for electronic and optoelectronic applications. The program incorporates several courses in electrical and computer engineering in addition to those in the materials science curriculum.

The graduate program allows for specialization in one of the following fields: ceramics and ceramic processing, electronic and optical materials, and structural materials.

## Department Mission

The Department of Materials Science and Engineering faculty members, students, and alumni foster a collegial atmosphere to produce (1) highly qualified students through an educational program that cultivates excellence, (2) novel and highly innovative research that advances basic and applied knowledge in materials, and (3) effective interactions with the external community through educational outreach, industrial collaborations, and service activities.



*Graduate students Aditya Deshpande (top) and Koichi Tanaka (bottom) carry out in situ growth and characterization of high-quality crystalline thin films in professor Suneel Kodambaka's laboratory.*

## Undergraduate Program Educational Objectives

The materials engineering program is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

The Materials Engineering major at UCLA prepares undergraduate students for employment and/or advanced studies within industry, the national laboratories, state and federal agencies, and academia. To meet the needs of these constituencies, the objectives of the undergraduate program are to produce graduates who (1) possess a solid foundation in materials science and engineering, with emphasis on the fundamental scientific and engineering principles that govern the microstructure, properties, processing, and performance of all classes of engineering materials, (2) understand materials processes and the application of general natural science and engineering principles to the analysis and design of materials systems of current and/or future importance to society, (3) have strong skills in independent learning, analysis, and problem solving, with special emphasis on design of engineering materials and processes, communication, and an ability to work in teams, and (4) understand and are aware of the broad issues relevant to materials, including professional and ethical responsibilities, impact of materials engineering on society and environment, contemporary issues, and need for lifelong learning.

## Undergraduate Study

The Materials Engineering major is a designated capstone major. Students undertake two individual projects involving materials selection, treatment, and serviceability. Successful completion requires working knowledge of physical properties of materials and strategies and methodologies of using materials properties in the materials selection process. Students learn and work independently and practice leadership and teamwork in and across disciplines. They are also expected to communicate effectively in oral, graphic, and written forms.

## Materials Engineering B.S.

***Capstone Major***

The materials engineering program is designed for students who wish to pursue a professional career in the materials field and desire a broad understanding of the relationship between microstructure and properties of materials. Metals, ceramics, and polymers, as well as the design, fabrication, and testing of metallic and other materials such as oxides, glasses, and fiber-reinforced composites, are included in the course contents.

## Learning Outcomes

The Materials Engineering major has the following learning outcomes:

- Application of knowledge of mathematics, natural science, and engineering to analysis of materials and other systems
- Learn and work independently
- Practice leadership and teamwork in and across disciplines
- Design of a system, component, or process to meet desired needs
- Effective oral, graphic, and written communication
- Identification, formulation, and solution of engineering problems

## Materials Engineering Option

### Preparation for the Major

*Required:* Chemistry and Biochemistry 20A, 20B, 20L; Civil and Environmental Engineering M20 or Computer Science 31 or Mechanical and Aerospace Engineering M20; Materials Science and Engineering 10, 90L; Mathematics 31A, 31B, 32A, 32B, 33A, 33B (or Mechanical and Aerospace Engineering 82); Physics 1A, 1B, 1C.

### The Major

*Required:* Civil and Environmental Engineering 91 (or Mechanical and Aerospace Engineering 101), 108, Electrical and Computer Engineering 100, Materials Science and Engineering 104, 110, 110L, 120, 130, 131, 131L, 132, 143A, 150, 160; one upper-division mathematics course selected from Civil and Environmental Engineering 103, Electrical and Computer Engineering 102, Mathematics 132, Mechanical and Aerospace Engineering 182B, 182C; two laboratory courses (4 units) from Materials Science and Engineering 121L, 141L, 143L, 161L, or up to 2 units of 199; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; two capstone design courses (Materials Science and Engineering 140A and 140B); and two major field elective courses (8 units) from Chemical Engineering CM114, Civil and Environmental Engineering 130, 135A, Electrical and Computer Engineering 2, 123A, 123B, Materials Science and Engineering 111, C112, 121, 122, 151, 161, 162, Mechanical and Aerospace Engineering 156A, 166C, plus at least one elective course (4 units) from Chemistry and Biochemistry 30A, 30AL, Electrical and Computer Engineering 131A, Materials Science and Engineering 170, 171, Mathematics 170A, or Statistics 100A.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

## Electronic Materials Option

### Preparation for the Major

*Required:* Chemistry and Biochemistry 20A, 20B, 20L; Civil and Environmental Engineering M20 or Computer Science 31 or Mechanical and Aerospace Engineering M20; Materials Science and Engineering 10, 90L; Mathematics 31A, 31B, 32A, 32B, 33A, 33B (or Mechanical and Aerospace Engineering 82); Physics 1A, 1B, 1C.

### The Major

*Required:* Electrical and Computer Engineering 100, 101A, 121B, Materials Science and Engineering 104, 110, 110L, 120, 121, 121L, 122, 130, 131, 131L, 132, Mechanical and Aerospace Engineering 101; one upper-division mathematics course selected from Civil and Environmental Engineering 103, Electrical and Computer Engineering 102, Mathematics 132, Mechanical and Aerospace Engineering 182B, 182C; either Materials Science and Engineering 150 or 160 and one course (4 units) from Electrical and Computer Engineering 123A, 123B, Materials Science and Engineering 150, 160; 4 laboratory units from Materials Science and Engineering 141L, 161L, or up to 2 units of 199; three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; two capstone design courses (Materials Science and Engineering 140A and 140B); and one major field elective course (4 units) from Electrical and Computer Engineering 110, 131A, Materials Science and Engineering 111, C112, 143A, or 162.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

# Graduate Study

For information on graduate admission, see Graduate Programs on page 26.

The following introductory information is based on 2019-20 program requirements for UCLA graduate degrees. Complete program requirements are available at https://grad.ucla.edu/academics/graduate-study/program-requirements-for-ucla-graduate-degrees/. Students are subject to the detailed degree requirements as published in program requirements for the year in which they enter the program.

The Department of Materials Science and Engineering offers Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees in Materials Science and Engineering.

# Materials Science and Engineering M.S.

## Areas of Study

There are three main areas in the M.S. program: ceramics and ceramic processing, electronic and optical materials, and structural materials. Students may specialize in any one of the three areas, although most students are more interested in a broader education and select a variety of courses. Basically, students select courses that serve their interests best in regard to thesis research and job prospects.

## Course Requirements

*Thesis Plan.* Nine courses are required, of which six must be graduate courses. The courses are to be selected from the following lists, although suitable substitutions can be made from other engineering disciplines or from chemistry and physics with the approval of the departmental graduate adviser. Two of the six graduate courses may be Materials Science and Engineering 598 (thesis research).

*Comprehensive Examination Plan.* Nine courses are required, six of which must be graduate courses, selected from the following lists with the same provisions listed under the thesis plan. Three of the nine courses may be upper-division courses.

Ceramics and ceramic processing: Materials Science and Engineering 121, 122, 143A, 151, 161, 162, 200, 201, 210, 211, 246D, 298.

Electronic and optical materials: Materials Science and Engineering 121, 122, 143A, 151, 161, 162, 200, 201, 210, 221, 222, 223, 298.

Structural materials: Materials Science and Engineering 121, 122, 143A, 151, 161, 162, 200, 201, 210, 211, 243A, 243C, 250B, 298.

As long as a majority of the courses taken are offered by the department, substitutions may be made with the consent of the departmental graduate adviser.

*Undergraduate Courses.* No lower-division courses may be applied toward graduate degrees. In addition, the following upper-division courses are not applicable toward graduate degrees: Chemical Engineering 102A, 199, Civil and Environmental Engineering 108, 199, Computer Science M152A, 152B, M171L, 199, Electrical and Computer Engineering 100, 101A, 102, 110L, M116L, 133A, M171L, 199, Materials Science and Engineering 110, 120, 130, 131, 131L, 132, 140, 141L, 150, 160, 161L, 199, Mechanical and Aerospace Engineering 102, 103, 105A, 105D, 199.

## Thesis Plan

In addition to the course requirements, under the thesis plan students are required to write a thesis on a research topic in materials science and engineering supervised by the thesis adviser. An M.S. thesis committee approves the thesis.

### Comprehensive Examination Plan

Consult the graduate adviser for details. If the comprehensive examination is failed, students may be reexamined once with the consent of the graduate adviser.

## Materials Science and Engineering Ph.D.

### Major Fields or Subdisciplines

Ceramics and ceramic processing, electronic and optical materials, and structural materials.

### Course Requirements

There is no formal course requirement for the Ph.D. degree, and students may substitute coursework by examinations. Normally, however, students take courses to acquire the knowledge needed to satisfy the written preliminary examination requirement. In this case, a grade-point average of at least 3.33 in all courses is required, with a grade of B– or better in each course.

The basic program of study for the Ph.D. degree is built around one major field and one minor field. The major field has a scope corresponding to a body of knowledge contained in nine courses, at least six of which must be graduate courses, plus the current literature in the area of specialization. Materials Science and Engineering 599 may not be applied toward the nine-course total. The major fields named above are described in a Ph.D. major field syllabus, each of which can be obtained in the department office.

The minor field normally embraces a body of knowledge equivalent to three courses, at least two of which are graduate courses. If students fail to satisfy the minor field requirements through coursework, a minor field examination may be taken (once only). The minor field is selected to support the major field and is usually a subset of the major field.

### Written and Oral Qualifying Examinations

During the first year of full-time enrollment in the Ph.D. program, students take the oral preliminary examination that encompasses the body of knowledge in materials science equivalent to that expected of a bachelor's degree. If students opt not to take courses, a written preliminary examination in the major field is required. Students may not take an examination more than twice.

After passing both preliminary examinations, students take the University Oral Qualifying Examination. The nature and content of the examination are at the discretion of the doctoral committee but ordinarily include a broad inquiry into the student's preparation for research. The doctoral committee also reviews the prospectus of the dissertation at the oral qualifying examination.

*Note: Doctoral Committees.* A doctoral committee consists of a minimum of four members. Three members, including the chair, are inside members and must hold appointments in the department. The outside member must be a UCLA faculty member in another department. Faculty members holding joint appointments with the department are considered inside members.

## Fields of Study

### Ceramics and Ceramic Processing

The ceramics and ceramic processing field is designed for students interested in ceramics and glasses, including electronic materials. As in the case of metallurgy, primary and secondary fabrication processes such as vapor deposition, sintering, melt forming, or extrusion strongly influence the microstructure and properties of ceramic components used in structural, electronic, or biological applications. Formal course and research programs emphasize the coupling of processing treatments, microstructure, and properties.

### Electronic and Optical Materials

The electronic and optical materials field provides an area of study in the science and technology of electronic materials that includes semiconductors, optical ceramics, and thin films (metal, dielectric, and multilayer) for electronic and optoelectronic applications.

Course offerings emphasize fundamental issues such as solid-state electronic and optical phenomena, bulk and interface thermodynamics and kinetics, and applications that include growth, processing, and characterization techniques. Active research programs address the relationship between microstructure and nanostructure and electronic/optical properties in these materials systems.

### Structural Materials

The structural materials field is designed primarily to provide broad understanding of the relationships between processing, microstructure, and performance of various structural materials, including metals, intermetallics, ceramics, and composite materials. Research programs include material synthesis and processing, ion implantation-induced strengthening and toughening, mechanisms and mechanics of fatigue, fracture and creep, structure/property characterization, nondestructive evaluation, high-temperature stability, and aging of materials.

## Facilities

Facilities in the Materials Science and Engineering Department include

- Ceramic Processing Laboratory
- Glass and Ceramics Research laboratories
- Mechanical Testing Laboratory
- Metallographic Sample Preparation Laboratory
- Microscopy laboratories with a transmission electron microscope (100 keV), access to several field-emission transmission electron microscopes (80–300 keV), and a scanning electron microscope equipped with a quantitative chemical/compositional analyzer, a stereo microscope, micro-cameras, and metallurgical microscopes
- Nano-Materials Laboratory
- Nondestructive Testing Laboratory
- Organic Electronic Materials Processing Laboratory
- Semiconductor and Optical Characterization Laboratory
- Thin Film Deposition Laboratory, including molecular beam epitaxy and wafer bonders
- X-Ray Diffraction Laboratory
- X-Ray Photoelectron Spectroscopy and Atomic Force Microscopy Facility

## Faculty Areas of Thesis Guidance

#### Professors

Gregory P. Carman, Ph.D. (Virginia Tech, 1991)
*Electromagnetoelasticity models and characterization, thin film shape memory, nanoscale multiferroics, magnetoelastics and piezoelectric materials*

Jane P. Chang, Ph.D. (MIT, 1998)
*Materials processing, gas-phase and surface reaction, plasma enhanced chemistries, atomic layer deposition, chemical microelectromechanical systems, and computational surface chemistry*

Yong Chen, Ph.D. (UC Berkeley, 1996)
*Nanoscale science and engineering, micro- and nano-fabrication, self-assembly phenomena, microscale and nanoscale electronic, mechanical, optical, biological, and sensing devices, circuits and systems*

Bruce S. Dunn, Ph.D. (UCLA, 1974)
*Synthesis and characterization of electromechanical materials, energy storage, sol-gel materials and chemistry*

Nasr M. Ghoniem, Ph.D. (U. Wisconsin, 1977)
*Mechanical behavior of high-temperature materials, radiation interaction with material (e.g., laser, ions, plasma, electrons, and neutrons), material processing by plasma and beam sources, physics and mechanics of material defects, fusion energy*

Mark S. Goorsky, Ph.D. (MIT, 1989)
*Electronic materials processing, strain relaxation in epitaxial semiconductors and device structures, high-resolution X-ray diffraction of semiconductors, ceramics, and high-strength alloys*

Vijay Gupta, Ph.D. (MIT, 1989)
*Experimental mechanics, fracture of engi neering solids, mechanics of thin film and interfaces, failure mechanisms and characterization of composite materials, ice mechanics*

Yu Huang, Ph.D. (Harvard, 2003)
*Nano-material fabrication and development, bio-nano structures*

Subramanian S. Iyer, Ph.D. (UCLA, 1981)
*System scaling technology, advanced packaging and 3D integration, technologies and techniques for memory subsystem integration and neuromorphic computing*

Ioanna Kakoulli, D.Phil. (Oxford, England, 1999)
*Chemical and physical properties of nonmetallic archaeological materials; alteration processes in archaeological vitreous materials and pigments*

Richard B. Kaner, Ph.D. (U. Pennsylvania, 1984)
*Synthesis, characterization, and applications of superhard metals, conducting polymers, thermoelectrics and graphene*

Suneel Kodambaka, Ph.D. (U. Illinois Urbana-Champaign, 2002)
*In situ microscopy, surface thermodynamics, kinetics of crystal growth, phase transformations and chemical reactions, thin film physics*

Xiaochun Li, Ph.D. (Stanford, 2001)
*Scifacturing (science-driven manufacturing), super metals by nanoparticles self-dispersion, scalable nanomanufacturing, smart manufacturing, additive manufacturing*

Ali Mosleh, Ph.D., NAE (UCLA, 1981)
*Reliability engineering, physics of failure modeling and system life prediction, resilient systems design, prognostics and health monitoring, hybrid systems simulation, theories and techniques for risk and safety analysis*

Qibing Pei, Ph.D. (Chinese Academy of Sciences, China, 1990)
*Electroactive polymers through molecular design and nano-engineering for electronic devices and artificial muscles*

Gaurav N. Sant, Ph.D. (Purdue, 2009)
*Development and design of sustainable low-$CO_2$ footprint materials for infrastructure construction applications*

Dwight C. Streit, Ph.D. (UCLA, 1986)
*Properties of electronic materials, characterization techniques, correlation of material and device performance*

Sarah H. Tolbert, Ph.D. (UC Berkeley, 1995)
*Self-organized nanostructured materials for energy storage, energy harvesting, nanomagnetics and nanoelectronics*

Kang L. Wang, Ph.D. (MIT, 1970)
*Nanoscale physics, materials and devices nanoelectronics, magnetics and photonics, nonlinear interactions of correlated devices and nanosystems*

Paul S. Weiss, Ph.D. (UC Berkeley, 1986)
*Atomic-scale surface chemistry and physics, molecular devices, nanolithography, biophysics and neuroscience, nanometer-scale electronics and storage, surface interactions, surface motion, dynamics, and direct manipulation, extending capabilities of scanning tunneling microscope, molecular-scale control and measurement of composition and properties in membranes*

Benjamin M. Wu, D.D.S. (U. Pacific, 1987), Ph.D. (MIT, 1997)
*Processing, characterization, and controlled delivery of biological molecules of bioerodible polymers; design and fabrication of tissue engineering scaffolds and precursor tissue analogs; tissue-material interactions and dental biomaterials*

Ya-Hong Xie, Ph.D. (UCLA, 1986)
*Physical properties and device application of graphene and other van der Waals materials; semiconductor physics, heterostructures, and devices; epitaxy pf semiconductor thin films; nanofabrication*

Jenn-Ming Yang, Ph.D. (U. Delaware, 1986)
*Nanomechanical testing, nanostructured materials, ceramic and ceramic matrix composites, hybrid materials and composites, material synthesis and processing*

Yang Yang, Ph.D. (U. Massachusetts Lowell, 1992)
*Organic and inorganic semiconductor materials and devices with emphasis on solution processes; fundamental understanding of material properties; optoelectronic devices (LEDs, PVs, TFT, sensors)*

### Professors Emeriti

Alan J. Ardell, Ph.D. (Stanford, 1964)
*Irradiation-induced precipitation, high-temperature deformation of solids, electron microscopy, physical metallurgy of aluminum/lithium alloys, precipitation hardening*

David L. Douglass, Ph.D. (Ohio State, 1958)
*Oxidation and sulfidation kinetics and mechanisms, materials compatibility, defect structures, diffusion*

John D. Mackenzie, Ph.D. (Imperial C. London, England, 1954)
*Glass science, ceramics, electrical properties of amorphous materials, materials recycling*

Kanji Ono, Ph.D. (Northwestern U., 1964)
*Mechanical behavior and nondestructive testing of structural materials, acoustic emission, dislocations and strengthening mechanisms, microstructural effects, and ultrasonics*

King-Ning Tu, Ph.D. (Harvard, 1968)
*Kinetic processes in thin films, metal-silicon interfaces, electromigration, Pb-free interconnects, 3D IC packaging*

### Associate Professor

Jaime Marian, Ph.D. (UC Berkeley, 2002)
*Computational materials modeling and simulation in solid mechanics, irradiation damage, plasticity, phase transformations, thermodynamics and kinetics of alloy systems, algorithm and method development for bridging time and length scales and parallel computing applications*

### Assistant Professors

Amartya Banerjee, Ph.D. (U. Minnesota, 2013)
*Computational materials science, first principles methods, discovery and simulation of novel materials, electronic materials, energy materials, multiscale methods and algorithms, merchanics of materials and structures, numerical methods and scientific computation*

Ximin He, Ph.D. (U. Cambridge, England, 2011)
*Biologically inspired materials based on stimuli-responsive polymers and micro-/nanostructure fabrication for applications in biomedicine, environment, and energy*

Aaswath P. Raman, Ph.D. (Stanford, 2013)
*Metamaterials, optical and photonic materials, nanophotonics, plasmonics, thermal sciences, energy systems, computational methods*

### Adjunct Associate Professors

Eric P. Bescher, Ph.D. (UCLA, 1987)
*Advanced cementitious materials, sol-gel materials, organic/inorganic hybrids*

Sergey Prikhodko, Ph.D. (Kurdyumov Institute for Metal Physics NASU, Ukraine, 1994)
*Characterization of materials by means of microscopes and spectroscopes*

### Adjunct Assistant Professors

Magdalena Balonis-Sant, Ph.D. (U. Aberdeen, Scotland, 2010)
*Development of functional materials for extending the service life of concrete infrastructure, design of new cementation agents with reduced $CO^2$ footprint, conservation and protection of cultural heritage*

Marta Pozuelo, Ph.D. (Complutense U. Madrid, Spain, 2004)
*In situ nanomechanical characterization of metallic materials*

## Lower-Division Courses

**10. Freshman Seminar: New Materials. (1)** Seminar, one hour; outside study, two hours. Preparation: high school chemistry and physics. Not open to students with credit for course 104. Introduction to basic concepts of materials science and new materials vital to advanced technology. Microstructural analysis and various material properties discussed in conjunction with such applications as biomedical sensors, pollution control, and microelectronics. Letter grading. Mr. Kodambaka (F)

**19. Fiat Lux Freshman Seminars. (1)** Seminar, one hour. Discussion of and critical thinking about topics of current intellectual importance, taught by faculty members in their areas of expertise and illuminating many paths of discovery at UCLA. P/NP grading.

**90L. Physical Measurement in Materials Engineering. (2)** Laboratory, four hours; outside study, two hours. Various physical measurement methods used in materials science and engineering. Mechanical, thermal, electrical, magnetic, and optical techniques. Letter grading. Mr. Kodambaka (W,Sp)

**99. Student Research Program. (1 to 2)** Tutorial (supervised research or other scholarly work), three hours per week per unit. Entry-level research for lower-division students under guidance of faculty mentor. Students must be in good academic standing and enrolled in minimum of 12 units (excluding this course). Individual contract required; consult Undergraduate Research Center. May be repeated. P/NP grading.

## Upper-Division Courses

**104. Science of Engineering Materials. (4)** Lecture, three hours; discussion, one hour; outside study, eight hours. Requisites: Chemistry 20A, 20B, 20L, Physics 1A, 1B. General introduction to different types of materials used in engineering designs: metals, ceramics, plastics, and composites, relationship between structure (crystals and microstructure) and properties of technological materials. Illustration of their fundamental differences and their applications in engineering. Letter grading. Mr. Dunn (F,W,Sp)

**M105. Principles of Nanoscience and Nanotechnology. (4)** (Same as Engineering M101.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Chemistry 20A, 20B, Physics 1C. Introduction to underlying science encompassing structure, properties, and fabrication of technologically important nanoscale systems. New phenomena that emerge in very small systems (typically with feature sizes below few hundred nanometers) explained using basic concepts from physics and chemistry. Chemical, optical, and electronic properties, electron transport, structural stability, self-assembly, templated assembly and applications of various nanostructures such as quantum dots, nanoparticles, quantum wires, quantum wells and multilayers, carbon nanotubes. Letter grading. Mr. Kodambaka (F)

**110. Introduction to Materials Characterization A (Crystal Structure, Nanostructures, and X-Ray Scattering). (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 104. Modern methods of materials characterization; fundamentals of crystallography, properties of X rays, X-ray scattering; powder method, Laue method; determination of crystal structures; phase diagram determination; high-resolution X-ray diffraction methods; X-ray spectroscopy; design of materials characterization procedures. Letter grading. Mr. Goorsky (F)

**110L. Introduction to Materials Characterization A Laboratory. (2)** Laboratory, four hours; outside study, two hours. Enforced requisite: course 104. Experimental techniques and analysis of materials through X-ray scattering techniques; powder method, crystal structure determination, high-resolution X-ray diffraction methods, and special projects. Letter grading. Mr. Goorsky (F)

**111. Introduction to Materials Characterization B (Electron Microscopy). (4)** Lecture, three hours; laboratory, two hours; outside study, seven hours. Requisites: courses 104, 110. Characterization of microstructure and microchemistry of materials; transmission electron microscopy; reciprocal lattice, electron diffraction, stereographic projection, direct observation of defects in crystals, replicas; scanning electron microscopy: emissive and reflective modes; chemical analysis; electron optics of both instruments. Letter grading. Mr. Kodambaka (W)

**C112. Cultural Materials Science II: Characterization Methods in Conservation of Materials. (4)** Lecture, four hours. Preparation: general chemistry, inorganic and organic chemistry, materials science. Principles and methods of materials characterization in conservation: optical and electron microscopy, X-ray and electron spectroscopy, X-ray diffraction, infrared spectroscopy, reflectance spectroscopy and multispectral imaging spectroscopy, chromatography, design of archaeological and ethnographic materials characterization procedures. Concurrently scheduled with course CM212. Letter grading. Ms. Kakoulli (Sp)

**120. Physics of Materials. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 104, 110 (or Chemistry 113A). Introduction to electrical, optical, and magnetic properties of solids. Free electron model, introduction to band theory and Schrödinger wave equation. Crystal bonding and lattice vibrations. Mechanisms and characterization of electrical conductivity, optical absorption, magnetic behavior, dielectrical properties, and p-n junctions. Letter grading. Mr. Y. Yang (W)

**121. Materials Science of Semiconductors. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 120. Structure and properties of elemental and compound semiconductors. Electrical and optical properties, defect chemistry, and doping. Electronic materials analysis and characterization, including electrical, optical, and ion-beam techniques. Heterostructures, band-gap engineering, development of new materials for optoelectronic applications. Letter grading. Ms. Huang (Sp)

**121L. Materials Science of Semiconductors Laboratory. (2)** Lecture, 30 minutes; discussion, 30 minutes; laboratory, two hours; outside study, three hours. Enforced corequisite: course 121. Experiments conducted on materials characterization, including measurements of contact resistance, dielectric constant, and thin film biaxial modulus and CTE. Letter grading. Mr. Goorsky (Sp)

**122. Principles of Electronic Materials Processing. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 104. Description of basic semiconductor materials for device processing; preparation and characterization of silicon, III-V compounds, and films. Discussion of principles of CVD, MOCVD, LPE, and MBE; metals and dielectrics. Letter grading. Mr. Goorsky (W)

**130. Phase Relations in Solids. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 104. Summary of thermodynamic laws, equilibrium criteria, solution thermodynamics, mass-action law, binary and ternary phase diagrams, glass transitions. Letter grading. Mr. Xie (F)

**131. Diffusion and Diffusion-Controlled Reactions. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 130 or Chemistry 110A. Diffusion in metals and ionic solids, nucleation and growth theory; precipitation from solid solution, eutectoid decomposition, design of heat treatment processes of alloys, growth of intermediate phases, gas-solid reactions, design of oxidation-resistant alloys, recrystallization, and grain growth. Letter grading. Mr. Dunn (W)

**131L. Diffusion and Diffusion-Controlled Reactions Laboratory. (2)** Laboratory, two hours; outside study, four hours. Enforced corequisite: course 131. Design of heat-treating cycles and performing experiments to study interdiffusion, growth of intermediate phases, recrystallization, and grain growth in metals. Analysis of data. Comparison of results with theory. Letter grading. Mr. Kodambaka (W)

**132. Structure and Properties of Metallic Alloys. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 131. Physical metallurgy of steels, lightweight alloys (Al and Ti), and superalloys. Strengthening mechanisms, microstructural control methods for strength and toughness improvement. Grain boundary segregation. Letter grading. Mr. J-M. Yang (Sp)

**140A. Materials Selection and Engineering Design A. (3)** Lecture, two hours; laboratory, two hours; outside study, five hours. Enforced requisites: two courses from 132, 150, 160. Explicit guidance among myriad materials available for design in engineering. Properties and applications of steels, nonferrous alloys, polymeric, ceramic, and composite materials, coatings. Materials selection, treatment, and serviceability emphasized as part of successful design. Design projects. Letter grading. Mr. J-M. Yang (W)

**140B. Materials Selection and Engineering Design B. (3)** (Formerly numbered 140.) Lecture, two hours; laboratory, two hours; outside study, five hours. Enforced requisite: course 140A. Explicit guidance among myriad materials available for design in engineering. Properties and applications of steels, nonferrous alloys, polymeric, ceramic, and composite materials, coatings. Materials selection, treatment, and serviceability emphasized as part of successful design. Design projects. Letter grading. Mr. J-M. Yang (Sp)

**141L. Computer Methods and Instrumentation in Materials Science. (2)** Laboratory, four hours. Preparation: knowledge of BASIC or C or assembly language. Limited to junior/senior Materials Science and Engineering majors. Interface and control techniques, real-time data acquisition and processing, computer-aided testing. Letter grading. Mr. Goorsky (W)

**143A. Mechanical Behavior of Materials. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: course 104, Mechanical and Aerospace Engineering 101. Plastic flow of metals under simple and combined loading, strain rate and temperature effects, dislocations, fracture, microstructural effects, mechanical and thermal treatment of steel for engineering applications. Letter grading. Mr. Marian (W)

**143L. Mechanical Behavior Laboratory. (2)** Laboratory, four hours. Requisites: courses 90L, 143A (may be taken concurrently). Methods of characterizating mechanical behavior of various materials; elastic and plastic deformation, fracture toughness, fatigue, and creep. Letter grading. Mr. Marian (Not offered 2019-20)

**150. Introduction to Polymers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Polymerization mechanisms, molecular weight and distribution, chemical structure and bonding, structure crystallinity, and morphology and their effects on physical properties. Glassy polymers, springy polymers, elastomers, adhesives. Fiber forming polymers, polymer processing technology, plasticiation. Letter grading. Mr. Pei (W)

**151. Structure and Properties of Composite Materials. (4)** Lecture, four hours; outside study, eight hours. Preparation: at least two courses from 132, 143A, 150, 160. Requisite: course 104. Relationship between structure and mechanical properties of composite materials with fiber and particulate reinforcement. Properties of fiber, matrix, and interfaces. Selection of macrostructures and material systems. Letter grading. Mr. J-M. Yang (Sp)

**160. Introduction to Ceramics and Glasses. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses 104, 130. Introduction to ceramics and glasses being used as important materials of engineering, processing techniques, and unique properties. Examples of design and control of properties for certain specific applications in engineering. Letter grading. Mr. Dunn (F)

**161. Processing of Ceramics and Glasses. (4)** Lecture, four hours; discussion, one hour. Requisite: course 160. Study of processes used in fabrication of ceramics and glasses for structural applications, optics, and electronics. Processing operations, including modern techniques of powder synthesis, greenware forming, sintering, glass melting. Microstructure properties relations in ceramics. Fracture analysis and design with ceramics. Letter grading. Mr. Dunn (Not offered 2019-20)

**161L. Laboratory in Ceramics. (2)** Laboratory, four hours. Requisite: course 160. Recommended corequisite: course 161. Processing of common ceramics and glasses. Attainment of specific properties through process control for engineering applications. Quantitative characterization and selection of raw materials. Slip casting and extrusion of clay bodies. Sintering of powders. Glass melting and fabrication. Determination of chemical and physical properties. Letter grading. Mr. Dunn (Sp)

**162. Electronic Ceramics. (4)** Lecture, four hours; outside study, eight hours. Requisites: course 104, Physics 1C. Utilization of ceramics in microelectronics; thick film and thin film resistors, capacitors, and substrates; design and processing of electronic ceramics and packaging; magnetic ceramics; ferroelectric ceramics and electro-optic devices; optical wave guide applications and designs. Letter grading. Mr. Dunn (Not offered 2019-20)

**CM163. Electrochemical Processes. (4)** (Same as Chemical Engineering CM114.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 130 (or Mechanical and Aerospace Engineering 105A), Chemical Engineering 102B. Fundamentals of electrochemistry and engineering applications to industrial electrochemical processes. Primary emphasis on fundamental approach to analyze electrochemical processes. Specific topics include electrochemical reactions on metal and semiconductor surfaces, electrodeposition, electroless deposition, electrosynthesis, fuel cells, aqueous and non-aqueous batteries, solid-state electrochemistry. May be concurrently scheduled with course CM263. Letter grading.

**170. Engaging Elements of Communication: Oral Communication. (2)** Lecture, one hour; discussion, one hour; outside study, four hours. Comprehensive oral presentation and communication skills provided by building on strengths of individual personal styles in creation of positive interpersonal relations. Skill set prepares students for different types of academic and professional presentations for wide range of audiences. Learning environment is highly supportive and interactive as it helps students creatively develop and greatly expand effectiveness of their communication and presentation skills. Letter grading. Mr. Xie (Not offered 2019-20)

**171. Engaging Elements of Communication: Writing for Technical Community. (2)** Lecture, one hour; discussion, one hour; outside study, four hours. Comprehensive technical writing skills on subjects specific to field of materials science and engineering. Students write review term paper in selected subject field of materials science and engineering from given set of journal publications. Instruction leads students through several crucial steps, including brainstorming, choosing title, coming up with outline, concise writing of abstract, conclusion, and final polishing. Other subjects include writing style, word choices, and grammar. Letter grading. Mr. Xie (Not offered 2019-20)

**CM180. Introduction to Biomaterials. (4)** (Same as Bioengineering CM178.) Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: course 104, or Chemistry 20A, 20B, and 20L. Engineering materials used in medicine and dentistry for repair and/or restoration of damaged natural tissues. Topics include relationships between material properties, suitability to task, surface chemistry, processing and treatment methods, and biocompatibility. Concurrently scheduled with course CM280. Letter grading. Mr. Wu (Not offered 2019-20)

**188. Special Courses in Materials Science and Engineering. (4)** Seminar, four hours; outside study, eight hours. Special topics in materials science and engineering for undergraduate students taught on experimental or temporary basis, such as those taught by resident and visiting faculty members. May be repeated once for credit with topic or instructor change. Letter grading. (Not offered 2019-20)

**194. Research Group Seminars: Materials Science and Engineering. (4)** Seminar, four hours; outside study, eight hours. Designed for undergraduate students who are part of research group. Discussion of research methods and current literature in field or of research of faculty members or students. May be repeated for credit. Letter grading.

**199. Directed Research in Materials Science and Engineering. (2 to 8)** Tutorial, to be arranged. Limited to juniors/seniors. Supervised individual research or investigation under guidance of faculty mentor. Culminating paper or project required. Occasional field trips may be arranged. May be repeated for credit with school approval. Individual contract required; enrollment petitions available in Office of Academic and Student Affairs. Letter grading. (F,W,Sp)

## Graduate Courses

**200. Principles of Materials Science I. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 120. Lattice dynamics and thermal properties of solids, classical and quantized free electron theory, electrons in a periodic potential, transport in semiconductors, dielectric and magnetic properties of solids. Letter grading. Mr. Y. Yang (F)

**201. Principles of Materials Science II. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 131. Kinetics of diffusional transformations in solids. Precipitation in solids. Nucleation theory. Theory of precipitate growth. Ostwald ripening. Spinodal decomposition. Cellular reactions. Letter grading. Mr. Xie (Sp)

**202. Thermodynamics of Materials. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Principles of thermodynamics and statistical mechanics and their application to physical and chemical phenomena in materials. Finite-temperature properties of single-component and multicomponent systems, equations of state, thermodynamic potentials and their derivatives, phase diagrams, and other equilibrium properties. First-order and second-order phase transitions in liquids and solids. Introduction to classical and modern theories of critical phenomena. Thermodynamic description of irreversible processes and entropy generation. Letter grading. Ms. He (F)

**210. Diffraction Methods in Science of Materials. (4)** Lecture, four hours; recitation, one hour; outside study, seven hours. Requisite: course 110. Theory of diffraction of waves (X rays, electrons, and neutrons) in crystalline and noncrystalline materials. Long- and short-range order in crystals, structural effects of plastic deformation, solid-state transformations, arrangements of atoms in liquids and amorphous solids. Letter grading. Mr. Goorsky (Sp, odd years)

**211. Introduction to Materials Characterization B (Electron Microscopy). (4)** Lecture, three hours; laboratory, two hours; outside study, seven hours. Requisites: courses 104, 110. Characterization of microstructure and microchemistry of materials; transmission electron microscopy; reciprocal lattice, electron diffraction, stereographic projection, direct observation of defects in crystals, replicas; scanning electron microscopy: emissive and reflective modes; chemical analysis; electron optics of both instruments. Letter grading. Mr. Kodambaka (W)

**CM212. Cultural Materials Science II: Characterization Methods in Conservation of Materials. (4)** (Same as Conservation M210.) Lecture, four hours. Preparation: general chemistry, inorganic and organic chemistry, materials science. Principles and methods of materials characterization in conservation: optical and electron microscopy, X-ray and electron spectroscopy, X-ray diffraction, infrared spectroscopy, reflectance spectroscopy and multispectral imaging spectroscopy, chromatography, design of archaeological and ethnographic materials characterization procedures. Concurrently scheduled with course C112. Letter grading. Ms. Kakoulli (Not offered 2019-20)

**M213. Cultural Materials Science I: Analytical Imaging and Documentation in Conservation of Materials. (4)** (Same as Conservation M215.) Lecture, two hours; laboratory, two hours. Basic and advanced techniques on digital photography, computer-aided recording tools, and scientific imaging to determine and document condition (defects) and technological features of archaeological and ethnographic materials. Development of basic theoretical knowledge on imaging and photonics technology and practical skills on conservation photo-documentation, analytical (forensic) photography, and advanced new imaging technologies. Letter grading. Ms. Kakoulli

**M213L. Cultural Materials Science Laboratory: Technical Study. (4)** (Same as Conservation M210L.) Laboratory, four hours. Requisites: courses M213 (or M216) and one course from Conservation 260 through M264. Corequisite: course C112 or CM212 (or Conservation M210). Research-based laboratory through object-based problem-solving approach in conservation materials science. Experimental techniques, characterization, and analysis of archaeological and ethnographic materials (using materials science principles and reverse engineering processes) to determine technological features, defects, and products of alteration. Hands-on experience with noninvasive imaging and spectroscopic techniques, sampling and sample preparation methods, analysis of microsamples. Letter grading. Ms. Kakoulli (Sp)

**M214. Structure, Properties, and Deterioration of Materials: Rock Art, Wall Paintings, Mosaics. (2)** (Same as Conservation M264.) Lecture, three hours. Recommended preparation: basic knowledge of general chemistry and materials science. Introduction to materials and techniques of rock art, wall paintings (including painted surfaces on cement and composite decorative architectural surfaces), and mosaics. Archaeological and ethnographic context, techniques, and materials. Pigments, colorants, and binding media. Chemical, optical, and structural properties. Relationship between composition (chemistry), structure (crystals, molecular arrangement, and microstructure), and properties explained using basic concepts from physics and chemistry. Intrinsic attributes and resistance to weathering. Causes, sources, and mechanisms of deterioration (physical, chemical, and biochemical). Letter grading. Ms. Kakoulli (F)

**M215. Conservation Laboratory: Rock Art, Wall Paintings, and Mosaics. (4)** (Same as Conservation M250.) Laboratory, four hours. Requisites: courses M214, M216 (or C112 or CM212), Conservation 210L. Recommended: course M213. Research-based laboratory on conservation of rock art, wall paintings (archaeological and modern composites on cements), mosaics, and decorated architectural surfaces. Experimental techniques and analysis of materials (using materials science and reverse engineering processes) for characterization of technology, constituent materials, and alteration products; development of conservation treatment proposals, testing of conservation products, and methods and conservation treatment. Letter grading. Ms. Kakoulli

**M216. Science of Conservation Materials and Methods I. (4)** (Same as Conservation M216.) Lecture, two hours; laboratory, two hours. Recommended requisite: laboratory safety fundamental concepts course by Office of Environment, Health, and Safety. Introduction to physical, chemical, and mechanical properties of conservation materials (employed for preservation of archaeological and cultural materials) and their aging characteristics. Science and application methods of traditional organic and inorganic systems and introduction of novel technology based on biomineralization processes and nanostructured materials. Letter grading. Ms. Kakoulli (W)

**221. Science of Electronic Materials. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 120. Study of major physical and chemical principles affecting properties and performance of semiconductor materials. Topics include bonding, carrier statistics, band-gap engineering, optical and transport properties, novel materials systems, and characterization. Letter grading. Mr. Goorsky (Sp)

**222. Growth and Processing of Electronic Materials. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: courses 120, 130, 131. Thermodynamics and kinetics that affect semiconductor growth and device processing. Particular emphasis on fundamentals of growth (bulk and epitaxial), heteroepitaxy, implantation, oxidation. Letter grading. Mr. Goorsky (W)

**223. Materials Science of Thin Films. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: courses 120, 131. Fabrication, structure, and property correlations of thin films used in microelectronics for data and information processing. Topics include film deposition, interfacial properties, stress and strain, electromigration, phase changes and kinetics, reliability. Letter grading. Mr. Goorsky

**224. Deposition Technologies and Their Applications. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Examination of physics behind majority of modern thin film deposition technologies based on vapor phase transport. Basic vacuum technology and gas kinetics. Deposition methods used in high-technology applications. Theory and experimental details of physical vapor deposition (PVD), chemical vapor deposition (CVD), plasma-enhanced chemical vapor deposition processes. Letter grading. Mr. Xie

**225. Materials Science of Surfaces. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 120, Chemistry 113A. Introduction to atomic and electronic structure of surfaces. Survey of methods for determining composition and structure of surfaces and near-surface layers of solid-state materials. Emphasis on scanning probe microscopy, Auger electron spectroscopy, X-ray photoelectron spectroscopy, ultraviolet photoelectron spectroscopy, secondary ion mass spectrometry, ion scattering spectroscopy, and Rutherford backscattering spectrometry. Applications in microelectronics, optoelectronics, metallurgy, polymers, biological and biocompatible materials, and catalysis. Letter grading. Mr. Goorsky (W)

**226. Si-CMOS Technology: Selected Topics in Materials Science. (4)** Lecture, three hours; discussion, one hour; outside study, eight hours. Recommended preparation: Electrical Engineering 221B. Requisites: courses 130, 131, 200, 221, 222. Selected topics in materials science from modern Si-CMOS technology, including technological challenges in high k/metal gate stacks, strained Si FETs, SOI and three-dimensional FETs, source/drain engineering including transient-enhanced diffusion, nonvolatile memory, and metallization for ohmic contacts. Letter grading. Mr. Xie

**243A. Fracture of Structural Materials. (4)** Lecture, four hours; laboratory, two hours; outside study, four hours. Requisite: course 143A. Engineering and scientific aspects of crack nucleation, slow crack growth, and unstable fracture. Fracture mechanics, dislocation models, fatigue, fracture in reactive environments, alloy development, fracture-safe design. Letter grading. Mr. J-M. Yang (W, even years)

**243C. Dislocations and Strengthening Mechanisms in Solids. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 143A. Elastic and plastic behavior of crystals, geometry, mechanics, and interaction of dislocations, mechanisms of yielding, work hardening, and other strengthening. Letter grading. Mr. Xie (F, odd years)

**246A. Mechanical Properties of Nonmetallic Crystalline Solids. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 160. Materials and environmental factors affecting mechanical properties of nonmetallic crystalline solids, including atomic bonding and structure, atomic-scale defects, microstructural features, residual stresses, temperature, stress state, strain rate, size and surface conditions. Letter grading. Mr. Dunn (W)

**246B. Structure and Properties of Glass. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 160. Structure of amorphous solids and glasses. Conditions of glass formation and theories of glass structure. Mechanical, electrical, and optical properties of glass and relationship to structure. Letter grading. Mr. Dunn (W, even years)

**246D. Electronic and Optical Properties of Ceramics. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 160. Principles governing electronic properties of ceramic single crystals and glasses and effects of processing and microstructure on these properties. Electronic conduction, ferroelectricity, and photochromism. Magnetic ceramics. Infrared, visible, and ultraviolet transmission. Unique application of ceramics. Letter grading. Mr. Dunn (Sp, even years)

**247. Nanoscale Materials: Challenges and Opportunities. (4)** Lecture, four hours; discussion, eight hours. Limited to graduate students. Literature studies of up-to-date subjects in novel materials and their potential applications, including nanoscale materials and biomaterials. Letter grading. Ms. Huang (W)

**248. Materials and Physics of Solar Cells. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Comprehensive introduction to materials and physics of photovoltaic cell, covering basic physics of semiconductors in photovoltaic devices, physical models of cell operation, characteristics and design of common types of solar cells, and approaches to increasing solar cell efficiency. Recent progress in solar cells, such as organic solar cell, thin-film solar cells, and multiple junction solar cells provided to increase student knowledge. Tour of research laboratory included. Letter grading. Mr. Y. Yang (Sp)

**250B. Advanced Composite Materials. (4)** Lecture, four hours; outside study, eight hours. Preparation: BS in Materials Science and Engineering. Requisite: course 151. Fabrication methods, structure and properties of advanced composite materials. Fibers; resin-, metal-, and ceramic-matrix composites. Physical, mechanical, and nondestructive characterization techniques. Letter grading. Mr. Y. Yang

**251. Chemistry of Soft Materials. (4)** Lecture, four hours. Introduction to organic soft materials, including essential basic organic chemistry and polymer chemistry. Topics include three main categories of soft materials: organic molecules, synthetic polymers, and biomolecules and biomaterials. Extensive description and discussion of structure-property relationship, spectroscopic and experimental techniques, and preparation methods for various soft materials. Letter grading. Mr. Pei (F)

**252. Organic Polymer Electronic Materials. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Preparation: knowledge of introductory organic chemistry and polymer science. Introduction to organic electronic materials with emphasis on materials chemistry and processing. Topics include conjugated polymers; heavily doped, highly conducting polymers; applications as processable metals and in various electrical, optical, and electrochemical devices. Synthesis of semiconductor polymers for organic light-emitting diodes, solar cells, thin-film transistors. Introduction to emerging field of organic electronics. Letter grading. Mr. Pei (F)

**261. Risk Analysis for Engineers and Scientists. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Topics include definition and fundamental concepts of risk, sociotechnical context of risk assessment and risk management, perception and reality of risk, risk-informed decision-making, domains of application (safety, health, security, economy, and environment), principal methods of risk assessment, including overview of probability and statistics, how to identify risk scenarios, techniques modeling failures of complex systems (e.g., fault tree and event tree analysis), data collection and analysis, model integration and computational algorithms for risk calculation and identification of risk drivers, simulation approach to risk modeling, uncertainty analysis, examples of risk assessment of engineered systems (e.g., space and aviation, nuclear power, petro-chemical plants), other applications (risk of medical procedures, financial risk, natural hazards risk). Letter grading.

**CM263. Electrochemical Processes. (4)** (Same as Chemical Engineering CM214.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: course 130 (or Mechanical and Aerospace Engineering 105A), Chemical Engineering 102B. Fundamentals of electrochemistry and engineering applications to industrial electrochemical processes. Primary emphasis on fundamental approach to analyze electrochemical processes. Specific topics include electrochemical reactions on metal and semiconductor surfaces, electrodeposition, electroless deposition, electrosynthesis, fuel cells, aqueous and non-aqueous batteries, solid-state electrochemistry. May be concurrently scheduled with course CM163. Letter grading.

**270. Computer Simulations of Materials. (4)** Lecture, four hours; outside study, eight hours. Introduction to modern methods of computational modeling in materials science. Topics include basic statistical mechanics, classical molecular dynamics, and Monte Carlo methods, with emphasis on understanding basic physical ideas and learning to design, run, and analyze computer simulations of materials. Use of examples from current literature to show how these methods can be used to study interesting phenomena in materials science. Hands-on computer experiments. Letter grading. Mr. Marian (F)

**271. Electronic Structure of Materials. (4)** Lecture, four hours; outside study, eight hours. Preparation: basic knowledge of quantum mechanics. Recommended requisite: course 200. Introduction to modern first-principles electronic structure calculations for various types of modern materials. Properties of electrons and interatomic bonding in molecules, crystals, and liquids, with emphasis on practical methods for solving Schrödinger equation and using it to calculate physical properties such as elastic constants, equilibrium structures, binding energies, vibrational frequencies, electronic band gaps and band structures, properties of defects, surfaces, interfaces, and magnetism. Extensive hands-on experience with modern density-functional theory code. Letter grading. Mr. Marian (W)

**272. Theory of Nanomaterials. (4)** Lecture, four hours; outside study, eight hours. Strongly recommended requisite: course 200. Introduction to properties and applications of nanoscale materials, with emphasis on understanding of basic principles that distinguish nanostructures (with feature size below 100 nm) from more common microstructured materials. Explanation of new phenomena that emerge only in very small systems, using simple concepts from quantum mechanics and thermodynamics. Topics include structure and electronic properties of quantum dots, wires, nanotubes, and multilayers, self-assembly on surfaces and in liquid solutions, mechanical properties of nanostructured metamaterials, molecular electronics, spin-based electronics, and proposed realizations of quantum computing. Discussion of current and future directions of this rapidly growing field using examples from modern scientific literature. Letter grading. Mr. Marian (F)

**CM280. Introduction to Biomaterials. (4)** (Same as Bioengineering CM278.) Lecture, three hours; discussion, two hours; outside study, seven hours. Requisites: course 104, or Chemistry 20A, 20B, and 20L. Engineering materials used in medicine and dentistry for repair and/or restoration of damaged natural tissues. Topics include relationships between material properties, suitability to task, surface chemistry, processing and treatment methods, and biocompatibility. Concurrently scheduled with course CM180. Letter grading. Mr. Wu (Not offered 2019-20)

**282. Exploration of Advanced Topics in Materials Science and Engineering. (2)** Lecture, one hour; discussion, one hour; outside study, four hours. Researchers from leading research institutions around world deliver lectures on advanced research topics in materials science and engineering. Student groups present summary previews of topics prior to lecture. Class discussions follow each presentation. May be repeated for credit. S/U grading. Mr. J-M. Yang

**296. Seminar: Advanced Topics in Materials Science and Engineering. (2)** Seminar, two hours; outside study, four hours. Advanced study and analysis of current topics in materials science and engineering. Discussion of current research and literature in research specialty of faculty members teaching course. May be repeated for credit. S/U grading.

**M297B. Material Processing in Manufacturing. (4)** (Same as Mechanical and Aerospace Engineering M297B.) Lecture, four hours; outside study, eight hours. Enforced requisite: Mechanical and Aerospace Engineering 183A. Thermodynamics, principles of material processing: phase equilibria and transitions, transport mechanisms of heat and mass, nucleation and growth of microstructure. Applications in casting/solidification, welding, consolidation, chemical vapor deposition, infiltration, composites. Letter grading.

**M297C. Composites Manufacturing. (4)** (Same as Mechanical and Aerospace Engineering M297C.) Lecture, four hours; outside study, eight hours. Requisites: course 151, Mechanical and Aerospace Engineering 166C. Matrix materials, fibers, fiber preforms, elements of processing, autoclave/compression molding, filament winding, pultrusion, resin transfer molding, automation, material removal and assembly, metal and ceramic matrix composites, quality assurance. Letter grading.

**298. Seminar: Engineering. (2 to 4)** Seminar, to be arranged. Limited to graduate materials science and engineering students. Seminars may be organized in advanced technical fields. If appropriate, field trips may be arranged. May be repeated with topic change. Letter grading.

**375. Teaching Apprentice Practicum. (1 to 4)** Seminar, to be arranged. Preparation: apprentice personnel employment as teaching assistant, associate, or fellow. Teaching apprenticeship under active guidance and supervision of regular faculty member responsible for curriculum and instruction at UCLA. May be repeated for credit. S/U grading. (F,W,Sp)

**596. Directed Individual or Tutorial Studies. (2 to 8)** Tutorial, to be arranged. Limited to graduate materials science and engineering students. Petition forms to request enrollment may be obtained from assistant dean, Graduate Studies. Supervised investigation of advanced technical problems. S/U grading.

**597A. Preparation for MS Comprehensive Examination. (2 to 12)** Tutorial, to be arranged. Limited to graduate materials science and engineering students. Reading and preparation for MS comprehensive examination. S/U grading.

**597B. Preparation for PhD Preliminary Examinations. (2 to 16)** Tutorial, to be arranged. Limited to graduate materials science and engineering students. S/U grading.

**597C. Preparation for PhD Oral Qualifying Examination. (2 to 16)** Tutorial, to be arranged. Limited to graduate materials science and engineering students. Preparation for oral qualifying examination, including preliminary research on dissertation. S/U grading.

**598. Research for and Preparation of MS Thesis. (2 to 12)** Tutorial, to be arranged. Limited to graduate materials science and engineering students. Supervised independent research for MS candidates, including thesis prospectus. S/U grading.

**599. Research for and Preparation of PhD Dissertation. (2 to 16)** Tutorial, to be arranged. Limited to graduate materials science and engineering students. Usually taken after students have been advanced to candidacy. S/U grading.

# Mechanical and Aerospace Engineering

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H. Pirouz Kavehpour, Ph.D., *Vice Chair*
Chang-Jin (CJ) Kim, Ph.D., *Vice Chair*
Ajit K. Mal, Ph.D., *Vice Chair*

### Professors

Mohamed A. Abdou, Ph.D.
Robert N. Candler, Ph.D.
Gregory P. Carman, Ph.D.
Yong Chen, Ph.D.
Pei-Yu Chiou, Ph.D.
Vijay K. Dhir, Ph.D.
Jeffrey D. Eldredge, Ph.D.
Timothy S. Fisher, Ph.D. *(John P. and Claudia H. Schauerman Endowed Professor of Engineering)*
Rajit Gadh, Ph.D.
Nasr M. Ghoniem, Ph.D.
Vijay Gupta, Ph.D.
Dennis W. Hong, Ph.D.
Tetsuya Iwasaki, Ph.D.
Y. Sungtaek Ju, Ph.D.
Ann R. Karagozian, Ph.D.
H. Pirouz Kavehpour, Ph.D.
Chang-Jin (CJ) Kim, Ph.D. *(Volgenau Endowed Professor of Engineering)*
Adrienne G. Lavine, Ph.D.
Xiaochun Li, Ph.D. *(Raytheon Company Professor of Manufacturing Engineering)*
Kuo-Nan Liou, Ph.D.
Ajit K. Mal, Ph.D.
Robert T. M'Closkey, Ph.D.
Ali Mosleh, Ph.D., NAE *(Evalyn Knight Professor of Engineering)*
Jayathi Y. Murthy, Ph.D., *Dean*
Laurent G. Pilon, Ph.D.
Jacob Rosen, Ph.D.
Jason L. Speyer, Ph.D. *(Ronald and Valerie Sugar Endowed Professor of Engineering)*
Tsu-Chin Tsao, Ph.D.
Xiaolin Zhong, Ph.D.

### Professors Emeriti

Oddvar O. Bendiksen, Ph.D.
Ivan Catton, Ph.D. *(Research Professor)*
Peretz P. Friedmann, Sc.D.
James S. Gibson, Ph.D.
Chih-Ming Ho, Ph.D. *(Ben Rich Lockheed Martin Professor Emeritus of Aeronautics)*
Robert E. Kelly, Sc.D.
J. John Kim, Ph.D. *(Rockwell Collins Professor Emeritus of Engineering)*
Anthony F. Mills, Ph.D.
D. Lewis Mingori, Ph.D.
Peter A. Monkewitz, Ph.D.
Philip F. O'Brien, M.S.
Lucien A. Schmit, Jr., M.S.
Owen I. Smith, Ph.D.
Richard Stern, Ph.D.
Russell A. Westmann, Ph.D.
Daniel C.H. Yang, Ph.D.

### Associate Professors

Elisa Franco, Ph.D.
Jaime Marian, Ph.D.
Veronica J. Santos, Ph.D.
Kunihiko (Sam) Taira, Ph.D.
Richard E. Wirz, Ph.D.

### Assistant Professors

Artur Davoyan, Ph.D.
Jonathan B. Hopkins, Ph.D.
Yongjie Hu, Ph.D.
M. Khalid Jawed, Ph.D.
Lihua Jin, Ph.D.
Raymond M. Spearrin, Ph.D.

### Lecturers

Ravnesh C. Amar, Ph.D.
Amiya K. Chatterjee, Ph.D.
Robert J. Kinsey, Ph.D.
Damian M. Toohey, M.S.

### Adjunct Professors

Dan M. Goebel, Ph.D.
Leslie M. Lackman, Ph.D.
Christopher S. Lynch, Ph.D.
Wilbur J. Marner, Ph.D.
Neil G. Siegel, Ph.D.

### Adjunct Associate Professor

Abdon E. Sepulveda, Ph.D.

## Scope and Objectives

The Department of Mechanical and Aerospace Engineering offers curricula in aerospace engineering and mechanical engineering at both the undergraduate and graduate levels. The scope of the departmental research and teaching program is broad, encompassing dynamics, fluid mechanics, heat and mass transfer, manufacturing and design, nanoelectromechanical and microelectromechanical systems, structural and solid mechanics, and systems and control. The applications of mechanical and aerospace engineering are quite diverse, including aircraft, spacecraft, automobiles, energy and propulsion systems, robotics, machinery, manufacturing and materials processing, microelectronics, biological systems, and more.

At the undergraduate level, the department offers accredited programs leading to B.S. degrees in Aerospace Engineering and in Mechanical Engineering. At the graduate level, the department offers programs leading to M.S. and Ph.D. degrees in Mechanical Engineering and in Aerospace Engineering. An M.S. in Manufacturing Engineering is also offered.

## Department Mission

The mission of the Mechanical and Aerospace Engineering Department is to educate the nation's future leaders in the science and art of mechanical and aerospace engineering. Further, the department seeks to expand the frontiers of engineering science and to encourage technological inno-

*Graduate student researchers (L to R) Abolfazl Sadeghpour, Navid Ebrahimi, and Hangjie Ji experiment with their novel water vapor capture system in professor Sungtaek Ju's Multiscale Thermosciences Laboratory.*

vation while fostering academic excellence and scholarly learning in a collegial environment.

## Undergraduate Program Educational Objectives

The aerospace engineering and mechanical engineering programs are accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

In consultation with its constituents, the Mechanical and Aerospace Engineering Department has set its educational objectives as follows: within a few years after graduation, the students will be successful in careers in aerospace or mechanical or other engineering fields, and/or in graduate studies in aerospace or mechanical or other engineering fields, and/or in further studies in other fields such as medicine, business, and law.

## Undergraduate Study

The Aerospace Engineering and Mechanical Engineering majors are designated capstone majors. Within their capstone courses, Aerospace Engineering students are exposed to the conceptual and design phases for aircraft development and produce a structural design of a component, such as a lightweight aircraft wing. Mechanical Engineering students work in teams in their capstone courses to propose, design, analyze, and build a mechanical or electromechanical device. Graduates of both programs should be able to apply their knowledge of mathematics, science, and engineering in technical systems; design a system, component, or process to meet desired needs; function as productive members of a team; identify, formulate, and solve engineering problems; and communicate effectively, both orally and in writing.

## Aerospace Engineering B.S.

***Capstone Major***

The aerospace engineering program is concerned with the design and construction of various types of fixed-wing and rotary-wing (helicopters) aircraft used for air transportation and national defense. It is also concerned with the design and construction of spacecraft, the exploration and utilization of space, and related technological fields.

Aerospace engineering is characterized by a very high level of technology. The aerospace engineer is likely to operate at the forefront of scientific discoveries, often stimulating these discoveries and providing the inspiration for the creation of new scientific concepts. Meeting these demands requires the imaginative use of many disciplines, including fluid mechanics and aerodynamics, structural mechanics, materials and aeroelasticity, dynamics, control and guidance, propulsion, and energy conversion.

### Learning Outcomes

The Aerospace Engineering major has the following learning outcomes:

- Application of knowledge of mathematics, science, and engineering
- Function as a productive member of a team that considers multiple aspects of an engineering problem
- Design of a system, component, or process to meet desired needs
- Effective oral and written communication
- Identification, formulation, and solution of engineering problems

### Preparation for the Major

*Required:* Chemistry and Biochemistry 20A, 20B, 20L; Mathematics 31A, 31B, 32A, 32B, 33A; Mechanical and Aerospace Engineering 1, M20 (or Computer Science 31), 82; Physics 1A, 1B, 1C, 4AL, 4BL.

### The Major

*Required:* Mechanical and Aerospace Engineering 101, 102, 103, 105A, 105D, 107, 150A, 157, 166A, 171A; two departmental breadth courses (Electrical and Computer Engineering 100 and Materials Science and Engineering 104—if one or both of these courses are taken as part of the technical breadth requirement, students must select a replacement upper-division course or courses from the department—except for Mechanical and Aerospace Engineering 156A—or, by petition, from outside the department); one of the following two tracks (16 units): *aeronautics* (150B, C150P, 154A, 154S) or *space* (C150R, 161A, 161B, 161C); three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; one capstone design course (Mechanical and Aerospace Engineering 157A); one major field elective course (4 units) from the track not chosen (150B or C150P; C150R or 161A) and one major field elective course (4 units) from Mechanical and Aerospace Engineering 150B, C150P, C150R, 154A, 154B, 154S, 161A, 161B, 161C (unless taken as a required course), or from 94, 131A, C131G, 133A, 135, 136, C137, C138, CM140, 150C, C150G, 155, C156B, 161D, 162A, 166C, M168, 169A, 171B, 172, 174, C175A, 181A, 182B, 182C, 183A, M183B, C183C, 185, C186, C187L.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

## Mechanical Engineering B.S.

***Capstone Major***

The mechanical engineering program is designed to provide basic knowledge in thermodynamics, fluid mechanics, heat transfer, solid mechanics, mechanical design, dynamics, control, mechanical systems, manufacturing, and materials. The program includes fundamental subjects important to all mechanical engineers.

## Learning Outcomes

The Mechanical Engineering major has the following learning outcomes:

- Application of knowledge of mathematics, science, and engineering
- Function as a productive member of a team that considers multiple aspects of an engineering problem
- Design of a system, component, or process to meet desired needs
- Effective oral and written communication
- Identification, formulation, and solution of engineering problems

## Preparation for the Major

*Required:* Chemistry and Biochemistry 20A, 20B, 20L; Mathematics 31A, 31B, 32A, 32B, 33A; Mechanical and Aerospace Engineering M20 (or Computer Science 31), 82, 94; Physics 1A, 1B, 1C, 4AL, 4BL.

## The Major

*Required:* Electrical and Computer Engineering 110L, Mechanical and Aerospace Engineering 101, 102, 103, 105A, 105D, 107, 131A or 133A, 156A, 157, 162A, 171A, 183A (or M183B); two departmental breadth courses (Electrical and Computer Engineering 100 and Materials Science and Engineering 104—if one or both of these courses are taken as part of the technical breadth requirement, students must select a replacement upper-division course or courses from the department—except for Mechanical and Aerospace Engineering 166A—or, by petition, from outside the department); three technical breadth courses (12 units) selected from an approved list available in the Office of Academic and Student Affairs; two capstone design courses (Mechanical and Aerospace Engineering 162D, 162E); and two major field elective courses (8 units) from Mechanical and Aerospace Engineering 131A (unless taken as a required course), C131G, 133A (unless taken as a required course), 135, 136, C137, C138, CM140, 150A, 150B, 150C, C150G, C150P, C150R, 154A, 154B, 154S, 155, C156B, 157A, 161A through 161D, 166C, M168, 169A, 171B, 172, 174, C175A, 181A, 182B, 182C, 183A (unless taken as a required course), M183B (unless taken as a required course), C183C, 185, C186, C187L.

For information on UC, school, and general education requirements, see Requirements for B.S. Degrees on page 22 or https://www.registrar.ucla.edu/Academics/GE-Requirement.

# Graduate Study

For information on graduate admission, see Graduate Programs on page 26.

The following introductory information is based on 2019-20 program requirements for UCLA graduate degrees. Complete program requirements are available at https://grad.ucla.edu/academics/graduate-study/program-requirements-for-ucla-graduate-degrees/. Students are subject to the detailed degree requirements as published in program requirements for the year in which they enter the program.

The Department of Mechanical and Aerospace Engineering offers the Master of Science (M.S.) degree in Manufacturing Engineering, Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees in Aerospace Engineering, and Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees in Mechanical Engineering.

All new M.S. and Ph.D. students who are pursuing an M.S. degree in the Mechanical and Aerospace Engineering Department must meet with their advisers in their first term at UCLA. The goal of the meeting is to discuss the students' plans for satisfying the M.S. degree requirements. Students should obtain an M.S. planning form from the department Student Affairs Office and return it with their advisers' signature by the end of the first term.

# Aerospace Engineering M.S. and Mechanical Engineering M.S.

## Course Requirements

Students may select either the thesis plan or comprehensive examination plan. At least nine courses (and 36 units) are required, of which at least five must be graduate courses. In the thesis plan, seven of the nine must be formal courses, including at least four from the 200 series. The remaining two may be 598 courses involving work on the thesis. In the comprehensive examination plan, no units of 500-series courses may be applied toward the minimum course requirement. Courses taken before the award of the bachelor's degree may not be applied toward a graduate degree at UCLA. The courses should be selected so that the breadth requirements and the requirements at the graduate level are met. The breadth requirements are only applicable to students who do not have a B.S. degree from an ABET-accredited aerospace or mechanical engineering program.

*Undergraduate Courses.* No lower-division courses may be applied toward graduate degrees. In addition, the following upper-division courses are not applicable toward graduate degrees: Chemical Engineering 102A, 199, Civil and Environmental Engineering 108, 199, Computer Science M152A, 152B, M171L, 199, Electrical and Computer Engineering 100, 101A, 102, 110L, M116L, 133A, M171L, 199, Materials Science and Engineering 110, 120, 130, 131, 131L, 132, 140, 141L, 150, 160, 161L, 199, Mechanical and Aerospace Engineering 101, 102, 103, 105A, 105D, 107, 188, 194, 199.

## Aerospace Engineering

*Breadth Requirements.* Students are required to take at least three courses from the following four categories: (1) Mechanical and Aerospace Engineering 154A or 154B or 154S, (2) 150B or C150P, (3) 155 or 166A or 169A, (4) 161A or 171A.

## Mechanical Engineering

*Breadth Requirements.* Students are required to take at least three courses from the following five categories: (1) Mechanical and Aerospace Engineering 162A or 169A or 171A, (2) 150A or 150B, (3) 131A or 133A, (4) 156A, (5) 162D or 183A.

## Comprehensive Examination Plan

The comprehensive examination is required in either written or oral form. A committee of at least three faculty members, with at least two members from within the department, and chaired by the academic adviser, is established to administer the examination. Students may, in consultation with their adviser and the M.S. committee, select one of the following options for the comprehensive examination: (1) take and pass the first part of the Ph.D. written qualifying examination (formerly referred to as the preliminary examination) as the comprehensive examination, (2) conduct a research or design project and submit a final report to the M.S. committee, or (3) take and pass three comprehensive examination questions offered in association with three mechanical and aerospace engineering graduate courses. Contact the department Student Affairs Office for more information.

## Thesis Plan

The thesis must describe some original piece of research that has been done under the supervision of the thesis committee. Students should normally start to plan the thesis at least one year before the award of the M.S. degree is expected. There is no examination under the thesis plan.

# Manufacturing Engineering M.S.

## Areas of Study

Consult the department.

### Course Requirements

Students may select either the thesis plan or comprehensive examination plan. At least nine courses (and 36 units) are required, of which at least five must be graduate courses. In the thesis plan, seven of the nine must be formal courses, including at least four from the 200 series. The remaining two may be 598 courses involving work on the thesis. In the comprehensive examination plan, no units of 500-series courses may be applied toward the minimum course requirement. Courses taken before the award of the bachelor's degree may not be applied toward a graduate degree at UCLA. Choices may be made from the following major areas:

*Undergraduate Courses*. No lower-division courses may be applied toward graduate degrees. In addition, the following upper-division courses are not applicable toward graduate degrees: Chemical Engineering 102A, 199, Civil and Environmental Engineering 108, 199, Computer Science M152A, 152B, M171L, 199, Electrical and Computer Engineering 100, 101A, 102, 110L, M116L, 133A, M171L, 199, Materials Science and Engineering 110, 120, 130, 131, 131L, 132, 141L, 150, 160, 161L, 199, Mechanical and Aerospace Engineering 101, 102, 103, 105A, 105D, 107, 188, 194, 199.

*Upper-Division Courses*. Students are required to take at least three courses from the following: Mechanical and Aerospace Engineering M168, 174, 183A, 185.

*Graduate Courses*. Students are required to take at least three courses from the following: Mechanical and Aerospace Engineering 263A, 263C, 263D, C296A, M297C.

*Additional Courses*. The remaining courses may be taken from other major fields of study in the department or from the following: Architecture and Urban Design 227D, Computer Science 241B, Management 241A, Management-PhD 241A, 241B, Mathematics 120A, 120B.

### Comprehensive Examination Plan

The comprehensive examination is required in either written or oral form. A committee of at least three faculty members, with at least two members from within the department, and chaired by the academic adviser, is established to administer the examination. Students may, in consultation with their adviser and the M.S. committee, select one of the following options for the comprehensive examination: (1) take and pass the first part of the Ph.D. written qualifying examination (formerly referred to as the preliminary examination) as the comprehensive examination, (2) conduct a research or design project and submit a final report to the M.S. committee, or (3) take and pass three comprehensive examination questions offered in association with three graduate courses. Contact the department Student Affairs Office for more information.

### Thesis Plan

The thesis must describe some original piece of research that has been done under the supervision of the thesis committee. Students would normally start to plan the thesis at least one year before the award of the M.S. degree is expected. There is no examination under the thesis plan.

## Aerospace Engineering Ph.D. and Mechanical Engineering Ph.D.

### Major Fields or Subdisciplines

Design, robotics, and manufacturing (mechanical engineering only); fluid mechanics; micro-nano engineering; structural and solid mechanics; systems and control; thermal science and engineering.

Ph.D. students may propose ad hoc major fields, which must differ substantially from established major fields and satisfy one of the following two conditions: (1) the field is interdisciplinary in nature or (2) the field represents an important research area for which there is no established major field in the department (condition 2 most often applies to recently evolving research areas or to areas for which there are too few faculty members to maintain an established major field).

Students in an ad hoc major field must be sponsored by at least three faculty members, at least two of whom must be from the department.

### Course Requirements

The basic program of study for the Ph.D. degree is built around major and minor fields. The established major fields are listed above, and a detailed syllabus describing each Ph.D. major field can be obtained from the Student Affairs Office.

The program of study for the Ph.D. requires students to perform original research leading to a doctoral dissertation and to master a body of knowledge that encompasses material from their major field and breadth material from outside the major field. The body of knowledge should include (1) six major field courses, at least four of which must be graduate courses, (2) one minor field, (3) any three additional courses, at least two of which must be graduate courses, that enhance the study of the major or minor field.

The major field syllabus advises students as to which courses contain the required knowledge, and students usually prepare for the written qualifying examination (formerly referred to as the preliminary examination) by taking these courses. However, students can acquire such knowledge by taking similar courses at other universities or even by self-study.

The minor field embraces a body of knowledge equivalent to three courses, at least two of which must be graduate courses. Minor fields are often subsets of major fields, and minor field requirements are then described in the syllabus of the appropriate major field. Established minor fields with no corresponding major field can also be used, such as applied mathematics and applied plasma physics and fusion engineering. Also, an ad hoc field can be used in exceptional circumstances, such as when certain knowledge is desirable for a program of study that is not available in established minor fields.

Grades of B– or better, with a grade-point average of at least 3.33 in all courses included in the minor field, and the three additional courses mentioned above are required. If students fail to satisfy the minor field requirements through coursework, a minor field examination may be taken (once only).

### Written and Oral Qualifying Examinations

After mastering the body of knowledge defined in the major field, students take a written qualifying (preliminary) examination covering this knowledge. Students must have been formally admitted to the Ph.D. program or admitted subject to completion of the M.S. degree by the end of the term following the term in which the examination is given. The examination must be taken within the first two calendar years from the time of admission into the Ph.D. program. Students must be registered during the term in which the examination is given and be in good academic standing (minimum GPA of 3.25). The student's major field proposal must be completed prior to taking the examination. Students may not take an examination more than twice. Students in an ad hoc major field must pass a written qualifying examination that is approximately equivalent in scope, length, and level to the written qualifying examination for an established major field.

After passing the written qualifying examination, students take the University Oral Qualifying Examination within four calendar years from the time of admission into the Ph.D. program. The nature and content of the examination are at the discretion of the doctoral committee but include a review of the dissertation prospectus and may include a broad inquiry into the student's preparation for research.

*Note: Doctoral Committees.* A doctoral committee consists of a minimum of four members. Three members, including the chair, are inside members and must hold appointments in the department. The outside member must be a UCLA faculty member in another department.

# Fields of Study

## Design, Robotics, and Manufacturing

The program is developed around an integrated approach to design, robotics, and manufacturing. It includes research on manufacturing and design aspects of mechanical systems, material behavior and processing, robotics and manufacturing systems, CAD/CAM theory and applications, computational geometry and geometrical modeling, composite materials and structures, automation and digital control systems, microdevices and nanodevices, radio frequency identification (RFID), and wireless systems.

## Fluid Mechanics

The graduate program in fluid mechanics includes experimental, numerical, and theoretical studies related to a range of topics in fluid mechanics, such as turbulent flows, hypersonic flows, microscale and nanoscale flow phenomena, aeroacoustics, biofluid mechanics, chemically reactive flows, chemical reaction kinetics, numerical methods for computational fluid dynamics (CFD), and experimental methods. The educational program for graduate students provides a strong foundational background in classical incompressible and compressible flows, while providing elective breadth courses in advanced specialty topics such as computational fluid dynamics, microfluidics, biofluid mechanics, hypersonics, reactive flow, fluid stability, turbulence, and experimental methods.

## Micro-Nano Engineering

The micro-nano engineering field focuses on science and engineering issues ranging in size from nanometers to millimeters and includes both experimental and theoretical studies covering fundamentals to applications. The study topics include microscience, top-down and bottom-up nanofabrication/microfabrication technologies, molecular fluidic phenomena, nanoscale/microscale material processing, biomolecular signatures, heat transfer at the nanoscale, and system integration. The program is highly interdisciplinary in nature.

## Structural and Solid Mechanics

The solid mechanics program features theoretical, numerical, and experimental studies, including fracture mechanics and damage tolerance, micromechanics with emphasis on technical applications, wave propagation and nondestructive evaluation, mechanics of composite materials, mechanics of thin films and interfaces, analysis of coupled electro-magneto-thermomechanical material systems, and ferroelectric materials. The structural mechanics program includes structural dynamics with applications to aircraft and spacecraft, fixed-wing and rotary-wing aeroelasticity, fluid structure interaction, computational transonic aeroelasticity, biomechanics with applications ranging from whole organs to molecular and cellular structures, structural optimization, finite element methods and related computational techniques, structural mechanics of composite material components, structural health monitoring, and analysis of adaptive structures.

## Systems and Control

The program features systems engineering principles and applied mathematical methods of modeling, analysis, and design of continuous- and discrete-time control systems. Emphasis is on modern applications in engineering, systems concepts, feedback and control principles, stability concepts, applied optimal control, differential games, computational methods, simulation, and computer process control. Systems and control research and education in the department cover a broad spectrum of topics primarily based in aerospace and mechanical engineering applications. However, the Chemical and Biomolecular Engineering and Electrical and Computer Engineering Departments also have active programs in control systems, and collaboration across departments among faculty members and students in both teaching and research is common.

## Thermal Science and Engineering

The thermal science and engineering field includes studies of convection, radiation, conduction, evaporation, condensation, boiling and two-phase flow, chemically reacting and radiating flow, instability and turbulent flow, reactive flows in porous media, as well as transport phenomena in support of micro-scale and nanoscale thermosciences, energy, bioMEMS/NEMS, and microfabrication/nanofabrication.

## Ad Hoc Major Fields

The ad hoc major fields program has sufficient flexibility that students can form academic major fields in their area of interest if the proposals are supported by several faculty members. Previous fields of study included acoustics, system risk and reliability, and engineering thermodynamics. Nuclear science and engineering, a former active major field, is available on an ad hoc basis only.

# Centers, Facilities, and Laboratories

The Mechanical and Aerospace Engineering Department has a number of experimental centers, facilities, and laboratories at which both fundamental and applied research is being conducted. More information is at **https://www.mae.ucla.edu**.

## Active Materials Laboratory

Gregory P. Carman, *Director*

The laboratory contains equipment to evaluate the coupled response of materials such as piezoelectric, magnetostrictive, shape memory alloys, and fiber-optic sensors. The laboratory has manufacturing facilities to fabricate magnetostrictive composites and thin film shape memory alloys. Testing active material systems is performed on one of four servo-hydraulic load frames in the lab. All of the load frames are equipped with thermal chambers, solenoids, and electrical power supplies.

## Autonomous Vehicle Systems Instrumentation Laboratory (AVSIL)

Jason L. Speyer, *Director*

AVSIL is a testbed for design, building, evaluation, and testing of hardware instrumentation and coordination algorithms for multiple vehicle autonomous systems. AVSIL contains a hardware-in-the-loop (HIL) simulator—designed and built at UCLA—that allows for real-time, systems-level tests of two formation control computer systems in a laboratory environment, using the Interstate Electronics Corporation GPS Satellite Constellation Simulator. The UCLA flight control software can be modified to accommodate satellite-system experiments using real-time software, GPS receivers, and inter-vehicle modem communication.

## Beam Control Laboratory

James S. Gibson, *Director*

The laboratory involves students, faculty, and postdoctoral scholars to develop novel methods for laser-beam control in applications including directed energy systems and laser communications. Algorithms developed at UCLA for adaptive and optimal control and filtering, as well as system identification, are being used in adaptive optics and beam steering. UCLA high-bandwidth controllers correct both higher-order wavefront errors and tilt jitter to levels not achievable by classical beam control methods.

## Biomechatronics Laboratory

Veronica J. Santos, *Director*

The laboratory is dedicated to improving quality of life by enhancing the functionality of artificial hands and their control in human-machine systems. The research is advancing the design and control of human-machine systems as well as autonomous robotic systems. Current research projects involve human biomechanics, tactile sensing, control of robotic systems, and machine learning.

## Bionics Laboratory

Jacob Rosen, *Director*

The laboratory performs research at the interface between robotics, biological systems, and medicine. Primary research fields are medical robotics and biorobotics including surgical robotics, and wearable robotics as they apply to human motor control, neural control, human- and brain-machine interfaces, motor control (stroke) rehabilitation, brain plasticity, haptics, virtual reality, tele-operation, and biomechanics (full-body kinematics and dynamics, and soft/hard tissues biomechanics).

## Boiling Heat Transfer Laboratory

Vijay K. Dhir, *Director*

The laboratory performs experimental and computational studies of phase-change phenomena. It is equipped with various flow loops, state-of-the-art data acquisition systems, holography, high-speed imaging systems, and a gamma densitometer.

## Center for Advanced Multifunctional Materials and Systems (CAMMS)

Christopher S. Lynch, *Director*

CAMMS is involved in all aspects of multifunctional (smart) materials characterization, modeling, and applications. Materials are characterized under combined mechanical, thermal, electrical, and magnetic loading. Constitutive laws are developed that govern domain switching and phase transformations. Component-level applications include miniature solid-state piezoelectric pumps; morphing piezocompostite actuators; and nanoscale magnetoelectric memory, antenna, and motors. Systems-level applications (team projects) include controlled optics for deep-space observing satellites, ultra-low-frequency magneto-mechanical antennas, morphing aircraft structures, and next-generation computer memory.

## Center for Translational Applications of Nanoscale Multiferroic Systems (TANMS)

Gregory P. Carman, *Director*

TANMS is a multi-institutional engineering research center (ERC) focused on research, technology translation, and education associated with magnetism on the small scale. The TANMS vision is to develop a fundamentally new approach that couples electricity to magnetism using engineered nanoscale multiferroic elements, to enable increased energy efficiency, reduced physical size, and increased power output in consumer electronics. This new approach overcomes scaling limitations present Oersted's magnetism control discovery of 1820. TANMS goal is to translate its research discoveries to industry while seamlessly integrating a cradle-to-career education philosophy involving its students, and future engineers, in unique research and entrepreneurial experiences.

## Chen Research Group

Yong Chen, *Director*

The group studies nanofabrication, nanoscale electronic materials and devices, micro-nano electronic/optical/bio/mechanical systems, and ultra-scale spatial and temporal characterization.

## Collaborative Center for Aerospace Sciences (CCAS)

Ann R. Karagozian, *Director*

CCAS is a multi-/trans-disciplinary research center focused on fundamental and applied basic studies relevant to aerospace systems. Research projects that broadly span the computational and experimental arenas are conducted at UCLA and at Air Force Research Laboratory (AFRL/RQ) at Edwards Air Force Base northeast of campus. UCLA faculty, students, and postdoctoral researchers collaborate with AFRL scientists and engineers on high-impact problems to advance U.S. capabilities in aerospace systems.

## Complex Fluids and Interfacial Physics Laboratory

H. Pirouz Kavehpour, *Director*

The laboratory is multidisciplinary, with areas of research ranging from rheology of biofluids to energy storage. The group is directed towards development of fundamental engineering and scientific knowledge.

## Cybernetic Control Laboratory (CyCLab)

Tetsuya Iwasaki, *Director*

CyCLab aims to develop biologically inspired control theories for rhythmic movements and dynamic pattern formation with applications to robotic vehicles, devices for human assist, and rehabilitation.

## Design and Manufacturing Laboratory

The laboratory offers an environment for synergistic integration of design and manufacturing. Available equipment includes four CNC machines, two rapid-prototyping systems, coordinate measuring, X-ray radiography, robots with vision systems, audiovisual equipment, and a distributed network of more than 30 workstations.

## Energy and Propulsion Research Laboratory

Ann R. Karagozian, *Director*

The laboratory involves the application of modem diagnostic methods and computational tools to the development of improved combustion, propulsion, and fluid flow systems. Research includes aspects of fluid mechanics, chemistry, optics, and numerical methods, as well as thermodynamics and heat transfer.

## Energy Innovation Laboratory

Richard E. Wirz, *Director*

The laboratory investigates high-impact renewable energy science and technology. Its current work primarily focuses on large-scale thermal energy storage for grid-scale applications and advanced wind energy capture.

## Flexible Research Group

Jonathan B. Hopkins, *Director*

The group is dedicated to the design and fabrication of flexible structures, mechanisms, and materials that achieve extraordinary capabilities. The laboratory is equipped with state-of-the-art synthesis tools, optimization software, and a number of commercial and custom-developed additive fabrication technologies for fabricating complex flexible structures at the macro- to nano-scale.

## Fusion Science and Technology Center

Mohamed A. Abdou, *Director*

The center includes experimental facilities for conducting research in fusion science and engineering, and multiple scientific disciplines in thermofluids, thermomechanics, heat/mass transfer, and materials interactions. The center includes experimental facilities for liquid metal magnetohydrodynamic fluid flow, thick and thin liquid metal systems exposed to intense particle and heat flux loads, and metallic and ceramic material thermomechanics.

## Ho Systems Laboratory – Personalized Medicine

Chih-Ming Ho, Director

The laboratory researches phenotypic personalized medicine (PPM). It has discovered that drug-dose inputs are correlated with phenotypic outputs with a parabolic response surface (PRS). With a few calibration tests to determine the coefficients of its quadratic governing algebraic equation, PRS dictates the composition and ratio of a globally optimized drug combination. Based on the PRS platform, phenotypic personalized medicine (PPM) can realize unprecedented adaptability to identify the optimized drug combination for a specific patient. PRS is an indication-agnostic and mechanism-free platform technology, which has been successfully demonstrated in about 30 diseases.

## Hu Research Laboratory (H-Lab)

Yongjie Hu, *Director*

H-Lab is focused on understanding and engineering nanoscale transport phenomena and nanomaterials for wide applications including energy conversion, storage, and thermal management. The lab uses a variety of experimental and theoretical techniques to investigate nanoscale transport processes, with a particular emphasis on design and chemical synthesis of advanced materials, ultrafast optical spectroscopy, pulsed electronics, and thermal spectral mapping techniques.

## Hypersonics and Computational Aerodynamics Group

Xiaolin Zhong, *Director*

The group primarily focuses on fundamental physics-based research of hyper-sonic flows using advanced numerical tools; and application of discovered fundamental knowledge to real-world aerospace systems, such as development of hypersonic planes and space vehicles. Its main research areas are computational fluid dynamics (CFD), hypersonic flows, instability and transition of hypersonic boundary layers, interaction of strong shocks and turbulence, and numerical simulation of wave energy harvesting.

## Laser Spectroscopy and Gas Dynamics Laboratory

Raymond M. Spearrin, *Director*

The laboratory conducts research driven by applications in propulsion and energy, with extensions to health and environment. Lab activities are united by a core focus in experimental thermofluids and applied spectroscopy. Projects commonly span fundamental spectroscopy science to design and deployment of prototype sensors to investigate dynamic flow-fields.

## Materials Degradation Characterization Laboratory

Ajit K. Mal, *Director*

The laboratory is used for characterization of the degradation of high-strength metallic alloys and advanced composites due to corrosion and fatigue, determination of adverse effects of materials degradation on the strength of structural components, and research on fracture mechanics and ultrasonic nondestructive evaluation.

## Materials in Extreme Environments Laboratory (MATRIX)

Nasr M. Ghoniem, *Director*

MATRIX seeks answers to two fundamental questions: What are the physical phenomena that control the mechanical properties of engineering materials operating in extreme environmental conditions; and knowing such behavior, can we design engineering materials to be more resilient.

## M'Closkey Laboratory

Robert T. M'Closkey, *Director*

The laboratory develops miniature, high-performance angular-rate sensors called vibratory gyroscopes. A separate long-term project seeks to understand the mixing dynamics of a jet injected into a cross-flow.

## Mechanics of Soft Materials Laboratory

Lihua Jin, *Director*

The laboratory investigates the fundamental physics and mechanics of soft materials, such as their constitutive relation, nonlinear deformation, instability, and fracture. The lab also strives to develop new materials, structures, and functions for soft robotics and stretchable electronics.

## Mechatronics and Controls Laboratory

Tsu-Chin Tsao, *Director*

The laboratory conducts research in theory and innovation in dynamic systems, controls, mechatronics, and robotics. It creates high-performance systems with novel sensors, actuators, and real-time digital signal processing and embedded control. Applications include precision motion and vibration control, manufacturing equipment and processes, medical devices, and robots.

## Micro- and Nano-Manufacturing Laboratory

Chang-Jin (CJ) Kim, *Director*

The laboratory is equipped with a fume hood, clean air bench, optical table, DI water generator, plating setup, probe station, various microscopes, test and measurement systems, and CAD programs for mask layout. It is used for micromachining and MEMS research, and complements the UCLA Samueli Nanoelectronics Research Facility.

## Modeling of Complex Thermal Systems Laboratory

Adrienne G. Lavine, *Director*

The laboratory addresses a variety of systems in which heat transfer plays an important role. Thermal aspects of these systems are coupled with other physical phenomena such as mechanical or electrical behavior. Modeling tools range from analytical to custom computer codes to commercial software.

## Morrin-Gier-Martinelli Heat Transfer Memorial Laboratory

Laurent G. Pilon, *Director*

The laboratory is engaged in a broad range of interdisciplinary research projects at the intersection of interfacial and transport phenomena, radiation transfer, material science, and biology for sustainable solar energy conversion; waste heat energy harvesting; electrical energy storage; and energy efficient buildings. The laboratory features state-of-the-art equipment for material synthesis and characterization such as glove boxes and high-temperature furnaces, potentiostats, calorimeters, and thermal conductivity analyzers. It is also equipped with a full set of instruments for optical characterization of solids, liquids, and suspensions from ultraviolet to infrared wavelengths (e.g., spectrometers, lasers, and detection systems). The laboratory also has various instrumented flow loops for rheological and convective heat transfer experiments with complex fluids.

## Multiscale Thermosciences Laboratory (MTSL)

Y. Sungtaek Ju, *Director*

MTSL is focused on heat and mass transfer phenomena at the nano- to macro-scales. A wide variety of applications are explored, including novel materials and devices for energy conversion; combined cooling, heating, and power generation; thermal management of electronics and buildings; energy-water nexus; and biomedical MEMS/NEMS devices.

## Nanoscale Transport Research Group

Timothy S. Fisher, *Director*

The group works on a broad range of problems, primarily involving transport processes by electrons, phonons, photons, and fluids. It seeks to solve problems with high importance to applications in energy transport, conversion, and storage, that are relevant to major industrial segments (aerospace, micro/nanoelectronics, and sensors). The lab solves these problems through a holistic, balanced approach that spans nanomaterial synthesis, basic material characterization and modeling, and functional characterization and simulation. The group includes the Center for Integrated Thermal Management of Aerospace Vehicles (CITMAV), which develops new solutions to highly transient transport problems that occur in aerospace applications.

## Optofluidics Systems Laboratory

Pei-Yu Chiou, *Director*

The laboratory develops heterogeneously integrated functional devices and systems for biomedical applications. Research areas include integrated photonics and fluidics devices; 3D micro- and nano-manufacturing technologies; and flexible mechanical, photonics, and electronics systems.

## Pilon Research Group

Laurent G. Pilon, *Director*

The group researches photobiological fuel production, mesoporous materials, electrochemical capacitors, waste heat energy harvesting, foams/microfoams, biomedical optics, and energy efficiency.

## Plasma and Beam Assisted Manufacturing Laboratory

The laboratory is an experimental facility for processing and manufacturing advanced materials by high-energy means (plasma and beam sources). It is equipped with plasma diagnostics, two vortex gas tunnel plasma guns, powder feeder and exhaust systems, vacuum and cooling equipment, high-power DC supplies (400kw), vacuum chambers, and large electromagnets. Current research is focused on ceramic coatings and nano-phase clusters for applications in thermal insulation, wear resistance, and high-temperature oxidation resistance.

## Plasma and Space Propulsion Laboratory

Richard E. Wirz, *Director*

The laboratory investigates plasma processes related to advanced space propulsion systems using a combination of experimental, computational, and analytical perspectives. Its research is directly inspired by the rapidly emerging field of electric propulsion (EP). Other applications of its work include microplasmas, plasma processing, and fusion.

## Robotics and Mechanisms Laboratory (RoMeLa)

Dennis W. Hong, *Director*

RoMeLa is a facility for robotics research and education with an emphasis on studying humanoid robots and novel mobile robot locomotion strategies. Research is in the areas of robot locomotion and manipulation, soft actuators, platform design, kinematics and mechanisms, and autonomous systems. RoMeLa is active in research-based international robotics competitions, winning numerous prizes including third place in the DARPA Urban Challenge. The laboratory also took first place in the RoboCup international autonomous robot soccer competition (kid-size and adult-size humanoid divisions), and was world champion five times in a row. It also brought the prestigious Louis Vuitton Cup Best Humanoid award to the U.S. for the first time, and most recently was one of six Track A teams chosen to participate in the DARPA Robotics Challenge disaster response robot competition.

## Scifacturing Laboratory

Xiaochun Li, *Director*

The laboratory furnishes a creative, interdisciplinary platform for science-driven manufacturing (scifacturing) as the next level of manufacturing. It seeks to enable application of physics and chemistry to empower breakthroughs in manufacturing. The laboratory links molecular, nano-, and micro-scale knowledge to scalable processes/systems in manufacturing and materials processing. Current focus areas include scale-up nanomanufacturing, solidification nanoprocessing of super-materials with dense nanoparticles, structurally integrated micro- and nano-systems (especially sensors and actuators) for manufacturing, clean energy and biomedical manufacturing, meso/micro 3D printing, and laser materials processing.

## Smart Grid Energy Research Center (SMERC)

Rajit Gadh, *Director*

SMERC performs research; creates innovations; and demonstrates advanced Internet-of-things, sense-and-control technologies, and data-enabled machine learning to enable development of the next-generation electric utility grid—the smart grid. SMERC also furnishes thought leadership through its ESmart Consortium between utilities, government, policy makers, technology providers, electric vehicle manufacturers, energy technology companies, Department of Energy research laboratories, and universities, so as to collectively work on envisioning, planning, and executing the smart grid of the future. This grid will enable integration of renewable energy sources. It will also reduce losses; improve efficiencies; increase grid flexibility; allow for integration of electric and autonomous vehicles; reduce power outages; allow for competitive energy pricing; and overall become more responsive to market, consumer, and societal needs. SMERC is currently working electric vehicle integration (G2V and V2G), automated demand response (ADR), microgrids, distributed energy resources, renewable integration, battery energy storage integration, and autonomous vehicle infrastructure.

## Simulations of Flow Physics and Acoustics Laboratory (SOFiA)

Jeffrey D. Eldredge, *Director*

SOFiA explores a wide variety of phenomena that occur in fluid flows in nature and technology. It investigates low-order modeling of unsteady aerodynamics of agile, bio-inspired, micro-air vehicles; microparticle manipulation by viscous streaming; the fluid dynamics of biological and biologically-inspired locomotion; interactions of fluid flows with flexible surfaces; transitional and turbulent hypersonic boundary layer flows; vortex estimation techniques for autonomous control of formation flight; and new computational tools for simulation of biomedical flows.

## Thermochemical Energy Storage Laboratory

Adrienne G. Lavine, *Director*

The laboratory is focused on use of reversible chemical reactions to store energy for renewable energy applications. The current focus is on ammonia synthesis for supercritical steam generation in a concentrating solar power plant. The ammonia synthesis reactor testing platform consists of three subsystems (dissociation, synthesis, and steam generation) that work in unison to create a closed-loop synthesis gas generator that can operate for an indefinite period of time.

## Thin Films, Interfaces, Composites, Characterization Laboratory

Vijay Gupta, *Director*

The laboratory includes a Nd:YAG laser of 1 Joule capacity with 3 ns pulse widths; a state-of-the-art optical interferometer including an ultra-high-speed digitizer, sputter deposition chamber, 56 Kip-capacity servohydraulic biaxial test frame, and polishing and imaging equipment for microstructural characterization; for measurement and control study of thin film interface strength.

## Turbulence Research Group

J. John Kim, *Director*

The group is primarily focused on the study of turbulence and stability. It has a long history of studying incompressible flow, and has recently begun studying compressible flow problems. All its work is carried out numerically with computational fluid dynamic (CFD) codes, which are written in-house. Its current research interests include real gas effects on compressible turbulent boundary-layer flow, drag reduction through the use of superhydrophobic surfaces on incompressible turbulent boundary-layer flow, and the effects of distributed roughness on compressible turbulent boundary-layer flows.

# Faculty Areas of Thesis Guidance

### Professors

Mohamed A. Abdou, Ph.D. (U. Wisconsin, 1973)
*Fusion, nuclear, and mechanical engineering design, testing, and system analysis, thermomechanics; thermal hydraulics; fluid dynamics, heat, and mass transfer in the presence of magnetic fields (MHD flows); neutronics; radiation transport; plasma-material interactions; blankets and high heat flux components; experiments, modeling and analysis*

Robert N. Candler, Ph.D. (Stanford, 2006)
*MEMS/NEMS for compact free-electron lasers, miniature medical devices, nanoscale magnetic structures and devices, additive manufacturing, fundamental limits of micro- and nano-scale devices*

Gregory P. Carman, Ph.D. (Virginia Tech, 1991)
*Electromagnetoelasticity models including micromagnetics, elastodynamics, and Maxwell coupled solutions. Characterization of piezoelectric ceramics, magnetostrictive shape memory alloys, and multiferroic materials.*

Yong Chen, Ph.D. (UC Berkeley, 1996)
*Nanoscale science and engineering, micro- and nano-fabrication, self-assembly phenomena, microscale and nanoscale electronic, mechanical, optical, biological, and sensing devices, circuits and systems*

Pei-Yu Chiou, Ph.D. (UC Berkeley, 2005)
*BioMEMS, biophotonics, electrokinetics, optical manipulation, optoelectronic devices*

Vijay K. Dhir, Ph.D. (U. Kentucky, 1972)
*Two-phase heat transfer, boiling and condensation, thermal hydraulics of nuclear reactors, microgravity heat transfer, soil remediation, high-power density electronic cooling*

Jeffrey D. Eldredge, Ph.D. (Caltech, 2002)
*Numerical simulations of fluid dynamics, bio-inspired locomotion in fluids, transition and turbulence of high-speed flows, aerodynamically generated sound, vorticity-based numerical methods, simulations of biomedical flows*

Timothy S. Fisher, Ph.D. (Cornell, 1998)
*Heat and mass transfer, interfacial transport, nanomaterial synthesis, nano-/micro-device fabrication, non-equilibrium thermodynamics, subcontinuum modeling and measurements of heat and charge transport, electrochemical and thermal energy storage, mechanics and transport in granular materials and porous media, plasma science and technology, aerospace thermal systems*

Rajit Gadh, Ph.D. (Carnegie Mellon, 1991)
*Smart grid, electric vehicle and grid integration, microgrid, distributed energy resource, solar- and renewable-grid integration, demand re-sponse, autonomous electric vehicle, machine learning from transportation data, radio frequency identification (RFID), Internet of things*

Nasr M. Ghoniem, Ph.D. (U. Wisconsin, 1977)
*Mechanics of materials in severe environments (nuclear, aerospace, transportation); radiation interaction with materials (e.g., laser, ions, plasma, electrons, and neutrons); multiscale modeling; physics and mechanics of material defects; fusion energy; materials for space propulsion*

Vijay Gupta, Ph.D. (MIT, 1989)
*Experimental mechanics, fracture of engineering solids, mechanics of thin film and interfaces, failure mechanisms and characterization of composite materials, ice mechanics*

Dennis W. Hong, Ph.D. (Purdue, 2002)
*Analysis and visualization of contact force solution space for multilimbed mobile robots*

Tetsuya Iwasaki, Ph.D. (Purdue, 1993)
*Dynamical systems, robust and optimal controls, nonlinear oscillators, resonance entrainment, modeling and analysis of neuronal control circuits for animal locomotion, central pattern generators, body-fluid interaction during undulatory and oscillatory swimming*

Y. Sungtaek Ju, Ph.D. (Stanford, 1999)
*Heat and mass transfer, energy, energy-water nexus, MEMS and nanotechnology*

Ann R. Karagozian, Ph.D. (Caltech, 1982)
*Fluid mechanics and combustion with applications to air breathing, rocket propulsion, and energy-generation systems, focusing on control of instabilities improved efficiency, and reduced emissions*

H. Pirouz Kavehpour, Ph.D. (MIT, 2003)
*Microscale fluid mechanics, transport phenomena in biological systems, biofluids, coating flows and physics of contact line phenomena, complex fluids, non-isothermal flows, energy systems and energy storage*

Chang-Jin (CJ) Kim, Ph.D. (UC Berkeley, 1991)
*Microelectromechanical systems (MEMS), micro/nano devices and fabrication technologies, microfluidics especially involving surface tension and droplets*

Adrienne Lavine, Ph.D. (UC Berkeley, 1984)
*Heat transfer: thermomechanical behavior of shape memory alloys, thermal aspects of manufacturing processes, natural and mixed convection*

Xiaochun Li, Ph.D. (Stanford, 2001)
*Embedded sensors in layered manufacturing*

Kuo-Nan Liou, Ph.D. (New York U., 1970)
*Radiative transfer and satellite remote sensing with application to clouds and aerosols in the earth's atmosphere*

Ajit K. Mal, Ph.D. (Calcutta U., India, 1964)
*Mechanics of solids, composite materials, wave propagation, nondestructive evaluation, structural health monitoring*

Robert T. M'Closkey, Ph.D. (Caltech, 1995)
*Nonlinear control theory and design with application to mechanical and aerospace systems, real-time implementation*

Ali Mosleh, Ph.D., NAE (UCLA, 1981)
*Reliability engineering, physics of failure modeling and system life prediction, resilient systems design, prognostics and health monitoring, hybrid systems simulation, theories and techniques for risk and safety analysis*

Jayathi Y. Murthy, Ph.D. (U. Minnesota, 1984)
*Nanoscale heat transfer, computational fluid dynamics, simulation of fluid flow and heat transfer for industrial applications, sub-micron thermal transport, multiscale multiphysics simulations and uncertainty quantifications*

Laurent G. Pilon, Ph.D. (Purdue, 2002)
*Interfacial and transport phenomena, radiation transfer, materials synthesis, multi-phase flow, heterogeneous media*

Jacob Rosen, Ph.D. (Tel Aviv U., Israel, 1997)
*Natural integration of a human arm/powered exoskeleton system*

Jason L. Speyer, Ph.D. (Harvard, 1968)
*Stochastic and deterministic optimal control and estimation with application to aerospace systems; guidance, flight control, and flight mechanics*

Tsu-Chin Tsao, Ph.D. (UC Berkeley, 1988)
*Mechatronics and control with applications in mechanical systems, manufacturing, vehicles, medical robots, and energy*

Xiaolin Zhong, Ph.D. (Stanford, 1991)
*Computational fluid dynamics, advanced high-order CFD methods, hypersonic flow, numerical simulation of transient hypersonic flow with nonequilibrium real-gas effects, instability and laminar-turbulent transition of hypersonic boundary layers*

### Professors Emeriti

Oddvar O. Bendiksen, Ph.D. (UCLA, 1980)
*Classical and computational aeroelasticity, structural dynamics and unsteady aerodynamics*

Ivan Catton, Ph.D. (UCLA, 1966)
*Heat transfer and fluid mechanics, transport phenomena in porous media, nucleonics heat transfer and thermal hydraulics, natural and forced convection, thermal/hydrodynamic stability, turbulence*

Peretz P. Friedmann, Sc.D. (MIT, 1972)
*Aeroelasticity of helicopters and fixed-wing aircraft, structural dynamics of rotating systems, rotor dynamics, unsteady aerodynamics, active control of structural dynamics, structural optimization with aeroelastic constraints*

James S. Gibson, Ph.D. (U. Texas Austin, 1975)
*Control and identification of dynamical systems; optimal and adaptive control of distributed systems, including flexible structures and fluid flows; adaptive filtering, identification, and noise cancellation*

Chih-Ming Ho, Ph.D. (Johns Hopkins, 1974)
*Molecular fluidic phenomena, microelectromechanical systems (MEMS), bionano technologies, biomolecular sensor arrays, control of cellular complex systems, rapid search of combinatorial medicine*

Robert E. Kelly, Sc.D. (MIT, 1964)
*Thermal convection, thermocapillary convection, stability of shear flows, stratified and rotating flows, interfacial phenomena, microgravity fluid dynamics*

J. John Kim, Ph.D. (Stanford, 1978)
*Numerical simulation of turbulent and transitional flows, physics and control of turbulent flows, application of modern control theories to flow control*

Anthony F. Mills, Ph.D. (UC Berkeley, 1965)
*Convective heat and mass transfer, condensation heat transfer, turbulent flows, ablation and transpiration cooling, perforated plate heat exchangers*

D. Lewis Mingori, Ph.D. (Stanford, 1966)
*Dynamics and control, stability theory, nonlinear methods, applications to space and ground vehicles*

Peter A. Monkewitz, Ph.D. (ETH Zürich, Switzerland, 1977)
*Fluid mechanics, internal acoustics and noise produced by turbulent jets*

Philip F. O'Brien, M.S. (UCLA, 1949)
*Industrial engineering, environmental design, thermal and luminous engineering systems*

Lucien A. Schmit, Jr., M.S. (MIT, 1950)
*Structural mechanics, optimization, automated design methods for structural systems and components, application of finite element analysis techniques and mathematical programming algorithms in structural design, analysis and synthesis methods for fiber composite structural components*

Owen I. Smith, Ph.D. (UC Berkeley, 1977)
*Combustion and combustion-generated air pollutants, hydrodynamics and chemical kinetics of combustion systems, semiconductor chemical vapor deposition*

Richard Stern, Ph.D. (UCLA, 1964)
*Experimentation in noise control, physical acoustics, engineering acoustics, medical acoustics*

Russell A. Westmann, Ph.D. (UC Berkeley, 1962)
*Mechanics of solid bodies, fracture mechanics, adhesive mechanics, composite materials, theoretical soil mechanics, mixed boundary value problems*

Daniel C.H. Yang, Ph.D. (Rutgers, 1982)
*Robotics and mechanisms; CAD/CAM systems, computer-controlled machines*

### Associate Professors

Elisa Franco, Ph.D. (U. Trieste, Italy, 2007; Caltech, 2011)
*Convergence of structural biology, dynamics, and controls using specialized biomolecular frameworks*

Jaime Marian, Ph.D. (UC Berkeley, 2002)
*Computational materials modeling and simulation in solid mechanics, irradiation damage, plasticity, phase transformations, thermodynamics and kinetics of alloy systems, algorithm and method development for bridging time and length scales and parallel computing applications*

Veronica J. Santos, Ph.D. (Cornell, 2007)
*Grasp and manipulation, hand biomechanics, haptics, human-machine systems, machine learning, machine perception, neural control of movement, prosthetics, robotics, stochastic modeling, tactile sensor*

Kunihiko (Sam) Taira, Ph.D. (Caltech, 2008)
*Development of computation fluid dynamics that incorporate unsteady aerodynamics, flow control, and network theory*

Richard E. Wirz, Ph.D. (Caltech, 2005)
*Electric propulsion (ion, Hall, electrosprays, cathodes); micro-electric propulsion; partially ionized plasma discharges; miniature plasma devices; spacecraft/space mission design; wind energy; solar thermal energy; thermal energy storage*

### Assistant Professors

Artur Davoyan, Ph.D. (Australian National U., 2011)
*Devising and development of new approaches for space propulsion and power using unique nanomaterials*

Jonathan B. Hopkins, Ph.D. (MIT, 2010)
*Design and manufacturing of microstructural architectures, flexure systems, and compliant mechanisms; screw theory kinematics; precision machine design; novel micro- and nanofabrication processes; MEMS*

Yongjie Hu, Ph.D. (Harvard, 2011)
*Heat transfer and electron transport in nanostructures; interfaces and packaging; thermal, electronic, optoelectronic, and thermoelectric devices and systems; energy conversion, storage, and thermal management; ultrafast optical spectroscopy and high-frequency electronics; nanomaterials design, processing, and manufacturing*

M. Khalid Jawed, Ph.D. (MIT, 2016)
*Data-driven approach to modeling the mechanics of structures and fluid-structure interaction using robotics, automation, computation, and machine learning*

Lihua Jin, Ph.D. (Harvard, 2014)
*Mechanics of soft materials; continuum mechanics and applications in technologies: additive manufacturing, soft robotics and stretchable electronics, nanomechanics, and multiscale modeling*

Raymond M. Spearrin, Ph.D. (Stanford, 2015)
*Sepctroscopy and gas dynamics, advanced optical sensors including laser absorption and fluorescence with experimental application to propulsion, energy systems and other reacting flow fields*

### Lecturers

Ravnesh C. Amar, Ph.D. (UCLA, 1974)
*Heat transfer and thermal science*

Amiya K. Chatterjee, Ph.D. (UCLA, 1976)
*Elastic wave propagation and penetration dynamics*

Robert J. Kinsey, Ph.D. (UCLA, 1991)
*Modeling, simulation, and analysis of spacecraft dynamics and pointing control systems; nonlinear dynamics of spinning bodies; concurrent engineering methods for space mission conceptual design*

Damian M. Toohey, M.S. (MIT, 2004)
*Guidance, navigation, and control for autonomous aircraft, launch vehicles, and missile systems, adaptive control techniques, automatic control reallocation for aircraft and reentry vehicles*

### Adjunct Professors

Dan M. Goebel, Ph.D. (UCLA, 1981)
*Hollow cathode, magnetic-multiple ion sources for neutral beam injection*

Leslie M. Lackman, Ph.D. (UC Berkeley, 1967)
*Structural analysis and design, composite structures, engineering management*

Christopher S. Lynch, Ph.D. (UC Santa Barbara, 1992)
*Field coupled materials, constitutive behavior, thermo-electro-mechanical properties, sensor and actuator applications, fracture mechanics and failure analysis*

Wilbur J. Marner, Ph.D. (U. South Carolina, 1969)
*Thermal sciences, system design*

Neil G. Siegel, Ph.D. (USC, 2011)
*Organizing complex projects around critical skills and mitigation of risks arising from system dynamic behavior*

### Adjunct Associate Professor

Abdon E. Sepulveda, Ph.D. (UCLA, 1990)
*Optimal placement of actuators and sensors in control augmented structural optimization*

## Lower-Division Courses

**1. Undergraduate Seminar. (1)** Seminar, one hour; outside study, two hours. Introduction by faculty members and industry lecturers to mechanical and aerospace engineering disciplines through current and emerging applications in aerospace, medical instrumentation, automotive, entertainment, energy, and manufacturing industries. P/NP grading.
Mr. Mal (F)

**19. Fiat Lux Freshman Seminars. (1)** Seminar, one hour. Discussion of and critical thinking about topics of current intellectual importance, taught by faculty members in their areas of expertise and illuminating many paths of discovery at UCLA. P/NP grading.

**M20. Introduction to Computer Programming with MATLAB. (4)** (Same as Civil Engineering M20.) Lecture, two hours; discussion, two hours; laboratory, two hours; outside study, six hours. Requisite: Mathematics 33A. Fundamentals of computer programming taught in context of MATLAB computing environment. Basic data types and control structures. Input/output. Functions. Data visualization. MATLAB-based data structures. Development of efficient codes. Introduction to object-oriented programming. Examples and exercises from engineering, mathematics, and physical sciences. Letter grading.
Mr. Eldredge, Mr. Taciroglu (F,W,Sp)

**82. Mathematics of Engineering. (4)** (Formerly numbered 182A.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: Mathematics 33A. Recommended requisite: course M20. Methods of solving ordinary differential equations in engineering. Review of matrix algebra. Solutions of systems of first- and second-order ordinary differential equations. Introduction to Laplace transforms and their application to ordinary differential equations. Introduction to boundary value problems, partial differential equating, and separation of variables. Letter grading.
Mr. Mal (F,W,Sp)

**94. Introduction to Computer-Aided Design and Drafting. (4)** Lecture, two hours; laboratory, four hours. Fundamentals of computer graphics and two- and three-dimensional modeling on computer-aided design and drafting systems. Students use one or more online computer systems to design and display various objects. Letter grading.
Mr. Gadh, Mr. Li (F,W,Sp)

**99. Student Research Program. (1 to 2)** Tutorial (supervised research or other scholarly work), three hours per week per unit. Entry-level research for lower-division students under guidance of faculty mentor. Students must be in good academic standing and enrolled in minimum of 12 units (excluding this course). Individual contract required; consult Undergraduate Research Center. May be repeated. P/NP grading.

## Upper-Division Courses

**101. Statics and Strength of Materials. (4)** (Formerly numbered 96.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: Mathematics 31A, 31B, Physics 1A. Review of vector representation of forces, resultant force and moment, equilibrium of concurrent and nonconcurrent forces. Area moments and products of inertia. Support reactions, free-body diagrams. Forces in simple models of mechanical and aerospace structures. Internal forces in beams, shear and moment diagrams. Stress and strain components in solids, equilibrium equations, Hooke's law for isotropic solids. Bending and shear stresses in beams. Deflection of symmetric beams and indeterminate problems. Stresses in thin-walled pressure vessels and in circular cylinders under torsion. Letter grading. Mr. Mal (F,W,Sp)

**102. Dynamics of Particles and Rigid Bodies. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course 101, Mathematics 33A, Physics 1A. Fundamental concepts of Newtonian mechanics. Kinematics and kinetics of particles and rigid bodies in two and three dimensions. Impulse-momentum and work-energy relationships. Applications. Letter grading.
Ms. Santos (F,W,Sp)

**103. Elementary Fluid Mechanics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: Mathematics 32B, 33A, Physics 1B. Introductory course dealing with application of principles of mechanics to flow of compressible and incompressible fluids. Letter grading.
Mr. Kavehpour, Mr. J. Kim (F,W,Sp)

**105A. Introduction to Engineering Thermodynamics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: Chemistry 20B, Mathematics 32B. Phenomenological thermodynamics. Concepts of equilibrium, temperature, and reversibility. First law and concept of energy; second law and concept of entropy. Equations of state and thermodynamic properties. Engineering applications of these principles in analysis and design of closed and open systems. Letter grading. Mr. Pilon (F,W,Sp)

**105D. Transport Phenomena. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 82, 103, 105A. Transport phenomena; heat conduction, mass species diffusion, convective heat and mass transfer, and radiation. Engineering applications in thermal and environmental control. Letter grading.
Mr. Ju, Ms. Lavine (F,W,Sp)

**107. Introduction to Modeling and Analysis of Dynamic Systems. (4)** Lecture, four hours; discussion, one hour; laboratory, two hours; outside study, five hours. Enforced requisites: courses M20 (or Computer Science 31), 82, Electrical Engineering 100. Introduction to modeling of physical systems, with examples of mechanical, fluid, thermal, and electrical systems. Description of these systems with coverage of impulse response, convolution, frequency response, first- and second-order system transient response analysis, and numerical solution. Nonlinear differential equation descriptions with discussion of equilibrium solutions, small signal linearization, large signal response. Block diagram representation and response of interconnections of systems. Hands-on experiments reinforce lecture material. Letter grading.
Mr. M'Closkey, Mr. Tsao (F,W,Sp)

**131A. Intermediate Heat Transfer. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: courses M20 (or Civil Engineering M20 or Computer Science 31), 82, 105D. Steady conduction: two-sided, two-ended, tapered, and circular fins; buried cylinders, thick fins. Transient conduction: slabs, cylinders, products. Convection: transpiration, laminar pipe flow, film condensation, boundary layers, dimensional analysis, working correlation, surface radiation. Two-stream heat exchangers. Elements of thermal design. Letter grading. Ms. Lavine (F)

**C131G. Microscopic Energy Transport. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 105D. Exploration of basic principles of transportation of energy in natural and fabricated structures by three carriers: electrons, phonons, and molecules. Study of statistical properties of heat carriers, common Landauer framework for heat flow, scattering and propagation of heat carriers, derivation of classical laws from microscopic transport equations, and deviation from classical laws at small scale. Concurrently scheduled with course C231G. Letter grading. Mr. Fisher (F)

**133A. Engineering Thermodynamics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 103, 105A. Applications of thermodynamic principles to engineering processes. Energy conversion systems. Rankine cycle and other cycles, refrigeration, psychrometry, reactive and nonreactive fluid flow systems. Elements of thermodynamic design. Letter grading. Mr. Fisher (W,Sp)

**135. Fundamentals of Nuclear Science and Engineering. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: course 82, Chemistry 20A. Review of nuclear physics, radioactivity and decay, and radiation interaction with matter. Nuclear fission and fusion processes and mass defect, chain reactions, criticality, neutron diffusion and multiplication, heat transfer issues, and applications. Introduction to nuclear power plants for commercial electricity production, space power, spacecraft propulsion, nuclear fusion, and nuclear science for medical uses. Letter grading.
Mr. Abdou (Not offered 2019-20)

**136. Energy and Environment. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 105A. Global energy use and supply, electrical power generation, fossil fuel and nuclear power plants, renewable energy such as hydropower, biomass, geothermal, solar, wind, and ocean, fuel cells, transportation, energy conservation, air and water pollution, global warming. Letter grading. Mr. Pilon (Sp)

**C137. Design and Analysis of Smart Grids. (4)** Lecture, four hours; outside study, eight hours. Demand response; transactive/price-based load control; home-area network, smart energy profile; advanced metering infrastructure; renewable energy integration; solar and wind generation intermittency and correction; microgrids; grid stability; energy storage and electric vehicles-simulation; monitoring; distribution and transmission grids; consumer-centric technologies; sensors, communications, and computing; wireless, wireline, and powerline communications for smart grids; grid modeling, stability, and control; frequency and voltage regulation; ancillary services; wide-area situational awareness, phasor measurements; analytical methods and tools for monitoring and control. Concurrently scheduled with course C237. Letter grading. Mr. Gadh (F)

**C138. Introduction to Statistical Thermodynamics. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 105A, 105D. Introduction to basic concepts and tools of statistical thermodynamics. Abstract concepts of entropy, temperature, and chemical potential are explained by developing these concepts from ground up using only mechanical and statistical principles. Discussion of equilibrium properties of thermodynamic systems and associated distributions. Provides sound foundation for further studies in transport phenomena, plasma, chemical kinetics, micro/nanoscale science and technology, and other related subjects. Concurrently scheduled with course C238. Letter grading. (Sp)

**CM140. Introduction to Biomechanics. (4)** (Same as Bioengineering CM140.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 101, 102, and 156A or 166A. Introduction to mechanical functions of human body; skeletal adaptations to optimize load transfer, mobility, and function. Dynamics and kinematics. Fluid mechanics applications. Heat and mass transfer. Power generation. Laboratory simulations and tests. Concurrently scheduled with course CM240. Letter grading.
Mr. Gupta (W)

**150A. Intermediate Fluid Mechanics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: courses 82, 103. Basic equations governing fluid motion. Fundamental solutions of Navier/Stokes equations. Lubrication theory. Elementary potential flow theory. Boundary layers. Turbulent flow in pipes and boundary layers. Compressible flow: normal shocks, channel flow with friction or heat addition. Letter grading.
Mr. Eldredge, Ms. Karagozian (F,W)

**150B. Aerodynamics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 103, 150A. Advanced aspects of potential flow theory. Incompressible flow around thin airfoils (lift and moment coefficients) and wings (lift, induced drag). Gas dynamics: oblique shocks, Prandtl/Meyer expansion. Linearized subsonic and supersonic flow around thin airfoils and wings. Wave drag. Transonic flow. Letter grading. Mr. Zhong (Sp)

**150C. Combustion Systems. (4)** Lecture, four hours; outside study, eight hours. Enforced requisites: courses 103, 105A. Chemical thermodynamics of ideal gas mixtures, premixed and diffusion flames, explosions and detonations, combustion chemistry, high explosives. Combustion processes in rocket, turbine, and internal combustion engines; heating applications. Letter grading.
Ms. Karagozian (Not offered 2019-20)

**C150G. Fluid Dynamics of Biological Systems. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 103. Mechanics of aquatic locomotion; insect and bird flight aerodynamics; pulsatile flow in circulatory system; rheology of blood; transport in microcirculation; role of fluid dynamics in arterial diseases. Concurrently scheduled with course C250G. Letter grading. Mr. Eldredge (Not offered 2019-20)

**C150P. Aircraft Propulsion Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 105A, 150A. Thermodynamic properties of gases, aircraft jet engine cycle analysis and component performance, component matching, advanced aircraft engine topics. Concurrently scheduled with course C250P. Letter grading.
Ms. Karagozian, Mr. Spearrin (F)

**C150R. Rocket Propulsion Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: courses 103, 105A. Rocket propulsion concepts, including chemical rockets (liquid, gas, and solid propellants), hybrid rocket engines, electric (ion, plasma) rockets, nuclear rockets, and solar-powered vehicles. Current issues in launch vehicle technologies. Concurrently scheduled with course C250R. Letter grading.
Ms. Karagozian, Mr. Wirz (Sp)

**154A. Preliminary Design of Aircraft. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 154S. Classical preliminary design of aircraft, including weight estimation, performance and stability, and control consideration. Term assignment consists of preliminary design of low-speed aircraft. Letter grading.
Mr. Wirz (W)

**154B. Design of Aerospace Structures. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 154A, 166A. Design of aircraft, helicopter, spacecraft, and related structures. External loads, internal stresses. Applied theory of thin-walled structures. Material selection, design using composite materials. Design for fatigue prevention and structural optimization. Field trips to aerospace companies. Letter grading. Mr. Wirz (Sp)

**154S. Flight Mechanics, Stability, and Control of Aircraft. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Requisites: courses 150A, 150B. Aircraft performance, flight mechanics, stability, and control; some basic ingredients needed for design of aircraft. Effects of airplane flexibility on stability derivatives. Letter grading. Mr. Wirz (F)

**155. Intermediate Dynamics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: course 102. Axioms of Newtonian mechanics, generalized coordinates, Lagrange equation, variational principles; central force motion; kinematics and dynamics of rigid bodies. Euler equations, motion of rotating bodies, oscillatory motion, normal coordinates, orthogonality relations. Letter grading.
Mr. Gibson (Not offered 2019-20)

**156A. Advanced Strength of Materials. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 82, 101. Not open to students with credit for course 166A. Concepts of stress, strain, and material behavior. Stresses in loaded beams with symmetric and asymmetric cross sections. Torsion of cylinders and thin-walled structures, shear flow. Stresses in pressure vessels, press-fit and shrink-fit problems, rotating shafts. Curved beams. Contact stresses. Strength and failure, plastic deformation, fatigue, elastic instability. Letter grading. Mr. Mal (F,W,Sp)

**C156B. Mechanical Design for Power Transmission. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 156A or 166A. Material selection in mechanical design. Load and stress analysis. Deflection and stiffness. Failure due to static loading. Fatigue failure. Design for safety factors and reliability. Applications of failure prevention in design of power transmission shafting. Design project involving computer-aided design (CAD) and finite element analysis (FEA) modeling. Concurrently scheduled with course C296A. Letter grading. Mr. Ghoniem (Sp)

**157. Basic Mechanical and Aerospace Engineering Laboratory. (4)** Laboratory, eight hours; outside study, four hours. Requisites: courses 101, 102, 103, 105A, Electrical Engineering 100. Methods of measurement of basic quantities and performance of basic experiments in fluid mechanics, structures, and thermodynamics. Primary sensors, transducers, recording equipment, signal processing, and data analysis. Letter grading. Mr. Ghoniem, Mr. Ju (F,W,Sp)

**157A. Aerospace Design Laboratory. (4)** Lecture, two hours; laboratory, six hours; outside study, four hours. Requisites: courses 150A, 157. Recommended: 150B, C150R. Experimental illustration of important physical phenomena in area of fluid mechanics/aerodynamics, as well as hands-on experience with design of experimental programs and use of modern experimental tools and techniques in field. Letter grading. Mr. Kavehpour (Sp)

**161A. Introduction to Astronautics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 102. Recommended: course 82. Spaceflight, including two-body and three-body problem, Kepler laws, and Keplerian orbits. Ground track and taxonomy of common orbits. Orbital and transfer maneuvers, patched conics, perturbation theory, low-thrust trajectories, spacecraft pointing, and spacecraft attitude control. Space mission design, space environment, rendezvous, reentry, and launch. Letter grading. Mr. Wirz (F)

**161B. Introduction to Space Technology. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Recommended preparation: courses 102, 161A. Spacecraft systems and dynamics, including spacecraft power, instruments, communications, structures, materials, thermal control, and attitude/orbit determination and control. Space mission design, launch vehicles/considerations, space propulsion. Letter grading. Mr. Wirz (W)

**161C. Spacecraft Design. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 161B. Preliminary design and analysis by students of Earth-orbiting or interplanetary space missions and spacecraft. Students work in groups of three or four, with each student responsible primarily for one subsystem and for integration with whole. Letter grading. Mr. Wirz (Sp)

**162A. Introduction to Mechanisms and Mechanical Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: courses M20 (or Computer Science 31), 102. Analysis and synthesis of mechanisms and mechanical systems. Kinematics, dynamics, and mechanical advantages of machinery. Displacement velocity and acceleration analyses of linkages. Fundamental law of gearing and various gear trains. Computer-aided mechanism design and analysis. Letter grading. Mr. Hopkins (F,Sp)

**162D. Mechanical Engineering Design I. (4)** Lecture, two hours; laboratory, four hours; outside study, six hours. Enforced requisites: courses 94, 156A (or 183A or M183B), 162A (or 171A). Limited to seniors. First of two mechanical engineering capstone design courses. Lectures on engineering project management, design of thermal systems, mechatronics, mechanical systems, and mechanical components. Students work in teams to begin their two-term design project. Laboratory modules include CAD design, CAD analysis, mechatronics, and conceptual design for team project. Letter grading. Mr. Ghoniem, Mr. Tsao (W)

**162E. Mechanical Engineering Design II. (4)** Lecture, two hours; laboratory, four hours; outside study, six hours. Enforced requisite: course 162D. Limited to seniors. Second of two mechanical engineering capstone design courses. Student groups continue design projects started in course 162D, making use of CAD design laboratory, CAD analysis laboratory, and mechatronics laboratory. Design theory, design tools, economics, marketing, manufacturability, quality, intellectual property, design for manufacture and assembly, design for safety and reliability, and engineering ethics. Students conduct hands-on design, fabrication, and testing. Culminating project demonstrations or competition. Preparation of design project presentations in both oral and written formats. Letter grading. Mr. Ghoniem, Mr. Tsao (Sp)

**166A. Analysis of Aerospace Structures. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 82, 101. Not open to students with credit for course 156A. Introduction to two-dimensional elasticity, stress-strain laws, yield and fatigue; bending of beams; torsion of beams; warping; torsion of thin-walled cross sections: shear flow, shear-lag; combined bending torsion of thin-walled, stiffened structures used in aerospace vehicles; elements of plate theory; buckling of columns. Letter grading. Mr. Carman (F)

**166C. Design of Composite Structures. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 156A or 166A. History of composites, stress-strain relations for composite materials, bending and extension of symmetric laminates, failure analysis, design examples and design studies, buckling of composite components, nonsymmetric laminates, micromechanics of composites. Letter grading. Mr. Carman (W)

**M168. Introduction to Finite Element Methods. (4)** (Same as Civil Engineering M135C.) Lecture, four hours; discussion, one hour; outside study, seven hours. Requisite: course 156A or 166A or Civil Engineering 130. Introduction to basic concepts of finite element methods (FEM) and applications to structural and solid mechanics and heat transfer. Direct matrix structural analysis; weighted residual, least squares, and Ritz approximation methods; shape functions; convergence properties; isoparametric formulation of multidimensional heat flow and elasticity; numerical integration. Practical use of FEM software; geometric and analytical modeling; preprocessing and postprocessing techniques; term projects with computers. Letter grading. Mr. Mal (Sp)

**169A. Introduction to Mechanical Vibrations. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 101, 102, 107. Fundamentals of vibration theory and applications. Free, forced, and transient vibration of one and two degrees of freedom systems, including damping. Normal modes, coupling, and normal coordinates. Vibration isolation devices, vibrations of continuous systems. Letter grading. Mr. Mal (F)

**171A. Introduction to Feedback and Control Systems: Dynamic Systems Control I. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 107. Introduction to feedback principles, control systems design, and system stability. Modeling of physical systems in engineering and other fields; transform methods; controller design using Nyquist, Bode, and root locus methods; compensation; computer-aided analysis and design. Letter grading. Mr. M'Closkey (F,W,Sp)

**171B. Digital Control of Physical Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 171A or Electrical Engineering 141. Analysis and design of digital control systems. Sampling theory. Z-transformation. Discrete-time system representation. Design using classical methods: performance specifications, root locus, frequency response, loop-shaping compensation. Design using state-space methods: state feedback, state estimator, state estimator feedback control. Simulation of sampled data systems and practical aspects: roundoff errors, sampling rate selection, computation delay. Letter grading. Mr. Tsao (Sp)

**172. Control System Design Laboratory. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Enforced requisite: course 171A. Introduction to loop shaping controller design with application to laboratory electromechanical systems. Power spectrum models of noise and disturbances, and performance trade-offs imposed by conflicting requirements. Constraints on sensitivity function and complementary sensitivity function imposed by nonminimum phase plants. Lecture topics supported by weekly hands-on laboratory work. Letter grading. Mr. M'Closkey (W)

**174. Probability and Its Applications to Risk, Reliability, and Quality Control. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: Mathematics 33A. Introduction to probability theory; random variables, distributions, functions of random variables, models of failure of components, reliability, redundancy, complex systems, stress-strength models, fault tree analysis, statistical quality control by variables and by attributes, acceptance sampling. Letter grading. Mr. Mosleh (F)

**C175A. Probability and Stochastic Processes in Dynamical Systems. (4)** Lecture, four hours; outside study, eight hours. Enforced requisites: courses 82, 107. Probability spaces, random variables, stochastic sequences and processes, expectation, conditional expectation, Gauss/Markov sequences, and minimum variance estimator (Kalman filter) with applications. Concurrently scheduled with course C271A. Letter grading. Mr. Speyer (F)

**181A. Complex Analysis and Integral Transforms. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 82. Complex variables, analytic functions, conformal mapping, contour integrals, singularities, residues, Cauchy integrals; Laplace transform: properties, convolution, inversion; Fourier transform: properties, convolution, FFT, applications in dynamics, vibrations, structures, and heat conduction. Letter grading. Mr. Ghoniem (Not offered 2019-20)

**182B. Mathematics of Engineering. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisite: course 82. Analytical methods for solving partial differential equations arising in engineering. Separation of variables, eigenvalue problems, Sturm/Liouville theory. Development and use of special functions. Representation by means of orthonormal functions; Galerkin method. Use of Green's function and transform methods. Letter grading. Mr. Eldredge, Mr. J. Kim (W)

**182C. Numerical Methods for Engineering Applications. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: courses M20 (or Civil Engineering M20 or Computer Science 31), 82. Basic topics from numerical analysis having wide application in solution of practical engineering problems, computer arithmetic, and errors. Solution of linear and nonlinear systems. Algebraic eigenvalue problem. Least-square methods, numerical quadrature, and finite difference approximations. Numerical solution of initial and boundary value problems for ordinary and partial differential equations. Letter grading. Mr. Zhong (F)

**183A. Introduction to Manufacturing Processes. (4)** (Formerly numbered 183.) Lecture, three hours; laboratory, four hours; outside study, five hours. Enforced requisite: Materials Science 104. Manufacturing fundamentals. Materials in manufacturing. Solidification processes. Metal forming processes. Material removal processes. Welding/joining. Rapid prototyping. Electronics manufacturing. Microelectromechanical systems (MEMS) and nanotechnology. Letter grading. Mr. C-J. Kim (F,W,Sp)

**M183B. Introduction to Microscale and Nanoscale Manufacturing. (4)** (Same as Bioengineering M153, Chemical Engineering M153, and Electrical and Computer Engineering M153.) Lecture, three hours; laboratory, four hours; outside study, five hours. Enforced requisites: Chemistry 20A, Physics 1A, 1B, 1C, 4AL, 4BL. Introduction to general manufacturing methods, mechanisms, constrains, and microfabrication and nanofabrication. Focus on concepts, physics, and instruments of various microfabrication and nanofabrication techniques that have been broadly applied in industry and academia, including various photolithography technologies, physical and chemical deposition methods, and physical and chemical etching methods. Hands-on experience for fabricating microstructures and nanostructures in modern cleanroom environment. Letter grading.
Mr. Chiou (F,Sp)

**C183C. Rapid Prototyping and Manufacturing. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Enforced requisite: course 183A. Rapid prototyping (RP), solid freeform fabrication, or additive manufacturing has emerged as popular manufacturing technology to accelerate product creation in last two decades. Machine for layered manufacturing builds parts directly from CAD models. This novel manufacturing technology enables building of parts that have traditionally been impossible to fabricate because of their complex shapes or of variety in materials. In analogy to speed and flexibility of desktop publishing, rapid prototyping is also called desktop manufacturing, with actual three-dimensional solid objects instead of mere two-dimensional images. Methodology of rapid prototyping has also been extended into meso-/micro-/nano-scale to produce three-dimensional functional miniature components. Concurrently scheduled with course C297A. Letter grading. Mr. Li (W)

**185. Introduction to Radio Frequency Identification and Its Application in Manufacturing and Supply Chain. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course M20 or Civil Engineering M20 or Computer Science 31. Manufacturing today requires assembling of individual components into assembled products, shipping of such products, and eventually use, maintenance, and recycling of such products. Radio frequency identification (RFID) chips installed on components, subassemblies, and assemblies of products allow them to be tracked automatically as they move and transform through manufacturing supply chain. RFID tags have memory and small CPU that allows information about product status to be written, stored, and transmitted wirelessly. Tag data can then be forwarded by reader to enterprise software by way of RFID middleware layer. Study of how RFID is being utilized in manufacturing, with focus on automotive and aerospace. Letter grading.
Mr. Gadh (Sp)

**C186. Applied Optics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: Physics 1C. Fundamental principles of optical systems. Geometric optics and aberration theory. Diffraction and interference. Fourier optics, beam optics. Propagation of light, Snell's law, and Huygen principle. Refraction and reflection. Plane waves, spherical waves, and image formation. Total internal reflection. Polarization, polarizers, and wave-plates. Lenses and aberrations, lens laws and formation of images, resolution and primary aberrations. Simple optical instruments, still cameras, shutters, apertures. Design of telescopes, microscope design, projection system design. Interference, Young's slit experiment and fringe visibility, Michelson interferometer, multiple-beam interference and thin film coatings. Diffraction theory, Fraunhofer and Fresnel diffraction, Fresnel zone plate. Fiber optics, waveguides and modes, fiber coupling, types of fiber: single and multimode. Concurrently scheduled with course C286. Letter grading. Mr. Chiou (Not offered 2019-20)

**C187L. Nanoscale Fabrication, Characterization, and Biodetection Laboratory. (4)** Lecture, two hours; laboratory, three hours; outside study, seven hours. Multidisciplinary course that introduces laboratory techniques of nanoscale fabrication, characterization, and biodetection. Basic physical, chemical, and biological principles related to these techniques, top-down and bottom-up (self-assembly) nanofabrication, nanocharacterization (AEM, SEM, etc.), and optical and electrochemical biosensors. Students encouraged to create their own ideas in self-designed experiments. Concurrently scheduled with course C287L. Letter grading. Mr. Y. Chen (Sp)

**188. Special Courses in Mechanical and Aerospace Engineering. (2 to 4)** Lecture, two to four hours; outside study, four to eight hours. Special topics in mechanical and aerospace engineering for undergraduate students taught on experimental or temporary basis, such as those taught by resident and visiting faculty members. May be repeated once for credit with topic or instructor change. P/NP or letter grading. (Not offered 2019-20)

**194. Research Group Seminars: Mechanical and Aerospace Engineering. (2 to 4)** Seminar, two hours. Designed for undergraduate students who are part of research group. Discussion of research methods and current literature in field. Student presentation of projects in research specialty. May be repeated for credit. P/NP or letter grading.

**199. Directed Research in Mechanical and Aerospace Engineering. (2 to 8)** Tutorial, to be arranged. Limited to juniors/seniors. Supervised individual research or investigation under guidance of faculty mentor. Culminating paper or project required. May be repeated for credit with school approval. Individual contract required; enrollment petitions available in Office of Academic and Student Affairs. Letter grading. (F,W,Sp)

# Graduate Courses

**231A. Convective Heat Transfer Theory. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 131A, 182B. Recommended: course 250A. Conservation equations for flow of real fluids. Analysis of heat transfer in laminar and turbulent, incompressible and compressible flows. Internal and external flows; free convection. Variable wall temperature; effects of variable fluid properties. Analogies among convective transfer processes. Letter grading. Ms. Lavine (F)

**231B. Radiation Heat Transfer. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 105D. Radiative properties of materials and radiative energy transfer. Emphasis on fundamental concepts, including energy levels and electromagnetic waves as well as analytical methods for calculating radiative properties and radiation transfer in absorbing, emitting, and scattering media. Applications cover laser-material interactions in addition to traditional areas such as combustion and thermal insulation. Letter grading. Mr. Pilon (W)

**231C. Phase Change Heat Transfer and Two-Phase Flow. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 131A, 150A. Two-phase flow, boiling, and condensation. Generalized constitutive equations for two-phase flow. Phenomenological theories of boiling and condensation, including forced flow effects. Letter grading.
Ms. Lavine (W)

**C231G. Microscopic Energy Transport. (4)** (Formerly numbered 231G.) Lecture, four hours; outside study, eight hours. Requisite: course 105D. Exploration of basic principles of transportation of energy in natural and fabricated structures by three carriers: electrons, phonons, and molecules. Study of statistical properties of heat carriers, common Landauer framework for heat flow, scattering and propagation of heat carriers, derivation of classical laws from microscopic transport equations, and deviation from classical laws at small scale. Term project. Concurrently scheduled with course C131G. Letter grading.
Mr. Ju (F)

**233. Nanoscience for Energy Technologies. (4)** Lecture, four hours; outside study, eight hours. Introduction to fundamental principles of energy transport, conversion, and storage at nanoscale, and recent development for these energy technologies involving nanotechnology. Focus on basics of thermal science, solid state, quantum mechanics, electromagnetics, and statistical physics. Topic discussions given for examples that connect technological application, fundamental challenge, and scientific-solution-based nanotechnology to improve device performance and energy efficiency. Letter grading.
Mr. Hu (Sp)

**235A. Nuclear Reactor Theory. (4)** Lecture, four hours; outside study, eight hours. Underlying physics and mathematics of nuclear reactor (fission) core design. Diffusion theory, reactor kinetics, slowing down and thermalization, multigroup methods, introduction to transport theory. Letter grading.
Mr. Abdou (Not offered 2019-20)

**C237. Design and Analysis of Smart Grids. (4)** Lecture, four hours; outside study, eight hours. Demand response; transactive/price-based load control; home-area network, smart energy profile; advanced metering infrastructure; renewable energy integration; solar and wind generation intermittency and correction; microgrids; grid stability; energy storage and electric vehicles-simulation; monitoring; distribution and transmission grids; consumer-centric technologies; sensors, communications, and computing; wireless, wireline, and powerline communications for smart grids; grid modeling, stability, and control; frequency and voltage regulation; ancillary services; wide-area situational awareness, phasor measurements; analytical methods and tools for monitoring and control. Concurrently scheduled with course C137. Letter grading. Mr. Gadh (F)

**M237B. Fusion Plasma Physics and Analysis. (4)** (Same as Electrical and Computer Engineering M287.) Lecture, four hours; outside study, eight hours. Fundamentals of plasmas at thermonuclear burning conditions. Fokker/Planck equation and applications to heating by neutral beams, RF, and fusion reaction products. Bremsstrahlung, synchrotron, and atomic radiation processes. Plasma surface interactions. Fluid description of burning plasma. Dynamics, stability, and control. Applications in tokamaks, tandem mirrors, and alternate concepts. Letter grading. Mr. Abdou (Not offered 2019-20)

**237D. Fusion Engineering and Design. (4)** Lecture, four hours; outside study, eight hours. Fusion reactions and fuel cycles. Principles of inertial and magnetic fusion. Plasma requirements for controlled fusion. Plasma-surface interactions. Fusion reactor concepts and technological components. Analysis and design of high heat flux components, energy conversion and tritium breeding components, radiation shielding, magnets, and heating. Letter grading.
Mr. Abdou (Sp)

**C238. Introduction to Statistical Thermodynamics. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 105A, 105D. Introduction to basic concepts and tools of statistical thermodynamics. Abstract concepts of entropy, temperature, and chemical potential are explained by developing these concepts from ground up using only mechanical and statistical principles. Discussion of equilibrium properties of thermodynamic systems and associated distributions. Provides sound foundation for further studies in transport phenomena, plasma, chemical kinetics, micro/nanoscale science and technology, and other related subjects. Concurrently scheduled with course C138. Letter grading.

**239B. Seminar: Current Topics in Transport Phenomena. (2 to 4)** Seminar, two to four hours; outside study, four to eight hours. Designed for graduate mechanical and aerospace engineering students. Lectures, discussions, student presentations, and projects in areas of current interest in transport phenomena. May be repeated for credit. S/U grading.

**239F. Special Topics in Transport Phenomena. (2 to 4)** Lecture, two to four hours; outside study, four to eight hours. Designed for graduate mechanical and aerospace engineering students. Advanced and current study of one or more aspects of heat and mass transfer, such as turbulence, stability and transition, buoyancy effects, variational methods, and measurement techniques. May be repeated for credit with topic change. S/U grading.

**239G. Special Topics in Nuclear Engineering. (2 to 4)** Lecture, two to four hours; outside study, four to eight hours. Designed for graduate mechanical and aerospace engineering students. Advanced study in areas of current interest in nuclear engineering, such as reactor safety, risk-benefit trade-offs, nuclear materials, and reactor design. May be repeated for credit with topic change. S/U grading.

**239H. Special Topics in Fusion Physics, Engineering, and Technology. (2 to 4)** Seminar, two to four hours; outside study, four to eight hours. Designed for graduate mechanical and aerospace engineering students. Advanced treatment of subjects selected from research areas in fusion science and engineering, such as instabilities in burning plasmas, alternate fusion confinement concepts, inertial confinement fusion, fission-fusion hybrid systems, and fusion reactor safety. May be repeated for credit with topic change. S/U grading.

**CM240. Introduction to Biomechanics. (4)** (Same as Bioengineering CM240.) Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 101, 102, and 156A or 166A. Introduction to mechanical functions of human body; skeletal adaptations to optimize load transfer, mobility, and function. Dynamics and kinematics. Fluid mechanics applications. Heat and mass transfer. Power generation. Laboratory simulations and tests. Concurrently scheduled with course CM140. Letter grading.
Mr. Gupta (W)

**242. Introduction to Multiferroic Materials. (4)** Lecture, four hours; outside study, eight hours. Overview of different types of multiferroic materials, including strain mediated. Basic crystal structure of single-phase multiferroics, as well as fundamental physics underlying ferroelectricity and ferromagnetism. Material science description of these materials, with focus on linear and nonlinear behavior with associated mechanisms such as spin reorientation. Presentation of analytical tools necessary to predict material response ranging from constitutive relations to governing equations, including elastodynamics and Maxwell's. Analytical and physical descriptions used to explain several devices manufactured with multiferroics, including magnetometers, memory devices, motors, and antennas. Letter grading.
Mr. Carman (Sp)

**250A. Foundations of Fluid Dynamics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 150A. Corequisite: course 182B. Development and application of fundamental principles of fluid mechanics at graduate level, with emphasis on incompressible flow. Flow kinematics, basic equations, constitutive relations, exact solutions on the Navier/Stokes equations, vorticity dynamics, decomposition of flow fields, potential flow. Letter grading.
Mr. Eldredge, Mr. J. Kim (W)

**250B. Viscous and Turbulent Flows. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 150A. Fundamental principles of fluid dynamics applied to study of fluid resistance. States of fluid motion discussed in order of advancing Reynolds number; wakes, boundary layers, instability, transition, and turbulent shear flows. Letter grading.
Ms. Karagozian, Mr. J. Kim (Sp)

**250C. Compressible Flows. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 150A, 150B. Effects of compressibility in viscous and inviscid flows. Steady and unsteady inviscid subsonic and supersonic flows; method of characteristics; small disturbance theories (linearized and hypersonic); shock dynamics. Letter grading.
Ms. Karagozian, Mr. Zhong (F)

**250D. Computational Aerodynamics. (4)** Lecture, eight hours. Requisites: courses 150A, 150B, 182C. Introduction to useful methods for computation of aerodynamic flow fields. Coverage of potential, Euler, and Navier/Stokes equations for subsonic to hypersonic speeds. Letter grading.
Mr. Zhong (Not offered 2019-20)

**250E. Spectral Methods in Fluid Dynamics. (4)** Lecture, four hours; outside study, eight hours. Enforced requisites: courses 82, 182B, 182C, 250A, 250B. Introduction to basic concepts and techniques of various spectral methods applied to solving partial differential equations. Particular emphasis on techniques of solving unsteady three-dimensional Navier/Stokes equations. Topics include spectral representation of functions, discrete Fourier transform, etc. Letter grading. Mr. J. Kim (Not offered 2019-20)

**250F. Hypersonic and High-Temperature Gas Dynamics. (4)** Lecture, four hours; outside study, eight hours. Recommended requisite: course 250C. Molecular and chemical description of equilibrium and nonequilibrium hypersonic and high-temperature gas flows, chemical thermodynamics and statistical thermodynamics for calculation gas properties, equilibrium flows of real gases, vibrational and chemical rate processes, nonequilibrium flows of real gases, and computational fluid dynamics methods for nonequilibrium hypersonic flows. Letter grading.
Mr. Zhong (W)

**C250G. Fluid Dynamics of Biological Systems. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 103. Mechanics of aquatic locomotion; insect and bird flight aerodynamics; pulsatile flow in circulatory system; rheology of blood; transport in microcirculation; role of fluid dynamics in arterial diseases. Concurrently scheduled with course C150G. Letter grading. Mr. Eldredge (Not offered 2019-20)

**250H. Numerical Methods for Incompressible Flows. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 150A, 182C. Review of equations of incompressible flow, finite difference methods and other methods of spatial approximation, time-marching schemes, numerical solution of model partial differential equations, application to Navier/Stokes equations, boundary conditions. Letter grading. Mr. Eldredge (Not offered 2019-20)

**250M. Introduction to Microfluids/Nanofluids. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 150A. Introduction to fundamentals of microfluids. No-slip and slip boundary conditions. Sedimentation and diffusion in liquids. Osmotic pressure and Donnan equilibrium in fluid mixtures. Fundamentals of surface phenomena, spreading, and contact angles. Introduction to van der Waals interactions, electrical double layer, and zeta potential. Basics of non-Newtonian fluid mechanics. Letter grading. Mr. Kavehpour (F)

**C250P. Aircraft Propulsion Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisites: courses 105A, 150A. Thermodynamic properties of gases, aircraft jet engine cycle analysis and component performance, component matching, advanced aircraft engine topics. Concurrently scheduled with course C150P. Letter grading.
Ms. Karagozian (F)

**C250R. Rocket Propulsion Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisites: courses 103, 105A. Rocket propulsion concepts, including chemical rockets (liquid, gas, and solid propellants), hybrid rocket engines, electric (ion, plasma) rockets, nuclear rockets, and solar-powered vehicles. Current issues in launch vehicle technologies. Concurrently scheduled with course C150R. Letter grading.
Ms. Karagozian, Mr. Wirz (Sp)

**252A. Stability of Fluid Motion. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 150A. Mechanisms by which laminar flows can become unstable and lead to turbulence of secondary motions. Linear stability theory; thermal, centrifugal, and shear instabilities; boundary layer instability. Nonlinear aspects: sufficient criteria for stability, subcritical instabilities, supercritical states, transition to turbulence. Letter grading.
Mr. Zhong (Not offered 2019-20)

**252B. Turbulence. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 250A, 250B. Characteristics of turbulent flows, conservation and transport equations, statistical description of turbulent flows, scales of turbulent motion, simple turbulent flows, free-shear flows, wall-bounded flows, turbulence modeling, numerical simulations of turbulent flows, and turbulence control. Letter grading.
Mr. J. Kim (Not offered 2019-20)

**252C. Fluid Mechanics of Combustion Systems. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 150A, 150B. Recommended: course 250C. Review of fluid mechanics and chemical thermodynamics applied to reactive systems, laminar diffusion flames, premixed laminar flames, stability, ignition, turbulent combustion, supersonic combustion. Letter grading.
Ms. Karagozian (Not offered 2019-20)

**252D. Combustion Rate Processes. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 252C. Basic concepts in chemical kinetics: molecular collisions, distribution functions and averaging, semiempirical and ab initio potential surfaces, trajectory calculations, statistical reaction rate theories. Practical examples of large-scale chain mechanisms from combustion chemistry of several elements, etc. Letter grading.
Ms. Karagozian (Not offered 2019-20)

**252P. Plasma and Ionized Gases. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 82, 102, 150A, 182B. Neutral and charged particle motion, magnetohydrodynamics, two-fluid plasma treatments, ion and electron diffusion, gas diffusion, Child/Langmuir law, basic plasma devices, electron emission and work function, thermal distributions, vacuum and vacuum systems, space-charge, particle collisions and ionization, plasma discharges, sheaths, and electric arcs. Letter grading. Mr. Wirz (Sp)

**254A. Special Topics in Aerodynamics. (4)** Lecture, four hours; outside study, eight hours. Enforced requisites: courses 82, 150A, 150B, 182B, 182C. Special topics of current interest in advanced aerodynamics. Examples include transonic flow, hypersonic flow, sonic booms, and unsteady aerodynamics. Letter grading. Mr. Zhong (Not offered 2019-20)

**255A. Advanced Dynamics. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 155, 169A. Variational principles and Lagrange equations. Kinematics and dynamics of rigid bodies; procession and nutation of spinning bodies. Letter grading.
Mr. Gibson (Sp)

**255B. Mathematical Methods in Dynamics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 255A. Concepts of stability; state-space interpretation; stability determination by simulation, linearization, and Lyapunov direct method; the Hamiltonian as a Lyapunov function; nonautonomous systems; averaging and perturbation methods of nonlinear analysis; parametric excitation and nonlinear resonance. Application to mechanical systems. Letter grading. Mr. M'Closkey (Not offered 2019-20)

**M256A. Linear Elasticity. (4)** (Same as Civil Engineering M230A.) Lecture, four hours; outside study, eight hours. Requisite: course 156A or 166A. Linear elastostatics. Cartesian tensors; infinitesimal strain tensor; Cauchy stress tensor; strain energy; equilibrium equations; linear constitutive relations; plane elastostatic problems, holes, corners, inclusions, cracks; three-dimensional problems of Kelvin, Boussinesq, and Cerruti. Introduction to boundary integral equation method. Letter grading. Mr. W. Ju, Mr. Mal (F)

**M256B. Nonlinear Elasticity. (4)** (Same as Civil Engineering M230B.) Lecture, four hours; outside study, eight hours. Requisite: course M256A. Kinematics of deformation, material and spatial coordinates, deformation gradient tensor, nonlinear and linear strain tensors, strain displacement relations; balance laws, Cauchy and Piola stresses, Cauchy equations of motion, balance of energy, stored energy; constitutive relations, elasticity, hyperelasticity, thermoelasticity; linearization of field equations; solution of selected problems. Letter grading. Mr. W. Ju, Mr. Mal (W)

**M256C. Plasticity. (4)** (Same as Civil Engineering M230C.) Lecture, four hours; outside study, eight hours. Requisites: courses M256A, M256B. Classical rate-independent plasticity theory, yield functions, flow rules and thermodynamics. Classical rate-dependent viscoplasticity, Perzyna and Duvant/Lions types of viscoplasticity. Thermoplasticity and creep. Return mapping algorithms for plasticity and viscoplasticity. Finite element implementations. Letter grading. Mr. Gupta (Not offered 2019-20)

**256F. Analytical Fracture Mechanics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course M256A. Review of modern fracture mechanics, elementary stress analyses; analytical and numerical methods for calculation of crack tip stress intensity factors; engineering applications in stiffened structures, pressure vessels, plates, and shells. Letter grading. Mr. Gupta (Not offered 2019-20)

**M257A. Elastodynamics. (4)** (Same as Earth, Planetary, and Space Sciences M224A.) Lecture, four hours; outside study, eight hours. Requisites: courses M256A, M256B. Equations of linear elasticity, Cauchy equation of motion, constitutive relations, boundary and initial conditions, principle of energy. Sources and waves in unbounded isotropic, anisotropic, and dissipative solids. Half-space problems. Guided waves in layered media. Applications to dynamic fracture, nondestructive evaluation (NDE), and mechanics of earthquakes. Letter grading. Mr. Mal (Not offered 2019-20)

**258A. Nanomechanics and Micromechanics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course M256A. Analytical and computational modeling methods to describe mechanics of materials at scales ranging from atomistic through microstructure or transitional and up to continuum. Discussion of atomistic simulation methods (e.g., molecular dynamics, Langevin dynamics, and kinetic Monte Carlo) and their applications at nanoscale. Developments and applications of dislocation dynamics and statistical mechanics methods in areas of nanostructure and microstructure self-organization, heterogeneous plastic deformation, material instabilities, and failure phenomena. Presentation of technical applications of these emerging modeling techniques to surfaces and interfaces, grain boundaries, dislocations and defects, surface growth, quantum dots, nanotubes, nanoclusters, thin films (e.g., optical thermal barrier coatings and ultrastrong nanolayer materials), nano-identification, smart (active) materials, nanobending and microbending, and torsion. Letter grading. Mr. Ghoniem (Not offered 2019-20)

**259A. Seminar: Advanced Topics in Fluid Mechanics. (4)** Seminar, four hours; outside study, eight hours. Advanced study of topics in fluid mechanics, with intensive student participation involving assignments in research problems leading to term paper or oral presentation (possible help from guest lecturers). Letter grading. Mr. Kavehpour, Mr. Spearrin (W,Sp)

**259B. Seminar: Advanced Topics in Solid Mechanics. (4)** Seminar, four hours; outside study, eight hours. Advanced study in various fields of solid mechanics on topics which may vary from term to term. Topics include dynamics, elasticity, plasticity, and stability of solids. Letter grading. Mr. Mal (Sp)

**260. Current Topics in Mechanical Engineering. (2 to 4)** Seminar, two to four hours; outside study, four to eight hours. Designed for graduate mechanical and aerospace engineering students. Lectures, discussions, and student presentations and projects in areas of current interest in mechanical engineering. May be repeated for credit. S/U grading.

**261A. Energy and Computational Methods in Structural Mechanics. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 156A or 166A. Review of theory of linear elasticity and reduced structural theories (rods, plates, and shells). Calculus of variations. Virtual work. Minimum and stationary variational principles. Variational approximation methods. Weighted residual methods, weak forms. Static finite element method. Isoparametric elements, beam and plate elements. Numerical quadrature. Letter grading. Mr. Mal (F)

**261B. Finite Element Analysis for Solids and Structures. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 156A or M256A, or consent of instructor. Strongly recommended requisites: courses M168, M256B, 261A. Application of finite element method to classical and state-of-art modeling and design problems for solids and structures. Introduction of commercial mainstream finite element program—ABAQUS—and demonstration of how to use it in advanced way. Topics include review of finite element method, static and dynamic linear elasticity, finite deformation of hyperelastic materials, instability analysis, fracture, and implementation of user-defined subroutines in ABAQUS. Term projects using computers. Letter grading. Mr. Mal (Not offered 2019-20)

**262. Mechanics of Intelligent Material Systems. (4)** Lecture, four hours; outside study, eight hours. Recommended requisite: course 166C. Constitutive relations for electro-magneto-mechanical materials. Fiber-optic sensor technology. Micro/macro analysis, including classical lamination theory, shear lag theory, concentric cylinder analysis, hexagonal models, and homogenization techniques as they apply to active materials. Active systems design, inch-worm, and bimorph. Letter grading. Mr. Carman (Sp)

**263A. Kinematics of Robotic Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Recommended requisites: courses 155, 171A. Kinematical models of serial robotic manipulators, including spatial descriptions and transformations (Euler angles, Denavit-Hartenberg/DH parameters, equivalent angle vector), frame assignment procedure, direct kinematics, inverse kinematics (geometric and algebraic approaches), mechanical design topics. Letter grading. Mr. Hong (F)

**263B. Dynamics of Robotic Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 263A. Recommended: course 255B. Dynamics models of serial and parallel robotic manipulators, including review of spatial descriptions and transformations along with direct and inverse kinematics, linear and angular velocities, Jacobian matrix (velocity and force), velocity propagation method, force propagation method, explicit formulation of Jacobian matrix, manipulator dynamics (Newton/Euler formulation, Lagrangian formulation), trajectory generation, introduction to parallel manipulators. Letter grading. Mr. Rosen (W)

**263C. Control of Robotic Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Enforced requisite: course 263B. Sensors, actuators, and control schemes for robotic systems, including computed torque control, linear feedback control, impedance and force feedback control, and advanced control topics from nonlinear and adaptive control, hybrid control, nonholonomic systems, vision-based control, and perception. Letter grading. Ms. Santos (Sp)

**263D. Advanced Topics in Robotics and Control. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course 263C. Current and advanced topics in robotics and control, including kinematics, dynamics, control, mechanical design, advanced sensors and actuators, flexible links, manipulability, redundant manipulators, human-robot interaction, teleoperation, haptics. Letter grading. Mr. Rosen (Not offered 2019-20)

**M269A. Dynamics of Structures. (4)** (Same as Civil Engineering M237A.) Lecture, four hours; outside study, eight hours. Requisite: course 169A. Principles of dynamics. Determination of normal modes and frequencies by differential and integral equation solutions. Transient and steady state response. Emphasis on derivation and solution of governing equations using matrix formulation. Letter grading. Mr. Mal (Not offered 2019-20)

**269B. Advanced Dynamics of Structures. (4)** Lecture, four hours; outside study, eight hours. Requisite: course M269A. Analysis of linear and nonlinear response of structures to dynamic loadings. Stresses and deflections in structures. Structural damping and self-induced vibrations. Letter grading. Mr. Mal (Not offered 2019-20)

**269D. Aeroelastic Effects in Structures. (4)** Lecture, four hours; outside study, eight hours. Requisite: course M269A. Presentation of field of aeroelasticity from unified viewpoint applicable to flight structures, suspension bridges, buildings, and other structures. Derivation of aeroelastic operators and unsteady airloads from governing variational principles. Flow induced instability and response of structural systems. Letter grading. Mr. Mal (Not offered 2019-20)

**M270A. Linear Dynamic Systems. (4)** (Same as Chemical Engineering M280A and Electrical and Computer Engineering M240A.) Lecture, four hours; outside study, eight hours. Requisite: course 171A or Electrical and Computer Engineering 141. State-space description of linear time-invariant (LTI) and time-varying (LTV) systems in continuous and discrete time. Linear algebra concepts such as eigenvalues and eigenvectors, singular values, Cayley/Hamilton theorem, Jordan form; solution of state equations; stability, controllability, observability, realizability, and minimality. Stabilization design via state feedback and observers; separation principle. Connections with transfer function techniques. Letter grading. Mr. M'Closkey (F)

**270B. Linear Optimal Control. (4)** Lecture, four hours; outside study, eight hours. Requisite: course M270A or Electrical Engineering M240A. Existence and uniqueness of solutions to linear quadratic (LQ) optimal control problems for continuous-time and discrete-time systems, finite-time and infinite-time problems; Hamiltonian systems and optimal control; algebraic and differential Riccati equations; implications of controllability, stabilizability, observability, and detectability solutions. Letter grading. Mr. Gibson (W)

**M270C. Optimal Control. (4)** (Same as Chemical Engineering M280C and Electrical and Computer Engineering M240C.) Lecture, four hours; outside study, eight hours. Requisite: course 270B. Applications of variational methods, Pontryagin maximum principle, Hamilton/Jacobi/Bellman equation (dynamic programming) to optimal control of dynamic systems modeled by nonlinear ordinary differential equations. Letter grading. Mr. Speyer (F)

**C271A. Probability and Stochastic Processes in Dynamical Systems. (4)** Lecture, four hours; outside study, eight hours. Enforced requisites: courses 82, 107. Probability spaces, random variables, stochastic sequences and processes, expectation, conditional expectation, Gauss/Markov sequences, and minimum variance estimator (Kalman filter) with applications. Concurrently scheduled with course C175A. Letter grading. Mr. Speyer (F)

**271B. Stochastic Estimation. (4)** Lecture, four hours; outside study, eight hours. Enforced requisite: course C271A. Linear and nonlinear estimation theory, orthogonal projection lemma, Bayesian filtering theory, conditional mean and risk estimators. Letter grading. Mr. Speyer (W)

**271C. Stochastic Optimal Control. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 271B. Stochastic dynamic programming, certainty equivalence principle, separation theorem, information statistics; linear-quadratic-Gaussian problem, linear-exponential-Gaussian problem. Relationship between stochastic control and robust control. Letter grading. Mr. Speyer (Not offered 2019-20)

**271D. Seminar: Special Topics in Dynamic Systems Control. (4)** Seminar, four hours; outside study, eight hours. Seminar on current research topics in dynamic systems modeling, control, and applications. Topics selected from process control, differential games, nonlinear estimation, adaptive filtering, industrial and aerospace applications, etc. Letter grading. Mr. Speyer (Not offered 2019-20)

**M272A. Nonlinear Dynamic Systems. (4)** (Same as Chemical Engineering M282A and Electrical and Computer Engineering M242A.) Lecture, four hours; outside study, eight hours. Requisite: course M270A or Chemical Engineering M280A or Electrical and Computer Engineering M240A. State-space techniques for studying solutions of time-invariant and time-varying nonlinear dynamic systems with emphasis on stability. Lyapunov theory (including converse theorems), invariance, center manifold theorem, input-to-state stability and small-gain theorem. Letter grading. (Not offered 2019-20)

**273A. Robust Control System Analysis and Design. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 171A, M270A. Graduate-level introduction to analysis and design of multivariable control systems. Multivariable loop-shaping, performance requirements, model uncertainty representations, and robustness covered in detail from frequency domain perspective. Structured singular value and its application to controller synthesis. Letter grading. Mr. M'Closkey (Not offered 2019-20)

**275A. System Identification. (4)** Lecture, four hours; outside study, eight hours. Methods for identification of dynamical systems from input/output data, with emphasis on identification of discrete-time (digital) models of sampled-data systems. Coverage of conversion to continuous-time models. Models identified include transfer functions and state-space models. Discussion of applications in mechanical and aerospace engineering, including identification of flexible structures, microelectromechanical systems (MEMS) devices, and acoustic ducts. Letter grading. Mr. Gibson (Not offered 2019-20)

**M276. Dynamic Programming. (4)** (Same as Electrical and Computer Engineering M237.) Lecture, four hours; outside study, eight hours. Recommended requisite: Electrical and Computer Engineering 232A or 236A or 236B. Introduction to mathematical analysis of sequential decision processes. Finite horizon model in both deterministic and stochastic cases. Finite-state infinite horizon model. Methods of solution. Examples from inventory theory, finance, optimal control and estimation, Markov decision processes, combinatorial optimization, communications. Letter grading. (Not offered 2019-20)

**277. Advanced Digital Control for Mechatronic Systems. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Requisites: courses 171B, M270A. Digital signal processing and control analysis of mechatronic systems. System inversion-based digital control algorithms and robustness properties, Youla parameterization of stabilizing controllers, previewed optimal feedforward compensator, repetitive and learning control, and adaptive control. Real-time control investigation of topics to selected mechatronic systems. Letter grading. Mr. Tsao (W)

**279. Dynamics and Control of Biological Oscillations. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 107, M270A. Analysis and design of dynamical mechanisms underlying biological control systems that generate coordinated oscillations. Topics include neuronal information processing through action potentials (spike train), central pattern generator, coupled nonlinear oscillators, optimal gaits (periodic motion) for animal locomotion, and entrainment to natural oscillations via feedback control. Letter grading. Mr. Iwasaki (Sp)

**M280B. Microelectromechanical Systems (MEMS) Fabrication. (4)** (Same as Bioengineering M250B and Electrical and Computer Engineering M250B.) Lecture, three hours; discussion, one hour; outside study, eight hours. Enforced requisite: course M183B. Advanced discussion of micromachining processes used to construct MEMS. Coverage of many lithographic, deposition, and etching processes, as well as their combination in process integration. Materials issues such as chemical resistance, corrosion, mechanical properties, and residual/intrinsic stress. Letter grading. Mr. C-J. Kim (Not offered 2019-20)

**281. Microsciences. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 102, 103, 105D. Fundamental issues of being in microscopic world and mechanical engineering of microscale devices. Topics include scale issues, surface tension, superhydrophobic surfaces and applications, and electrowetting and applications. Letter grading. Mr. C-J. Kim (F)

**M282. Microelectromechanical Systems (MEMS) Device Physics and Design. (4)** (Same as Bioengineering M252 and Electrical and Computer Engineering M252.) Lecture, four hours; discussion, one hour; outside study, seven hours. Introduction to MEMS design. Design methods, design rules, sensing and actuation mechanisms, microsensors, and microactuators. Designing MEMS to be produced with both foundry and nonfoundry processes. Computer-aided design for MEMS. Design project required. Letter grading. Mr. Chiou (Not offered 2019-20)

**284. Sensors, Actuators, and Signal Processing. (4)** Lecture, four hours; outside study, eight hours. Principles and performance of micro transducers. Applications of using unique properties of micro transducers for distributed and real-time control of engineering problems. Associated signal processing requirements for these applications. Letter grading. Mr. C-J. Kim (Not offered 2019-20)

**285. Interfacial Phenomena. (4)** Lecture, four hours; outside study, eight hours. Requisites: courses 82, 103, 105A, 105D. Introduction to fundamental physical phenomena occurring at interfaces and application of their knowledge to engineering problems. Fundamental concepts of interfacial phenomena, including surface tension, surfactants, interfacial thermodynamics, interfacial forces, interfacial hydrodynamics, and dynamics of triple line. Presentation of various applications, including wetting, change of phase (boiling and condensation), forms and emulsions, microelectromechanical systems, and biological systems. Letter grading. Mr. Pilon (Not offered 2019-20)

**C286. Applied Optics. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Requisite: Physics 1C. Fundamental principles of optical systems. Geometric optics and aberration theory. Diffraction and interference. Fourier optics, beam optics. Propagation of light, Snell's law, and Huygen principle. Refraction and reflection. Plane waves, spherical waves, and image formation. Total internal reflection. Polarization, polarizers, and wave-plates. Lenses and aberrations, lens laws and formation of images, resolution and primary aberrations. Simple optical instruments, still cameras, shutters, apertures. Design of telescopes, microscope design, projection system design. Interference, Young's slit experiment and fringe visibility, Michelson interferometer, multiple-beam interference and thin film coatings. Diffraction theory, Fraunhofer and Fresnel diffraction, Fresnel zone plate. Fiber optics, waveguides and modes, fiber coupling, types of fiber: single and multimode. Concurrently scheduled with course C186. Letter grading. Mr. Chiou (Not offered 2019-20)

**M287. Nanoscience and Technology. (4)** (Same as Electrical and Computer Engineering M257.) Lecture, four hours; outside study, eight hours. Introduction to fundamentals of nanoscale science and technology. Basic physical principles, quantum mechanics, chemical bonding and nanostructures, top-down and bottom-up (self-assembly) nanofabrication; nanocharacterization; nanomaterials, nanoelectronics, and nanobiodetection technology. Introduction to new knowledge and techniques in nano areas to understand scientific principles behind nanotechnology and inspire students to create new ideas in multidisciplinary nano areas. Letter grading. Mr. Y. Chen (W)

**C287L. Nanoscale Fabrication, Characterization, and Biodetection Laboratory. (4)** Lecture, two hours; laboratory, three hours; outside study, seven hours. Multidisciplinary course that introduces laboratory techniques of nanoscale fabrication, characterization, and biodetection. Basic physical, chemical, and biological principles related to these techniques, top-down and bottom-up (self-assembly) nanofabrication, nanocharacterization (AEM, SEM, etc.), and optical and electrochemical biosensors. Students encouraged to create their own ideas in self-designed experiments. Concurrently scheduled with course C187L. Letter grading. Mr. Y. Chen (Sp)

**294A. Compliant Mechanism Design. (4)** (Formerly numbered 294B.) Lecture, four hours; outside study, eight hours. Requisite: linear algebra. Advanced compliant mechanism synthesis approaches, modeling techniques, and optimization tools. Fundamentals of flexible constraint theory, principles of constraint-based design, projective geometry, screw theory kinematics, and freedom and constraint topologies. Applications: precision motion stages, general purpose flexure bearings, microstructural architectures, MEMs, optical mounts, and nanoscale positioning systems. Hands-on exercises include build-your-own flexure kits, CAD and FEA simulations, and term project. Letter grading. Mr. Hopkins (W)

**295A. Radio Frequency Identification Systems: Analysis, Design, and Applications. (4)** Lecture, four hours; outside study, eight hours. Designed for graduate engineering students. Examination of emerging discipline of radio frequency identification (RFID), including basics of RFID, how RFID systems function, design and analysis of RFID systems, and applications to fields such as supply chain, manufacturing, retail, and homeland security. Letter grading. Mr. Gadh (Not offered 2019-20)

**C296A. Mechanical Design for Power Transmission. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 156A or 166A. Material selection in mechanical design. Load and stress analysis. Deflection and stiffness. Failure due to static loading. Fatigue failure. Design for safety factors and reliability. Applications of failure prevention in design of power transmission shafting. Design project involving computer-aided design (CAD) and finite element analysis (FEA) modeling. Concurrently scheduled with course C156B. Letter grading. Mr. Ghoniem (Sp)

**296B. High-Temperature Mechanical Design. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 156A or equivalent. Review of elasticity and continuum thermodynamics, multiaxial plasticity, flow rules, cyclic plasticity, viscoplasticity, creep, creep damage in cyclic loading. Damage mechanics: thermodynamics, ductile, creep, fatigue, and fatigue-creep interaction damage. Fracture mechanics: elastic and elastoplastic analysis, J-integral, brittle fracture, ductile fracture, fatigue and creep crack propagation. Applications in design of high-temperature components such as turbine blades, pressure vessels, heat exchangers, connecting rods. Design project involving CAD and FEM modeling. Letter grading. Mr. Ghoniem (F)

**C297A. Rapid Prototyping and Manufacturing. (4)** Lecture, four hours; laboratory, two hours; outside study, six hours. Recommended requisite: level of knowledge in manufacturing equivalent to course 183A and CAD capability. Rapid prototyping (RP), solid freeform fabrication, or additive manufacturing has emerged as popular manufacturing technology to accelerate product creation in last two decades. Machine for layered manufacturing builds parts directly from CAD models. This novel manufacturing technology enables building of parts that have traditionally been impossible to fabricate because of their complex shapes or of variety in materials. In analogy to speed and flexibility of desktop publishing, rapid prototyping is also called desktop manufacturing, with actual three-dimensional solid objects instead of mere two-dimensional images. Methodology of rapid prototyping has also been extended into meso-/micro-/nano-scale to produce three-dimensional functional miniature components. Concurrently scheduled with course C183C. Letter grading. Mr. Li (W)

**M297B. Material Processing in Manufacturing. (4)** (Formerly numbered 297A.) (Same as Materials Science M297B.) Lecture, four hours; outside study, eight hours. Enforced requisite: course 183A. Thermodynamics, principles of material processing: phase equilibria and transitions, transport mechanisms of heat and mass, nucleation and growth of microstructure. Applications in casting/solidification, welding, consolidation, chemical vapor deposition, infiltration, composites. Letter grading. Mr. Li (Not offered 2019-20)

**M297C. Composites Manufacturing. (4)** (Formerly numbered 297D.) (Same as Materials Science M297C.) Lecture, four hours; outside study, eight hours. Requisites: course 166C, Materials Science 151. Matrix materials, fibers, fiber preforms, elements of processing, autoclave/compression molding, filament winding, pultrusion, resin transfer molding, automation, material removal and assembly, metal and ceramic matrix composites, quality assurance. Letter grading. Mr. Ghoniem (Not offered 2019-20)

**298. Seminar: Engineering. (2 to 4)** Seminar, to be arranged. Limited to graduate mechanical and aerospace engineering students. Seminars may be organized in advanced technical fields. If appropriate, field trips may be arranged. May be repeated with topic change. Letter grading. (F)

**M299A. Seminar: Systems, Dynamics, and Control Topics. (2)** (Same as Chemical Engineering M297 and Electrical and Computer Engineering M248S.) Seminar, two hours; outside study, six hours. Limited to graduate engineering students. Presentations of research topics by leading academic researchers from fields of systems, dynamics, and control. Students who work in these fields present their papers and results. S/U grading. (Not offered 2019-20)

**375. Teaching Apprentice Practicum. (1 to 4)** Seminar, to be arranged. Preparation: apprentice personnel employment as teaching assistant, associate, or fellow. Teaching apprenticeship under active guidance and supervision of regular faculty member responsible for curriculum and instruction at UCLA. May be repeated for credit. S/U grading. Mr. Mal (F,W,Sp)

**495. Teaching Assistant Training Seminar. (2)** Seminar, two hours; outside study, four hours. Preparation: appointment as teaching assistant in department. Seminar on communication of mechanical and aerospace engineering principles, concepts, and methods; teaching assistant preparation, organization, and presentation of material, including use of visual aids; grading, advising, and rapport with students. S/U grading. Mr. Mal (F)

**596. Directed Individual or Tutorial Studies. (2 to 8)** Tutorial, to be arranged. Limited to graduate mechanical and aerospace engineering students. Petition forms to request enrollment may be obtained from assistant dean, Graduate Studies. Supervised investigation of advanced technical problems. S/U grading.

**597A. Preparation for MS Comprehensive Examination. (2 to 12)** Tutorial, to be arranged. Limited to graduate mechanical and aerospace engineering students. Reading and preparation for MS comprehensive examination. S/U grading.

**597B. Preparation for PhD Preliminary Examinations. (2 to 16)** Tutorial, to be arranged. Limited to graduate mechanical and aerospace engineering students. S/U grading.

**597C. Preparation for PhD Oral Qualifying Examination. (2 to 16)** Tutorial, to be arranged. Limited to graduate mechanical and aerospace engineering students. Preparation for oral qualifying examination, including preliminary research on dissertation. S/U grading.

**598. Research for and Preparation of MS Thesis. (2 to 12)** Tutorial, to be arranged. Limited to graduate mechanical and aerospace engineering students. Supervised independent research for MS candidates, including thesis prospectus. S/U grading.

**599. Research for and Preparation of PhD Dissertation. (2 to 16)** Tutorial, to be arranged. Limited to graduate mechanical and aerospace engineering students. Usually taken after students have been advanced to candidacy. S/U grading.

# Master of Science in Engineering Online Programs

4732 Boelter Hall
Box 951601
Los Angeles, CA 90095-1601

310-825-6542
**https://www.msol.ucla.edu**

Jenn-Ming Yang, Ph.D., *Associate Dean*

## Scope and Objectives

The primary purpose of the Master of Science in Engineering online degree programs is to enable employed engineers and computer scientists to augment their technical education beyond the Bachelor of Science degree and to enhance their value to the technical organizations in which they are employed. The training and education that the programs offer are of significant importance and usefulness to engineers, their employers, California, and the nation. It is at the M.S. level that engineers have the opportunity to learn a specialization in depth, and those engineers with advanced degrees may also renew and update their knowledge of the technology advances that continue to occur at an accelerating rate.

The M.S. programs are addressed to those highly qualified employed engineers who, for various reasons, do not attend the on-campus M.S. programs and who are keenly interested in developing up-to-date knowledge of cutting-edge engineering and technology.

## Graduate Study

For information on graduate admission, see Graduate Programs on page 26.

The following introductory information is based on 2019-20 program requirements for UCLA graduate degrees. Complete program requirements are available at **https://grad.ucla.edu/academics/graduate-study/program-requirements-for-ucla-graduate-degrees/**. Students are subject to the detailed degree requirements as published in program requirements for the year in which they enter the program.

## M.S. in Engineering Online Programs

### Course Requirements

The programs consist of nine courses that make up a program of study. At least five courses must be at the 200 level, and one must be a directed study course. The latter course satisfies the University of California requirement for a capstone event (in the on-campus program the requirement is covered by a comprehensive examination or a thesis); the directed study course consists of an engineering design project that is better suited for the working engineer/computer scientist.

The programs are structured in a manner that allows employed engineers/computer scientists to complete the requirements at a part-time pace (e.g., one 100/200-level course per term). Courses are scheduled so that the programs can be completed within two academic years plus one additional term.

## Areas of Study

### Data Science Engineering Program

Junghoo (John) Cho, Ph.D. (Computer Science), *Area Director*; **cho@cs.ucla.edu**

Vwani P. Roychowdhury, Ph.D. (Electrical and Computer Engineering), *Area Director;* **vwani@ee.ucla.edu**

The exponential growth of data generated by machines and humans present unprecedented challenges and opportunities. From the analysis of this big data, businesses can learn key insights about their customers to make informed business decisions. Scientists can discover previously unknown patterns hidden deep inside the mountains of data. In this program, students will learn key techniques used to design and build big data systems and gain familiarity with data-mining and machine-learning techniques that are the foundations behind successful information search, predictive analysis, smart personalization, and many other technology-based solutions to important problems in business and science.

### Engineering Management Program

Leslie M. Lackman, Ph.D. (Mechanical and Aerospace Engineering), *Area Director*; **llackman@support.ucla.edu**

The engineering management program focuses on providing entering and current engineering management personnel an opportunity to expand their business-related knowledge base and skills to enhance employment performance to the benefit of both the employee and employer. The program offers similar curriculum to that currently offered on campus by the professional schools.

All Internet-available lecturers are offered 24/7, with a weekly homeroom time to enhance the taped lectures and promote class interaction. The homerooms are held in early evenings to facilitate nonimpact with employee work schedules.

## Environment and Water Resources Program

Jennifer A. Jay, Ph.D. (Civil and Environmental Engineering), *Area Director*; jjay@seas.ucla.edu

Plentiful high-quality water is fundamental for society. However, drought, climate change, contamination, and growing populations pose challenges for water sustainability. Engineers are needed worldwide to find novel solutions in providing access to clean water. Key elements in this degree program are surface and groundwater processes; hydroclimatology; watershed response to disturbance; remote sensing for hydrologic applications; membrane separation in aqueous systems; aquatic chemistry; environmental microbiology; and the chemical fate, geochemical modeling, and transport of contaminants in the environment.

## Mechanics of Structures Program

Ajit K. Mal, Ph.D. (Mechanical and Aerospace Engineering), *Area Director;* ajit@seas.ucla.edu

The main objective of the mechanics of structures program is to provide students with the opportunity to develop the knowledge required for the analysis and synthesis of modern engineered structures. The fundamental concepts of linear and nonlinear elasticity, plasticity, fracture mechanics, finite element analysis, mechanics of composites, and structural vibrations are developed in a series of undergraduate and graduate courses.

These concepts are then applied in solving industry-relevant problems in a number of graduate-level courses. Students develop hands-on experience in using popular finite element packages for solving realistic structural analysis problems.

## Reliability Engineering Program

Ali Mosleh, Ph.D. (Civil and Environmental Engineering, Materials Science and Engineering, Mechanical and Aerospace Engineering), *Area Director;* mosleh@.ucla.edu

The program is designed with a fresh perspective that addresses the current needs of the industry for ensuring reliability of engineered products and services, but also anticipates future needs and pushes frontiers into the realms of machine learning, advanced prognostics and health monitoring, and advanced methods to tackle reliability of complex cyber-physical-human (CPH) systems.

## Systems Engineering Program

Jenn-Ming Yang, Ph.D. (Materials Science and Engineering), *Interim Area Director;* jyang@seas.ucla.edu

Systems engineering has broad applications that include software, hardware, materials, and electrical and mechanical systems. A set of four core courses is offered that form the foundation of the system engineering program. The sequence of courses is designed for working professionals who are faced with design, development, support, and maintenance of complex systems.

## M.S. in Engineering—Aerospace

Xiaolin Zhong, Ph.D. (Mechanical and Aerospace Engineering), *Area Director;* xiaolin@seas.ucla.edu

The objective of this program is to provide students with a broad knowledge of major technical areas of aerospace engineering in order to fulfill the current and future needs of the aerospace industry. The major technical areas of this program include aerodynamics and computational fluid dynamics (CFD), propulsion, systems and control, and structures and dynamics. Undergraduate and graduate courses in the area of aerospace engineering cover a wide range of fundamental concepts of the science and engineering of aerodynamics, space technology, compressible flow, computational aerodynamics, aircraft and rocket propulsion systems, digital control of physical systems, linear dynamic systems, linear optimal control, design of aerospace structures, dynamics of structures, robust control system analysis and design, and probability and stochastic processes in dynamical systems.

## M.S. in Engineering—Computer Networking

Mario Gerla, Ph.D. (Computer Science), *Area Director*; gerla@cs.ucla.edu

Three undergraduate elective courses complement the basic background of the undergraduate computer science degree with concepts in security, sensors, and wireless communications. The graduate courses expose students to key applications and research areas in the network and distributed systems field. Two required graduate courses cover the Internet and emerging sensor embedded systems. The electives probe different applications domains, including wireless mobile networks, security, network management, distributed P2P systems, and multimedia applications.

## M.S. in Engineering—Electrical

Izhak Rubin, Ph.D. (Electrical and Computer Engineering), *Area Director*; rubin@ee.ucla.edu

The electrical engineering program covers a broad spectrum of specializations in communications and telecommunications, control systems, electromagnetics, embedded computing systems, engineering optimization, integrated circuits and systems, microelectromechanical systems (MEMS), nanotechnology, photonics and optoelectronics, plasma electronics, signal processing, and solid-state electronics.

## M.S. in Engineering—Electronic Materials

Ya-Hong Xie, Ph.D. (Materials Science and Engineering), *Area Director*; yhx@ucla.edu

The electronic materials program provides students with a knowledge set that is highly relevant to the semiconductor industry. The program has four essential attributes: theoretical background, applied knowledge, exposure to theoretical approaches, and introduction to the emerging field of microelectronics, namely organic electronics. All faculty members have industrial experience and are currently conducting active research in these subject areas.

## M.S. in Engineering—Integrated Circuits

Dejan Markovic, Ph.D. (Electrical and Computer Engineering), *Area Director;* dejan@ee.ucla.edu

The integrated circuits program includes analog integrated circuit (IC) design, design and modeling of VLSI circuits and systems, RF circuit and system design, signaling and synchronization, VLSI signal processing, and communication system design. Summer courses are not yet offered in this program; therefore it cannot currently be completed in two calendar years.

## M.S. in Engineering—Manufacturing and Design

Nasr M. Ghoniem, Ph.D. (Mechanical and Aerospace Engineering), *Area Director;* ghoniem@ucla.edu

An advanced program of study that covers fundamental and applied topics in modern manufacturing and mechanical design. The program includes finite element methods in design, mechanics of intelligent materials systems, nano- and micro-manufacturing, material processing, rapid prototyping, composites manufacturing, design with composites, digital control, design of power transmission systems, design of high-temperature components, and design of smart grids. The program prepares students with the higher educational background and the competence that are necessary for today's rapidly changing technology needs.

## M.S. in Engineering—Materials Science

Jenn-Ming Yang, Ph.D. (Materials Science and Engineering), *Area Director;* jyang@seas.ucla.edu

Materials engineering is concerned with the design, fabrication, and testing of engineering materials that must simultaneously fulfill dimensional properties, quality control, and economic requirements. Several manufacturing steps may be involved: (1) primary fabrication, such as solidification or vapor deposition of homogeneous or composite materials, (2) secondary fabrication, including shaping and microstructural control by operations such as mechanical working, machining, sintering, joining, and heat treatment, and (3) testing, which measures the degree of reliability of a processed part, destructively or nondestructively.

## M.S. in Engineering—Mechanical

Ajit K. Mal, Ph.D. (Mechanical and Aerospace Engineering), *Area Director*; ajit@seas.ucla.edu

An advanced program of study that covers fundamental and applied topics in modern manufacturing and mechanical design. The program includes finite element methods in design, mechanics of intelligent material systems, nano- and micro-manufacturing, material processing, rapid prototyping, composites manufacturing, design with composites, digital control, design of power transmission systems, design of high-temperature components, and design of smart grids. The program prepares students with the higher educational background and the competence that are necessary for today's rapidly changing technology needs.

## M.S. in Engineering—Signal Processing and Communications

Izhak Rubin, Ph.D. (Electrical and Computer Engineering), *Area Director*; rubin@ee.ucla.edu

The program provides training in a set of related topics in signal processing and communications. Students receive advanced training in multimedia systems from the fundamentals of media representation and compression through transmission of signals over communications links and networks.

## M.S. in Engineering—Structural Materials

Jenn-Ming Yang, Ph.D. (Materials Science and Engineering), *Area Director;* jyang@seas.ucla.edu

The program provides students with a broad knowledge of structural materials. Courses cover fundamental concepts of science and engineering of lightweight advanced metallic and composite materials, fracture mechanics, damage tolerance and durability, failure analysis and prevention, nondestructive evaluation, structural integrity and life prediction, and design of aerospace structures. Students are required to complete a project on a topic related to structural materials.

# Schoolwide Programs and Courses

6426 Boelter Hall
Box 951601
Los Angeles, CA 90095-1601

310-825-9580
https://samueli.ucla.edu

## Graduate Study

For information on graduate admission to the schoolwide engineering programs and requirements for the Engineer degree and certificate of specialization, see Graduate Programs, page 26.

## Lower-Division Courses

**2. Technology and Society. (2)** Lecture, two hours; discussion, one hour; outside study, three hours. Introduction of broader societal opportunities, impacts, and challenges associated with technology. Drawing from historical and contemporary examples, consideration of some of ethical, policy, and legal questions spurred by rapid technological change. Development of perspectives to take broad, contextualized view of role of technology in society. Letter grading. (W)

**10A. Introduction to Complex Systems Science. (5)** Lecture, four hours; outside study, eight hours. How macroscopic patterns emerge dynamically from local interactions of large number of interdependent (often heterogeneous) entities, without global design or central control. Such emergent order, whose explanation cannot be reduced to explanations at level of individual entities, is ubiquitous in biology and human social collectives, but also exists in certain physical processes such as earthquakes and some chemical reactions. Complexity also deals with how such systems undergo sudden changes, including catastrophic breakdowns, in absence of external force or central influence. Key aspect of biological and social collectives is their nature as complex adaptive systems, where individuals and groups adjust their behavior to external conditions. In biological and social systems, complexity science goes beyond traditional mathematics and statistics in its use of multiagent computational models that better capture these complex, adaptive, and self-organizing phenomena. Letter grading. Mr. Bragin (Not offered 2019-20)

**19. Fiat Lux Freshman Seminars. (1)** Seminar, one hour. Discussion of and critical thinking about topics of current intellectual importance, taught by faculty members in their areas of expertise and illuminating many paths of discovery at UCLA. P/NP grading.

**20. First-Year Engineering Transition Bridge. (2)** Seminar, 32 hours. Designed primarily for new students to help them understand UCLA, its culture, structure, and academic policies and to facilitate their transition from high school to college. Examination of research on first-year experience of college students, studying at UCLA versus high school, policies and procedures, and campus resources. Advanced preparation and early exposure to Fall Quarter mathematics, chemistry, and computer science curricula. Collaborative learning techniques and community-building activities are integral processes to both day and evening programs. Intensive classroom instruction and collaborative learning workshops. Offered in summer only. P/NP grading.

**21. Computing Immersion Summer Experience. (2)** Seminar, 32 hours. Designed primarily for new students to help them understand UCLA, its culture, structure, and academic policies and to facilitate their transition from high school to college. Examination of research on first-year experience of college students, studying at UCLA versus high school, policies and procedures, and campus resources. Designed to immerse incoming computing students in foundation concepts and principles of computer science, with focus on fundamental computer programming principles, methodologies, and techniques. Basic concepts of programming and C++ computing language. Offered in summer only. P/NP grading.

**22. Summer Bridge Review for Enhancing Engineering Students. (2)** Seminar, 32 hours. Designed primarily for new students to help them understand UCLA, its culture, structure, and academic policies and to facilitate their transition from high school to college. Examination of research on first-year experience of college students, studying at UCLA versus high school, policies and procedures, and campus resources. Intensive introduction of advanced topics covered in upper-division engineering courses. Offered in summer only. P/NP grading.

**23. Finding Industry Internship. (2)** Seminar, two hours; outside study, four hours. Designed to engage engineering students in process of formal career development. Students learn about various components of internship/job application and practice preparing relevant materials. Prepares students for career-related social interactions. Development of skills and insights to successfully secure future opportunities, such as first industry internship. P/NP grading. (F,W,Sp)

**24. Finding Undergraduate Research Opportunity. (2)** Seminar, two hours; outside study, four hours. Designed to engage engineering students, primarily those without prior experience, in process of soliciting, securing, and beginning research. Students learn about various methods and resources used to obtain laboratory position. Exploration of opportunities and guidance on how to approach those openings. Offers students smooth transition into research laboratory. P/NP grading. (F,W,Sp)

**25. Communicating Undergraduate Research Results. (2)** Seminar, two hours; outside study, four hours. Designed to engage engineering students in process of communicating formal research. Students learn about various components required in publishing research. Offers templates and examples as guides for understanding technical presentations and writing. Development of skills and insights to successfully publish first research project. P/NP grading. (W)

**87. Introduction to Engineering Disciplines. (4)** Lecture, four hours; discussion, four hours; outside study, four hours. Introduction to engineering as professional opportunity for freshman students by exploring difference between engineering disciplines and functions engineers perform. Development of skills and techniques for academic excellence through team process. Investigation of national need underlying current effort to increase participation of historically underrepresented groups in U.S. technological work force. Letter grading. Mr. Wesel (F)

**95. Internship Studies in Engineering. (2 to 4)** Tutorial, two to four hours. Limited to freshmen/sophomores. Internship studies course supervised by associate dean or designated faculty members. Further supervision to be provided by organization for which students are doing internship. Students may be required to meet on regular basis with instructor and provide periodic reports of their experience. May not be applied toward major requirements. May be repeated for credit. Individual contract with associate dean required. P/NP grading. Mr. Wesel (F,W,Sp)

**96A. Introduction to Engineering Design. (2)** (Formerly numbered 96.) Lecture, one hour; laboratory, one hour; outside study, four hours. Introduction to engineering design while building teamwork and communication skills and examination of engineering majors offered at UCLA and of engineering careers. Completion of hands-on engineering design projects, preparation of short report describing projects, and presentation of results. Specific project details and relevant majors explored vary with instructor. May be repeated once for credit with topic or instructor change. Letter grading. Mr. Reiher (F,W,Sp)

**96B. Introduction to Engineering Design: Digital Imaging. (2)** Lecture, one hour; laboratory, one hour; outside study, four hours. Recommended for undergraduate Aerospace Engineering, Bioengineering, Computer Science, Electrical Engineering, and Mechanical Engineering majors. Introduction to engineering design while building teamwork and communication skills and examination of engineering majors offered at UCLA and of engineering careers. Hands-on experience with state-of-art solid-state imaging devices. How to focus, expose, record, and manipulate telescopic images. Development of photographic technology from early chemical experiments to wide spread use of cell phone camera. Completion of hands-on engineering design projects, preparation of short report describing projects, and presentation of results. Letter grading. Mr.Stafsudd (F,Sp)

**96C. Introduction to Engineering Design: Internet of Things. (2)** Lecture, one hour; laboratory, one hour; outside study, four hours. Recommended for undergraduate Aerospace Engineering, Bioengineering, Computer Science, Electrical Engineering, and Mechanical Engineering majors. Introduction to engineering design while building teamwork and communication skills and examination of engineering majors offered at UCLA and of engineering careers. Hands-on experience with state-of-art Internet of things (IoT) technology to offer students opportunity to rapidly develop innovative and inspiring systems that provide ideal introduction to computing systems and IoT applications specific to their major field. IoT technology has become one of most important advances in technology history with applications ranging from wearable devices for healthcare to residential monitoring systems, natural resource protection and management, intelligent vehicles and transportation systems, robotics systems, and energy conservation. Completion of hands-on engineering design projects, preparation of short report describing projects, and presentation of results. Letter grading. Mr. Kaiser (F,Sp)

**96E. Introduction to Engineering Design: Electrocardiogram. (2)** Lecture, 90 minutes; laboratory, 90 minutes; outside study, three hours. Students learn and use concepts and techniques in electrical circuit design and analysis, cardiac electrophysiology, biophysics, microcontrollers, and computer programming. Students work in teams to design, construct, and test circuit boards capable of measuring human electrocardiograms by capturing data with microcontroller, with computer analysis and display. Students present their designs orally and in writing. Letter grading. (F,W,Sp)

**96G. Introduction to Engineering Design: Go-Karts. (2)** Lecture, 90 minutes; laboratory, 90 minutes; outside study, three hours. Students learn and use concepts and techniques in computer-aided design, finite element analysis, machining, electric motor performance, steering linkages, and general mechanical design and assembly to work in teams and construct and test go-karts. Students present their designs orally and in writing. Letter grading. (F,W,Sp)

**96R. Introduction to Engineering Design: Rockets. (2)** Lecture, 90 minutes; laboratory, 90 minutes; outside study, three hours. Introduction to basic concepts in aerospace engineering, computer-aided design, finite element analysis, 3D printing, carbon fiber layup, telemetry, general mechanical design and assembly, and machine shop fabrication. Concepts applied to team-based design, construction, and testing of small 3D-printed rockets and larger, high-power rockets. Students present their designs orally and in writing, and evaluate their performance against other student teams. Rockets fired from Mojave Desert launch site in class field trip. No prior experience or coursework needed. Study led by experienced undergraduate members of Bruin Rocket Project. Meetings, and design and fabrication homework, make use of Makerspace facilities and tools. Letter grading. (F,W,Sp)

**99. Student Research Program. (1 to 2)** Tutorial (supervised research or other scholarly work), three hours per week per unit. Entry-level research for lower-division students under guidance of faculty mentor. Students must be in good academic standing and enrolled in minimum of 12 units (excluding this course). Individual contract required; consult Undergraduate Research Center. May be repeated. P/NP grading.

# Upper-Division Courses

**M101. Principles of Nanoscience and Nanotechnology. (4)** (Same as Materials Science M105.) Lecture, four hours; discussion, one hour; outside study, seven hours. Enforced requisites: Chemistry 20A, 20B, Physics 1C. Introduction to underlying science encompassing structure, properties, and fabrication of technologically important nanoscale systems. New phenomena that emerge in very small systems (typically with feature sizes below few hundred nanometers) explained using basic concepts from physics and chemistry. Chemical, optical, and electronic properties, electron transport, structural stability, self-assembly, templated assembly and applications of various nanostructures such as quantum dots, nanoparticles, quantum wires, quantum wells and multilayers, carbon nanotubes. Letter grading. Mr. Ozolins (F)

**102. Synthetic Biosystems and Nanosystems Design. (4)** Lecture, four hours; outside study, eight hours. Requisites: course M101, Life Sciences 3. Introduction to current progress in engineering to integrate biosciences and nanosciences into synthetic systems, where biological components are reengineered and rewired to perform desirable functions in both intracellular and cell-free environments. Discussion of basic technologies and systems analysis that deal with dynamic behavior, noise, and uncertainties. Design project in which students are challenged to design novel biosystems and nanosystems for nontrivial task required. Letter grading. Mr. Liao

**M103. Environmental Nanotechnology: Implications and Applications. (4)** (Same as Civil Engineering M165.) Lecture, four hours; discussion, two hours; outside study, six hours. Recommended requisite: course M101. Introduction to potential implications of nanotechnology to environmental systems as well as potential application of nanotechnology to environmental protection. Technical contents include three multidisciplinary areas: (1) physical, chemical, and biological properties of nanomaterials, (2) transport, reactivity, and toxicity of nanoscale materials in natural environmental systems, and (3) use of nanotechnology for energy and water production, plus environmental protection, monitoring, and remediation. Letter grading. Mr. Hoek (Sp)

**110. Introduction to Technology Management and Economics for Engineers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Fundamental principles of micro-level (individual, firm, and industry) and macro-level (government, international) economics as they relate to technology management. How individuals, firms, and governments impact successful commercialization of high technology products and services. Letter grading. Mr. Monbouquette (F,W)

**111. Introduction to Finance and Marketing for Engineers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Critical components of finance and marketing research and practice as they impact management of technology commercialization. Internal (within firm) and external (in marketplace) marketing and financing of high-technology innovation. Concepts include present value, future value, discounted cash flow, internal rate of return, return on assets, return on equity, return on investment, interest rates, cost of capital, and product, price, positioning, and promotion. Use of market research, segmentation, and forecasting in management of technological innovation. Letter grading. Mr. Monbouquette (W,Sp)

**112. Laboratory to Market, Entrepreneurship for Engineers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Critical components of entrepreneurship, finance, marketing, human resources, and accounting disciplines as they impact management of technology commercialization.

Topics include intellectual property management, team building, market forecasting, and entrepreneurial finance. Students work in small teams studying technology management plans to bring new technologies to market. Students select from set of available technology concepts, many generated at UCLA, that are in need of plans for movement from laboratory to market. Letter grading.
Mr. Monbouquette (F,Sp)

**113. Product Strategy. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Designed for juniors/seniors. Introduction to current management concept of product development. Topics include product strategy, product platform, and product lines; competitive strategy, vectors of differentiation, product pricing, first-to-market versus fast-follower; growth strategy, growth through acquisition, and new ventures; product portfolio management. Case studies, class projects, group discussions, and guest lectures by speakers from industry. Letter grading. Mr. Pao (F,W)

**116. Statistics for Management Decisions. (4)** Lecture, four hours; outside study, eight hours. Management as well as engineering decisions nearly always take place in environment characterized by uncertainty. Probability provides mathematical framework for understanding how to make rational decisions when outcomes of actions are uncertain. Application of probability to problem of reasoning from sample data, encompassing estimation, hypothesis testing, and regression analysis. Discussion of specific analytical techniques needed in later courses in program. Development of basic understanding of statistical analysis. Letter grading. Ms. Dolecek

**120. Entrepreneurship for Scientists and Engineers. (2)** Seminar, two hours; outside study, four hours. Designed for seniors and graduate students. Identification of business opportunities and outline of basic requisites for viable business plans, followed by specific topics related to securing basic assets and resources needed to execute those plans. P/NP grading. Mr. Wesel

**160. Entrepreneurship and Venture Initiation for Engineers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Focus on process and methodology for starting new venture. Introduction to entrepreneurship from perspective of entrepreneur. Examination of core concepts and frameworks on idea generation, market analysis, fundraising, corporate structures, and financial accounting for entrepreneurial endeavors. Focus on fundamentals of building business, and also emphasis on inherent experiential nature of entrepreneurship and need for constant learning on this subject. Letter grading. (W)

**163. Entrepreneurship and New Product Development for Engineers. (4)** Lecture, four hours; discussion, one hour; outside study, seven hours. Limited to juniors/seniors. Designed to deepen understanding of innovations and innovative processes related to creating new products. Inquiry into why, what, and how of making new products. New products are essential to any business (start-up or well-established) and thriving economies. Making successful new products requires various types of innovation. Availability of digital technologies and global outsources have accelerated pace of these innovations. Letter grading. (F)

**180. Engineering of Complex Systems. (4)** Lecture, four hours; discussion, two hours; outside study, six hours. Designed for junior/senior engineering majors. Holistic view of engineering discipline, covering lifecycle of engineering, processes, and techniques used in industry today. Multidisciplinary systems engineering perspective in which aspects of electrical, mechanical, material, and software engineering are incorporated. Three specific case studies in communication, sensor, and processing systems included to help students understand these concepts. Special attention paid to link material covered to engineering curriculum offered by UCLA to help students integrate and enhance their understanding of knowledge already acquired. Motivation of students to continue their learning and reinforce lifelong learning habits. Letter grading. Mr. Wesel (Sp)

**181EW. Ethics and Impact of Technology on Society. (4)** Lecture, five hours; discussion, three hours; outside study, four hours. Requisite: English Composition 3. Not open for credit to students with credit for course 182EW, 183EW, or 185EW. Focuses on changing nature of technology and complex ethical issues that emerge as result in areas such as biotechnology, information technology, nanotechnology, and energy technology. Discussion of nature of these issues; their ethical, legal, and social ramifications; and what society values in relation to these issues. Exploration of philosophy, religion, and natural and social sciences in relation to these issues. Emphasis on research and writing within engineering environments. Writing and revision of about 20 pages total, including two individual technical essays and one team-written research report. Readings address technical issues and writing form. Satisfies engineering writing requirement. Letter grading.
Mr. Wesel (Not offered 2019-20)

**182EW. Technology and Society. (4)** Lecture, four hours; discussion, three hours; outside study, five hours. Requisite: English Composition 3, and one course from Civil Engineering 110, Electrical and Computer Engineering 131A, Mathematics 170, Mechanical and Aerospace Engineering 174, or Statistics 100A. Not open for credit to students with credit for course 182EW, 183EW, or 185EW. Places engineering in broader societal context through examination of some of key ethical, legal, and regulatory issues and frameworks relevant to design and deployment of emerging technology products and services. Historical examination of ethical and legal frameworks generally and in relation to technology. Exploration of series of specific contemporary technology-related topics to examine their broader ramifications. Topics include driverless cars, algorithms and artificial intelligence, global supply chain for engineering products, cryptocurrencies and blockchain, net neutrality, and impact of technology on employment. Offers students tools enabling them to think more proactively and holistically about ethical and societal dimensions of their work as technology creators. Satisfies engineering writing requirement. Letter grading. Mr. Villasenor (F)

**183EW. Engineering and Society. (4)** Lecture, four hours; discussion, three hours; outside study, five hours. Enforced requisite: English Composition 3 or 3E. Not open for credit to students with credit for course 185EW. Limited to sophomore/junior/senior engineering students. Professional and ethical considerations in practice of engineering. Impact of technology on society and on development of moral and ethical values. Contemporary environmental, biological, legal, and other issues created by new technologies. Emphasis on research and writing within engineering environments. Writing and revision of about 20 pages total, including two individual technical essays and one team-written research report. Readings address technical issues and writing form. Satisfies engineering writing requirement. Letter grading.
Mr. Wesel (F,W,Sp)

**185EW. Art of Engineering Endeavors. (4)** Lecture, four hours; discussion, three hours; outside study, five hours. Enforced requisite: English Composition 3 or 3E. Not open for credit to students with credit for course 183EW. Designed for junior/senior engineering students. Nontechnical skills and experiences necessary for engineering career success. Importance of group dynamics in engineering practice. Teamwork and effective group skills in engineering environments. Organization and control of multidisciplinary complex engineering projects. Forms of leadership and qualities and characteristics of effective leaders. How engineering, computer sciences, and technology relate to major ethical and social issues. Societal demands on practice of engineering. Emphasis on research and writing in engineering environments. Satisfies engineering writing requirement. Letter grading. Mr. Wesel (F,W,Sp)

**188. Special Courses in Engineering. (4)** Seminar, four hours; outside study, eight hours. Special topics in engineering for undergraduate students taught on experimental or temporary basis, such as those taught by resident and visiting faculty members. May be repeated for credit with topic or instructor change. Letter grading.

**191. Seminar Series in Engineering Research. (1)** Seminar, one hour. Seminar series in cutting-edge engineering research at UCLA. Each seminar is given by UCLA graduate student researcher or post-doctoral scholar. Designed to be accessible to undergraduate students in any science, technology, engineering, and mathematics (STEM) major. Offers undergraduate students window into excitement of graduate student research experience. Also offers opportunity for graduate students to learn about what their peers are doing. P/NP grading.

**192. Fundamentals of Engineering Mentorship. (2)** Seminar, two hours; outside study, four hours. Principles and practical techniques for instruction of hands-on engineering design projects in high school outreach programs. Curriculum planning, project preparation, classroom management, team collaboration, diversity awareness, fostering of group cohesion, and emergency procedures. Preparation of lessons and project for summer outreach program, with practice presentations. P/NP grading. Mr. Pottie (F,W,Sp)

**195. Internship Studies in Engineering. (2 to 4)** Tutorial, two to four hours. Limited to juniors/seniors. Internship studies course supervised by associate dean or designated faculty members. Further supervision to be provided by organization for which students are doing internship. Students may be required to meet on regular basis with instructor and provide periodic reports of their experience. May not be applied toward major requirements. May be repeated for credit. Individual contract with associate dean required. P/NP grading. Mr. Wesel (F,W,Sp)

**199. Directed Research in Engineering. (2 to 8)** Tutorial, to be arranged. Limited to juniors/seniors. Supervised individual research or investigation under guidance of faculty mentor. Culminating paper or project required. May be repeated for credit with school approval. Individual contract required; enrollment petitions available in Office of Academic and Student Affairs. Letter grading. (F,W,Sp)

## Graduate Courses

**200. Program Management Principles for Engineers and Professionals. (4)** Lecture, four hours; outside study, eight hours. Designed for graduate students. Practical review of necessary processes and procedures to successfully manage technology programs. Review of fundamentals of program planning, organizational structure, implementation, and performance tracking methods to provide program manager with necessary information to support decision-making process that provides high-quality products on time and within budget. Letter grading. Mr. Wesel

**201. Systems Engineering. (4)** Lecture, four hours; outside study, eight hours. Designed for graduate students. Practical review of major elements of system engineering process. Coverage of key elements: system requirements and flow down, product development cycle, functional analysis, system synthesis and trade studies, budget allocations, risk management metrics, review and audit activities and documentation. Letter grading. (W)

**202. Reliability, Maintainability, and Supportability. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 201. Designed for graduate students with one to two years work experience. Integrated logistic support (ILS) is major driver of system life-cycle cost and one key element of system engineering activities. Overview of engineering disciplines critical to this function—reliability, maintainability, and supportability—and their relationships, taught using probability theory. Topics also include fault detections and isolations and parts obsolescence. Discussion of 6-sigma process, one effective design and manufacturing methodology, to ensure system reliability, maintainability, and supportability. Letter grading.
Mr. Lynch, Mr. Wesel

**203. System Architecture. (4)** Lecture, four hours; outside study, eight hours. Requisite: course 201. Designed for graduate students with BS degrees in engineering or science and one to two years work experience in selected domain. Art and science of architecting. Introduction to architecting methodology—paradigm and tools. Principles of architecting through analysis of architecture designs of major existing systems. Discussion of selected elements of architectural practices, such as representation models, design progression, and architecture frameworks. Examination of professionalization of system architecting. Letter grading. Mr. Lynch, Mr. Wesel

**204. Trusted Systems Engineering. (4)** Lecture, four hours; outside study, eight hours. Trust is placed in information systems to behave properly, but cyber threats and breaches have become routine, including penetration of financial, medical, government, and national security systems. To build systems that can protect confidentiality, integrity, and availability involves more than composing systems from network security, computer security, data security, cryptography, etc. One can use most secure components, and resulting system could still be vulnerable. Skills learned ensure that systems are architected, designed, implemented, tested, and operated for specific levels of trust. Aspects include assessing vulnerability and risk for systems, establishing protection principles, and using them as guide to formulate system architectures; translating architecture into system design and verifying correctness of design; and constructing and following trusted development and implementation process. Letter grading.

**205. Model-Based Systems Engineering. (4)** Lecture, four hours; outside study, eight hours. Model-based systems engineering (MBSE) and systems modeling language (SysML) taught through lectures and readings, individual projects, and one group project. Lectures and readings to provide students with conceptual framework and vocabulary. Individual projects enable students to develop basic skills for creating SysML requirements and structural and behavioral diagrams. In group project students learn how to package, compartmentalize, and integrate smaller efforts while being constrained to meet schedules. Industry-recognized credentials may be obtained, as course covers Object Management Group (OMG) Certified Systems Modeling Professional (OCSMP) tests, such as Model User and Model Builder Fundamentals and Model Builder Intermediate. Letter grading. Mr. Mosleh (F)

**206. Engineering for Systems Assurance. (4)** Lecture, four hours; outside study, eight hours. Recommended requisites: course 204, Computer Science 236. Systems are constructed to perform complex functions and services. How to understand needs of users, analysis of requirements and derived requirements, creation of various system architecture products, and design and integration of various components into systems that perform these functions and services. System assurance addresses confidence that systems meet specified operational requirements based on evidence provided by applying assurance techniques. Introduction, investigation, and analysis of framework of assurance to accomplish total system assurance. Development of secure, reliable, and dependable systems that range from commercial realm such as air traffic control, Supervisory Control and Data Acquisition (SCADA), and autonomous vehicles to military realm such as command, control, communication, intelligence, and cyber. Letter grading.

**210. Operations and Supply Chain Management. (4)** Lecture, four hours; outside study, eight hours. Introduction to strategic and operating issues and decisions involved in managing enterprises. Operational processes use organization's resources to transform inputs into goods and utilizes them to provide service, or does both. Conceptual framework and set of analytical tools provided to enable students to better understand why processes behave as they do. Given this understanding, students are able to involve themselves in organization's defining strategic decisions, those related to key processes affecting organizational unit's performance. Letter grading. Mr. Vandenberghe (Sp)

**211. Financial Management. (4)** Lecture, four hours; outside study, eight hours. Introduction to concepts reflecting material generally covered in certain MBA core and elective courses. Integration of both theory—to introduce essential conceptual building blocks in accounting and finance—and empirical practice—to emphasize how these theories are actually implemented in real world. Cases, comprehensive problems, and recent events presented to provide students with as much hands-on experience in applying material presented as possible. Letter grading. Mr. J-M. Yang

**212. Intellectual Property Law and Strategy. (4)** Lecture, four hours; outside study, eight hours. Prior knowledge of legal doctrines or materials not required. Intellectual property law is not just topic for lawyers. Engineers who have design responsibilities must understand how legal system in some instances protects their designs and in other instances stands as obstacle to what would otherwise be most efficient design choice. Engineers with management responsibilities must understand intellectual property law implications for everything from pricing to strategic partnerships. Examination of intellectual property law, not only by learning fundamental rules associated with patent, copyright, trademark, and trade secret protection, but by studying business strategies that these rules support. Examples and case studies to be taken from across content, technology, and pharmaceutical industries. Letter grading. Mr. Lichtman, Mr. J-M. Yang (F)

**213. Data and Business Analytics. (4)** Lecture, four hours; outside study, eight hours. Coverage of wide variety of spreadsheet models that can be used to solve business and engineering problems, with emphasis on mastery of Excel spreadsheet modeling as integral part of analytic decision making. Managerial models include data modeling, regression and forecasting, linear programming, network and distribution models, integer programming, nonlinear programming, and Monte Carlo simulation. Problems from operations, finance, and marketing taught by spreadsheet examples and describe general managerial situations from various industries and disciplines. Development of spreadsheet models to facilitate decision making. Letter grading. Mr. Mosleh (W)

**214. Management Communication. (4)** Lecture, four hours. Exploration of knowledge, attributes, skills, and strategies necessary to succeed communicatively in workplace, with focus on business presentation skills, visual and verbal persuasion skills, and interpersonal communication skills. Letter grading. Mr. J-M. Yang

**215. Entrepreneurship for Engineers. (4)** Lecture, four hours; outside study, eight hours. Limited to graduate engineering students. Topics in starting and developing high-tech enterprises and intended for students who wish to complement their technical education with introduction to entrepreneurship. Letter grading. Mr. Abe, Mr. Cong, Mr. Wesel (W)

**299. Capstone Project. (4)** Activity, 10 hours. Preparation: completion of minimum of four 200-level courses in online MS program. Project course that satisfies UCLA final comprehensive examination requirement of MS online degree in Engineering. Project is completed under individual guidance from UCLA Engineering faculty member and incorporates advanced knowledge learned in MS program of study. Letter grading. Mr. Lynch (F,W,Sp)

**375. Teaching Apprentice Practicum. (1 to 4)** Seminar, to be arranged. Preparation: apprentice personnel employment as teaching assistant, associate, or fellow. Teaching apprenticeship under active guidance and supervision of regular faculty member responsible for curriculum and instruction at UCLA. May be repeated for credit. S/U grading. (F,W,Sp)

**470A-470D. Engineer in Technical Environment. (3 each)** Lecture, three hours; outside study, six hours. Limited to Engineering Executive Program students. Theory and application of quantitative methods in analysis and synthesis of engineering systems for purpose of making management decisions. Optimization of outputs with respect to dollar costs, time, material, energy, information, and manpower. Case studies and individual projects. S/U or letter grading.

**471A-471B-471C. Engineer in General Environment. (3–3–1.5)** Lecture, three hours (courses 471A, 471B) and 90 minutes (course 471C). Limited to Engineering Executive Program students. Influences of human relations, laws, social sciences, humanities, and fine arts on development and utilization of natural and human resources. Interaction of technology and society past, present, and future. Change agents and resistance to change. S/U or letter (471A) grading; In Progress (471B) and S/U or letter (471C) grading.

**472A-472D. Engineer in Business Environment. (3–3-3–1.5)** Lecture, three hours (courses 472A, 472B, 472C) and 90 minutes (course 472D). Limited to Engineering Executive Program students. Language of business for engineering executive. Accounting, finance, business economics, business law, and marketing. Laboratory in organization and management problem solving. Analysis of actual business problems of firm, community, and nation, provided through cooperation and participation with California business corporations and government agencies. In Progress (472A, 472C) and S/U or letter grading (credit to be given on completion of courses 472B and 472D).

**473A-473B. Analysis and Synthesis of Large-Scale System. (3–3)** Lecture, two and one half hours; outside study, six hours. Limited to Engineering Executive Program students. Problem area of modern industry or government is selected as class project, and its solution is synthesized using quantitative tools and methods. Project also serves as laboratory in organization for goal-oriented technical group. In Progress (473A) and S/U (473B) grading.

**495A. Teaching Assistant Training Seminar. (4)** Seminar, four hours; outside study, eight hours. Preparation: appointment as teaching assistant. Limited to graduate engineering students. Seminar on communication of engineering principles, concepts, and methods, preparation, organization of material, presentation, use of visual aids, grading, advising, and rapport with students. S/U grading. (F)

**M495I. Teaching Preparation Seminar: Writing for Engineers. (4)** (Formerly numbered M495B.) (Same as English Composition M495I.) Seminar, two and one half hours; outside study, nine and one half hours. Limited to graduate students. Required of all teaching assistants for Engineering writing courses not exempt by appropriate departmental or program training. Training and mentoring, with focus on composition pedagogy, assessment of student writing, guidance of revision process, and specialized writing problems that may occur in engineering writing contexts. Practical concerns of preparing students to write course assignments, marking and grading essays, and conducting peer reviews and conferences. S/U grading. (F,W,Sp)

**M495J. Supervised Teaching of Writing for Engineers. (2)** (Formerly numbered M495C.) (Same as English Composition M495J.) Seminar, one hour; outside study, five hours. Enforced requisite: course M495I. Required of all teaching assistants in their initial term of teaching Engineering writing courses. Mentoring in group and individual meetings. Continued focus on composition pedagogy, assessment of student writing, guidance of revision process, and specialized writing problems that may occur in engineering writing contexts. Practical concerns of preparing students to write course assignments, marking and grading essays, and conducting peer reviews and conferences. S/U grading. (F,W,Sp)

**501. Cooperative Program. (2 to 8)** Tutorial, to be arranged. Preparation: consent of UCLA graduate adviser and graduate dean, and host campus instructor, department chair, and graduate dean. Used to record enrollment of UCLA students in courses taken under cooperative arrangements with USC. S/U grading.

# Externally Funded Research Centers and Institutes

## Center for Domain-Specific Computing (CDSC)

*National Science Foundation (NSF) Expeditions in Computing Program and InTrans Program*

*Jason Cong, Ph.D. (Computer Science), Director;* **https://cdsc.ucla.edu**

To meet ever-increasing computing needs and overcome power density limitations, the computing industry has entered the era of parallelization, with tens to hundreds of computing cores integrated into a single processor and hundreds to thousands of computing servers connected in warehouse-scale data centers. However, such highly parallel, general-purpose computing systems still face serious challenges in terms of performance, energy, heat dissipation, space, and cost. CDSC looks beyond parallelization and focuses on domain-specific customization as the next disruptive technology, to bring orders-of-magnitude power-performance efficiency improvement to important application domains.

CDSC develops a general methodology for creating novel customizable computing platforms, and the associated compilation tools and runtime management environment to support domain-specific computing. Its recent focus is on design and implementation of accelerator-rich architectures, from single chips to data centers. It also includes highly automated compilation tools and runtime management software systems for customizable heterogeneous platforms, including multi-core CPUs, many-core GPUs, and FPGAs; as well as a general, reusable methodology for customizable computing applicable across different domains. By combining these critical capabilities, the goal is to deliver a supercomputer-in-a-box or -in-a-cluster, customized to an application domain, to enable disruptive innovations in that domain. CDSC has successfully demonstrated this approach in the domains of machine learning, medical image processing, and precision medicine.

The current team consists of highly accomplished researchers with diversified backgrounds, including computer science and engineering, electrical engineering, medicine, and applied mathematics from UCLA, Cornell University, and Georgia Institute of Technology. CDSC offers many research opportunities for graduate students, and summer research opportunities for undergraduate students.

CDSC was originally funded by the National Science Foundation (NSF) with a $10 million award from the 2009 Expeditions in Computing program, which was among the largest single investments made by the NSF Computer and Information Science and Engineering (CISE) Directorate. In July 2014, CDSC was awarded an additional $3 million by Intel Corporation, with matching support from NSF under its Innovation Transition (InTrans) program. This award supports follow-on research on accelerator-rich architectures with applications to health care, in which personalized cancer treatment was added as an application domain in addition to medical imaging. Currently, CDSC research programs are supported by NSF, Semiconductor Research Corporation (SRC) Joint University Microelectronics Program (JUMP), and a number of industrial partners worldwide.

## Center for Encrypted Functionalities

*National Science Foundation (NSF) Secure and Trustworthy Cyberspace FRONTIER Award*

*Amit Sahai, Ph.D. (Computer Science), Director;* **http://web.cs.ucla.edu/cef/**

The center tackles the deep and far-reaching problem of general-purpose program obfuscation, which aims to make an arbitrary computer program unintelligible while preserving its functionality. Viewed in a different way, the goal of obfuscation is to enable software that can keep secrets: it makes use of secrets, but such that these secrets remain hidden even if an adversary can examine the software code in its entirety and analyze its behavior as it runs. Secure obfuscation could enable a host of applications, from hiding the existence of many vulnerabilities introduced by human error to hiding cryptographic keys within software.

The center's primary mission is to transform program obfuscation from an art to a rigorous mathematical discipline. In addition to its direct research program, the center organizes retreats and workshops to bring together researchers to carry out its mission. The center also engages in high-impact outreach efforts, such as the development of free massive open online courses (MOOCs).

## Center for Translational Applications of Nanoscale Multiferroic Systems (TANMS)

*National Science Foundation (NSF) Engineering Research Center*

*Gregory P. Carman, Ph.D. (Mechanical and Aerospace Engineering), Director; Jane P. Chang, Ph.D. (Chemical and Biomolecular Engineering), Deputy Director;* **http://www.tanms-erc.org**

TANMS is a 10-year program focused on miniaturizing electromagnetic devices using a three-pillar strategy involving research, translation, and education. The research strategy engages the best researchers from the six TANMS campuses (California State University, Northridge; Cornell University; Northeastern University; UC Berkeley; UCLA; and University of Texas at Dallas) to understand and develop new nanoscale multiferroic devices. The fundamental research activities work synergistically with the center's 13 industrial partners to translate the concepts into applications such as memory, antennas, and motors. These research and translational efforts rely on a workforce of postgraduate, graduate, undergraduate, and K-12 students that also help educate the next generation of engineering leaders. TANMS promotes an inclusive atmosphere, producing a more innovative and diverse research environment compared to conventional engineering center cultures.

## Center of Excellence for Green Nanotechnologies (CEGN)

*Kang L. Wang, Ph.D. (Electrical and Computer Engineering), Director*

CEGN undertakes frontier research and development in the areas of nanotechnology in energy and nanoelectronics. It tackles major issues of scaling, energy efficiency, energy generation, and energy storage faced by the electronics industry. CEGN researchers are innovating novel solutions through a number of complementary efforts that minimize power usage and cost without compromising electronic device performance. The approach is based on the integration of magnetic, carbon-based, organic, and optoelectronic materials and devices.

King Abdulaziz City for Science and Technology (KACST) in Saudi Arabia and UCLA Samueli collaborate in CEGN under KACST's established Joint Center of Excellence Program (JCEP) to promote educational technology transfer and research exchanges. KACST has an agreement with UCLA for research in nanoelectronics and clean energy for the next three years. KACST is both Saudi Arabia's national science agency and its premier national laboratory. CEGN was awarded an additional $11 million through 2021 in its recent renewal effort, expanding on the work that was originally funded at $3.7 million.

## Named Data Networking Project

*National Science Foundation (NSF) Future Internet Architecture (FIA) Program*

*Lixia Zhang, Ph.D. (Computer Science), Principal Investigator*
*http://named-data.net*

While the Internet has far exceeded expectations, it has also stretched initial assumptions, often creating tussles that challenge its underlying communication model. The TCP/ IP architecture was designed to create a communication network where packets named only communication endpoints. Sustained growth in e-commerce, digital media, social networking, and smartphone applications has led to dominant use of the Internet as a distribution network. Solving distribution problems through a point-to-point communication protocol is complex and error-prone.

This project investigates a new Internet architecture, called named data networking (NDN), that changes the host-centric TCP/IP architecture to a data-centric architecture. This conceptually simple shift has far-reaching implications for how we design, develop, deploy, and use networks and applications. Today's TCP/ IP architecture uses addresses to communicate; NDN directly uses application data names to fetch data. TCP/IP secures the data container and communication channels; NDN directly secures the data, decoupling trust in data from trust in hosts. The project takes an application-driven, experimental approach to design and build a variety of applications on NDN to drive the development and deployment of the architecture and its supporting modules, test prototype implementations, and encourage community use, experimentation, and feedback into the design.

The new Future Internet Architectures—Next Phase (FIA-NP) program began in May 2014. The Named Data Networking Project is now under FIA-NP funding.

## Smart Grid Energy Research Center (SMERC)

*Rajit Gadh, Ph.D. (Mechanical and Aerospace Engineering), Director*
*http://smartgrid.ucla.edu*

SMERC performs research, develops technology, creates innovations, and demonstrates advanced technologies to enable the development of the next generation of the electric utility grid—the smart grid. SMERC is currently working on electric vehicle-to-grid integration (V1G and V2G), microgrids, distributed renewable integration including solar and wind, energy storage integration within microgrids, autonomous electric vehicles, distributed energy resources, automated demand response, cybersecurity, and consumer behavior. SMERC also furnishes thought leadership through partnership between utilities, renewable energy companies, technology providers, electric vehicle and electric appliance manufacturers, Department of Energy (DOE) research laboratories, and universities, so as to collectively work on envisioning, planning, and executing the smart grid of the future. The partnership recently launched the Energy for a Smart Grid (ESmart) Industry Consortium. It is expected that this smart grid will enable integration of renewable energy sources, allow for integration of electric vehicles and energy storage, improve grid efficiency and resilience, reduce power outages, allow for competitive energy pricing, and overall become more responsive to market, consumer, and societal needs. SMERC was a participant in the Los Angeles Department of Water and Power (LADWP) Regional Smart Grid Demonstration Project, which was funded by DOE at an estimated $120 million for LADWP and its partners combined. Also, a SMERC electric vehicle microgrid demonstration project was funded by the California Energy Commission.

## Center for Synthetic Control Across Lengthscales for Advancing Rechargeables (SCALAR)

*Department of Energy (DOE) Energy Frontier Research Center*

*Sarah Tolbert, Ph.D. (Chemistry and Biochemistry, Materials Science and Engineering), Director*

UCLA-led SCALAR is working to integrate new chemistry, materials, and architectures into rechargeable batteries. Researchers seek to increase battery capacity, efficiency, and stability.

## WIN Institute of Neurotronics (WINs)

*Nanoelectronics Research Initiative National Institute of Excellence*

*Kang L. Wang, Ph.D. (Electrical and Computer Engineering), Director*
*http://win-nano.org*

Successor to the Western Institute of Nanoelectronics, WINs focuses on cutting-edge research including nanostructures for high-efficiency solar cells, patterned nanostructures for integrated active optoelectronics on silicon, and carbon nanotube circuits.

Through the multidisciplinary research efforts of WINs, the National Institute of Standards and Technology (NIST) awarded UCLA $6 million to build the Western Institute of Nanotechnology on Green Engineering and Metrology (WIN-GEM) building as part of the Engineering Building I replacement, which broke ground in 2013.

## Wireless Health Institute (WHI)

*Benjamin M. Wu, D.D.S, Ph.D. (Bioengineering), Director; Bruce Dobkin, M.D. (Medicine/Neurology), William Kaiser, Ph.D. (Electrical and Computer Engineering), Gregory J. Pottie, Ph.D. (Electrical and Computer Engineering), Co-Directors*

Advances in engineering and computer science are enabling the design of powerful home and mobile technologies that can augment functional independence and daily activities of people with physical impairments, disabilities, chronic diseases, and the accumulative impairments associated with aging. These wireless mobile-health technologies can serve as monitoring devices of health and activity, provide feedback to train more healthy behaviors and lessen risk factors for stroke and heart disease, and offer novel outcome measures for individual care and large clinical trials.

WHI believes that tiny sensors—including accelerometers, gyroscopes, force transducers, and visual and sound recorders worn on the body and in clothing—will become essential components for the delivery of health care and health maintenance. Sensors created by micro- and nano-technologies will simplify communications with health providers seamlessly over Internet and wi-fi transmission using telephones and other convenient devices. To pursue these applications, WHI collaborators include the highly ranked UCLA schools of Medicine, Nursing, Engineering and Applied Science, and Management; the Clinical Translational Science Institute for medical research; the Ronald Reagan UCLA Medical Center; and faculty from many campus departments. WHI education programs span high school, undergraduate, and graduate students, and physicians; and provide training in end-to-end product development and delivery for WHI program managers.

WHI strategies and products appear in diverse health care scenarios including motion sensing of the type, quantity, and quality of exercise and practice in disabled persons; prevention of pressure sores; recovery after orthopaedic procedures; assessment of the recovery of bowel motility after surgery; monitoring cardiac output and predicting an exacerbation of heart failure; advancing athletic performance; and others. UCLA and international clinical trials, funded by the National Institutes of Health and American Heart Association, have validated motion pattern recognition and sensor feedback to increase walking and exercise after stroke. Several WHI products developed by the UCLA team are now in the marketplace in the U.S. and Europe. WHI welcomes new team members; and continuously forms new collaborations with colleagues and organizations in engineering, medical science, and health care delivery.

# B.S. in Aerospace Engineering
## Aeronautics Track Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| ***1st Quarter*** | |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| Mechanical and Aerospace Engineering 1—Undergraduate Seminar[2] | 1 |
| ***2nd Quarter*** | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| ***3rd Quarter*** | |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| UCLA Samueli GE Elective[3] | 5 |
| **SOPHOMORE YEAR** | |
| ***1st Quarter*** | |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C/4BL—Electrodynamics, Optics, and Special Relativity/Electricity and Magnetism Laboratory[1] | 7 |
| UCLA Samueli GE Elective[3] | 5 |
| ***2nd Quarter*** | |
| Materials Science and Engineering 104—Science of Engineering Materials[2] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| Mechanical and Aerospace Engineering 101—Statics and Strength of Materials[2] | 4 |
| Mechanical and Aerospace Engineering 105A—Introduction to Engineering Thermodynamics[2] | 4 |
| ***3rd Quarter*** | |
| Mechanical and Aerospace Engineering M20 (Intro to Computer Programming with MATLAB) or Computer Science 31 (Intro to Computer Science I)[2] | 4 |
| Mechanical and Aerospace Engineering 82—Mathematics of Engineering[2] | 4 |
| Mechanical and Aerospace Engineering 102—Dynamics of Particles and Rigid Bodies[2] | 4 |
| Mechanical and Aerospace Engineering 103—Elementary Fluid Mechanics[2] | 4 |
| **JUNIOR YEAR** | |
| ***1st Quarter*** | |
| Electrical and Computer Engineering 100—Electrical and Electronic Circuits[2] | 4 |
| Mechanical and Aerospace Engineering 105D—Transport Phenomena[2] | 4 |
| Mechanical and Aerospace Engineering 166A—Analysis of Aerospace Structures[2] | 4 |
| UCLA Samueli Ethics Course | 4 |
| ***2nd Quarter*** | |
| Mechanical and Aerospace Engineering 107—Introduction to Modeling and Analysis of Dynamic Systems[2] | 4 |
| Mechanical and Aerospace Engineering 150A—Intermediate Fluid Mechanics[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Mechanical and Aerospace Engineering 150B—Aerodynamics[2] | 4 |
| Mechanical and Aerospace Engineering C150R (Rocket Propulsion Systems) or 161A (Intro to Astronautics) or 161B (Intro to Space Technology)[2] | 4 |
| Mechanical and Aerospace Engineering 171A—Introduction to Feedback and Control Systems[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **SENIOR YEAR** | |
| ***1st Quarter*** | |
| Aerospace Engineering Elective[2,4] | 4 |
| Mechanical and Aerospace Engineering C150P—Aircraft Propulsion Systems[2] | 4 |
| Mechanical and Aerospace Engineering 154S—Flight Mechanics, Stability, and Control of Aircraft[2] | 4 |
| Technical Breadth Course[3] | 4 |
| ***2nd Quarter*** | |
| Mechanical and Aerospace Engineering 154A—Preliminary Design of Aircraft[2] | 4 |
| Mechanical and Aerospace Engineering 157—Basic Mechanical and Aerospace Engineering Laboratory[2] | 4 |
| Technical Breadth Course[3] | 4 |
| ***3rd Quarter*** | |
| Mechanical and Aerospace Engineering 157A—Fluid Mechanics and Aerodynamics Laboratory[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 4 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 50.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 85.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. See page 110 for list of electives.

# B.S. in Aerospace Engineering
## Space Track Curriculum

| | |
|---|---|
| **FRESHMAN YEAR** | **UNITS** |
| *1st Quarter* | |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| Mechanical and Aerospace Engineering 1—Undergraduate Seminar[2] | 1 |
| *2nd Quarter* | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| *3rd Quarter* | |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| UCLA Samueli GE Elective[3] | 5 |
| **SOPHOMORE YEAR** | |
| *1st Quarter* | |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C/4BL—Electrodynamics, Optics, and Special Relativity/Electricity and Magnetism Laboratory[1] | 7 |
| UCLA Samueli GE Elective[3] | 5 |
| *2nd Quarter* | |
| Materials Science and Engineering 104—Science of Engineering Materials[2] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| Mechanical and Aerospace Engineering 101—Statics and Strength of Materials[2] | 4 |
| Mechanical and Aerospace Engineering 105A—Introduction to Engineering Thermodynamics[2] | 4 |
| *3rd Quarter* | |
| Mechanical and Aerospace Engineering M20 (Intro to Computer Programming with MATLAB) or Computer Science 31 (Intro to Computer Science I)[2] | 4 |
| Mechanical and Aerospace Engineering 82—Mathematics of Engineering[2] | 4 |
| Mechanical and Aerospace Engineering 102—Dynamics of Particles and Rigid Bodies[2] | 4 |
| Mechanical and Aerospace Engineering 103—Elementary Fluid Mechanics[2] | 4 |
| **JUNIOR YEAR** | |
| *1st Quarter* | |
| Electrical and Computer Engineering 100—Electrical and Electronic Circuits[2] | 4 |
| Mechanical and Aerospace Engineering 105D—Transport Phenomena[2] | 4 |
| Mechanical and Aerospace Engineering 166A—Analysis of Aerospace Structures[2] | 4 |
| UCLA Samueli Ethics Course | 4 |
| *2nd Quarter* | |
| Mechanical and Aerospace Engineering 107—Introduction to Modeling and Analysis of Dynamic Systems[2] | 4 |
| Mechanical and Aerospace Engineering 150A—Intermediate Fluid Mechanics[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Mechanical and Aerospace Engineering 150B (Aerodynamics) or C150P (Aircraft Propulsion Systems)[2] | 4 |
| Mechanical and Aerospace Engineering C150R—Rocket Propulsion Systems[2] | 4 |
| Mechanical and Aerospace Engineering 171A—Introduction to Feedback and Control Systems[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **SENIOR YEAR** | |
| *1st Quarter* | |
| Aerospace Engineering Elective[2,4] | 4 |
| Mechanical and Aerospace Engineering 157—Basic Mechanical and Aerospace Engineering Laboratory[2] | 4 |
| Mechanical and Aerospace Engineering 161A—Introduction to Astronautics[2] | 4 |
| Technical Breadth Course[3] | 4 |
| *2nd Quarter* | |
| Mechanical and Aerospace Engineering 161B—Introduction to Space Technology[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 4 |
| *3rd Quarter* | |
| Mechanical and Aerospace Engineering 157A—Fluid Mechanics and Aerodynamics Laboratory[2] | 4 |
| Mechanical and Aerospace Engineering 161C—Spacecraft Design[2] | 4 |
| Technical Breadth Course[3] | 4 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 50.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 85.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. See page 110 for list of electives.

# B.S. in Bioengineering Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| *1st Quarter* | |
| Bioengineering 10—Introduction to Bioengineering[2] | 2 |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| *2nd Quarter* | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| *3rd Quarter* | |
| Chemistry and Biochemistry 30A—Organic Chemistry I: Structure and Reactivity[1] | 4 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| **SOPHOMORE YEAR** | |
| *1st Quarter* | |
| Bioengineering 100—Bioengineering Fundamentals[2] | 4 |
| Chemistry and Biochemistry 30B—Organic Chemistry II: Reactivity, Synthesis, and Spectroscopy[1] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| *2nd Quarter* | |
| Chemistry and Biochemistry 30AL—General Chemistry Laboratory II[1] | 4 |
| Life Sciences 7A—Cell and Molecular Biology[1] | 5 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Bioengineering 167L—Bioengineering Laboratory[2] | 4 |
| Computer Science 31 (Intro to Computer Science I) or Mechanical and Aerospace Engineering M20 (Intro to Computer Programming with MATLAB)[2] | 4 |
| Life Sciences 7C—Physiology and Human Biology[1] | 5 |
| Mathematics 33B—Differential Equations[1] | 4 |
| **JUNIOR YEAR** | |
| *1st Quarter* | |
| Electrical and Computer Engineering 100—Electrical and Electronic Circuits[2] | 4 |
| UCLA Samueli Ethics Course | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *2nd Quarter* | |
| Bioengineering 120—Biomedical Transducers[2] | 4 |
| Bioengineering Elective[2,4] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| Technical Breadth Course[3] | 4 |
| *3rd Quarter* | |
| Bioengineering 110—Biotransport and Bioreaction Processes[2] | 4 |
| Bioengineering 176—Principles of Biocompatibility[2] | 4 |
| Bioengineering Elective[2,4] | 4 |
| Technical Breadth Course[3] | 4 |
| **SENIOR YEAR** | |
| *1st Quarter* | |
| Bioengineering 177A—Bioengineering Capstone Design I[2] | 4 |
| Bioengineering Elective[2,4] | 4 |
| Restricted Elective[2,5] | 4 |
| Technical Breadth Course[3] | 4 |
| *2nd Quarter* | |
| Bioengineering 177B—Bioengineering Capstone Design II[2] | 4 |
| Bioengineering 180—System Integration in Biology, Engineering, and Medicine I[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Bioengineering Electives (2)[2,4] | 8 |
| Restricted Elective[2,5] | 4 |
| **TOTAL** | **185** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 74.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 70.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. Bioengineering electives include C101, CM102, CM103, C104, C105, C106, C131, CM140, CM145, C147, C155, C170, C171, CM178, C179, 180L, C183, C185, CM186, CM187, 199 (8 units maximum).
5. Restricted electives include Bioengineering C101, C106, C131, C155, M260 (a petition is required for M260).

# B.S. in Chemical Engineering

## Chemical Engineering Core Option Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| ***1st Quarter*** | |
| Chemical Engineering 10—Introduction to Chemical and Biomolecular Engineering[2] | 1 |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| ***2nd Quarter*** | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| ***3rd Quarter*** | |
| Chemistry and Biochemistry 30A—Organic Chemistry I: Structure and Reactivity[1] | 4 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| **SOPHOMORE YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 100—Fundamentals of Chemical and Biomolecular Engineering[2] | 4 |
| Chemistry and Biochemistry 30AL—General Chemistry Laboratory II[1] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| ***2nd Quarter*** | |
| Chemical Engineering 45—Biomolecular Engineering Fundamentals[2] | 4 |
| Chemical Engineering 102A—Thermodynamics I[2] | 4 |
| Chemistry and Biochemistry 30B—Organic Chemistry II: Reactivity, Synthesis, and Spectroscopy[1] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| ***3rd Quarter*** | |
| Chemical Engineering 102B—Thermodynamics II[2] | 4 |
| Civil and Environmental Engineering M20—Introduction to Computer Programming with MATLAB[2] | 4 |
| Mathematics 33B—Differential Equations[1] | 4 |
| UCLA Samueli Ethics Course | 4 |
| **JUNIOR YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 101A—Transport Phenomena I[2] | 4 |
| Chemical Engineering 109—Numerical and Mathematical Methods in Chemical and Biological Engineering[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***2nd Quarter*** | |
| Chemical Engineering 101B—Transport Phenomena II: Heat Transfer[2] | 4 |
| Chemical Engineering 104A—Chemical and Biomolecular Engineering Laboratory I[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Chemical Engineering 101C—Mass Transfer[2] | 4 |
| Chemical Engineering 103—Separation Processes[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **SENIOR YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 104B—Chemical and Biomolecular Engineering Laboratory II[2] | 6 |
| Chemical Engineering 106—Chemical Reaction Engineering[2] | 4 |
| Chemical Engineering Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| ***2nd Quarter*** | |
| Chemical Engineering 107—Process Dynamics and Control[2] | 4 |
| Chemical Engineering 108A—Process Economics and Analysis[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Chemical Engineering 108B—Chemical Process Computer-Aided Design and Analysis[2] | 4 |
| Chemical Engineering Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 64.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 75.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).

# B.S. in Chemical Engineering
## Biomedical Engineering Option Curriculum

| | UNITS |
|---|---|
| **FRESHMAN YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 10—Introduction to Chemical and Biomolecular Engineering[2] | 1 |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| ***2nd Quarter*** | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| ***3rd Quarter*** | |
| Chemistry and Biochemistry 30A—Organic Chemistry I: Structure and Reactivity[1] | 4 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| **SOPHOMORE YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 100—Fundamentals of Chemical and Biomolecular Engineering[2] | 4 |
| Chemistry and Biochemistry 30AL—General Chemistry Laboratory II[1] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| ***2nd Quarter*** | |
| Chemical Engineering 45—Biomolecular Engineering Fundamentals[2] | 4 |
| Chemical Engineering 102A—Thermodynamics I[2] | 4 |
| Chemistry and Biochemistry 30B—Organic Chemistry II: Reactivity, Synthesis, and Spectroscopy[1] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| ***3rd Quarter*** | |
| Chemical Engineering 102B—Thermodynamics II[2] | 4 |
| Civil and Environmental Engineering M20—Introduction to Computer Programming with MATLAB[2] | 4 |
| Mathematics 33B—Differential Equations[1] | 4 |
| UCLA Samueli Ethics Course | 4 |
| **JUNIOR YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 101A—Transport Phenomena I[2] | 4 |
| Chemical Engineering 109—Numerical and Mathematical Methods in Chemical and Biological Engineering[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***2nd Quarter*** | |
| Chemical Engineering 101B—Transport Phenomena II: Heat Transfer[2] | 4 |
| Chemical Engineering 104A—Chemical and Biomolecular Engineering Laboratory I[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Chemical Engineering 101C—Mass Transfer[2] | 4 |
| Chemical Engineering 103—Separation Processes[2] | 4 |
| Technical Breadth Course[3] | 4 |
| **SENIOR YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 104B—Chemical and Biomolecular Engineering Laboratory II[2] | 6 |
| Chemical Engineering 106—Chemical Reaction Engineering[2] | 4 |
| Chemical Engineering CM145—Molecular Biotechnology for Engineers[2] | 4 |
| Chemical Engineering Biomedical Elective[2] | 4 |
| ***2nd Quarter*** | |
| Chemical Engineering 107—Process Dynamics and Control[2] | 4 |
| Chemical Engineering 108A—Process Economics and Analysis[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Chemical Engineering 108B—Chemical Process Computer-Aided Design and Analysis[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 64.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 75.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).

# B.S. in Chemical Engineering
## Biomolecular Engineering Option Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| *1st Quarter* | |
| Chemical Engineering 10—Introduction to Chemical and Biomolecular Engineering[2] | 1 |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| *2nd Quarter* | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| *3rd Quarter* | |
| Chemistry and Biochemistry 30A—Organic Chemistry I: Structure and Reactivity[1] | 4 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| **SOPHOMORE YEAR** | |
| *1st Quarter* | |
| Chemical Engineering 100—Fundamentals of Chemical and Biomolecular Engineering[2] | 4 |
| Chemistry and Biochemistry 30AL—General Chemistry Laboratory II[1] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| *2nd Quarter* | |
| Chemical Engineering 45—Biomolecular Engineering Fundamentals[2] | 4 |
| Chemical Engineering 102A—Thermodynamics I[2] | 4 |
| Chemistry and Biochemistry 30B—Organic Chemistry II: Reactivity, Synthesis, and Spectroscopy[1] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| *3rd Quarter* | |
| Chemical Engineering 102B—Thermodynamics II[2] | 4 |
| Civil and Environmental Engineering M20—Introduction to Computer Programming with MATLAB[2] | 4 |
| Mathematics 33B—Differential Equations[1] | 4 |
| UCLA Samueli Ethics Course | 4 |
| **JUNIOR YEAR** | |
| *1st Quarter* | |
| Chemical Engineering 101A—Transport Phenomena I[2] | 4 |
| Chemical Engineering 109—Numerical and Mathematical Methods in Chemical and Biological Engineering[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *2nd Quarter* | |
| Chemical Engineering 101B—Transport Phenomena II: Heat Transfer[2] | 4 |
| Chemical Engineering 104A—Chemical and Biomolecular Engineering Laboratory I[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Chemical Engineering 101C—Mass Transfer[2] | 4 |
| Chemical Engineering C125—Bioseparations and Bioprocess Engineering[2] | 4 |
| Technical Breadth Course[3] | 4 |
| **SENIOR YEAR** | |
| *1st Quarter* | |
| Chemical Engineering 104D—Molecular Biotechnology Laboratory: From Gene to Product[2] | 6 |
| Chemical Engineering C115—Biochemical Reaction Engineering[2] | 4 |
| Chemical Engineering CM145—Molecular Biotechnology for Engineers[2] | 4 |
| Chemical Engineering Biomolecular Elective[2] | 4 |
| *2nd Quarter* | |
| Chemical Engineering 107—Process Dynamics and Control[2] | 4 |
| Chemical Engineering 108A—Process Economics and Analysis[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Chemical Engineering 108B—Chemical Process Computer-Aided Design and Analysis[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 64.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 75.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).

# B.S. in Chemical Engineering
## Environmental Engineering Option Curriculum

| | |
|---|---|
| **FRESHMAN YEAR** | **UNITS** |
| *1st Quarter* | |
| Chemical Engineering 10—Introduction to Chemical and Biomolecular Engineering[2] | 1 |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| *2nd Quarter* | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| *3rd Quarter* | |
| Chemistry and Biochemistry 30A—Organic Chemistry I: Structure and Reactivity[1] | 4 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| **SOPHOMORE YEAR** | |
| *1st Quarter* | |
| Chemical Engineering 100—Fundamentals of Chemical and Biomolecular Engineering[2] | 4 |
| Chemistry and Biochemistry 30AL—General Chemistry Laboratory II[1] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| *2nd Quarter* | |
| Chemical Engineering 45—Biomolecular Engineering Fundamentals[2] | 4 |
| Chemical Engineering 102A—Thermodynamics I[2] | 4 |
| Chemistry and Biochemistry 30B—Organic Chemistry II: Reactivity, Synthesis, and Spectroscopy[1] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| *3rd Quarter* | |
| Chemical Engineering 102B—Thermodynamics II[2] | 4 |
| Civil and Environmental Engineering M20—Introduction to Computer Programming with MATLAB[2] | 4 |
| Mathematics 33B—Differential Equations[1] | 4 |
| UCLA Samueli Ethics Course | 4 |
| **JUNIOR YEAR** | |
| *1st Quarter* | |
| Chemical Engineering 101A—Transport Phenomena I[2] | 4 |
| Chemical Engineering 109—Numerical and Mathematical Methods in Chemical and Biological Engineering[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *2nd Quarter* | |
| Chemical Engineering 101B—Transport Phenomena II: Heat Transfer[2] | 4 |
| Chemical Engineering 104A—Chemical and Biomolecular Engineering Laboratory I[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Chemical Engineering 101C—Mass Transfer[2] | 4 |
| Chemical Engineering 103—Separation Processes[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **SENIOR YEAR** | |
| *1st Quarter* | |
| Chemical Engineering 104B—Chemical and Biomolecular Engineering Laboratory II[2] | 6 |
| Chemical Engineering 106—Chemical Reaction Engineering[2] | 4 |
| Chemical Engineering Environmental Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| *2nd Quarter* | |
| Chemical Engineering 107—Process Dynamics and Control[2] | 4 |
| Chemical Engineering 108A—Process Economics and Analysis[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Chemical Engineering 108B—Chemical Process Computer-Aided Design and Analysis[2] | 4 |
| Chemical Engineering Environmental Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 64.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 75.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).

# B.S. in Chemical Engineering
## Semiconductor Manufacturing Engineering Option Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| ***1st Quarter*** | |
| Chemical Engineering 10—Introduction to Chemical and Biomolecular Engineering[2] | 1 |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| ***2nd Quarter*** | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| ***3rd Quarter*** | |
| Chemistry and Biochemistry 30A—Organic Chemistry I: Structure and Reactivity[1] | 4 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| **SOPHOMORE YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 100—Fundamentals of Chemical and Biomolecular Engineering[2] | 4 |
| Chemistry and Biochemistry 30AL—General Chemistry Laboratory II[1] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| ***2nd Quarter*** | |
| Chemical Engineering 45—Biomolecular Engineering Fundamentals[2] | 4 |
| Chemical Engineering 102A—Thermodynamics I[2] | 4 |
| Chemistry and Biochemistry 30B—Organic Chemistry II: Reactivity, Synthesis, and Spectroscopy[1] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| ***3rd Quarter*** | |
| Chemical Engineering 102B—Thermodynamics II[2] | 4 |
| Civil and Environmental Engineering M20—Introduction to Computer Programming with MATLAB[2] | 4 |
| Mathematics 33B—Differential Equations[1] | 4 |
| UCLA Samueli Ethics Course | 4 |
| **JUNIOR YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 101A—Transport Phenomena I[2] | 4 |
| Chemical Engineering 109—Numerical and Mathematical Methods in Chemical and Biological Engineering[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***2nd Quarter*** | |
| Chemical Engineering 101B—Transport Phenomena II: Heat Transfer[2] | 4 |
| Chemical Engineering 104A—Chemical and Biomolecular Engineering Laboratory I[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Chemical Engineering 101C—Mass Transfer[2] | 4 |
| Chemical Engineering 103—Separation Processes[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **SENIOR YEAR** | |
| ***1st Quarter*** | |
| Chemical Engineering 106—Chemical Reaction Engineering[2] | 4 |
| Chemical Engineering or Materials Science and Engineering Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| ***2nd Quarter*** | |
| Chemical Engineering 107—Process Dynamics and Control[2] | 4 |
| Chemical Engineering 108A—Process Economics and Analysis[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| Technical Breadth Course[3] | 4 |
| ***3rd Quarter*** | |
| Chemical Engineering 104C/104CL—Semiconductor Processing/Laboratory[2] | 6 |
| Chemical Engineering 108B—Chemical Process Computer-Aided Design and Analysis[2] | 4 |
| Chemical Engineering C116—Surface and Interface Engineering[2] | 4 |
| Technical Breadth Course[3] | 4 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 64.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 75.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).

# B.S. in Civil Engineering Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| ***1st Quarter*** | |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| Civil and Environmental Engineering 1—Civil Engineering and Infrastructure[2] | 2 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| ***2nd Quarter*** | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| ***3rd Quarter*** | |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| UCLA Samueli GE Elective[3] | 5 |
| **SOPHOMORE YEAR** | |
| ***1st Quarter*** | |
| Civil and Environmental Engineering 91—Statics[2] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| UCLA Samueli Ethics Course | 4 |
| ***2nd Quarter*** | |
| Civil and Environmental Engineering 102—Dynamics of Particles and Bodies[2] | 2 |
| Civil and Environmental Engineering C104 (Structure, Processing, and Properties of Civil Engineering Materials) or Materials Science and Engineering 104 (Science of Engineering Materials)[2] | 4 |
| Civil and Environmental Engineering 108—Introduction to Mechanics of Deformable Solids[2] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| ***3rd Quarter*** | |
| Civil and Environmental Engineering M20 (Introduction to Computer Programming with MATLAB) or Computer Science 31 (Introduction to Computer Science I)[2] | 4 |
| Mathematics 33B (Differential Equations) or Mechanical and Aerospace Engineering 82 (Mathematics of Engineering)[1] | 4 |
| Mechanical and Aerospace Engineering 103—Elementary Fluid Mechanics[2] | 4 |
| **JUNIOR YEAR** | |
| ***1st Quarter*** | |
| Civil and Environmental Engineering 120—Principles of Soil Mechanics[2] | 4 |
| Civil and Environmental Engineering 135A—Elementary Structural Analysis[2] | 4 |
| Civil and Environmental Engineering 150—Introduction to Hydrology[2] | 4 |
| Civil and Environmental Engineering 153—Introduction to Environmental Engineering Science[2] | 4 |
| ***2nd Quarter*** | |
| Chemical Engineering 102A (Thermodynamics I) or Mechanical and Aerospace Engineering 105A (Introduction to Engineering Thermodynamics)[2] | 4 |
| Major Field Elective[2,4] | 4 |
| Natural Science Course[1] | 4 |
| ***3rd Quarter*** | |
| Civil and Environmental Engineering 103—Applied Numerical Computing and Modeling in Civil and Environmental Engineering[2] | 4 |
| Civil and Environmental Engineering 110—Introduction to Probability and Statistics for Engineers[2] | 4 |
| Major Field Electives (2)[2,4] | 8 |
| **SENIOR YEAR** | |
| ***1st Quarter*** | |
| Major Field Electives (2)[2,4] | 8 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***2nd Quarter*** | |
| Major Field Electives (2)[2,4] | 8 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Major Field Elective[2,4] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **TOTAL** | **181** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 56.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 84.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. Must include required courses for two of the major field areas listed on page 51.

# B.S. in Computer Engineering Curriculum

## FRESHMAN YEAR

| Course | UNITS |
|---|---|
| ***1st Quarter*** | |
| Computer Science 1 (Freshman Computer Science Seminar) or Electrical and Computer Engineering 1 (Undergraduate Seminar)[2] | 1 |
| Computer Science 31—Introduction to Computer Science I[2] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| ***2nd Quarter*** | |
| Computer Science 32—Introduction to Computer Science II[2] | 4 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Computer Science 33—Introduction to Computer Organization[2] | 5 |
| Engineering 96C—Introduction to Engineering Design: Internet of Things[2] | 2 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B—Oscillations, Waves, Electric and Magnetic Fields[1] | 5 |

## SOPHOMORE YEAR

| Course | UNITS |
|---|---|
| ***1st Quarter*** | |
| Electrical and Computer Engineering 3—Introduction to Electrical Engineering[2] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| Physics 4AL (Mechanics Laboratory) or 4BL (Electricity and Magnetism Laboratory)[1] | 2 |
| ***2nd Quarter*** | |
| Computer Science 35L—Software Construction Laboratory[2] | 3 |
| Computer Science M51A or Electrical and Computer Engineering M16—Logic Design of Digital Systems[2] | 4 |
| Electrical and Computer Engineering 100—Electrical and Electronic Circuits[2] | 4 |
| Mathematics 33B—Differential Equations[1] | 4 |
| ***3rd Quarter*** | |
| Electrical and Computer Engineering 102—Systems and Signals[2] | 4 |
| Mathematics 61—Introduction to Discrete Structures[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |

## JUNIOR YEAR

| Course | UNITS |
|---|---|
| ***1st Quarter*** | |
| Computer Science 111—Operating Systems Principles[2] | 5 |
| Probability Elective[1, 4] | 4 |
| UCLA Samueli Ethics Course | 4 |
| ***2nd Quarter*** | |
| Computer Science 118 (Computer Network Fundamentals) or Electrical and Computer Engineering 132B (Data Communications and Telecommunication Networks)[2] | 4 |
| Computer Science M152A or Electrical and Computer Engineering M116L—Introductory Digital Design Laboratory[2] | 2 |
| Computer Science 180—Introduction to Algorithms and Complexity[2] | 4 |
| Electrical and Computer Engineering 115C—Digital Electronic Circuits[2] | 4 |
| ***3rd Quarter*** | |
| Computer Science M151B or Electrical and Computer Engineering M116C—Computer Systems Architecture[2] | 4 |
| Computer Science Elective[2,4] | 4 |
| Electrical and Computer Engineering Elective[2,4] | 4 |
| UCLA Samueli GE Elective[3] | 4 |

## SENIOR YEAR

| Course | UNITS |
|---|---|
| ***1st Quarter*** | |
| Electrical and Computer Engineering 113[2] | 4 |
| Electrical and Computer Engineering Elective[2,4] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***2nd Quarter*** | |
| Computer Science Elective[2,4] | 4 |
| Electrical and Computer Engineering Design Course[2,4] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Electrical and Computer Engineering Design Course[2,4] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 49.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 86.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. See page 65 or 86 for list of electives.

# B.S. in Computer Science Curriculum

| FRESHMAN YEAR | UNITS |
| --- | --- |
| ***1st Quarter*** | |
| Computer Science 1—Freshman Computer Science Seminar[2] | 1 |
| Computer Science 31—Introduction to Computer Science I[2] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| ***2nd Quarter*** | |
| Computer Science 32—Introduction to Computer Science II[2] | 4 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| ***3rd Quarter*** | |
| Computer Science 33—Introduction to Computer Organization[2] | 5 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B—Oscillations, Waves, Electric and Magnetic Fields[1] | 5 |
| **SOPHOMORE YEAR** | |
| ***1st Quarter*** | |
| Computer Science 35L—Software Construction Laboratory[2] | 3 |
| Computer Science M51A or Electrical and Computer Engineering M16—Logic Design of Digital Systems[2] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| UCLA Samueli Ethics Course | 4 |
| ***2nd Quarter*** | |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| Mathematics 61—Introduction to Discrete Structures[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| Physics 4AL (Mechanics Laboratory) or 4BL (Electricity and Magnetism Laboratory)[1] | 2 |
| ***3rd Quarter*** | |
| Computer Science 111—Operating Systems Principles[2] | 5 |
| Computer Science M152A or Electrical and Computer Engineering M116L—Introductory Digital Design Laboratory[2] | 2 |
| Mathematics 33B—Differential Equations[1] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **JUNIOR YEAR** | |
| ***1st Quarter*** | |
| Computer Science 118—Computer Network Fundamentals[2] | 4 |
| Computer Science 180—Introduction to Algorithms and Complexity[2] | 4 |
| Science and Technology Elective[2] | 4 |
| UCLA Samueli GE Elective[3] | 4 |
| ***2nd Quarter*** | |
| Computer Science 131—Programming Languages[2] | 4 |
| Computer Science M151B or Electrical and Computer Engineering M116C—Computer Systems Architecture[2] | 4 |
| Probability Elective[1, 4] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Computer Science 181—Introduction to Formal Languages and Automata Theory[2] | 4 |
| Computer Science Elective[2,4] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **SENIOR YEAR** | |
| ***1st Quarter*** | |
| Computer Science 130 (Software Engineering) or 152B (Digital Design Project Laboratory)[2] | 4 |
| Computer Science Elective[2,4] | 4 |
| Science and Technology Elective[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***2nd Quarter*** | |
| Computer Science Electives (2)[2,4] | 8 |
| Technical Breadth Course[3] | 4 |
| ***3rd Quarter*** | |
| Computer Science Elective[2,4] | 4 |
| Science and Technology Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| Additional coursework to meet 180 unit requirement[5] | 2 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 49.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 83.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. See page 65 for list of electives.
5. Any excess or available units not already applied to another degree requirement will satisfy these units.

# B.S. in Computer Science and Engineering Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| *1st Quarter* | |
| Computer Science 1—Freshman Computer Science Seminar[2] | 1 |
| Computer Science 31—Introduction to Computer Science I[2] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| *2nd Quarter* | |
| Computer Science 32—Introduction to Computer Science II[2] | 4 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| *3rd Quarter* | |
| Computer Science 33—Introduction to Computer Organization[2] | 5 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B—Oscillations, Waves, Electric and Magnetic Fields[1] | 5 |
| **SOPHOMORE YEAR** | |
| *1st Quarter* | |
| Computer Science 35L—Software Construction Laboratory[2] | 3 |
| Computer Science M51A or Electrical and Computer Engineering M16—Logic Design of Digital Systems[2] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| *2nd Quarter* | |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| Mathematics 61—Introduction to Discrete Structures[1] | 4 |
| Physics 4AL (Mechanics Laboratory) or 4BL (Electricity and Magnetism Laboratory)[1] | 2 |
| UCLA Samueli Ethics Course | 4 |
| *3rd Quarter* | |
| Computer Science 180—Introduction to Algorithms and Complexity[2] | 4 |
| Electrical and Computer Engineering 3—Introduction to Electrical Engineering[2] | 4 |
| Mathematics 33B—Differential Equations[1] | 4 |
| Probability Elective[1, 4] | 4 |
| **JUNIOR YEAR** | |
| *1st Quarter* | |
| Computer Science 111—Operating Systems Principles[2] | 5 |
| Electrical and Computer Engineering 100—Electrical and Electronic Circuits[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *2nd Quarter* | |
| Computer Science 131—Programming Languages[2] | 4 |
| Computer Science M152A or Electrical and Computer Engineering M116L—Introductory Digital Design Laboratory[2] | 2 |
| Electrical and Computer Engineering 102—Systems and Signals[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Computer Science 118—Computer Network Fundamentals[2] | 4 |
| Computer Science M151B or Electrical and Computer Engineering M116C—Computer Systems Architecture[2] | 4 |
| Electrical and Computer Engineering 115C—Digital Electronic Circuits[2] | 4 |
| Technical Breadth Course[3] | 4 |
| **SENIOR YEAR** | |
| *1st Quarter* | |
| Computer Science 152B—Digital Design Project Laboratory[2] | 4 |
| Computer Science 181—Introduction to Formal Languages and Automata Theory[2] | 4 |
| Computer Science Elective[2,4] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *2nd Quarter* | |
| Computer Science Elective[2,4] | 4 |
| Electrical and Computer Engineering Elective[2,4] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Computer Science Elective[2,4] | 4 |
| UCLA Samueli GE Elective[3] | 4 |
| Technical Breadth Course[3] | 4 |
| Additional coursework to meet 180 unit requirement[5] | 2 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 49.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 84.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. See page 64 for list of electives.
5. Any excess or available units not already applied to another degree requirement will satisfy this unit.

# B.S. in Electrical Engineering Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| *1st Quarter* | |
| Computer Science 31—Introduction to Computer Science I[2] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| *2nd Quarter* | |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| Computer Science 32—Introduction to Computer Science II[2] | 4 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| *3rd Quarter* | |
| Electrical and Computer Engineering M16 (or Computer Science M51A)—Logic Design of Digital Systems[2] | 4 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| **SOPHOMORE YEAR** | |
| *1st Quarter* | |
| Electrical and Computer Engineering 3—Introduction to Electrical Engineering[2] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| *2nd Quarter* | |
| Electrical and Computer Engineering 10 (Circuit Theory I) and 11L (Circuits Laboratory I)[2] | 5 |
| Electrical and Computer Engineering 102—Systems and Signals[2] | 4 |
| Mathematics 33B—Differential Equations[1] | 4 |
| Physics 4BL—Electricity and Magnetism Laboratory[1] | 2 |
| *3rd Quarter* | |
| Electrical and Computer Engineering 2—Physics for Electrical Engineers[2] | 4 |
| Electrical and Computer Engineering 110 (Circuit Theory II) and 111L (Circuits Laboratory II)[2] | 5 |
| UCLA Samueli Ethics Course | 4 |
| UCLA Samueli GE Elective[3] | 4 |
| **JUNIOR YEAR** | |
| *1st Quarter* | |
| Electrical and Computer Engineering 113—Digital Signal Processing[2] | 4 |
| Electrical and Computer Engineering 131A—Probability and Statistics[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *2nd Quarter* | |
| Electrical and Computer Engineering 101A—Engineering Electromagnetics[2] | 4 |
| Electrical and Computer Engineering Core Course[2,4] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Electrical and Computer Engineering Core Course[2,4] | 4 |
| Electrical and Computer Engineering Core Course[2,4] | 4 |
| Electrical and Computer Engineering Core Course[2,4] | 4 |
| Electrical and Computer Engineering Core Course or Computer Science 33 (Introduction to Computer Organization)[2,4] | 4 |
| **SENIOR YEAR** | |
| *1st Quarter* | |
| Electrical and Computer Engineering Core Course[2,4] | 4 |
| Electrical and Computer Engineering Design Course[2] | 4 |
| Electrical and Computer Engineering Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| *2nd Quarter* | |
| Electrical and Computer Engineering Design Course[2] | 4 |
| Electrical and Computer Engineering Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Electrical and Computer Engineering or UCLA Samueli Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **TOTAL** | **182** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 47.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 90.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. See page 84 for list of core courses.

# B.S. in Materials Engineering Curriculum

## Materials Engineering Option Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| ***1st Quarter*** | |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Materials Science and Engineering 10—Freshman Seminar: New Materials[2] | 1 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| ***2nd Quarter*** | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| ***3rd Quarter*** | |
| Materials Science and Engineering 104—Science of Engineering Materials[2] | 4 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B—Oscillations, Waves, Electric and Magnetic Fields[1] | 5 |
| **SOPHOMORE YEAR** | |
| ***1st Quarter*** | |
| Materials Science and Engineering 110/110L—Introduction to Materials Characterization A/Laboratory[2] | 6 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| ***2nd Quarter*** | |
| Materials Science and Engineering 90L—Physical Measurement in Materials Engineering[2] | 2 |
| Materials Science and Engineering 150—Introduction to Polymers[2] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Civil and Environmental Engineering M20 (Intro to Computer Programming with MATLAB) or Computer Science 31 (Intro to Computer Science I)[2] | 4 |
| Electrical and Computer Engineering 100—Electrical and Electronic Circuits[2] | 4 |
| Mathematics 33B (Differential Equations) or Mechanical and Aerospace Engineering 82 (Mathematics of Engineering)[1] | 4 |
| Technical Breadth Course[3] | 4 |
| **JUNIOR YEAR** | |
| ***1st Quarter*** | |
| Materials Engineering Laboratory Course[2] | 2 |
| Materials Science and Engineering 130—Phase Relations in Solids[2] | 4 |
| Mechanical and Aerospace Engineering 101—Statics and Strength of Materials[2] | 4 |
| Technical Breadth Course[3] | 4 |
| ***2nd Quarter*** | |
| Materials Science and Engineering 131/131L—Diffusion and Diffusion-Controlled Reactions/Laboratory[2] | 6 |
| Materials Science and Engineering 143A—Mechanical Behavior of Materials[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Civil and Environmental Engineering 108—Introduction to Mechanics of Deformable Solids[2] | 4 |
| Materials Science and Engineering 132—Structures and Properties of Metallic Alloys[2] | 4 |
| Materials Engineering Laboratory Course[2] | 2 |
| UCLA Samueli GE Elective[3] | 5 |
| **SENIOR YEAR** | |
| ***1st Quarter*** | |
| Materials Engineering Elective[2,4] | 4 |
| Materials Science and Engineering 160—Introduction to Ceramics and Glasses[2] | 4 |
| UCLA Samueli Ethics Course | 4 |
| Upper-Division Mathematics Course[1,5] | 4 |
| ***2nd Quarter*** | |
| Materials Engineering Elective[2,4] | 4 |
| Materials Science and Engineering 120—Physics of Materials[2] | 4 |
| Materials Science and Engineering 140A—Materials Selection and Engineering Design A[2] | 3 |
| UCLA Samueli GE Elective[3] | 5 |
| ***3rd Quarter*** | |
| Materials Science and Engineering 140B—Materials Selection and Engineering Design B[2] | 3 |
| Materials Engineering Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 4 |
| **TOTAL** | **180** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 54.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 81.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. See counselor in 6426 Boelter Hall for details.
5. See page 103 for list of approved mathematics courses.

# B.S. in Materials Engineering
## Electronic Materials Option Curriculum

| FRESHMAN YEAR | UNITS |
|---|---|
| *1st Quarter* | |
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Materials Science and Engineering 10—Freshman Seminar: New Materials[2] | 1 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |
| *2nd Quarter* | |
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |
| *3rd Quarter* | |
| Materials Science and Engineering 104—Science of Engineering Materials[2] | 4 |
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B—Oscillations, Waves, Electric and Magnetic Fields[1] | 5 |
| UCLA Samueli GE Elective[3] | 5 |
| **SOPHOMORE YEAR** | |
| *1st Quarter* | |
| Materials Science and Engineering 110/110L—Introduction to Materials Characterization A/Laboratory[2] | 6 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C—Electrodynamics, Optics, and Special Relativity[1] | 5 |
| *2nd Quarter* | |
| Electrical and Computer Engineering 101A—Engineering Electromagnetics[2] | 4 |
| Materials Science and Engineering 90L—Physical Measurement in Materials Engineering[2] | 2 |
| Materials Science and Engineering 122—Principles of Electronic Materials Processing[2] | 4 |
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| *3rd Quarter* | |
| Civil and Environmental Engineering M20 (Intro to Computer Programming with MATLAB) or Computer Science 31 (Intro to Computer Science I)[2] | 4 |
| Electrical and Computer Engineering 100—Electrical and Electronic Circuits[2] | 4 |
| Mathematics 33B (Differential Equations) or Mechanical and Aerospace Engineering 82 (Mathematics of Engineering)[1] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| **JUNIOR YEAR** | |
| *1st Quarter* | |
| Electronic Materials Laboratory Course[2] | 2 |
| Materials Science and Engineering 130—Phase Relations in Solids[2] | 4 |
| Mechanical and Aerospace Engineering 101—Statics and Strength of Materials[2] | 4 |
| Technical Breadth Course[3] | 4 |
| *2nd Quarter* | |
| Materials Science and Engineering 120 (Physics of Materials)[2] | 4 |
| Materials Science and Engineering 131/131L—Diffusion and Diffusion-Controlled Reactions/Laboratory[2] | 6 |
| UCLA Samueli GE Elective[3] | 5 |
| *3rd Quarter* | |
| Materials Science and Engineering 121/121L—Materials Science of Semiconductors/Laboratory[2] | 6 |
| Materials Science and Engineering 132—Structures and Properties of Metallic Alloys[2] | 4 |
| Electronic Materials Elective[2] | 4 |
| **SENIOR YEAR** | |
| *1st Quarter* | |
| Electrical and Computer Engineering 121B—Principles of Semiconductor Device Design[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |
| Upper-Division Mathematics Course[1,5] | 4 |
| *2nd Quarter* | |
| Electronic Materials Elective (Materials Science and Engineering 150—Introduction to Polymers or 160—Introduction to Ceramics and Glasses)[2,4] | 4 |
| Materials Science and Engineering 140A—Materials Selection and Engineering Design A[2] | 3 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli Ethics Course | 4 |
| *3rd Quarter* | |
| Electronic Materials Elective[2,4] | 4 |
| Electronic Materials Laboratory Course[2,4] | 2 |
| Materials Science and Engineering 140B—Materials Selection and Engineering Design B[2] | 3 |
| UCLA Samueli GE Elective[3] | 4 |
| **TOTAL** | **182** |

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 54.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 83.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).
4. See counselor in 6426 Boelter Hall for details.
5. See page 103 for list of approved mathematics courses.

# B.S. in Mechanical Engineering Curriculum

## FRESHMAN YEAR

*1st Quarter*

| Course | UNITS |
|---|---|
| Chemistry and Biochemistry 20A—Chemical Structure[1] | 4 |
| English Composition 3—English Composition, Rhetoric, and Language | 5 |
| Mathematics 31A—Differential and Integral Calculus[1] | 4 |

*2nd Quarter*

| Course | UNITS |
|---|---|
| Chemistry and Biochemistry 20B/20L—Chemical Energetics and Change/General Chemistry Laboratory[1] | 7 |
| Mathematics 31B—Integration and Infinite Series[1] | 4 |
| Physics 1A—Mechanics[1] | 5 |

*3rd Quarter*

| Course | UNITS |
|---|---|
| Mathematics 32A—Calculus of Several Variables[1] | 4 |
| Physics 1B/4AL—Oscillations, Waves, Electric and Magnetic Fields/Mechanics Laboratory[1] | 7 |
| UCLA Samueli GE Elective[3] | 5 |

## SOPHOMORE YEAR

*1st Quarter*

| Course | UNITS |
|---|---|
| Materials Science and Engineering 104—Science of Engineering Materials[2] | 4 |
| Mathematics 32B—Calculus of Several Variables[1] | 4 |
| Physics 1C/4BL—Electrodynamics, Optics, and Special Relativity/Electricity and Magnetism Laboratory[1] | 7 |

*2nd Quarter*

| Course | UNITS |
|---|---|
| Mathematics 33A—Linear Algebra and Applications[1] | 4 |
| Mechanical and Aerospace Engineering 94—Introduction to Computer-Aided Design and Drafting[2] | 4 |
| Mechanical and Aerospace Engineering 101—Statics and Strength of Materials[2] | 4 |
| Mechanical and Aerospace Engineering 105A—Introduction to Engineering Thermodynamics[2] | 4 |

*3rd Quarter*

| Course | UNITS |
|---|---|
| Mechanical and Aerospace Engineering M20 (Intro to Computer Programming with MATLAB) or Computer Science 31 (Intro to Computer Science I)[2] | 4 |
| Mechanical and Aerospace Engineering 82—Mathematics of Engineering[2] | 4 |
| Mechanical and Aerospace Engineering 102—Dynamics of Particles and Rigid Bodies[2] | 4 |
| Mechanical and Aerospace Engineering 103—Elementary Fluid Mechanics[2] | 4 |

## JUNIOR YEAR

*1st Quarter*

| Course | UNITS |
|---|---|
| Electrical and Computer Engineering 100—Electrical and Electronic Circuits[2] | 4 |
| Mechanical and Aerospace Engineering 156A—Advanced Strength of Materials[2] | 4 |
| Mechanical and Aerospace Engineering 183A (Intro to Manufacturing Processes) or M183B (Intro to Microscale and Nanoscale Manufacturing)[2] | 4 |
| UCLA Samueli Ethics Course | 4 |

*2nd Quarter*

| Course | UNITS |
|---|---|
| Mechanical and Aerospace Engineering 105D—Transport Phenomena[2] | 4 |
| Mechanical and Aerospace Engineering 107—Introduction to Modeling and Analysis of Dynamic Systems[2] | 4 |
| UCLA Samueli GE Elective[3] | 4 |

*3rd Quarter*

| Course | UNITS |
|---|---|
| Mechanical and Aerospace Engineering 131A (Intermediate Heat Transfer) or 133A (Engineering Thermodynamics)[2] | 4 |
| Mechanical and Aerospace Engineering 157—Basic Mechanical and Aerospace Engineering Laboratory[2] | 4 |
| Mechanical and Aerospace Engineering 162A—Introduction to Mechanisms and Mechanical Systems[2] | 4 |
| Technical Breadth Course[3] | 4 |

## SENIOR YEAR

*1st Quarter*

| Course | UNITS |
|---|---|
| Electrical and Computer Engineering 110L—Circuit Measurements Laboratory[2] | 2 |
| Mechanical and Aerospace Engineering 171A—Introduction to Feedback and Control Systems[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |

*2nd Quarter*

| Course | UNITS |
|---|---|
| Mechanical and Aerospace Engineering 162D—Mechanical Engineering Design I[2] | 4 |
| Mechanical Engineering Elective[2] | 4 |
| Technical Breadth Course[3] | 4 |
| UCLA Samueli GE Elective[3] | 5 |

*3rd Quarter*

| Course | UNITS |
|---|---|
| Mechanical and Aerospace Engineering 162E—Mechanical Engineering Design II[2] | 4 |
| Mechanical Engineering Elective[2] | 4 |
| UCLA Samueli GE Elective[3] | 5 |

**TOTAL ... 181**

1. Counts as Mathematics and Basic Sciences for ABET, total units Mathematics and Basic Sciences = 50.
2. Counts as Engineering Concepts for ABET, total units Engineering Concepts = 86.
3. Students should contact the Office of Academic and Student Affairs for approved lists in the categories of technical breadth and GE (see page 23 for details).

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