DEPARTMENT OF ELECTRICAL, COMPUTER, AND SYSTEMS ENGINEERING

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http://engineering.case.edu/eecs/
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Pedram Mohseni (pedram.mohseni@case.edu), Professor and Interim Chair of Electrical, Computer, and Systems Engineering (ECSE)

Effective as of June 1, 2019, the Electrical Engineering and Computer Science Department in the Case School of Engineering has been renamed to be the Department of Electrical, Computer, and Systems Engineering (ECSE).

The ECSE Department spans a spectrum of topics from (i) materials, devices, circuits, and processors through (ii) control, signal processing, and systems analysis to (iii) human-machine interfaces, computation, computer systems, embedded systems and networking. The ECSE Department at Case Western Reserve supports three synergistic degree programs: Electrical Engineering, Computer Engineering, and Systems & Control Engineering. Each degree program leads to the Bachelor of Science degree at the undergraduate level. At the graduate level, the department offers the Master of Science and Doctor of Philosophy degrees in Electrical Engineering, Computer Engineering, and Systems & Control Engineering. We offer minors in Electrical Engineering, Computer Engineering, Systems & Control Engineering, and also in Computer Gaming, Artificial Intelligence (AI), and Electronics. For supplemental information to this bulletin as well as the latest updates, please visit the ECSE Department web site at http://ecse.case.edu.

ECSE is at the heart of modern technology. ECSE disciplines are responsible for the devices and microprocessors powering our computers and embedded into everyday devices, from cell phones and tablets to automobiles and airplanes. Healthcare is increasingly building on ECSE technologies: micro/nano-systems, electronics/instrumentation, implantable systems, embedded microprocessors, wireless medical devices, surgical robots, imaging, system biology, and visualization. The future of energy will be profoundly impacted by ECSE technologies, from smart appliances connected to the Internet, smart buildings that incorporate distributed sensing and control, to the envisioned smart grid that must be controlled, stabilized, and kept secure over an immense network. ECSE drives job creation and starting salaries in our fields.

Research
The research thrusts of the Electrical, Computer, and Systems Engineering department include:

1. Micro/Nano Systems
2. Electronics and Instrumentation
3. Robotics and Human-Machine Interfaces
4. Embedded Systems, including VLSI and FPGA design
6. Systems Biology
7. Machine Learning and Data Mining
8. Computer Networks and Distributed Systems
9. Energy Systems, including Wind and Power Grid Management/Control
10. Gaming, Simulation, Optimization
11. Medical Informatics and Wireless Health

ECSE participates in a number of groundbreaking collaborative research and educational programs, including the Microelectromechanical Systems Research Program, the Center for Computational Genomics, graduate program in Systems Biology and Bioinformatics, the Clinical & Translational Science Collaborative, the Great Lakes Energy Institute, and the VA Center for Advanced Platform Technology.

Faculty
Marc Buchner, PhD
(Michigan State University)
Associate Professor
Computer gaming and simulation, virtual reality, software-defined radio, wavelets, joint time-frequency analysis

M. Cenk Cavusoglu, PhD
(University of California, Berkeley)
Nord Professor of Engineering
Robotics, systems and control theory, and human-machine interfaces; with emphasis on medical robotics, haptics, virtual environments, surgical simulation, and bio-system modeling and simulation

Educational Philosophy
The ECSE department is dedicated to developing high-quality graduates who will take positions of leadership as their careers advance. We recognize that the increasing role of technology in virtually every facet of our society, life, and culture makes it vital that our students have access to progressive and cutting-edge higher education programs. The core values for all of the degree programs in the department are:

- mastery of fundamentals
- creativity
- social awareness
- leadership skills
- professionalism

Stressing excellence in these core values helps to ensure that our graduates are valued and contributing members of our global society and that they will carry on the tradition of engineering leadership established by our alumni.

Our goal is to graduate students who have fundamental technical knowledge of their profession and the requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies which will advance their fields. To achieve this goal, the department offers a wide range of technical specialties consistent with the breadth of electrical engineering, computer engineering, and systems engineering, including recent developments in the fields. Because of the rapid pace of advancement in these fields, our degree programs emphasize a broad and foundational science and technology background that equips students for future developments. Our programs include a wide range of electives and our students are encouraged to develop individualized programs which can combine many aspects of electrical engineering, Computer engineering, and systems engineering.
Vira Chankong, PhD  
(Case Western Reserve University)  
Associate Professor  
Large-scale optimization, logic-based optimization; multi-objective optimization; optimization applications in radiation therapy treatment planning, medical imaging, manufacturing and production systems, and engineering design problems

Michael Fu, PhD  
(Case Western Reserve University)  
Assistant Professor  
Neuro-rehabilitation and motor-relearning, with emphasis on virtual environments, neuromuscular electrical stimulation, and haptic interfaces

Mario Garcia-Sanz, DrEng  
(University of Navarra, Spain)  
Professor  
Robust and nonlinear control, quantitative feedback theory, multivariable control, dynamic systems, systems modeling and identification; energy innovation, wind energy, spacecraft, electrical, mechanical, environmental and industrial applications

Evren Gurkan-Cavusoglu, PhD  
(Middle East Technical University)  
Associate Professor  
Systems and control theory, systems biology, computational biology, systems model building, signal processing applied to biological systems, signal processing

Ming-Chun Huang, PhD  
(University of California, Los Angeles)  
Associate Professor  
Mobile health (mHealth) technology and application, Internet of wearable things (IoWT), interactive rehabilitation, GPU architecture and acceleration for scientific computing, distributed deep-learning optimization system (DDOS)

Hossein Miri Lavasani, PhD  
(The Georgia Institute of Technology)  
Assistant Professor  
High performance integrated circuits and systems, Low power interface circuits for MEMS and sensors

Gregory S. Lee, PhD  
(University of Washington)  
Assistant Professor  
Haptic devices, including low-power design and effects on perception; applications to robotic surgery and telesurgery; secure teleoperation

Pan Li, PhD  
(University of Florida)  
Associate Professor  
Networks, Cybersecurity, Big data, Cyber-physical systems, Bioinformatics

Wei Lin, PhD  
(Washington University in St. Louis)  
Professor  
Nonlinear control, dynamic systems and homogeneous systems theory, H-infinity and robust control, adaptive control, system parameter estimation and fault detection, nonlinear control applications to under-actuated mechanical systems, biologically-inspired systems and systems biology

Kenneth A. Loparo, PhD  
(Case Western Reserve University)  
Arthur L. Parker Professor  
Stability and control of nonlinear and stochastic systems; fault detection, diagnosis, and prognosis; recent applications work in advanced control and failure detection of rotating machines, signal processing for the monitoring and diagnostics of physiological systems, and modeling, analysis, and control of power and energy systems

Behnam Malakooti, PhD, PE  
(Purdue University)  
Professor  
Design and multi-objective optimization, manufacturing/production/operations systems, intelligent systems and networks, artificial neural networks, biological systems, intelligent decision making

Mehran Mehregany, PhD  
(Massachusetts Institute of Technology)  
Veale Professor of Wireless Health Innovation  
Research and development at the intersections of micro/nano-electro-mechanical systems, semiconductor silicon carbide and integrated circuits

Pedram Mohseni, PhD  
(University of Michigan)  
Leonard Case Jr. Professor of Engineering and Interim Chair  
Biomedical microsystems, bioelectronics, wireless neural interfaces, CMOS interface circuits for MEMS, low-power wireless sensing/actuating microsystems

Wyatt S. Newman, PhD, PE  
(Massachusetts Institute of Technology)  
Professor  
Mechatronics, high-speed robot design, force- and vision-based machine control, artificial reflexes for autonomous machines, rapid prototyping, agile manufacturing, mobile robotic platforms

Christos Papachristou, PhD  
(Johns Hopkins University)  
Professor  
VLSI design and CAD, computer architecture and parallel processing, design automation, embedded system design

Daniel Saab, PhD  
(University of Illinois at Urbana-Champaign)  
Associate Professor  
Computer architecture, VLSI system design and test, CAD design automation

Sree N. Sreenath, PhD  
(University of Maryland)  
Professor  
Systems biology complexity research (modeling, structural issues, and simulation); cell signaling, population behavior, and large-scale behavior; global issues and sustainable development

Christian A. Zorman, PhD  
(Case Western Reserve University)  
Leonard Case Jr. Professor of Engineering  
Materials and processing techniques for MEMS and NEMS, wide bandgap semiconductors, development of materials and fabrication techniques for polymer-based MEMS and bioMEMS
Secondary Faculty Appointments

Kathryn Daltorio, PhD  
(Case Western Reserve University)  
Assistant Professor

Dominique Durand, Ph.D.  
(University of Toronto)  
Professor

Mark Griswold, PhD  
(University of Würzburg, Germany)  
Professor, Radiology

Anant Madabhushi, Ph.D.  
(University of Pennsylvania)  
Professor

Soumyajit Mandal, PhD  
Research Associate Professor

Roger D. Quinn, PhD  
(Virginia Polytechnic Institute and State University)  
Professor, Mechanical and Aerospace Engineering

Satya S. Sahoo, PhD  
(Wright State University)  
Associate Professor, Dept of Population & Quantitative Health Sciences

Peter Thomas, PhD  
(University of Chicago)  
Associate Professor, Mathematics, Applied Mathematics, and Statistics

Xiong (Bill) Yu, PhD, PE  
(Purdue University)  
Professor, Civil Engineering

Research Faculty

Mahdi Bayat, PhD  
(University of Minnesota)  
Research Assistant Professor  
Signal processing, biomedical imaging, machine learning

Farhad Kaffashi, PhD  
(Case Western Reserve University)  
Research Assistant Professor  
Signal processing of physiological time series data, systems and control

Adjunct Faculty Appointments

Nicholas Barendt, MSEE  
(Case Western Reserve University)  
Adjunct Sr. Instructor

Gurkan Bebek, Ph.D.  
(Case Western Reserve University)  
Adjunct Instructor

Swarup Bhunia, Ph.D.  
(Purdue University)  
Adjunct Associate Professor

Michael S. Branicky, ScD, PE  
(Massachusetts Institute of Technology)  
Adjunct Professor

Mahdi Cheraghchi, Ph.D.  
(Swiss Federal Institute of Technology)  
Adjunct Assistant Professor

Andrew Eckford, PhD  
(University of Toronto)  
Adjunct Associate Professor

Robert Eckman  
Adjunct Instructor

Philip Feng  
Adjunct Professor

Lev Gonick, Ph.D.  
(York University, Toronto)  
Adjunct Professor

John C. Hoag, Ph.D.  
(The Ohio State University)  
Adjunct Associate Professor

Mingguo Hong  
Adjunct Associate Professor

Suparerk Janjarasjitt, PhD  
(Case Western Reserve University)  
Adjunct Assistant Professor

David Kazdan, Ph.D.  
(Case Western Reserve University)  
Adjunct Assistant Professor

John R. Miller, Ph.D.  
(Massachusetts Institute of Technology)  
Adjunct Professor

Srinivas Raghavan, PhD  
(Ohio State University)  
Adjunct Professor

Amirhossein Sajadi  
Adjunct Assistant Professor

Gideon Samid, PhD  
(Israel Institute of Technology)  
Adjunct Assistant Professor

Marvin S. Schwartz, PhD  
(Case Western Reserve University)  
Adjunct Professor

Lawrence Sears  
(Case Western Reserve University)  
Adjunct Instructor

Amit Sinha, PhD  
(Case Western Reserve University)  
Adjunct Assistant Professor
Theodore Theofrastous, JD  
(Case Western Reserve University)  
Adjunct Professor  

Peter J. Tsivitse, PhD  
(Case Western Reserve University)  
Adjunct Professor  

Benjamin Vandendriessche, PhD  
(Ghent University)  
Adjunct Assistant Professor  

Francis G. Wolff, Ph.D.  
(Case Western Reserve University)  
Adjunct Associate Professor  

Olaf Wolkenhauer, PhD  
(UMIST, Manchester)  
Adjunct Professor  

Jackie Wu, PhD  
(Mayo Graduate School)  
Adjunct Professor  

Guo-Qiang "GQ" Zhang, Ph.D.  
(Cambridge University)  
Adjunct Professor  

Hongping Zhao, PhD  
(Lehigh University)  
Adjunct Associate Professor  

Emeritus Faculty  
Sheldon Gruber, PhD  
Emeritus Professor  
Electrical Engineering and Applied Physics  

Francis "Frank" L. Merat, PhD, PE  
(Case Western Reserve University)  
Emeritus Professor  
Computer and robot vision, digital image processing, sensors, titanium capacitors and power electronics; RF and wireless systems; optical sensors; engineering education  

Undergraduate Programs  
The ECSE department offers programs leading to degrees in:  
1. Electrical Engineering (Bachelor of Science in Engineering)  
2. Computer Engineering (Bachelor of Science in Engineering)  
3. Systems and Control Engineering (Bachelor of Science in Engineering)  

These programs provide students with a strong background in the fundamentals of mathematics, science, and engineering. Students can use their technical and open electives to pursue concentrations in bioelectrical engineering, complex systems, automation and control, digital systems design, embedded systems, micro/nano systems, robotics and intelligent systems, signal processing and communications. In addition to an excellent technical education, all students in the department are exposed to societal issues, ethics, professionalism, and have the opportunity to develop leadership and creativity skills.  

Bachelor of Science in Electrical Engineering  
The Bachelor of Science in Engineering degree program with a major in Electrical Engineering provides our students with a broad foundation in electrical engineering through combined classroom and laboratory work which prepares our students for entering the profession of electrical engineering, as well as for further study at the graduate level.  
The Bachelor of Science in Electrical Engineering degree program with a major in Electrical Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org/.  

Mission  
The educational mission of the electrical engineering program is to graduate students who have fundamental technical knowledge of their profession and the requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies that will advance the general field of electrical engineering.  

Program Educational Objectives  
1. Graduates will be successful professionals obtaining positions appropriate to their background, interests, and education.  
2. Graduates will use continuous learning opportunities to improve and enhance their professional skills.  
3. Graduates will demonstrate leadership in their profession.  

Student Outcomes  
As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Electrical Engineering is designed so that students attain:  
- an ability to apply knowledge of mathematics, science, and engineering  
- an ability to design and conduct experiments, as well as to analyze and interpret data  
- an ability to design a system, component, or process to meet desired needs  
- an ability to function in multi-disciplinary teams  
- an ability to identify, formulate, and solve engineering problems  
- an understanding of professional and ethical responsibility  
- an ability to communicate effectively  

Core courses provide our students with a strong background in signals and systems, computers, electronics (both analog and digital), and semiconductor devices. Students are required to develop depth in at least one of the following technical areas: signals and systems, solid state, computer hardware, computer software, control, circuits, robotics, and biomedical applications. Each electrical engineering student must complete the following requirements:  

Major in Electrical Engineering  
In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree/) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degroeprograms/), the major requires the following courses:
**Major Requirements**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 309</td>
<td>Electromagnetic Fields I</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 313</td>
<td>Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 321</td>
<td>Semiconductor Electronic Devices</td>
<td>4</td>
</tr>
</tbody>
</table>

Core courses provide our students with a strong background in signals and systems, computers, electronics (both analog and digital), and semiconductor devices. Students are required to develop depth in at least one of the following technical areas: signals and systems, solid state, computer hardware, computer software, control, circuits, robotics, and biomedical applications. Each electrical engineering student must complete the following requirements:

**Technical Elective Requirement**

Each student must complete eighteen (18) credit hours of approved technical electives. Technical electives shall be chosen to fulfill the depth requirement (see next) and otherwise increase the student’s understanding of electrical engineering. Technical electives not used to satisfy the depth requirement are more generally defined as any course related to the principles and practice of electrical engineering. This includes all ECSE courses at the 200 level and above and can include courses from other programs. All non-ECSE technical electives must be approved by the student’s academic advisor.

**Depth Requirement**

Each student must show a depth of competence in one technical area by taking at least three courses from one of the following areas. This depth requirement may be met using a combination of the above core courses and a selection of open and technical electives. Alternative depth areas may be considered by petition to the program faculty.

**Area I: Signals & Control**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 304</td>
<td>Control Engineering I with Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 313</td>
<td>Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 351</td>
<td>Communications and Signal Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 354</td>
<td>Digital Communications</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 374</td>
<td>Advanced Control and Energy Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 375</td>
<td>Applied Control</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 490</td>
<td>Digital Image Processing</td>
<td>3</td>
</tr>
<tr>
<td>MATH 307</td>
<td>Linear Algebra</td>
<td>3</td>
</tr>
</tbody>
</table>

**Area II: Computer Software**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSDS 293</td>
<td>Software Craftsmanship</td>
<td>4</td>
</tr>
<tr>
<td>CSDS 302</td>
<td>Discrete Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>CSDS 310</td>
<td>Algorithms</td>
<td>3</td>
</tr>
<tr>
<td>CSDS 391</td>
<td>Introduction to Artificial Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>CSDS 393</td>
<td>Software Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 338</td>
<td>Intro to Operating Systems and Concurrent Programming</td>
<td>4</td>
</tr>
</tbody>
</table>

**Area III: Solid State**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 321</td>
<td>Semiconductor Electronic Devices</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 322/415</td>
<td>Integrated Circuits and Electronic Devices</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 422</td>
<td>Solid State Electronics II</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 221</td>
<td>Introduction to Modern Physics</td>
<td>3</td>
</tr>
</tbody>
</table>

**Area IV: Circuits**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 310</td>
<td>Principles of Biomedical Instrumentation</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 326</td>
<td>Instrumentation Electronics</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 344</td>
<td>Electronic Analysis and Design</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 371</td>
<td>Applied Circuit Design</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 426</td>
<td>MOS Integrated Circuit Design</td>
<td>3</td>
</tr>
</tbody>
</table>

**Area V: Computer Hardware**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 301</td>
<td>Digital Logic Laboratory</td>
<td>2</td>
</tr>
<tr>
<td>ECSE 314</td>
<td>Computer Architecture</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 315</td>
<td>Digital Systems Design</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 317</td>
<td>Computer Design - FPGAs</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 318</td>
<td>VLSI/CAD</td>
<td>4</td>
</tr>
</tbody>
</table>

**Area VI: Biomedical Applications**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBME 201</td>
<td>Physiology-Biophysics I (and 2 of the following 4 courses)</td>
<td>3</td>
</tr>
<tr>
<td>EBME 310</td>
<td>Principles of Biomedical Instrumentation</td>
<td>3</td>
</tr>
<tr>
<td>EBME 320</td>
<td>Biomedical Imaging</td>
<td>3</td>
</tr>
<tr>
<td>EBME 327</td>
<td>Bioelectric Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EBME 401D</td>
<td>Biomedical Instrumentation and Signal Processing</td>
<td>3</td>
</tr>
</tbody>
</table>

**Area VII: Robotics**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 275</td>
<td>Fundamentals of Robotics</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 304</td>
<td>Control Engineering I with Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 373</td>
<td>Modern Robot Programming</td>
<td>3</td>
</tr>
<tr>
<td>or ECSE 473</td>
<td>Modern Robot Programming</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 376</td>
<td>Mobile Robotics</td>
<td>4</td>
</tr>
<tr>
<td>or ECSE 476</td>
<td>Mobile Robotics</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 484</td>
<td>Computational Intelligence I: Basic Principles</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 489</td>
<td>Robotics I</td>
<td>3</td>
</tr>
</tbody>
</table>

**Statistics Requirement**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
</tr>
</tbody>
</table>

* STAT 333 Uncertainty in Engineering and Science may be substituted with approval of advisor
Design Requirement

In consultation with a faculty advisor, a student completes the program by selecting technical and open elective courses that provide in-depth training in one or more of a spectrum of specialties, such as, control, signal processing, electronics, integrated circuit design and fabrication, and robotics. With the approval of the advisor, a student may emphasize other specialties by selecting elective courses from other programs or departments.

Additionally, math and statistics classes are highly recommended as an integral part of the student’s technical electives to prepare for work in industry and government and for graduate school. The following math/statistics classes are recommended and would be accepted as approved technical electives:

- MATH 201 Introduction to Linear Algebra for Applications
- MATH 307 Linear Algebra
- MATH 330 Introduction of Scientific Computing
- MATH 380 Introduction to Probability

Other Math/Statistics may be used as technical electives with the approval of the student’s academic advisor.

Many courses have integral or associated laboratories in which students gain “hands-on” experience with electrical engineering principles and instrumentation. Students have ready access to the teaching laboratory facilities and are encouraged to use them during nonscheduled hours in addition to the regularly scheduled laboratory sessions. Opportunities also exist for undergraduate student participation in the wide spectrum of research projects being conducted in the department.

Suggested Program of Study: Major in Electrical Engineering

The following is a suggested program of study. Current students should always consult their advisors and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

<table>
<thead>
<tr>
<th>First Year</th>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES First Year Seminar*</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elementary Computer Programming (ENGR 131)**</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>SAGES University Seminar*</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Physics I - Mechanics (PHYS 121)**</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculus for Science and Engineering II (MATH 122)**</td>
<td>4</td>
<td></td>
<td></td>
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<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
<td>4</td>
<td></td>
<td></td>
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<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>Year Total:</td>
<td>18</td>
<td>15</td>
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<table>
<thead>
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<th>Second Year</th>
<th>Units</th>
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<th>Spring</th>
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<tbody>
<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
<td>4</td>
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<tr>
<td>Calculus for Science and Engineering III (MATH 223)**</td>
<td>3</td>
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<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
<td>4</td>
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<tr>
<td>Logic Design and Computer Organization (ECSE 281)</td>
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<tr>
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<tr>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
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<tr>
<td>Elementary Differential Equations (MATH 224)**</td>
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<tr>
<td>Electronic Circuits (ECSE 245)</td>
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</tr>
<tr>
<td>Electromagnetic Fields I (ECSE 309)</td>
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<td>Year Total:</td>
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<table>
<thead>
<tr>
<th>Third Year</th>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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</thead>
<tbody>
<tr>
<td>Breadth elective**</td>
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<tr>
<td>Statics and Strength of Materials (ENGR 200)**</td>
<td>3</td>
<td></td>
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<tr>
<td>Statistics for Signal Processing (STAT 332)c</td>
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<tr>
<td>Approved technical electived</td>
<td>3</td>
<td></td>
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</tr>
<tr>
<td>Signals and Systems (ECSE 246)</td>
<td>4</td>
<td></td>
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<tr>
<td>Breadth elective**</td>
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<td></td>
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<td>Approved technical electived</td>
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<td>Professional Communication for Engineers (ENGR 398)</td>
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<td>Semiconductor Electronic Devices (ECSE 321)</td>
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<td>Signal Processing (ECSE 313)</td>
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<thead>
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<th>Spring</th>
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<tbody>
<tr>
<td>Breadth elective**</td>
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<tr>
<td>Approved technical elective(d</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Approved technical elective(d</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Projects I (ECSE 398)</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breadth elective**</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approved technical elective(d</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approved technical elective(d</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
<td></td>
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</tr>
<tr>
<td>Engineering Projects II (ECSE 399)</td>
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<tr>
<td>Year Total:</td>
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<td>15</td>
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<tr>
<td>Total Units in Sequence:</td>
<td>128</td>
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<tr>
<td>Hours Required for Graduation: 128g</td>
<td></td>
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</tbody>
</table>
Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics and PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics. Students may replace STAT 332 Statistics for Signal Processing with STAT 333 Uncertainty in Engineering and Science if approved by their advisor.

Technical electives will be chosen to fulfill the depth requirement and otherwise increase the student's understanding of electrical engineering. Courses used to satisfy the depth requirement must come from the department's list of depth areas and related courses. Technical electives not used to satisfy the depth requirement are more generally defined as any course related to the principles and practice of electrical engineering. This includes all ECSE courses at the 200 level and above, and can include courses from other programs. All non-ECSE technical electives must be approved by the student's advisor.

BS/MS students may double count ECSE 651 Thesis M.S. to fulfill the ECSE 399 Engineering Projects II requirement.

CO-OP students may obtain design credit for ECSE 399 Engineering Projects II if their co-op assignment included significant design responsibility; however, the student is still responsible for such course obligations as reports, presentations, and ethics assignments. Design credit and fulfillment of remaining course responsibilities are arranged through the course instructor.


Double Major: Systems and Control Engineering & Electrical Engineering

The department also offers a double major in Systems and Control Engineering and Electrical Engineering. Students pursuing the Bachelor of Science in Engineering degree program with a major in Electrical Engineering can take the following courses as technical and open electives to earn a second major in Systems and Control Engineering:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 216</td>
<td>Fundamental System Concepts</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 304</td>
<td>Control Engineering I with Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 305</td>
<td>Control Engineering I Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>ECSE 324</td>
<td>Modeling and Simulation of Continuous Dynamical Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 342</td>
<td>Introduction to Global Issues</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 352</td>
<td>Engineering Economics and Decision Analysis</td>
<td>3</td>
</tr>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications (SC)</td>
<td>3</td>
</tr>
<tr>
<td>OPRE 432</td>
<td>Computer Simulation (SC)</td>
<td>3</td>
</tr>
</tbody>
</table>

And one of the following two courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 374</td>
<td>Advanced Control and Energy Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 375</td>
<td>Applied Control</td>
<td>3</td>
</tr>
</tbody>
</table>

Cooperative Education Program in Electrical Engineering

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at http://engineering.case.edu/coop/. Alternatively or additionally, students may obtain employment as summer interns.

BS/MS Program in Electrical Engineering

The department encourages highly motivated and qualified students to apply for admission to the five-year BS/MS Program in the junior year. This integrated program, which permits up to 9 credit hours of graduate level coursework to be counted towards both BS and MS degree requirements (including an option to substitute MS thesis work for ECSE 399 Engineering Projects II. It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatetudies/gradprofessional/accelerationtowardgraduatedegreetext).

Minor in Electrical Engineering

Students enrolled in degree programs in other engineering departments can have a minor specialization by completing the following courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 245</td>
<td>Electronic Circuits</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 309</td>
<td>Electromagnetic Fields I</td>
<td>3</td>
</tr>
</tbody>
</table>

Total Units 18

Minor in Electronics

The department also offers a minor in electronics for students in the College of Arts and Sciences. This program requires the completion of 31 credit hours, of which 10 credit hours may be used to satisfy portions of the students’ skills and distribution requirements. The following courses are required for the electronics minor:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 131</td>
<td>Elementary Computer Programming</td>
<td>3</td>
</tr>
<tr>
<td>ENGR 210</td>
<td>Introduction to Circuits and Instrumentation</td>
<td>4</td>
</tr>
<tr>
<td>MATH 125</td>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci I</td>
<td>4</td>
</tr>
<tr>
<td>MATH 126</td>
<td>Math and Calculus Applications for Life, Managerial, and Social Sci II</td>
<td>4</td>
</tr>
</tbody>
</table>
Bachelor of Science in Systems and Control Engineering

The Bachelor of Science in Engineering degree program with a major in Systems and Control Engineering provides our students with the basic concepts, analytical tools, and engineering methods which are needed in analyzing and designing complex technological and non-technological systems. Problems relating to modeling, simulation, decision-making, control, and optimization are studied. Some examples of systems problems which are studied include: modeling and analysis of complex biological systems, computer control of industrial plants, developing world models for studying environmental policies, and optimal planning and management in large-scale systems. In each case, the relationship and interaction among the various components of a given system must be modeled. This information is used to determine the best way of coordinating and regulating these individual contributions to achieve the overall goal of the system.

The Bachelor of Science in Engineering with a major in Systems and Control Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org/.

Mission

The mission of the Systems and Control Engineering program is to provide internationally recognized excellence for graduate and undergraduate education and research in systems analysis, design, and control. These theoretical and applied areas require cross-disciplinary tools and methods for their solution.

Program Educational Objectives

1. Graduates apply systems methodology to multi-disciplinary projects that include technical, social, environmental, and/or economic factors.
2. Graduates use systems understanding, thinking and problem-solving skills to analyze and design systems or processes that respond to technical and societal needs.
3. Graduates use teamwork, leadership, communication, and management skills to facilitate multidisciplinary projects that bring together practitioners of various engineering fields in an effective, professional, and ethical manner.

Student Outcomes

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs
- an ability to function in multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively

Major in Systems and Control Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree/) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms/), the major requires the following courses:

### Major Requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 216</td>
<td>Fundamental System Concepts</td>
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</tr>
<tr>
<td>ECSE 246</td>
<td>Signals and Systems</td>
<td>4</td>
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<td>ECSE 304</td>
<td>Control Engineering I with Laboratory</td>
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</tr>
<tr>
<td>ECSE 305</td>
<td>Control Engineering I Laboratory</td>
<td>1</td>
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<td>ECSE 313</td>
<td>Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 324</td>
<td>Modeling and Simulation of Continuous Dynamical Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 342</td>
<td>Introduction to Global Issues</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 346</td>
<td>Engineering Optimization</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 352</td>
<td>Engineering Economics and Decision Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 399</td>
<td>Engineering Projects II</td>
<td>3</td>
</tr>
<tr>
<td>OPRE 432</td>
<td>Computer Simulation</td>
<td>3</td>
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</table>

Fifteen hours of approved technical electives including at least 9 hours of approved courses to constitute a depth of study.

### Breadth Requirement

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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<tbody>
<tr>
<td>MATH 201</td>
<td>Introduction to Linear Algebra for Applications</td>
<td>3</td>
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<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
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### Statistics Requirement

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
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<tr>
<td>*</td>
<td>STAT 333 Uncertainty in Engineering and Science may be substituted with approval of advisor</td>
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### Design Requirement

<table>
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<tbody>
<tr>
<td>ECSE 398</td>
<td>Engineering Projects I</td>
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</table>

### Depth Requirement

Each student must show a depth of competence in one technical area by taking at least three courses from one of the three tracks/program concentration areas, namely energy systems, control systems and data analytics, listed below:

#### Track 1: Energy Systems

<table>
<thead>
<tr>
<th>Course</th>
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<tbody>
<tr>
<td>ECSE 368</td>
<td>Power System Analysis I</td>
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<tr>
<td>ECSE 369</td>
<td>Power System Analysis II</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 370</td>
<td>Smart Grid</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 374</td>
<td>Advanced Control and Energy Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 375</td>
<td>Applied Control</td>
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</table>

#### Track 2: Control Systems

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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<tbody>
<tr>
<td>ECSE 374</td>
<td>Advanced Control and Energy Systems</td>
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<tr>
<td>ECSE 375</td>
<td>Applied Control</td>
<td>3</td>
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</tbody>
</table>
ECSE 281 Logic Design and Computer Organization 4

Technical Elective from the Energy Systems or Data Analytics tracks 3

**Track 3: Data Analytics**
- CSDS 313 Introduction to Data Analysis
- "Core Tools" list:
  - CSDS 339 Web Data Mining 3
  - CSDS 435 Data Mining 3
  - ECSE 452 Random Signals 3
  - ECSE 490 Digital Image Processing 3
  - OPRE 433 Foundations of Probability and Statistics 3
  - STAT 325 Data Analysis and Linear Models 3
  - STAT 326 Multivariate Analysis and Data Mining 3
- "Application" lists:
  - Business/Manufacturing Analytics:
    - BAFI 361 Empirical Analysis in Finance 3
    - ECSE 350 Operations and Systems Design 3
    - ECSE 360 Manufacturing and Automated Systems 3
    - ECSE 490 Digital Image Processing 3
    - MKMR 310 Marketing Analytics 3
    - OPMT 475 Supply Chain Logistics 3
    - OPMT 477 Enterprise Resource Planning in the Supply Chain 3
  - Healthcare Analytics
    - BIOL 304 Fitting Models to Data: Maximum Likelihood Methods and Model Selection 3
    - EBME 410 Medical Imaging Fundamentals 3
    - ECSE 319 Applied Probability and Stochastic Processes for Biology 3
    - ECSE 365 Complex Systems Biology 3
    - MATH 378 Computational Neuroscience 3
    - SYBB 421 Fundamentals of Clinical Information Systems 3
    - SYBB 422 Clinical Informatics at the Bedside and the Bench (Part II) 3
  - Energy Systems Analytics
    - ECSE 370 Smart Grid 3

**Suggested Program of Study: Major in Systems and Control Engineering**

The following is a suggested program of study. Current students should always consult their advisors and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu/).

<table>
<thead>
<tr>
<th>First Year</th>
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<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
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<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
<td>4</td>
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<td>Elementary Computer Programming (ENGR 131)**</td>
<td>3</td>
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<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
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<tr>
<td>SAGES University Seminar*</td>
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<tr>
<td>General Physics I - Mechanics (PHYS 121)**</td>
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<td>Calculus for Science and Engineering II (MATH 122)**</td>
<td>4</td>
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<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
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<td>PHED (2 half semester courses)*</td>
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</tr>
<tr>
<td>Year Total:</td>
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<table>
<thead>
<tr>
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<th>Units</th>
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<tbody>
<tr>
<td>Fall</td>
<td>Spring</td>
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<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
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<td>Calculus for Science and Engineering III (MATH 223)**</td>
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<tr>
<td>Computer Simulation (OPRE 432)</td>
<td>3</td>
</tr>
<tr>
<td>Control Engineering I with Laboratory (ECSE 304)</td>
<td>3</td>
</tr>
<tr>
<td>Control Engineering I Laboratory (ECSE 305)</td>
<td>1</td>
</tr>
<tr>
<td>Engineering Optimization (ECSE 346)</td>
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<tr>
<td>Signal Processing (ECSE 313)</td>
<td>3</td>
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<table>
<thead>
<tr>
<th>Fourth Year</th>
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<tbody>
<tr>
<td>Fall</td>
<td>Spring</td>
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<tr>
<td>Breadth elective**</td>
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</tr>
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</table>
Professional Communication for Engineers (ENGL 398)**  
Professional Communication for Engineers (ENGR 398)**  
Approved technical elective\(^c\)  
Engineering Economics and Decision Analysis (ECSE 352)  
Engineering Projects I (ECSE 398)  
Breadth elective\(^a\)**  
Approved technical elective\(^c\)  
Approved technical elective\(^c\)  
Approved technical elective\(^c\)  
Engineering Projects II (ECSE 399)  
Year Total:  

Total Units in Sequence: 129

Hours Required for Graduation: 129

\(a\) University general education requirement  
\(**\) Engineering general education requirement  
\(a\) Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics and PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics I - Mechanics and PHYS 122 General Physics II - Electricity and Magnetism.  
\(b\) Co-op students may obtain design credit for one semester of Senior Project Lab if their co-op assignment includes significant design responsibility. This credit can be obtained by submitting a suitable written report and making an oral presentation on the co-op work in coordination with the senior project instructor  
\(c\) Technical electives from approved list of courses in the three tracks/program concentration areas (Energy systems, Control systems, and Data Analytics) listed under “Depth Requirement” above.  

There are five technical elective courses available within the Bachelor of Science in Engineering degree program with a major in Systems and Control Engineering curriculum that represent a depth of the discipline. Students can satisfy these four technical elective requirements by choosing three courses from one of the three tracks (to meet the Depth Requirement) with the fourth and fifth courses chosen from any of the three tracks listed under the Depth Requirement section above.

As the three courses ECSE 281, ECSE 245, and ECSE 321 are 4 credit-hours instead of 3, the three credit-hour “Open Elective” course in the original S&CE program is not needed.

| ECSE 374 | Advanced Control and Energy Systems | 3 |
| ECSE 375 | Applied Control | 3 |

Cooperative Education Program in Systems and Control Engineering

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at [http://engineering.case.edu/coop/](http://engineering.case.edu/coop/). Alternatively or additionally, students may obtain employment as summer interns.

BS/MS Program in Systems and Control Engineering

The department encourages highly motivated and qualified students to apply for admission to the five-year BS/MS Program in the junior year. This integrated program, which permits up to 9 credit hours of graduate level coursework to be counted towards both BS and MS degree requirements (including an option to substitute MS thesis work for ECSE 399 Engineering Projects II, the second senior project). It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years. Review the Office of Undergraduate Studies BS/MS program requirements [here](http://bulletin.case.edu/undergraduatestudies/gradprofessional/#accelerationtowardgraduatedegreetext).

Minor Program in Systems and Control Engineering

A total of five courses (15 credit hours) are required to obtain a minor in systems and control engineering. This includes:

- ECSE 246 Signals and Systems
- Three of the following four courses selected in consultation with the program minor advisor: ECSE 304 Control Engineering I with Laboratory/ECSE 305 Control Engineering II Laboratory; ECSE 324 Modeling and Simulation of Continuous Dynamical Systems; ECSE 346 Engineering Optimization; ECSE 352 Engineering Economics and Decision Analysis;
- One of ECSE 313 Signal Processing, ECSE 351 Communications and Signal Analysis, or ECSE 354 Digital Communications.

Bachelor of Science in Computer Engineering

The Bachelor of Science in Engineering degree program with a major in Computer Engineering is designed to give a student a strong background in the fundamentals of computer engineering through combined classroom and laboratory work. A graduate of this program will be able to use these fundamentals to analyze and evaluate computer systems, both hardware and software. A computer engineering graduate would also be able to design and implement a computer system for general purpose or embedded computing incorporating state-of-the-art solutions to a variety
of computing problems. This includes systems which have both hardware and software components, whose design requires a well-defined interface between the two and the evaluation of the associated trade-offs.

The Bachelor of Science in Engineering degree program with a major in Computer Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org/.

**Mission**

The educational mission of the computer engineering program is to graduate students who have fundamental technical knowledge of their profession along with requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies which will advance the general field of computer engineering. Core courses provide our students with a strong background in digital systems design, computer organization, hardware architecture, and digital electronics.

**Program Educational Objectives**

1. Graduates will be successful professionals obtaining positions appropriate to their background, interests, and education.
2. Graduates will engage in life-long learning to improve and enhance their professional skills.
3. Graduates will demonstrate leadership in their profession by using their knowledge, communication skills, and engineering ability.

**Student Outcomes**

As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Computer Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs
- an ability to function in multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively

**Major in Computer Engineering**

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree/) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms/), the major requires the following courses:

**Major Requirements**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSDS 302</td>
<td>Discrete Mathematics</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 132</td>
<td>Introduction to Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 301</td>
<td>Digital Logic Laboratory</td>
<td>2</td>
</tr>
<tr>
<td>ECSE 314</td>
<td>Computer Architecture</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 315</td>
<td>Digital Systems Design</td>
<td>4</td>
</tr>
</tbody>
</table>

**Statistics Requirement**

One Statistics elective may be chosen from:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 312</td>
<td>Basic Statistics for Engineering and Science</td>
<td>3</td>
</tr>
<tr>
<td>STAT 313</td>
<td>Statistics for Experimenters</td>
<td>3</td>
</tr>
<tr>
<td>STAT 332</td>
<td>Statistics for Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>STAT 333</td>
<td>Uncertainty in Engineering and Science</td>
<td>3</td>
</tr>
</tbody>
</table>

**Design Requirement**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSE 398</td>
<td>Engineering Projects I</td>
<td>4</td>
</tr>
</tbody>
</table>

In consultation with a faculty advisor, a student completes the program by selecting technical and open elective courses that provide in-depth training in the principles and practice of computer engineering. Students must take 5-6 courses, that add up to 18 credit hours of technical electives, to fulfill this requirement. With the approval of the advisor, a student may emphasize a specialty of his/her choice by selecting elective courses from other programs or departments.

Many courses have integral or associated laboratories in which students gain "hands-on" experience with computer engineering principles and instrumentation. Students have ready access to the teaching laboratory facilities and are encouraged to use them during nonscheduled hours in addition to the regularly scheduled laboratory sessions. Opportunities also exist for undergraduate student participation in the wide spectrum of research projects being conducted in the department.

**Suggested Program of Study: Major in Computer Engineering**

The following is a suggested program of study. Current students should always consult their advisors and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu/).

**First Year**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES First Year Seminar*</td>
<td>4</td>
</tr>
<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
<td>4</td>
</tr>
<tr>
<td>Calculus for Science and Engineering I (MATH 121)**</td>
<td>4</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
</tr>
<tr>
<td>Introduction to Programming in Java (ECSE 132)</td>
<td>3</td>
</tr>
<tr>
<td>SAGES University Seminar*</td>
<td>3</td>
</tr>
<tr>
<td>General Physics I - Mechanics (PHYS 121)**</td>
<td>4</td>
</tr>
<tr>
<td>Calculus for Science and Engineering II (MATH 122)**</td>
<td>4</td>
</tr>
<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
<td>4</td>
</tr>
<tr>
<td>PHED (2 half semester courses)*</td>
<td>0</td>
</tr>
</tbody>
</table>

Year Total: 18 15

**Second Year**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGES University Seminar*</td>
<td>3</td>
</tr>
<tr>
<td>General Physics II - Electricity and Magnetism (PHYS 122)**</td>
<td>4</td>
</tr>
<tr>
<td>Calculus for Science and Engineering III (MATH 223)**</td>
<td>3</td>
</tr>
</tbody>
</table>
**Department of Electrical, Computer, and Systems Engineering**

### Hours Required for Graduation: 129

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210)**</td>
<td>4</td>
</tr>
<tr>
<td>Introduction to Data Structures (ECSE 233)</td>
<td>4</td>
</tr>
<tr>
<td>Breadth elective**</td>
<td>3</td>
</tr>
<tr>
<td>Elementary Differential Equations (MATH 224)**</td>
<td>3</td>
</tr>
<tr>
<td>Statics and Strength of Materials (ENGR 200)**</td>
<td>3</td>
</tr>
<tr>
<td>Technical electivea</td>
<td>3</td>
</tr>
<tr>
<td>Logic Design and Computer Organization (ECSE 281)</td>
<td>4</td>
</tr>
</tbody>
</table>

**Total Units in Sequence:** 128

---

### Third Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth elective**</td>
<td>3</td>
</tr>
<tr>
<td>Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**</td>
<td>4</td>
</tr>
<tr>
<td>Technical electiveb</td>
<td>7</td>
</tr>
<tr>
<td>Discrete Mathematics (CSDS 302)</td>
<td>3</td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGL 398)**</td>
<td>2</td>
</tr>
<tr>
<td>Professional Communication for Engineers (ENGR 398)**</td>
<td>1</td>
</tr>
<tr>
<td>Digital Logic Laboratory (ECSE 301)</td>
<td>2</td>
</tr>
<tr>
<td>Computer Architecture (ECSE 314)</td>
<td>3</td>
</tr>
<tr>
<td>Digital Systems Design (ECSE 315)</td>
<td>4</td>
</tr>
<tr>
<td>Embedded Systems Design and Laboratory (ECSE 303)</td>
<td>3</td>
</tr>
</tbody>
</table>

**Year Total:** 17 15

---

### Fourth Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth elective**</td>
<td>3</td>
</tr>
<tr>
<td>Statistics electivec</td>
<td>3</td>
</tr>
<tr>
<td>Technical electivea</td>
<td>3</td>
</tr>
<tr>
<td>Technical elective (or ECSE 318 VLSI/CAD) **</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
</tr>
<tr>
<td>Breadth elective**</td>
<td>3</td>
</tr>
<tr>
<td>Technical electivea</td>
<td>3</td>
</tr>
<tr>
<td>Open elective</td>
<td>4</td>
</tr>
<tr>
<td>Engineering Projects I (ECSE 398)d</td>
<td>4</td>
</tr>
</tbody>
</table>

**Year Total:** 15 14

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### Minor in Computer Engineering

The department also offers a minor in computer engineering. The minor has a required two-course sequence followed by a two-course sequence in either hardware or software aspects of computer engineering.

The following two courses are required for any minor in computer engineering:

- **ECSE 281 Logic Design and Computer Organization** 4
- **ECSE 315 Digital Systems Design** 4

The two-course hardware sequence is:

- **ECSE 314 Computer Architecture** 3
- **ECSE 315 Digital Systems Design** 4

The corresponding two-course software sequence is:

- **ECSE 303 Embedded Systems Design and Laboratory** 3
- **ECSE 3XX Approved by advisor** 4

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### Minor in Artificial Intelligence

The minor consists of five courses. Every student who takes the minor in artificial intelligence must take the two courses, ENGR 131

---
Elementary Computer Programming and CSDS 391 Introduction to Artificial Intelligence. Students who take the Artificial Intelligence minor must also take an additional three courses from one of two minor tracks.

**Technology Track (requires 3 of the following courses):**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 373</td>
<td>Introduction to Neurobiology</td>
<td>3</td>
</tr>
<tr>
<td>BIOL 374</td>
<td>Neurobiology of Behavior</td>
<td>3</td>
</tr>
<tr>
<td>CSDS 477</td>
<td>Advanced Algorithms</td>
<td>3</td>
</tr>
<tr>
<td>CSDS/BION 478</td>
<td>Computational Neuroscience</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 350</td>
<td>Operations and Systems Design</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 352</td>
<td>Engineering Economics and Decision Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 360</td>
<td>Manufacturing and Automated Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 375</td>
<td>Applied Control</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 411</td>
<td>Applied Engineering Statistics</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 475</td>
<td>Applied Control</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 484</td>
<td>Computational Intelligence I: Basic Principles</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 489</td>
<td>Robotics I</td>
<td>3</td>
</tr>
<tr>
<td>ECSE/CSDS 531</td>
<td>Computer Vision</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 589</td>
<td>Robotics II</td>
<td>3</td>
</tr>
<tr>
<td>PHIL 201</td>
<td>Introduction to Logic</td>
<td>3</td>
</tr>
<tr>
<td>PHIL 306</td>
<td>Mathematical Logic and Model Theory</td>
<td>3</td>
</tr>
</tbody>
</table>

**Cognitive Science Track (requires 3 of the following courses):**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 373</td>
<td>Introduction to Neurobiology</td>
<td>3</td>
</tr>
<tr>
<td>BIOL 374</td>
<td>Neurobiology of Behavior</td>
<td>3</td>
</tr>
<tr>
<td>ENGL 301</td>
<td>Linguistic Analysis</td>
<td>3</td>
</tr>
<tr>
<td>PHIL 201</td>
<td>Introduction to Logic</td>
<td>3</td>
</tr>
<tr>
<td>PHIL 306</td>
<td>Mathematical Logic and Model Theory</td>
<td>3</td>
</tr>
<tr>
<td>PSCL 101</td>
<td>General Psychology I</td>
<td>3</td>
</tr>
<tr>
<td>PSCL 352</td>
<td>Physiological Psychology</td>
<td>3</td>
</tr>
<tr>
<td>PSCL 353</td>
<td>Psychology of Learning</td>
<td>3</td>
</tr>
<tr>
<td>PSCL 355</td>
<td>Sensation and Perception</td>
<td>3</td>
</tr>
<tr>
<td>PSCL 357</td>
<td>Cognitive Psychology</td>
<td>3</td>
</tr>
<tr>
<td>PSCL 370</td>
<td>Human Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>PSCL 402</td>
<td>Cognition and Information Processing</td>
<td>3</td>
</tr>
</tbody>
</table>

**Minor in Computer Gaming (CGM)**

The minor is 16 hours as follows:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSDS 391</td>
<td>Introduction to Artificial Intelligence</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 233</td>
<td>Introduction to Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>ECSE 290</td>
<td>Introduction to Game Design and Implementation</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 366</td>
<td>Computer Graphics</td>
<td>3</td>
</tr>
<tr>
<td>ECSE 390</td>
<td>Advanced Game Development Project</td>
<td>3</td>
</tr>
</tbody>
</table>

It is recommended that one additional open elective be a “content creation” course taken from the following areas: Art, English, or Music.

Students should note that ECSE 132 Introduction to Programming in Java is a prerequisite for ECSE 233 Introduction to Data Structures.

**Graduate Programs**

**MS Degree Program (Electrical Engineering, Computer Engineering, Systems and Control Engineering)**

**Admission**

Graduate students shall be admitted to one of three MS degree tracks (thesis-focused, project-focused, course-focused) upon recommendation of the faculty of the Department. Requirements for admission include a strong record of scholarship in a completed bachelor's degree program in a field of engineering, mathematical or physical sciences, and fluency in written and spoken English. The University requires all foreign applicants to show English proficiency by achieving a TOEFL score of at least 90 on the internet-based exam for a thesis-focused or a project-focused track. For a course-focused track, a minimum TOEFL score of 80 is required. If there is any professional student to student interaction, e.g. as a teaching assistant, a lab instructor, or a tutor, then a minimum TOEFL score of 90 is required. It is required that all students submit original copies of GRE scores, with the exception of CWRU students applying to the BS/MS program. Applications from students with a bachelor's degree in fields other than those listed above may be granted admission on a provisional basis. Such provisional students may be advanced to full standing upon completion of prerequisite conditions stipulated in the letter of admission.

**Registration**

Course registration is performed through the SIS system. Each semester before registration, students should update any personal information that may have changed by logging onto the SIS and editing the appropriate information. All registration holds must be lifted in order to successfully complete the registration process.

**Advising**

Upon admission to the graduate program, each graduate student is assigned an academic advisor to assist in registration as well as planning a program of study. This is a temporary assignment made by the Department Chairperson based on the student’s academic and research interests as identified at the time of application. During the first semester in the program, it is strongly suggested that each student meet with various members of faculty to discuss academic objectives/goals and research opportunities. In order to complete the research component of their respective degree program, each student must identify a faculty member who is willing to serve as the student’s research advisor. The research advisor will also serve as the student’s permanent academic advisor if he/she is a member of the department faculty. If, however, the research advisor is not a member of the department faculty, the student is required to find a permanent academic advisor from the department faculty. For students enrolled in the MS Thesis-Focused degree program, the research advisor is commonly known as the “thesis advisor”.

Students may change advisors for a variety of reasons of which one of the most common is a change of the student’s field of interest. It should be noted that a change in research advisor may require that the student start a new research project, which could result in delaying graduation. It is the responsibility of the student to inform the ECSE Office of Student Affairs in the event of a change in advisor. In addition, the student must file all appropriate forms with Graduate Studies.

**The MS Thesis-Focused Track**

The MS Thesis-Focused track is composed of two components: (1) graduate-level coursework and (2) a research-oriented thesis.
Progression through the program is monitored by an Academic Program that is required to be filed through SIS. This contains a comprehensive list of all courses to be applied to the degree (including transfer courses) and must be approved by his/her academic advisor, Department Chairperson, and Dean of Graduate Studies. At least 30 semester credit hours of coursework at the 400 level or above, of which a minimum of 18 credits must be from non-thesis related courses is required. Each MS Thesis-Focused student must complete at least 9 credit hours of ECSE 651 Thesis M.S., which is the course associated with MS thesis research. Each student must complete an approved Academic Program with a cumulative grade point average of 3.0 or greater.

Completion of the MS Thesis-Focused track requires that the student submit a written thesis and make an oral presentation of the findings (hereafter known as the defense) to a thesis guidance committee. The thesis guidance committee shall consist of the student’s research advisor and at least two additional faculty members recommended by the advisor. At least two members of the committee must be faculty members in the ECSE department. The chairperson of the guidance committee is normally the candidate's research advisor. The student is responsible for forming the thesis guidance committee. The student will work closely with his/her advisor to determine when the thesis is ready for review by the guidance committee. The student shall provide an announcement containing a title, abstract, date, time and location of the defense to the ECSE Office of Student Affairs for general distribution at least 10 days in advance of the thesis defense.

The MS Project-Focused Track
The MS Project-Focused track is composed of two components: (1) graduate-level coursework and (2) a research-oriented project. Progression through the program is monitored by an Academic Program that is required to be filed through SIS. The Academic Program contains a comprehensive list of all courses to be applied to the degree (including transfer courses) and must be approved by his/her academic advisor, Department Chairperson, and Dean of Graduate Studies. The Academic Program must contain at least 30 semester credit hours of coursework at the 400 level or above, of which a minimum of 21 credits must be from courses other than ECSE 695 Project M.S. (which is the course associated with the MS research project). An MS Project-Focused student must complete at least 3 credit hours of ECSE 695 Project M.S.

Each student must complete an approved Academic Program with a cumulative grade point average of 3.0 or greater. Full-time students are strongly recommended to file an Academic Program before the beginning of the second semester.

Each candidate for the master’s degree under a Project-Focused track must pass a comprehensive examination to be administered by a committee of department faculty. The examination committee should be composed of the student’s academic advisor and at least two additional members of the department faculty. In such cases, the chairperson of the committee is normally the candidate's academic advisor. The examination may be written, oral or a combination as determined by the committee. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master’s Comprehensive Exam.

The MS Course-Focused Track
The Course-Focused MS track requirements consist of the completion of 30 hours of approved coursework at the 400 level or higher, satisfactory completion of the culminating course-focused experience, i.e. passing the course ENGR 600 with requirements defined by the student’s curricular program, and additional requirements as specified by the program.

Students should consult with their academic advisor and/or department to determine the detailed requirements within this framework.

Appeals
Any decision by an academic advisor, thesis guidance committee, or department associate chairperson may be appealed, in writing, to the department associate chairperson who shall present the appeal, with his recommendations, to the faculty at its next regular faculty meeting. The faculty’s decision shall be final.

Other Regulations
All students pursuing graduate studies in the Department of Electrical, Computer, and Systems Engineering must abide by the academic regulations of the School of Graduate Studies and the Case School of Engineering contained in the most recent issue of the Bulletin of Case Western Reserve University, and supplemented by the Department of Electrical, Computer, and Systems Engineering regulations.

NOTE: The above regulations apply to graduate students who entered the degree programs in computer engineering, electrical engineering, and systems & control engineering after January 1, 2005.

Registration
Course registration can be performed through the SIS system. Each semester before registration, students should update any personal information that may have changed by logging onto the SIS and editing the appropriate information. All registration holds must be lifted in order to successfully complete the registration process.

Advising
Each MS student has a faculty advisor who assists the student in formulating an academic program. Initially, the advisor is the chair of the CS graduate committee. Students are expected to pick a research advisor by the end of their first semester in the program who will supervise their thesis or project. Each student, in consultation with their advisor, must submit an Academic Program preferably before completing 9 credit hours of coursework. This should specify all courses and thesis work that will be counted toward the 30 credit hour requirement.

The MS Thesis-Focused, Project-Focused, Course-Focused Tracks
There are three tracks for the Master of Science degree, each requiring 30 semester hours of credit. The Thesis-Focused track requires at least 9 semester hours of thesis (ECSE 651 Thesis M.S. and at least 18 semester hours of courses. The additional 3 semester hours can be either thesis (ECSE 651 Thesis M.S.) or a regular course. The Project-Focused track requires 6 semester hours of project (ECSE 695 Project M.S.) and 24 semester hours of coursework credit. The Project-Focused track is normally restricted to part-time students or students in the BS/MS program with the approval of their project advisor’s. (A BS/MS student who follows the Project-Focused track is required to do a two-semester 6 credit hours MS project.)

All coursework must be at the 400-level or higher. Students must achieve a grade point average of 3.0 or higher; it is computed for all of the courses, excluding project and thesis credits, on the student’s academic program.

Both the Thesis-Focused and the Project-Focused track require a formal written report, as well as a final oral examination by a committee of at least three faculty members, two of whom must be primarily affiliated with the CS program. A student whose thesis is supervised by a faculty member not in the ECSE department must also have academic advisor in
the CS program. For Project-Focused track students, the oral examination fulfills the Comprehensive Examination requirement of the School of Graduate Studies.

The Course-Focused MS degree program requirements consist of the completion of 30 hours of approved coursework at the 400 level or higher, satisfactory completion of the culminating course-focused experience, i.e. passing the course ENGR 600 with requirements defined by the student's curricular program, and additional requirements as specified by the program. Students should consult with their academic advisor and/or department to determine the detailed requirements within this framework.

**Course Requirements**

Students are required to have specialized knowledge in at least one of the following tracks, by taking at least three graduate-level classes from that track. The list of acceptable classes is shown below. Generally, the chosen track should correspond to the student's thesis research area or project. ECSE 600 Special Topics classes relevant to the student's research area or project will also qualify in this category with approval from the student's advisor.

The remaining classes can be (i) any other class from the classes listed below, or (ii) any CS-related class offered by ECSE, or (iii) graduate-level classes in other departments necessary for the student's research or project. At most two classes can be from the third category.

All coursework must be at the 400-level or higher. Students must achieve a grade point average of 3.0 or higher; it is computed for all of the courses, excluding project and thesis credits, on the student's program of study.

**List of tracks and corresponding courses**

1. **Algorithms & Theory**:
   a. CSDS 440 Machine Learning
   b. CSDS 410 Analysis of Algorithms
   c. CSDS 455 Applied Graph Theory
   d. CSDS 456 Data Privacy
   e. CSDS 477 Advanced Algorithms
   f. MATH 408 Introduction to Cryptology

2. **Artificial Intelligence**:
   a. CSDS 440 Machine Learning
   b. CSDS 442 Causal Learning from Data
   c. CSDS 455 Applied Graph Theory
   d. ECSE 484 Computational Intelligence I: Basic Principles
   e. CSDS 491 Artificial Intelligence: Probabilistic Graphical Models
   f. CSDS 496 Artificial Intelligence: Sequential Decision Making
   g. CSDS 497 Artificial Intelligence: Statistical Natural Language Processing
   h. ECSE 499 Algorithmic Robotics
   i. ECSE 531 Computer Vision

3. **Bioinformatics**:
   a. CSDS 435 Data Mining
   b. CSDS 440 Machine Learning
   c. CSDS 410 Analysis of Algorithms
   d. CSDS 456 Data Privacy
   e. CSDS 458 Introduction to Bioinformatics
   f. CSDS 459 Bioinformatics for Systems Biology
   g. SYBB 412 Survey of Bioinformatics: Programming for Bioinformatics

4. **Computer Networks and Systems**:
   a. CSDS 427 Internet Security and Privacy
   b. ECSE 414 Wireless Communications
   c. CSDS 425 Computer Networks I
   d. CSDS 428 Computer Communications Networks II
   e. ECSE 438 High Performance Computing
   f. CSDS 441 Internet Applications
   g. CSDS 444 Computer Security

5. **Databases and Data Mining**:
   a. CSDS 405 Data Structures and File Management
   b. CSDS 433 Database Systems
   c. CSDS 435 Data Mining
   d. CSDS 439 Web Data Mining
   e. CSDS 440 Machine Learning
   f. STAT 426 Multivariate Analysis and Data Mining
   g. PQHS 471 Machine Learning & Data Mining

6. **Security and Privacy**:
   a. CSDS 427 Internet Security and Privacy
   b. CSDS 444 Computer Security
   c. CSDS 448 Smartphone Security
   d. CSDS 456 Data Privacy
   e. CSDS 493 Software Engineering
   f. MATH 408 Introduction to Cryptology

7. **Software Engineering**:
be noted that a change in research advisor may require that the student
the most common is a change of the student's field of interest. It should
Students may change advisors for a variety of reasons of which one of
in the PhD program, the research advisor is commonly known as the
academic advisor from the department faculty. For students enrolled
department faculty. If, however, the research advisor is not a member
the student's permanent academic advisor if he/she is a member of the
the student's research advisor. The research advisor will also serve as
each student must identify a faculty member who is willing to serve as

PhD Graduate Student Requirements (Electrical Engineering,
Computer Engineering, Systems and Control Engineering)
These regulations are in addition to the Academics Regulations of the
School of Graduate Studies and the Specific Requirements for the PhD
Degree of the Graduate Program in the Case School of Engineering as found in the General Catalog of Case Western Reserve University.

Admission
Requirements for admission include a strong record of scholarship in a completed bachelor’s degree program in a field of engineering, mathematical or physical sciences, and fluency in written and spoken English. The University requires all foreign applicants to show English proficiency by achieving a TOEFL score of at least 577 on the paper-based exam or 90 on the internet-based exam. It is required that all students submit original copies of GRE scores. Applications from students with a bachelor’s degree in fields other than those listed above may be granted admission on a provisional basis. Such provisional students may be advanced to full standing upon completion of prerequisite conditions stipulated in the letter of admission.

Registration
Course registration is performed through SIS. Each semester before registration, students should update any personal information that may have changed by logging onto the SIS and editing the appropriate information. All registration holds must be lifted in order to successfully complete the registration process.

Advising
Upon admission to the graduate program, each graduate student is assigned an academic advisor to assist in registration. This is a temporary assignment made by the Department Chairperson based on the student's academic and research interests as identified at the time of application. During the first two semesters in the program, it is strongly suggested that each student meet with various members of faculty to discuss academic objectives/goals and research opportunities. In order to complete the research component of their respective degree program, each student must identify a faculty member who is willing to serve as the student's research advisor. The research advisor will also serve as the student's permanent academic advisor if he/she is a member of the department faculty. If, however, the research advisor is not a member of the department faculty, the student is required to find a permanent academic advisor from the department faculty. For students enrolled in the PhD program, the research advisor is commonly known as the “dissertation” advisor.

An Academic Program must meet the following requirements:

- Select a major dissertation subject area in Electrical Engineering, Computer Engineering, or Systems and Control Engineering
- Fulfill all PhD course requirements in the chosen major area
- Have an approved Program of Study and complete the CWRU courses in the approved Program of Study with a cumulative grade point average of 3.25 or greater
- Successfully complete the PhD Qualifying Examination
- Successfully complete the PhD Proposal Defense
- Successfully complete and defend the PhD Dissertation
- Fulfill the PhD residency requirement

PhD Course Requirements and Academic Program
Each PhD student is required to have an Academic Program, approved by the academic advisor, Department Chairperson, and Dean of Graduate Studies, that includes a minimum of 36 credit hours of coursework beyond the BS degree. At least 18 credit hours of coursework must be taken at CWRU. In addition, the student is also required to complete a minimum of 18 credit hours of ECSE 701 Dissertation Ph.D. to fulfill the requirement for PhD-level research. Acceptable courses include suitable CWRU courses at the 400 level or higher and approved graduate-level courses taken at other institutions. Students holding a MS degree in an appropriate field of study from CWRU or another degree-granting institution may apply up to 18 credit hours of coursework completed for their MS degree towards the aforementioned 36 credit hour requirement.

Each PhD student is required to have a fully-approved Academic Program before taking the PhD Qualifying examination and before registering for the final 18 credit hours of the program. The Academic Program shall be prepared by the student and approved by the research advisor or the permanent academic advisor in the case where the research advisor is not in the Department.

An Academic Program must meet the following requirements:

- a. CSDS 425 Computer Networks I
- b. CSDS 433 Database Systems
- c. ECSE 438 High Performance Computing
- d. CSDS 441 Internet Applications
- e. CSDS 442 Causal Learning from Data
- f. CSDS 444 Computer Security
- g. CSDS 448 Smartphone Security
- h. CSDS 493 Software Engineering

start a new research project, which could result in delaying graduation. It is the responsibility of the student to inform the ECSE Office of Student Affairs in the event of a change in advisor.

The student shall be responsible for forming a dissertation guidance committee which shall consist of the student’s academic advisor and additional faculty members recommended by the advisor. For the PhD program, the minimum number of additional faculty members on the dissertation guidance committee is three, and at least two of the committee must be within the ECSE program areas (Computer Engineering, Electrical Engineering, and Systems and Control Engineering). The chairperson of the guidance committee is normally the candidate’s research advisor. Each student is required to file an Academic Program, which must be approved by the student’s advisor and the Department Chairperson, and submitted to the Dean of Graduate Studies. Full-time PhD students should choose a research advisor and file an Academic Program before taking the qualifier but no later than the beginning of the third semester. Upon passing the qualifier, full-time PhD students will be required to assemble the dissertation guidance committee, prepare a dissertation proposal, and present this proposal to the committee for their approval. This process should be completed within one semester of passing the PhD qualifier.

The PhD Degree Program
In order to successfully complete the PhD Degree Program, a student must satisfy the following requirements:

- Successfully complete the PhD Qualifying Examination
- Successfully complete the PhD Proposal Defense
- Successfully complete and defend the PhD Dissertation
- Fulfill the PhD residency requirement

- Fulfill all PhD course requirements in the chosen major area
• A minimum of two courses in mathematics, statistics, or basic science.
• At least six approved courses from the student’s major area of study. At least 4 of these courses must be from within the ECSE department.
• Four additional courses that are not listed under the student’s major program area. These courses should satisfy the requirement for breadth in the student’s program of study.
• A minimum of 18 hours of PhD Dissertation research as noted by enrollment in and successful completion of ECSE 701 Dissertation Ph.D.
• Successful completion of ECSE 400T Graduate Teaching I, ECSE 500T Graduate Teaching II and ECSE 600T Graduate Teaching III.
• Successful completion of the ECSE 500 ECSE Colloquium requirement (see below)

The above represents the minimum course requirements beyond the BS degree. The total number of 3 credit hour courses in the Academic Program is at least 12 (twelve) beyond the BS level. The selection of these courses should be done with the guidance from the student’s permanent academic advisor. Any additional courses may be in any one of the above categories as approved by the student’s advisor.

The PhD program includes a colloquium and public presentation requirement. For those who matriculated during or after Fall 2012, the requirement involves passing 3 semesters of ECSE 500 ECSE Colloquium and a public presentation of their research. Public presentations include conference presentations, department seminars, workshop presentations or similar presentations in a public venue. MS thesis and PhD dissertation defenses cannot be used to fulfill the public presentation requirement. It is expected that the ECSE 500 ECSE Colloquium requirement will be completed before the student applied for Advancement to Candidacy. Alternatively, the student may complete this requirement by giving a presentation as part of the ECSE department seminar series. Additional details and the associated forms can be acquired from the ECSE Office of Student Affairs. For students who matriculated before Fall 2012, the requirement can be met in one of two ways: (1) completing the requirements detailed above, or (2) passing 5 semesters of ECSE 500 ECSE Colloquium. Students (such as part-time students working in industry) may propose an alternative arrangement for fulfilling this requirement by submitting a written petition to the ECSE Graduate Studies Committee.

PhD Qualifying Examination
A student shall be admitted to PhD candidacy only after he or she has passed the PhD Qualifying Examination. The Qualifying Exam is intended to test the students’ knowledge in the student’s chosen major program area: Electrical Engineering, Computer Engineering, or Systems and Control Engineering. The objectives of the exam are:

1. To assess the PhD student’s understanding of the fundamental concepts in Electrical Engineering, Computer Engineering, or Systems and Control Engineering, as embodied in the respective graduate curriculum.

2. To ensure that the student have the ability to pursue PhD level research, and have mastered the graduate level coursework necessary to succeed as researchers

Full-time PhD students are recommended to take the PhD qualifier before the beginning of their third semester of full-time (or equivalent) enrollment, and must pass the exam within two years of being admitted to the program. For part-time students, the Qualifying Exam must be passed before more than 27 credit-hours of coursework have been completed. For students who must take remedial courses to make up for shortcomings in their engineering and mathematics knowledge base, the deadline can be extended to the fifth semester of full-time (or equivalent) enrollment, but this requires a petition to the ECSE Graduate Committee. Students have two opportunities to pass the PhD Qualifier. A student who fails to pass the Qualifier after two attempts will not be allowed to continue in the PhD program in the Department of Electrical, Computer, and Systems Engineering.

To pass the PhD Qualifier, the student must demonstrate proficiency in two parts:

Part 1
The first part of the PhD Qualifier assesses the student’s fundamental knowledge and proficiency in the student’s major program area:

Computer Engineering
Part 1 of the PhD Qualifier will consist of a written examination with questions drawn from several course areas listed below. At least three (3) topic areas must be pursued by the student for a complete qualifier. The exam style is a mini-project oriented, take home test that must be completed within a one week period.

1. ECSE 419 Computer System Architecture
2. CSDS 425 Computer Networks I
3. ECSE 315 Digital Systems Design
4. ECSE 488 Embedded Systems Design
5. ECSE 485 VLSI Systems
6. ECSE 401 Digital Signal Processing

Additional topic areas may be assigned depending on the student interests and recommendations from their advisors.

If a student fails all three areas of the written examination, the entire exam must be taken again. If a student fails some areas, the faculty may elect to give another exam to the student in just the areas failed.

The written part of the Qualifying Exam for Computer Engineering will be offered at least once a year at the end of the spring semester.

Electrical Engineering
(For students matriculating after 8/1/2014)
Students must demonstrate competency in one of the following areas within electrical engineering in which the electrical engineering faculty have established research thrust areas:

1. Circuits and Instrumentation
2. Robotics
3. Micro- and Nano-systems

To demonstrate competency in one of these areas, the student must do one of the following: (1) take the course for that area and pass that course with a grade of A, or (2) pass a written exam for that specific area. The designated courses for each of the areas are:

1. ECSE 426 MOS Integrated Circuit Design
2. ECSE 489 Robotics I
3. ECSE 422 Solid State Electronics II
In the event that a designated course is not offered within a reasonable period of time, the student may petition the faculty in electrical engineering to designate a suitable substitute.

A student failing to meet the requirements prescribed above may, with the support of his/her dissertation research advisor, petition the faculty for an oral exam. The oral exam will consist of a 30-minute presentation by the student to a 3-member examination committee made up of electrical engineering faculty. The topic will be drawn from the student's area of interest as selected by his/her advisor and approved by the committee. The topic may not come directly from the student's MS thesis conducted at CWRU or elsewhere.

A student has completed the PhD Qualifier in electrical engineering when: (1) he/she has successfully completed the aforementioned competency requirement, (2) a group of faculty within his/her selected research area has conducted a review of the student's academic record and determined that adequate progress has been made, and (3) the student has formally identified a dissertation advisor.

(For students matriculating prior to 8/1/2014)

The written portion of the PhD Qualifier in Electrical Engineering is designed to assess a student's knowledge and understanding of topics fundamental to all electrical engineering students pursuing a doctorate in the field. The written exam will consist of questions at the advanced undergraduate level covering material from the three topic areas listed below. Courses currently in the EE undergraduate curriculum corresponding to a particular topic area are listed in parentheses.

1. ECSE 309 Electromagnetic Fields I
2. ECSE 245 Electronic Circuits, ECSE 281 Logic Design and Computer Organization
3. ECSE 246 Signals and Systems

Exam problems will be limited to materials contained in the selected references as well as the aforementioned courses. Sample problems from previous exams as well as a list of relevant references are available upon request.

Students must show competency in all three tested areas. Upon recommendation of the faculty, a student showing marginal proficiency in one area may be required to correct this deficiency, for example, by taking an appropriate course (as determined by the faculty) and pass this course with at least a B grade or by serving as a teaching assistant of an appropriate course.

The written part of the Qualifying Exam for Electrical Engineering will be offered at least once a year during the month of January, prior to the beginning of the spring semester.

**Systems and Control Engineering**

Students must show competency in control systems engineering, signals and systems, and systems analysis (optimization, simulation, stochastic modeling, and decision and economic analysis). Students must demonstrate proficiency in at least three of the following areas:

1. Control Systems (ECSE 408 Introduction to Linear Systems, ECSE 304 Control Engineering I with Laboratory)
2. Optimization (ECSE 416 Convex Optimization for Engineering, ECSE 346 Engineering Optimization)

(For students matriculating after 8/1/2014)

Does not apply

(For students matriculating prior to 8/1/2014)

Only those students performing adequately on the written exam will advance to the oral portion of the qualifier. The exam will be administered by a three-member examination committee assembled from the ECSE faculty. The oral portion of the PhD Qualifier will consist of a two-part examination. The first part of the oral exam will consist of a 20-minute presentation by the student on a topic selected by the examination committee. The topic will be one that is well documented in the scientific/engineering literature. In selecting the topic, the examination committee will take into account the student's research interests, academic background, and experience in the field. The student will be given the topic 15 working days prior to the examination. The topic will be presented to the student in the form of a published paper or collection of papers. The student will be required to demonstrate competency in the following areas: (1) the material directly covered by the paper(s), (2) the material covered in the important references in the paper(s), and (3) any relevant background material that is necessary for the fundamental understanding of the paper.

The second part of the oral exam will consist of a series of questions drawn from the topic areas covered by the written exam.

As with the written exam, a student showing marginal proficiency during the oral exam may be asked to perform some sort of remediation at the discretion of the oral examination committee.

**Electrical Engineering**

A typical exam begins with a selection by the student's dissertation guidance committee of 5-6 research articles relevant to the student's research area. The students will be given 4 weeks to write a report answering questions formulated from those papers by the dissertation guidance committee. This will be followed within one week by an oral
exam during which the student will give an oral presentation based on the report and answer questions from the dissertation guidance committee and other attending ECSE faculty. Questions will be based on the report as well as miscellaneous questions on advanced topics in Systems and Control Engineering as deemed appropriate by committee members and/or other attending faculty.

**PhD Candidacy**
The final consideration of whether to admit the student to PhD candidacy will be taken by the PhD Qualifying Committee (for Electrical Engineering and Computer Engineering students) or the student’s dissertation guidance committee (for Systems and Control Engineering students) after the student has passed the PhD Qualifier. A written report on the results of the qualifier and PhD candidacy will be prepared by the committee and submitted to the Department Chairperson, who, in turn, will notify the School of Graduate Studies of the results.

**PhD Proposal**
After passing the Qualifier and being admitted to PhD candidacy, the PhD candidate is required to pass a Dissertation Proposal Exam on a timely basis, generally within one semester after being admitted to candidacy. This exam shall be administered by the student’s dissertation guidance committee and consists of a written dissertation proposal and an oral presentation of the proposed dissertation research. As part of the oral presentation, the student will be expected to answer questions covering the proposed research as well as questions on related topics as deemed appropriate by the student’s dissertation guidance committee. The written dissertation proposal must be received by the committee members at least ten days before the date scheduled for the oral exam and presentation. The Dissertation Proposal Exam, the PhD research, the final oral dissertation defense, and all other requirements in the student’s PhD program of study must be completed within five years after the student is admitted to PhD candidacy.

**The PhD Oral Defense**
The student shall provide an announcement containing a title, abstract, date, time and location of the defense to the ECSE Office of Student Affairs for general distribution at least 10 days in advance of the thesis defense.

**The PhD Residency Requirements**
All PhD students shall fulfill the PhD residency requirements set forth by the Case School of Engineering and the School of Graduate Studies. Specifically, the PhD student is required either to register for at least 9 credit hours during each of two consecutive semesters or to engage in academic work (taking courses, assisting in course development and/or teaching, fully engaging in research, or some other scholarly activities) in at least six consecutive terms (fall, spring, or summer) between matriculation and a period not exceeding 5 years after the first credited hour of ECSE 701 Dissertation Ph.D. The period during a leave of absence cannot be counted to fulfill the residency requirement.

**Appeals**
Any decision by an academic advisor, dissertation guidance committee, or Department Associate Chairperson may be appealed, in writing, to the Department Associate Chairperson who shall present the appeal, with his recommendations, to the faculty at its next regular faculty meeting. The faculty’s decision shall be final.

**Other Regulations**
All students pursuing graduate studies in the Electrical, Computer, and Systems Engineering department must abide by the academic regulations of the School of Graduate Studies and the Case School of Engineering contained in the most recent issue of the General Catalog of Case Western Reserve University, and supplemented by the Department of Electrical, Computer, and Systems Engineering regulations.

**NOTE:** The above regulations apply to graduate students who entered the degree programs in computer engineering, electrical engineering, and systems & control engineering after January 1, 2005.

**ECSE Colloquium and Presentation Requirement**

**PhD Students**
The requirement has two parts: (1) passing 3 semesters of ECSE 500 ECSE Colloquium, and (2) a public presentation.

1. **All PhD students are required to register for and pass ECSE 500 ECSE Colloquium for a total of three semesters of the PhD Program, and this is expected before Advancement to Candidacy.** (This is a 0 credit hour required course.) Students (such as students working in industry) may propose an alternative arrangement for fulfilling this requirement, by submitting a written petition to the Graduate Studies Committee.

2. **All PhD students must give a public presentation of their research, in addition to their PhD dissertation defense. This presentation must be given either at a research conference or in the ECSE seminar series.**

**Facilities**

**Computer Facilities**
The department computer facilities incorporate both Unix (primarily Linux) and Microsoft Windows-based operating systems on high-end computing workstations for education and research. A number of file, printing, database, and authentication servers support these workstations, as well as the administrative functions of the department. Labs are primarily located in the Olin and Glennan buildings, but include Nord Hall, and are networked via the Case network.

The Case network is a state-of-the-art, high-speed fiber optic campus-wide computer network that interconnects laboratories, faculty and student offices, classrooms, and student residence halls. It is one of the largest fiber-to-desktop networks anywhere in the world. Every desktop has a 1 Gbps (gigabit per second) connection to a fault-tolerant 10 Gbps backbone. To complement the wired network, over 1,200 wireless access points (WAPs) are also deployed allowing anyone with a laptop or wireless enabled PDA to access resources from practically anywhere on campus.

Off-campus users, through the use of virtual private network (VPN) servers, can use their broadband connections to access many on-campus resources, as well as software, as if they were physically connected to the Case network. The department and the university participate in the Internet2 and National Lambda Rail projects, which provides high-speed, inter-university network infrastructure allowing for enhanced collaboration between institutions. The Internet2 infrastructure allows students, faculty and staff alike the ability to enjoy extremely high-performance connections to other Internet2 member institutions.

Aside from services provided through a commodity Internet connection, Case network users can take advantage of numerous online databases such as EUCLIDplus, the University Libraries’ circulation and public access catalog, as well as Lexus-Nexus™ and various CD-ROM based dictionaries, thesauri, encyclopedias, and research databases. Many regional and national institutional library catalogs are accessible over the network, as well.
ECSE faculty are active users of the Microfabrication Laboratory and participants in the Advanced Platform Technology Center described under Interdisciplinary Research Centers.

**Additional Department Facilities**

**Sally & Larry Sears Undergraduate Design Laboratory**

This laboratory supports all departmental courses in circuits and includes a state-of-the-art lecture hall, a modernistic glass-walled lab, an electronics "store", and a student lounge and meeting area. Specialized lab space is available for senior projects and sponsored undergraduate programs. The lab is open to all undergraduates, and components are provided free of charge, so students can "play and tinker" with electronics and foster innovation and creativity. The laboratory provides access to PCs, oscilloscopes, signal generators, logic analyzers, and specialized equipment such as RF analyzers and generators. In addition, the lab includes full-time staff dedicated to the education, guidance and mentoring of undergraduates in the "art and practice" of hands-on engineering.

This is the central educational resource for students taking analog, digital, and mixed-signal courses in electronics, and has been supported by various corporations in addition to alumnus Larry Sears, a successful engineer and entrepreneur. Basic workstations consist of Windows-based computers equipped with LabView software, as well as Agilent 5466x oscilloscopes, 33120A Waveform Generators, 34401A Digital Multimeters, and E3631A power supplies. Advanced workstations are similarly configured, but with a wider variety of high-performance test equipment.

**ECSE Undergraduate Computer Lab**

This laboratory (recently renovated with major funding provided by Rockwell Automation) on the 8th floor of the Olin building is accompanied by a suite of instructor/TA offices and supports the freshman computing classes: ENGR 131 Elementary Computer Programming and ECSE 132 Introduction to Programming in Java. Thirty student Macintosh workstations with underlying UNIX operating systems are available for hands-on instruction and support the study of introductory programming at the university.

**Nord Computer Laboratory**

This is a general-purpose computer facility that is open 24 hours a day, to all students. The lab contains 50 PCs running Windows and four Apple Macintosh computers. Facilities for color printing, faxing, copying and scanning are provided. Special software includes PRO/Engineer, ChemCAD and Visual Studio. Blank CDs, floppy disks, transparencies and other supplies are available for purchase. Visit the website (https://engineering.case.edu/it/nord-computer-lab/) for more information.

**Kevin Kranzusch Virtual Worlds (Gaming and Simulation) Laboratory**

The Kevin Kranzusch Virtual Worlds Gaming and Simulation Laboratory provides software and hardware to support education and research in computer gaming and simulation activities within the Electrical, Computer, and Systems Engineering Department and the University at large. The lab has been leveraged to provide students with extensive game play opportunities and excellent, strongly experiential simulation and game development educational opportunities – primarily targeted to the ECSE undergraduate population.

The lab also stimulates large amounts of cross-disciplinary collaboration in both education and research. Simulation and visualization techniques are of great value in all science and engineering fields, and the lab is capable of supporting advanced applications of these techniques in real-time applications. In addition, interactive technologies and video games require substantial artistic resources, that has resulted in excellent opportunities for educational and research collaboration with the Cleveland Institute of Art (CIA), the School of Nursing, the Medical School, and the Psychology Department. Of particular note has been the Advanced Game Project course (ECSE 390 Advanced Game Development Project) taught jointly by CWRU and CIA for juniors and seniors. This course has been very popular and has provided truly excellent student game design and production experiences while receiving industrial and popular recognition and acclaim. In addition, an entry-level computer game programming course (ECSE 290 Introduction to Computer Game Design and Implementation) is available for students who have taken both a Java-based programming course and a data structures course to provide an introduction to many of the technical aspects of computer game development. Many other courses in the department also use the lab as an important part of their curriculum including courses on computer graphics, artificial intelligence, simulation, digital signal processing, and control systems. The lab also supports research in the department requiring significant computational resources, e.g. GPU acceleration, VLSI simulation, etc.

A recent large donation for the lab has allowed for the update and renovation of the entire lab including the physical infrastructure (carpeting, furniture, etc.), the gaming PCs, and the gaming consoles. In addition, a new VR and AR room has been added to represent this new area connected strongly to computer gaming. The lab is now structured into a PC gaming area and an adjacent gaming console area, a VR/AR room, a portable gaming development room, and a team collaboration area connected strongly to computer gaming. The lab is now structured into a PC gaming area and an adjacent gaming console area, a VR/AR room, a portable gaming development room, and a team collaboration room.

The renovated lab includes the following primary equipment:

- 24 New Alienware PCs with Dell 27” 4K monitors
- 4 Sony Bravia Television monitors 75” 3DTV
- 2 Microsoft HoloLens AR Units
- 4 Oculus Rift VR units with Haptic Touch Input devices
- A 3D projector (and large wall screen) with 3D capability for common presentations
- 4 Xbox One Units with Xbox One controllers
- 4 PS4 Sony PlayStation units with controllers

**Networks Laboratory**

Supported through donations from both Cisco Systems and Microsoft Research, the networks lab has 15 stations complete with a PC, a Cisco switch and router, IP telephony equipment, as well as network patches back to a central rack where devices at one workstation may be routed to other equipment in the lab. A “library” of related equipment is also available.

**Intelligent Networks & Systems Architeciting (INSA) Research Laboratory**

The Intelligent Networks & Systems Architeciting (INSA) Research Laboratory is a state-of-the-art research facility dedicated to intelligent computer networks, systems engineering, design, and architecting. It includes optimization, simulation, artificial intelligence, visualization, and emulation. This lab has been partially supported by NASA’s Space Exploration programs for Human and Robotic Technology (H&RT). The INSA Lab is equipped with 10 high-performance workstations and 2 servers in a mixed Windows and Linux environment, with over 40 installed network interface cards providing connectivity to its wired and wireless network.
research networks. It includes software packages such as GINO and LINDDO, Arena simulation, ns2 and OPNET, as well as the STK satellite toolkit, artificial neural network, systems architecting and modeling, and statistical analysis and data management packages such as SPSS. The INSA Lab is also used for research in heterogeneous, sensor web, and mobile ad-hoc networks with space and battlefield applications.

**VLSI/CAD Design Laboratory**

This lab has been supported by the Semiconductor Research Corporation, NSF, AFRL, NASA, Synopsys, Mentor, and Sun Microsystems. This laboratory has a number of advanced UNIX/Linux workstations that run commercial CAD software tools for VLSI ASIC and microchip design, simulation and testing. The lab is currently being used to develop design and testing techniques for embedded system-on-chip (SoC).

**Embedded Systems Laboratory**

The Embedded Systems Laboratory is equipped with several Sun Blade Workstations running Solaris and Intel PCs running Linux. This lab has been recently equipped with advanced FPGA Virtex II prototype boards from Xilinx, including many Xilinx Virtex II FPGAs and Xilinx CAD tools for development work. A grant-in-aid from Synopsys has provided the Synopsys commercial CAD tools for software development and simulation. More recently, the lab has been equipped with many modern embedded platforms based on Raspberry Pi 3 and 4 models with numerous sensor devices. The lab has also been equipped with advanced embedded FPGA/ARM boards based on the Xilinx Zynq platform. This lab is also equipped with NIOS FPGA boards from Altera, including software tools. Together with software CAD EDK tools, these modern equipment and tools will be of great help to students’ education and research work.

**Mixed-Signal Integrated Circuit Laboratory**

This research laboratory includes a cluster of Windows workstations and a UNIX server with integrated circuit design software (Cadence Custom IC Bundle), as well as a variety of equipment used in the characterization of mixed-signal (analog and digital) integrated circuits, which are typically fabricated using the MOSIS foundry service. Test equipment includes an IC probe station, surface-mount soldering equipment, logic and network/spectrum analyzers, an assortment of digital oscilloscopes with sample rates up to 1 GHz, and a variety of function generators, multi-meters, and power supplies.

**Microelectromechanical Systems (MEMS) Research Laboratory**

The MEMS Research Laboratory is equipped for microfabrication processes that do not require a clean room environment. These include chemical-mechanical polishing (two systems), bulk silicon etching, aqueous chemical release of free-standing micromechanical components, and supercritical point drying. In addition to the fabrication capabilities, the lab is also well equipped for testing and evaluation of MEMS components as it houses wafer-scale probe stations, a vacuum probe station, a multipurpose vacuum chamber, and an interferometric load-deflection station. Two large (8 x 2 ft2) vibration isolated air tables are available for custom testing setups. The laboratory has a wide variety of electronic testing instruments, including a complete IV-CV testing setup.

**BioMicroSystems Laboratory**

This research laboratory focuses on developing wireless integrated circuits and microsystems for a variety of applications in biomedical and neural engineering. The laboratory contains several PC computers, software packages for design, simulation, and layout of high-performance, low-noise, analog/mixed-signal/RF circuits and systems, and testing/measurement equipment such as dc power supply, arbitrary function generator, multichannel mixed-signal oscilloscope, data acquisition hardware, spectrum analyzer, potentiostat, and current source meter. Visit the website (http://www.mohsenilab-cwru.org/) for more information.

**Emerging Materials Development and Evaluation Laboratory**

The EMDE Laboratory is equipped with tooling useful in characterizing materials for MEMS applications. The laboratory contains a PC-based apparatus for load-deflection and burst testing of micromachined membranes, a custom-built test chamber for evaluation and reliability testing of MEMS-based pressure transducers and other membrane-based devices, a probe station for electrical characterization of micro-devices, a fume hood configured for wet chemical etching of Si, polymers, and a wide variety of metals, tooling for electroplating, an optical reflectometer, and a supercritical-point dryer for release of surface micromachined devices. The lab also has a PC with layout and finite element modeling software for device design, fabrication process design, and analysis of testing data.

**Control and Energy Systems Center (CESC)**

The Control and Energy Systems Center (CESC) looks for new transformational research and engineering breakthroughs to build a better world, improving our industry, economy, energy, environment, water resources and society, all with sustainability and within an international collaboration framework. With an interdisciplinary and concurrent engineering approach, the CESC focuses on bridging the gap between fundamental and applied research in advanced control and systems engineering, with special emphasis on energy innovation, wind energy, power systems, water treatment plants, sustainability, spacecraft, environmental and industrial applications. Fundamental research foci are to gain knowledge and understanding on multi-input-multi-output physical worlds, nonlinear plants, distributed parameter systems, plants with non-minimum phase, time delay and/or uncertainty, etc., and to develop new methodologies to design quantitative robust controllers to improve the efficiency and reliability of such systems. Applied research aims to develop advanced solutions with industrial partners, for practical control engineering problems in energy systems, multi-megawatt wind turbines, renewable energy plants, power system dynamics and control, grid integration, energy storage, power electronics, wastewater treatment plants, desalination systems, formation flying spacecraft, satellites with flexible appendages, heating systems, robotics, parallel kinematics, telescope control, etc. The Center was established in 2009 with the support of the Milton and Tamar Maltz Family Foundation and the Cleveland Foundation.

**Process Control Laboratory**

This laboratory contains process control pilot plants and computerized hardware for data acquisition and process control that is used for demonstrations, teaching, and research. This laboratory also has access to steam and compressed air for use in the pilot processes that include systems for flow and temperature control, level and temperature control, pH control, and pressure control plants.

**Dynamics and Control Laboratory**

This laboratory contains data acquisition and control devices, PLCs, electromechanical systems, and mechanical, pneumatic, and electrical laboratory experiments for demonstrations, teaching, and research. Particular systems include: AC/DC servo systems, multi-degree-of-
freedom robotic systems, rectilinear and torsional multi-degree-of-freedom vibration systems, inverted pendulum, magnetic levitation system, and a PLC-controlled low-voltage AC smart grid demonstration system that includes conventional and renewable (wind and solar) generation, battery and compressed air energy storage, residential, commercial and industry loads, a capacitor bank for real-time power factor correction, and advanced sensing and controls implemented through an interconnected system of intelligent software agents.

Courses

ECSE 132. Introduction to Programming in Java. 3 Units.
An introduction to modern programming language features, computer programming and algorithmic problem solving with an emphasis on the Java language. Computers and code compilation; conditional statements, subprograms, loops, methods; object-oriented design, inheritance and polymorphism, abstract classes and interfaces; types, type systems, generic types, abstract data types, strings, arrays, linked lists; software development, modular code design, unit testing; strings, text and file I/O; GUI components, GUI event handling; threads; comparison of Java to C, C++, and C#. Offered as CSDS 132 and ECSE 132. Counts for CAS Quantitative Reasoning Requirement.

ECSE 216. Fundamental System Concepts. 3 Units.
Develops framework for addressing problems in science and engineering that require an integrated, interdisciplinary approach, including the effective management of complexity and uncertainty. Introduces fundamental system concepts in an integrated framework. Properties and behavior of phenomena regardless of the physical implementation through a focus on the structure and logic of information flow. Systematic problem solving methodology using systems concepts. Recommended preparation: MATH 224.

ECSE 233. Introduction to Data Structures. 4 Units.
Different representations of data: lists, stacks and queues, trees, graphs, and files. Manipulation of data: searching and sorting, hashing, recursion and higher order functions. Abstract data types, templating, and the separation of interface and implementation. Introduction to asymptotic analysis. The Java language is used to illustrate the concepts and as an implementation vehicle throughout the course. Offered as CSDS 233 and ECSE 233. Prereq: CSDS 132 or ECSE 132 or EECS 132.

ECSE 245. Electronic Circuits. 4 Units.

ECSE 246. Signals and Systems. 4 Units.

ECSE 275. Fundamentals of Robotics. 4 Units.
The Fundamentals of Robotics course will expose students to fundamental principles of robotics. Students will explore high level conceptual foundations of robotics beginning with Braitenberg vehicles and apply this knowledge to simulated and physical robot hardware in laboratory experiences and in a final project. Laboratory experiences will guide students through applying theory to practice increasingly complex tasks in a project oriented, group work environment. The course culminates in a robotics challenge project at the end of the semester. Topics covered are: sensors, actuators, kinematics, control, planning and programming. Programming languages and concepts (e.g., C++, object oriented programming) used in robotics will be introduced and used with modern robotics programming toolboxes and frameworks. Prior experience with these languages will not be necessary. Previous experience with robotics is not required for this course. Offered as CSDS 275 and ECSE 275. Prereq: (ENGR 131 or EECS 132) and PHYS 121 and MATH 121.

ECSE 281. Logic Design and Computer Organization. 4 Units.
Fundamentals of digital systems in terms of both computer organization and logic level design. Organization of digital computers; information representation; boolean algebra; analysis and synthesis of combinational and sequential circuits; datapaths and register transfers; instruction sets and assembly language; input/output and communication; memory. Offered as CSDS 281 and ECSE 281. Prereq: ENGR 131 or EECS 132.

ECSE 290. Introduction to Computer Game Design and Implementation. 3 Units.
This class begins with an examination of the history of video games and of game design. Games will be examined in a systems context to understand gaming and game design fundamentals. Various topics relating directly to the implementation of computer games will be introduced including graphics, animation, artificial intelligence, user interfaces, the simulation of motion, sound generation, and networking. Extensive study of past and current computer games will be used to illustrate course concepts. Individual and group projects will be used throughout the semester to motivate, illustrate and demonstrate the course concepts and ideas. Group game development and implementation projects will culminate in classroom presentation and evaluation. Offered as CSDS 290 and ECSE 290. Prereq: EECS 132 or ENGR 131.

ECSE 296. Independent Projects. 1 - 3 Units.
Independent projects in Electrical Engineering, Computer Engineering and Systems Engineering. Recommended preparation: ENGR 131 or EECS/CSDS/ECSE 132. Prereq: Limited to freshmen and sophomore students.

ECSE 297. Special Topics. 1 - 3 Units.
Special topics in Electrical Engineering, Computer Engineering and Systems and Control Engineering. Prereq: Limited to freshmen and sophomores.

ECSE 301. Digital Logic Laboratory. 2 Units.
This course is an introductory experimental laboratory for digital networks. The course introduces students to the process of design, analysis, synthesis and implementation of digital networks. The course culminates in a robotics design project at the end of the semester. Topics covered are: sensors, actuators, kinematics, control, planning and programming. Programming languages and concepts (e.g., C++, object oriented programming) used in robotics will be introduced and used with modern robotics programming toolboxes and frameworks. Prior experience with these languages will not be necessary. Previous experience with robotics is not required for this course. Offered as CSDS 275 and ECSE 275. Prereq: (ENGR 131 or EECS 132) and PHYS 121 and MATH 121.

ECSE 290. Introduction to Computer Game Design and Implementation. 3 Units.
This class begins with an examination of the history of video games and of game design. Games will be examined in a systems context to understand gaming and game design fundamentals. Various topics relating directly to the implementation of computer games will be introduced including graphics, animation, artificial intelligence, user interfaces, the simulation of motion, sound generation, and networking. Extensive study of past and current computer games will be used to illustrate course concepts. Individual and group projects will be used throughout the semester to motivate, illustrate and demonstrate the course concepts and ideas. Group game development and implementation projects will culminate in classroom presentation and evaluation. Offered as CSDS 290 and ECSE 290. Prereq: EECS 132 or ENGR 131.

ECSE 296. Independent Projects. 1 - 3 Units.
Independent projects in Electrical Engineering, Computer Engineering and Systems Engineering. Recommended preparation: ENGR 131 or EECS/CSDS/ECSE 132. Prereq: Limited to freshmen and sophomore students.

ECSE 297. Special Topics. 1 - 3 Units.
Special topics in Electrical Engineering, Computer Engineering and Systems and Control Engineering. Prereq: Limited to freshmen and sophomores.

ECSE 301. Digital Logic Laboratory. 2 Units.
This course is an introductory experimental laboratory for digital networks. The course introduces students to the process of design, analysis, synthesis and implementation of digital networks. The course culminates in a robotics design project at the end of the semester. Topics covered are: sensors, actuators, kinematics, control, planning and programming. Programming languages and concepts (e.g., C++, object oriented programming) used in robotics will be introduced and used with modern robotics programming toolboxes and frameworks. Prior experience with these languages will not be necessary. Previous experience with robotics is not required for this course. Offered as CSDS 275 and ECSE 275. Prereq: (ENGR 131 or EECS 132) and PHYS 121 and MATH 121.

ECSE 281. Logic Design and Computer Organization. 4 Units.
Fundamentals of digital systems in terms of both computer organization and logic level design. Organization of digital computers; information representation; boolean algebra; analysis and synthesis of combinational and sequential circuits; datapaths and register transfers; instruction sets and assembly language; input/output and communication; memory. Offered as CSDS 281 and ECSE 281. Prereq: ENGR 131 or EECS 132.

ECSE 290. Introduction to Computer Game Design and Implementation. 3 Units.
This class begins with an examination of the history of video games and of game design. Games will be examined in a systems context to understand gaming and game design fundamentals. Various topics relating directly to the implementation of computer games will be introduced including graphics, animation, artificial intelligence, user interfaces, the simulation of motion, sound generation, and networking. Extensive study of past and current computer games will be used to illustrate course concepts. Individual and group projects will be used throughout the semester to motivate, illustrate and demonstrate the course concepts and ideas. Group game development and implementation projects will culminate in classroom presentation and evaluation. Offered as CSDS 290 and ECSE 290. Prereq: EECS 132 or ENGR 131.

ECSE 296. Independent Projects. 1 - 3 Units.
Independent projects in Electrical Engineering, Computer Engineering and Systems Engineering. Recommended preparation: ENGR 131 or EECS/CSDS/ECSE 132. Prereq: Limited to freshmen and sophomore students.

ECSE 297. Special Topics. 1 - 3 Units.
Special topics in Electrical Engineering, Computer Engineering and Systems and Control Engineering. Prereq: Limited to freshmen and sophomores.

ECSE 301. Digital Logic Laboratory. 2 Units.
This course is an introductory experimental laboratory for digital networks. The course introduces students to the process of design, analysis, synthesis and implementation of digital networks. The course culminates in a robotics design project at the end of the semester. Topics covered are: sensors, actuators, kinematics, control, planning and programming. Programming languages and concepts (e.g., C++, object oriented programming) used in robotics will be introduced and used with modern robotics programming toolboxes and frameworks. Prior experience with these languages will not be necessary. Previous experience with robotics is not required for this course. Offered as CSDS 275 and ECSE 275. Prereq: (ENGR 131 or EECS 132) and PHYS 121 and MATH 121.
ECSE 302. Discrete Mathematics. 3 Units.
A general introduction to basic mathematical terminology and the techniques of abstract mathematics in the context of discrete mathematics. Topics introduced are mathematical reasoning, Boolean connectives, deduction, mathematical induction, sets, functions and relations, algorithms, graphs, combinatorial reasoning. Offered as CSDS 302, ECSE 302 and MATH 304. Prereq: MATH 122 or MATH 124 or MATH 126.

ECSE 303. Embedded Systems Design and Laboratory. 3 Units.
The purpose of this Course and Laboratory is to expose and train the students in modern embedded systems software and hardware design techniques and practices including networking and mobile connectivity. The rationale for the Course and Lab is based on the explosive growth of embedded systems in the industry, specifically industrial automation, aviation, surveillance, medical devices, but also common consumer products. The course topics cover a wide range of material as follows. Microcontroller systems based on the ARM processor. Essential components, memories, busses interfaces. Devices, peripherals, GPIOs, device drivers. Sensors and Actuators, A/D, D/A, DSP. Embedded Linux, kernels, kernel modules, compilers and assemblers. Libraries, and debugging facilities. The Lab will be based on common platforms such as Raspberry pi, Arduino, ARM embed, supported by a network of Linux workstations.

ECSE 304. Control Engineering I with Laboratory. 3 Units.
Analysis and design techniques for control applications. Linearization of nonlinear systems. Design specifications. Classical design methods: root locus, bode, nyquist. PID, lead, lag, lead-lag controller design. State space modeling, solution, controllability, observability and stability. Modeling and control demonstrations and experiments single-input/single-output and multivariable systems. Control system analysis/design/implementation software. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: EECS 246 or EMAE 350.

ECSE 305. Control Engineering I Laboratory. 1 Unit.
A laboratory course based on the material in ECSE 304. Modeling, simulation, and analysis using MATLAB. Physical experiments involving control of mechanical systems, process control systems, and design of PID controllers. Coreq: ECSE 304.

ECSE 309. Electromagnetic Fields I. 3 Units.
Maxwell’s integral and differential equations, boundary conditions, constitutive relations, energy conservation and Pointing vector, wave equation, plane waves, propagating waves and transmission lines, characteristic impedance, reflection coefficient and standing wave ratio, in-depth analysis of coaxial and strip lines, electro- and magneto-quasistatics, simple boundary value problems, correspondence between fields and circuit concepts, energy and forces. Prereq: PHYS 124 or PHYS 124. Prereq or Coreq: MATH 224.

ECSE 313. Signal Processing. 3 Units.
Fourier series and transforms. Analog and digital filters. Fast-Fourier transforms, sampling, and modulation for discrete time signals and systems. Consideration of stochastic signals and linear processing of stochastic signals using correlation functions and spectral analysis. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: EECS 246.

ECSE 314. Computer Architecture. 3 Units.
This course provides students the opportunity to study and evaluate a modern computer architecture design. The course covers topics in fundamentals of computer design, performance, cost, instruction set design, processor implementation, control unit, pipelining, communication and network, memory hierarchy, computer arithmetic, input-output, and an introduction to RISC and super-scalar processors. Offered as CSDS 314 and ECSE 314. Prereq: EECS 246.

ECSE 315. Digital Systems Design. 4 Units.
This course gives students the ability to design modern digital circuits. The course covers topics in logic level analysis and synthesis, digital electronics: transistors, CMOS logic gates, CMOS lay-out, design metrics space, power, delay. Programmable logic (partitioning, routing), state machine analysis and synthesis, register transfer level block design, datapath, controllers, ASM charts, microsequencers, emulation and rapid prototyping, and switch/logic-level simulation. Prereq: EECS 281.

ECSE 316. Wireless Communications. 3 Units.
This course introduces the fundamentals of wireless communications including backgrounds, important concepts, and cutting-edge technologies. In particular, the course focuses on interesting and important topics in wireless communications, such as (but not limited to): Overview of wireless communication networks and protocols, the cellular concept, system design fundamentals, brief introduction to wireless physical layer fundamentals, multiple access control protocols for wireless systems, wireless networking (routing/rerouting, wireless TCP/IP), mobility management, call admission control and resource allocation, revolution/evolution towards future generation wireless networks, overview of wireless mesh networks, mobile ad hoc networks and wireless sensor networks, and wireless security (optional). Offered as ECSE 316 and ECSE 414. Prereq: (ECSE 351 or ECSE 351) with a C or better, or a Graduate student.

ECSE 317. Computer Design - FPGAs. 3 Units.
The aim is to expose the student to methodologies for systematic design of digital systems with emphasis on programmable logic implementations and prototyping. The course requires a number of hands-on experiments and an overall lab project. The lab involves a number of class lectures to familiarize the students with the modern design techniques based on VHDL/Verilog Hardware Design Languages, CAD tools, and FPGAs. Offered as ECSE 317 and ECSE 417. Prereq: EECS 281.
ECSE 318. VLSI/CAD. 4 Units.
With Very Large Scale Integration (VLSI) technology there is an increased need for Computer-Aided Design (CAD) techniques and tools to help in the design of large digital systems that deliver both performance and functionality. Such high performance tools are of great importance in the VLSI design process, both to perform functional, logical, and behavioral modeling and verification to aid the testing process. This course discusses the fundamentals in behavioral languages, both VHDL and Verilog, with hands-on experience. Prereq: EECS 281 and EECS 315.

ECSE 319. Applied Probability and Stochastic Processes for Biology. 3 Units.
Applications of probability and stochastic processes to biological systems. Mathematical topics will include: introduction to discrete and continuous probability spaces (including numerical generation of pseudo random samples from specified probability distributions), Markov processes in discrete and continuous time with discrete and continuous sample spaces, point processes including homogeneous and inhomogeneous Poisson processes and Markov chains on graphs, and diffusion processes including Brownian motion and the Ornstein-Uhlenbeck process. Biological topics will be determined by the interests of the students and the instructor. Likely topics include: stochastic ion channels, molecular motors and stochastic ratchets, actin and tubulin polymerization, random walk models for neural spike trains, bacterial chemotaxis, signaling and genetic regulatory networks, and stochastic predator-prey dynamics. The emphasis will be on practical simulation and analysis of stochastic phenomena in biological systems. Numerical methods will be developed using a combination of MATLAB, the R statistical package, MCell, and/or URDME, at the discretion of the instructor. Student projects will comprise a major part of the course. Offered as BIOL 319, ECSE 319, MATH 319, SYBB 319, BIOL 419, EBME 419, MATH 419, PHOL 419, and SYBB 419. Prereq: MATH 224 or MATH 223 and BIOL 300 or BIOL 306 and MATH 201 or MATH 307 or consent of instructor.

ECSE 321. Semiconductor Electronic Devices. 4 Units.
Energy bands and charge carriers in semiconductors and their experimental verifications. Excess carriers in semiconductors. Principles of operation of semiconductor devices that rely on the electrical properties of semiconductor surfaces and junctions. Development of equivalent circuit models and performance limitations of these devices. Devices covered include: junctions, bipolar transistors, Schottky junctions, MOS capacitors, junction gate and MOS field effect transistors, optical devices such as photodetectors, light-emitting diodes, solar cells, and lasers. Prereq: PHYS 122. Prereq or Coreq: MATH 224.

ECSE 322. Integrated Circuits and Electronic Devices. 3 Units.
Technology of monolithic integrated circuits and devices, including crystal growth and doping, photolithography, vacuum technology, metallization, wet etching, thin film basics, oxidation, diffusion, ion implantation, epitaxy, chemical vapor deposition, plasma processing, and micromachining. Basics of semiconductor devices including junction diodes, bipolar junction transistors, and field effect transistors. Prereq: PHYS 122. Prereq or Coreq: MATH 224.

ECSE 324. Modeling and Simulation of Continuous Dynamical Systems. 3 Units.
This course examines the computer-based modeling and simulation of continuous dynamical system behavior in a variety of systems including electric power systems, industrial control systems, and signal processing that are represented by a set of differential equations need to be solved numerically in order to compute and represent their behavior for study. In addition to these applications, there are many other important applications of these tools in computer games, virtual worlds, weather forecasting, and population models, to name a few examples. Numerical integration techniques are developed to perform these computations. Multiple computational engines such as Matlab, Simulink, Unity, and physics engines etc. are also examined as examples of commonly used software to solve for and visualize continuous-time system behavior. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide motivation and a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: MATH 224.

ECSE 326. Instrumentation Electronics. 3 Units.
A second course in instrumentation with emphasis on sensor interface electronics. General concepts in measurement systems, including accuracy, precision, sensitivity, linearity, and resolution. The physics and modeling of resistive, reactive, self-generating, and direct-digital sensors. Signal conditioning for same, including bridge circuits, coherent detectors, and a variety of amplifier topologies: differential, instrumentation, charge, and transimpedance. Noise and drift in amplifiers and resistors. Practical issues of interference, including grounding, shielding, supply/return, and isolation amplifiers. Prereq: ENGR 210 and (EECS 246, EBME 308 or EMAE 350).

ECSE 329. Introduction to Nanomaterials: Material Synthesis, Properties and Device Applications. 3 Units.
The behavior of nanoscale materials is close to, atomic behavior rather than that of bulk materials. The growth of nanomaterials, such as quantum dots, has the tendency to be viewed as an art rather than science. These nanostructures have changed our view of Nature. This course is designed to provide an introduction to nanomaterials and devices to both senior undergraduate and graduate students in engineering. Topics covered include an introduction to growth issues, quantum mechanics, quantization of electronic energy levels in periodic potentials, tunneling, distribution functions and density of states, optical and electronic properties, and devices. Offered as ECSE 329 and ECSE 429. Coreq: ECE 309.

ECSE 337. Compiler Design. 4 Units.
Design and implementation of compilers and other language processors. Scanners and lexical analysis; regular expressions and finite automata; scanner generators; parsers and syntax analysis; context free grammars; parser generators; semantic analysis; intermediate code generation; runtime environments; code generation; machine independent optimizations; data flow and dependence analysis. There will be a significant programming project involving the use of compiler tools and software development tools and techniques. Offered as CSDS 337 and ECSE 337. Prereq: (CSDS 233 or ECSE 233 or EECS 233) and (CSDS 281 or ECSE 281 or EECS 281).
ECSE 338. Intro to Operating Systems and Concurrent Programming. 4 Units.
Intro to OS: OS Structures, processes, threads, CPU scheduling, deadlocks, memory management, file system implementations, virtual machines, cloud computing. Concurrent programming: fork, join, concurrent statement, critical section problem, safety and liveness properties of concurrent programs, process synchronization algorithms, semaphores, monitors. UNIX systems programming: system calls, UNIX System V IPCs, threads, RPCs, shell programming. Offered as CSDS 338, ECSE, 338, CSDS 338N and ECSE 338N. Prereq: Computer Science Major or Minor and (CSDS 233 or ECSE 233 or EECS 233) with a C or higher.

ECSE 338N. Intro to Operating Systems and Concurrent Programming. 4 Units.
Intro to OS: OS Structures, processes, threads, CPU scheduling, deadlocks, memory management, file system implementations, virtual machines, cloud computing. Concurrent programming: fork, join, concurrent statement, critical section problem, safety and liveness properties of concurrent programs, process synchronization algorithms, semaphores, monitors. UNIX systems programming: system calls, UNIX System V IPCs, threads, RPCs, shell programming. Offered as CSDS 338, ECSE, 338, CSDS 338N and ECSE 338N. Prereq: (CSDS 233 or ECSE 233 or EECS 233) with a C or higher.

ECSE 342. Introduction to Global Issues. 3 Units.
This systems course is based on the paradigm of the world as a complex system. Global issues such as population, world trade and financial markets, resources (energy, water, land), global climate change, and others are considered with particular emphasis put on their mutual interdependence. A reasoning support computer system which contains extensive data and a family of models is used for future assessment. Students are engaged in individual, custom-tailored, projects of creating conditions for a desirable or sustainable future based on data and scientific knowledge available. Students at CWRU will interact with students from fifteen universities that have been strategically selected in order to give global coverage to UNESCO’S Global-problematique Education Network Initiative (GENIe) in joint, participatory scenario analysis via the internet.

ECSE 342I. Global Issues, Health, & Sustainability in India. 3 Units.
Global Issues, Health, & Sustainability in India is an interdisciplinary social work and engineering collaboration that includes a short-term cross-cultural immersion. This course brings together social work (knowledge, values, and skills) and health care (promotion, education, and community) perspectives to the understanding of technical project assessment, selection, planning and implementation in India. The course is also designed to help students understand culturally relevant community engagement strategies to ensure project acceptance in underserved and developing communities. Many field sites will be visited in order to observe first-hand the community assessment and development of projects that engineers implement. An example of these projects could include infrastructure to support green energy and water (resource planning, development, conservation, and sanitation). This study abroad course will acquaint students with history and culture of India, its social, political and economic development and the impact it has on health and the delivery of social services. Participants will learn about factors affecting the abilities to reach, treat, educate, and equip communities to improve health outcomes. Engineering students will learn the quantitative aspects using a paradigm of hierarchical systems, mathematical modeling, and scenario analysis using a ‘reasoning support’ system. Together the engineering, social work, and health sciences students in disciplinary-balanced teams will jointly work on real and meaningful projects marrying the descriptive scenarios (that is the ‘subjective’ aspect) with the numerical scenario analysis based on mathematical modeling (or ‘objective’ aspect) to form a coherent view of the future. The course will be taught using both lecture and experiential modalities. Engineering students will conduct computer modeling work. Along with visiting a variety of governmental and non-governmental institutions, organizations and projects, students will visit historical sites and attend cultural events. Offered as ECSE 342I and SASS 375I. Counts for CAS Global & Cultural Diversity Requirement.

ECSE 344. Electronic Analysis and Design. 3 Units.
The design and analysis of real-world circuits. Topics include: junction diodes, non-ideal op-amp models, characteristics and models for large and small signal operation of bipolar junction transistors (BJTs) and field effect transistors (FETs), selection of operating point and biasing for BJT and FET amplifiers. Hybrid-pi model and other advanced circuit models, cascaded amplifiers, negative feedback, differential amplifiers, oscillators, tuned circuits, and phase-locked loops. Computers will be extensively used to model circuits. Selected experiments and/or laboratory projects. Prereq: EECS 245.

ECSE 346. Engineering Optimization. 3 Units.
Optimization techniques including linear programming and extensions; transportation and assignment problems; network flow optimization; quadratic, integer, and separable programming; geometric programming; and dynamic programming. Nonlinear optimization topics: optimality criteria, gradient and other practical unconstrained and constrained methods. Computer applications using engineering and business case studies. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Recommended preparation: MATH 201.
ECSE 350. Operations and Systems Design. 3 Units.
Introduction to design, modeling, and optimization of operations and scheduling systems with applications to computer science and engineering problems. Topics include, forecasting and time series, strategic, tactical, and operational planning, life cycle analysis, learning curves, resources allocation, materials requirement and capacity planning, sequencing, scheduling, inventory control, project management and planning. Tools for analysis include: multi-objective optimization, queuing models, simulation, and artificial intelligence.

ECSE 351. Communications and Signal Analysis. 3 Units.
Fourier transform analysis and sampling of signals. AM, FM and SSB modulation and other modulation methods such as pulse code, delta, pulse position, PSK and FSK. Detection, multiplexing, performance evaluation in terms of signal-to-noise ratio and bandwidth requirements. Prereq: ECES 246 or requisites not met permission.

ECSE 352. Engineering Economics and Decision Analysis. 3 Units.
Economic analysis of engineering projects, focusing on financial decisions concerning capital investments. Present worth, annual worth, internal rate of return, benefit/cost ratio. Replacement and abandonment policies, effects of taxes, and inflation. Decision making under risk and uncertainty. Decision trees. Value of information. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course.

ECSE 354. Digital Communications. 3 Units.

ECSE 360. Manufacturing and Automated Systems. 3 Units.
Formulation, modeling, planning, and control of manufacturing and automated systems with applications to computer science and engineering problems. Topics include, design of products and processes, location/spatial problems, transportation and assignment, product and process layout, group technology and clustering, cellular and network flow layouts, computer control systems, reliability and maintenance, and statistical quality control. Tools and analysis include: multi-objective optimization, artificial intelligence, and heuristics for combinatorial problems. Offered as ECSE 360 and ECSE 460.

ECSE 365. Complex Systems Biology. 3 Units.
Complex Systems Biology is an interdisciplinary course based on systems science, engineering, biology, and medicine. The objective is to provide students with an understanding of the current state of systems biology and major challenges ahead. The biological phenomena across the level of complexity will be considered from molecular to organisms and ecology to provide universality of the systems concepts for understanding the functions and behavior of biological systems. Case studies are used and a course project is required to be completed. Prereq: Junior Standing.

ECSE 366. Computer Graphics. 3 Units.
Theory and practice of computer graphics: object and environment representation including coordinate transformations, image extraction including perspective, hidden surface, and shading algorithms; and interaction. Covers a wide range of graphic display devices and systems with emphasis in interactive shaded graphics. Offered as CSDS 366, ECSE 366, CSDS 466 and ECSE 466. Prereq: EECS 233.

ECSE 368. Power System Analysis I. 3 Units.
This course introduces the steady-state modeling and analysis of electric power systems. The course discusses the modeling of essential power system network components such as transformers and transmission lines. The course also discusses important steady-state analysis of three-phase power system network, such as the power flow and economic operation studies. Through the use of PowerWorld Simulator education software, further understanding and knowledge can be gained on the operational characteristics of AC power systems. Special topics concerning new grid technologies will be discussed towards the semester end. The prerequisite requirements of the course include the concepts and computational techniques of Alternative Current (AC) circuit and electromagnetic field. Offered as ECSE 368 and ECSE 468. Prereq: EECS 245.

ECSE 369. Power System Analysis II. 3 Units.
This course extends upon the steady state analysis of power systems to cover study topics that are essential for power system planning and operation. Special system operating conditions are considered, such as unbalanced network operation and component faults. Among the most important analytical methods developed, are symmetrical components and sequence networks. Other study topics discussed include the electric machine modeling and power system transient stability. The latter half of the course presents computational methods and control algorithms that are essential for power system operation, such as generation control and state estimation. Offered as ECSE 369 and ECSE 469. Prereq: EECS 368.

ECSE 370. Smart Grid. 3 Units.
This course starts with an introduction to the US electric power system infrastructure and national electricity policy. Then power system operations and reliability practices are described. In the context of currently existing infrastructure and operation strategies, the course discusses the new Smart Grid technologies such as renewable resources, distributed generation, demand response, energy storage and electric vehicles. Additional important topics of discussion include Advanced Meter Infrastructure, microgrids, the IEEE 1547 Interconnection Standard, and other interoperability standards. The course captures the evolving progress made in Smart Grid technologies and the impacts on power system economics and reliability. Offered as ECSE 370 and ECSE 470. Prereq: EECS 368.
ECSE 371. Applied Circuit Design. 4 Units.
This course will consist of lectures and lab projects designed to provide students with an opportunity to consolidate their theoretical knowledge of electronics and to acquaint them with the art and practice of circuit and product design. The lectures will cover electrical and electronic circuits and many electronic and electrical devices and applications. Examples include mixed-signal circuits, power electronics, magnetic and piezo components, gas discharge devices, sensors, motors and generators, and power systems. In addition, there will be discussion of professional topics such as regulatory agencies, manufacturing, testing, reliability, and product cost. Weekly labs will be true "design" opportunities representing real-world applications. A specification or functional description will be provided, and the students will design the circuit, select all components, construct a breadboard, and test. The objective will be functional, pragmatic, cost-effective designs. Prereq: EECS 245.

ECSE 372. Introduction to Distribution Systems. 3 Units.
Introduction to Distribution Systems provides students with a fundamental understanding of distribution power system configurations, equipment and loads. It also provides a detailed review of distributed energy resources and their impacts on utility distribution systems. Since today's distribution utilities are facing the challenge of managing a distribution network made up of assets from proven and mature technologies while integrating new technologies this course will also discuss a concept of smart grid and its application to distribution systems. The first part of the course reviews the fundamental methods used in the steady state analysis of AC circuits as applied to power distribution systems following by the steady-state modeling of electric power distribution systems. The second part of the course introduces fundamental analysis of electric power distribution systems such as power flow, state estimation, and fault calculation and discusses concerns such as reliability, power quality and voltage regulation. Offered as EECS 372 and EECS 472. Prereq: PHYS 122 and MATH 224.

ECSE 373. Modern Robot Programming. 3 Units.
The goal of this course is to learn modern methods for building up robot capabilities using the Robot Operating System (ROS). Through a sequence of assignments, students learn how to write software to control both simulated and physical robots. Material includes: interfacing software to robot I/O; path and trajectory planning for robot arms; object identification and localization from 3-D sensing; manipulation planning; and development of graphical interfaces for supervisory robot control. Laboratory assignments are scheduled in small groups to explore implementations on specific robots. Graduate students will also perform an independent project. Offered as CSDS 373, ECSE 373, CSDS 473 and ECSE 473. Prereq: ENGR 131 or EECS 132. Coreq: EECS 373L.

ECSE 374. Advanced Control and Energy Systems. 3 Units.
This course introduces applied quantitative robust and nonlinear control engineering techniques to regulate automatically renewable energy systems in general and wind turbines in particular. The course also studies the fundamentals for dynamic multidisciplinary modeling and analysis of large multi-megawatt wind turbines (mechanics, aerodynamics, electrical systems, control concepts, etc.). The course combines lecture sessions and lab hours. The 400-level includes an experimental lab competition, where the object is to design, implement, and experimentally validate a control strategy to regulate a real system in the laboratory (helicopter control competition or similar); it will also include additional project design reports. Offered as ECSE 374 and ECSE 474. Prereq: EECS 304.

ECSE 375. Applied Control. 3 Units.
This course provides a practical treatment of the study of control engineering systems. It emphasizes best practices in industry so that students learn what aspects of plant and control system design are critical. The course develops theory and practice for digital computer control systems; PID controller design (modes, forms and tuning methods); Control structure design (feed-forward, cascade control, predictive control, disturbance observers, multi-loop configurations, multivariable control); Actuators, sensors and common loops; Dynamic performance evaluation; and some advanced control techniques (quantitative robust control, gain-scheduling and adaptive control) to achieve a good performance over a range of operating conditions. Recommended preparation: EECS/ECSE 374 or EECS/ECSE 474. Offered as ECSE 375 and ECSE 475. Prereq: EECS 304 or Requisites Not Met permission.

ECSE 376. Mobile Robotics. 4 Units.
Design of software systems for mobile robot control, including: motion control; sensory processing; localization and mapping; mobile-robot planning and navigation; and implementation of goal-directed behaviors. The course has a heavy lab component involving a sequence of design challenges and competitions performed in teams. Offered as CSDS 376 and ECSE 376. Prereq: EECS 373 or EECS 473.

ECSE 377. Introduction to Connected Devices. 3 Units.
Introduction to Connected Devices (e.g., Internet of Things). Undergraduates work in pairs to build a complete connected-device system, an embedded device with wireless networking, cloud and web, and mobile, and then develop hands-on experience with systems-level aspects of the connected-device system, including analytics, remote firmware update, load testing, and essential security. Students learn about current architectures, languages, and technologies, such as Pub/Sub (MQTT), Python, Objective-C, Python Django, JavaScript, HTML/CSS, and Bluetooth Low Energy. Offered as CSDS 377 and ECSE 377.

ECSE 379. Introduction to Relay Protection. 3 Units.
Protection does not mean prevention, but rather, minimizing the duration of the trouble and limiting the damage, outage time, and related problems that may result otherwise. Introduction to Relay Protection introduces the power system protection, including basic fundamental understanding of relaying, common protection methods and relay applications. The first part of the course reviews the technical tools of the relay engineering (phasors, polarity and symmetrical components), fault analyzes, protection fundamentals and basic design principles. The second part of the course focuses on the line, transformer, bus, generation and motor protection. The course will be accompanied by relay protection laboratory where students will have hands on experience with main types of protective relays. Offered as ECSE 379 and ECS3 479. Prereq: MATH 224 and PHYS 122.
ECSE 390. Advanced Game Development Project. 3 Units.
This game development project course will bring together an inter-
professional group of students in the fields of engineering, computer
science, and art to focus on the design and development of a complete,
fully functioning computer game as an interdisciplinary team. The
student teams are given complete liberty to design their own fully
functional games from their original concept to a playable game
published in an online marketplace. Student teams will experience the
entire game development cycle as they execute their projects.
Responsibilities include creating a game idea, writing a story, developing
the artwork, designing characters, implementing music and sound
effects, programming and testing the game, and publishing the final
project. Students enrolled in 487 will develop a healthcare or education
virtual environment or video game in collaboration with a mentor who
has expertise in the chosen area. Offered as CSDS 390, ECSE 390, and

ECSE 394. Introduction to Information Theory. 3 Units.
This course is intended as an introduction to information and coding
theory with emphasis on the mathematical aspects. It is suitable for
advanced undergraduate and graduate students in mathematics, applied
mathematics, statistics, physics, computer science and electrical
engineering. Course content: Information measures-entropy, relative
entropy, mutual information, and their properties. Typical sets and
sequences, asymptotic equipartition property, data compression.
Channel coding and capacity; channel coding theorem. Differential
entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory
inequalities (400 level). Additional topics, which may include compressed
sensing and elements of quantum information theory. Recommended
preparation: MATH 201 or MATH 307. Offered as MATH 394, CSDS 394,
ECSE 394, MATH 494, CSDS 494 and ECSE 494. Prereq: MATH 223 and
MATH 380 or requisites not met permission.

ECSE 396. Independent Projects. 1 - 6 Units.
Independent projects in Computer Engineering, Electrical Engineering,
and Systems and Control Engineering. Prereq: Limited to juniors and
seniors.

ECSE 397. Special Topics. 1 - 6 Units.
Special topics in Computer Engineering, Electrical Engineering,
and Systems and Control Engineering. Prereq: Limited to juniors and
seniors.

ECSE 398. Engineering Projects I. 4 Units.
Capstone course for electrical, computer, and systems and control
engineering seniors. Material from previous and concurrent courses used
to solve engineering design problems. Professional engineering topics
such as project management, engineering design, communications,
multidisciplinary teaming, and professional ethics. Requirements include
periodic reporting of progress, plus a final oral presentation and written
report. Scheduled formal project presentations during last week of
classes. Counts as SAGES Senior Capstone. Prereq: Senior Standing.
Prereq or Coreq: ENGR 398 and ENGL 398.

ECSE 399. Engineering Projects II. 3 Units.
Continuation of ECSE 398. Material from previous and concurrent
courses applied to engineering design and research. Requirements
include periodic reporting of progress, plus a final oral presentation and
written report. Prereq: Senior Standing.

ECSE 400T. Graduate Teaching I. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching
undergraduate or graduate students. The experience is expected to
involve direct student contact but will be based upon the specific
departmental needs and teaching obligations. This teaching experience
will be conducted under the supervision of the faculty member who is
responsible for the course, but the academic advisor will assess the
educational plan to ensure that it provides an educational experience for
the student. Students in this course may be expected to perform one or
more of the following teaching related activities: grading homeworks,
quizzes, and exams, having office hours for students, tutoring students.
Recommended preparation: Ph.D. student in ECSE department.

ECSE 401. Digital Signal Processing. 3 Units.
Characterization of discrete-time signals and systems. Fourier analysis:
the Discrete-time Fourier Transform, the Discrete-time Fourier series, the
Discrete Fourier Transform and the Fast Fourier Transform. Continuous-
time signal sampling and signal reconstruction. Digital filter design:
infinite impulse response filters, finite impulse response filters, filter
realization and quantization effects. Random signals: discrete correlation
sequences and power density spectra, response of linear systems.
Recommended preparation: EEC 431 or equivalent.

ECSE 404. Digital Control Systems. 3 Units.
Analysis and design techniques for computer based control systems.
Sampling, hybrid continuous-time/discrete-time system modeling;
sampled data and state space representations, controllability,
observability and stability, transformation of analog controllers, design
of deadbeat and state feedback controllers; pole placement controllers
based on input/output models, introduction to model identification,
optimal control and adaptive control. Recommended preparation:
EECS/ECSE 304 or equivalent.

In this course, money and profit as measures of "goodness" in
engineering design are studied. Methods for economic analysis of capital
investments are developed and the financial evaluation of machinery,
manufacturing processes, buildings, R&D personnel development, and
other long-lived investments is emphasized. Optimization methods and
decision analysis techniques are examined to identify economically
attractive alternatives. Basic concepts of cost accounting are also
covered. Topics include: economics criteria for comparing projects:
present worth, annual worth analysis; depreciation and taxation;
retirement and replacement; effect of inflation and escalation on
economic evaluations; case studies; use of optimization methods to
evaluate many alternatives; decision analysis; accounting fundamentals:
income and balance sheets; cost accounting. Offered as ECSE 407 and
EPOM 407.

ECSE 408. Introduction to Linear Systems. 3 Units.
Analysis and design of linear feedback systems using state-space
techniques. Review of matrix theory, linearization, transition maps
and variations of constants formula, structural properties of state-
space models, controllability and observability, realization theory, pole
assignment and stabilization, linear quadratic regulator problems,
observers, and the separation theorem. Recommended preparation:
EECS/ECSE 304.
ECSE 410. Mobile Health (mHealth) Technology. 3 Units.
Advances in communications, computer, and medical technology have facilitated the practice of personalized health, which utilizes sensory computational communication systems to support improved and more personalized healthcare and healthy lifestyle choices. The current proliferation of broadband wireless services, along with more powerful and convenient handheld devices, is helping to introduce real-time monitoring and guidance for a wide array of patients. Indeed, a large research community and a nascent industry is beginning to connect medical care with technology developers, vendors of wireless and sensing hardware systems, network service providers, and enterprise data management communities. Students in the course and labs will explore cutting-edge technologies in 1) information technologies and 2) healthcare/medical applications, through lectures, lab assignments, exams, presentations, and final projects. The overall course objectives are to introduce electrical engineering, computer engineering, and computer science students the fundamentals of wearable sensors, mobile health informatics, big data analysis, telehealthcare security & privacy, and human computer interaction considerations. Prereq: MS and PhD student only.

ECSE 411. Applied Engineering Statistics. 3 Units.
In this course a combination of lectures, demonstrations, case studies, and individual and group computer problems provides an intensive introduction to fundamental concepts, applications and the practice of contemporary engineering statistics. Each topic is introduced through realistic sample problems to be solved first by using standard spreadsheet programs and then using more sophisticated software packages. Primary attention is given to teaching the fundamental concepts underlying standard analysis methods. Offered as EPOM 405 and ECSE 411.

ECSE 413. Nonlinear Systems I. 3 Units.
This course will provide an introduction to techniques used for the analysis of nonlinear dynamic systems. Topics will include existence and uniqueness of solutions, phase plane analysis of two dimensional systems including Poincare-Bendixson, describing functions for single-input single-output systems, averaging methods, bifurcation theory, stability, and an introduction to the study of complicated dynamics and chaos. Recommended preparation: Concurrent enrollment in ECSE 408.

ECSE 414. Wireless Communications. 3 Units.
This course introduces the fundamentals of wireless communications including backgrounds, important concepts, and cutting-edge technologies. In particular, the course focuses on interesting and important topics in wireless communications, such as (but not limited to): Overview of wireless communication networks and protocols, the cellular concept, system design fundamentals, brief introduction to wireless physical layer fundamentals, multiple access control protocols for wireless systems, wireless networking (routing/rerouting, wireless TCP/IP), mobility management, call admission control and resource allocation, revolution/evolution towards future generation wireless networks, overview of wireless mesh networks, mobile ad hoc networks and wireless sensor networks, and wireless security (optional). Offered as ECSE 316 and ECSE 414. Prereq: Graduate student or (EECS 351 or ECSE 351) with a C or better.

ECSE 415. Integrated Circuit Technology I. 3 Units.

ECSE 416. Convex Optimization for Engineering. 3 Units.
This course will focus on the development of a working knowledge and skills to recognize, formulate, and solve convex optimization problems that are so prevalent in engineering. Applications in control systems; parameter and state estimation; signal processing; communications and networks; circuit design; data modeling and analysis; data mining including clustering and classification; and combinatorial and global optimization will be highlighted. New reliable and efficient methods, particular those based on interior-point methods and other special methods to solve convex optimization problems will be emphasized. Implementation issues will also be underscored. Recommended preparation: MATH 201 or equivalent.

ECSE 417. Computer Design - FPGAs. 3 Units.
The aim is to expose the student to methodologies for systematic design of digital systems with emphasis on programmable logic implementations and prototyping. The course requires a number of hands-on experiments and an overall lab project. The lab involves a number of class lectures to familiarize the students with the modern design techniques based on VHDL/Verilog Hardware Design Languages, CAD tools, and FPGAs. Offered as ECSE 317 and ECSE 417.

ECSE 418. System Identification and Adaptive Control. 3 Units.

ECSE 419. Computer System Architecture. 3 Units.
Interaction between computer systems hardware and software. Pipeline techniques - instruction pipelining - arithmetic pipelines. Instruction level parallelism. Cache mechanism. I/O structures. Examples taken from existing computer systems.

ECSE 420. Numerical Methods. 3 Units.

ECSE 421. Optimization of Dynamic Systems. 3 Units.
This course will focus on the development of a working knowledge and skills to recognize, formulate, and solve convex optimization problems that are so prevalent in engineering. Applications in control systems; parameter and state estimation; signal processing; communications and networks; circuit design; data modeling and analysis; data mining including clustering and classification; and combinatorial and global optimization will be highlighted. New reliable and efficient methods, particular those based on interior-point methods and other special methods to solve convex optimization problems will be emphasized. Implementation issues will also be underscored. Recommended preparation: MATH 201 or equivalent.

ECSE 424. Introduction to Nanotechnology. 3 Units.
An exploration of emerging nanotechnology research. Lectures and class discussion on 1) nanostructures: superlattices, nanowires, nanotubes, quantum dots, nanoparticles, nanocomposites, proteins, bacteria, DNA; 2) nanoscale physical phenomena: mechanical, electrical, chemical, thermal, biological, optical, magnetic; 3) nanofabrication: bottom up and top down methods; 4) characterization: microscopy, property measurement techniques; 5) devices/applications: electronics, sensors, actuators, biomedical, energy conversion. Topics will cover interdisciplinary aspects of the field. Offered as ECSE 424 and EMAE 424.
ECSE 426. MOS Integrated Circuit Design. 3 Units.

ECSE 427. Optoelectronic and Photonic Devices. 3 Units.
In this course, we will study the optical transitions, absorptions, and gains in semiconductors. We will discuss the optical processes in semiconductor bulk as well as low dimensional structures such as quantum well and quantum dot. The fundamentals, technologies, and applications of important optoelectronic devices (e.g., light-emitting diodes, semiconductor lasers, solar cells and photo-detectors) will be introduced. We will learn the current state-of-the-art of these devices. Recommended preparation: ECSE 329 and ECSE 429.

ECSE 429. Introduction to Nanomaterials: Material Synthesis, Properties and Device Applications. 3 Units.
The behavior of nanoscale materials is close, to atomic behavior rather than that of bulk materials. The growth of nanomaterials, such as quantum dots, has the tendency to be viewed as an art rather than science. These nanostructures have changed our view of Nature. This course is designed to provide an introduction to nanomaterials and devices to both senior undergraduate and graduate students in engineering. Topics covered include an introduction to growth issues, quantum mechanics, quantization of electronic energy levels in periodic potentials, tunneling, distribution functions and density of states, optical and electronic properties, and devices. Offered as ECSE 329 and ECSE 429.

ECSE 434. Microsystems Technology. 3 Units.
This course provides an overarching coverage of microsystems technology, which is rooted in micro-electromechanical systems (MEMS). It covers the convergence of sensors and actuators, with wireless communications, computing and (social) networks. Microsystems incorporate sensors and actuators to interface computing with its physical environment-enabling perception and control. Microsystems are key enablers of smartphones, wearables, drones, robots, cars, aircrafts, weapons, etc. Recommended preparation: ECES/ECSE 322.

ECSE 438. High Performance Computing. 3 Units.
High performance computing (HPC) leverages parallel processing in order to maximize speed and throughput. This hands-on course will cover theoretical and practical aspects of HPC. Theoretical concepts covered include computer architecture, parallel programming, and performance optimization. Practical applications will be discussed from various information and scientific fields. Practical considerations will include HPC job management and Unix scripting. Weekly assessments and a course project will be required. Offered as CSDS 438 and ECSE 438. Prereq: EECS 233 or graduate standing.

ECSE 443. Flexible Electronics. 3 Units.
Learning about flexible and stretchable electronics from materials to applications. Covering organic and inorganic semiconductors, vacuum and solution-based metal-oxide semiconductors, nanomembranes and nanocrystals, conductors and insulators, flexible and ultra-high-resolution displays, light-emitting transistors, organic and inorganic photovoltaics, large-area imagers and sensors, non-volatile memories and radio-frequency identification tags. Discussing applications of flexible, stretchable and large-area electronics as part of the foregoing topics. Recommended preparation: EECS/ECSE 322.
ECSE 467. Commercialization and Intellectual Property Management. 3 Units.
This interdisciplinary course covers a variety of topics, including principles of intellectual property and intellectual property management, business strategies and modeling relevant to the creation of start-up companies and exploitation of IP rights as they relate to biomedical-related inventions. The goal of this course is to address issues relating to the commercialization of biomedical-related inventions by exposing law students, MBA students, and Ph.D. candidates (in genetics and proteomics) to the challenges and opportunities encountered when attempting to develop biomedical intellectual property from the point of early discovery to the clinic and market. Specifically, this course seeks to provide students with the ability to value a given technological advance or invention holistically, focusing on issues that extend beyond scientific efficacy and include patient and practitioner value propositions, legal and intellectual property protection, business modeling, potential market impacts, market competition, and ethical, social, and healthcare practitioner acceptance. During this course, law students, MBA students, and Ph.D. candidates in genomics and proteomics will work in teams of five (two laws students, two MBA students and one Ph.D. candidate), focusing on issues of commercialization and IP management of biomedical-related inventions. The instructors will be drawn from the law school, business school, and technology-transfer office. Please visit the following website for more information: fusioninnovate.com. Offered as LAWS 5341, MGMT 467, GENE 467, GENE 467, EBME 467 and ECSE 467.

ECSE 468. Power System Analysis I. 3 Units.
This course introduces the steady-state modeling and analysis of electric power systems. The course discusses the modeling of essential power system network components such as transformers and transmission lines. The course also discusses important steady-state analysis of three-phase power system network, such as the power flow and economic operation studies. Through the use of PowerWorld Simulator education software, further understanding and knowledge can be gained on the operational characteristics of AC power systems. Special topics concerning new grid technologies will be discussed towards the semester end. The prerequisite requirements of the course include the concepts and computational techniques of Alternative Current (AC) circuit and electromagnetic field. Offered as ECSE 368 and ECSE 468. Prereq: EECS 245.

ECSE 469. Power System Analysis II. 3 Units.
This course extends upon the steady state analysis of power systems to cover study topics that are essential for power system planning and operation. Special system operating conditions are considered, such as unbalanced network operation and component faults. Among the most important analytical methods developed, are symmetrical components and sequence networks. Other study topics discussed include the electric machine modeling and power system transient stability. The latter half of the course presents computational methods and control algorithms that are essential for power system operation, such as generation control and state estimation. Offered as ECSE 369 and ECSE 469. Prereq: EECS 368.

ECSE 470. Smart Grid. 3 Units.
This course starts with an introduction to the US electric power system infrastructure and national electricity policy. Then power system operations and reliability practices are described. In the context of currently existing infrastructure and operation strategies, the course discusses the new Smart Grid technologies such as renewable resources, distributed generation, demand response, energy storage and electric vehicles. Additional important topics of discussion include Advanced Meter Infrastructure, microgrids, the IEEE 1547 Interconnection Standard, and other interoperability standards. The course captures the evolving progress made in Smart Grid technologies and the impacts on power system economics and reliability. Offered as ECSE 370 and ECSE 470. Prereq: ECSE 368.

ECSE 472. Introduction to Distribution Systems. 3 Units.
Introduction to Distribution Systems provides students with a fundamental understanding of distribution power system configurations, equipment and loads. It also provides a detailed review of distributed energy resources and their impacts on utility distribution systems. Since today's distribution utilities are facing the challenge of managing a distribution network made up of assets from proven and mature technologies while integrating new technologies this course will also discuss a concept of smart grid and its application to distribution systems. The first part of the course reviews the fundamental methods used in the steady state analysis of AC circuits as applied to power distribution systems following by the steady-state modeling of electric power distribution systems. The second part of the course introduces fundamental analysis of electric power distribution systems such as power flow, state estimation, and fault calculation and discusses concerns such as reliability, power quality and voltage regulation. Offered as ECSE 372 and ECSE 472. Prereq: Graduate student standing.

ECSE 473. Modern Robot Programming. 3 Units.
The goal of this course is to learn modern methods for building up robot capabilities using the Robot Operating System (ROS). Through a sequence of assignments, students learn how to write software to control both simulated and physical robots. Material includes: interfacing software to robot I/O; path and trajectory planning for robot arms; object identification and localization from 3-D sensing; manipulation planning; and development of graphical interfaces for supervisory robot control. Laboratory assignments are scheduled in small groups to explore implementations on specific robots. Graduate students will also perform an independent project. Offered as CSDS 373, ECSE 373, CSDS 473 and ECSE 473. Prereq: ENGR 131 or ECES 132.

ECSE 474. Advanced Control and Energy Systems. 3 Units.
This course introduces applied quantitative robust and nonlinear control engineering techniques to regulate automatically renewable energy systems in general and wind turbines in particular. The course also studies the fundamentals for dynamic multidisciplinary modeling and analysis of large multi-megawatt wind turbines (mechanics, aerodynamics, electrical systems, control concepts, etc.). The course combines lecture sessions and lab hours. The 400-level includes an experimental lab competition, where the object is to design, implement, and experimentally validate a control strategy to regulate a real system in the laboratory (helicopter control competition or similar); it will also include additional project design reports. Offered as ECSE 374 and ECSE 474. Prereq: EECS 304.
ECSE 475. Applied Control. 3 Units.
This course provides a practical treatment of the study of control engineering systems. It emphasizes best practices in industry so that students learn what aspects of plant and control system design are critical. The course develops theory and practice for digital computer control systems; PID controller design (modes, forms and tuning methods); Control structure design (feed-forward, cascade control, predictive control, disturbance observers, multi-loop configurations, multivariable control); Actuators, sensors and common loops; Dynamic performance evaluation; and some advanced control techniques (quantitative robust control, gain-scheduling and adaptive control) to achieve a good performance over a range of operating conditions. Recommended preparation: EECS/ECSE 374 or EECS/ECSE 474. Offered as ECSE 375 and ECSE 475. Prereq: EECS 304 or Requisites Not Met permission.

ECSE 476. Mobile Robotics. 3 Units.
Design of software systems for mobile robot control, including: motion control; sensory processing; localization and mapping; mobile-robot planning and navigation; and implementation of goal-directed behaviors. The course has a heavy lab component involving a sequence of design challenges and competitions performed in teams. Offered as CSDS 476 and ECSE 476. Prereq: EECS 373 or ECES 473.

ECSE 478. Computational Neuroscience. 3 Units.
Computer simulations and mathematical analysis of neurons and neural circuits, and the computational properties of nervous systems. Students are taught a range of models for neurons and neural circuits, and are asked to implement and explore the computational and dynamic properties of these models. The course introduces students to dynamical systems theory for the analysis of neurons and neural learning, models of brain systems, and their relationship to artificial and neural networks. Term project required. Students enrolled in MATH 478 will make arrangements with the instructor to attend additional lectures and complete additional assignments addressing mathematical topics related to the course. Recommended preparation: MATH 223 and MATH 224 or BIOL 300 and BIOL 306. Offered as BIOL 378, COGS 378, MATH 378, BIOL 478, CSDS 478, EBME 478, ECSE 478, MATH 478 and NEUR 478.

ECSE 479. Introduction to Relay Protection. 3 Units.
Protection does not mean prevention, but rather, minimizing the duration of the trouble and limiting the damage, outage time, and related problems that may result otherwise. Introduction to Relay Protection introduces the power system protection, including basic fundamental understanding of relaying, common protection methods and relay applications. The first part of the course reviews the technical tools of the relay engineering (phasors, polarity and symmetrical components), fault analyzes, protection fundamentals and basic design principles. The second part of the course focuses on the line, transformer, bus, generation and motor protection. The course will be accompanied by relay protection laboratory where students will have hands on experience with main types of protective relays. Offered as ECSE 379 and ECS3 479. Prereq: Graduate student standing.

ECSE 480A. Introduction to Wireless Health. 3 Units.
Study of convergence of wireless communications, microsystems, information technology, persuasive psychology, and health care. Discussion of health care delivery system, medical decision-making, persuasive psychology, and wireless health value chain and business models. Understanding of health information technology, processing of monitoring data, wireless communication, biomedical sensing techniques, and health monitoring technical approaches and solutions. Offered as ECSE 480A and EBME 480A.

ECSE 480B. The Human Body. 3 Units.
Study of structural organization of the body. Introduction to anatomy, physiology, and pathology, covering the various systems of the body. Comparison of elegant and efficient operation of the body and the related consequences of when things go wrong, presented in the context of each system of the body. Introduction to medical diagnosis and terminology in the course of covering the foregoing. Offered as ECSE 480B and EBME 480B.

ECSE 480C. Biomedical Sensing Instrumentation. 3 Units.
Study of principles, applications, and design of biomedical instruments with special emphasis on transducers. Understanding of basic sensors, amplifiers, and signal processing. Discussion of the origin of biopotential, and biopotential electrodes and amplifiers (including biotelemetry). Understanding of chemical sensors and clinical laboratory instrumentation, including microfluidics. Offered as ECSE 480C and EBME 480C. Prereq: EECS/EBME 480A, EECS/EBME 480B

ECSE 480D. The Health Care Delivery Ecosystem. 3 Units.
Perspective on health care delivery in other countries. Offered as ECSE 480D and EBME 480D.

ECSE 480E. Wireless Communications and Networking. 3 Units.
Essentials of wireless communications and networking, including teletraffic engineering, radio propagation, digital and cellular communications, wireless wide-area network architecture, speech and channel coding, modulation schemes, antennas, security, networking and transport layers, and 4G systems. Hands-on learning of the anatomy of a cell phone, and a paired wireless health device and its gateway. Offered as ECSE 480E and EBME 480E.

ECSE 480F. Physicians, Hospitals and Clinics. 3 Units.
Rotation through one or more health care provider facilities for a first-hand understanding of care delivery practice, coordination, and management issues. First-hand exposure to clinical personnel, patients, medical devices and instruments, and organizational workflow. Familiarity with provider protocols, physician referral practices, electronic records, clinical decision support systems, acute and chronic care, and inpatient and ambulatory care. Offered as ECSE 480F and EBME 480F.

ECSE 480G. Applied Cryptography. 3 Units.
This course begins with a discussion of how mobility-driven computing and communication systems use cryptography to protect data and protocols. The foundation for critical cryptographic concepts, techniques, and algorithms are covered. The fundamental cryptographic concepts are studied, including: symmetric encryption, public key encryption, digital signatures, cryptographic hash function, and message authentication codes; cryptographic protocols, such as key exchange, remote user authentication, and interactive proofs; cryptanalysis of cryptographic primitives and protocols, such as by side-channel attacks, differential cryptanalysis, or replay attacks; and cryptanalytic techniques on deployed systems, such as memory remanence, timing attacks, fault attacks, and differential power analysis. Techniques used for code making (cryptographic) and break codes (cryptanalytic) are covered, as well as how these techniques are used within larger security systems.
ECSE 480H. Software Security. 3 Units.
This course begins with discussions of good software engineering practices to ensure security in modern software systems and additional challenges to security due to code mobility in software for mobility-driven computing. The basics of software security and threat models, methods to protect software (operating systems, databases, distributed software) - including risk analysis, authentication and authorization, access control, and software architecture for security - are studied. Principles of secure coding, validation and verification of secure software, software and data watermarking, code obfuscation, tamper resistant software are studied, as well as the benefits of open source and closed source software. Use of software as an attack mechanism and emerging attack models (including joint hardware-software attacks) are studied.

ECSE 480K. Hardware Security. 3 Units.
This course begins with the keys to enabling secure, trustworthy operation of computer hardware - understanding security issues and how appropriate security measures are included during design, verification, test, and deployment. Increasingly the security primitives such as the Trusted Computing Module are being introduced at the hardware level to prevent the compromise of security in systems being deployed today. A comprehensive coverage of security issues in computer hardware is provided. Topics of embedded systems security, hardware Trojans, security in implantable medical devices, security in RFID/NFC, protection from side channel attacks, tamper resistance and crypto processor design, trusted FPGA design/JTAG, hardware-based cryptanalysis, and hardware IP protection against piracy and reverse-engineering are covered. A course project (Can you Hack It?) that challenges students to hack a hardware is included.

ECSE 480O. Introduction to Medical Informatics. 3 Units.
Current state and emerging trends in Medical Informatics (MI) and associated health information systems. Principles, data, data management, system interoperability, patient privacy, information security, electronic records, telehealth, regulatory issues, clinical decision support, mobile documentation, devices and wireless communications in healthcare. Impact of wireless technology on emerging health information systems and processes. Offered as ECSE 480M and EBME 480M.

ECSE 480Q. Regulatory Policy and Regulations. 3 Units.
Introduction of wireless health technologies: spectrum, licensed versus unlicensed; personal area networks; body area networks; ultra-wideband low energy level short-range radios; wireless local area networks; wide area networks. The Federal system: separation of powers; the executive branch and its departments; the House of Representatives and its committees; the Senate and its committees; the FCC; policy versus regulatory versus legislative. What is a medical device: FDA; classification system; radiation-emitting products; software; RF in medical devices; converged medical devices; international aspects. Regulation of health information technology and wireless health: American Recovery and Reinvestment Act; Patient Protection and Affordable Care Act; FCC/ FDA MoU; CMS and Reimbursement; privacy and security. Offered as ECSE 480O and EBME 480Q.

ECSE 480T. Wearable Computing Design. 3 Units.
Learning about wearable devices using flexible/conformal electronics designed for convenience and uninterrupted wear-ability. Examining related design challenges from the technology, human and business points of view. Understanding wearable product design for general and special-purpose tasks in information processing, media operations, and information extraction from sensed data. Learning about the technological challenges for design, including miniaturization, power delivery and management, data storage, and wireless networking. Learning about hardware choices (processor, field programmable gate array or custom ASIC based design) for wearable computers and software architectures for smart data processing. Learning about wearable designs centered on the human experience, including sensing and interfacing with the human body, as well as user interaction, convenience, and support for non-intrusive social appearance. Case studies tying the business requirements with the technology and design issues.
ECSE 480U. Wearable Computing Technology. 3 Units.
Learning about a broad range of cutting-edge technologies suitable for wearable computing. Understanding printed and flexible electronics technologies required for creating wearable computing, in particular organics for active components due to their flexibility or conformity. Examine the tradeoffs between flexible/conformal versus rigid electronics in the context of wearable computing. Reviewing the history of printed electronics used as conductors for membrane keypads, car windscreen heaters and RFID tag antennas-to name a few application examples. Reviewing the latest technology advances in functional components such as displays, lighting, transistors (p-type & n-type), memory, batteries, photovoltaics (PV), sensors, and conductors as well as integration/packaging steps. Understanding the market potential of these technologies by reviewing emerging products.

ECSE 480W. Wearable Computing Manufacturing. 3 Units.
Learning about the supply chain and manufacturing processes for flexible electronics, sensors, and other technologies contributing to the development of wearable products. Understanding supply chain issues in low mobility materials, multilayer substrates, nanocomposites, materials for low power sensors, and inks suitable for direct printing. Identifying the tradeoffs involved in various manufacturing methods such as roll-to-roll manufacturing a mature coating technology yet to be proven for full device integration. Studying other manufacturing techniques such as plate-to-plate, direct printing, 3D printing, and screening techniques for their applicability to the manufacturing and integration of flexible electronics. Understanding the use of lithography and vapor deposition techniques in the context of flexible electronics. Examining the issues of systems integration and packaging of the manufactured products.

ECSE 480X. Mobility-Driven Computing. 3 Units.
Fundamental concepts in computing and architecture for mobile devices, mobile operating systems, mobility and mobile data management. Application of technologies for location awareness, context awareness, integrated sensors, mobile Internet, displays, pattern recognition and natural language processing, and touch/gesture based user interaction. Understanding of the tradeoffs in design (smartphones, tablets) due to resource constraints such as wireless connectivity, application processing, power management, and graphics. Integration of near- and wide-area wireless communication technologies (Bluetooth, Wireless WAN). Exploration of emerging technologies and services for the mobile platform. Integration of the foregoing concepts in a specific mobile context application (home/office, pedestrian, vehicular).

ECSE 480Y. Mobility-Driven Embedded Systems. 3 Units.
Foundations of reliable, energy-efficient and secure design of embedded systems. Fundamentals of mobility in embedded systems including wireless technology, location awareness, sensors, and actuators. Design consideration for processors, DSP, memory, and interfaces under mobility constraints (connectivity, power, and data management). Systems software for embedded computing, device management, and real-time I/O. Software design under constraints of size, performance, availability, and reliability. Software development techniques and practices (compilers, OS, and runtime systems). Case studies of mobility driven real-time embedded systems and software. Applications of mobility driven embedded systems, for example in in biomedical implant systems.

ECSE 480Z. Mobile Applications Development. 3 Units.
Understanding of the mobile application architecture, operating systems, and platforms. Challenges and opportunities in mobile application development. Evaluation of the leading mobile platform frameworks with respect to their features, functions, libraries, support, and ease of development. Software design for mobile applications in gaming, multimedia, entertainment, and enterprise applications. Development of enhanced user experience in a multi-touch, multi-sensor (accelerometer, gyroscopes, camera, geo-location) environment. Understanding of software development environments and testing tools, and use of wireless connectivity and data in mobile applications. Development of or extension of a modest application based on a major mobile platforms (iOS, Windows Phone 7, or Android).

ECSE 484. Computational Intelligence I: Basic Principles. 3 Units.
This course is concerned with learning the fundamentals of a number of computational methodologies which are used in adaptive parallel distributed information processing. Such methodologies include neural net computing, evolutionary programming, genetic algorithms, fuzzy set theory, and "artificial life." These computational paradigms complement and supplement the traditional practices of pattern recognition and artificial intelligence. Functionalities covered include self-organization, learning a model or supervised learning, optimization, and memorization.

ECSE 485. VLSI Systems. 3 Units.
Basic MOSFET models, inverters, steering logic, the silicon gate, NMOS process, design rules, basic design structures (e.g., NAND and NOR gates, PLA, ROM, RAM), design methodology and tools (spice, N.mpc, Caesar, mkpla), VLSI technology and system architecture. Requires project and student presentation, laboratory.

ECSE 487. Advanced Game Development Project. 3 Units.
This game development project course will bring together an interdisciplinary group of students in the fields of engineering, computer science, and art to focus on the design and development of a complete, fully functioning computer game as an interdisciplinary team. The student teams are given complete liberty to design their own fully functional games from their original concept to a playable game published in an online marketplace. Student teams will experience the entire game development cycle as they execute their projects. Responsibilities include creating a game idea, writing a story, developing the artwork, designing characters, implementing music and sound effects, programming and testing the game, and publishing the final project. Students enrolled in 487 will develop a healthcare or education virtual environment or video game in collaboration with a mentor who has expertise in the chosen area. Offered as CSDS 390, ECSE 390, and ECSE 487. Prereq: Graduate student standing.

ECSE 488. Embedded Systems Design. 3 Units.
Objective: to introduce and expose the student to methodologies for systematic design of embedded system. The topics include, but are not limited to, system specification, architecture modeling, component partitioning, estimation metrics, hardware software codesign, diagnostics.

ECSE 489. Robotics I. 3 Units.
ECSE 490. Digital Image Processing. 3 Units.
Digital images are introduced as two-dimensional sampled arrays of data. The course begins with one-to-one operations such as image addition and subtraction and image descriptors such as the histogram. Basic filters such as the gradient and Laplacian in the spatial domain are used to enhance images. The 2-D Fourier transform is introduced and frequency domain operations such as high and low-pass filtering are developed. It is shown how filtering techniques can be used to remove noise and other image degradation. The different methods of representing color images are described and fundamental concepts of color image transformations and color image processing are developed. One or more advanced topics such as wavelets, image compression, and pattern recognition will be covered as time permits. Programming assignments using software such as MATLAB will illustrate the application and implementation of digital image processing. Offered as CSDS 490 and ECSE 490.

ECSE 494. Introduction to Information Theory. 3 Units.
This course is intended as an introduction to information and coding theory with emphasis on the mathematical aspects. It is suitable for advanced undergraduate and graduate students in mathematics, applied mathematics, statistics, physics, computer science and electrical engineering. Course content: Information measures-entropy, relative entropy, mutual information, and their properties. Typical sets and sequences, asymptotic equipartition property, data compression. Channel coding and capacity: channel coding theorem. Differential entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory inequalities (400 level). Additional topics, which may include compressed sensing and elements of quantum information theory. Recommended preparation: MATH 201 or MATH 307. Offered as MATH 394, CSDS 394, ECSE 394, MATH 494, CSDS 494 and ECSE 494.

ECSE 499. Algorithmic Robotics. 3 Units.
This course introduces basic algorithmic techniques in robotic perception and planning. Course is divided into two parts. The first part introduces probabilistic modeling of robotic motion and sensing. Gaussian and nonparametric filters, and algorithms for mobile robot localization. The second part introduces fundamental deterministic and randomized algorithms for motion planning. Offered as CSDS 499 and ECSE 499. Prereq: Graduate Standing or Requisites Not Met permission.

ECSE 500. ECSE Colloquium. 0 Unit.
Seminars on current topics in Electrical, Computer and Systems Engineering.

ECSE 500T. Graduate Teaching II. 0 Unit.
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities: grading homeworks, quizzes, and exams, having office hours for students, running recitation sessions, providing laboratory assistance. Recommended preparation: Ph.D. student in ECSE department.

ECSE 516. Large Scale Optimization. 3 Units.
Concepts and techniques for dealing with large optimization problems encountered in designing large engineering structure, control of interconnected systems, pattern recognition, and planning and operations of complex systems; partitioning, relaxation, restriction, decomposition, approximation, and other problem simplification devices; specific algorithms; potential use of parallel and symbolic computation; student seminars and projects. Recommended preparation: EECS/ECSE 416.

ECSE 526. Integrated Mixed-Signal Systems. 3 Units.
Mixed-signal (analog/digital) integrated circuit design. D-to-A and A-to-D conversion, applications in mixed-signal VLSI, low-noise and low-power techniques, and communication sub-circuits. System simulation at the transistor and behavioral levels using SPICE. Class will design a mixed-signal CMOS IC for fabrication by MOSIS. Recommended preparation: EECS/ECSE 426.

ECSE 527. Advanced Sensors: Theory and Techniques. 3 Units.
Sensor technology with a primary focus on semiconductor-based devices. Physical principles of energy conversion devices (sensors) with a review of relevant fundamentals: elasticity theory, fluid mechanics, silicon fabrication and micromachining technology, semiconductor device physics. Classification and terminology of sensors, defining and measuring sensor characteristics and performance, effect of the environment on sensors, predicting and controlling sensor error. Mechanical, acoustic, magnetic, thermal, radiation, chemical and biological sensors will be examined. Sensor packaging and sensor interface circuitry.

ECSE 531. Computer Vision. 3 Units.
The goal of computer vision is to create visual systems that recognize objects and recover structures in complex 3D scenes. This course emphasizes both the science behind our understanding of the fundamental problems in vision and the engineering that develops mathematical models and inference algorithms to solve these problems. Specific topics include feature detection, matching, and classification; visual representations and dimensionality reduction; motion detection and optical flow; image segmentation; depth perception, multi-view geometry, and 3D reconstruction; shape and surface perception; visual scene analysis and object recognition. Offered as CSDS 531 and ECSE 531.

ECSE 589. Robotics II. 3 Units.
Survey of research issues in robotics. Force control, visual servoing, robot autonomy, on-line planning, high-speed control, man/machine interfaces, robot learning, sensory processing for real-time control. Primarily a project-based lab course in which students design real-time software executing on multi-processors to control an industrial robot. Recommended preparation: EECS/CSDS/ECSE 489. Offered as CSDS 589 and ECSE 589.
ECSE 600. Special Topics. 1 - 18 Units.

ECSE 600T. Graduate Teaching III. 0 Unit.
This course will provide Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities running recitation sessions, providing laboratory assistance, developing teaching or lecture materials presenting lectures. Recommended preparation: Ph.D. student in ECSE department.

ECSE 601. Independent Study. 1 - 18 Units.

ECSE 620. Special Topics. 1 - 18 Units.

ECSE 621. Special Projects. 1 - 18 Units.

ECSE 651. Thesis M.S.. 1 - 18 Units.
Credit as arranged.

ECSE 695. Project M.S.. 1 - 9 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in the EECS Plan B MS Program.

ECSE 701. Dissertation Ph.D.. 1 - 9 Units.
Credit as arranged.