Computer Engineering

Administered by the Department of Electrical and Computer Engineering

Undergraduate Study

For the undergraduate curriculum in computer engineering leading to the degree Bachelor of Science. This curriculum is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org .

The Department of Electrical and Computer Engineering (ECpE) at Iowa State University provides undergraduate students with the opportunity to learn electrical and computer engineering fundamentals, study applications of the most recent advances in state-of-the-art technologies, and to prepare for the practice of computer engineering. The student-faculty interaction necessary to realize this opportunity occurs within an environment that is motivated by the principle that excellence in undergraduate education is enhanced by an integrated commitment to successful, long-term research and outreach programs.

The computer engineering curriculum offers focus areas in software systems, embedded systems, networking, information security, computer architecture, and VLSI.

Students also may take elective courses in control systems, electromagnetics, microelectronics, VLSI, power systems, and communications and signal processing.

The program objectives for the computer engineering programs describe accomplishments that graduates are expected to attain within five years after graduation. Graduates will have applied their expertise to contemporary problem solving, be engaged professionally, have continued to learn and adapt, and have contributed to their organizations through leadership and teamwork. More specifically, the objectives for expertise, engagement, learning, leadership and teamwork are defined below for each program.

The objectives of the computer engineering program at Iowa State University are:

- Graduates, within five years of graduation, should demonstrate peer-recognized **expertise** together with the ability to articulate that expertise and use it for contemporary problem solving in the analysis, design, and evaluation of computer and software systems, including system integration and implementation.
- Graduates, within five years of graduation, should demonstrate **engagement** in the engineering profession, locally and globally, by contributing to the ethical, competent, and creative practice of engineering or other professional careers.
- Graduates, within five years of graduation, should demonstrate sustained **learning** and adapting to a constantly changing field through graduate work, professional development, and self study.
- Graduates, within five years of graduation, should demonstrate **leadership** and initiative to ethically advance professional and organizational goals, facilitate the achievements of others, and obtain substantive results.
- Graduates, within five years of graduation, should demonstrate a commitment to **teamwork** while working with others of diverse cultural and interdisciplinary backgrounds.

As a complement to the instructional activity, the ECpE department provides opportunities for each student to have experience with broadening activities. Through the cooperative education and internship program, students have the opportunity to gain practical industry experience. Students have the opportunity to participate in advanced research activities, and through international exchange programs, students learn about engineering practices in other parts of the world. Well-qualified juniors and seniors in computer engineering who are interested in graduate study may apply for concurrent enrollment in the Graduate College to simultaneously pursue both the Bachelor of Science and Master of Science, the Bachelor of Science and Master of Business Administration, or the Bachelor of Science and Master of Engineering degrees.

Students are required to prepare and to maintain a portfolio of their technical and non-technical skills. This portfolio is evaluated for student preparation during the student's curriculum planning process. Results of the evaluation are used to advise students of core strengths and weaknesses.

Graduate Study

The department offers work for the degrees Master of Engineering, Master of Science, and Doctor of Philosophy with a major in computer engineering and minor work to students with other majors. Minor work for computer engineering majors is usually selected from a wide range of courses outside computer engineering.

The Master of Engineering degree is course-work only. It is recommended for off-campus students.

The Master of Science degree with thesis is recommended for students who intend to continue toward the Doctor of Philosophy degree or to undertake a career in research and development. The non-thesis Master of Science degree requires a creative component.

The department also offers three graduate certificate programs in embedded systems, computer networking, and software systems.

The normal prerequisite to graduate major work in computer engineering is the completion of undergraduate work substantially equivalent to that required of computer engineering students at this university. It is possible for a student to qualify for graduate study in computer engineering even though the student's undergraduate or prior graduate training has been in a discipline other than computer engineering. Supporting work, if required, will depend on the student's background and area of research interest. Prospective students from a discipline other than computer engineering are required to submit, with the application for admission, a statement of the proposed area of graduate study.

The department requires submission of GRE General test scores by applicants. All students whose first language is not English and who have no U.S. degree must submit TOEFL examination scores. Students pursuing the Doctor of Philosophy must complete the department qualifying process.

The Department of Electrical and Computer Engineering is a participating department in the interdepartmental Master of Science and Doctor of Philosophy degree programs in bioinformatics and computational biology. Students interested in these programs may earn their degrees while working under an adviser in electrical and computer engineering.

The Department of Electrical and Computer Engineering also is a participating department in the interdepartmental certificate, Master of Engineering, and Master of Science in Information Assurance programs. Students interested in studying information assurance topics may earn a degree in computer engineering or in information assurance. (See catalog section on Information Assurance.)

Well-qualified juniors and seniors in computer engineering who are interested in graduate study may apply for concurrent enrollment in the Graduate College to simultaneously pursue both Bachelor of Science and Master of Science, or Bachelor of Science and Master of Business Administration, or Bachelor of Science and Master of Engineering degrees. Under concurrent enrollment, students are eligible for assistantships and simultaneously take undergraduate and graduate courses. Details are available in the Student Services Office and on the department's web site.

Curriculum in Computer Engineering

Administered by the Department of Electrical and Computer Engineering.

Leading to the degree Bachelor of Science.

Total credits required: 127 See also Basic Program and Special Programs.

International Perspectives: 3 cr. [1]

U.S. Diversity: 3 cr. [1]

Communication Proficiency/Library requirement:

ENGL 150	Critical Thinking and Communication [*]	3
ENGL 250	Written, Oral, Visual, and Electronic Composition [*]	3
LIB 160	Information Literacy	1

[*]   minimum grade of C

General Education Electives: 15 cr. [2]

Basic Program: 27 cr. [4]

CHEM 167	General Chemistry for Engineering Students	4
or CHEM 177	General Chemistry I	
ENGL 150	Critical Thinking and Communication (see above for grade requirements)	3
ENGL 250	Written, Oral, Visual, and Electronic Composition (see above for grade requirements)	3
ENGR 101	Engineering Orientation	R

CPR E 185	Introduction to Computer Engineering and Problem Solving I [3]	3
LIB 160	Information Literacy	1
MATH 165	Calculus I	4
MATH 166	Calculus II	4
PHYS 221	Introduction to Classical Physics I (See Basic Program rule)	5
Total Credits		27

Math and Physical Science: 20 cr.

COM S 227	Introduction to Object-oriented Programming	4
COM S 228	Introduction to Data Structures	3
MATH 265	Calculus III	4
MATH 267	Elementary Differential Equations and Laplace Transforms	4
PHYS 222	Introduction to Classical Physics II	5
Total Credits		20

Computer Engineering Core: 33 cr. [4]

CPR E 281	Digital Logic	4
CPR E 288	Embedded Systems I: Introduction	4
CPR E 308	Operating Systems: Principles and Practice	4
CPR E 310	Theoretical Foundations of Computer Engineering	3
CPR E 381	Computer Organization and Assembly Level Programming	4
COM S 309	Software Development Practices	3
CPR E 315	Applications of Algorithms in Computer Engineering	3
or COM S 311	Design and Analysis of Algorithms	
E E 201	Electric Circuits	4
E E 230	Electronic Circuits and Systems	4
Total Credits		33

Other Remaining Courses: 32 cr.

CPR E 491	Senior Design Project I and Professionalism	3
CPR E 492	Senior Design Project II	2
STAT 330	Probability and Statistics for Computer Science	3
One of the following:		3
ENGL 314	Technical Communication [*]	
ENGL 309	Report and Proposal Writing [*]	
Computer Science course [5]		3
Computer Engineering [5]		6
Technical Electives [5]		9
Electrical Engineering course [5]		3
Total Credits		32

[*]   minimum grade of C

Seminar/Co-op/Internships:

CPR E 166	Professional Programs Orientation	R
CPR E 294	Program Discovery	R
CPR E 394	Program Exploration	R
CPR E 494	Portfolio Assessment	R

Co-op or internship is optional.

Outcomes Assessment - Students are required to prepare and to maintain a portfolio of their technical and non-technical skills. This portfolio is evaluated for student preparation during the student's curriculum planning process. Results of the evaluation are used to advise students of core strengths and weaknesses.

Transfer Credit Requirements

The degree program must include a minimum of 30 credits at the 300-level or above in professional and technical courses earned at ISU in order to receive a B.S. in computer engineering. These 30 credits must include CPR E 491 Senior Design Project I and Professionalism, CPR E 492 Senior Design Project II, and credits in the core professional curriculum and/or in technical electives. The

Electrical and Computer Engineering Department requires a grade of C or better for any transfer credit course that is applied to the degree program.

1. These university requirements will add to the minimum credits of the program unless the university-approved courses are also approved by the department to meet other course requirements within the degree program. U.S. diversity and international perspectives courses may not be taken Pass/Not Pass, but are used to meet the general education electives.
2. Complete minimum of 6 cr. from Approved General Education Component at 300- or higher level. Complete additional 9 cr. from Approved General Education Component.
3. See Basic Program for Professional Engineering Curricula for accepted substitutions for curriculum designated courses in the Basic Program.
4. 2.00 required including transfer courses.
5. From department approved lists.

Courses primarily for undergraduates:

CPR E 131. Introduction to Computer Security Literacy.
(Cross-listed with INFAS). (1-0) Cr. 1.
Basic concepts of practical computer and Internet security: passwords, firewalls, antivirus software, malware, social networking, surfing the Internet, phishing, and wireless networks. This class is intended for students with little or no background in information technology or security. Basic knowledge of word processing required. Offered on a satisfactory-fail basis only.

CPR E 166. Professional Programs Orientation.
(Cross-listed with E E). Cr. R. F.S.
(1-0) Overview of the nature and scope of electrical engineering and computer engineering professions. Overview of portfolios. Departmental rules, advising center operations, degree requirements, program of study planning, career options, and student organizations.

CPR E 185. Introduction to Computer Engineering and Problem Solving I.
(2-2) Cr. 3. *Prereq: Credit or enrollment in MATH 141*
Introduction to Computer Engineering. Project based examples from computer engineering. Individual interactive skills for small and large groups. Computer-based projects. Solving engineering problems and presenting solutions through technical reports. Solution of engineering problems using a programming language.

CPR E 186. Introduction to Computer Engineering and Problem Solving II.
(0-2) Cr. 1. S. *Prereq: CPR E 185*
Project based examples from computer engineering. Group skills needed to work effectively in teams. Group problem solving. Computer based projects. Technical reports and presentations. Students will work on 2 or 3 self-directed team based projects that are representative of problems faced by computer engineers.

CPR E 261. Transfer Orientation.
(Cross-listed with E E). Cr. R.
Introduction to the College of Engineering and the engineering profession specifically for transfer students. Information concerning university and college policies, procedures, and resources. Offered on a satisfactory-fail basis only.

CPR E 281. Digital Logic.
(3-2) Cr. 4. F.S. *Prereq: sophomore classification*
Number systems and representation. Boolean algebra and logic minimization. Combinational and sequential logic design. Arithmetic circuits and finite state machines. Use of programmable logic devices. Introduction to computer-aided schematic capture systems, simulation tools, and hardware description languages. Design of simple digital systems.

CPR E 288. Embedded Systems I: Introduction.
(3-2) Cr. 4. F.S. *Prereq: CPR E 281, COM S 207 or COM S 227 or E E 285*
Embedded C programming. Interrupt handling. Memory mapped I/O in the context of an application. Elementary embedded design flow/methodology. Timers, scheduling, resource allocation, optimization, state machine based controllers, real time constraints within the context of an application. Applications laboratory exercises with embedded devices.

CPR E 294. Program Discovery.
(Cross-listed with E E). Cr. R. *Prereq: CPR E 166 or E E 166*
The roles of professionals in computer and electrical engineering. Relationship of coursework to industry and academic careers. Issues relevant to today's world. Offered on a satisfactory-fail basis only.

CPR E 298. Cooperative Education.
Cr. R. F.S.SS. *Prereq: Permission of department and Engineering Career Services*
First professional work period in the cooperative education program. Students must register for this course before commencing work.

CPR E 308. Operating Systems: Principles and Practice.
(3-3) Cr. 4. F.S. *Prereq: CPR E 381, CPR E 310*
Operating system concepts, processes, threads, synchronization between threads, process and thread scheduling, deadlocks, memory management, file systems, I/O systems,security, Linux-based lab experiments. Nonmajor graduate credit.

CPR E 310. Theoretical Foundations of Computer Engineering.
(3-0) Cr. 3. F.S. *Prereq: Credit or enrollment in CPR E 288, COM S 228*
Propositional logic and methods of proof; set theory and its applications; mathematical induction and recurrence relations; functions and relations; and counting; trees and graphs; applications in computer engineering.

CPR E 315. Applications of Algorithms in Computer Engineering.
(3-0) Cr. 3. F.S.SS. *Prereq: CPR E 310*
Solving computer engineering problems using algorithms. Emphasis on problems related to the core focus areas in computer engineering. Real world examples of algorithms used in the computer engineering domain. Algorithm engineering. Prototyping of algorithms. Nonmajor graduate credit.

CPR E 329. Software Project Management.
(Cross-listed with S E). (3-0) Cr. 3. *Prereq: COM S 309*
Process-based software development. Capability Maturity Model (CMM). Project planning, cost estimation, and scheduling. Project management tools. Factors influencing productivity and success. Productivity metrics. Analysis of options and risks. Version control and configuration management. Inspections and reviews. Managing the testing process. Software quality metrics. Modern software engineering techniques and practices. Nonmajor graduate credit.

CPR E 330. Integrated Electronics.
(Cross-listed with E E). (3-3) Cr. 4. *Prereq: E E 201, credit or enrollment in E E 230, CPR E 281*
Semiconductor technology for integrated circuits. Modeling of integrated devices including diodes, BJTs, and MOSFETs. Physical layout. Circuit simulation. Digital building blocks and digital circuit synthesis. Analysis and design of analog building blocks. Laboratory exercises and design projects with CAD tools and standard cells. Nonmajor graduate credit. Credit for only one of E E 330 or 331 may be counted toward graduation.

CPR E 339. Software Architecture and Design.
(Cross-listed with S E). (3-0) Cr. 3. *Prereq: S E 319*
Modeling and design of software at the architectural level. Architectural styles. Basics of model-driven architecture. Object-oriented design and analysis. Iterative development and unified process. Design patterns. Design by contract. Component based design. Product families. Measurement theory and appropriate use of metrics in design. Designing for qualities such as performance, safety, security, reliability, reusability, etc. Analysis and evaluation of software architectures. Introduction to architecture definition languages. Basics of software evolution, reengineering, and reverse engineering. Case studies. Introduction to distributed system software. Nonmajor graduate credit.

CPR E 370. Toying with Technology.
(Cross-listed with MAT E). (2-2) Cr. 3. F.S. *Prereq: C I 201 or C I 202*
A project-based, hands-on learning course. Technology literacy, appreciation for technological innovations, principles behind many technological innovations, hands-on laboratory experiences based upon simple systems constructed out of LEGOs and controlled by small microcomputers. Future K-12 teachers will leave the course with complete lesson plans for use in their upcoming careers.

CPR E 381. Computer Organization and Assembly Level Programming.
(3-2) Cr. 4. F.S. *Prereq: CPR E 288*
Introduction to computer organization, evaluating performance of computer systems, instruction set design. Assembly level programming: arithmetic operations, control flow instructions, procedure calls, stack management. Processor design. Datapath and control, scalar pipelines, introduction to memory and I/O systems.

CPR E 388. Embedded Systems II: Mobile Platforms.
(3-2) Cr. 4. *Prereq: CPR E 288*
Contemporary programming techniques for event driven systems - Xcode and COCOA for objective-C. Location and motion sensors based user interfaces. Threading and scheduling. Resource management - measurement and control techniques - for memory and energy. Client-server application design. Distributed applications. Laboratory includes exercises based on a mobile platform such as iPhone.

CPR E 394. Program Exploration.
(Cross-listed with E E). Cr. R. *Prereq: CPR E 294 or E E 294*
Exploration of academic and career fields for electrical and computer engineers. Examination of professionalism in the context of engineering and technology with competencies based skills. Introduction to professional portfolio development and construction. Offered on a satisfactory-fail basis only.

CPR E 396. Summer Internship.
Cr. R. Repeatable. SS. *Prereq: Permission of department and Engineering Career Services*
Summer professional work period.

CPR E 397. Engineering Internship.
Cr. R. Repeatable. F.S.SS. *Prereq: Permission of department and Engineering Career Services*
One semester maximum per academic year professional work period.

CPR E 398. Cooperative Education.
Cr. R. F.S.SS. *Prereq: CPR E 298, permission of department and Engineering Career Services*
Second professional work period in the cooperative education program. Students must register for this course before commencing work.

CPR E 412. Formal Aspects of Specification and Verification.
(Cross-listed with COM S, S E). (3-0) Cr. 3. *Prereq: S E 319, COM S 309*
Introduction to prepositional/predicate/temporal logic, program verification using theorem proving, model-based verification using model checking, and tools for verification. Nonmajor graduate credit.

CPR E 416. Software Evolution and Maintenance.
(Cross-listed with S E). (3-0) Cr. 3. *Prereq: COM S 309*
Practical importance of software evolution and maintenance, systematic defect analysis and debugging techniques, tracing and understanding large software, impact analysis, program migration and transformation, refactoring, tools for software evolution and maintenance, experimental studies and quantitative measurements of software evolution. Written reports and oral presentation. Nonmajor graduate credit.

CPR E 418. High Speed System Engineering Measurement and Testing.
(Cross-listed with CPR E). (3-2) Cr. 4. F. *Prereq: E E 230 and CPR E 311*
Measurement of high speed systems and mixed signal systems. Measurement accuracy and error. Network analysis and spectrum analysis used in high speed measurement and testing. Test specification process and parametric measurement. Sampling and digital signal processing concepts. Design for testability. Testing equipment. Applications. Nonmajor graduate credit.

CPR E 425. High Performance Computing for Scientific and Engineering Applications.
(Cross-listed with COM S). (3-1) Cr. 3. S. *Prereq: COM S 311, COM S 330, ENGL 250, SP CM 212*
Introduction to high performance computing platforms including parallel computers and workstation clusters. Discussion of parallel architectures, performance, programming models, and software development issues. Sample applications from science and engineering. Practical issues in high performance computing will be emphasized via a number of programming projects using a variety of programming models and case studies. Oral and written reports. Nonmajor graduate credit.

CPR E 426. Introduction to Parallel Algorithms and Programming.
(Dual-listed with CPR E 526). (Cross-listed with COM S). (3-2) Cr. 4. F. *Prereq: CPR E 308 or COM S 321, COM S 311*
Models of parallel computation, performance measures, basic parallel constructs and communication primitives, parallel programming using MPI, parallel algorithms for selected problems including sorting, matrix, tree and graph problems, fast Fourier transforms. Nonmajor graduate credit.

CPR E 431. Basics of Information System Security.
(3-0) Cr. 3. S. *Prereq: credit or enrollment in CPR E 489 or COM S 454*
Introduction to and application of basic mechanisms for protecting information systems from accidental and intentional threats. Basic cryptography use and practice. Computer security issues including authentication, access control, and malicious code. Network security mechanisms such as intrusion detection, firewalls, IPSEC, and related protocols. Ethics and legal issues in information security. Other selected topics. Programming and system configuration assignments. Nonmajor graduate credit.

CPR E 435. Analog VLSI Circuit Design.
(Cross-listed with E E). (3-3) Cr. 4. S. *Prereq: E E 324, E E 330, E E 332, and either E E 322 or STAT 330*
Basic analog integrated circuit and system design including design space exploration, performance enhancement strategies, operational amplifiers, references, integrated filters, and data converters. Nonmajor graduate credit.

CPR E 444. Introduction to Bioinformatics.
(Cross-listed with BCB, BCBIO, COM S, BIOL, GEN). (4-0) Cr. 4. F. *Prereq: MATH 165 or STAT 401 or equivalent*
Broad overview of bioinformatics with a significant problem-solving component, including hands-on practice using computational tools to solve a variety of biological problems. Topics include: database searching, sequence alignment, gene prediction, RNA and protein structure prediction, construction of phylogenetic trees, comparative and functional genomics, systems biology. Nonmajor graduate credit.

CPR E 450. Distributed Systems and Middleware.
(Dual-listed with CPR E 550). (3-0) Cr. 3. *Prereq: CPR E 308 or COM S 352*
Fundamentals of distributed computing, software agents, naming services, distributed transactions, security management, distributed object-based systems, web-based systems, middleware-based application design and development, case studies of middleware and internet applications. Nonmajor graduate credit.

CPR E 454. Distributed and Network Operating Systems.
(Dual-listed with CPR E 554). (Cross-listed with COM S). (3-1) Cr. 3. Alt. S., offered 2013. *Prereq: COM S 311, COM S 352*
Laboratory course dealing with practical issues of design and implementation of distributed and network operating systems and distributed computing environments (DCE). The client server paradigm, inter-process communications, layered communication protocols, synchronization and concurrency control, and distributed file systems. Graduate credit requires additional in-depth study of advanced operating systems. Written reports.

CPR E 458. Real Time Systems.
(Dual-listed with CPR E 558). (3-0) Cr. 3. *Prereq: CPR E 308 or COM S 352*
Fundamental concepts in real-time systems. Real time task scheduling paradigms. Resource management in uniprocessor, multiprocessor, and distributed real-time systems. Fault-tolerance, resource reclaiming, and overload handling. Real-time channel, packet scheduling, and real-time LAN protocols. Case study of real-time operating systems. Laboratory experiments. Nonmajor graduate credit.

CPR E 465. Digital VLSI Design.
(Cross-listed with E E). (3-3) Cr. 4. S. *Prereq: E E 330*
Digital design of integrated circuits employing very large scale integration (VLSI) methodologies. Technology considerations in design. High level hardware design languages, CMOS logic design styles, area-energy-delay design space characterization, datapath blocks: arithmetic and memory, architectures and systems on a chip (SOC) considerations. VLSI chip hardware design project. Nonmajor graduate credit.

CPR E 466. Multidisciplinary Engineering Design.
(Cross-listed with A E, AER E, E E, ENGR, I E, M E, MAT E). (1-4) Cr. 3. Repeatable. F.S. *Prereq: Student must be within two semesters of graduation and receive permission of instructor*
Application of team design concepts to projects of a multidisciplinary nature. Concurrent treatment of design, manufacturing and life cycle considerations. Application of design tools such as CAD, CAM, and FEM. Design methodologies, project scheduling, cost estimating, quality control, manufacturing processes. Development of a prototype and appropriate documentation in the form of written reports, oral presentations and computer models and engineering drawings.

CPR E 467. Multidisciplinary Engineering Design II.
(Cross-listed with AER E, ENGR, E E, I E, MAT E, M E). (1-4) Cr. 3. Repeatable, maximum of 2 times. F.S. *Prereq: Student must be within two semesters of graduation or receive permission of instructor.*
Build and test of a conceptual design. Detail design, manufacturability, test criteria and procedures. Application of design tools such as CAD and CAM and manufacturing techniques such as rapid prototyping. Development and testing of a full-scale prototype with appropriate documentation in the form of design journals, written reports, oral presentations and computer models and engineering drawings.

CPR E 480. Graphics Processing and Architecture.
(3-3) Cr. 4. S. *Prereq: CPR E 381 or COM S 321*
Introduction to hardware architectures for computer graphics and their programming models. System-level view, including framebuffers, video output devices, displays, 2D and 3D graphics acceleration, and device interfacing. Architectural design of GPUs, from 2D and 3D sprite engines to 3D rendering pipelines to unified shader architectures. Computing models for graphics processors. GPGPU and GPU computing. Nonmajor graduate credit.

CPR E 483. Hardware Software Integration.
(3-3) Cr. 4. S. *Prereq: CPR E 381*
Embedded system design using hardware description language (HDL) and field programmable gate array (FPGA). HDL modeling concepts and styles are introduced; focus on synthesizability, optimality, reusability and portability in hardware design description. Introduction to complex hardware cores for data buffering, data input/output interfacing, data processing. System design with HDL cores and implementation in FPGA. Laboratory-oriented design projects. Nonmajor graduate credit.

CPR E 488. Embedded Systems Design.
(3-3) Cr. 4. *Prereq: CPR E 381 or COM S 321*
Embedded microprocessors, embedded memory and I/O devices, component interfaces, embedded software, program development, basic compiler techniques, platform-based FPGA technology, hardware synthesis, design methodology, real-time operating system concepts, performance analysis and optimizations. Nonmajor graduate credit.

CPR E 489. Computer Networking and Data Communications.
(3-2) Cr. 4. F.S. *Prereq: CPR E 381 or E E 324*
Modern computer networking and data communications concepts. TCP/IP, OSI protocols, client server programming, data link protocols, local area networks, and routing protocols. Nonmajor graduate credit.

CPR E 490. Independent Study.
Cr. arr. Repeatable. *Prereq: Senior classification in computer engineering*
Investigation of an approved topic.

CPR E 490H. Independent Study: Honors.
Cr. arr. Repeatable. *Prereq: Senior classification in computer engineering*
Investigation of an approved topic.

CPR E 491. Senior Design Project I and Professionalism.
(Cross-listed with E E). (2-3) Cr. 3. F.S. *Prereq: E E 322 or CPR E 308, completion of 24 credits in the E E core professional program or 29 credits in the Cpr E core professional program, ENGL 314*
Preparing for entry to the workplace. Selected professional topics. Use of technical writing skills in developing project plan and design report; design review presentation. First of two-semester team-oriented, project design and implementation experience.

CPR E 492. Senior Design Project II.
(Cross-listed with E E). (1-3) Cr. 2. F.S. *Prereq: CPR E 491 or E E 491*
Second semester of a team design project experience. Emphasis on the successful implementation and demonstration of the design completed in E E 491 or Cpr E 491 and the evaluation of project results. Technical writing of final project report; oral presentation of project achievements; project poster.

CPR E 494. Portfolio Assessment.
(Cross-listed with E E). Cr. R. *Prereq: CPR E 394 or E E 394, credit or enrollment in CPR E 491 or E E 491*
Portfolio update and evaluation. Portfolios as a tool to enhance career opportunities.

CPR E 498. Cooperative Education.
Cr. R. Repeatable. F.S.SS. *Prereq: CPR E 398, permission of department and Engineering Career Services*
Third and subsequent professional work periods in the cooperative education program. Students must register for this course before commencing work.

Courses primarily for graduate students, open to qualified undergraduates:

CPR E 501. Analog and Mixed-Signal VLSI Circuit Design Techniques.
(Cross-listed with E E). (3-3) Cr. 4. F. *Prereq: E E 435*
Design techniques for analog and mixed-signal VLSI circuits. Amplifiers; operational amplifiers, transconductance amplifiers, finite gain amplifiers and current amplifiers. Linear building blocks; differential amplifiers, current mirrors, references, cascading and buffering. Performance characterization of linear integrated circuits; offset, noise, sensitivity and stability. Layout considerations, simulation, yield and modeling for high-performance linear integrated circuits.

CPR E 504. Power Management for VLSI Systems.
(Cross-listed with E E). (3-3) Cr. 4. *Prereq: E E 435, Credit or Registration for E E 501*
Theory, design and applications of power management and regulation circuits (Linear and switching regulators, battery chargers, and reference circuits) including: Architectures, Performance metrics and characterization, Noise and stability analysis, Practical implementation and on-chip integration issues, design considerations for portable, wireless, and RF SoCs.

CPR E 505. CMOS and BiCMOS Data Conversion Circuits.
(Cross-listed with E E). (3-3) Cr. 4. Alt. S., offered 2012. *Prereq: E E 501*
Theory, design and applications of data conversion circuits (A/D and D/A converters) including: architectures, characterization, quantization effects, conversion algorithms, spectral performance, element matching, design for yield, and practical comparators, implementation issues.

CPR E 506. Design of CMOS Phase-Locked Loops.
(Cross-listed with E E). (3-3) Cr. 4. *Prereq: E E 435 or E E 501 or instructor approval*
Analysis and design of phase-locked loops implemented in modern CMOS processes including: architectures, performance metrics, and characterization; noise and stability analysis; and design issues of phase-frequency detectors, charge pumps, loop filters (passive and active), voltage controlled oscillators, and frequency dividers.

CPR E 507. VLSI Communication Circuits.
(Cross-listed with E E). (3-3) Cr. 4. Alt. S., offered 2013. *Prereq: CPR E 330 or CPR E 501*
Radio frequency integrated circuits for wireless and wired communications with a focus on CMOS implementations. Discussions on fundamental concepts in RF design such as nonlinearity, sensitivity, and dynamic range will be followed with a detailed analysis and design of low-noise amplifiers, mixer, oscillators, and transceivers.

CPR E 511. Design and Analysis of Algorithms.
(Cross-listed with COM S). (3-0) Cr. 3. F. *Prereq: COM S 311*
A study of basic algorithm design and analysis techniques. Advanced data structures, amortized analysis and randomized algorithms. Applications to sorting, graphs, and geometry. NP-completeness and approximation algorithms.

CPR E 525. Numerical Analysis of High Performance Computing.
(Cross-listed with COM S, MATH). (3-0) Cr. 3. Alt. S., offered 2015. *Prereq: CPR E 308 or MATH 481; experience in scientific programming; knowledge of FORTRAN or C*
Introduction to parallelization techniques and numerical methods for state-of-the-art high performance computers. A major component will be a final project in an area related to each student's research interests.

CPR E 526. Introduction to Parallel Algorithms and Programming.
(Dual-listed with CPR E 426). (Cross-listed with COM S). (3-2) Cr. 4. F. *Prereq: CPR E 308 or COM S 321, COM S 311*
Models of parallel computation, performance measures, basic parallel constructs and communication primitives, parallel programming using MPI, parallel algorithms for selected problems including sorting, matrix, tree and graph problems, fast Fourier transforms.

CPR E 528. Probabilistic Methods in Computer Engineering.
(3-0) Cr. 3. *Prereq: COM S 311*
The application of randomization and probabilistic methods in the design of computer algorithms, and their efficient implementation. Discrete random variables in modeling algorithm behavior, with applications to sorting, selection, graph algorithms, hashing, pattern matching, cryptography, distributed systems, and massive data set algorithmics.

CPR E 530. Advanced Protocols and Network Security.
(Cross-listed with INFAS). (3-0) Cr. 3. *Prereq: CPR E 381*
Detailed examination of networking standards, protocols, and their implementation. TCP/IP protocol suite, network application protocols, IP routing, network security issues. Emphasis on laboratory experiments.

CPR E 531. Information System Security.
(Cross-listed with INFAS). (3-0) Cr. 3. *Prereq: CPR E 489 or CPR E 530 or COM S 586 or MIS 535*
Computer and network security: basic cryptography, security policies, multilevel security models, attack and protection mechanisms, legal and ethical issues.

CPR E 532. Information Warfare.
(Cross-listed with INFAS). (3-0) Cr. 3. S. *Prereq: CPR E 531*
Computer system and network security: implementation, configuration, testing of security software and hardware, network monitoring. Authentication, firewalls, vulnerabilities, exploits, countermeasures. Ethics in information assurance. Emphasis on laboratory experiments.

CPR E 533. Cryptography.
(Cross-listed with MATH, INFAS). (3-0) Cr. 3. S. *Prereq: MATH 301 or CPR E 310 or COM S 330*
Basic concepts of secure communication, DES and AES, public-key cryptosystems, elliptic curves, hash algorithms, digital signatures, applications. Relevant material on number theory and finite fields.

CPR E 534. Legal and Ethical Issues in Information Assurance.
(Cross-listed with POL S, INFAS). (3-0) Cr. 3. S. *Prereq: Graduate classification; CPR E 531 or INFAS 531*
Legal and ethical issues in computer security. State and local codes and regulations. Privacy issues.

CPR E 535. Steganography and Digital Image Forensics.
(Cross-listed with MATH, INFAS). (3-0) Cr. 3. S. *Prereq: E E 524 or MATH 307 or COM S 330*
Basic principles of covert communication, steganalysis, and forensic analysis for digital images. Steganographic security and capacity, matrix embedding, blind attacks, image forensic detection and device identification techniques. Related material on coding theory, statistics, image processing, pattern recognition.

CPR E 536. Computer and Network Forensics.
(Cross-listed with INFAS). (3-0) Cr. 3. *Prereq: CPR E 381 and CPR E 489 or CPR E 530*
Fundamentals of computer and network forensics, forensic duplication and analysis, network surveillance, intrusion detection and response, incident response, anonymity and pseudonymity, privacy-protection techniques, cyber law, computer security policies and guidelines, court testimony and report writing, and case studies. Emphasis on hands-on experiments.

CPR E 537. Wireless Network Security.
(3-0) Cr. 3. S. *Prereq: Credit or enrollment in CPR E 489 or CPR E 530*
Introduction to the physical layer and special issues associated with security of the airlink interface. Communication system modeling, wireless networking, base stations, mobile stations, airlink multiple access, jamming, spoofing, signal intercept, wireless LANS and modems, cellular, position location, spread spectrum, signal modeling, propagation modeling, wireless security terminology.

CPR E 541. High-Performance Communication Networks.
(3-0) Cr. 3. *Prereq: CPR E 489 or CPR E 530*
Selected topics from recent advances in high performance networks; next generation internet; asynchronous transfer mode; traffic management, quality of service; high speed switching.

CPR E 542. Optical Communication Networks.
(3-0) Cr. 3. S. *Prereq: CPR E 489*
Optical components and interfaces; optical transmission and reception techniques; wavelength division multiplexing; network architectures and protocol for first generation, single and multihop optical network; routing and wavelength assignment in second generation wavelength routing networks; traffic grooming, optical network control; survivability; access networks; metro networks.

CPR E 543. Wireless Network Architecture.
(3-0) Cr. 3. *Prereq: Credit or enrollment in CPR E 489 or CPR E 530*
Introduction to the protocol architecture of the data link layer, network layer and transport layer for wireless networking. Operation and management of Medium Access Control in Wireless Local Area Networks (WLAN) and Wireless Metropolitan Area Networks (WMAN); recent developments in IEEE 802.11 & 802.16 and Bluetooth; Mobile IP; Mobile TCP.

CPR E 544. Introduction to Bioinformatics.
(Cross-listed with BCB, GDCB, COM S). (4-0) Cr. 4. F. *Prereq: MATH 165 or STAT 401 or equivalent*
Broad overview of bioinformatics with a significant problem-solving component, including hands-on practice using computational tools to solve a variety of biological problems. Topics include: database searching, sequence alignment, gene prediction, RNA and protein structure prediction, construction of phylogenetic trees, comparative, functional genomics, and systems biology.

CPR E 545. Fault-Tolerant Systems.
(3-0) Cr. 3. *Prereq: CPR E 381*
Faults and their manifestations, errors, and failures; fault detection, location and reconfiguration techniques; time, space, and information (coding) redundancy management; design for testability; self-checking and fail-safe circuits; system-level fault diagnosis; Byzantine agreement; stable storage and RAID; clock synchronization; fault-tolerant networks; fault tolerance in real-time systems; reliable software design; checkpointing and rollback recovery; atomic actions; replica management protocols; and reliability evaluation techniques and tools.

CPR E 546. Wireless and Sensor Networks.
(3-0) Cr. 3. *Prereq: CPR E 489 or CPR E 530*
Fundamental and well-known protocols for wireless ad hoc and sensor networks at various layers, including physical layer issues, MAC (medium access control) layer protocols, routing protocols for wireless ad hoc and sensor networks, data management in sensor networks, coverage and connectivity, localization and tracking, security and privacy issues. Introduction to TinyOS and the nesC language. Hands-on experiments with Crossbow Mote sensor devices.

CPR E 547. Resource Allocation in Communication Networks.
(3-0) Cr. 3.
Analytical approach to resource allocation on communication networks (e.g. the Internet, multihop wireless networks, etc.). Network utility maximization and the internet congestion control algorithm. Layering as optimization decomposition: a cross-layer design approach in multihop wireless networks. Capacity of ad hoc wireless networks.

CPR E 549. Advanced Algorithms in Computational Biology.
(Cross-listed with COM S). (3-0) Cr. 3. Alt. S., offered 2012. *Prereq: COM S 311 and either COM S 228 or COM S 208*
Design and analysis of algorithms for applications in computational biology, pairwise and multiple sequence alignments, approximation algorithms, string algorithms including in-depth coverage of suffix trees, semi-numerical string algorithms, algorithms for selected problems in fragment assembly, phylogenetic trees and protein folding. No background in biology is assumed. Also useful as an advanced algorithms course in string processing.

CPR E 550. Distributed Systems and Middleware.
(Dual-listed with CPR E 450). (3-0) Cr. 3. *Prereq: CPR E 308 or COM S 352*
Fundamentals of distributed computing, software agents, naming services, distributed transactions, security management, distributed object-based systems, web-based systems, middleware-based application design and development, case studies of middleware and internet applications.

CPR E 554. Distributed and Network Operating Systems.
(Dual-listed with CPR E 454). (Cross-listed with COM S). (3-1) Cr. 3. Alt. S., offered 2013. *Prereq: COM S 311, COM S 352*
Laboratory course dealing with practical issues of design and implementation of distributed and network operating systems and distributed computing environments (DCE). The client server paradigm, inter-process communications, layered communication protocols, synchronization and concurrency control, and distributed file systems. Graduate credit requires additional in-depth study of advanced operating systems. Written reports.

CPR E 556. Scalable Software Engineering.
(3-0) Cr. 3. *Prereq: COM S 309*
Design and analysis techniques scalable to large software, project-based learning of problem solving techniques, automation tools for high productivity and reliability of software, analysis-based measurement and estimation techniques for predictable software engineering.

CPR E 557. Computer Graphics and Geometric Modeling.
(Cross-listed with M E, COM S). (3-0) Cr. 3. F.S. *Prereq: M E 421, programming experience in C*
Fundamentals of computer graphics technology. Data structures. Parametric curve and surface modeling. Solid model representations. Applications in engineering design, analysis, and manufacturing.

CPR E 558. Real-Time Systems.
(Dual-listed with CPR E 458). (3-0) Cr. 3. *Prereq: CPR E 308 or COM S 352*
Fundamental concepts in real-time systems. Real-time task scheduling paradigms. Resource management in uniprocessor, multiprocessor, and distributed real-time systems. Fault-tolerance, resource reclaiming, and overload handling. Real-time channel, packet scheduling, and real-time LAN protocols. Case study of real-time operating systems. Laboratory experiments.

CPR E 566. Physical Design of VLSI Systems.
(3-0) Cr. 3. *Prereq: CPR E 465*
Physical design of VLSI systems. Partitioning algorithms. Placement and floorplanning algorithms. Routing-global and detailed. Layout compaction. Physical design of FPGA's and MCM's. Performance-driven layout synthesis.

CPR E 567. Bioinformatics I (Fundamentals of Genome Informatics).
(Cross-listed with BCB, COM S). (3-0) Cr. 3. F. *Prereq: COM S 208; COM S 330; STAT 341; credit or enrollment in BIOL 315, STAT 430*
Biology as an information science. Review of algorithms and information processing. Generative models for sequences. String algorithms. Pairwise sequence alignment. Multiple sequence alignment. Searching sequence databases. Genome sequence assembly.

CPR E 569. Bioinformatics III (Structural Genome Informatics).
(Cross-listed with BCB, COM S, BBMB). (3-0) Cr. 3. F. *Prereq: BCB 567, GEN 411, STAT 430*
Algorithmic and statistical approaches in structural genomics including protein, DNA and RNA structure. Structure determination, refinement, representation, comparison, visualization, and modeling. Analysis and prediction of protein secondary and tertiary structure, disorder, protein cores and surfaces, protein-protein and protein-nucleic acid interactions, protein localization and function.

CPR E 570. Bioinformatics IV (Computational Functional Genomics and Systems Biology).
(Cross-listed with BCB, COM S, GDCB, STAT). (3-0) Cr. 3. S. *Prereq: BCB 567, BIOL 315, COM S 311 and either 208 or 228, GEN 411, STAT 430*
Algorithmic and statistical approaches in computational functional genomics and systems biology. Elements of experiment design. Analysis of high throughput gene expression, proteomics, and other datasets obtained using system-wide measurements. Topological analysis, module discovery, and comparative analysis of gene and protein networks. Modeling, analysis, simulation and inference of transcriptional regulatory modules and networks, protein-protein interaction networks, metabolic networks, cells and systems: Dynamic systems, Boolean, and probabilistic models. Multi-scale, multi-granularity models. Ontology-driven, network based, and probabilistic approaches to information integration.

CPR E 575. Computational Perception.
(Cross-listed with COM S, HCI). (3-0) Cr. 3. S. *Prereq: Graduate standing or permission of instructor*
This class covers statistical and algorithmic methods for sensing, recognizing, and interpreting the activities of people by a computer. This semester we will focus on machine perception techniques that facilitate and augment human-computer interaction. The main goal of the class is to introduce computational perception on both theoretical and practical levels. Participation in small groups to design, implement, and evaluate a prototype of a human-computer interaction system that uses one or more of the techniques covered in the lectures.

CPR E 581. Computer Systems Architecture.
(Cross-listed with COM S). (3-0) Cr. 3. F. *Prereq: CPR E 381*
Quantitative principles of computer architecture design, instruction set design, processor architecture: pipelining and superscalar design, instruction level parallelism, memory organization: cache and virtual memory systems, multiprocessor architecture, cache coherency, interconnection networks and message routing, I/O devices and peripherals.

CPR E 582. Computer Systems Performance.
(3-0) Cr. 3. *Prereq: CPR E 381, CPR E 310 and STAT 330*
Review of probability and stochastic processes concepts; Markovian processes; Markovian queues; renewal theory; semi-Markovian queues; queueing networks, applications to multiprocessor architectures, computer networks, and switching systems.

CPR E 583. Reconfigurable Computing Systems.
(Cross-listed with COM S). (3-0) Cr. 3. *Prereq: Background in computer architecture, design, and organization*
Introduction to reconfigurable computing, FPGA technology and architectures, spatial computing architectures such as systolic and bit serial adaptive network architectures, static and dynamic rearrangeable interconnection architectures, processor architectures incorporating reconfigurabiltiy.

CPR E 584. Models and Techniques in Embedded Systems.
(3-0) Cr. 3.
Industry-standard tools and optimization strategies; practical embedded platforms and technology (reconfigurable platforms, multi-core platforms, low-power platforms); instruction augmentation, memory-mapped accelerator design, embedded software optimization. Students will be encouraged to compete as teams in an embedded system design competition.

CPR E 585. Developmental Robotics.
(Cross-listed with HCI). (3-0) Cr. 3. Alt. S., offered 2011. *Prereq: knowledge of C/C++ programming language.*
An introduction to the emerging interdisciplinary field of Developmental Robotics, which crosses the boundaries between robotics, artificial intelligence, developmental psychology, and philosophy. The main goal of this field is to create autonomous robots that are more intelligent, more adaptable, and more useful than the robots of today, which can only function in very limited domains and situations.

CPR E 586. Pervasive Computing.
(3-0) Cr. 3. *Prereq: CPR E 489 or CPR E 530*
Fundamentals of pervasive computing, including location and context awareness, mobile and location services, ubiquitous data access, low power computing and energy management, middleware, security and privacy issues.

CPR E 588. Embedded Computer Systems.
(3-0) Cr. 3. *Prereq: CPR E 308*
Hardware/software systems and codesign. Models of computation for embedded systems. System-level design. Modeling, specification, synthesis, and verification. Hardware/software implementation. Design space exploration. Performance analysis and optimization. Multiprocessor system on chip. Platform-based design. Design methodologies and tools. Case studies and design projects.

CPR E 590. Special Topics.
Cr. 1-6. Repeatable.
Formulation and solution of theoretical or practical problems in computer engineering.

CPR E 592. Seminar in Computer Engineering.
Cr. 1-4. Repeatable. *Prereq: Permission of instructor*
Projects or seminar in Computer Engineering.

CPR E 594. Selected Topics in Computer Engineering.
(3-0) Cr. 3. Repeatable.

CPR E 599. Creative Component.
Cr. arr. Repeatable.

Courses for graduate students:

CPR E 626. Parallel Algorithms for Scientific Applications.
(Cross-listed with COM S). (3-0) Cr. 3. *Prereq: CPR E 526*
Algorithm design for high-performance computing. Parallel algorithms for multidimensional tree data structures, space-filling curves, random number generation, graph partitioning and load balancing. Applications to grid and particle-based methods and computational biology.

CPR E 632. Information Assurance Capstone Design.
(Cross-listed with INFAS). (3-0) Cr. 3. *Prereq: INFAS 531, INFAS 532, INFAS 534*
Capstone design course which integrates the security design process. Design of a security policy. Creation of a security plan. Implementation of the security plan. The students will attach each other's secure environments in an effort to defeat the security systems. Students evaluate the security plans and the performance of the plans. Social, political and ethics issues. Student self-evaluation, journaling, final written report, and an oral report.

CPR E 681. Advanced Topics in Computer Architecture.
(Cross-listed with COM S). (3-0) Cr. 3. Alt. S., offered 2013. *Prereq: CPR E 581. Repeatable with Instructor permission*
Current topics in computer architecture design and implementation. Advanced pipelining, cache and memory design techniques. Interaction of algorithms with architecture models and implementations. Tradeoffs in architecture models and implementations.

CPR E 697. Engineering Internship.
(Cross-listed with E E). Cr. R. Repeatable.
One semester and one summer maximum per academic year professional work period. Offered on a satisfactory-fail basis only.

CPR E 699. Research.
Cr. arr. Repeatable.