Department of Electrical and Computer Engineering Courses

About Course Numbers:

Each Carnegie Mellon course number begins with a two-digit prefix that designates the department offering the course (i.e., 76-xxx courses are offered by the Department of English). Although each department maintains its own course numbering practices, typically, the first digit after the prefix indicates the class level: xx-1xx courses are freshmen-level, xx-2xx courses are sophomore level, etc. Depending on the department, xx-3xx courses may be either undergraduate senior-level or graduate-level, and xx-7xx courses and higher are graduate-level. Consult the Schedule of Classes (https://enr-apps.as.cmu.edu/open/SOC/SOCServlet) each semester for course offerings and for any necessary pre-requisites or co-requisites.

18-090 Twisted Signals: Multimedia Processing for the Arts
Fall: 10 units
[IDEATe portal course] - This course presents an overview on manipulating and synthesizing sound, video, and control signals. Signals are the raw materials used in many forms of electronic art and design - electronic music, interactive art, video art, kinetic sculpture, and more. In these fields, signals are used to represent information about sound, images, sensors, and movement. By transforming and manipulating these types of signals, we are able to create powerful new tools for digital art, multimedia applications, music, responsive environments, video and sound installation, smart products, and beyond. In this course we will study Signal Processing from a practical point-of-view, developing tools that can be easily integrated into art-making using the graphical programming environment Max (a.k.a. Max/MSP/Jitter). We will present a survey of Signal Processing techniques used in the sonic and visual arts, and will discuss the mathematical theories underlying these techniques. Students will be encouraged to combine, modify, and extend working examples of software to create original digital artworks.

18-099 Special Topics: Mobile App Design & Development
Fall: 12 units
[IDEATe collaborative course] IDEATe is partnering with YinzCam to develop and offer a studio course on mobile app design and development. The course will leverage the extensive expertise of YinzCam on mobile-app development in the sports and entertainment space, both for real-time and asynchronous enrichment of the fan experience and the stadium experience. However, the lessons learned will apply to mobile-app development broadly. Issues covered will include cross-platform development, mobile video, streaming media, real-time content delivery, along with best practices in server-side cloud management for large-scale mobile-app deployment. Please note that this course is for students to take as one of their IDEATe concentration/minor options and will NOT fulfill a CIT/ECE requirement. Open to juniors and seniors. DC and MCS students should take the course after completing another IDEATe collaborative course. Prerequisites: 18-090 or 62-150 or 15-104

18-100 Introduction to Electrical and Computer Engineering
Fall and Spring: 12 units
The goals of this freshman engineering course are: * To introduce basic concepts in electrical and computer engineering in an integrated manner; * To motivate basic concepts in the context of real applications; * To illustrate a logical way of thinking about problems and their solutions, and; * To convey the excitement of the profession. These goals are attained through analysis, construction and testing of an electromechanical system (e.g., a robot) that incorporates concepts from a broad range of areas within Electrical and Computer Engineering. Some of the specific topics that will be covered include system decomposition, ideal and real sources, Kirchoff's Current and Voltage Laws, Ohm's Law, piecewise linear modeling of nonlinear circuit elements, Ideal Op-Amp characteristics, combinatorial logic circuits, Karnaugh Maps, Flip-Flops, sequential logic circuits, and finite state machines. 3 hrs. lect., 1 hr. rec., 3 hr. lab.

18-200 ECE Sophomore Seminar
Fall: 1 unit
"The class comprises of a series of lectures from our own faculty and alumni, Department and University staff, and student groups. Students are required to attend each lecture. The lectures are designed to serve the following purposes: 1. Introduce to students to the faculty member's research field and the most current world advancements in engineering and technology in that area; 2. Provide students a good understanding of our curriculum structure and the courses in various areas; 3. Present correlations between the present technological developments and our courses for each course area; 4. Introduce new undergraduate courses; 5. Advertise on-campus/off-campus research opportunities for undergraduate students and explain the corresponding research projects; 6. Motivate students with positive presentations on the importance of obtaining education and gaining self-learning ability; 7. Provide basic education on learning and working ethics.*
Prerequisite: 18-100

18-202 Mathematical Foundations of Electrical Engineering
Fall and Spring: 12 units
This course covers topics from engineering mathematics that serve as foundations for descriptions of electrical engineering devices and systems. It is the corequisite mathematics course for 18-220, Fundamentals of Electrical Engineering. The topics include: 1. MATLAB as a robust computational tool, used to reinforce, enrich and integrate ideas throughout the course, including software exercises and projects in combination with homework assignments; 2. Complex Analysis, including rectangular and polar representations in the complex plane with associated forms of complex arithmetic, powers, roots and complex logarithms, complex differentiation, analytic functions and Cauchy-Riemann equations, complex Taylor series, complex exponential, sinusoidal and hyperbolic functions, and Euler's formula; 3. Fourier Analysis, including orthogonality of sinusoids, trigonometric and exponential forms of Fourier series, Fourier integrals and Fourier transforms; 4. Linear, Constant-Coefficient Differential Equations, including complex exponential solutions to homogeneous equations and particular solutions with polynomial and sinusoidal driving functions described by phasors; 5. Difference Equations, with emphasis upon their relationship to differential equations, and; 6. Linear Algebra and Matrices, including matrix arithmetic, linear systems of equations and Gaussian elimination, vector spaces and rank of matrices, matrix inverses and determinants, eigenvalue problems and their relationship to systems of homogeneous differential equations. Prerequisite: 21-122 Min. grade C

18-213 Introduction to Computer Systems
Spring and Summer: 12 units
This course provides a programmer's view of how computer systems execute programs, store information, and communicate. It enables students to become more effective programmers, especially in dealing with issues of performance, portability and robustness. It also serves as a foundation for courses on compilers, networks, operating systems, and computer architecture, where a deeper understanding of systems-level issues is required. Topics covered include: machine-level code and its generation by optimizing compilers, performance evaluation and optimization, computer arithmetic, memory organization and management, networking technology and protocols, and supporting concurrent computation. NOTE: students must achieve a C or better in order to use this course to satisfy the prerequisite for any subsequent Computer Science course. Prerequisites: 15-123 (Grade of C or higher is required in the prerequisite) Prerequisite: 15-122 Min. grade C

Course Website: http://www.cs.cmu.edu/~213/
**Department of Electrical and Computer Engineering Courses**

18-220 Electronic Devices and Analog Circuits
Fall and Spring: 12 units
This course covers fundamental topics that are common to a wide variety of electrical engineering devices and systems. The topics include an introduction to semiconductor devices and technology, DC circuit analysis techniques, operational amplifiers, energy storage elements, sinusoidal steady-state response, frequency domain analysis, filters, and transient response of first- and second-order systems. The laboratory provides hands-on experience in the design and implementation of analog circuits that address specific concepts covered in the lectures, including semiconductor devices and sensors, layout, operational amplifiers, filters, signal detection and processing, power converters and circuit transients. 3 hrs. lec., 1 hr. rec., 3 hrs. lab.
Prerequisite: 18-100
Course Website: [https://www.ece.cmu.edu/courses/items/18220.html](https://www.ece.cmu.edu/courses/items/18220.html)

18-231 Sophomore Projects
Fall
The Department of Electrical and Computer Engineering at Carnegie Mellon considers experiential learning opportunities important educational options for its undergraduate students. One such option is conducting undergraduate research with a faculty member. Students do not need to officially register for undergraduate research unless they want it listed on their official transcripts. An ECE student who is involved in a research project and is interested in registering this undergraduate research for course credit on the official transcript may request to be enrolled in this course. To do this, the student should first complete the on-line undergraduate research form available on the ECE undergraduate student page. Once the form has been submitted and approved by the faculty member the student is conducting the research with, the ECE Undergraduate Office will add the course to the student's schedule. Typical credit is granted as one hour of research per week is equal to one unit of credit.

18-232 Sophomore Projects
Spring
The Department of Electrical and Computer Engineering at Carnegie Mellon considers experiential learning opportunities important educational options for its undergraduate students. One such option is conducting undergraduate research with a faculty member. Students do not need to officially register for undergraduate research unless they want it listed on their official transcripts. An ECE student who is involved in a research project and is interested in registering this undergraduate research for course credit on the official transcript may request to be enrolled in this course. To do this, the student should first complete the on-line undergraduate research form available on the ECE undergraduate student page. Once the form has been submitted and approved by the faculty member the student is conducting the research with, the ECE Undergraduate Office will add the course to the student's schedule. Typical credit is granted as one hour of research per week is equal to one unit of credit.

18-240 Structure and Design of Digital Systems
Fall and Spring: 12 units
This course introduces fundamental topics that are common to a wide variety of digital systems. The topics include: Boolean algebra, digital number systems and computer arithmetic, combinational logic design and simplification, sequential logic design and optimization, register-transfer design of digital systems, basic processor organization and instruction set issues, assembly language programming and debugging, and a hardware description language. Emphasis is on the fundamentals: the levels of abstraction and hardware description language methods that allow designers to cope with complex systems, and connections to practical hardware implementation problems. Students will use computer-aided design software and actual hardware implementation laboratories to learn about real digital systems. 3 hrs. lec., 1 hr. rec., 3 hrs. lab.
Prerequisite: 18-100

18-290 Signals and Systems
Fall and Spring: 12 units
This course develops the mathematical foundation and computational tools for processing continuous-time and discrete-time signals in both time and frequency domain. Key concepts and tools introduced and discussed in this class include linear time-invariant systems, impulse response, frequency response, convolution, filtering, sampling, and Fourier transform. Efficient algorithms like the fast Fourier transform (FFT) will be covered. The course provides hands-on experience in the design and implementation of analog and digital circuits. Labs will employ both design using discrete, SSI, and MSI parts, as well as using CAD tools.
Prerequisite: 18-220

18-300 Fundamentals of Electromagnetics
Fall: 12 units
This course introduces fundamental topics that are common to a wide variety of systems including telecommunication, computer architecture, sensor networks, communication systems, and control systems. The topics include: vector calculus as a mathematical foundation for field descriptions, Maxwell's equations in integral and differential forms with associated boundary conditions as descriptions of all electromagnetic principles, quasistatic electric fields in free space and in materials, superposition for known charge sources, conduction and polarization, resistance and capacitance, charge relaxation, analytic and numerical methods for electric field boundary value problems, quasistatic magnetic fields in free space and in materials, superposition for known current sources, magnetization, inductance, magnetic diffusion, and analytic and numerical methods for magnetic field boundary value problems. 4 hrs. lec.
Prerequisite: 18-220

18-310 Fundamentals of Semiconductor Devices
Spring: 12 units
This course is divided into two parts. The first part is a general introduction to the operation and fabrication of the most important semiconductor devices used in integrated circuit technology together with device design and layout. At the end of the course you will have a basic understanding of pn diodes, bipolar transistors, and MOSFETs as well as some light emitting and light detecting devices such as photodiodes, LEDs and solar cells. You will also receive an introduction to the fundamental concepts of semiconductor physics such as doping, electron and hole transport, and band diagrams. In the laboratory you will learn how to lay out both bipolar and MOS devices and you will design small (2-3 transistor) circuits. The laboratory portion of the course emphasizes the relation between device design and layout and circuit performance. You will also experimentally evaluate the operation of amplifier and gate circuits fabricated with discrete devices. This course will give you an excellent understanding of the operation and fabrication of the devices which is necessary for high-performance analog and digital circuit design. 3 hrs. lec.
Prerequisite: 18-220

18-320 Microelectronic Circuits
Spring: 12 units
This course introduces students to the fundamentals of microelectronic circuits. The course will emphasize the analysis and design of basic analog and digital integrated circuits in preparation for further study in analog, digital, mixed-signal, and radio-frequency integrated circuit design. Additionally, students will learn to design and analyze microelectronic circuits using industry standard computer aided design (CAD) software. Topics to be covered include: MOSFET fabrication and layout MOSFET models for analog and digital design Analysis and design of digital CMOS logic gates Analysis and design of clocked storage elements (e.g., flip-flops, latches, memory cells) Delay optimization of digital circuits Circuit topologies for arithmetic and logical functional units Analysis and design of single-stage MOS amplifiers Frequency response characteristics of single-stage amplifiers Differential amplifiers and simple operational amplifiers Analog filters using operational amplifiers The course includes a lab component which will give students hands-on experience in the design and implementation of analog and digital circuits. Labs will employ both design using discrete, SSI, and MSI parts, as well as using CAD design tools.
Prerequisite: 18-220
18-330 Introduction to Computer Security
Fall: 12 units

Security is becoming one of the core requirements in the design of critical systems. This course will introduce students to the intro-level fundamental knowledge of computer security and applied cryptography. Students will learn the basic concepts in computer security including software vulnerability analysis and defense, networking and wireless security, and applied cryptography. Students will also learn the fundamental methodology for how to design and analyze security critical systems.

Prerequisite: 18-213

18-331 Junior Projects
Fall

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18-332 Junior Projects
Spring

The Department of Electrical and Computer Engineering at Carnegie Mellon considers experiential learning opportunities important educational options for its undergraduate students. One such option is conducting undergraduate research with a faculty member. Students do not need to officially register for undergraduate research unless they want it listed on their official transcripts. An ECE student who is involved in a research project and is interested in registering this undergraduate research for course credit on the official transcript may request to be enrolled in this course. To do this, the student should first complete the on-line undergraduate research form available on the ECE undergraduate student page. Once the form has been submitted and approved by the faculty member the student is conducting the research with, the ECE Undergraduate Office will add the course to the student's schedule. Typical credit is granted as one hour of research per week is equal to one unit of credit.

18-334 Network Security
Spring: 12 units

Some of today's most damaging attacks on computer systems involve exploitation of network infrastructure, either as the target of attack or as a vehicle to advance attacks on end systems. This course provides an in-depth study of network attack techniques and methods to defend against them. The course will cover topics spanning five broad themes: (1) infrastructure topics such as firewalls, network intrusion detection, secure routing protocols, and recent advances such as software-defined networking; (2) network attacks such as denial of service (DoS) and distributed denial-of-service (DDoS) attacks, worm and virus propagation; (3) analysis and inference topics such as network forensics and attack economics; (4) user related topics such as authentication, anonymity and censorship resilience; and (5) new technologies related to next-generation networks, and cellular and wireless networks. Students in 18-334 will share lectures and homeworks with students in 18-731. However, 18-731 will have additional requirements not shared by 18-334, including the requirement to produce scribe notes and to practice and demonstrate the ability to read and summarize scientific papers on the topics covered by the course.

Prerequisites: 15-330 or 18-330

18-335 Secure Software Systems
Spring: 12 units

Poor software design and engineering are the root causes of most security vulnerabilities in deployed systems today. Moreover, with code mobility now commonplace—particularly in the context of web technologies and digital rights management—system designers are increasingly faced with protecting hosts from foreign software and protecting software from foreign hosts running it. This class takes a close look at software as a mechanism for attack, as a tool for protecting resources, and as a resource to be defended. Topics covered include the software design process; choices of programming languages, operating systems, databases and distributed object platforms for building secure systems; common software vulnerabilities, such as buffer overflows and race conditions; auditing software; proving properties of software; software and data watermarking; code obfuscation; tamper resistant software; and the benefits of open and closed source development. Students in 18-335 will share lectures and homeworks with students in 18-732. However, 18-732 has additional requirements not shared by 18-335, including the requirement to produce scribe notes and to practice and demonstrate the ability to read and summarize scientific papers on the topics covered by the course.

Prerequisites: 15-330 or 18-330

18-340 Hardware Arithmetic for Machine Learning
Fall: 12 units

In this course, students explore the techniques for designing high-performance digital circuits for computation along with methods for evaluating their characteristics. We begin by reviewing number systems and digital arithmetic along with basic arithmetic circuits such as ripple-carry adders. From there, we move to more complex adders (carry-look-ahead, carry-skip, carry-bypass, etc.), multipliers, dividers, and floating-point units. For each circuit introduced, we will develop techniques and present theory for evaluating their functionality and speed. Other methods will be described for analyzing a circuit's power consumption, testability, silicon area requirements, correctness, and cost. In addition, we will utilize various CAD tools to evaluate the circuits described. Finally, advanced timing and clocking concepts will be investigated. For example, the notion of clock skew will be introduced and its impact on clock period for sequential circuits will be analyzed. We will also learn how to analyze and design asynchronous circuits, a class of sequential circuits that do not utilize a clock signal. Course projects focus on key arithmetic aspects of various machine learning algorithms including: K-nearest neighbors, neural networks, decision trees, and support vector machines. *Note: Although students in 18-340 and 18-640 will share lectures, labs, and recitations, students in 18-340 and 18-640 will receive different homework assignments, design projects, and exams. In some cases 18-640 students will also have different or additional lab sessions. The homework assignments, design projects, and exams that are given to the students registered for 18-640 will be more challenging than those given to the students registered for 18-340 in that they will have more complex designs, involve additional theoretical analysis, and have more stringent specifications (e.g., in area, power, performance, and robustness).

Prerequisite: 18-240

18-341 Logic Design and Verification
Fall: 12 units

This course is a second level logic design course, studying the techniques of designing at the register-transfer and logic levels of complex digital systems using modern modeling, simulation, synthesis, and verification tools. Topics include register-transfer level systems (i.e., finite state machines and data paths), bus and communication system interfacing (such as a simplified USB interface), discrete-event simulation, testbench organization, assertion-based verification and functional coverage. Design examples will be drawn from bus and communication interfaces, and computation systems, emphasizing how these systems are designed and how their functionality can be verified. A modern hardware description language, such as SystemVerilog, will serve as the basis for unifying these topics. Quizzes, homeworks and design projects will serve to exercise these topics.

Prerequisite: 18-240
18-342 Fundamentals of Embedded Systems  
Fall: 12 units  
This practical, hands-on course introduces students to the basic building-blocks and the underlying scientific principles of embedded systems. The course covers both the hardware and software aspects of embedded processor architectures, along with operating system fundamentals, such as virtual memory, concurrency, task scheduling and synchronization. Through a series of laboratory projects involving state-of-the-art processors, students will learn to understand implementation details and to write assembly-language and C programs that implement core embedded OS functionality, and that control/debug features such as timers, interrupts, serial communications, flash memory, device drivers and other components used in typical embedded applications. Relevant topics, such as optimization, profiling, digital signal processing, feedback control, real-time operating systems and embedded middleware, will also be discussed. This course is intended for IWI students. Anti-requisites: 18348 or 18349  
Prerequisite: 18-240

18-345 Introduction to Telecommunication Networks  
Spring: 12 units  
This course introduces the fundamental concepts of telecommunication networks. Underlying engineering principles of telephone networks, computer networks and integrated digital networks are discussed. Topics in the course include: telephone and data networks overview; OSI layers; data link protocol: flow control, congestion control, routing; local area networks; transport layer; introduction to high-speed networks; performance evaluation techniques. The course also reviews important aspects of network security and widely used classes of Internet application and services, such as peer-to-peer, content delivery networks, and video streaming.  
Prerequisites: (36-217 or 36-226 or 36-212) and 18-213

18-349 Introduction to Embedded Systems  
Fall and Spring: 12 units  
This practical, hands-on course introduces the various building blocks and underlying scientific and engineering principles behind embedded real-time systems. The course covers the integrated hardware and software aspects of embedded processor architectures, along with advanced topics such as real-time, resource/device and memory management. Students can expect to learn how to program with the embedded architecture that is ubiquitous in smartphones, portable gaming devices, robots, etc. Students will then go on to learn and apply real-time principles that are used to drive critical embedded systems like automobiles, avionics, medical equipment, etc. Topics covered include embedded architectures (building up to modern 16/32/64-bit embedded processors); interaction with devices (buses, memory architectures, memory management, device drivers); concurrency (software and hardware interrupts, timers); real-time principles (multi-tasking, scheduling, synchronization); implementation trade-offs, profiling and code optimization (for performance and memory); embedded software (exception handling, loading, mode-switching, programming embedded systems). Through a series of laboratory exercises with state-of-the-art embedded processors, sensors, actuators and industry-strength development tools, students will acquire skills in the design/implementation/debugging of core embedded real-time functionality.  
Prerequisites: 18-213 and 18-240

Course Website: http://www.ece.cmu.edu/~ee349

18-372 Fundamental Electrical Power Systems  
Fall: 12 units  
This course introduces the fundamentals in electric energy systems which will enable you to understand current issues and challenges in electric power systems ("smart grid") and what it takes for you to have a reliable electric power supply at your house. First, the general structure of an electric power system (current and future trends) will be introduced. This includes electric power plants (renewable and non-renewable); transmission and distribution; and consumers. Then, electric power is addressed from a mathematical point of view. The mathematical formulae for AC power and models for the above mentioned elements are derived which will enable you to calculate how much power is flowing over which lines on its way from the power plant to the consumer. Maintaining the balance between generation and consumption is important to avoid catastrophic blackout events. Hence, the notion of stability and available control concepts will be introduced.  
Prerequisites: 18-220 and 18-202

18-390 ECE CO-OP  
Fall and Spring  
The Department of Electrical and Computer Engineering at Carnegie Mellon considers experiential learning opportunities important educational options for its undergraduate students. One such option is cooperative education, which provides a student with an extended period of exposure with a company. To participate, students must complete an ECE Co-op Approval form (located in HH 1116) and submit for approval. Students must possess at least junior status and have an overall grade point average of 3.0 or above. All co-ops must be approved. The ECE Undergraduate Studies Office will add the course to the student's schedule. Upon completion of the co-op experience, students must submit a 1-2 page report of their work experience, and a 1-2 page evaluation from the company supervisor to the ECE Undergraduate Studies Office. Due to federal restrictions on student work experiences, international students are not eligible for co-ops. Please visit the CPT page for information regarding international student internships.

18-401 Electromechanics  
12 units  
This course provides a broadly based introduction to interactions between mechanical media and electromagnetic fields. Attention is focused on the electromechanical dynamics of lumped-parameter systems, wherein electrical and mechanical subsystems may be modeled in terms of discrete elements. Interactions of quasistatic electric and magnetic fields with moving media are described and exemplified. Unifying examples are drawn from a wide range of technological applications, including energy conversion in synchronous, induction, and commutator rotating machines, electromechanical relays, a capacitor microphone and speaker, and a feedback-controlled magnetic levitation system.  
4.5 hrs. rec.  
Prerequisite: 18-300

18-402 Applied Electrodynamics  
Spring: 12 units  
This course builds upon the electric and magnetic field foundations established in 18-300 to describe phenomena and devices where electromagnetic waves are a central issue. Topics include: review of Maxwell's equations, propagation of uniform plane waves in lossless and lossy media, energy conservation as described by the Poynting theorem, reflection and transmission with normal and oblique incidence upon boundaries, sinusoidal steady state and transients on 2-conductor transmission lines, modal descriptions of waveguides, radiation and antennas. 4 hrs. lec.  
Prerequisite: 18-300

18-403 Microfabrication Methods and Technology  
Fall: 12 units  
This course is a laboratory-based introduction to the theory and practice of microfabrication. Lectures and laboratory sessions cover fundamental processing techniques such as photo-mask creation, lithographic patterning, thin film vacuum deposition processes, wet-chemical and dryetching processes. This is primarily a hands-on laboratory course which brings students into the microfabrication facility and device testing laboratories. Students will fabricate electronic and opto-electronic devices such the metal-oxide-semiconductor (MOS) capacitor, the Schottky diode, the MOS transistor, the solar cell, and the light-emitting diode. An understanding of the operation of these building block devices will be gained by performing measurements of their electrical and opto-electronic characteristics. Emphasis is placed on understanding the interrelationships between the materials properties, processing, device structure, and the electrical and optical behavior of the devices. The course is intended to provide a background for a deeper appreciation of solid state electronic devices and integrated circuits. 2 lecture periods per week and a minimum of 4 laboratory hours.  
Prerequisite: 18-310
18-411 Computational Techniques in Engineering
Spring: 12 units
This course develops the methods to formulate basic engineering problems in a way that makes them amenable to computational/numerical analysis. The course will consist of three main modules: basic programming skills, discretization of ordinary and partial differential equations, and numerical methods. These modules are followed by two modules taken from a larger list: Monte Carlo-based methods, molecular dynamics methods, image analysis methods, and so on. Students will learn how to work with numerical libraries and how to compile and execute scientific code written in Fortran-90 and C++. Students will be required to work on a course project in which aspects from at least two course modules must be integrated.
Prerequisites: 21-260 and 15-100 and 21-120 and 21-122 and 21-259

18-415 From Design to the Market for Deep Submicron IC’s
Spring: 12 units
The general objective of the 18-415 class is to introduce and analyze all major design-dependent trade-offs which decide about the IC product commercial success. This objective will be achieved via playing in the class an “imaginary fabless IC design house startup game” - a main class activity. In this game students will be asked to construct “business plans” for a startup fabless IC design house. Each team in the class will have to envision, as an IC design objective, a new product with a functionality, which is already provided by another existing IC product (i.e. by microprocessor). The envisioned product should provide a subset of functionality of the existing product but it should be “better” in some other respect (e.g. it could be less expensive to fabricate, faster etc.). To handle the above assignment, students in the class will be using skills learned in 18-322 as well as all legal sources of “industrial intelligence” typically available for the IC industry. They can also use the class teacher as a source of free consulting, as well as, they can ask for any sequence of lectures or literature sources which they will need to meet the class objectives.
Prerequisite: 18-320

18-416 Nano-Bio-Photonics
Spring: 12 units
Light can penetrate biological tissues non-invasively. Most of the available bio-optic tools are bulky. With the advent of novel nanotechnologies, building on-chip integrated photonic devices for applications such as spectroscopy, imaging, and neural stimulation, and monitoring is now a possibility. These devices can be embedded in portable electronic devices such as cell phones for point of care diagnostics. This course is designed to convey the concepts of nano-bio-photonics in a practical way to prepare students to engage in emerging photonic technologies. The course starts with a review of electrodynamics of lightwaves. The appropriate choice of wavelength and material platform is the next topic. Then optical waveguides and resonators are discussed. Resonance-based sensing is introduced followed by a discussion of the Figure of Merits (FOMs) used to design on-chip sensors. Silicon photonics is introduced as an example of a CMOS-compatible platform. On-chip spectroscopy is the next topic. The second part covers nano-plasmonics for bio-detection and therapy. The design methods are discussed, followed by an overview of nano-lasers and chemical synthesis, and then a discussion of applications. The last part of this course will be dedicated to a review of recent applications such as Optogenetic neural stimulation, Calcium imaging, Cancer Imaging and Therapy. Senior or graduate standing required. This course is cross-listed with 18616. Although students in 18-616 and 18-416 will share the same lectures and recitations, students in 18-616 will receive different homework assignments, distinct design problems, and different exams from the ones given to students in 18-416 and will be graded on a separate curve from students taking 18-416.
Prerequisites: 18-320 Min. grade C and 18-290 Min. grade C

18-421 Analog Integrated Circuits
Fall: 12 units
This course covers the design and implementation of digital circuits in a modern VLSI process technology. Topics will include logic gate design, functional unit design, latch/flip-flop design, system clocking, memory design, clock distribution, power supply distribution, design for test, and design for manufacturability. The lab component of the course will focus on using modern computer aided design (CAD) software to design, simulate, and lay out digital circuits. The final project for the course involves the design and implementation to the layout level of a small microprocessor. 18-240 and 18-320 or equivalent background material with permission of the instructor. Although students in 18-623 will share Lectures and Recitations with students in 18-421, students in 18-623 will receive distinct homework assignments, distinct design problems, and different exams from the ones given to students in 18-421 and will be graded on a separate curve from students taking 18-421.
Prerequisites: 18-320 Min. grade C and 18-290 Min. grade C

18-422 Digital Integrated Circuit Design
Fall: 12 units
This course covers the design and implementation of digital circuits in a modern VLSI technology. Topics will include logic gate design, functional unit design, latch/flip-flop design, system clocking, memory design, clock distribution, power supply distribution, design for test, and design for manufacturability. The course will focus on using modern computer aided design (CAD) software to design, simulate, and lay out digital circuits. The final project for the course involves the design and implementation to the layout level of a small microprocessor. 18-240 and 18-320 or equivalent background material with permission of the instructor. Although students in 18-623 will share Lectures and Recitations with students in 18-421, students in 18-623 will receive distinct homework assignments, design projects, and exams, and in some cases 18-622 students will also have different or additional lab sessions.
Prerequisites: 18-320 and 18-240

18-431 Undergraduate Projects - Senior
Fall
The Department of Electrical and Computer Engineering at Carnegie Mellon considers experiential learning opportunities important educational options for its undergraduate students. One such option is conducting undergraduate research with a faculty member. Students do not need to officially register for undergraduate research course credit on the official transcript. An ECE student who is involved in a research project and is interested in registering this undergraduate research for course credit on the official transcript may request to be enrolled in this course. To do this, the student should first complete the on-line undergraduate research form available on the ECE undergraduate student page. Once the form has been submitted and approved by the faculty member the student is conducting the research with, the ECE Undergraduate Office will add the course to the student's schedule. Typical credit is granted as one hour of research per week is equal to one unit of credit.

18-432 Senior Projects
Spring
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**18-411 Computer Architecture**

Spring: 12 units

Computer architecture is the science and art of selecting and interconnecting hardware components to create a computer that meets functional, performance and cost goals. This course introduces the basic hardware structure of a modern programmable computer, including the basic laws underlying performance evaluation. We will learn, for example, how to design the control and data path hardware for a MIPS-like processor, how to make machine instructions execute simultaneously through pipelining and simple superscalar execution, and how to design fast memory and storage systems. The principles presented in the lecture are reinforced in the laboratory through the design and simulation of a register transfer (RT) implementation of a MIPS-like pipelined superscalar in Verilog. Learning to design programmable systems requires that you already have the knowledge of building RT systems, the knowledge of the behavior storage hierarchies (e.g., cache memories) and virtual memory, and the knowledge of assembly language programming.

Prerequisites: 18-240 and (18-213 or 15-213) and (18-349 or 18-340 or 18-346 or 18-320 or 18-341)

**18-447 Introduction to Computer Architecture**

Spring: 12 units

Computer architecture is the science and art of selecting and interconnecting hardware components to create a computer that meets functional, performance and cost goals. This course introduces the basic hardware structure of a modern programmable computer, including the basic laws underlying performance evaluation. We will learn, for example, how to design the control and data path hardware for a MIPS-like processor, how to make machine instructions execute simultaneously through pipelining and simple superscalar execution, and how to design fast memory and storage systems. The principles presented in the lecture are reinforced in the laboratory through the design and simulation of a register transfer (RT) implementation of a MIPS-like pipelined superscalar in Verilog. Learning to design programmable systems requires that you already have the knowledge of building RT systems, the knowledge of the behavior storage hierarchies (e.g., cache memories) and virtual memory, and the knowledge of assembly language programming.

Prerequisites: 18-240 and (18-213 or 15-213) and (18-349 or 18-340 or 18-346 or 18-320 or 18-341)

**18-451 Networked Cyberphysical Systems**

Spring: 12 units

Cyber-physical systems (CPS) represent a new class of systems that bring together sensing, computation, communication, control and actuation to enable continuous interactions with physical processes. This integration of networked devices, people, and physical systems provides huge opportunities and challenges for applications in automotive, transportation, and healthcare. This course is primarily an in-depth introduction to networked CPS with an emphasis on methods for modeling, design, and optimization. Focus is on the dominant design paradigms like low-power and communication-centric design. Topics to be covered include: physical processes, models of concurrency, sensing and workload modeling, human behavior modeling, data-driven modeling, networking at micro- and macro-scale, system-wide resources management, programming, validation and integration. From a practical standpoint, students will directly experiment with hardware prototypes and software tools to explore concrete CPS examples. By structure and contents, this class is primarily targeted to ECE students; it can also provide a valuable basis for interdisciplinary research to students in CS and related disciplines.

Prerequisites: 18-349 or (18-240 and 18-213)

**18-452 Wireless Networking and Applications**

Spring: 12 units

This course introduces fundamental concepts of wireless networks. The design of wireless networks is influenced heavily by how signals travel through space, so the course starts with an introduction to the wireless physical layer, presented in a way that is accessible to a broad range of students. The focus of the course is on wireless MAC concepts including CSMA, TDMA/FDMA, and CDMA. It also covers a broad range of wireless networking standards, and reviews important wireless network application areas (e.g., sensor networks, vehicular) and other applications of wireless technologies (e.g., GPS, RFID, sensing, etc.). Finally, we will touch on public policy issues, e.g., as related to spectrum use. The course will specifically cover: Wireless networking challenges Wireless communication overview Wireless MAC concepts Overview of cellular standards and LTE Overview of wireless MAC protocols WiFi, Bluetooth and personal area networks, etc. Wireless in today's Internet: TCP over wireless, mobility, security, etc. Advanced topics, e.g., mesh and vehicular networks, sensor networks, DTNs, localization, sensing, etc. Although students in 18-750 will share Lectures and Recitations with students in 18-452, they will receive distinct homework assignments and exams from students in 18-452. The main project will also be different. The students in the two versions of the course will also be graded on a separate curve.

Prerequisites: 15-213 or 18-600 or 18-213
18-464 ULSI Technology Status and Roadmap for System on Chips and System in Package
Fall and Spring: 12 units
This course will provide the necessary background for the state-of-the-art technologies utilized by the leading edge products covering full spectrum of market drivers from mobile platforms, microprocessors, game chips to the highest performance systems for enterprise solutions computing. We will present all key components of such systems, i.e., logic, analog/RF and embedded memories. Then we present the technology roadmap for the upcoming generations in terms of device architecture options for logic devices (FinFET, Nanowire and Tunnel FET) and memories (Phase Change Memory, Resistive RAM and Magnetic RAM/Spin-Transfer Torque RAM) from the device level all the way to the system level specifications. The last part of the class will be devoted to the system integration issues, namely 3-dimensional integration approaches. This course is designed for MS and PhD students from diverse areas: System/Hardware Design, Circuits and Devices/Nanofabrication and is aimed at bridging the gap among these areas.
Prerequisites: 18-422 or 18-320

18-474 Embedded Control Systems
Spring; 12 units
This course introduces principles for design of embedded controllers. In applications ranging from airplanes, to automobiles, to manufacturing systems, embedded computers now close feedback loops that were previously closed by mechanical devices or by humans in the loop. This course emphasizes practical insight into the tools for modeling and simulating these dynamic physical systems, and methods for designing the real-time software for embedded computers to control them. Lectures cover relevant theory and background from real-time systems and control engineering, including event-based and clock-based sampling, switching control, PWM (pulse-width modulation), PID (proportional-integral-derivative) design, state-variable feedback, state estimation, and methods for setpoint control and trajectory tracking. Basic embedded computing, sensor, and actuator technologies are reviewed, including microcontrollers, DC motors and optical encoders. In the laboratory, students use commercial tools for simulation and automatic code generation to design and implement embedded control system experiments. 3 hrs. lecture, 3 hrs. lab.
Prerequisites: (15-213 or 18-213) and (18-396 or 18-370)

18-482 Telecommunications Technology and Policy for the Internet Age
Spring: 12 units
Modern telecommunications is the nervous system of society. The Internet and wireless communications have transformed every aspect of our modern life. This course provides a comprehensive introduction to basic principles of telecommunication technology and the legal, economic, and regulatory environment of today’s networks. Topics covered include the fundamentals of communication network technologies, including video, voice, and data networks; the rising dominance of wireless networks; principles behind telecommunications regulation from common carrier licenses through current spectrum auctions. Of course such regulatory analysis will be completed during the summer. Students do not need to officially register for an internship unless they want it listed on their official transcripts. ECE students interested in registering their internship for course credit on their transcript may request to be enrolled in this course. The ECE Undergraduate Office will add the course to the student's schedule, and the student will be assessed tuition for 3 units. This process should be used by international students interested in Curricular Practical Training (CPT) or by any other engineering undergraduate wishing to have their internship experience reflected on their official University transcript. International students should also be authorized by the Office of International Education (OIE). More information regarding CPT is available on OIE's website.

18-491 Fundamentals of Signal Processing
Fall: 12 units
This course addresses the mathematics, implementation, design and application of the digital signal processing algorithms widely used in areas such as multimedia telecommunications and speech and image processing. Topics include discrete-time signals and systems, discrete-time Fourier transforms and Z-transforms, discrete Fourier transforms and fast Fourier transforms, digital filter design and implementation, and multi-rate signal processing. The course will include introductory discussions of 2-dimensional signal processing, linear prediction, adaptive filtering, and selected application areas. Classroom lectures are supplemented with implementation exercises using MATLAB.
Prerequisite: 18-290

18-493 Electroacoustics
Fall: 12 units
This course provides an introduction to physical, engineering, and architectural acoustics. The course begins with a review of the wave equation and some of its solutions that are relevant to the propagation of sound from planar and spherical sources, and from arrays of simple sources. Lumped-parameter electrical circuit analogies are developed to describe mechanical and acoustical systems, leading to a discussion of the constraints and tradeoffs involved in the design of loudspeakers, microphones, and other transducers. The characteristics of sound in regular and irregular enclosures will be developed and discussed in the context of the acoustical design for rooms and auditoriums. The interaction of sound and man is also discussed, with introductory lectures on auditory perception and the acoustics of speech production, with applications in the areas of efficient perceptually-based coding of music and speech, and virtual acoustical environments.
Prerequisites: 18-290 and 18-220

18-496 Introduction to Biomedical Imaging and Image Analysis
Fall: 12 units
Bioimage Informatics (formerly Bioimaging) This course gives an overview of the biological tasks in various biomedical and biophysical imaging modalities, such as fluorescence microscopy, electron microscopy, magnetic resonance imaging, ultrasound and others. The major focus will be on automating and solving the fundamental tasks required for interpreting these images, including (but not restricted to) deconvolution, registration, segmentation, pattern recognition, and modeling, as well as tools needed to solve those tasks (such as Fourier and wavelet methods). The discussion of these topics will draw on approaches from many fields, including statistics, signal processing, and machine learning. As part of the course, students will be expected to complete an independent project.
Prerequisite: 18-290

18-499 Internship
All Semesters
The Department of Electrical and Computer Engineering at Carnegie Mellon considers experiential learning opportunities important educational options for undergraduate students. In such opportunities an internship must be completed during the summer. Students do not need to officially register for an internship unless they want it listed on their official transcripts. ECE students interested in registering their internship for course credit on their transcript may request to be enrolled in this course. The ECE Undergraduate Office will add the course to the student’s schedule, and the student will be assessed tuition for 3 units. This process should be used by international students interested in Curricular Practical Training (CPT) or by any other engineering undergraduate wishing to have their internship experience reflected on their official University transcript. International students should also be authorized by the Office of International Education (OIE). More information regarding CPT is available on OIE's website.

18-500 ECE Design Experience
Fall and Spring; 12 units
The ECE Design Experience is a capstone design course that serves to introduce students to broad-based, practical engineering design and applications through an open-ended design problem. Students will work with a team on a project of their choosing (subject to instructor approval) throughout the semester culminating with a final project presentation, report, and public demonstration. The projects will need to encompass a minimum of two ECE areas. Throughout the semester, teams will need to give both written and oral project proposals and periodic performance updates. Team-building experiences designed to educate students on group dynamics, resource management, decision making, Big-picture implications of engineering applications; societal, human, ethical, and long-term impact will be explored. PREREQUISITES: Any TWO 18-xxx ECE Area courses AND all four ECE Sophomore Core courses, 18-213, 18-220, 18-240 and 18-290.
Prerequisites: 18-213 and 18-240 and 18-220 and 18-290
18-540 Rapid Prototyping of Computer Systems
Spring: 12 units
This is a project-oriented course which will deal with all four aspects of project development; the application, the artifact, the computer-aided design environment, and the physical prototyping facilities. The class, in conjunction with the instructors, will develop specifications for a mobile computer to assist in inspection and maintenance. The application will be partitioned between human computer interaction, electronics, industrial design, mechanism, and software components. The class will be divided into groups to specify, design, and implement the various subsystems. The goal is to produce a working hardware/software prototype of the system and to evaluate the user acceptability of the system. We will also monitor our progress in the design process by capturing our design decisions (errors) with the Orthogonal Defect Classification (ODC). Upon completion of this course the student will be able to: generate systems specifications from a perceived need; partition functionality between hardware and software; produce interface specifications for a system composed of numerous subsystems; use computer-aided design tools; fabricate, integrate, and debug a hardware/software system; and evaluate the system in the context of an end user application. Senior standing is required. This course is crosslisted as 18745.
Prerequisites: (18-320 or 18-491 or 18-370) and (18-349 or 18-341 or 18-340)

18-578 Mechatronic Design
Spring: 12 units
Mechatronics is the synergistic integration of mechanism, electronics, and computer control to achieve a functional system. Because of the emphasis upon integration, this course will center around system integration in which small teams of students will configure, design, and implement a succession of mechatronic subsystems, leading to a main project. Lectures will complement the laboratory experience with comparative surveys, operational principles, and integrated design issues associated with the spectrum of mechanism, electronics, and control components. Class lectures will cover topics intended to complement the laboratory work, including mechanisms, actuators, motor drives, sensors and electronic interfaces, microcontroller hardware and programming and basic controls. During the first week of class, each student will be asked to complete a questionnaire about their technical background. The class will then be divided into multi-disciplinary teams of three students. During the first half of the class, lab assignments will be made every 1-2 weeks to construct useful subsystems based on material learned in lecture. The lab assignments are geared to build to the main project. This course is crosslisted as 16-778 and 24-778. Students in other departments may take the course upon availability of slots with permission of instructor. Non ECE students may take the course upon availability of slots with permission of the instructor.
Prerequisites: (18-320 and 18-348) or (15-313 and 18-348) or (18-348 and 18-370) or (18-370 and 18-349) or (18-349 and 15-313) or (18-320 and 18-349) or (18-320 and 18-370)

18-661 Introduction to Machine Learning for Engineers
Fall: 12 units
This course provides an introduction to machine learning with a special focus on engineering applications. The course starts with a mathematical background required for machine learning and covers approaches for supervised learning (linear models, kernel methods, decision trees, neural networks) and unsupervised learning (clustering, dimensionality reduction), as well as theoretical foundations of machine learning (learning theory, optimization). Evaluation will consist of mathematical problem sets and programming projects targeting real-world engineering applications. This course is crosslisted with 18461. Although students in 18461 will share lectures with students in 18661, students in 18461 will receive distinct homework assignments, distinct programming projects, and distinct exams from the ones given to students in 18661. Specifically, the homework assignments, programming projects, and exams that are given to the 18661 students will be more challenging than those given to the 18461 students.
Prerequisites: 21-127 and 15-122 and 18-202 and 36-217

18-663 Hardware Architectures for Machine Learning
Fall and Spring: 12 units
Machine learning is poised to change the landscape of computing in more ways than its broad societal applications. Indeed, hardware architectures that can efficiently run machine learning face increasing challenges due to power consumption or run time constraints that technology, platforms, or users impose. This course provides an overview of current advance hardware architectures that can enable fast and energy efficient machine learning applications from the edge to the cloud. Topics include hardware accelerators, hardware-software co-design, and general or application specific system design and resource management for machine learning applications.
Prerequisites: (18-661 or 10-601 or 10-401 or 18-461 or 10-701) and (18-447 or 18-340)

18-883 Special Topics in Energy Systems
Spring: 6 units
Please see the ECE website for a full course description describing the sections of this course.

18-899 Introduction to Graduate Studies
Fall and Spring: 1 unit
The Introduction to Graduate Studies course is designed to increase awareness and understanding of academic integrity issues. Carnegie Mellon community standards and the ethical job search. This is done via various sessions/modules that are already offered via several entities throughout campus (such as the CPDC, ICC, and GCC). Topics covered include: paraphrasing and citation, participating in the US classroom, avoiding plagiarism, unconscious bias, combating sexual violence on campus, finding jobs and internships, negotiation, communication, relationship building and other topics of interest. The course culminates in students writing a reflection paper. For international students, the paper should compare western academic and cultural standards to those of their home country. For domestic students, the paper should be a reflection on CMU’s community standards. Active participation in 5 sessions/modules in the above mentioned areas and the submission of the reflection paper will determine a pass/fail grade.