Computer Science & Engineering

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Website: https://cse.wustl.edu/academics/graduate/index.html

Courses

Visit online course listings to view semester offerings for E81 CSE (https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E81&crsrlv=5:8).

E81 CSE 500 Independent Study
Proposal form can be located at https://cse.wustl.edu/undergraduate/PublishingImages/Pages/undergraduate-research/Independent%20Study%20Form%20400.pdf Credit variable, maximum 3 units.

E81 CSE 501N Introduction to Computer Science
An introduction to software concepts and implementation, emphasizing problem solving through abstraction and decomposition. Introduces processes and algorithms, procedural abstraction, data abstraction, encapsulation, and object-oriented programming. Recursion, iteration, and simple data structures are covered. Concepts and skills are mastered through programming projects, many of which employ graphics to enhance conceptual understanding. Java, an object-oriented programming language, is the vehicle of exploration. Active-learning sessions are conducted in a studio setting in which students interact with each other and the professor to solve problems collaboratively. Prerequisites: Comfort with algebra and geometry at the high school level is assumed. Patience, good planning, and organization will promote success. This course assumes no prior experience with programming.

Same as E81 CSE 131
Credit 3 units. BU: SCI EN: TU

E81 CSE 502N Data Structures and Algorithms
This course involves the study of fundamental algorithms, data structures, and their effective use in a variety of applications. It emphasizes the importance of data structure choice and implementation for obtaining the most efficient algorithm for solving a given problem. A key component of this course is worst-case asymptotic analysis, which provides a quick and simple method for determining the scalability and effectiveness of an algorithm. Prerequisites: CSE 131 and fluency with summations, derivatives, and proofs by induction.

Same as E81 CSE 247
Credit 3 units. EN: TU

E81 CSE 503S Rapid Prototype Development and Creative Programming
This course uses web development as a vehicle for developing skills in rapid prototyping. Students acquire the skills to build a Linux web server in Apache, to write a website from scratch in PHP, to run an SQL database, to perform scripting in Python, to employ various web frameworks, and to develop modern web applications in client-side and server-side JavaScript. The course culminates with a creative project in which students are able to synthesize the course material into a project of their own interest. The course implements an interactive studio format: after the formal presentation of a topic, students develop a related project under the supervision of the instructor. Prerequisite: CSE 131. Same as E81 CSE 330S
Credit 3 units. EN: BME T, TU

E81 CSE 504N Object-Oriented Software Development Laboratory
Intensive focus on practical aspects of designing, implementing and debugging software, using object-oriented, procedural, and generic programming techniques. The course emphasizes familiarity and proficiency with a wide range of C++ language features through hands-on practice completing studio exercises and lab assignments, supplemented with readings and summary presentations for each session. Prerequisites: CSE 131 and CSE 247
Same as E81 CSE 332S
Credit 3 units. EN: BME T, TU

E81 CSE 505N Introduction to Digital Logic and Computer Design
Introduction to design methods for digital logic and fundamentals of computer architecture. Boolean algebra and logic minimization techniques; sources of delay in combinational circuits and effect on circuit performance; survey of common combinational circuit components; sequential circuit design and analysis; timing analysis of sequential circuits; use of computer-aided design tools for digital logic design (schematic capture, hardware description languages, simulation); design of simple processors and memory subsystems; program execution in simple processors; basic techniques for enhancing processor performance; configurable logic devices. Prerequisite: CSE 131.

Same as E81 CSE 260M
Credit 3 units.

E81 CSE 507A Technology Entrepreneurship
This is a course for students who plan to be or to work with entrepreneurs. An entrepreneurial mindset is needed to create or grow economically viable enterprises, be they new companies, new groups within companies, or new university laboratories. This course aims to cultivate an entrepreneurial perspective, with particular emphasis on information technology (IT)-related activities. The course is jointly offered for business and CSE students, allowing for acculturation between these disciplines. In addition to an introductory treatment of business and technology fundamentals, course topics will include business ethics, opportunity assessment, team formation, financing, intellectual property, and technology transfer. The course will feature significant participant and guest instruction from experienced practitioners.
Credit 3 units.

E81 CSE 511A Introduction to Artificial Intelligence
The discipline of artificial intelligence (AI) is concerned with building systems that think and act like humans or rationally on some absolute scale. This course is an introduction to the field, with special emphasis on sound modern methods. The topics include knowledge representation, problem solving via search, game playing, logical and probabilistic reasoning, planning, dynamic programming, and reinforcement learning.

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Same as E81 CSE 247
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Credit 3 units.

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Programming exercises concretize the key methods. The course targets graduate students and advanced undergraduates. Evaluation is based on written and programming assignments, a midterm exam and a final exam. Prerequisites: CSE 247, ESE 326, Math 233.
Credit 3 units. EN: BME T, TU

**E81 CSE 513T Theory of Artificial Intelligence and Machine Learning**

Mathematical foundations for Artificial Intelligence and Machine Learning. An introduction to the PAC-Semantics ("Probably Approximately Correct") as a common semantics for knowledge obtained from learning and declarative sources, and the computational problems underlying the acquisition and processing of such knowledge. We emphasize the design and analysis of efficient algorithms for these problems, and examine for which representations these problems are known or believed to be tractable. Prerequisite: CSE 347.
Credit 3 units. EN: TU

**E81 CSE 514A Data Mining**

With the vast advancements in science and technology, the acquisition of large quantities of data is routinely performed in many fields. Examples of large data include various types of data on the internet, high-throughput sequencing data in biology and medicine, extraterrestrial data from telescopes in astronomy, and images from surveillance cameras in security settings. Analyzing a large amount of data through data mining has become an effective means of extracting knowledge from data. This course introduces the basic concepts and methods of data mining and provides hands-on experience for processing, analyzing and modeling structured and unstructured data. Homework problems, exams, and programming assignments will be administrated throughout the course to enhance students' learning. Prerequisites: CSE 247, ESE 326 (or Math 3200), and Math 233.
Credit 3 units. EN: BME T, TU

**E81 CSE 515T Bayesian Methods in Machine Learning**

This course will cover machine learning from a Bayesian probabilistic perspective. Bayesian probability allows us to model and reason about all types of uncertainty. The result is a powerful, consistent framework for approaching many problems that arise in machine learning, including parameter estimation, model comparison, and decision making. We will begin with a high-level introduction to Bayesian inference and then proceed to cover more advanced topics. These will include inference techniques (e.g., exact, MAP, sampling methods, the Laplace approximation), Bayesian decision theory, Bayesian model comparison, Bayesian nonparametrics, and Bayesian optimization. Prerequisites: CSE 417T and ESE 326.
Credit 3 units. EN: BME T, TU

**E81 CSE 516A Multi-Agent Systems**

This course introduces the fundamental techniques and concepts needed to study multi-agent systems, in which multiple autonomous entities with different information sets and goals interact. We will study algorithmic, mathematical, and game-theoretic foundations, and how these foundations can help us understand and design systems ranging from robot teams to online markets to social computing platforms. Topics covered may include game theory, distributed optimization, multi-agent learning and decision-making, preference elicitation and aggregation, mechanism design, and incentives in social computing systems. Prerequisites: CSE 347 (may be taken concurrently), ESE 326 (or Math 3200), and Math 233 or equivalents. Some prior exposure to artificial intelligence, machine learning, game theory, and microeconomics may be helpful, but is not required.
Credit 3 units. EN: BME T, TU

**E81 CSE 517A Machine Learning**

This course assumes a basic understanding of machine learning and covers advanced topics at the frontier of the field in-depth. Topics to be covered include kernel methods (support vector machines, Gaussian processes), neural networks (deep learning), and unsupervised learning. Depending on developments in the field, the course will also cover some advanced topics, which may include learning from structured data, active learning, and practical machine learning (feature selection, dimensionality reduction). Prerequisites: CSE 417T.
Credit 3 units. EN: TU

**E81 CSE 518A Human-in-the-Loop Computation**

This course is an exploration of the opportunities and challenges of human-in-the-loop computation, an emerging field that examines how humans and computers can work together to solve problems neither can yet solve alone. We will explore ways in which techniques from machine learning, game theory, optimization, online behavioral social science, and human-computer interactions can be used to model and analyze human-in-the-loop systems such as crowdsourcing markets, prediction markets, and user-generated content platforms. We will also look into recent developments in the interactions between humans and AIs, such as learning with the presence of strategic behavior and ethical issues in AI systems. Prerequisites: CSE 247, ESE 326, Math 233, and Math 309.
Credit 3 units. EN: TU

**E81 CSE 519T Advanced Machine Learning**

This course provides a close look at advanced machine learning algorithms, including their theoretical guarantees (computational learning theory) and tricks to make them work in practice. In addition, this course focuses on more specialized learning settings, including unsupervised learning, semi-supervised learning, domain adaptation, multi-task learning, structured prediction, metric learning, and learning of data representations. Learning approaches may include graphical models, non-parametric Bayesian statistics, and technical topics such as sampling, approximate inference, and non-linear function optimization. Mathematical maturity and general familiarity with machine learning are required. Prerequisites: CSE 511A, CSE 517A, and CSE 571A.
Credit 3 units. EN: TU

**E81 CSE 520S Real-Time Systems**

This course covers software systems and network technologies for real-time applications such as automobiles, avionics, industrial automation, and the Internet of Things. Topics include real-time scheduling, real-time operating systems and middleware, quality of service, industrial networks, and real-time cloud computing. Prerequisite: CSE 381S.
Credit 3 units. EN: BME T, TU
E81 CSE 521S Wireless Sensor Networks
Dense collections of smart sensors networked to form self-configuring pervasive computing systems provide a basis for a new computing paradigm that challenges many classical approaches to distributed computing. Naming, wireless networking protocols, data management, and approaches to dependability, real-time, security, and middleware services all fundamentally change when confronted with this new environment. Embedded sensor networks and pervasive computing are among the most exciting research areas with many open research questions. This course will study a large number of research papers that deal with various aspects of wireless sensor networks. Students will perform a project on a real wireless sensor network comprised of tiny devices, each consisting of sensors, a radio transceiver, and a microcontroller. Prerequisite: CSE 361S. Credit 3 units. EN: BME T, TU

E81 CSE 522S Advanced Operating Systems
This course offers an in-depth hands-on exploration of core OS abstractions, mechanisms and policies, with an increasing focus on understanding and evaluating their behaviors and interactions. Readings, lecture material, studio exercises, and lab assignments are closely integrated in an active-learning environment in which students gain experience and proficiency writing, tracing, and evaluating user-space and kernel-space code. Topics include: inter-process communication, real-time systems, memory forensics, file-system forensics, timing forensics, process and thread forensics, hypervisor forensics, and managing internal or external causes of anomalous behavior. Prerequisite: CSE 422S. Credit 3 units. EN: BME T, TU

E81 CSE 523S Systems Security
This course examines the intersection between computer design and information security. While performance and efficiency in digital systems have improved markedly in recent decades, computer security has worsened overall in this time frame. To understand why, we will explore the role that design choices play in the security characteristics of modern computer and network systems. Students will use and write software to illustrate mastery of the material. Projects will include identifying security vulnerabilities, exploiting vulnerabilities, and detecting and defending against exploits. Prerequisite: CSE 361S. Credit 3 units. EN: BME T, TU

E81 CSE 530S Database Management Systems
A study of data models and the database management systems that support these data models. The design theory for databases is developed and various tools are utilized to apply the theory. General query languages are studied and techniques for query optimization are investigated. Integrity and security requirements are studied in the context of concurrent operations on a database, where the database may be distributed over one or more locations. The unique requirements for engineering design databases, image databases, and long transaction systems are analyzed. Prerequisite: CSE 247. Credit 3 units.

E81 CSE 532S Advanced Multiparadigm Software Development
Intensive focus on advanced design and implementation of concurrent and distributed system software in C++. Topics covered include concurrency and synchronization features and software architecture patterns. Prerequisites: CSE 332S or graduate standing and strong familiarity with C++; and CSE 422S. Credit 3 units. EN: BME T, TU

E81 CSE 534A Large-Scale Optimization for Data Science
Large-scale optimization is an essential component of modern data science, artificial intelligence, and machine learning. This graduate-level course rigorously introduces optimization methods that are suitable for large-scale problems arising in these areas. Students will learn several algorithms suitable for both smooth and nonsmooth optimization, including gradient methods, proximal methods, mirror descent, Nesterov's acceleration, ADMM, quasi-Newton methods, stochastic optimization, variance reduction, and distributed optimization. Throughout the class, we will discuss the efficacy of these methods in concrete data science problems, under appropriate statistical models. Students will be required to program in Python or MATLAB. Prerequisites: CSE 247, Math 309, Math 3200 or ESE 326. Same as E35 ESE 513 Credit 3 units. EN: TU

E81 CSE 538T Modeling and Performance Evaluation of Computer Systems
Modern computing systems consist of multiple interconnected components that all influence performance. The focus of this course is on developing modeling tools aimed at understanding how to design and provision such systems to meet certain performance or efficiency targets and the trade-offs involved. The course covers Markov chains and their applications to simple queues, and it proceeds to explore more complex systems, including server farms and how to optimize their performance through scheduling and task assignment policies. The course includes a brief review of the necessary probability and mathematical concepts. Prerequisite: ESE 326. Credit 3 units. EN: BME T, TU

E81 CSE 539S Concepts in Multicore Computing
Nowadays, the vast majority of computer systems are built using multicore processor chips. This fundamental shift in hardware design impacts all areas of computer science - one must write parallel programs in order to unlock the computational power provided by modern hardware. The goal of this course is to study concepts in multicore computing. We will examine the implications of the multicore hardware design, discuss challenges in writing high performance software, and study emerging technologies relevant to developing software for multicore systems. Topics include memory hierarchy, cache coherence protocol, memory models, scheduling, high-level parallel language models, concurrent programming (synchronization and concurrent data structures), algorithms for debugging parallel software, and performance analysis. Prerequisites: CSE 247 and CSE 361S. Credit 3 units. EN: BME T, TU
E81 CSE 541T Advanced Algorithms
Provides a broad coverage of fundamental algorithm design techniques, with a focus on developing efficient algorithms for solving combinatorial and optimization problems. The topics covered include the review of greedy algorithms, dynamic programming, NP-completeness, approximation algorithms, the use of linear and convex programming for approximation, and online algorithms. Throughout this course, there is an emphasis on correctness proofs and the ability to apply the techniques taught to design efficient algorithms for problems from a wide variety of application areas. Prerequisite: CSE 347.
Credit 3 units. EN: BME T, TU

E81 CSE 543S Advanced Secure Software Engineering
The aim of this course is to provide students with broader and deeper knowledge as well as hands-on experience in understanding security techniques and methods needed in software development. Students complete an independent research project which will involve synthesizing multiple software security techniques and applying them to an actual software program or system.
Credit 3 units. EN: TU

E81 CSE 543T Algorithms for Nonlinear Optimization
The course will provide an in-depth coverage of modern algorithms for the numerical solution of multidimensional optimization problems. Unconstrained optimization techniques including Gradient methods, Newton’s methods, Quasi-Newton methods, and conjugate methods will be introduced. The emphasis is on constrained optimization techniques: Lagrange theory, Lagrangian methods, penalty methods, sequential quadratic programming, primal-dual methods, duality theory, nondifferentiable dual methods, and decomposition methods.
The course will also discuss applications in engineering systems and use of state-of-the-art computer codes. Special topics may include large-scale systems, parallel optimization, and convex optimization.
Prerequisites: Calculus I and Math 309.
Credit 3 units. EN: TU

E81 CSE 544A Special Topics in Artificial Intelligence
The material for this course varies among offerings, but this course generally covers advanced or specialized topics in artificial intelligence.
Credit 3 units. EN: BME T, TU

E81 CSE 544T Special Topics in Computer Science Theory
The material for this course varies among offerings, but this course generally covers advanced or specialized topics in computer science theory.
Credit 3 units. EN: BME T, TU

E81 CSE 546T Computational Geometry
Computational geometry is the algorithmic study of problems that involve geometric shapes such as points, lines, and polygons. Such problems appear in computer graphics, vision, robotics, animation, visualization, molecular biology, and geographic information systems. This course covers data structures that are unique to geometric computing, such as convex hull, Voronoi diagram, Delaunay triangulation, arrangement, range searching, KD-trees, and segment trees. Also covered are algorithms for polygon triangulation, path planning, and the art gallery problem.
Prerequisite: CSE 347.
Credit 3 units.

E81 CSE 547T Introduction to Formal Languages and Automata
An introduction to the theory of computation, with emphasis on the relationship between formal models of computation and the computational problems solvable by those models. Specifically, this course covers finite automata and regular languages; Turing machines and computability; and basic measures of computational complexity and the corresponding complexity classes.
Prerequisites: CSE 240 and CSE 247.
Credit 3 units.

E81 CSE 549T Theory of Parallel Systems
The course covers various aspects of parallel programming such as algorithms, schedulers and systems from a theoretical perspective. We will cover both classic and recent results in parallel computing. Topics include parallel algorithms and analysis in the work/span model, scheduling algorithms, external memory algorithms and their analysis, cache-coherence protocols, etc. The focus will be on design and analysis.
Prerequisite: CSE 247.
Credit 3 units. EN: BME T, TU

E81 CSE 554A Geometric Computing for Biomedicine
With the advance of imaging technologies deployed in medicine, engineering and science, there is a rapidly increasing amount of spatial data sets (e.g., images, volumes, point clouds) that need to be processed, visualized, and analyzed. This course will focus on a number of geometry-related computing problems that are essential in the knowledge discovery process in various spatial-data-driven biomedical applications. These problems include visualization, segmentation, mesh construction and processing, and shape representation and analysis.
This course consists of lectures that cover theories and algorithms, and it includes a series of hands-on programming projects using real-world data collected by various imaging techniques (e.g., CT, MRI, electron cryomicroscopy). Prerequisites: CSE 332 (or proficiency in programming in C++ or Java or Python) and CSE 247.
Credit 3 units. EN: BME T, TU

E81 CSE 555A Computational Photography
Computational Photography describes the convergence of computer graphics, computer vision, and the internet with photography. Its goal is to overcome the limitations of traditional photography using computational techniques to enhance the way we capture, manipulate and interact with visual media.
In this course we study many interesting, recent image-based algorithms and implement them to the degree that is possible. Topics may include: cameras and image formation, human visual perception, image processing (filtering, pyramids), image blending and compositing, image retargeting, texture synthesis and transfer, image completion/inpainting, super-resolution, deblurring, denoising, image-based lighting and rendering, high dynamic range, depth and defocus, flash/no flash photography, coded aperture photography, single/multiview reconstruction, photo quality assessment, non photorealistic rendering, modeling and synthesis using internet data, and others.
Prerequisites: CSE 452A, CSE 554A, or CSE 559A.
Credit 3 units. EN: BME T, TU
E81 CSE 556A Human-Computer Interaction Methods
An introduction to user centered design processes. The course covers a variety of HCI techniques for use at different stages in the software development cycle, including techniques that can be used with and without users. Students will gain experience using these techniques through in-class exercises and then apply them in greater depth through a semester long interface development project. Students who enroll in this course are expected to be comfortable with building user interfaces in at least one framework and be willing to learn whatever framework is most appropriate for their project. Over the course of the semester, students will be expected to present their interface evaluation results through written reports and in class presentations. Prerequisites: 3xxS or 4xxS.
Credit 3 units. EN: BME T, TU

E81 CSE 557A Advanced Visualization
We are in an era where it is possible to have all of the world's information at our fingertips. However, the more information we can access, the more difficult it is to obtain a holistic view of the data or to determine what's important to make decisions. Computer-based visualization systems provide the opportunity to represent large or complex data visually to aid comprehension and cognition. In this course, we learn about the state of the art in visualization research and gain hands-on experience with the research pipeline. We also learn how to critique existing work and how to formulate and explore sound research questions. We will cover advanced visualization topics including user modeling, adaptation, personalization, perception, and visual analytics for non-experts. Prerequisite: CSE 457A or permission of instructor. Credit 3 units. EN: BME T, TU

E81 CSE 559A Computer Vision
This course introduces the fundamentals of designing computer vision systems that can "look at" images and videos and reason about the physical objects and scenes they represent. Topics include image restoration and enhancement; estimation of color, shape, geometry, and motion from images; and image segmentation, recognition, and classification. The focus of this course will be on the mathematical tools and intuition underlying algorithms for these tasks: models for the physics and geometry of image formation and statistical and machine learning-based techniques for inference. Prerequisites: Math 309 or ESE 318 or equivalent; Math 3200 or ESE 326 or equivalent; and CSE 247 or equivalent. Credit 3 units. EN: BME T, TU

E81 CSE 560M Computer Systems Architecture I
An exploration of the central issues in computer architecture: instruction set design, addressing and register set design, control unit design, microprogramming, memory hierarchies (cache and main memories, mass storage, virtual memory), pipelining, and bus organization. The course emphasizes understanding the performance implications of design choices, using architecture modeling and evaluation using VHDL and/or instruction set simulation. Prerequisites: CSE 361S and CSE 260M. Credit 3 units. EN: BME T, TU

E81 CSE 563M Digital Integrated Circuit Design and Architecture
This is a project-oriented course on digital VLSI design. The course material focuses on bottom-up design of digital integrated circuits, starting from CMOS transistors, CMOS inverters, combinational circuits and sequential logic designs. Important design aspects of digital integrated circuits such as propagation delay, noise margins and power dissipation are covered in the class, and design challenges in sub-micron technology are addressed. The students design combinational and sequential circuits at various levels of abstraction using a state-of-the-art CAD environment provided by Cadence Design Systems. The goal of the course is to design a microprocessor in 0.5 micron technology that will be fabricated by a semiconductor foundry. Prerequisites: CSE 260M and ESE 292. Same as E81 CSE 463M
Credit 3 units. EN: BME T, TU

E81 CSE 566S High Performance Computer Systems
Many applications make substantial performance demands upon the computer systems upon which those applications are deployed. In this context, performance is frequently multidimensional, including resource efficiency, power, execution speed (which can be quantified via elapsed run time, data throughput, or latency), and so on. Modern computing platforms exploit parallelism and architectural diversity (e.g., co-processors such as graphics engines and/or reconfigurable logic) to achieve the desired performance goals. This course addresses the practical aspects of achieving high performance on modern computing platforms. This includes questions ranging from how the computing platform is designed to how are applications and algorithms expressed to exploit the platform's properties. Particular attention is given to the role of application development tools. Prerequisite: familiarity with software development in Linux preferred, graduate standing or permission of instructor. Credit 3 units. EN: BME T, TU

E81 CSE 567M Computer Systems Analysis
A comprehensive course on performance analysis techniques. The topics include common mistakes, selection of techniques and metrics, summarizing measured data, comparing systems using random data, simple linear regression models, other regression models, experimental designs, 2^k experimental designs, factorial designs with replication, fractional factorial designs, one factor experiments, two factor full factorial designs with replications, general full factorial designs, introduction to queueing theory, analysis of single queues, queueing networks, operational laws, mean-value analysis, time series analysis, heavy tailed distributions, self-similar processes, long-range dependence, random number generation, analysis of simulation results, and art of data presentation. Prerequisites: CSE 260M. Credit 3 units. EN: BME T, TU

E81 CSE 569S Recent Advances in Computer Security and Privacy
The aim of this course is to provide students with knowledge and hands-on experience in understanding the security techniques and methods needed for IoT, real-time, and embedded systems. Students complete an independent research project which will involve synthesizing multiple security techniques and applying them to an actual IoT, real-time, or embedded system or device. Credit 3 units. EN: BME T, TU

E81 CSE 570S Recent Advances in Networking
This course covers the latest advances in networking. Topics include the application of blockchains, quantum computing, and AI to networking along with networking trends, data center network topologies, data center ethernet, carrier IP, multi-
protocol label switching (MPLS), carrier ethernet, virtual bridging, LAN extension and virtualization using layer 3 protocols, virtual routing protocols, Internet of Things (IoT), data link layer and management protocols for IoT, networking layer protocols for IoT, 6LoWPAN, RPL, messaging protocols for IoT, MQTT, OpenFlow, software-defined networking (SDN), network function virtualization (NFV), big data, networking issues for big data, network configuration, data modeling, NETCONF, YIN, YANG, BEEP, and UML. Prerequisite: CSE 473S or equivalent. Credit 3 units. EN: BME T, TU

E81 CSE 571S Network Security
This course covers principles and techniques in securing computer networks. Real world examples will be used to illustrate the rationales behind various security designs. There are three main components in the course, preliminary cryptography, network protocol security and network application security. Topics include IPSec, SSL/TLS, HTTPS, network fingerprinting, network malware, anonymous communication, and blockchain. The class project allows students to take a deep dive into a topic of choice in network security. Prerequisite: CSE 473S.
Credit 3 units. EN: BME T, TU

E81 CSE 574S Wireless and Mobile Networking
First course in wireless networking providing a comprehensive treatment of wireless data and telecommunication networks. Topics include recent trends in wireless and mobile networking, wireless coding and modulation, wireless signal propagation, IEEE 802.11a/b/g/n/ac wireless local area networks, 60 GHz millimeter wave gigabit wireless networks, vehicular wireless networks, white spaces, IEEE 802.22 regional area networks, Bluetooth and Bluetooth Smart, wireless personal area networks, wireless protocols for the "internet of things," ZigBee, cellular networks: 1G/2G/3G, LTE, LTE-Advanced, and 5G.
Prerequisites: CSE 473S or permission of the instructor.
Credit 3 units. EN: BME T, TU

E81 CSE 581T Approximation Algorithms
Numerous optimization problems are intractable to solve optimally. The intractability of a problem could come from the problem's computational complexity, for instance the problem is NP-Hard, or other computational barriers. To cope with the inability to find an optimal algorithm, one may desire an algorithm that is guaranteed to return a solution that is comparable to the optimum. Such an algorithm is known as an approximation algorithm. Approximation algorithms are a robust way to cope with intractability, and they are widely used in practice or are used to guide the development of practical heuristics. The area of approximation algorithms has developed a vast theory, revealing the underlying structure of problems as well as their different levels of difficulty. The majority of this course will focus on fundamental results and widely applicable algorithmic and analysis techniques for approximation algorithms. Prerequisite: CSE 347.
Credit 3 units. EN: BME T, TU

E81 CSE 584A Algorithms for Biosequence Comparison
This course surveys algorithms for comparing and organizing discrete sequential data, especially nucleic acid and protein sequences. Emphasis is on tools to support searches of massive biosequence databases and to perform fundamental comparison tasks such as DNA short-read alignment. These techniques are also of interest for more general string processing and for building and mining textual databases. Algorithms are presented rigorously, including proofs of correctness and running time, where feasible. Topics include classical string matching, suffix array string indices, space-efficient string indices, rapid inexact matching by filtering (including BLAST and related tools), and alignment-free algorithms. Students complete written assignments and implement advanced comparison algorithms to address problems in bioinformatics. This course does not require a biology background. Prerequisite: CSE 347 or permission of instructor.
Credit 3 units. EN: BME T, TU

E81 CSE 586A Analysis of Imaging Data
This course focuses on an in-depth study of advanced topics and interests in image data analysis. Students will learn about hardcore imaging techniques and gain the mathematical fundamentals needed to build their own models for effective problem solving. Topics of deformable image registration, numerical analysis, probabilistic modeling, data dimensionality reduction, and convolutional neural networks for image segmentation will be covered. The main focus might change from semester to semester. Prerequisites: Math 309, ESE 326, and CSE 247.
Credit 3 units.

E81 CSE 587A Algorithms for Computational Biology
This course is a survey of algorithms and mathematical methods in biological sequence analysis (with a strong emphasis on probabilistic methods) and systems biology. Sequence analysis topics include introduction to probability, probabilistic inference in missing data problems, hidden Markov models (HMMs), profile HMMs, sequence alignment, and identification of transcription-factor binding sites. Systems biology topics include the discovery of gene regulatory networks, quantitative modeling of gene regulatory networks, synthetic biology, and (in some years) quantitative modeling of metabolism. Prerequisite: CSE 131 or CSE 501N.
Credit 3 units. EN: BME T, TU

E81 CSE 591 Introduction to Graduate Study in CSE
Introduces students to the different areas of research conducted in the department. Provides an introduction to research skills, including literature review, problem formulation, presentation, and research ethics. Lecture and discussion are supplemented by exercises in the different research areas and in critical reading, idea generation, and proposal writing.
Credit 3 units.

E81 CSE 598 Master's Project
Students electing the project option for their master's degree perform their project work under this course. In order to successfully complete this course, students must defend their project before a three-person committee and present a 2-3 page extended abstract. Prerequisite: permission of adviser and submission of a research proposal form.
Credit variable, maximum 6 units.
E81 CSE 599 Master's Research
Students electing the thesis option for their master's degree perform their thesis research under this course. In order to successfully complete a master's thesis, students must enroll in 6 units of this course typically over the course of two consecutive semesters, produce a written thesis, and defend the thesis before a three-person committee. Prerequisite: permission of adviser and submission of a research proposal form. Credit variable, maximum 6 units.

E81 CSE 637S Software Security
In this course, students will be introduced to the foundations of software security. We will explore different classes of software vulnerabilities and analyze the fundamental problems behind these vulnerabilities, and we will study the methods and techniques used to discover, exploit, prevent, and mitigate these vulnerabilities. Topics of interest include buffer overflow, integer overflow, type confusion, use-after-free, and so on. Throughout the course, we take a defense-in-depth mentality and see how systems can be protected. Students are expected to have a solid understanding of assembly language, C/C++, and operating systems. Prerequisite: CSE 361S. Credit 3 units.

E81 CSE 659A Advances in Computer Vision
Computer vision is a fast-moving field, with the past few years seeing tremendous advances in the development of computational algorithms for solving visual tasks. This course is designed to introduce students to advanced and recently published techniques for problems in low-level vision, recognition and classification, and computational photography. Prerequisite: CSE 559A. Credit 3 units.

E81 CSE 699 Doctoral Research
Credit variable, maximum 9 units.

E81 CSE 7001 Research Seminar on Computer Science Pedagogy
This seminar will examine research, techniques, approaches, and strategies for teaching computer science at the undergraduate and graduate levels. Participants will take turns presenting a particular paper or concept and then leading an ensuing discussion. While this seminar may be especially helpful for those contemplating an academic career, the seminar is open to all interested participants. Credit 1 unit.

E81 CSE 7100 Research Seminar on Machine Learning
Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor. Credit 1 unit.

E81 CSE 7200 Research Seminar on Robotics and Human-Computer Interaction
Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor. Credit 1 unit.

E81 CSE 7300 Research Seminar on Software Systems
Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor. Credit 1 unit.

E81 CSE 7400 Research Seminar on Algorithms and Theory
Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor. Credit 1 unit.

E81 CSE 7401 Research Seminar on Computer Science Pedagogy
This seminar will examine research, techniques, approaches, and strategies for teaching computer science at the undergraduate and graduate levels. Participants will take turns presenting a particular paper or concept and then leading an ensuing discussion. While this seminar may be especially helpful for those contemplating an academic career, the seminar is open to all interested participants. Credit 1 unit.

E81 CSE 7402 Research Seminar on Computer Science Pedagogy
This seminar will examine research, techniques, approaches, and strategies for teaching computer science at the undergraduate and graduate levels. Participants will take turns presenting a particular paper or concept and then leading an ensuing discussion. While this seminar may be especially helpful for those contemplating an academic career, the seminar is open to all interested participants. Credit 1 unit.

E81 CSE 7500 Research Seminar on Graphics and Vision
Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor. Credit 1 unit.

E81 CSE 7600 Research Seminar on Analog Computing
This seminar will focus on classic and recent papers on analog, stochastic and neuromorphic computing. Students will read, present, and discuss journal papers on analog techniques for implementing sensors and processors. Focus will be placed on fundamental advances and challenges of implementing analog processors. No prerequisites. Credit 1 unit.
E81 CSE 7700 Research Seminar on Networking and Communications
Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor.
Credit 1 unit.

E81 CSE 7800 Research Seminar on Computational Systems Biology
Research seminars examine publications, techniques, approaches and strategies within an area of computer science and engineering. Seminars are highly participational: Students are expected to take turns presenting material, to prepare for seminar by reading any required material, and to contribute to the group's discussions. The actual topics covered in a seminar will vary by semester and instructor. Interested students are encouraged to obtain a syllabus from the instructor's webpage or by contacting the instructor.
Credit 1 unit.

E81 CSE 7900 Research Seminar on Parallel Computing
This seminar will focus on classic and recent papers on parallel computing. Students will read, present and discuss papers on parallel models, algorithms and architectures from top conferences and journals. Focus will be placed on fundamental advances and theoretical models and algorithms, rather than on implementation papers. No prerequisites.
Credit 1 unit.

E81 CSE 801 Pedagogy
A student taking this course studies the fundamentals of teaching in the discipline of computer science and computer engineering. A student enrolled in this course staffs some other course taught by our department, serving as its primary instructor or co-instructor. That student receives frequent mentoring and feedback on preparation and delivery. This course is recommended especially for doctoral students who seek a career in computer science and engineering education.
Credit 3 units.