Chair
• Michael Franklin

Professors
• Yali Amit
• Laszlo Babai
• Andrew Chien
• Frederic Chong
• Todd Dupont
• Nick Feamster
• Ian Foster
• Michael Franklin
• John Goldsmith
• Robert Grossman
• Stuart A. Kurtz
• Shan Lu
• Ketan Mulmuley
• Alexander Razborov
• John Reppy
• Janos Simon
• Rick L. Stevens
• Rebecca Willett
• Ben Zhao
• Heather Zheng

Associate Professors
• David Cash
• Diana Franklin
• Haryadi Gunawi
• Henry Hoffmann
• Gordon Kindlmann
• Risi Kondor
• Anne Rogers

Assistant Professors
• Raul Castro Fernandez
• Yuxin Chen
• Marshini Chetty
• Ravi Chugh
• Andrew Drucker
• Aaron Elmore
• William Fefferman
• Junchen Jiang
• Eric Jonas
• Sanjay Krishnan
• Yanjing Li
• Pedro Lopes
• Michael Maire
• Lorenzo Orecchia
• Aaron Potechin
• Robert Rand
• Sarah Sebo
The Department of Computer Science is dedicated to advancing and improving the knowledge, understanding, and practice of computer science through basic research and education.

RESEARCH

We have a broad view of Computer Science, that includes the whole spectrum of computing, from relevant mathematics and statistics to building hardware devices, networks, data science, machine learning, human computer interaction, and Computer Science education. The list is not exhaustive, but an attempt to convey some of the research interests of current faculty. We investigate computation, information, communication and data as fundamental phenomena to be studied in Computer Science. We also investigate the many interdisciplinary ways the study of computation interacts with other disciplines like the sciences, society, and learning.

There is an ongoing major thrust to expand the role of Computer Science and computation at the University, with considerable expansion of the faculty, and expanded support to explore new research areas. These include the new Center for Data Science, a joint effort of the Statistics and Computer Science Departments, that is also experiencing rapid growth. Accordingly, the descriptions below, a snapshot of our current active research, are likely to expand.

Current active research areas include computing systems, computer architecture, computer security and privacy, error-tolerant computing and error recovery in computing systems, databases and data intensive computing, theoretical computer science, discrete mathematics, quantum computing, programming languages, machine learning, computational linguistics, computer vision, cloud computing, sustainable computing, scientific computing and visualization, high performance computing, human-computer interaction, computer science education, and interdisciplinary research in computing in the physical, biological, and social sciences.

Current major research areas include:

Theoretical Computer Science
Programming Languages
Data Science
Machine Learning and AI
HIC
Scientific and High Performance Computing
Computer Science Education

For more information about current research groups and active research areas, refer to the Research section of the departmental webpage (https://www.cs.uchicago.edu/research/research-areas/).

Our research efforts are enhanced by the interdisciplinary nature of the University, and, specifically, by strong connections to the Center for Data and Computing (CDAC), the Center for Translational Data Science, the James Frank Institute, the Institute for Biophysical Dynamics, with the Pritzker School of Molecular Engineering, and with the Booth School of Business. Our research collaborations involve faculty from many different departments, including Mathematics, Statistics, Physics, Linguistics, Psychology, and Sociology. We have very strong research ties with ANL, the Argonne National Laboratory, operated by the University for the US DOE.
We also have almost seamless collaborations with the Toyota Technological Institute Chicago, on campus: many TTIC faculty have part-time appointments in the Department.

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**GRADUATE PROGRAMS**

We offer two graduate curricula in computer science.

1. A graduate professional curriculum leading to the Master of Science (MS) degree, for students who wish to enter or advance themselves in computer science practice.

2. A graduate research curriculum leading to the PhD degree that prepares students to perform advanced basic research in computer science either in industry or academia. Teaching experience is available for students preparing for academic careers.

Acquire further information about our Masters Program in Computer Science (MPCS) through the MPCS website (http://masters.cs.uchicago.edu/), by writing to our MPCS Admissions, Department of Computer Science, University of Chicago, 5730 S Ellis Avenue, IL 60637, or by telephoning 773.834.3388. You may also email any questions to our questions@cs.uchicago.edu email address.

Acquire further information about our PhD program through our PhD admissions website, (https://www.cs.uchicago.edu/graduate/phd-programs/) by writing to Admissions, Department of Computer Science, University of Chicago, 5730 S. Ellis Avenue, Chicago, IL 60637, or by telephoning 773.702.6011.

General information about our department is available from the departmental website (https://computerscience.uchicago.edu/).

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**THE PhD PROGRAM**

The PhD program is done in three phases:

**QUALIFYING PHASE**

The objective of the Qualifying Phase is to provide the scientific foundations in their area, a breadth of knowledge within Computer Science, and the ability to write up research results. Students without a previous MS should satisfy course requirements, and write and defend an MS paper.

The course requirement consists of five core courses (two in Theory, two in Systems, and one in ML), three electives, and a seminar. In order to ensure breadth, no more than four of these courses should be in the student’s main research area.

After the public defense of the paper, the student may be eligible to receive an MS in Computer Science from the University. Please refer to the departmental webpage (https://www.cs.uchicago.edu/graduate/phd-programs/phase-1-masters-degree-within-the-phd-program/) for details.

Students with a previous MS may receive credit for their previous work: up to waiving the core course requirement. The details of the mechanism to do so can be found on our website (https://www.cs.uchicago.edu/graduate/phd-programs/).

The minimum formal requirements for the core courses (“Ph.D. Pass”) are the following: Students are required to complete the five core courses with a grade point average (GPA) of at least 3.25 in the five core courses. In computing the GPA, A=4, B=3, and a + or a - counts as .3 of a point. Note that for the core courses, students who significantly outperform even the typical “A” students may receive a grade of “A+” (recorded internally by the CS Department Student Representative since the University does not officially grant the grade of A+.) So, for instance a student with grades A+, B+, B+, B-, B- in the five core courses has a GPA of 3.26 and thus satisfies the minimum GPA requirement, as does a student with grades of A+, A, B+, B, and C-. In the graduate program grades below C are not passing grades.

Students must complete their electives with a grade of B or better in each course.

**CANDIDACY EXAM**

After the Qualifying Phase, students must pass an exam for Admission to Candidacy, that is a plan for their dissertation research.

**DISSERTATION AND DISSERTATION DEFENSE**

Finally, they must write and defend their dissertation.

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**TEACHING OPPORTUNITIES FOR STUDENTS IN THE PhD PROGRAM**

The department takes its undergraduate teaching responsibilities very seriously, and offers supervised teaching opportunities, including lecturing, acting as teaching assistants, and working as lab assistants to its best graduate students.
Computing Facilities

In addition to the general University computing facilities including the Research Computing Center (https://rcc.uchicago.edu/resources) and access to high performance computers at ANL, and our Computer Science Instructional Laboratory (which contains about 50 Macintosh computers and 40 desktops running Linux), our department provides the faculty, students, and postdoctoral associates in computer science with computing resources. We have the flexibility to adapt quickly to new research needs.

The resources include: 24 hour 7 day interactive computing on a number of shared computing servers as well as individually assigned desktops. These servers and desktops run the Linux operating system and are interconnected via high speed Ethernet. These systems are supported by substantial amounts of both local and networked disk storage for individual group use and are backed up regularly. Linux servers are available for general instructional and research purposes as well as hardware and virtual machines which are adapted to specialized needs.

Individual research groups operate additional computing facilities, often with considerable computing and storage resources. Some have specialized hardware, and fabrication tools (for example, GPU arrays, 3-D printers, etc.). Information about these resources is available from the research group’s webpage.

Joint Math/CS PhD Program

The Department of Computer Science and the Department of Mathematics offer a joint PhD program. For more details see https://mathematics.uchicago.edu/academics/graduate-programs/joint-math-cs-phd-program/

Courses

For the list of courses offered and the course descriptions, please consult the courses section of the departmental web page (https://computerscience.uchicago.edu/graduate/courses/).

Computer Science Courses

CMSC 30100. Technical Writing and Presentation. 100 Units.
Clear, logical writing and presentations are foundational skills for computer scientists. This class is meant to introduce computer science students to basic ideas and techniques for effective communication in both writing and presentations. The class will include several complementary components, including critical analysis of technical papers, weekly writing assignments focusing on writing style, clarity, and logical flow, and discussions of style for different research areas and venues. Later weeks will focus on skills for effective technical presentations in different settings, e.g. conference presentations, job talks, and keynotes. The course is primarily targeted towards graduates students, although undergraduates can audit the class (or enroll with permission from the instructor).
Instructor(s): Ben Zhao Terms Offered: Autumn
Prerequisite(s): None

CMSC 30370. Inclusive Technology, Graduate. 100 Units.
Creating technologies that are inclusive of people in marginalized communities involves more than having technically sophisticated algorithms, systems, and infrastructure. It involves deeply understanding various community needs and using this understanding coupled with our knowledge of how people think and behave to design user-facing interfaces that can enhance and augment human capabilities. When dealing with underserved and marginalized communities, achieving these goals requires us to think through how different constraints such as costs, access to resources, and various cognitive and physical capabilities shape what socio-technical systems can best address a particular issue. This course leverages human-computer interaction and the tools, techniques, and principles that guide research on people to introduce you to the concepts of inclusive technology design. You will learn about different underserved and marginalized communities such as children, the elderly, those needing assistive technology, and users in developing countries, and their particular needs. In addition, you will learn how to be mindful of working with populations that can easily be exploited and how to think creatively of inclusive technology solutions. You will also put your skills into practice in a quarter long group project involving the creation of an interactive system for one of the user populations we study.
Terms Offered: Winter
Prerequisite(s): None

CMSC 30900. Computers for Learning, Graduate. 100 Units.
Over time, technology has occupied an increasing role in education, with mixed results. Massive Open Online Courses (MOOCs) were created to bring education to those without access to universities, yet most of the students who succeed in them are those who are already successful in the current educational model. This course focuses on one intersection of technology and learning: computer games. This course covers education theory, psychology (e.g., motivation, engagement), and game design so that students can design and build an educational learning application. Labs focus on developing expertise in technology, and readings supplement lecture discussions on the human components of education.
Instructor(s): Diana Franklin Terms Offered: Autumn
CMSC 31010. Mathematical Foundations. 100 Units.
This course is an introduction to formal tools and techniques which can be used to better understand linguistic phenomena. A major goal of this course is to enable students to formalize and evaluate theoretical claims. Equivalent Course(s): CMSC 21010, LING 21010, LING 31010

CMSC 31140. Computational Imaging: Theory and Methods. 100 Units.
Computational imaging refers to the process of forming images from data where computation plays an integral role. This course will cover basic principles of computational imaging, including image denoising, regularization techniques, linear inverse problems and optimization-based solvers, and data acquisition models associated with tomography and interferometry. Specific topics may include patch-based denoising, sparse coding, total variation, dictionary learning, computational photography, compressive imaging, inpainting, and deep learning for image reconstruction.
Instructor(s): R. Willett Terms Offered: To be determined Equivalent Course(s): STAT 31140, CAAM 31140

CMSC 31150. Mathematical Toolkit. 100 Units.
Introduction to mathematical techniques of linear algebra and probability used in different areas of computer science. Topics in include Linear Algebra (Hilbert spaces, eigenvalues and eigenvectors, SVD, least squares), discrete probability, Gaussian variables, concentration inequalities and dimension reduction, Linear Programming and LP duality. Time permitting, martingales, stochastic processes.
Instructor(s): Madhur Tulsiani Terms Offered: Autumn Equivalent Course(s): TTIC 31150

CMSC 31230. Fundamentals of Deep Learning. 100 Units.
Introduction to fundamental principles of deep learning. Deep learning systems are evolving rapidly and this course presents up to date material at a conceptual level. The course emphasizes theoretical and intuitive understanding rather than particular programming formalisms. Topics: Information theory as an organizing principle for machine learning and deep learning in particular. Deep learning frameworks. The “educational framework” (EDF) written in directly in NumPy. Deep networks for computer vision: Convolutional neural networks (CNNs) and Resnet and the general principles behind them. Deep networks for language processing: Recurrent neural networks (RNNs), the Transformer, their applications and the general principles behind them. The theory and practice of stochastic gradient descent. Regularization and Generalization. Generative Adversarial Networks (GANs) Variational Autoencoders (VAEs) Deep Graphical Models Reinforcement learning and AlphaZero Expected outcomes: An understanding of the general issues sufficient to guide architecture design and training. An ability to read and understand the current research literature in deep learning. Prerequisites: linear algebra, vector calculus and general mathematical sophistication.
Instructor(s): David McAllester Terms Offered: Autumn Prerequisite(s): An introduction to machine learning course Equivalent Course(s): TTIC 31230

CMSC 32001. Topics in Programming Languages. 100 Units.
This course covers a selection of advanced topics in programming languages. Terms Offered: Autumn, Winter, Spring Prerequisite(s): Consent of department counselor and instructor

CMSC 32200. Computer Architecture. 100 Units.
This course is a survey of contemporary computer organization covering CPU design, instruction sets, control, processors, busses, ALU, memory, pipelined computers, multiprocessors, networking, and case studies. We focus on the techniques of quantitative analysis and evaluation of modern computing systems, such as the selection of appropriate benchmarks to reveal and compare the performance of alternative design choices in system design. We emphasize major component subsystems of high-performance computers: pipelining, instruction-level parallelism, memory hierarchies, input/output, and network-oriented interconnections.
Instructor(s): Hoffmann Terms Offered: Autumn

CMSC 32201. Topics in Computer Architecture. 100 Units.
This course covers a selection of advanced topics in computer architecture. Terms Offered: Autumn, Winter, Spring Prerequisite(s): Consent of department counselor and instructor

CMSC 32250. Intro to Computer Security. 100 Units.
This course introduces the principles and practice of computer security. It aims to teach how to model threats to computer systems and how to think like a potential attacker. It presents standard cryptographic functions and protocols and gives an overview of threats and defenses for software, host systems, networks, and the Web. It also touches on some of the legal, policy, and ethical issues surrounding computer security in areas such as privacy, surveillance, and the disclosure of security vulnerabilities. The goal of this course is to provide a foundation for further study in computer security and to help better understand how to design, build, and use computer systems more securely.

CMSC 32400. Programming Proofs, Graduate. 100 Units.
In this course, we will explore the use of proof assistants, computer programs that allow us to write, automate, and mechanically check proofs. These tools have two main uses. They allow us to prove properties of our
programs, thereby guaranteeing that our code is free of software errors. They also allow us to formalize mathematics, stating and proving mathematical theorems in a manner that leaves no doubt as to their meaning or veracity. At the intersection of these two uses lies mechanized computer science, involving proofs about data structures, algorithms, programming languages and verification itself.

Terms Offered: Winter

Prerequisite(s): Experience in discrete math and functional programming.

CMSC 32700. Quantum Programming and Verification. 100 Units.

As quantum computing comes into its own, a growing number of researchers are trying to address two key challenges that will face computer scientists over the coming years: How do we program quantum computers and how do we ensure that the programs we write reflect our intent? In this course, we will survey a range of papers on quantum programming languages, verification tools, and debugging frameworks for quantum programs. We will identify a variety of abstractions used in quantum programming languages and different approaches to guaranteeing program correctness, including hands-on work in the Coq proof assistant. The course will culminate in a final project that either develops techniques for quantum programming/verification or applies existing ones to new problems.

Instructor(s): Rand

Terms Offered: Spring

CMSC 32900. Quantum Computer Systems, Graduate. 100 Units.

This course will explore the design, optimization, and verification of the software and hardware involved in practical quantum computer systems. The course will provide an introduction to quantum computation and quantum technologies, as well as classical and quantum compiler techniques to optimize computations for technologies. Verification techniques to evaluate the correctness of quantum software and hardware will also be explored.

Instructor(s): Chong

Terms Offered: Spring

CMSC 33000. Operating Systems. 100 Units.
CMSC 33001. Topics in Systems. 100 Units.

Graduate study of current topics in systems.

Terms Offered: Autumn Spring Winter

Prerequisite(s): Consent of department counselor and instructor

CMSC 33100. Advanced Operating Systems. 100 Units.

This course covers advanced topics in operating systems and systems research. Possible topics include, but are not limited to the following: OS philosophies, networked operating systems, distributed file systems, virtual machines, fault-tolerant systems, resource allocation, parallel computing and multiprocessing, cloud computing, and security.

Instructor(s): Lu

Terms Offered: Autumn

Prerequisite(s): Consent of department counselor and instructor

CMSC 33200. Topics: Operating Systems. 100 Units.
CMSC 33210. Usable Security and Privacy. 100 Units.

Questions of usability and privacy in computer systems, including human factors.

Instructor(s): Ur

Terms Offered: Spring

Prerequisite(s): Consent of department counselor and instructor

CMSC 33218. Surveillance Aesthetics: Provocations About Privacy and Security in the Digital Age, Graduate. 100 Units.

In the modern world, individuals’ activities in both the physical and digital worlds are tracked, surveilled, and computationally modeled to both beneficial and problematic ends. Working jointly with students and faculty from the School of the Art Institute of Chicago (SAIC), this course will examine privacy and security issues at the intersection between the physical and digital world. Coursework will encompass both technical problem sets with substantial programming components and the creation of a capstone interactive art installation following the studio art process. The course will introduce algorithms for processing and modeling various types of data: (i) mobility data; (ii) video data; (iii) audio data; (iv) natural language data; (v) structured information archives. Through both the lenses of computer science and studio art, students will be asked to design algorithms, implement systems, and create artworks that communicate, provoke, and reframe pervasive issues in modern privacy and security. The course will both unpack and re-entangle computational connections and data-driven interactions between people, built space, sensors, structures, devices, and data. Synthesizing technology and aesthetics, the collaboration between UChicago and SAIC will communicate its findings to the broader public not only through typical academic avenues, but also via provocative and compelling public art and media.

CMSC 33230. Engineering Interactive Electronics onto Printed Circuit Boards, Graduate. 100 Units.

In this class we will engineer electronics onto Printed Circuit Boards (PCBs). We will focus on designing and laying out the circuit and PCB for our own custom-made I/O devices, such as wearable or haptic devices. In order for you to be successful in engineering a functional PCB, we will (1) review digital circuits and three microcontrollers (ATMEGA, NRF, SAMD); (2) use KICAD to build circuit schematics; (3) learn how to wire analog/digital sensors or actuators to our microcontroller, including SPI and I2C protocols; (4) use KICAD to
build PCB schematics; (5) actually manufacture our designs; (6) receive in our hands our PCBs from factory; (7) finally, learn how to debug our custom-made PCBs.

Instructor(s): Lopes

CMSC 33231. Topics in Human Computer Interaction. 100 Units.
This course will explore methods for practicing and research about the subset of HCI involving educational interventions for CS learning. We will go over learning theory, followed by seminal papers, analyzing them for how they integrate and follow the theory, their research outcomes, and their research methodology, as well as critique their paper writing and brainstorm next steps based on their research. Each student will choose a CS subject and age group for their own project. The final product, which will be written gradually with milestones, will be a 15-page research proposal. This way, students get practice with many of the important aspects of writing - writing the motivation and introduction, theory, related work, the idea itself, and the evaluation of the idea. They won’t be required to actually perform the research, which is why the proposal format is appropriate. In addition, students will each present one or two papers in their topic area to the group, emphasizing the elements above (theory integration, research methodology, research outcomes).

Instructor(s): Pedro Lopes Terms Offered: Winter

CMSC 33240. Emergent Interface Technologies. 100 Units.
In this class, we critically examine emergent technologies that might impact the future generations of computing interfaces, these include: physiological I/O (e.g., brain and muscle computer interfaces), tangible computing (giving shape and form to interfaces), wearable computing (I/O devices closer to the user's body), rendering new realities (e.g., virtual and augmented reality), haptics (giving computers the ability to generate touch and forces) and unusual auditory interfaces (e.g., silent speech and microphones as sensors). In this class you will: (1) learn about these new developments during the lectures, (2) read HCI papers and summarize these in short weekly assignments, and lastly, (3) start inventing the future of computing interfaces by proposing a new idea in the form of a paper abstract, which you will present at the end of the semester and have it peer-reviewed in class by your classmates.

Terms Offered: Winter

CMSC 33250. Introduction to Computer Security. 100 Units.
This course introduces the principles and practice of computer security. It aims to teach how to model threats to computer systems and how to think like a potential attacker. It presents standard cryptographic functions and protocols and gives an overview of threats and defenses for software, host systems, networks, and the Web. It also touches on some of the legal, policy, and ethical issues surrounding computer security in areas such as privacy, surveillance, and the disclosure of security vulnerabilities. The goal of this course is to provide a foundation for further study in computer security and to help better understand how to design, build, and use computer systems more securely.

Instructor(s): A. Feldman Terms Offered: Autumn

Prerequisite(s): Consent of department counselor and instructor

CMSC 33251. Topics in Computer Security. 100 Units.
Seminar on current topics in computer security.

CMSC 33260. Internet Censorship and Online Speech. 100 Units.
Information dissemination and online discourse on the Internet are subject to the algorithms and filters that operate on Internet infrastructure, from network firewalls to search engines. This course will explore the technologies that are used to control access to online speech and information, and cutting-edge technologies that can empower citizens in the face of these information controls. Students will learn about and experiment with technologies to control online discourse, ranging from firewalls that perform network traffic filtering to algorithms for content personalization and content moderation. We will also explore underlying technical trends, such as the increasing consolidation of Internet infrastructure and protocols, and the implications of consolidation for control over online discourse. Each course meeting will include a technical overview, reading discussion, and a hands-on laboratory activity.

Terms Offered: Winter

Prerequisite(s): None

CMSC 33281. Topics in Human Robot Interaction. 100 Units.
The field of human-robot interaction (HRI) is a new and growing field of research, seeking to create seamless interactions between people and robots. Applications of HRI research include developing robots to tutor elementary students, assist human workers in manufacturing contexts, provide museum tours, interact with families within their homes, and help care for the elderly. The field of HRI is highly interdisciplinary, incorporating methods and techniques from human-computer interaction, robotics, psychology, artificial intelligence, and other fields. This course exposes students to a broad range of recent and cutting-edge research in HRI. The topics covered in this course include: nonverbal robot behavior, verbal robot behavior, social dynamics, norms & ethics, collaboration & learning, group interactions, applications, and future challenges of HRI.

Instructor(s): Sarah Sebo Terms Offered: Autumn

Equivalent Course(s): MAAD 23281
CMSC 33300. Networks and Distributed Systems. 100 Units.
This course will focus on studying the state of the art in networking and networked systems, from a research and design perspective. We will cover a variety of topics from routing protocols to Internet stability, peer-to-peer, social networks and networking for data centers. Coverage of each topic will dive into fundamental design questions of protocols and systems, including updates from results of currently active research. Readings will focus on classic and current research publications, and students are expected to come in with a solid background on networking basics. Students will learn tools, techniques, and concepts while learning to carry out original research in an open-ended course project, with the end goal of producing real, publishable results by the end of the quarter. Students are also expected to gain experience in two skills: quickly reading technical papers (without sacrificing understanding), and giving clear and well-organized presentations.
Instructor(s): B. Sotomayor Terms Offered: Winter

CMSC 33400. Mobile Computing. 100 Units.
Mobile computing is pervasive and changing nearly every aspect of society. Sensing, actuation, and mediation capabilities of mobile devices are transforming all aspects of computing: uses, networking, interface, form, etc. This course explores new technologies driving mobile computing and their implications for systems and society. Current focus areas include expanded visual experience with computational photography, video and interactive augmented reality, and synchronicity and proximity-detection to enable shared social experiences. Labs expose students to software and hardware capabilities of mobile computing systems, and develop the capability to envision radical new applications for a large-scale course project.
Prerequisite(s): A. Chien Terms Offered: Not offered 2017-2018.
Prerequisite(s): CMSC 23000 or 23300 or equivalent are required.

CMSC 33501. Topics in Databases. 100 Units.
This course covers a selection of advanced topics in database systems.
Instructor(s): A. Chien Terms Offered: Autumn, Winter, Spring
Prerequisite(s): Consent of department counselor and instructor

CMSC 33520. Data Intensive Computer Systems. 100 Units.
Big Data and Data Analytics have become hot topics as well as drivers of multi-billion dollar industries. With unprecedented data collection from e-commerce, the WWW, scientific instruments, mobile phones, and IoT. The course objective is to expose students to the technical challenges of data-intensive computing systems, including canonical driving problems, research systems, and emerging technologies. While other classes focus on analysis algorithms (or even underlying statistical or machine learning methods), we focus on the computer systems and technology needed to achieve scalable and efficient data-intensive computing systems. Through paper reading, discussions, presentation, and in-depth projects, students will develop a broad familiarity with current challenges and hands-on experience with a range of systems which together provide a solid preparation for research in the area.
Course topics include: parallel filesystems, SQL databases, NoSQL/Mapreduce systems, storage class memories (from Flash to Memristor to ReRAM), and popular open source infrastructures such as Spark, Hadoop, VoltDB, Cassandra, Memcached, MongoDB, and others.
Instructor(s): Chien
Prerequisite(s): Consent of department counselor and instructor

CMSC 33550. Introduction to Databases. 100 Units.
This course is an introduction to database design and programming using the relational model. Topics include DBMS architecture, entity-relationship and relational models, relational algebra, relational calculus, functional dependencies and normal forms, web DBs and PHP, query optimization, and physical data organization. The lab section will guide students through the collaborative implementation of a relational database management system, allowing students to see topics such as physical data organization and DBMS architecture in practice, and exercise general skills such as collaborative software development.
Instructor(s): Eilmor
Prerequisite(s): Consent of department counselor and instructor

CMSC 33580. The Value of Data. 100 Units.
While data and artificial intelligence are driving many changes to our economic, social, political, financial, and legal systems, we know little about their foundations and governing dynamics. While the recombination and integration of diverse data creates vast new value, we currently have neither theory for how data can be combined nor an industrial policy for how to protect against the personal exposures and abuses that grow in proportion. Many of these issues call for treating data as a first-class citizen and thinking of it as an asset. What is the value of data, and how do we measure it? This course explores these questions from a multidisciplinary perspective that includes computer science, economy, social science, among others. The sessions are organized around broad themes related to the value of data. A typical session will consist of a short introduction by the instructor, followed by a paper discussion (students are expected to read the assigned papers ahead of the class), and finishing with a discussion about individual projects. The course can be taken pass-fail or for a letter grade. For a letter grade, you need to complete an individual, quarter-long project. You also need to attend classes, participate in discussions, and scribe for two/three classes. For pass-fail, you do not need to complete the individual project but all other requirements apply.
Terms Offered: Autumn
CMSC 33581. Topics in Big Data. 100 Units.
The amount of data generated is growing faster than our computational infrastructure, and ever-smarter algorithms will be needed to structure, analyze, and manage such scales. This 10-week seminar studies key “great ideas” in scalable algorithms for data analysis. Topics include: sampling, sketching, randomized index structures, basic coding theory, and query optimization.
Instructor(s): S. Krishnan Terms Offered: Winter

CMSC 33700. Computer Graphics. 100 Units.
This course introduces the basic concepts and techniques used in three-dimensional computer graphics. The focus is on real-time rendering techniques, such as those found in computer games. These include coordinate systems and transformations, the graphics pipeline, basic geometric algorithms, texture mapping, level-of-detail optimizations, and shadows. Students are required to complete both written assignments and programming projects using OpenGL.
Instructor(s): J. Reppy Terms Offered: TBD
Prerequisite(s): Consent of department counselor and instructor

CMSC 33710. Scientific Visualization. 100 Units.
Scientific visualization combines computer graphics, numerical methods, and mathematical models of the physical world to create a visual framework for understanding and solving scientific problems. The mathematical and algorithmic foundations of scientific visualization (for example, scalar, vector, and tensor fields) will be explained in the context of real-world data from scientific and biomedical domains. The course is also intended for students outside computer science who are experienced with programming and computing with scientific data. Programming projects will be in C and C++.
Instructor(s): G. Kindlmann Terms Offered: Winter
Prerequisite(s): Strong programming skills and basic knowledge of linear algebra and calculus
Note(s): This course is offered in alternate years.

CMSC 33750. Machine Learning and Cancer. 100 Units.
In this topics course we will investigate the use of machine learning methods in the study of Cancer and the development of precision oncology. Cancer is a complex disease that impacts millions each year. Recently the concept of precision oncology has gained popularity as an approach to customize Cancer treatments based on the genomic profile and history of the patient, the molecular properties of the patient’s tumor and the action and mode of treatments that are available. At the center of any precision medicine approach are large-scale datasets from which predictive models can be built, scalable analysis methods for processing and integrating data and machine learning methods for constructing and evaluating predictive models that can be used in diagnosis, treatment planning, and outcome prediction for patient care. In this course we will work through the development of the entire pipeline from raw data to predictive models. We will develop and evaluate predictive models for drug response, tumor typing, image based diagnosis, and treatment outcomes. We will also develop some population based models that include environmental factors. Students will work through key papers, representative datasets and a variety of machine learning methods including some deep learning models under development in the joint DOE/NCI Cancer project. Familiarity with python and machine learning will be helpful. Students will have an opportunity to do significant project work as part of the course.
Instructor(s): Rick Stevens, Robert Grossman Terms Offered: Autumn

CMSC 33900. Data Visualization. 100 Units.
Data visualizations provide a visual setting in which to explore, understand, and explain datasets. This class describes mathematical and perceptual principles, methods, and applications of “data visualization” (as it is popularly understood to refer primarily to tabulated data). A range of data types and visual encodings will be presented and evaluated. Visualizations will be primarily web-based, using D3.js, and possibly other higher-level languages and libraries.

CMSC 34702. Topics in Networks: 100 Units.

CMSC 34703. Topics in Distributed Systems. 100 Units.
Topics in Distributed Systems
Instructor(s): Junchen Jiang Terms Offered: Autumn

CMSC 34900. Topics in Scientific Computing. 100 Units.
This course covers a selection of advanced topics in Scientific Computing.
Instructor(s): Scott Terms Offered: Autumn
Prerequisite(s): Consent of department counselor and instructor
Equivalent Course(s): MAAD 24850

CMSC 34901. Special Topics in Operations Mgt./Mgt. Science. 100 Units.
Course Search (https://intranet.chicagobooth.edu/pub/coursesearch/coursesearch/)
Equivalent Course(s): BUSN 40901

CMSC 35050. Graduate Computational Linguistics. 100 Units.
This course introduces the problems of computational linguistics and the techniques used to deal with them, focusing primarily on probabilistic models and techniques. Topics are drawn primarily from phonology,
CMSC 35100. Natural Language Processing. 100 Units.
This course introduces the theory and practice of natural language processing, with applications to both text and speech. Topics include regular expressions, finite state automata, morphology, part of speech tagging, context free grammars, parsing, semantics, discourse, and dialogue. Symbolic and probabilistic models are presented. Techniques for automatic acquisition of linguistic knowledge are emphasized.

CMSC 35220. Deep Learning Systems. 100 Units.
Deep learning is emerging as a major technique for solving problems in a variety of fields, including computer vision, personalized medicine, autonomous vehicles, and natural language processing. Critical to success in these target domains is the development of learning systems: deep learning frameworks that support the tasks of learning complex models and inferencing with those models, and targeting heterogeneous computing devices. This course is aimed as an introduction to this topic. We will cover various aspects of deep learning systems, including: basics of deep learning, programming models for expressing machine learning models, automatic differentiation methods used to compute gradients for training, memory optimization, scheduling, data and model parallel and distributed learning, hardware acceleration, domain specific languages, workflows for large-scale machine learning, including hyper parameter optimization and uncertainty quantification, and training data and model serving. The goal is to present a comprehensive picture of how current deep learning systems work, discuss and explore research opportunities, for extending and building on existing frameworks, and deep dive into the accelerators being developed by numerous startups to address the needs of the machine learning community. A typical week will contain one lecture on a specific aspect of deep learning systems and one lab session exploring technologies such as Keras, Tensorflow, CNTK, Mxnet, and PyTorch.
Instructor(s): Ian Foster, Rick Stevens Terms Offered: Autumn
Note(s): This course will provide useful background for students wishing to take our Spring 2019 class on Neuromorphic Computing.

CMSC 35230. Applications of Machine Learning in Large-Scale Computing Systems. 100 Units.
Recent research has demonstrated the feasibility of replacing the traditional heuristics used in computer systems with ones learned from data in areas such as scheduling, data structure design, query optimization, compilers, and control of warehouse scale computing systems. This seminar overviews this recent research trend and studies the characteristics of successful research in this space. The objective is to understand whether this trend will have a long-term impact on the design and implementation of large-scale computing systems. The seminar hopes to highlight the remaining bottlenecks to practical acceptance of machine learning in computing infrastructure and to inspire future systems and learning research.
Terms Offered: Winter
Prerequisite(s): Good working knowledge of computer systems, especially in the areas of operating systems and databases.

CMSC 35246. Deep Learning. 100 Units.
Deep Neural Networks are remarkably effective in large scale learning problems, especially in speech recognition and computer vision. This course aims to cover the basics of Deep Learning, some of the underlying theory, and specific architectures, including Convolutional Neural Networks, Recurrent Neural Networks and the Long Short Term Memory Networks.

CMSC 35300. Mathematical Foundations of Machine Learning. 100 Units.
This course is an introduction to the mathematical foundations of machine learning that focuses on matrix methods and features real-world applications ranging from classification and clustering to denoising and data analysis. Mathematical topics covered include linear equations, regression, regularization, the singular value decomposition, and iterative algorithms. Machine learning topics include the lasso, support vector machines, kernel methods, clustering, dictionary learning, neural networks, and deep learning. Students are expected to have taken calculus and have exposure to numerical computing (e.g. Matlab, Python, Julia, R). Appropriate for graduate students or advanced undergraduates.
Instructor(s): Rebecca Willett Terms Offered: Winter
Prerequisite(s): Competence programming in Matlab, Julia, R, Python, or an equivalent system; knowledge of calculus, mathematical maturity.

CMSC 35350. Neuromorphic Computing. 100 Units.
The human brain consumes around 20 watts-less energy than a lightbulb-but can perform tasks, such as understanding natural language and interpreting images, that tax megawatt-scale supercomputers. Thus, we may wonder: can we achieve energy efficiencies similar to those of the human brain by building analog electronic circuits that mimic the neuro-biological architectures found in animal nervous systems? This concept, named neuromorphic computing, has become increasingly popular as the energy demands of conventional computers increase. Research in this area is producing a great variety of new computational architectures, microelectronics concepts, algorithmic approaches, and even neuroscience insights. Our goal in this course is to introduce students to the state of knowledge in neuromorphic computing and thus to prepare them to undertake original
research in this area. The class will be organized primarily around reading, presenting, and discussing research papers. Topics to be covered include: Neuromorphic concepts Theory and algorithms Microelectronics and devices Programming models and environments Applications: Machine learning, deep learning, robot control, ...

Platforms: BrainScaleS, Loihi, SpiNNaker Neuroscience

Terms Offered: Spring TBD

**CMSC 35360. Autonomous Laboratories. 100 Units.**
Autonomous laboratories leverage robotics, machine learning (ML), and artificial intelligence (AI) methods to accelerate discovery and design processes in science and engineering. They build on advances in robotic instruments, which enable faster, cheaper, and more reproducible experiments, but go further, leveraging AI/ML methods to explore large and complex search spaces more efficiently than humans can do unaided. This course introduces students to the principles and practice of automated laboratories, with a particular focus on AI/ML methods such as active learning, Bayesian optimization, and reinforcement learning. The class will combine lectures, readings, programming assignments on AI/ML methods, and a project in which students will investigate an autonomous laboratory problem.

Instructor(s): Foster, Stevens Terms Offered: Spring TBD

**CMSC 35400. Machine Learning. 100 Units.**
This course provides hands-on experience with a range of contemporary machine learning algorithms, as well as an introduction to the theoretical aspects of the subject. Topics covered include: the PAC framework, Bayesian learning, graphical models, clustering, dimensionality reduction, kernel methods including SVMs, matrix completion, neural networks, and an introduction to statistical learning theory.

Terms Offered: To be determined
Prerequisite(s): Consent of instructor
Equivalent Course(s): CAAM 37710, STAT 37710

**CMSC 35401. Topics in Machine Learning: Applied Machine Learning. 100 Units.**
Graduate study in current topics in machine learning.

Terms Offered: TBD

**CMSC 35410. Spectral Methods for Machine Learning and Network Analysis. 100 Units.**
An introduction to spectral algorithms, emphasizing their power to tackle practical problems in the analysis of networks and high-dimensional data. Topics include spectral graph theory, random walks over networks and their convergence, spectral clustering, subspace projections and embeddings, and numerical algorithms for fundamental linear-algebraic problems.

Instructor(s): Lorenzo Orecchia Terms Offered: Autumn

**CMSC 35425. Topics in Statistical Machine Learning. 100 Units.**
Topics in Statistical Machine Learning is a second graduate level course in machine learning, assuming students have had previous exposure to machine learning and statistical theory. The emphasis of the course is on statistical methodology, learning theory, and algorithms for large-scale, high dimensional data. The selection of topics is influenced by recent research results, and students can take the course in more than one quarter.

Terms Offered: To be determined
Equivalent Course(s): STAT 37790

**CMSC 35440. Machine Learning in Biology and Medicine. 100 Units.**

[Machine Learning in Biology and Medicine]

Terms Offered: Autumn
Note(s): [still awaiting course description from instructors]

**CMSC 35470. Mathematical Computation IIA: Convex Optimization. 100 Units.**
The course will cover techniques in unconstrained and constrained convex optimization and a practical introduction to convex duality. The course will focus on (1) formulating and understanding convex optimization problems and studying their properties; (2) understanding and using the dual; and (3) presenting and understanding optimization approaches, including interior point methods and first order methods for non-smooth problems. Examples will be mostly from data fitting, statistics and machine learning.

Instructor(s): Nathan Srebro Terms Offered: Winter
Prerequisite(s): STAT 30900/CMSC 37810
Equivalent Course(s): BUSN 36903, CAAM 31015, TTIC 31070, STAT 31015

**CMSC 35480. Topics in Optimization. 100 Units.**
Graduate study of topic in optimization.

Instructor(s): Lorenzo Orecchia Terms Offered: Autumn

**CMSC 35490. Special Topics in Machine Learning. 100 Units.**
Learned emulators leverage neural networks to increase the speed of physics simulations in climate models, astrophysics, high-energy physics, and more. Recent empirical results have illustrated that these emulators can speed up traditional simulations by up to eight orders of magnitude. However, little is understood about these emulators. While it is possible that recent results are representative of what is possible in most settings, a more likely scenario is that these approaches are more effective for some simulators than others, and that learned emulators achieve strong average-case performance but fail to capture rare but important phenomena. In this
graduate seminar course we will provide an overview and investigate recent literature on this topic, focusing on the following questions: 1. Introduction to learned emulators: how do they work, where have they been successful so far and what are the goals in this field? 2. Two different paradigms of learned emulation: physics vs. data driven. What are the advantages and pitfalls of each? 3. Robustness of emulation to noise: what is known so far? 4. Parameter estimation: how to handle parameter uncertainty? We will provide a list of papers covering the above topics and students will be evaluated on in-class presentations.

Instructor(s): Dana Mendelson (Math) and Rebecca Willett (CS/Stats) Terms Offered: Autumn

Prerequisite(s): Students should be familiar with a numerical programming language like Python, Julia, R, or Matlab and the content of CMSC 35400. Students should also have familiarity with the contents of MATH 27300 and MATH 27500 or similar.

Note(s): This is a seminar course, it will be capped at 15 students, 4 Math, 4 CS/Stats, and 7 with instructor permission.

Equivalent Course(s): STAT 37794, MATH 37794, CAAM 37794

CMSC 35600. Image Processing/Computer Vision. 100 Units.

Equivalent Course(s): MPHY 39600

CMSC 35620. Computational Linguistics II. 100 Units.

This course is a graduate-level introduction to topics at the intersection of computation and language. We will study computational linguistics from both scientific and engineering angles: the use of computational modeling to address scientific questions in linguistics and cognitive science, as well as the design of computational systems to solve engineering problems in natural language processing (NLP). The course will combine analysis and discussion of these approaches with training in the programming and mathematical foundations necessary to put these methods into practice. The course is designed to accommodate students both with and without prior programming experience. Our goal is for all students to leave the course able to engage with and critically evaluate research in cognitive/linguistic modeling and NLP, and to be able to implement intermediate-level computational models for novel computational linguistics research.

Instructor(s): Allyson Ettinger Terms Offered: Winter

Prerequisite(s): Computational Linguistics I or permission of instructor

Equivalent Course(s): LING 38620

CMSC 36500. Algorithms in Finite Groups. 100 Units.

We consider the asymptotic complexity of some of the basic problems of computational group theory. The course demonstrates the relevance of a mix of mathematical techniques, ranging from combinatorial ideas, the elements of probability theory, and elementary group theory, to the theories of rapidly mixing Markov chains, applications of simply stated consequences of the Classification of Finite Simple Groups (CFSG), and, occasionally, detailed information about finite simple groups. No programming problems are assigned.

Instructor(s): L. Babai Terms Offered: Spring

Prerequisite(s): Consent of department counselor. Linear algebra, finite fields, and a first course in group theory (Jordan-Holder and Sylow theorems) required; prior knowledge of algorithms not required.

Note(s): This course is offered in alternate years.

Equivalent Course(s): MATH 37500

CMSC 37000. Algorithms. 100 Units.

This is a graduate level course on algorithms with the emphasis on central combinatorial optimization problems and advanced methods for algorithm design and analysis. Topics covered include asymptotic analysis, greedy algorithms, dynamic programming, amortized analysis, randomized algorithms and probabilistic methods, combinatorial optimization and approximation algorithms, linear programming, and advanced data structures. Expected outcomes: Ability to design and rigorously analyze algorithms using paradigms such as greedy or dynamic programming. Understand the use of linear programming in optimization. Be able to formulate problems as linear programs. Understand linear programming duality and applications to problems such as max-flow/min-cut. Be able to write duals for linear programs.

Instructor(s): Yury Makarychev Terms Offered: Winter

Prerequisite(s): Assumes familiarity with proofs and an asymptotic notation. Some basic knowledge of the notion of NP-hardness is also required.

Equivalent Course(s): TTIC 31010

CMSC 37110. Discrete Mathematics. 100 Units.

This course emphasizes mathematical discovery and rigorous proof, illustrated on a variety of accessible and useful topics, including basic number theory, asymptotic growth of sequences, combinatorics and graph theory, discrete probability, and finite Markov chains. This course includes an introduction to linear algebra.

Instructor(s): L. Babai Terms Offered: Autumn

Prerequisite(s): Consent of department counselor and instructor

CMSC 37115. Introduction to Mathematical Reasoning via Discrete Mathematics. 100 Units.

In this course, students with little prior exposure to rigorous mathematical reasoning gain experience in approaching mathematical questions, developing concepts, formalizing ideas, turning intuition into rigorous proof. These phases of mathematical thinking are illustrated on a variety of accessible and useful topics. Students practice the quantifier notation both as a shorthand and as one of the organizing principles of formal statements.

New concepts are built from such basic mathematical primitives as numbers, sets, and functions. Basic counting
is a recurring theme and provides a source for sequences, another recurring theme, which in turn feeds into
the study of asymptotic behavior (rates of growth). Further topics to be covered include proof by induction;
the elements of number theory (gcd, congruences, the Chinese Remainder Theorem, Fermat's little Theorem);
recurrences, Fibonacci numbers, generating functions; the elements of graph theory (trees, paths and cycle,
cromatic number, independent sets and cliques, connectivity, planarity, directed graphs), finite probability
spaces, random variables, expected value and variance, independence, concentration inequalities, and random
graphs.
Terms Offered: Winter
Prerequisite(s): One quarter of calculus

CMSC 37200. Combinatorics. 100 Units.
Methods of enumeration, construction, and proof of existence of discrete structures are discussed. The course
emphasizes applications of linear algebra, number theory, and the probabilistic method to combinatorics.
Applications to the theory of computing are indicated, and open problems are discussed.
Instructor(s): L. Babai Terms Offered: Spring
Prerequisite(s): Consent of department counselor. Linear algebra, basic combinatorics, or consent of instructor.

CMSC 37220. Information and Coding Theory. 100 Units.
This course is meant to serve as an introduction to some basic concepts in information theory and error-
correcting codes, and some of their applications in computer science and statistics. We plan to cover the
following topics: Introduction to entropy and source coding. Applications of entropy to counting
problems. Mutual information and KL-divergence. Method of types and hypothesis testing. L-projections and
applications. Introduction to error-correcting codes. Unique and list decoding of Reed-Solomon and Reed-Muller
codes. Applications of information theory to lower bounds in computational complexity and communication
complexity. Expected outcomes: Familiarity with concepts such as Entropy, Mutual information and KL-
divergence. Familiarity with source and channel coding. Understanding of the method of types and ability to
derive large-deviation bounds using information-theoretic concepts. Understanding of the notions of unique and
list decoding for various codes.
Instructor(s): Tulsiani, Madhur Terms Offered: Autumn
Prerequisite(s): Discrete probability. Some knowledge of finite-field algebra is required for the part on error-
correcting codes but required basics are reviewed in class.
Equivalent Course(s): TTIC 31200

CMSC 37503. Approximation Algorithms. 100 Units.
This is a basic course on approximation algorithms, with the main focus on approximation algorithms for
central combinatorial optimization problems. We will mostly focus on classical algorithmic results, but will also
present some state of the art results and challenges in the area of approximation. The course will cover major
algorithmic techniques, including LP-rounding, primal-dual schema, metric methods, SDP rounding and so on.
While the main focus of the course is on algorithms, we will also discuss lower bounds on approximation and
connections between algorithm design and lower bound proofs. Assumes the knowledge of material covered in
the Algorithms course. Expected outcomes: Understand concepts such as approximation factor, polynomial time
approximation schemes and hardness of approximation. Understand applications of linear programs (LPs) to
design of approximation algorithms. Learn to analyze rounding algorithms for LPs and understand integrality
gaps. Be able to apply LP duality. Understand semi-definite programming and its applications to approximation.
Instructor(s): Julia Chuzhoy Terms Offered: Autumn
Equivalent Course(s): TTIC 31080

CMSC 37530. Graph Theory. 100 Units.
This course covers the basics of the theory of finite graphs. Topics include shortest paths, spanning trees,
counting techniques, matchings, Hamiltonian cycles, chromatic number, extremal graph theory, Turan's theorem,
planarity, Menger's theorem, the max-flow/min-cut theorem, Ramsey theory, directed graphs, strongly connected
components, directly acyclic graphs, and tournaments. Techniques studied include the probabilistic method.
Instructor(s): Laszlo Babai Terms Offered: Spring

CMSC 37810. Mathematical Computation I: Matrix Computation Course. 100 Units.
This is an introductory course on numerical linear algebra, which is quite different from linear algebra. We will
be much less interested in algebraic results that follow from axiomatic definitions of fields and vector spaces
but much more interested in analytic results that hold only over the real and complex fields. The main objects of
interest are real- or complex-valued matrices, which may come from differential operators, integral transforms,
bilinear and quadratic forms, boundary and coboundary maps, Markov chains, correlations, DNA microarray
measurements, movie ratings by viewers, friendship relations in social networks, etc. Numerical linear algebra
provides the mathematical and algorithmic tools for analyzing these matrices. Topics covered: basic matrix
decompositions LU, QR, SVD; Gaussian elimination and LU/LDU decompositions; backward error analysis,
Gram-Schmidt orthogonalization and QR/complete orthogonal decompositions; solving linear systems, least
squares, and total least squares problem; low-rank matrix approximations and matrix completion. We shall also
include a brief overview of stationary and Krylov subspace iterative methods; eigenvalue and singular value
problems; and sparse linear algebra.
Terms Offered: Autumn
Prerequisite(s): Linear algebra (STAT 24300 or equivalent) and some previous experience with statistics.
CMSC 37812. Mathematical Computation III: Numerical Methods for PDE’ s. 100 Units.
The first part of this course introduces basic properties of PDE’ s; finite difference discretizations; and stability, consistency, convergence, and Lax’s equivalence theorem. We also cover examples of finite difference schemes; simple stability analysis; convergence analysis and order of accuracy; consistency analysis and errors (i.e., dissipative and dispersive errors); and unconditional stability and implicit schemes. The second part of this course includes solution of stiff systems in 1, 2, and 3D; direct vs. iterative methods (i.e., banded and sparse LU factorizations); and Jacobi, Gauss-Seidel, multigrid, conjugate gradient, and GMRES iterations.
Terms Offered: Spring
Prerequisite(s): Some prior exposure to differential equations and linear algebra
Equivalent Course(s): STAT 31000, CAAM 31000, MATH 38309

CMSC 38000. Computability Theory I. 100 Units.
We investigate the computability and relative computability of functions and sets. Topics include mathematical models for computations, basic results such as the recursion theorem, computably enumerable sets, and priority methods.
Instructor(s): D. Hirschfeldt Terms Offered: Spring
Prerequisite(s): Consent of department counselor. MATH 25500 or consent of instructor.
Equivalent Course(s): MATH 30200

CMSC 38130. Honors Introduction to Complexity Theory. 100 Units.
Computability topics are discussed (e.g., the s-m-n theorem and the recursion theorem, resource-bounded computation). This course introduces complexity theory. Relationships between space and time, determinism and non-determinism, NP-completeness, and the P versus NP question are investigated.
Terms Offered: Winter

CMSC 38300. Numerical Solutions to Partial Differential Equations. 100 Units.
This course covers the basic mathematical theory behind numerical solution of partial differential equations. We investigate the convergence properties of finite element, finite difference and other discretization methods for solving partial differential equations, introducing Sobolev spaces and polynomial approximation theory. We emphasize error estimators, adaptivity, and optimal-order solvers for linear systems arising from PDEs. Special topics include PDEs of fluid mechanics, max-norm error estimates, and Banach-space operator-interpolation techniques.
Instructor(s): L. R. Scott Terms Offered: Spring. This course is offered in alternate years.
Prerequisite(s): Consent of department counselor and instructor
Equivalent Course(s): MATH 38300

CMSC 38400. Cryptography. 100 Units.
Cryptography is the use of algorithms to protect information from adversaries. Though its origins are ancient, cryptography now underlies everyday technologies including the Internet, wifi, cell phones, payment systems, and more. This course is an introduction to the design and analysis of cryptography, including how “security” is defined, how practical cryptographic algorithms work, and how to exploit flaws in cryptography. The course will cover algorithms for symmetric-key and public-key encryption, authentication, digital signatures, hash functions, and other primitives.
Instructor(s): David Cash Terms Offered: Winter

CMSC 38405. Arithmetic Combinatorics. 100 Units.
This course covers a variety of topics in arithmetic combinatorics such as inverse problems, incidence geometry, uniformity, regularity and pseudo-randomness. A special attention will be paid to connections to classical mathematics and theoretical computer science.
Instructor(s): Alexander Razborov Terms Offered: Spring
Equivalent Course(s): MATH 38405

CMSC 38410. Quantum Computing. 100 Units.
This course covers mathematical and complexity aspects of quantum computing, putting aside all questions pertaining to its physical realizability. Possible topics include: (1) quantum model of computation, quantum complexity classes, and relations to their classical counterparts; (2) famous quantum algorithms (including Shor and Grover); (3) black-box quantum models (lower and upper bounds); (4) quantum communication complexity (lower and upper bounds); and (5) quantum information theory.
Instructor(s): A. Razborov Terms Offered: Winter. This course is offered in alternate years.
Prerequisite(s): Consent of department counselor. Basic knowledge of computational complexity and linear algebra required; knowledge of quantum mechanics not required
Note(s): Not offered in 2016-17.
Equivalent Course(s): MATH 38410

CMSC 38500. Computability and Complexity Theory. 100 Units.
Part one of this course consists of models for defining computable functions: primitive recursive functions, (general) recursive functions, and Turing machines; the Church-Turing Thesis; unsolvable problems; diagonalization; and properties of computably enumerable sets. Part two of this course deals with Kolmogorov (resource bounded) complexity: the quantity of information in individual objects. Part three of this course covers
functions computable with time and space bounds of the Turing machine: polynomial time computability, the classes P and NP, NP-complete problems, polynomial time hierarchy, and P-space complete problems.

Instructor(s): A. Razborov
Terms Offered: Winter
Prerequisite(s): Consent of department counselor and instructor
Note(s): Not offered in 2016-17.
Equivalent Course(s): TTIC 31060, MATH 30500

CMSC 38502. Topics in Combinatorics and Logic. 100 Units.
We will discuss several ideas, methods and results in Combinatorics and those parts of Mathematical Logic that are close to Theoretical Computer Science. Complexity Theory itself is excluded this year since I will teach a more systematic course on the subject in the Spring Quarter.

Instructor(s): Alexander Razborov
Terms Offered: Winter
Prerequisite(s): None

CMSC 38700. Complexity Theory B. 100 Units.
This course covers topics in computational complexity theory, with an emphasis on combinatorial problems in complexity.

Instructor(s): A. Razborov
Terms Offered: Spring
Prerequisite(s): Consent of department counselor and instructor

CMSC 38800. Complexity Theory. 100 Units.
Complexity Theory is the branch of Theoretical Computer Science that studies inherent limitations on the efficiency of performing various computational tasks. In this course I hope to cover at least the most fundamental results from uniform (Turing) complexity, circuit complexity, communication complexity, algebraic complexity and proof complexity.

Instructor(s): Alexander Razborov
Terms Offered: Spring
Prerequisite(s): None, but some familiarity with the book "Computational Complexity" by Arora and Barak might be helpful.

CMSC 38815. Geometric Complexity. 100 Units.
This course provides a basic introduction to geometric complexity theory, an approach to the P vs. NP and related problems through algebraic geometry and representation theory. No background in algebraic geometry or representation theory will be assumed.

Instructor(s): K. Mulmuley
Terms Offered: Autumn. This course is offered in alternate years.
Prerequisite(s): Consent of department counselor and instructor
Note(s): Background in algebraic geometry or representation theory not required
Equivalent Course(s): MATH 38815

CMSC 39000. Computational Geometry. 100 Units.
This course is a seminar on topics in computational geometry.

Instructor(s): K. Mulmuley
Terms Offered: Spring. This course is offered in alternate years.
Note(s): Not offered in 2016-17.

CMSC 39010. Computational and Metric Geometry. 100 Units.
The course covers fundamental concepts, algorithms and techniques in computational and metric geometry. Topics covered include: convex hulls, polygon triangulations, range searching, segment intersection, Voronoi diagrams, Delaunay triangulations, metric and normed spaces, low-distortion metric embeddings and their applications in approximation algorithms, padded decomposition of metric spaces, Johnson-Lindenstrauss transform and dimension reduction, approximate nearest neighbor search and locality-sensitive hashing.

Expected outcomes: -- Know standard algorithms and data structures for solving geometric problems -- Be able to design efficient algorithms and data structures for solving geometric problems -- Understand basic concepts of metric geometry such as metric and normed space, low distortion embedding, dimension reduction, nearest neighbor search. -- Understand applications of metric geometry to the field of approximation algorithms and other areas of computer science.

Instructor(s): Makarychev, Yury
Terms Offered: Spring
Prerequisite(s): Undergraduate-level algorithms, linear algebra and probability classes; a good background in mathematical analysis/calculus.
Equivalent Course(s): TTIC 31100

CMSC 39020. Geometry, Complexity and Algorithms. 100 Units.
This course will try to explore these three topics and their interactions. Among the topics likely to be discussed are metric measure geometry (e.g. concentration of measure) and its use designing algorithms, machine learning, manifold learning, the complexity of the construction of isotopies and nullcobordisms, the Blum-Cucker-Smale theory of real computation and estimates for the complexity of root finding and related problems, persistence homology and applications, and other topics that seem like a good idea as the course develops.

Equivalent Course(s): MATH 38900
CMSC 39100. The Physics of Computation. 100 Units.
The class will focus on the theory of quantum information, covering specific topics at the intersection of theoretical computer science and physics and bringing students to the research frontier in these areas. Of particular interest are the theoretical foundations needed to characterize the computational power of quantum experiments in the "Near-term Intermediate Scale Quantum" era, Hamiltonian complexity and the theory of QMA completeness, and the power of resource limited models of quantum computation. While no formal prerequisites are required, a working familiarity with the basics of computational complexity theory and quantum mechanics is recommended.
Instructor(s): Fefferman Terms Offered: Spring

CMSC 39600. Topics in Theoretical Computer Science. 100 Units.
In this class we will examine central tasks in learning, estimation, and decision-making with rewards and penalties. We will review fundamentals of statistics and decision theory, with an additional concern for efficient algorithms. We will then study topics in computational learning theory, online algorithms, and games against nature (decision processes). Where possible we will aim to understand barriers arising either from information-theoretic uncertainty (e.g. sample-complexity lower bounds) or from computational hardness conjectures. This class aims to build a broad toolkit applicable to several areas in CS and machine learning. The format is participatory and flexible to student interests and the challenges and opportunities of e-learning. Students can expect to present topics/papers and engage in group discussion and problem-solving.
Instructor(s): Drucker Terms Offered: Autumn Spring Winter
Prerequisite(s): Coursework in probability, and familiarity with linear algebra.

CMSC 39800. Rdg/Rsch: Computer Science. 300.00 Units.
Directed reading and research in computer science, under the guidance of a faculty member.

CMSC 70000. Advanced Study: Computer Science. 300.00 Units.
Advanced Study: Computer Science