Computer Science

Department Website: https://www.cs.uchicago.edu

PROGRAM OF STUDY

The computer science program offers BA and BS degrees, as well as combined BA/MS and BS/MS degrees. Students who earn the BA are prepared either for graduate study in computer science or a career in industry. Students who earn the BS degree build strength in an additional field by following an approved course of study in a related area. The department also offers a minor.

WHERE TO START

The Department of Computer Science offers several different introductory pathways into the program. In consultation with their College adviser and the Computer Science Department advisers, students should choose their introductory courses carefully. Some guidelines follow.

For students intending to pursue further study in computer science, we recommend CMSC 15100 Introduction to Computer Science I or CMSC 16100 Honors Introduction to Computer Science I as the first course. CMSC 15100 does not assume prior experience or unusually strong preparation in mathematics. Students with programming experience and strong preparation in mathematics should consider CMSC 16100 Honors Introduction to Computer Science I. First-year students considering a computer science major are strongly advised to register for an introductory sequence in the Winter or Spring Quarter of their first year, and it is all but essential that they start the introductory sequence no later than the second quarter of their second year.

Students who are not intending to major in computer science, but are interested in getting a rigorous introduction to computational thinking with a focus on applications are encouraged to start with CMSC 12100 Computer Science with Applications I. Incoming students should note that while CMSC 12100 can be used as the first course in the major, it is not open to first-year students, and it is not intended as an entry point for students who plan to major in computer science.

Students who are interested in data science should consider starting with CMSC 11800 Introduction to Data Science I.

Students who are interested in the visual arts or design should consider a new course, CMSC 11111 Creative Coding.

PROGRAM REQUIREMENTS

Both the BA and BS in computer science require fulfillment of the general education requirement in the mathematical sciences by completing an approved two-quarter calculus sequence. To earn a BA in computer science any sequence or pair of courses approved by the Physical Sciences Collegiate Division may be used to complete the general education requirement in the physical sciences. To earn a BS in computer science, the general education requirement in the physical sciences must be satisfied by completing a two-quarter sequence chosen from the General Education Sequences for Science Majors (http://collegecatalog.uchicago.edu/thecollege/physicalsciences/#generaleducationsequencesforsciencemajors). Students are encouraged, but not required, to fulfill this requirement with a physics sequence. Students may petition to take more advanced courses to fulfill this requirement. Both BA and BS students take at least fourteen computer science courses chosen from an approved program. BS students also take three courses in an approved related field outside computer science.

SUMMARY OF REQUIREMENTS

GENERAL EDUCATION

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 13100-13200 Elementary Functions and Calculus I-II (or higher)</td>
<td>200</td>
</tr>
<tr>
<td>One of the following:</td>
<td></td>
</tr>
<tr>
<td>BA: Any sequence or pair of courses that fulfills the general education requirement in the physical sciences</td>
<td>200</td>
</tr>
<tr>
<td>BS: Any two-quarter sequence that fulfills the general education requirement in the physical sciences for science majors</td>
<td></td>
</tr>
</tbody>
</table>

Total Units 400

MAJOR

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory Sequence (see below)</td>
<td>300</td>
</tr>
<tr>
<td>Programming Languages and Systems Sequence (three courses from the list below)</td>
<td>300</td>
</tr>
<tr>
<td>Theory Sequence (three courses from the list below)</td>
<td>300</td>
</tr>
<tr>
<td>Five electives numbered CMSC 20000 or above §</td>
<td>500</td>
</tr>
<tr>
<td>Plus the following requirements:</td>
<td></td>
</tr>
<tr>
<td>BA (no other courses required)</td>
<td>0-300</td>
</tr>
</tbody>
</table>
BS (three courses in an approved program in a related field)

| Total Units | 1400-1700 |

* Credit may be granted by examination.
§ While a student may enroll in CMSC 29700 or CMSC 29900 for multiple quarters, only one instance of each may be counted toward the major. A small number of courses, such as CMSC 29512 Entrepreneurship in Technology, may be used as College electives, but not as major electives. Courses that fall into this category will be marked as such.

Approved Programs

The Computer Science major adviser is responsible for approval of specific courses and sequences, and responds as needed to changing course offerings in our program and other programs. Students should consult the major adviser with questions about specific courses they are considering taking to meet the requirements. The major adviser maintains a website with up-to-date program details at majors.cs.uchicago.edu (http://majors.cs.uchicago.edu).

Approved Computer Science Program

There is one approved general program for both the BA and BS degrees, comprised of introductory courses, a sequence in Theory, and a sequence in Programming Languages and Systems, followed by advanced electives. Students may substitute upper-level or graduate courses in similar topics for those on the list that follows with the approval of the departmental counselor.

The course information in this catalog, with respect to who is teaching which course and in which quarter(s), is subject to change during the academic year. For up-to-date information on our course offerings, please consult course-info.cs.uchicago.edu (http://course-info.cs.uchicago.edu).

1. Introductory Sequence (three courses required, one course from areas A, B, and C):

<table>
<thead>
<tr>
<th>Area A</th>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 15100</td>
<td>Introduction to Computer Science I</td>
</tr>
<tr>
<td>CMSC 16100</td>
<td>Honors Introduction to Computer Science I</td>
</tr>
<tr>
<td>CMSC 12100</td>
<td>Computer Science with Applications I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area B</th>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 15200</td>
<td>Introduction to Computer Science II</td>
</tr>
<tr>
<td>CMSC 16200</td>
<td>Honors Introduction to Computer Science II</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area C</th>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 15400</td>
<td>Introduction to Computer Systems</td>
</tr>
</tbody>
</table>

The standard paths through the required introductory sequence for computer science majors are:

- CMSC 15100 Introduction to Computer Science I - CMSC 15200 Introduction to Computer Science II - CMSC 15400 Introduction to Computer Systems
- CMSC 16100 Honors Introduction to Computer Science I - CMSC 16200 Honors Introduction to Computer Science II - CMSC 15400 Introduction to Computer Systems
- CMSC 16100 Honors Introduction to Computer Science I - CMSC 15200 Introduction to Computer Science II - CMSC 15400 Introduction to Computer Systems

Students may take CMSC 16200 Honors Introduction to Computer Science II (and then CMSC 15400 Introduction to Computer Systems) after completing CMSC 15100 Introduction to Computer Science I with permission of the instructor.

Students who decide to pursue a computer science major or minor after completing CMSC 12100 Computer Science with Applications I or CMSC 12200 Computer Science with Applications II may continue with CMSC 15200 Introduction to Computer Science II followed by 15400. Specifically, these paths are allowed:

- CMSC 12100 Computer Science with Applications I - CMSC 15200 Introduction to Computer Science II - CMSC 15400 Introduction to Computer Systems
- CMSC 12100 Computer Science with Applications I - CMSC 12200 Computer Science with Applications II - CMSC 15200 Introduction to Computer Science II - CMSC 15400 Introduction to Computer Systems

Students may receive credit towards the 4200 units required for graduation for only one of CMSC 12100 Computer Science with Applications I, CMSC 15100 Introduction to Computer Science I, or CMSC 16100 Honors Introduction to Computer Science I. Students who have completed CMSC 15200 Introduction to Computer Science II or CMSC 16200 Honors Introduction to Computer Science II may not register for either CMSC 12100 Computer Science with Applications I or CMSC 12200 Computer Science with Applications II. Students may not
register concurrently for CMSC 12200 Computer Science with Applications II and CMSC 15200 Introduction to Computer Science II.

2. Programming Languages and Systems Sequence (three courses required):

Three of the following:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 22001</td>
<td>Software Construction</td>
</tr>
<tr>
<td>CMSC 22100</td>
<td>Programming Languages</td>
</tr>
<tr>
<td>CMSC 22200</td>
<td>Computer Architecture</td>
</tr>
<tr>
<td>CMSC 22240</td>
<td>Computer Architecture for Scientists</td>
</tr>
<tr>
<td>CMSC 22300</td>
<td>Functional Programming</td>
</tr>
<tr>
<td>CMSC 22600</td>
<td>Compilers for Computer Languages</td>
</tr>
<tr>
<td>CMSC 23000</td>
<td>Operating Systems</td>
</tr>
<tr>
<td>CMSC 23010</td>
<td>Parallel Computing</td>
</tr>
<tr>
<td>CMSC 23200</td>
<td>Introduction to Computer Security</td>
</tr>
<tr>
<td>CMSC 23230</td>
<td>Engineering Interactive Electronics onto Printed Circuit Boards</td>
</tr>
<tr>
<td>CMSC 23300</td>
<td>Networks and Distributed Systems</td>
</tr>
<tr>
<td>CMSC 23310</td>
<td>Advanced Distributed Systems</td>
</tr>
<tr>
<td>CMSC 23320</td>
<td>Foundations of Computer Networks</td>
</tr>
<tr>
<td>CMSC 23360</td>
<td>Advanced Networks</td>
</tr>
<tr>
<td>CMSC 23400</td>
<td>Mobile Computing</td>
</tr>
<tr>
<td>CMSC 23500</td>
<td>Introduction to Database Systems</td>
</tr>
<tr>
<td>CMSC 23700</td>
<td>Introduction to Computer Graphics</td>
</tr>
<tr>
<td>CMSC 23710</td>
<td>Scientific Visualization</td>
</tr>
</tbody>
</table>

3. Theory Sequence (three courses required):

Students must choose three courses from the following (one course each from areas A, B, and C).

Area A

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 27100</td>
<td>Discrete Mathematics</td>
</tr>
<tr>
<td>CMSC 27130</td>
<td>Honors Discrete Mathematics</td>
</tr>
</tbody>
</table>

Area B

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 27200</td>
<td>Theory of Algorithms</td>
</tr>
<tr>
<td>CMSC 27230</td>
<td>Honors Theory of Algorithms</td>
</tr>
</tbody>
</table>

Area C

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 27410</td>
<td>Honors Combinatorics</td>
</tr>
<tr>
<td>CMSC 27500</td>
<td>Graph Theory</td>
</tr>
<tr>
<td>CMSC 27502</td>
<td>Advanced Algorithms</td>
</tr>
<tr>
<td>CMSC 27530</td>
<td>Honors Graph Theory</td>
</tr>
<tr>
<td>CMSC 27700</td>
<td>Mathematical Logic I</td>
</tr>
<tr>
<td>CMSC 27800</td>
<td>Mathematical Logic II</td>
</tr>
<tr>
<td>CMSC 28000</td>
<td>Introduction to Formal Languages</td>
</tr>
<tr>
<td>CMSC 28100</td>
<td>Introduction to Complexity Theory</td>
</tr>
<tr>
<td>CMSC 28130</td>
<td>Honors Introduction to Complexity Theory</td>
</tr>
<tr>
<td>CMSC 28400</td>
<td>Introduction to Cryptography</td>
</tr>
</tbody>
</table>

The graduate versions of Discrete Mathematics and/or Theory of Algorithms can be substituted for their undergraduate counterparts. We strongly encourage all computer science majors to complete their theory courses by the end of their third year.

4. Electives (five courses required):

The major requires five additional elective computer science courses numbered 20000 or above. Students may enroll in CMSC 29700 Reading and Research in Computer Science and CMSC 29900 Bachelor’s Thesis for multiple quarters, but only one of each may be counted as a major elective.

A small number of courses, such as CMSC 29512 Entrepreneurship in Technology, may be used as College electives, but not as major electives. Courses that fall into this category will be marked as such.
**Specializations**

Students who major in computer science have the option to complete one specialization. To do so, students must choose three of their electives from the relevant approved specialization list. Please note that a course that is counted towards a specialization may not also be counted towards a major sequence requirement (i.e., Programming Languages and Systems, or Theory).

Please refer to the Computer Science Department’s website (https://course-info.cs.uchicago.edu/static/specializations.html) for an up-to-date list of courses that fulfill each specialization, including graduate courses. Students may petition to have graduate courses count towards their specialization via this same page.

The following specializations are currently available:

- **Computer Security**: CMSC 23200 Introduction to Computer Security and two other courses from this list
  a. CMSC 23210 Usable Security and Privacy
  b. CMSC 23280 Cryptocurrencies
  c. CMSC 28400 Introduction to Cryptography
  d. Bachelor’s thesis in computer security, approved as such

- **Computer Systems**: three courses from this list, over and above those taken to fulfill the programming languages and systems requirement
  a. CMSC 22200 Computer Architecture
  b. CMSC 22240 Computer Architecture for Scientists
  c. CMSC 23000 Operating Systems
  d. CMSC 23010 Parallel Computing
  e. CMSC 23300 Networks and Distributed Systems
  f. CMSC 23310 Advanced Distributed Systems
  g. CMSC 23320 Foundations of Computer Networks
  h. CMSC 23500 Introduction to Database Systems
  i. Bachelor’s thesis in computer systems, approved as such

- **Data Science**: CMSC 21800 Data Science for Computer Scientists and two other courses from this list
  a. CMSC 23900 Data Visualization
  b. CMSC 25025 Machine Learning and Large-Scale Data Analysis
  c. CMSC 25300 Mathematical Foundations of Machine Learning
  d. CMSC 25400 Machine Learning
  e. Bachelor’s thesis in data science, approved as such

- **Human Computer Interaction**: CMSC 20300 Introduction to Human-Computer Interaction and two other courses from this list
  a. CMSC 20370 Inclusive Technology: Designing for Underserved and Marginalized Populations
  b. CMSC 20900 Computers for Learning
  c. CMSC 23210 Usable Security and Privacy
  d. CMSC 23220 Inventing, Engineering and Understanding Interactive Devices
  e. CMSC 23240 Emergent Interface Technologies
  f. CMSC 23400 Mobile Computing
  g. CMSC 23900 Data Visualization
  h. Bachelor’s thesis in human computer interaction, approved as such

- **Machine Learning**: three courses from this list
a. CMSC 25025 Machine Learning and Large-Scale Data Analysis
b. CMSC 25040 Introduction to Computer Vision
c. CMSC 25300 Mathematical Foundations of Machine Learning
d. CMSC 25400 Machine Learning
e. CMSC 25440 Machine Learning in Medicine
f. CMSC 25460 Introduction to Optimization
g. CMSC 25700 Natural Language Processing
h. Bachelor’s thesis in machine learning, approved as such

- **Programming Languages:** three courses from this list, over and above those courses taken to fulfill the programming languages and systems requirements
  a. CMSC 22100 Programming Languages
  b. CMSC 22300 Functional Programming
  c. CMSC 22400 Programming Proofs
  d. CMSC 22500 Type Theory
e. CMSC 22600 Compilers for Computer Languages
f. Bachelor’s thesis in programming languages, approved as such

- **Theory:** three courses from this list, over and above those taken to fulfill the theory requirements
  a. CMSC 27410 Honors Combinatorics
  b. CMSC 27500 Graph Theory
c. CMSC 27502 Advanced Algorithms
d. CMSC 27530 Honors Graph Theory
e. CMSC 27700 Mathematical Logic I
f. CMSC 27800 Mathematical Logic II
g. CMSC 28000 Introduction to Formal Languages
h. CMSC 28100 Introduction to Complexity Theory
i. CMSC 28130 Honors Introduction to Complexity Theory
j. CMSC 28400 Introduction to Cryptography
k. Bachelor’s thesis in theory, approved as such

**GRADING**

Computer science majors must take courses in the major for quality grades. A grade of C- or higher must be received in each course counted towards the major. Any 20000-level computer science course taken as an elective beyond requirements for the major may, with consent of the instructor, be taken for P/F grading.

Non-majors may take courses either for quality grades or, subject to College regulations and with consent of the instructor, for P/F grading. A Pass grade is given only for work of C- quality or higher. Courses fulfilling general education requirements must be taken for quality grades.

**HONORS**

Students can earn a BA or BS degree with honors by attaining a grade of B or higher in all courses in the major and a grade of B or higher in three approved graduate computer science courses (30000-level and above). These courses may be courses taken for the major or as electives.

Students may also earn a BA or BS degree with honors by attaining the same minimum B grade in all courses in the major and by writing a successful bachelor’s thesis as part of CMSC 29900 Bachelor’s Thesis. This thesis must be based on an approved research project that is directed by a faculty member and approved by the department counselor.
MINOR PROGRAM IN COMPUTER SCIENCE

The Department of Computer Science offers a seven-course minor: an introductory sequence of three courses followed by four approved upper-level courses. Courses in the minor must be taken for quality grades, with a grade of C- or higher in each course.

No courses in the minor can be double counted with the student’s major(s) or with other minors, nor can they be counted toward general education requirements. More than half of the requirements for the minor must be met by registering for courses bearing University of Chicago course numbers. Students may not use AP credit for computer science to meet minor requirements. Prospective minors should arrange to meet the departmental counselor for the minor no later than May 1 of their third year. The minor adviser must approve the student’s Consent to Complete a Minor Program (https://humanities-web.s3.us-east-2.amazonaws.com/college-prod/s3fs-public/documents/Consent_Minor_Program.pdf) form, and the student must submit that form to the student’s College adviser by the end of Spring Quarter of the student’s third year.

Introductory Courses

Students must choose three courses from the following (one course each from areas A, B, and C). Please note that not all possible pathways through these courses are valid: for example, CMSC 15200 is not a prerequisite for CMSC 12300. Please consult the prerequisite information below and/or talk to the minor advisor to discuss viable plans.

<table>
<thead>
<tr>
<th>Area A</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 12100</td>
<td>Computer Science with Applications I</td>
</tr>
<tr>
<td>CMSC 15100</td>
<td>Introduction to Computer Science I</td>
</tr>
<tr>
<td>CMSC 16100</td>
<td>Honors Introduction to Computer Science I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area B</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 12200</td>
<td>Computer Science with Applications II</td>
</tr>
<tr>
<td>CMSC 15200</td>
<td>Introduction to Computer Science II</td>
</tr>
<tr>
<td>CMSC 16200</td>
<td>Honors Introduction to Computer Science II</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Area C</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSC 12300</td>
<td>Computer Science with Applications III</td>
</tr>
<tr>
<td>CMSC 15400</td>
<td>Introduction to Computer Systems</td>
</tr>
</tbody>
</table>

Upper-Level Courses

The computer science minor must include four courses chosen from among all 20000-level CMSC courses and above. CMSC 12300 may be used as an elective if a student has used CMSC 15400 as the Area C introductory course. A 20000-level course must replace each 10000-level course in the list above that was used to meet general education requirements or the requirements of a major. CMSC 29512 may not be used for minor credit.

JOINT BA/MS OR BS/MS PROGRAM

Outstanding undergraduates may apply to complete an MS in computer science along with a BA or BS (generalized to "Bx") during their four years at the College. Students must be admitted to the joint MS program. There are three different paths to a Bx/MS (https://www.cs.uchicago.edu/undergraduate/ba-ms-or-bs-ms-program/): a research-oriented program for computer science majors, a professionally oriented program for computer science majors, and a professionally oriented program for non-majors.

GRADUATE COURSES

Graduate courses and seminars offered by the Department of Computer Science are open to College students with consent of the instructor and department counselor. For more information, consult the department counselor.

SCHEDULE CHANGES

Please be aware that course information is subject to change, and the catalog does not necessarily reflect the most recent information. Students should consult course-info.cs.uchicago.edu (http://course-info.cs.uchicago.edu) for up-to-date information.

COMPUTER SCIENCE COURSES

CMSC 11000. Multimedia Programming as an Interdisciplinary Art I. 100 Units.

This course presented introductory techniques of problem solving, algorithm construction, program coding, and debugging, as interdisciplinary arts adaptable to a wide range of disciplines.

Instructor(s): W. Sterner

Terms Offered: Spring

Prerequisite(s): Placement into MATH 13100 or higher, or by consent.

Note(s): This course meets the general education requirement in the mathematical sciences. This course will not be offered again.
CMSC 11111. Creative Coding. 100 Units.
This course is an introduction to programming, using exercises in graphic design and digital art to motivate and employ basic tools of computation (such as variables, conditional logic, and procedural abstraction). We will write code in JavaScript or related technologies, and we will work with a variety of digital media, including vector graphics, raster images, animations, and web applications. Throughout the course, we will reflect on how graphical user interfaces of the future might unleash the fundamental building blocks of programming for everyday computer use.  
Instructor(s): Professor Ravi Chugh Terms Offered: Spring  
Equivalent Course(s): MAAD 21111

CMSC 11710. Networks. 100 Units.  
Networks help explain phenomena in such technological, social, and biological domains as the spread of opinions, knowledge, and infectious diseases. Networks also help us understand properties of financial markets, food webs, and web technologies. At the same time, the structure and evolution of networks is determined by the set of interactions in the domain. Our study of networks will employ formalisms such as graph theory, game theory, information networks, and network dynamics, with the goal of building formal models and translating their observed properties into qualitative explanations.  
Instructor(s): I. Simon Terms Offered: TBD  
Prerequisite(s): Completion of the general education requirement in the mathematical sciences, and familiarity with basic concepts of probability at the high school level.  
Note(s): Necessary mathematical concepts will be presented in class.

CMSC 11800. Introduction to Data Science I. 100 Units.  
Data science provides tools for gaining insight into specific problems using data, through computation, statistics and visualization. This course introduces students to all aspects of a data analysis process, from posing questions, designing data collection strategies, management+storing and processing of data, exploratory tools and visualization, statistical inference, prediction, interpretation and communication of results. Simple techniques for data analysis are used to illustrate both effective and fallacious uses of data science tools. Although this course is designed to be at the level of mathematical sciences courses in the Core, with little background required, we expect the students to develop computational skills that will allow them to analyze data. Computation will be done using Python and Jupyter Notebook.  
Instructor(s): Michael J. Franklin, Dan Nicolae Terms Offered: Autumn  
Prerequisite(s): None  
Equivalent Course(s): STAT 11800

CMSC 11900. Introduction to Data Science II. 100 Units.  
This course is the second quarter of a two-quarter systematic introduction to the foundations of data science as well as to practical considerations in data analysis. A broad background on probability and statistical methodology as well as a basic proficiency in RStudio will be provided. More advanced topics on data privacy and ethics, reproducibility in science, data encryption, and basic machine learning will be introduced. We will explore these concepts with real-world problems from different domains.  
Instructor(s): Michael J. Franklin, Dan Nicolae Terms Offered: Winter  
Prerequisite(s): STAT 11800/CMSC 11800 or consent of instructor.  
Equivalent Course(s): STAT 11900

CMSC 12100-12200-12300. Computer Science with Applications I-II-III.  
This three-quarter sequence teaches computational thinking and skills to students who are majoring in the sciences, mathematics, and economics, etc. Lectures cover topics in (1) programming, such as recursion, abstract data types, and processing data; (2) computer science, such as clustering methods, event-driven simulation, and theory of computation; and to a lesser extent (3) numerical computation, such as approximating functions and their derivatives and integrals, solving systems of linear equations, and simple Monte Carlo techniques.  

CMSC 12100. Computer Science with Applications I. 100 Units.  
This course is the first in a three-quarter sequence that teaches computational thinking and skills to students in the sciences, mathematics, economics, etc. The course will cover abstraction and decomposition, simple modeling, basic algorithms, and programming in Python. Applications from a wide variety of fields serve both as examples in lectures and as the basis for programming assignments. In recent offerings, students have written programs to simulate a model of housing segregation, determine the number of machines needed at a polling place, and analyze tweets from presidential debates. Students can find more information about this course at http://bit.ly/cmsc12100-aut-20.  
Instructor(s): B. Sotomayor, B. Ur Terms Offered: Autumn  
Prerequisite(s): First year students are not allowed to register for CMSC 12100. Placement into MATH 15100 or completion of MATH 13100.  
Note(s): First year students are not allowed to register for CMSC 12100. This course meets the general education requirement in the mathematical sciences.

CMSC 12200. Computer Science with Applications II. 100 Units.  
This course is the second in a three-quarter sequence that teaches computational thinking and skills to students in the sciences, mathematics, economics, etc. Lectures cover topics in (1) data representation, (2) basics of relational databases, (3) shell scripting, (4) data analysis algorithms, such as clustering and
decision trees, and (5) data structures, such as hash tables and heaps. Applications and datasets from a wide variety of fields serve both as examples in lectures and as the basis for programming assignments. In recent offerings, students have written a course search engine and a system to do speaker identification. Students will program in Python and do a quarter-long programming project.

Instructor(s): A. Rogers, M. Wachs
Terms Offered: Winter
Prerequisite(s): CMSC 12100.

Note(s): This course meets the general education requirement in the mathematical sciences.

CMSC 12300. Computer Science with Applications III. 100 Units.
The course revolves around core ideas behind the management and computation of large volumes of data ("Big Data"). Topics include (1) Statistical methods for large data analysis, (2) Parallelism and concurrency, including models of parallelism and synchronization primitives, and (3) Distributed computing, including distributed architectures and the algorithms and techniques that enable these architectures to be fault-tolerant, reliable, and scalable. Students will continue to use Python, and will also learn C and distributed computing tools and platforms, including Amazon AWS and Hadoop. This course includes a project where students will have to formulate hypotheses about a large dataset, develop statistical models to test those hypotheses, implement a prototype that performs an initial exploration of the data, and a final system to process the entire dataset.

Instructor(s): M. Wachs
Terms Offered: Spring
Prerequisite(s): CMSC 12200.

CMSC 13600. Introduction to Data Engineering. 100 Units.
Data-driven models are revolutionizing science and industry. Scalable systems are needed to collect, stream, process, and validate data at scale. This course is an introduction to "big" data engineering where students will receive hands-on experience building and deploying realistic data-intensive systems. It will cover streaming, data cleaning, relational data modeling and SQL, and Machine Learning model training. A core theme of the course is "scale," and we will discuss the theory and the practice of programming with large external datasets that cannot fit in main memory on a single machine. The course will consist of bi-weekly programming assignments, a midterm examination, and a final.

Terms Offered: Spring
Prerequisite(s): CMSC 11900, CMSC 12200, CMSC 15200, or CMSC 16200.

CMSC 15100-15200. Introduction to Computer Science I-II.
This sequence, which is recommended for all students planning to take more advanced courses in computer science, introduces computer science mostly through the study of programming in functional (Scheme) and imperative (C) programming languages. Topics include program design, control and data abstraction, recursion and induction, higher-order programming, types and polymorphism, time and space analysis, memory management, and data structures including lists, trees, and graphs. NOTE: Non-majors may use either course in this sequence to meet the general education requirement in the mathematical sciences; students who are majoring in Computer Science must use either CMSC 15100-15200 or 16100-16200 to meet requirements for the major.

Prerequisite(s): Placement into MATH 15100 or completion of MATH 13100.

Note(s): This course meets the general education requirement in the mathematical sciences. Non-majors may use either course in this sequence to meet the general education requirement in the mathematical sciences; students who are majoring in Computer Science must use either CMSC 15100-15200 or 16100-16200 to meet requirements for the major.

CMSC 15100. Introduction to Computer Science I. 100 Units.
This sequence, which is recommended for all students planning to take more advanced courses in computer science, introduces computer science mostly through the study of programming in functional (Scheme) and imperative (C) programming languages. Topics include program design, control and data abstraction, recursion and induction, higher-order programming, types and polymorphism, time and space analysis, memory management, and data structures including lists, trees, and graphs. NOTE: Non-majors may use either course in this sequence to meet the general education requirement in the mathematical sciences; students who are majoring in Computer Science must use either CMSC 15100-15200 or 16100-16200 to meet requirements for the major.

Instructor(s): A. Feldman, A. Shaw
Terms Offered: Winter
Prerequisite(s): CMSC 15100, CMSC 16100, CMSC 12100, or CMSC 10500.

Note(s): This course meets the general education requirement in the mathematical sciences. Non-majors may use either course in this sequence to meet the general education requirement in the mathematical sciences;
students who are majoring in Computer Science must use either CMSC 15100-15200 or 16100-16200 to meet requirements for the major.

CMSC 15400. Introduction to Computer Systems. 100 Units.
This course covers the basics of computer systems from a programmer’s perspective. Topics include data representation, machine language programming, exceptions, code optimization, performance measurement, memory systems, and system-level I/O. Extensive programming required.
Instructor(s): H. Gunawi (Spring), H. Hoffmann (Spring), M. Wachs (Autumn, Spring) Terms Offered: Autumn, Spring
Prerequisite(s): CMSC 12100, 15100, or 16100, and CMSC 15200, 16200, or 12300.
Note(s): Required of students who are majoring in Computer Science.

CMSC 16100-16200. Honors Introduction to Computer Science I-II.
Both courses in this sequence meet the general education requirement in the mathematical sciences; students who are majoring in Computer Science must use either CMSC 15200 or 16200 to meet requirements for the major.

CMSC 16100. Honors Introduction to Computer Science I. 100 Units.
Programming in a functional language (currently Haskell), including higher-order functions, type definition, algebraic data types, modules, parsing, I/O, and monads. Basic data structures, including lists, binary search trees, and tree balancing. Basic mathematics for reasoning about programs, including induction, inductive definition, propositional logic, and proofs.
Prerequisite(s): Placement into MATH 16100 or equivalent and programming experience, or by consent.
Note(s): This course meets the general education requirement in the mathematical sciences.

CMSC 16200. Honors Introduction to Computer Science II. 100 Units.
This course emphasizes the C Programming Language, but not in isolation. Instead, C is developed as a part of a larger programming toolkit that includes the shell (specifically ksh), shell programming, and standard Unix utilities (including awk). Nonshell scripting languages, in particular perl and python, are introduced, as well as interpreter (#!) files that use the command-line version of DrScheme. We cover various standard data structures, both abstractly, and in terms of concrete implementations—primarily in C, but also from time to time in other contexts like scheme and ksh. The course uses a team programming approach. There is a mixture of individual programming assignments that focus on current lecture material, together with team programming assignments that can be tackled using any Unix technology. Team projects are assessed based on correctness, elegance, and quality of documentation. We teach the "Unix way" of breaking a complex computational problem into smaller pieces, most or all of which can be solved using pre-existing, well-debugged, and documented components, and then composed in a variety of ways.
Instructor(s): F. Chong Terms Offered: Winter
Prerequisite(s): CMSC 16100, or CMSC 15100 and by consent.
Note(s): Students who have taken CMSC 15100 may take 16200 with consent of instructor. This course meets the general education requirement in the mathematical sciences.

CMSC 19911. Introduction to Creative Coding. 100 Units.
This course is an introduction to programming, using exercises in graphic design and digital art to motivate and employ basic tools of computation (such as variables, conditional logic, and procedural abstraction). We will write code in JavaScript or related technologies, and we will work with a variety of digital media, including vector graphics, raster images, animations, and web applications.
Terms Offered: Summer

CMSC 20300. Introduction to Human-Computer Interaction. 100 Units.
An introduction to the field of Human-Computer Interaction (HCI), with a particular emphasis in understanding and designing user-facing software and hardware systems. This class covers the core concepts of HCI: affordances and mental models, selection techniques (pointing, touch, menus, text entry, widgets, etc), and conducting user studies and interviews. It also includes a project in which students program a simple interactive system.
Prerequisite(s): CMSC 15400

CMSC 20370. Inclusive Technology: Designing for Underserved and Marginalized Populations. 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 semester long group project involving the creation of an interactive system for one of the user populations we study.
CMSC 20600. Introduction to Robotics. 100 Units.
This course gives students a hands-on introduction to robot programming covering topics including sensing in real-world environments, path planning, localization, kinematics, and decision making under uncertainty. This course will be centered around four to five main problem sets exploring some of these central concepts to robot programming. Each of these problem sets will involve students programming real, physical robots interacting with the real world (during the 2020-2021 academic year, students will program robots in simulation due to covid-19 restrictions). Through this hands-on robot programming, students will be able to 1) see the result of their programs come to life in a physical environment and 2) gain experience facing and overcoming the challenges of programming robots (e.g., uncertainty, sensor noise, edge cases due to environment variability, physical constraints of the robot and environment).
Instructor(s): Sarah Sebo Terms Offered: Winter
Prerequisite(s): CMSC 20300

CMSC 20900. Computers for Learning. 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): D. Franklin Terms Offered: Autumn
Prerequisite(s): CMSC 15400
Equivalent Course(s): MAAD 20900

CMSC 21010. 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 31010, LING 31010, LING 21010

CMSC 21400. Creative Machines and Innovative Instrumentation. 100 Units.
An understanding of the techniques, tricks, and traps of building creative machines and innovative instrumentation is essential for a range of fields from the physical sciences to the arts. In this hands-on, practical course, you will design and build functional devices as a means to learn the systematic processes of engineering and fundamentals of design and construction. The kinds of things you will learn may include mechanical design and machining, computer-aided design, rapid prototyping, circuitry, electrical measurement methods, and other techniques for resolving real-world design problems. In collaboration with others, you will complete a mini-project and a final project, which will involve the design and fabrication of a functional scientific instrument. The course will be taught at an introductory level; no previous experience is expected. The iterative nature of the design process will require an appreciable amount of time outside of class for completing projects. The course is open to undergraduates in all majors (subject to the pre-requisites), as well as Master's and Ph.D. students. Instructor(s): Scott Wakely (Autumn), Erik Shirokoff (Winter), Stephan Meyer (Spring) Terms Offered: Autumn Spring Winter
Prerequisite(s): PHYS 12200 or PHYS 13200 or PHYS 14200; or CMSC 12100 or CMSC 12200 or CMSC 12300; or consent of instructor.
Equivalent Course(s): PSMS 31400, ASTR 31400, ASTR 21400, CHEM 21400, PHYS 21400

CMSC 21800. Data Science for Computer Scientists. 100 Units.
Data-driven models are revolutionizing science and industry. This course covers computational methods for structuring and analyzing data to facilitate decision-making. We will cover algorithms for transforming and matching data; hypothesis testing and statistical validation; and bias and error in real-world datasets. A core theme of the course is “generalization”; ensuring that the insights gleaned from data are predictive of future phenomena. The course will include bi-weekly programming assignments, a midterm examination, and a final. Prerequisite(s): CMSC 15400 or CMSC 22000

CMSC 22000. Introduction to Software Development. 100 Units.
Besides providing an introduction to the software development process and the lifecycle of a software project, this course focuses on imparting a number of skills and industry best practices that are valuable in the development of large software projects, such as source control techniques and workflows, issue tracking, code reviews, testing, continuous integration, working with existing codebases, integrating APIs and frameworks, generating documentation, deployment, and logging and monitoring. The course also emphasizes the importance of collaboration in real-world software development, including interpersonal collaboration and team management. The course will be organized primarily around the development of a class-wide software project, with students organized into teams. Collaboration both within and across teams will be essential to the success of the project.
Instructor(s): B. Sotomayor Terms Offered: Spring
CMSC 22001. Software Construction. 100 Units.
Large software systems are difficult to build. The course discusses both the empirical aspects of software engineering and the underlying theory. Topics will include, among others, software specifications, software design, software architecture, software testing, software reliability, and software maintenance. Students will be expected to actively participate in team projects in this course.
Instructor(s): S. Lu Terms Offered: Autumn
Prerequisite(s): CMSC 15400.

CMSC 22010. Digital Fabrication. 100 Units.
Digital fabrication involves translation of a digital design into a physical object. While digital fabrication has been around for decades, only now has it become possible for individuals to take advantage of this technology through low cost 3D printers and open source tools for 3D design and modeling. In this course we will cover the foundations of 3D object design including computational geometry, the type of models that can and can't be fabricated, the uses and applications of digital fabrication, the algorithms, methods and tools for conversion of 3D models to representations that can be directly manufactured using computer controlled machines, the concepts and technology used in additive manufacturing (aka 3D printing) and the research and practical challenges of developing self-replicating machines. We will have several 3D printers available for use during the class and students will design and fabricate several parts during the course.
Instructor(s): R. Stevens Terms Offered: TBD
Prerequisite(s): CMSC 15400 and some experience with 3D modeling concepts.

CMSC 22100. Programming Languages. 100 Units.
This course is an introduction to scientific programming language design, whereby design choices are made according to rigorous and well-founded lines of reasoning. The curriculum includes the lambda calculus, type systems, formal semantics, logic and proof, and, time permitting, a light introduction to machine assisted formal reasoning. Practical exercises in writing language transformers reinforce the the theory. While this course is not a survey of different programming languages, we do examine the design decisions embodied by various popular languages in light of their underlying formal systems.
Prerequisite(s): CMSC 15400

CMSC 22200. 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): F. Chong (Spring), Y. Li (Autumn) Terms Offered: Autumn, Spring
Prerequisite(s): CMSC 15400.

CMSC 22240. Computer Architecture for Scientists. 100 Units.
Designed to provide an understanding of the key scientific ideas that underpin the extraordinary capabilities of today’s computers, including speed (gigahertz), illusion of sequential order (relativity), dynamic locality (warping space), parallelism, keeping it cheap - and low-energy (e-field scaling), and of course their ability as universal information processing engines. These scientific "miracles" are robust, and provide a valuable longer-term understanding of computer capabilities, performance, and limits to the wealth of computer scientists practicing data science, software development, or machine learning. This course can be used towards fulfilling the Programming Languages and Systems requirement for the CS major.
Terms Offered: Winter
Prerequisite(s): CMSC 15400.

CMSC 22300. Functional Programming. 100 Units.
We will explore various aspects of advanced functional programming in this course. Topics will vary from quarter to quarter and may include: untyped and typed programming; pure and impure programming; eager and lazy semantics; “object-functional programming”; functional reactive programming; and concurrent functional programming.
Prerequisite(s): CMSC 15400 required, CMSC 15100 or CMSC 16100 recommended.

CMSC 22400. Programming Proofs. 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): (CMSC 27100 or CMSC 27130 or CMSC 37000), and (CMSC 15100 or CMSC 16100 or CMSC 22100 or CMSC 22300 or CMSC 22500 or CMSC 22600), or by consent.
CMSC 22500. Type Theory. 100 Units.
Instructor(s): Stuart Kurtz Terms Offered: TBD
Prerequisite(s): CMSC 15100 or CMSC 16100, and CMSC 27100 or CMSC 27700 or MATH 27700, or by consent.

CMSC 22600. Compilers for Computer Languages. 100 Units.
This course covers principles of modern compiler design and implementation. Topics include lexical analysis, parsing, type checking, optimization, and code generation. This is a project oriented course in which students will construct a fully working compiler, using Standard ML as the implementation language.
Terms Offered: Alternate years.
Prerequisite(s): CMSC 15400 required; CMSC 22100 recommended. (Note: Prior experience with ML programming not required.)
Note(s): This course is offered in alternate years.

CMSC 22880. Introduction to Quantum Computing. 100 Units.
This introduction to quantum computing will cover the key principles of quantum information science and how they relate to quantum computing as well as the notation and operations used in QIS. We will then take these building blocks and linear algebra principles to build up to several quantum algorithms and complete several quantum programs using a mainstream quantum programming language.
Terms Offered: Winter
Prerequisite(s): CMSC 15400

CMSC 22900. Quantum Computer Systems. 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
Prerequisite(s): CMSC 22880

CMSC 23000. Operating Systems. 100 Units.
This course provides an introduction to basic Operating System principles and concepts that form as fundamental building blocks for many modern systems from personal devices to Internet-scale services. Basic topics include processes, threads, concurrency, synchronization, memory management, virtual memory, segmentation, paging, caching, process and I/O scheduling, file systems, storage devices. The course will also cover special topics such as journaling/transactions, SSD, RAID, virtual machines, and data-center operating systems. The course project will revolve around the implementation of a mini x86 operating system kernel.
Instructor(s): H. Gunawi Terms Offered: Autumn
Prerequisite(s): CMSC 15400 and one of CMSC 22200, CMSC 22600, CMSC 22610, CMSC 23300, CMSC 23400, CMSC 23500, CMSC 23700, CMSC 27310, or CMSC 23800 strongly recommended.

CMSC 23010. Parallel Computing. 100 Units.
This course provides an introduction to the concepts of parallel programming, with an emphasis on programming multicore processors. Topics include: Processes and threads, shared memory, message passing, direct-memory access (DMA), hardware mechanisms for parallel computing, synchronization and communication, patterns of parallel programming. The course will involve a substantial programming project implementing a parallel computations.
Instructor(s): H. Hoffmann Terms Offered: Winter
Prerequisite(s): CMSC 15400 and one of the following: CMSC 22200, CMSC 23000, CMSC 23300; or by consent.

CMSC 23200. 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): CMSC 15400.

CMSC 23210. Usable Security and Privacy. 100 Units.
Regardless of how secure a system is in theory, failing to consider how humans actually use the system leads to disaster in practice. This course will examine how to design for security and privacy from a user-centered perspective by combining insights from computer systems, human-computer interaction (HCI), and public policy. We will introduce core security and privacy technologies, as well as HCI techniques for conducting robust user studies. Topics will include usable authentication, user-centered web security, anonymity software, privacy
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notices, security warnings, and data-driven privacy tools in domains ranging from social media to the Internet of Things. Students will complete weekly problem sets, as well as conduct novel research in a group capstone project. No prior experience in security, privacy, or HCI is required.

Instructor(s): B. Ur
Terms Offered: Spring
Prerequisite(s): CMSC 15400

CMSC 23220. Inventing, Engineering and Understanding Interactive Devices. 100 Units.
A physical computing class, dedicated to micro-controllers, sensors, actuators and fabrication techniques. The objective is that everyone creates their own, custom-made, functional I/O device.

Terms Offered: Spring
Prerequisite(s): CMSC 15400
Equivalent Course(s): MAAD 23220

CMSC 23230. Engineering Interactive Electronics onto Printed Circuit Boards. 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): B. Sotomayor
Terms Offered: Spring
Prerequisite(s): CMSC 15400

CMSC 23240. 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
Prerequisite(s): CMSC 15400

CMSC 23300. Networks and Distributed Systems. 100 Units.
This course focuses on the principles and techniques used in the development of networked and distributed software. Topics include programming with sockets; concurrent programming; data link layer (Ethernet, packet switching, etc.); internet and routing protocols (IP, IPv6, ARP, etc.); end-to-end protocols (UDP, TCP); and other commonly used network protocols and techniques. This is a project-oriented course in which students are required to develop software in C on a UNIX environment.

Instructor(s): B. Sotomayor
Terms Offered: Winter
Prerequisite(s): CMSC 15400

CMSC 23310. Advanced Distributed Systems. 100 Units.
In recent years, large distributed systems have taken a prominent role not just in scientific inquiry, but also in our daily lives. When we perform a search on Google, stream content from Netflix, place an order on Amazon, or catch up on the latest comings-and-goings on Facebook, our seemingly minute requests are processed by complex systems that sometimes include hundreds of thousands of computers, connected by both local and wide area networks. Recent papers in the field of Distributed Systems have described several solutions (such as MapReduce, BigTable, Dynamo, Cassandra, etc.) for managing large-scale data and computation. However, building and using these systems pose a number of more fundamental challenges: How do we keep the system operating correctly even when individual machines fail? How do we ensure that all the machines have a consistent view of the system’s state? (And how do we ensure this in the presence of failures?) How can we determine the order of events in a system where we can’t assume a single global clock? Many of these fundamental problems were identified and solved over the course of several decades, starting in the 1970s. To better appreciate the challenges of recent developments in the field of Distributed Systems, this course will guide students through seminal work in Distributed Systems from the 1970s, ’80s, and ’90s, leading up to a discussion of recent work in the field.

Prerequisite(s): CMSC 23300 with at least a B+, or by consent.

CMSC 23320. Foundations of Computer Networks. 100 Units.
This course focuses on the principles and techniques used in the development of networked and distributed software. Topics include programming with sockets; concurrent programming; data link layer (Ethernet, packet switching, etc.); internet and routing protocols (IP, IPv6, ARP, etc.); end-to-end protocols (UDP, TCP); and other commonly used network protocols and techniques. This is a project-oriented course in which students are required to develop software in C on a UNIX environment. This course can be used towards fulfilling the Programming Languages and Systems requirement for the CS major.
Terms Offered: Winter
Prerequisite(s): CMSC 15400
Note(s): This course can be used towards fulfilling the Programming Languages and Systems requirement for the CS major. Students who have taken CMSC 23300 may not take CMSC 23320.

CMSC 23360. Advanced Networks. 100 Units.
Advanced networks
Terms Offered: Spring
Prerequisite(s): CMSC 23300 or CMSC 23320
Note(s): A more detailed course description should be available later.

CMSC 23400. 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 new techniques to capture 3d models (depth sensors, stereo vision), drones that enable targeted, adaptive, focused sensing, and new 3d interactive applications (augmented reality, cyberphysical, and virtual reality). 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.
Instructor(s): A. Chien Terms Offered: Winter
Prerequisite(s): CMSC 15400. CMSC 23000 or 23300 recommended. Knowledge of Java required.

CMSC 23500. Introduction to Database Systems. 100 Units.
This course is an introduction to database design and implementation. Topics include DBMS architecture, entity-relationship and relational models, relational algebra, concurrency control, recovery, indexing, physical data organization, and modern database systems. The lab section guides students through the 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 software systems development.
Instructor(s): A. Elmore Terms Offered: Winter
Prerequisite(s): CMSC 15400.

CMSC 23700. Introduction to Computer Graphics. 100 Units.
This course introduces the basic concepts and techniques used in three-dimensional computer graphics. The course covers both the foundations of 3D graphics (coordinate systems and transformations, lighting, texture mapping, and basic geometric algorithms and data structures), and the practice of real-time rendering using programmable shaders. Students are required to complete both written assignments and programming projects using OpenGL.
Instructor(s): J. Reppy Terms Offered: Autumn
Prerequisite(s): CMSC 15400.
Note(s): This course is offered in alternate years.

CMSC 23710. 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): CMSC 15400 and knowledge of linear algebra, or by consent.

CMSC 23900. 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.
Instructor(s): G. Kindlmann Terms Offered: Spring
Prerequisite(s): CMSC 12200, CMSC 15200 or CMSC 16200.

CMSC 25025. Machine Learning and Large-Scale Data Analysis. 100 Units.
This course is an introduction to machine learning and the analysis of large data sets using distributed computation and storage infrastructure. Basic machine learning methodology and relevant statistical theory will be presented in lectures. Homework exercises will give students hands-on experience with the methods on different types of data. Methods include algorithms for clustering, binary classification, and hierarchical Bayesian modeling. Data types include images, archives of scientific articles, online ad clickthrough logs, and public records of the City of Chicago. Programming will be based on Python and R, but previous exposure to these languages is not assumed.
Instructor(s): Staff
CMSC 25040. Introduction to Computer Vision. 100 Units.
This course covers the fundamentals of digital image formation; image processing, detection and analysis of visual features; representation shape and recovery of 3D information from images and video; analysis of motion. We also study some prominent applications of modern computer vision such as face recognition and object and scene classification. Our emphasis is on basic principles, mathematical models, and efficient algorithms established in modern computer vision.
Instructor(s): Michael Maire Terms Offered: Winter
Prerequisite(s): CMSC 25300, CMSC 25400, or CMSC 25025. Linear algebra strongly recommended; a 200-level Statistics course recommended.

CMSC 25300. 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).
Prerequisite(s): CMSC 12200 or CMSC 15200 or CMSC 16200, and the equivalent of two quarters of calculus (MATH 13200 or higher).
Equivalent Course(s): STAT 27700

CMSC 25400. Machine Learning. 100 Units.
This course offers a practical, problem-centered introduction to machine learning. Topics covered include the Perceptron and other online algorithms; boosting; graphical models and message passing; dimensionality reduction and manifold learning; SVMs and other kernel methods; artificial neural networks; and a short introduction to statistical learning theory. Weekly programming assignments give students the opportunity to try out each learning algorithm on real world datasets.
Instructor(s): R. Kondor Terms Offered: Winter
Prerequisite(s): CMSC 15400 or CMSC 12300. STAT 22000 or STAT 23400 strongly recommended.
Equivalent Course(s): STAT 27725

CMSC 25440. Machine Learning in Medicine. 100 Units.
In this course we will study the how machine learning is used in biomedical research and in healthcare delivery. We will build and explore a range of models in areas such as infectious disease and drug resistance, cancer diagnosis and treatment, drug design, genomics analysis, patient outcome prediction, medical records interpretation and medical imaging. Students will become familiar with the types and scale of data used to train and validate models and with the approaches to build, tune and deploy machine learned models. We will use traditional machine learning methods as well as deep learning depending on the problem. The course will be fast moving and will involve weekly program assignments. We will introduce the machine learning methods as we go, but previous familiarity with machine learning will be helpful. Programming assignments will be in python and we will use Google Collaboratory and Amazon AWS for compute intensive training.
Instructor(s): Rick Stevens Terms Offered: Autumn
Prerequisite(s): CMSC 12200 or CMSC 15200 or CMSC 16200. Proficiency in Python is expected.

CMSC 25460. Introduction to Optimization. 100 Units.
Introduction to Optimization
Instructor(s): Lorenzo Orecchia Terms Offered: Spring
Prerequisite(s): (CMSC 27100 or CMSC 27130 or CMSC 37000) and CMSC 25300

CMSC 25610. Undergraduate Computational Linguistics. 100 Units.
This course is an 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 evaluate research in cognitive/linguistic modeling and NLP, and to be able to implement intermediate-level computational models.
Instructor(s): Allyson Ettinger Terms Offered: Autumn
Equivalent Course(s): LING 28610

CMSC 25700. Natural Language Processing. 100 Units.
This course will introduce fundamental concepts in natural language processing (NLP). NLP includes a range of research problems that involve computing with natural language. Some are user-facing applications, such as spam classification, question answering, summarization, and machine translation. Others serve supporting roles,
such as part-of-speech tagging and syntactic parsing. Solutions draw from machine learning (especially deep learning), algorithms, linguistics, and social sciences.

Instructor(s): Chenhao Tan Terms Offered: Winter
Prerequisite(s): CMSC 25300, CMSC 25400, or CMSC 25025

CMSC 25900. Ethics, Fairness, Responsibility, and Privacy in Data Science. 100 Units.
This course takes a technical approach to understanding ethical issues in the design and implementation of computer systems. Tensions often arise between a computer system’s utility and its privacy-invasiveness, between its robustness and its flexibility, and between its ability to leverage existing data and existing data’s tendency to encode biases. The course will demonstrate how computer systems can violate individuals’ privacy and agency, impact sub-populations in disparate ways, and harm both society and the environment. It will also introduce algorithmic approaches to fairness, privacy, transparency, and explainability in machine learning systems. Through hands-on programming assignments and projects, students will design and implement computer systems that reflect both ethics and privacy by design. They will also wrestle with fundamental questions about who bears responsibility for a system’s shortcomings, how to balance different stakeholders’ goals, and what societal values computer systems should embed.
Prerequisite(s): CMSC 11900 or CMSC 12300 or CMSC 21800 or CMSC 23710 or CMSC 23900 or CMSC 25025 or CMSC 25300

CMSC 27100. Discrete Mathematics. 100 Units.
This course emphasizes mathematical discovery and rigorous proof, which are illustrated on a refreshing variety of accessible and useful topics. Basic counting is a recurring theme and provides the most important source for sequences, which is another recurring theme. Further topics include proof by induction; recurrences and Fibonacci numbers; graph theory and trees; number theory, congruences, and Fermat’s little theorem; counting, factorials, and binomial coefficients; combinatorial probability; random variables, expected value, and variance; and limits of sequences, asymptotic equality, and rates of growth.
Instructor(s): S. Kurtz (Winter), J. Simon (Autumn) Terms Offered: Autumn Winter
Prerequisite(s): (CMSC 15200 or CMSC 16200 or CMSC 12200), or (MATH 15910 or MATH 16300 or higher), or by consent.
Note(s): This is a directed course in mathematical topics and techniques that is a prerequisite for courses such as CMSC 27200 and 27400.

CMSC 27130. Honors Discrete Mathematics. 100 Units.
We emphasize mathematical discovery and rigorous proof, which are illustrated on a refreshing variety of accessible and useful topics. Basic counting is a recurring theme. Further topics include proof by induction; number theory, congruences, and Fermat’s little theorem; relations; factorials, binomial coefficients and advanced counting; combinatorial probability; random variables, expected value, and variance; graph theory and trees. Time permitting, material on recurrences, asymptotic equality, rates of growth and Markov chains may be included as well. The honors version of Discrete Mathematics covers topics at a deeper level.
Instructor(s): A. Razborov Terms Offered: Autumn
Prerequisite(s): (CMSC 12300 or CMSC 15400), or MATH 16300 or higher, or by consent.
Equivalent Course(s): MATH 28130

CMSC 27200. Theory of Algorithms. 100 Units.
This course covers design and analysis of efficient algorithms, with emphasis on ideas rather than on implementation. Algorithmic questions include sorting and searching, graph algorithms, elementary algorithmic number theory, combinatorial optimization, randomized algorithms, as well as techniques to deal with intractability, like approximation algorithms. Design techniques include “divide-and-conquer” methods, dynamic programming, greedy algorithms, and graph search, as well as the design of efficient data structures. Methods of algorithm analysis include asymptotic notation, evaluation of recurrent inequalities, amortized analysis, analysis of probabilistic algorithms, the concepts of polynomial-time algorithms, and of NP-completeness.
Prerequisite(s): CMSC 27100 or CMSC 27130 or CMSC 37110, or by consent.

CMSC 27230. Honors Theory of Algorithms. 100 Units.
This course covers design and analysis of efficient algorithms, with emphasis on ideas rather than on implementation. Algorithmic questions include sorting and searching, discrete optimization, algorithmic graph theory, algorithmic number theory, and cryptography. Design techniques include divide-and-conquer methods, dynamic programming, greedy algorithms, and graph search, as well as the design of efficient data structures. Methods of algorithm analysis include asymptotic notation, evaluation of recurrent inequalities, the concepts of polynomial-time algorithms, and NP-completeness. The honors version of Theory of Algorithms covers topics at a deeper level.
Instructor(s): A. Drucker Terms Offered: Winter
Prerequisite(s): CMSC 27100 or CMSC 27130 or CMSC 37110 or consent of the instructor.

CMSC 27410. Honors Combinatorics. 100 Units.
Methods of enumeration, construction, and proof of existence of discrete structures are discussed in conjunction with the basic concepts of probability theory over a finite sample space. Enumeration techniques are applied to the calculation of probabilities, and, conversely, probabilistic arguments are used in the analysis of combinatorial structures. Other topics include basic counting, linear recurrences, generating functions, Latin squares,
finite projective planes, graph theory, Ramsey theory, coloring graphs and set systems, random variables, independence, expected value, standard deviation, and Chebyshev's and Chernoff's inequalities.

Prerequisite(s): MATH 15900 or MATH 25400, or CMSC 27100, or by consent. Experience with mathematical proofs.

Note(s): This course is offered in alternate years.
Equivalent Course(s): MATH 28410

CMSC 27500. 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, directed acyclic graphs, and tournaments. Techniques studied include the probabilistic method.
Instructor(s): K. Mulmuley
Prerequisite(s): CMSC 27100, or MATH 20400 or higher.

CMSC 27530. Honors 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
Prerequisite(s): CMSC 27100, CMSC 27130, or CMSC 37110, or MATH 20400 or MATH 20800.
Equivalent Course(s): MATH 28530

CMSC 27620. Introduction to Bioinformatics. 100 Units.
This course aims to introduce computer scientists to the field of bioinformatics. The vast amounts of data produced in genomics related research has significantly transformed the role of biological research. High-throughput automated biological experiments require advanced algorithms, implemented in high-performance computing systems, to interpret their results. This course will focus on analyzing complex data sets in the context of biological problems. Students will design and implement systems that are reliable, capable of handling huge amounts of data, and utilize best practices in interface and usability design to accomplish common bioinformatics problems. While this course should be of interest for students interested in biological sciences and biotechnology, techniques and approaches taught will be applicable to other fields. This course will present a practical, hands-on approach to the field of bioinformatics. The topics covered in this course will include software, data mining, high-performance computing, mathematical models and other areas of computer science that play an important role in bioinformatics. Existing methods for analyzing genomes, sequences and protein structures will be explored, as well related computing infrastructure. Students will be introduced to all of the biology necessary to understand the applications of bioinformatics algorithms and software taught in this course. No previous biology coursework is required or expected.
Terms Offered: Autumn
Prerequisite(s): (CMSC 12200 or CMSC 15200 or CMSC 16200) and (CMSC 27200 or CMSC 27230 or CMSC 37000)

CMSC 27700-27800. Mathematical Logic I-II.
Mathematical Logic I-II

CMSC 27700. Mathematical Logic I. 100 Units.
This course introduces mathematical logic. Topics include propositional and predicate logic and the syntactic notion of proof versus the semantic notion of truth (e.g., soundness, completeness). We also discuss the Gödel completeness theorem, the compactness theorem, and applications of compactness to algebraic problems. Prerequisite(s): MATH 25400 or MATH 25700 or (CMSC 15400 and (MATH 15910 or MATH 15900 or MATH 19900 or MATH 16300))
Equivalent Course(s): CMSC 27700
Terms Offered: Autumn
Prerequisite(s): MATH 25400 or 25700; open to students who are majoring in computer science who have taken CMSC 15400 along with MATH 16300 or MATH 16310 or Math 15910 or MATH 15900 or MATH 19900
Equivalent Course(s): MATH 27700

CMSC 27800. Mathematical Logic II. 100 Units.
Topics include number theory, Peano arithmetic, Turing compatibility, unsolvable problems, Gödel's incompleteness theorem, undecidable problems (e.g., the theory of groups), quantifier elimination, and decidable theories (e.g., the theory of algebraically closed fields).
Terms Offered: Winter
Prerequisite(s): MATH 27700 or equivalent
Equivalent Course(s): MATH 27800

CMSC 28000. Introduction to Formal Languages. 100 Units.
This course is a basic introduction to computability theory and formal languages. Topics include automata theory, regular languages, context-free languages, and Turing machines.
Instructor(s): S. Kurtz Terms Offered: Spring
Prerequisite(s): CMSC 12300 or CMSC 15400, or MATH 15900 or MATH 25500.
Equivalent Course(s): MATH 28000
CMSC 28100. 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.
Instructor(s): K. Mulmuley Terms Offered: Autumn
Prerequisite(s): CMSC 27100, or MATH 15900 or MATH 25500; experience with mathematical proofs.
Equivalent Course(s): MATH 28100

CMSC 28130. 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.
Instructor(s): Ketan Mulmuley Terms Offered: Autumn
Prerequisite(s): CMSC 27100 or CMSC 27130, or MATH 15900 or MATH 19900 or MATH 25500; experience with mathematical proofs.

CMSC 28400. Introduction to 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. Weekly problem sets will include both theoretical problems and programming tasks. No experience in security is required.
Prerequisite(s): CMSC 15400 and (CMSC 27100 or CMSC 27130 or CMSC 37110)

CMSC 28510. Introduction to Scientific Computing. 100 Units.
Basic processes of numerical computation are examined from both an experimental and theoretical point of view. This course deals with numerical linear algebra, approximation of functions, approximate integration and differentiation, Fourier transformation, solution of nonlinear equations, and the approximate solution of initial value problems for ordinary differential equations. We concentrate on a few widely used methods in each area covered.
Instructor(s): T. Dupont Terms Offered: Autumn. Generally offered alternate years.
Prerequisite(s): A year of calculus (MATH 15300 or higher), a quarter of linear algebra (MATH 19620 or higher), and CMSC 10600 or higher; or consent of instructor

CMSC 28515. Introduction to Numerical Partial Differential Equations. 100 Units.
This course deals with finite element and finite difference methods for second-order elliptic equations (diffusion) and the associated parabolic and hyperbolic equations. Some methods for solving linear algebraic systems will be used. Scalar first-order hyperbolic equations will be considered.

CMSC 28540. Numerical Methods. 100 Units.
This is a practical programming course focused on the basic theory and efficient implementation of a broad sampling of common numerical methods. Each topic will be introduced conceptually followed by detailed exercises focused on both prototyping (using matlab) and programming the key foundational algorithms efficiently on modern (serial and multicore) architectures. The ideal student in this course would have a strong interest in the use of computer modeling as predictive tool in a range of disciplines -- for example risk management, optimized engineering design, safety analysis, etc. The numerical methods studied in this course underlie the modeling and simulation of a huge range of physical and social phenomena, and are being put to increasing use to an increasing extent in industrial applications. After successfully completing this course, a student should have the necessary foundation to quickly gain expertise in any application-specific area of computer modeling.
Terms Offered: Spring
Prerequisite(s): CMSC 15200 or CMSC 16200. Basic apprehension of calculus and linear algebra is essential

CMSC 29512. Entrepreneurship in Technology. 100 Units.
The core theme for the Entrepreneurship in Technology course is that computer science students need exposure to the broad challenges of capturing opportunities and creating companies. Most of the skills required for this process have nothing to do with one’s technical capacity. We’ll explore creating a story, pitching the idea, raising money, hiring, marketing, selling, and more. Real-world examples, case-studies, and lessons-learned will be blended with fundamental concepts and principles. The course will involve a business plan, case-studies, and supplemental reading to provide students with significant insights into the resolve required to take an idea to market. Class discussion will also be a key part of the student experience.
Prerequisite(s): MPCS 51036 or 51040 or 51042 or 51046 or 51100
Note(s): If an undergraduate takes this course as CMSC 29512, it may not be used for CS major or minor credit. Non-MPCS students must receive approval from program prior to registering. Request form available online https://masters.cs.uchicago.edu
Equivalent Course(s): MPCS 51250
CMSC 29700. Reading and Research in Computer Science. 100 Units.
Students do reading and research in an area of computer science under the guidance of a faculty member. A written report is typically required.
Terms Offered: Autumn, Spring, Summer, Winter
Prerequisite(s): By consent of instructor and approval of department counselor.
Note(s): Open both to students who are majoring in Computer Science and to nonmajors. Students are required to submit the College Reading and Research Course Form.

CMSC 29900. Bachelor's Thesis. 100 Units.
Open to fourth-year students who are candidates for honors in Computer Science.
Terms Offered: Autumn, Spring, Summer, Winter
Prerequisite(s): By consent of instructor and approval of department counselor.