DATA SCIENCE

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Director of Undergraduate Studies: Dr. Jae Woo Lee, 715 CEPSR; 212-939-7066; jae@cs.columbia.edu

Departmental Advisers:

For administrative advising issues please contact: advising@cs.columbia.edu.

The majors in the Department of Computer Science provide students with the appropriate computer science background necessary for graduate study or a professional career. Computers impact nearly all areas of human endeavor. Therefore, the department also offers courses for students who do not plan a computer science major or concentration. The computer science majors offer maximum flexibility by providing students with a range of options for program specialization. The department offers four majors: computer science; information science; data science; and computer science-mathematics, offered jointly with the Mathematics Department.

Computer Science Major

Students study a common core of fundamental topics, supplemented by a track that identifies specific areas for deeper study. The foundations track prepares students for advanced work in fundamental, theoretical, and mathematical aspects of computing, including analysis of algorithms, scientific computing, and security. The systems track prepares students for immediate employment in the computer industry as well as advanced study in software engineering, operating systems, computer-aided digital design, computer architecture, programming languages, and user interfaces. The intelligent systems track provides specialization for the student interested in natural language processing and systems capable of exhibiting “human-like” intelligence. The applications track is for students interested in the implementation of interactive multimedia content for the Internet and wireless applications. The vision, graphics, interaction, and robotics track exposes students to computer vision, graphics, human-computer interaction, and robotics.

A combination track is available to students who wish to pursue an interdisciplinary course of study combining computer science and another field in the arts, humanities, mathematics, natural sciences, or social sciences. A student planning a combination track should be aware that one additional course is required to complete this option.

Information Science Major

Information science is an interdisciplinary major designed to provide a student with an understanding of how information is organized, accessed, stored, distributed, and processed in strategic segments of today’s society. Recent years have seen an explosive growth of on-line information, with people of all ages and all walks of life making use of the World Wide Web and other information in digital form.

This major puts students at the forefront of the information revolution, studying how on-line access touches on all disciplines and changing the very way people communicate. Organizations have large stores of in-house information that are crucial to their daily operation. Today’s systems must enable quick access to relevant information, must ensure that confidential information is secure, and must enable new forms of communication among people and their access to information.

The information science major can choose a scientific focus on algorithms and systems for organizing, accessing, and processing information, or an interdisciplinary focus in order to develop an understanding of, and tools for, information modeling and use within an important sector of modern society such as economics or health.

Advanced Placement

The department grants 3 points for a score of 4 or 5 on the AP Computer Science exam along with exemption from COMS W1004 Introduction to Computer Science and Programming in Java. However, we still recommend that you take COMS W1004 or W1007 even if you have credits from the CS AP exam. COMS W1007 Honors Introduction to Computer Science is recommended if you scored 5 on the AP exam, and COMS W1004 is recommended if you scored 4.

Pre-Introductory Courses

COMS W1004 is the first course in the Computer Science major curriculum, and it does not require any previous computing experience. Before taking COMS W1004, however, students have an option to start with one of the pre-introductory courses: ENGI E1006 or COMS W1002.

ENGI E1006 Introduction to Computing for Engineers and Applied Scientist is a general introduction to computing for STEM students. ENGI E1006 is in fact a required course for all engineering students. COMS W1002 Computing In Context is a course primarily intended for humanities majors, but it also serves as a pre-introductory course for CS majors. ENGI E1006 and COMS W1002 do not count towards Computer Science major.

Laboratory Facilities

The department has well-equipped lab areas for research in computer graphics, computer-aided digital design, computer vision, databases and digital libraries, data mining and knowledge discovery, distributed systems, mobile and wearable computing, natural language processing, networking, operating systems, programming systems, robotics, user interfaces, and real-time multimedia.

Research labs contain several large Linux and Solaris clusters; Puma 500 and IBM robotic arms; a UTAH/MIT dexterous hand; an Adept-1 robot; three mobile research robots; a real-time defocus range sensor; interactive 3-D graphics workstations with 3-D position and orientation trackers; prototype wearable computers, wall-sized stereo projection systems; see-through head-mounted displays; a networking testbed with three Cisco 7500 backbone routers, traffic generators; an IDS testbed with secured LAN, Cisco routers, EMC storage, and Linux servers; and a simulation testbed with several Sun servers and Cisco Catalyst routers. The department uses a SIP IP phone system. The protocol was developed in the department.

The department’s computers are connected via a switched 1Gb/s Ethernet network, which has direct connectivity to the campus OC-3 Internet and internet 2 gateways. The campus has 802.11b/g wireless LAN coverage.

The research facility is supported by a full-time staff of professional system administrators and programmers.
Professors
Alfred V. Aho
Peter K. Allen
Peter Bellahumeur
Steven M. Bellovin
David Blei
Luca Carloni
Michael J. Collins
Steven K. Feiner
Luis Gravano
Julia Hirschberg
Gail E. Kaiser
John R. Kender
Kathleen R. McKeown
Vishal Misra
Shree K. Nayar
Jason Nieh
Steven M. Nowick
Christos Papadimitriou
Kenneth A. Ross
Henning G. Schulzrinne
Rocco A. Servedio
Salvatore J. Stolfo
Jeannette Wing
Luis Gravano

Associate Professors
Alexandr Andoni
Augustin Chaintreau
Xi Chen
Stephen A. Edwards
Yaniv Erlich
Roxana Geambasu
Eitan Grinspun
Daniel Hsu
Tony Jebara
Martha Allen Kim
Tal Malkin
Itsik Pe’er
Daniel S. Rubenstein
Simha Sethumadhavan
Junfeng Yang
Changxi Zheng

Assistant Professors
Lydia Chilton
Ronghui Gu
Suman Jana
Baishakhi Ray
Carl Vondrick
Omri Weinstein
Eugene Wu

Senior Lecturer in Discipline
Paul Blaer
Adam Cannon
Jae Woo Lee

Lecturer in Discipline
Daniel Bauer
Tony Dear
Ansaf Salleb-Aouissi
Nakul Verma

Associated Faculty Joint
Shih-Fu Chang
Clifford Stein

Associated Faculty
Matei Ciocarlie
Edward G. Coffman Jr. (emeritus)
Eleni Drinea
Jonathan Gross (emeritus)
Andreas Mueller
Steven H. Unger (emeritus)
Vladimir Vapnik
Yechiam Yemini (emeritus)

Senior Research Scientists
Moti Yung

Research Scientists
Smaranda Muresan*

Associated Research Scientists
Allison Breton Bishop
Giuseppe DiGuglielmo
Paolo Mantovani
Hiroshi Sasaki
Eran Tromer

Professor of Practice
Donald F. Ferguson

Guidelines for all Computer Science Majors and Concentrators

Courses
Students may receive credit for only one of the following two courses:

- COMS W1004 Introduction to Computer Science and Programming in Java
- COMS W1005 Introduction to Computer Science and Programming in MATLAB.

Students may receive credit for only one of the following three courses:

- COMS W3134 Data Structures in Java
- COMS W3136 Data Structures with C/C++
- COMS W3137 Honors Data Structures and Algorithms

However, COMS W1005 and COMS W3136 cannot be counted towards the Computer Science major, minor, and concentration.

Transfer Credit
As a rule, no more than 12 transfer credits are accepted toward the major.
Grading
A maximum of one course worth no more than 4 points passed with a grade of D may be counted toward the major or concentration.

Major in Computer Science

Please read Guidelines for all Computer Science Majors and Concentrators above.

All majors should confer with their program adviser each term to plan their programs of study. Students considering a major in computer science are encouraged to talk to a program adviser during their first or second year. A typical program of study is as follows:

Program of Study

Computer Science Core (22-24 points)

For students who declare in Spring 2014 and beyond:

<table>
<thead>
<tr>
<th>Year</th>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Year</td>
<td>COMS W1004</td>
<td>Introduction to Computer Science and Programming in Java</td>
</tr>
<tr>
<td></td>
<td>or COMS W1007</td>
<td>Honors Introduction to Computer Science</td>
</tr>
<tr>
<td>Sophomore Year</td>
<td>COMS W3134</td>
<td>Data Structures in Java</td>
</tr>
<tr>
<td></td>
<td>or COMS W3137</td>
<td>Honors Data Structures and Algorithms</td>
</tr>
<tr>
<td></td>
<td>COMS W3157</td>
<td>Advanced Programming</td>
</tr>
<tr>
<td></td>
<td>COMS W3203</td>
<td>Discrete Mathematics: Introduction to Combinatorics and Graph Theory</td>
</tr>
<tr>
<td>Junior and Senior Year</td>
<td>COMS W3261</td>
<td>Computer Science Theory</td>
</tr>
<tr>
<td></td>
<td>CSEE W3827</td>
<td>Fundamentals of Computer Systems</td>
</tr>
</tbody>
</table>

Select one of the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH UN2010</td>
<td>Linear Algebra</td>
</tr>
<tr>
<td>APMA E2101</td>
<td>Introduction to Applied Mathematics</td>
</tr>
<tr>
<td>APMA E3101</td>
<td>Linear Algebra</td>
</tr>
<tr>
<td>STAT GU4001</td>
<td>Introduction to Probability and Statistics</td>
</tr>
</tbody>
</table>

For students who declared prior to Spring 2014:

<table>
<thead>
<tr>
<th>Year</th>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Year</td>
<td>COMS W1004</td>
<td>Introduction to Computer Science and Programming in Java</td>
</tr>
<tr>
<td></td>
<td>COMS W1007</td>
<td>Honors Introduction to Computer Science</td>
</tr>
<tr>
<td>Sophomore Year</td>
<td>COMS W3137</td>
<td>Honors Data Structures and Algorithms</td>
</tr>
<tr>
<td></td>
<td>COMS W3157</td>
<td>Advanced Programming</td>
</tr>
<tr>
<td></td>
<td>COMS W3203</td>
<td>Discrete Mathematics: Introduction to Combinatorics and Graph Theory</td>
</tr>
<tr>
<td>Junior and Senior Year</td>
<td>COMS W3261</td>
<td>Computer Science Theory</td>
</tr>
<tr>
<td></td>
<td>CSEE W3827</td>
<td>Fundamentals of Computer Systems</td>
</tr>
</tbody>
</table>

In addition to the CS Core (22-24 points), all CS majors must complete the Calculus Requirement (3 points) and a Track Requirement (15 or 18 points). The CS major therefore requires 40-45 points total.

Mathematics (3 points)

Calculus II or Calculus III.

Note that Calculus III does NOT depend on Calculus II. You can take either Calculus II or III, but we recommend Calculus III, which covers topics that are a bit more relevant for upper-level Computer Science courses.

If you have received equivalent credits for Calculus I & II already (through a 4 or 5 on the AP Calculus exam for example), you are not required to take any more Calculus courses. But we recommend taking one more semester of Calculus, either Math UN1201 Calculus III or APAM E2000 Multivariate Calculus for Engineers and Scientists. APAM E2000 covers relevant topics from Calculus III and IV.

Track Requirement (15 or 18 points)

Students must select one of the following six upper-level tracks. Each track, except the combination track, requires five courses consisting of required, elective breadth, and elective track courses. The combination track requires a selection of six advanced courses: three 3000- or 4000-level computer science courses and three 3000- or 4000-level courses from another field. The elective breadth requirement in each track can be fulfilled with any 3-point computer science 3000-level or higher course that is not a computer science core course or a technical elective course in that track. In addition to the breadth elective, the track requirements are as follows:

Foundations Track (15 points)

For students interested in algorithms, computational complexity, and other areas of theoretical Computer Science.

Note: Students who declared their Computer Science major prior to Fall 2016 may also count COMS 4241, COMS 4205, COMS 4281, COMS 4444, COMS 4771, and COMS 4772 as track elective courses.

Required Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSOR W4231</td>
<td>Analysis of Algorithms I</td>
</tr>
<tr>
<td>COMS W4236</td>
<td>Introduction to Computational Complexity</td>
</tr>
</tbody>
</table>

Track Electives

Select 2 from:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH UN3020</td>
<td>Number Theory and Cryptography</td>
</tr>
<tr>
<td>MATH UN3025</td>
<td>Making, Breaking Codes</td>
</tr>
<tr>
<td>COMS W4203</td>
<td>Graph Theory</td>
</tr>
<tr>
<td>MATH GU4032</td>
<td>Fourier Analysis</td>
</tr>
<tr>
<td>MATH GU4041</td>
<td>Introduction to Modern Algebra I</td>
</tr>
<tr>
<td>MATH GU4042</td>
<td>Introduction to Modern Algebra II</td>
</tr>
<tr>
<td>MATH GU4061</td>
<td>Introduction To Modern Analysis I</td>
</tr>
<tr>
<td>MATH GU4155</td>
<td>Probability Theory</td>
</tr>
<tr>
<td>COMS W4252</td>
<td>Introduction to Computational Learning Theory</td>
</tr>
<tr>
<td>COMS W4261</td>
<td>Introduction to Cryptography</td>
</tr>
<tr>
<td>APMA E4300</td>
<td>Computational Math: Introduction to Numerical Methods</td>
</tr>
<tr>
<td>IEOR E4407</td>
<td>Game Theoretic Models of Operations</td>
</tr>
<tr>
<td>CSPH G4802</td>
<td>Math Logic II: Incompleteness</td>
</tr>
<tr>
<td>COMS E6232</td>
<td>Analysis of Algorithms, II</td>
</tr>
<tr>
<td>MATH G6238</td>
<td>Enumerative Combinatorics</td>
</tr>
<tr>
<td>COMS E6253</td>
<td>Advanced Topics in Computational Learning Theory</td>
</tr>
<tr>
<td>COMS E6261</td>
<td>Advanced Cryptography</td>
</tr>
<tr>
<td>EEOR E6616</td>
<td>Convex optimization</td>
</tr>
<tr>
<td>IEOR E6613</td>
<td>Optimization, I</td>
</tr>
</tbody>
</table>

Guidelines for all Computer Science Majors and Concentrators above.
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEOR E6614</td>
<td>Optimization, II</td>
</tr>
<tr>
<td>IEOR E6711</td>
<td>Stochastic models, I</td>
</tr>
<tr>
<td>IEOR E6712</td>
<td>Stochastic models, II</td>
</tr>
<tr>
<td>ELEN E6717</td>
<td>Information theory</td>
</tr>
<tr>
<td>ELEN E6718</td>
<td>Error Correcting Codes: Classical and Modern</td>
</tr>
</tbody>
</table>

### Adviser Approved:

- COMS W3902: Undergraduate Thesis
- COMS W3998: Undergraduate Projects in Computer Science
- COMS W4901: Projects in Computer Science
- COMS W4995: Special topics in computer science, I
- COMS E6998: Topics in Computer Science

### One Breadth Course

Any 3-point COMS 3000- or 4000-level course except those courses in the CS core or in the required or elective courses for this track

### Software Systems Track (15 points)

For students interested in networks, programming languages, operating systems, software engineering, databases, security, and distributed systems.

#### Required Courses

- COMS W4115: Programming Languages and Translators
- COMS W4118: Operating Systems I
- CSEE W4119: Computer Networks

#### Track Electives

Select 1 from:
- Any COMS W41xx course
- COMS W4444: Programming and Problem Solving
- Any COMS W48xx course

### Adviser Approved:

- COMS W3902: Undergraduate Thesis
- COMS W3998: Undergraduate Projects in Computer Science
- COMS W4901: Projects in Computer Science
- COMS W4995: Special topics in computer science, I
- Any COMS E68XX course
- Any COMS E61XX course

### One Breadth Course

Any 3-point COMS 3000- or 4000-level course except those courses in the CS core or in the required or elective courses for this track

### Applications Track (15 points)

For students interested in the implementation of interactive multimedia applications for the internet and wireless networks.

#### Required Courses

- COMS W4115: Programming Languages and Translators
- COMS W4170: User Interface Design

#### Track Electives

Select 2 from:
- Any COMS W41xx course
- Any COMS W47xx course

### Adviser Approved:

- COMS W3902: Undergraduate Thesis
- COMS W3998: Undergraduate Projects in Computer Science
- COMS W4901: Projects in Computer Science
- COMS W4995: Special topics in computer science, I
- Any COMS E69XX course

### One Breadth Course

Any 3-point COMS 3000- or 4000-level course except those courses in the CS core or in the required or elective courses for this track

### Vision, Graphics, Interaction, and Robotics Track (15 points)

For students in the vision, interaction, graphics, and robotics track. It focuses on visual information with topics in vision, graphics, human-computer interaction, robotics, modeling, and learning. Students learn about fundamental ways in which visual information is captured, manipulated, and experienced.

#### Required Courses

Select two of the following courses:
- COMS W4160: Computer Graphics
- COMS W4167: Computer Animation
- COMS W4731: Computer Vision

#### Track Electives

Select 2 from:
- COMS W4162: Advanced Computer Graphics
- COMS W4170: User Interface Design
- COMS W4172: 3D User Interfaces and Augmented Reality
- COMS W4701: Artificial Intelligence
- COMS W4733: Computational Aspects of Robotics
- COMS W4735: Visual Interfaces to Computers
- COMS W4771: Machine Learning

### Intelligent Systems Track (15 points)

For students interested in machine learning, robotics, and systems capable of exhibiting “human-like” intelligence.

#### Required Courses

Select two of the following courses:
- COMS W4701: Artificial Intelligence
- COMS W4705: Natural Language Processing
- COMS W4706: Spoken Language Processing
- COMS W4731: Computer Vision
- COMS W4733: Computational Aspects of Robotics
- COMS W4771: Machine Learning

#### Track Electives

Select 2 from:
- COMS W4252: Introduction to Computational Learning Theory
- Any COMS W47xx course
- Any COMS E67XX course

### Adviser Approved:

- COMS W3902: Undergraduate Thesis
- COMS W3998: Undergraduate Projects in Computer Science
- COMS W4901: Projects in Computer Science
- COMS W4995: Special topics in computer science, I
- COMS E6998: Topics in Computer Science

### One Breadth Course

Any 3-point COMS 3000- or 4000-level course except those courses in the CS core or in the required or elective courses for this track
Adviser Approved:
COMS W3902 Undergraduate Thesis
COMS W3998 Undergraduate Projects in Computer Science
COMS W4901 Projects in Computer Science
COMS W4995 Special topics in computer science, I
Any COMS E69XX course

**One Breadth Course**
Any 3-point COMS 3000- or 4000-level course except those courses in the CS core or in the required or elective courses for this track.

**Combination Track (18 points)**
For students who wish to combine computer science with another discipline in the arts, humanities, social or natural sciences. A coherent selection of six upper-level courses is required: three from computer science and three from another discipline.

The courses should be planned with and approved by the student’s CS faculty advisor by the first semester of the junior year. The six courses are typically 4000-level elective courses that would count towards the individual majors. Moreover, the six courses should have a common theme. The combination track is not intended for those students who pursue double majors.

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**Major in Computer Science—Mathematics**

For a description of the joint major in computer science—mathematics, see the Mathematics section in this bulletin.

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**Major in Information Science**

Please read Guidelines for all Computer Science Majors and Concentrators above.

The major in information science requires a minimum of 33 points including a core requirement of five courses.

The elective courses must be chosen with a faculty adviser to focus on the modeling and use of information within the context of a disciplinary theme. After discussing potential selections students prepare a proposal of study that must be approved by the faculty adviser. In all cases the six courses must be at the 3000-level or above with at least three courses chosen from computer science. Following are some example programs. For more examples or templates for the program proposal, see a faculty adviser.

Note: In most cases additional courses will be necessary as prerequisites in order to take some of the elective courses. This will depend on the student’s proposed program of study.

**Core Requirement**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W1001</td>
<td>Introduction to Information Science</td>
</tr>
<tr>
<td>or COMS W1002</td>
<td>Computing in Context</td>
</tr>
<tr>
<td>COMS W1004</td>
<td>Introduction to Computer Science and Programming in Java</td>
</tr>
<tr>
<td>COMS W1007</td>
<td>Honors Introduction to Computer Science</td>
</tr>
<tr>
<td>COMS W3134</td>
<td>Data Structures in Java</td>
</tr>
<tr>
<td>STAT GU4001</td>
<td>Introduction to Probability and Statistics</td>
</tr>
</tbody>
</table>

Following are some suggested programs of instruction:

**Information Science and Contemporary Society**

Students may focus on how humans use technology and how technology has changed society.

The requirements include:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W4111</td>
<td>Introduction to Databases</td>
</tr>
<tr>
<td>COMS W4170</td>
<td>User Interface Design</td>
</tr>
<tr>
<td>COMS W4701</td>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>COMS W3410</td>
<td>Computers and Society</td>
</tr>
<tr>
<td>SOCI UN3010</td>
<td>Methods for Social Research</td>
</tr>
<tr>
<td>SOCI UN3960</td>
<td>Law, Science, and Society</td>
</tr>
</tbody>
</table>

**Information Science and the Economy**

Students may focus on understanding information modeling together with existing and emerging needs in economics and finance as well as algorithms and systems to address those needs.

The requirements include:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W4111</td>
<td>Introduction to Databases</td>
</tr>
<tr>
<td>COMS W4701</td>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>COMS W4771</td>
<td>Machine Learning</td>
</tr>
<tr>
<td>ECON UN3412</td>
<td>Introduction To Econometrics</td>
</tr>
<tr>
<td>ECON UN3025</td>
<td>Financial Economics</td>
</tr>
<tr>
<td>ECON UN3265</td>
<td>The Economics of Money and Banking</td>
</tr>
</tbody>
</table>

**Information Science and Health Sciences**

Students may focus on understanding information modeling together with existing and emerging needs in health sciences, as well as algorithms and systems to address those needs.

The requirements include:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W4111</td>
<td>Introduction to Databases</td>
</tr>
<tr>
<td>COMS W4170</td>
<td>User Interface Design</td>
</tr>
<tr>
<td>COMS W4701</td>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>BINF G4001</td>
<td></td>
</tr>
<tr>
<td>BIOL W4037</td>
<td>Bioinformatics of Gene Expression</td>
</tr>
<tr>
<td>ECBM E3060/E4060</td>
<td>Introduction to genomic information science and technology</td>
</tr>
</tbody>
</table>

**Major in Data Science**

Please read Guidelines for all Computer Science Majors and Concentrators above.

In response to the ever growing importance of “big data” in scientific and policy endeavors, the last few years have seen an explosive growth in theory, methods, and applications at the interface between computer science and statistics. The statistics and computer science departments have responded with a joint-major that emphasizes the interface between the disciplines.

**Prerequisites (15 points)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH UN1101</td>
<td>Calculus I</td>
</tr>
<tr>
<td>MATH UN1102</td>
<td>Calculus II</td>
</tr>
<tr>
<td>MATH UN1201</td>
<td>Calculus III</td>
</tr>
<tr>
<td>MATH UN2010</td>
<td>Linear Algebra</td>
</tr>
</tbody>
</table>
This introductory Statistics course:
STAT UN1201 Calculus-Based Introduction to Statistics
Statistics (12 points)
STAT GU4203 PROBABILITY THEORY
STAT GU4204 Statistical Inference
STAT GU4205 Linear Regression Models
STAT GU4241 Statistical Machine Learning
or COMS W4771 Machine Learning

Computer Science (12 points)
Select one of the following courses:
COMS W1004 Introduction to Computer Science and Programming in Java
COMS W1005 Introduction to Computer Science and Programming in MATLAB
COMS W1007 Honors Introduction to Computer Science
ENGI E1006 Introduction to Computing for Engineers and Applied Scientists

Select one of the following courses:
COMS W3134 Data Structures in Java
COMS W3136 Data Structures with C/C++
COMS W3137 Honors Data Structures and Algorithms

Two required courses:
COMS W3203 Discrete Mathematics: Introduction to Combinatorics and Graph Theory
CSOR W4231 Analysis of Algorithms I

Electives (15 points)
Select two of the following courses:
STAT UN3106 Applied Data Mining
STAT GU4206 Statistical Computing and Introduction to Data Science
STAT GU4224 Bayesian Statistics
STAT GU4243 Applied Data Science
STAT Q4242 Advanced Machine Learning

Select three of the following courses:
COMS W3261 Computer Science Theory
COMS W4111 Introduction to Databases
COMS W4130 Principles and Practice of Parallel Programming
COMS W4236 Introduction to Computational Complexity
COMS W4252 Introduction to Computational Learning Theory

Any COMS W47xx course EXCEPT W4771

### Concentration in Computer Science

Please read Guidelines for all Computer Science Majors and Concentrators above.

For students who declare in Spring 2014 and beyond:
The concentration in computer science requires a minimum of 22-24 points, as follows:

COMS W1004 Introduction to Computer Science and Programming in Java
or COMS W1007 Honors Introduction to Computer Science
COMS W3134 Data Structures in Java
or COMS W3137 Honors Data Structures and Algorithms
COMS W3157 Advanced Programming
COMS W3203 Discrete Mathematics: Introduction to Combinatorics and Graph Theory
COMS W3261 Computer Science Theory
CSEE W3827 Fundamentals of Computer Systems (or any 3 point 4000-level computer science course)

Select one of the following courses:
MATH UN2010 Linear Algebra
MATH V2020 Honors Linear Algebra
APMA E2101 Introduction to Applied Mathematics
APMA E3101 Linear Algebra
STAT GU4001 Introduction to Probability and Statistics
SIEO W3600

For students who declared prior to Spring 2014:
The concentration requires a minimum of 23 points, as follows:

COMS W1004 Introduction to Computer Science and Programming in Java
COMS W1007 Honors Introduction to Computer Science
COMS W3137 Honors Data Structures and Algorithms
COMS W3157 Advanced Programming
COMS W3261 Computer Science Theory
CSEE W3827 Fundamentals of Computer Systems (or any 3-point 4000-level computer science course)

### Computer Science

COMS W1001 Introduction to Information Science. 3 points.
Lect: 3.

Basic introduction to concepts and skills in Information Sciences: human-computer interfaces, representing information digitally, organizing and searching information on the internet, principles of algorithmic problem solving, introduction to database concepts, and introduction to programming in Python.

Fall 2019: COMS W1001

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<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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<th>Enrollment</th>
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<tr>
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<td>001/35954</td>
<td>T Th 1:10pm - 2:25pm, 451 Computer Science Bldg</td>
<td>Adam Cannon</td>
<td>3</td>
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COMS W1002 Computing in Context. 4 points.

CC/GS: Partial Fulfillment of Science Requirement

Introduction to elementary computing concepts and Python programming with domain-specific applications. Shared CS concepts and Python programming lectures with track-specific sections. Track themes will vary but may include computing for the social sciences, computing for economics and finance, digital humanities, and more. Intended for nonmajors. Students may only receive credit for one of ENGI E1006 or COMS W1002.

Fall 2019: COMS W1002

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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
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<td>COMS 1002</td>
<td>001/35955</td>
<td>T Th 2:40pm - 3:55pm, 417 International Affairs Bldg</td>
<td>Adam Cannon</td>
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</table>
COMS W1004 Introduction to Computer Science and Programming in Java. 3 points.
Lect: 3.

A general introduction to computer science for science and engineering students interested in majoring in computer science or engineering. Covers fundamental concepts of computer science, algorithmic problem-solving capabilities, and introductory Java programming skills. Assumes no prior programming background. Columbia University students may receive credit for only one of the following two courses: 1004 or 1005.

Spring 2019: COMS W1004
Course Number Section/Call Number Times/Location Instructor Points Enrollment
COMS 1004 001/12775 M W 5:40pm - 6:55pm Room TBA Paul Blaer 3 316/398

Fall 2019: COMS W1004
Course Number Section/Call Number Times/Location Instructor Points Enrollment
COMS 1004 001/35930 M W 5:40pm - 6:55pm 417 International Affairs Bldg Paul Blaer 3 386/400

COMS W1005 Introduction to Computer Science and Programming in MATLAB. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

A general introduction to computer science concepts, algorithmic problem-solving capabilities, and programming skills in MATLAB. Assumes no prior programming background. Columbia University students may receive credit for only one of the following two courses: W1004 or W1005.

COMS W1007 Honors Introduction to Computer Science. 3 points.
Lect: 3.

Prerequisites: AP Computer Science with a grade of 4 or 5 or similar experience.

An honors-level introduction to computer science, intended primarily for students considering a major in computer science. Computer science as a science of abstraction. Creating models for reasoning about and solving problems. The basic elements of computers and computer programs. Implementing abstractions using data structures and algorithms. Taught in Java.

COMS W1404 Emerging Scholars Program Seminar. 1 point.
Pass/Fail only.

Prerequisites: the instructor's permission. Corequisites: COMS W1002 or COMS W1004 or COMS W1007
Corequisites: COMS W1004,COMS W1007,COMS W1002
Peer-led weekly seminar intended for first and second year undergraduates considering a major in Computer Science. Pass/fail only. May not be used towards satisfying the major or SEAS credit requirements.

COMS W3101 Programming Languages. 1 point.
Lect: 1.

Prerequisites: Fluency in at least one programming language. Introduction to a programming language. Each section is devoted to a specific language. Intended only for those who are already fluent in at least one programming language. Sections may meet for one hour per week for the whole term, for three hours per week for the first third of the term, or for two hours per week for the first six weeks. May be repeated for credit if different languages are involved.
COMS W3102 Development Technologies. 1-2 points.

Due to significant overlap, students may only receive credit for either programming in C++, trees, graphs, generic programming, hash tables, linked lists, C programming in UNIX environment, object-oriented programming in C and C++, array-based data structures, heaps, one semester of introductory programming experience. Basic elements of programming in C and C++, array-based data structures, heaps, linked lists, C programming in UNIX environment, object-oriented programming in C++, trees, graphs, generic programming, hash tables. Due to significant overlap, students may only receive credit for either COMS W3102, W3136, or W3137.

COMS W3134 Data Structures in Java. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: (COMS W1004) or knowledge of Java.
Data types and structures: arrays, stacks, singly and doubly linked lists, queues, trees, sets, and graphs. Programming techniques for processing such structures: sorting and searching, hashing, garbage collection. Storage management. Rudiments of the analysis of algorithms. Taught in Java. Note: Due to significant overlap, students may receive credit for only one of the following three courses: COMS W3134, COMS W3136, COMS W3137.

COMS W3137 Honors Data Structures and Algorithms. 4 points.
Prerequisites: (COMS W1004) or (COMS W1007)
Corequisites: COMS W3203
An honors introduction to data types and structures: arrays, stacks, singly and doubly linked lists, queues, trees, sets, and graphs. Programming techniques for processing such structures: sorting and searching, hashing, garbage collection. Storage management. Design and analysis of algorithms. Taught in Java. Note: Due to significant overlap, students may receive credit for only one of the following three courses: COMS W3134, W3136, or W3137.

COMS W3157 Advanced Programming. 4 points.
Lect: 4.

Prerequisites: (COMS W3134) or (COMS W3137)
C programming language and Unix systems programming. Also covers Git, Make, TCP/IP networking basics, C++ fundamentals.

COMS W3203 Discrete Mathematics: Introduction to Combinatorics and Graph Theory. 3 points.
Lect: 3.

Prerequisites: Any introductory course in computer programming. Logic and formal proofs, sequences and summation, mathematical induction, binomial coefficients, elements of finite probability, recurrence relations, equivalence relations and partial orderings, and topics in graph theory (including isomorphism, traversability, planarity, and colorings).
COMS W3210 Scientific Computation. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: two terms of calculus.

COMS W3261 Computer Science Theory. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: (COMS W3203)
Corequisites: COMS W3134,COMS W3136,COMS W3137

COMS W3410 Computers and Society. 3 points.
Lect: 3.


COMS W3902 Undergraduate Thesis. 1-6 points.
Prerequisites: Agreement by a faculty member to serve as thesis adviser. An independent theoretical or experimental investigation by an undergraduate major of an appropriate problem in computer science carried out under the supervision of a faculty member. A formal written report is mandatory and an oral presentation may also be required. May be taken over more than one term, in which case the grade is deferred until all 6 points have been completed. Consult the department for section assignment.

COMS W3995 Special Topics in Computer Science. 3 points.
Lect: 3.

Prerequisites: the instructor’s permission.
Consult the department for section assignment. Special topics arranged as the need and availability arise. Topics are usually offered on a one-time basis. Since the content of this course changes each time it is offered, it may be repeated for credit.

COMS W3998 Undergraduate Projects in Computer Science. 1-3 points.
Prerequisites: Approval by a faculty member who agrees to supervise the work. Independent project involving laboratory work, computer programming, analytical investigation, or engineering design. May be repeated for credit, but not for a total of more than 3 points of degree credit. Consult the department for section assignment.

COMS E3999 Fieldwork. 1 point.
Prerequisites: Obtained internship and approval from faculty advisor. May be repeated for credit, but no more than 3 total points may be used toward the 128-credit degree requirement. Only for SEAS computer science undergraduate students who include relevant off-campus work experience as part of their approved program of study. Final report and letter of evaluation required. May not be used as a technical or non-technical elective. May not be taken for pass/fail credit or audited.

COMS W4111 Introduction to Databases. 3 points.
Lect: 3.

Prerequisites: (COMS W3134) or (COMS W3137) or (COMS W3136) and fluency in Java; or the instructor’s permission.
The fundamentals of database design and application development using databases: entity-relationship modeling, logical design of relational databases, relational data definition and manipulation languages, SQL, XML, query processing, physical database tuning, transaction processing, security. Programming projects are required.
COMS W4112 Database System Implementation. 3 points.
Lect: 2.5.
Prerequisites: (COMS W4111) and fluency in Java or C++. CSEE W3827 is recommended.
The principles and practice of building large-scale database management systems. Storage methods and indexing, query processing and optimization, materialized views, transaction processing and recovery, object-relational databases, parallel and distributed databases, performance considerations. Programming projects are required.

COMS W4113 Fundamentals of Large-Scale Distributed Systems. 3 points.
Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) and (COMS W3157 or COMS W4118 or CSEE W4119)
Design and implementation of large-scale distributed and cloud systems. Teaches abstractions, design and implementation techniques that enable the building of fast, scalable, fault-tolerant distributed systems. Topics include distributed communication models (e.g., sockets, remote procedure calls, distributed shared memory), distributed synchronization (clock synchronization, logical clocks, distributed mutex), distributed file systems, replication, consistency models, fault tolerance, distributed transactions, agreement and commitment, Paxos-based consensus, MapReduce infrastructures, scalable distributed databases. Combines concepts and algorithms with descriptions of real-world implementations at Google, Facebook, Yahoo, Microsoft, Linkedin, etc.

COMS W4115 Programming Languages and Translators. 3 points.
Lect: 3.
Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) and (COMS W3261) and (COMS W3157 or CSEE W4119) or equivalent, or the instructor's permission.
Modern programming languages and compiler design. Imperative, object-oriented, declarative, functional, and scripting languages. Language syntax, control structures, data types, procedures and parameters, binding, scope, run-time organization, and exception handling. Implementation of language translation tools including compilers and interpreters. Lexical, syntactic and semantic analysis; code generation; introduction to code optimization. Teams implement a language and its compiler.

COMS W4117 Compilers and Interpreters. 3 points.
Prerequisites: (COMS W4115) or instructor's permission.
Continuation of COMS W4115, with broader and deeper investigation into the design and implementation of contemporary language translators, be they compilers or interpreters. Topics include parsing, semantic analysis, code generation and optimization, run-time environments, and compiler-compilers. A programming project is required.

COMS W4118 Operating Systems I. 3 points.
Lect: 3.
Prerequisites: (CSEE W3827) and knowledge of C and programming tools as covered in COMS W3136, W3157, or W3101, or the instructor's permission.
Design and implementation of operating systems. Topics include process management, process synchronization and interprocess communication, memory management, virtual memory, interrupt handling, processor scheduling, device management, I/O, and file systems. Case study of the UNIX operating system. A programming project is required.

COMS W4121 Computer Systems for Data Science. 3 points.
Prerequisites: background in Computer System Organization and good working knowledge of C/C++
Corequisites: CSOR W4246, STAT GU4203
An introduction to computer architecture and distributed systems with an emphasis on warehouse scale computing systems. Topics will include fundamental tradeoffs in computer systems, hardware and software techniques for exploiting instruction-level parallelism, data-level parallelism and task level parallelism, scheduling, caching, prefetching, network and memory architecture, latency and throughput optimizations, specialization, and an introduction to programming data center computers.

COMS W4130 Principles and Practice of Parallel Programming. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: (COMS W3134 or COMS W3137 or COMS W3136 and experience in Java) and basic understanding of analysis of algorithms. Principles of parallel software design. Topics include task and data decomposition, load-balancing, reasoning about correctness, determinacy, safety, and deadlock-freedom. Application of techniques through semester-long design project implementing performant, parallel application in a modern parallel programming language.
COMS W4156 Advanced Software Engineering. 3 points.
Lect: 3.
Prerequisites: (COMS W3157) or equivalent. Software lifecycle using frameworks, libraries and services. Major emphasis on software testing. Centers on a team project.

COMS W4160 Computer Graphics. 3 points.
Lect: 3.
Prerequisites: (COMS W3134) or (COMS W3136) or (COMS W3137) COMS W4156 is recommended. Strong programming background and some mathematical familiarity including linear algebra is required. Introduction to computer graphics. Topics include 3D viewing and projections, geometric modeling using spline curves, graphics systems such as OpenGL, lighting and shading, and global illumination. Significant implementation is required: the final project involves writing an interactive 3D video game in OpenGL.

Spring 2019: COMS W4160

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<th>Course Number</th>
<th>Section/Call Number</th>
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<th>Instructor</th>
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<td>001/23283</td>
<td>F 10:10am - 12:40pm 1127 Seeley W. Mudd Building</td>
<td>Changxi Zheng</td>
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<td>COMS 4160</td>
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<td>F 10:10am - 12:40pm 1127 Seeley W. Mudd Building</td>
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<td>COMS 4160</td>
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<td>Changxi Zheng</td>
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COMS W4162 Advanced Computer Graphics. 3 points.
Lect: 3.
Prerequisites: (COMS W4160) or equivalent, or the instructor’s permission.
A second course in computer graphics covering more advanced topics including image and signal processing, geometric modeling with meshes, advanced image synthesis including ray tracing and global illumination, and other topics as time permits. Emphasis will be placed both on implementation of systems and important mathematical and geometric concepts such as Fourier analysis, mesh algorithms and subdivision, and Monte Carlo sampling for rendering. Note: Course will be taught every two years.

COMS W4167 Computer Animation. 3 points.
Lect: 3.
Prerequisites: Multivariable calculus, linear algebra, C++ programming proficiency. COMS W4156 recommended. Theory and practice of physics-based animation algorithms, including animated clothing, hair, smoke, water, collisions, impact, and kitchen sinks. Topics covered: Integration of ordinary differential equations, formulation of physical models, treatment of discontinuities including collisions/contact, animation control, constrained Lagrangian Mechanics, friction/dissipation, continuum mechanics, finite elements, rigid bodies, thin shells, discretization of Navier-Stokes equations. General education requirement: quantitative and deductive reasoning (QUA).

COMS W4170 User Interface Design. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) Introduction to the theory and practice of computer user interface design, emphasizing the software design of graphical user interfaces. Topics include basic interaction devices and techniques, human factors, interaction styles, dialogue design, and software infrastructure. Design and programming projects are required.

Spring 2019: COMS W4170

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<td>M W 4:10pm - 5:25pm 451 Computer Science Bldg</td>
<td>Lydia Chilton</td>
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Fall 2019: COMS W4170

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<td>001/35953</td>
<td>T Th 1:10pm - 2:25pm 1024 Seeley W. Mudd Building</td>
<td>Brian Smith</td>
<td>3</td>
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COMS W4172 3D User Interfaces and Augmented Reality. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: (COMS W4160) or (COMS W4170) or the instructor's permission.

Spring 2019: COMS W4172

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<th>Course Number</th>
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<td>Steven Feiner</td>
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<td>COMS 4172</td>
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<td>T Th 1:10pm - 2:25pm 627 Seeley W. Mudd Building</td>
<td>Steven Feiner</td>
<td>3</td>
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</table>

COMS W4180 Network Security. 3 points.
Lect: 3.
Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) and (CSEE W4119) or instructor's permission.
Introduction to network security concepts and mechanisms. Foundations of network security and an in-depth review of commonly-used security mechanisms and techniques, security threats and network-based attacks, applications of cryptography, authentication, access control, intrusion detection and response, security protocols (IPsec, SSL, Kerberos), denial of service, viruses and worms, software vulnerabilities, web security, wireless security, and privacy. Note: May not earn credit for both W4180 and W4181.
COMS W4181 Security I. 3 points.
Not offered during 2019-20 academic year.

Prerequisites: COMS W3157 or equivalent.

COMS W4182 Security II. 3 points.
Not offered during 2019-20 academic year.

Prerequisites: COMS W4181, COMS W4118, COMS W4119

COMS W4186 Malware Analysis and Reverse Engineering. 3 points.
Not offered during 2019-20 academic year.

Prerequisites: COMS W3157 or equivalent. COMS W3827

COMS W4187 Security Architecture and Engineering. 3 points.
Lect: 3.

Prerequisites: (COMS W4118) COMS W4180 and/or CSEE W4119 recommended.
Secure programming. Cryptographic engineering and key handling. Access controls. Tradeoffs in security design. Design for security. Note: May not earn credit for both W4187 and W4182.

COMS W4203 Graph Theory. 3 points.
Lect: 3.

Prerequisites: (COMS W3203)
General introduction to graph theory. Isomorphism testing, algebraic specification, symmetries, spanning trees, traversability, planarity, drawings on higher-order surfaces, colorings, extremal graphs, random graphs, graphical measurement, directed graphs, Burnside-Polya counting, voltage graph theory.

COMS W4205 Combinatorial Theory. 3 points.

Prerequisites: (COMS W3203) and course in calculus.
Sequences and recursions, calculus of finite differences and sums, elementary number theory, permutation group structures, binomial coefficients, Stirling numbers, harmonic numbers, generating functions.

COMS W4236 Introduction to Computational Complexity. 3 points.
Lect: 3.

Prerequisites: (COMS W3261)
Develops a quantitative theory of the computational difficulty of problems in terms of the resources (e.g. time, space) needed to solve them. Classification of problems into complexity classes, reductions, and completeness. Power and limitations of different modes of computation such as nondeterminism, randomization, interaction, and parallelism.

COMS W4241 Numerical Algorithms and Complexity. 3 points.
Lect: 3.

Prerequisites: Knowledge of a programming language. Some knowledge of scientific computation is desirable. Modern theory and practice of computation on digital computers. Introduction to concepts of computational complexity. Design and analysis of numerical algorithms. Applications to computational finance, computational science, and computational engineering.

COMS W4244 Numerical Algorithms and Their Complexity II. 3 points.
Prerequisites: COMS W4241.
A continuation of COMS W4241.

COMS W4252 Introduction to Computational Learning Theory. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: (CSOR W4231) or (COMS W4236) or COMS W3203 and the instructor’s permission, or COMS W3261 and the instructor’s permission. Possibilities and limitations of performing learning by computational agents. Topics include computational models of learning, polynomial time learnability, learning from examples and learning from queries to oracles. Computational and statistical limitations of learning. Applications to Boolean functions, geometric functions, automata.
COMS W4444 Programming and Problem Solving. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) and (CSEE W3827)
Hands-on introduction to solving open-ended computational problems. Emphasis on creativity, cooperation, and collaboration. Projects spanning a variety of areas within computer science, typically requiring the development of computer programs. Generalization of solutions to broader problems, and specialization of complex problems to make them manageable. Team-oriented projects, student presentations, and in-class participation required.

COMS W4460 Principles of Innovation and Entrepreneurship. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) or the instructor’s permission
Team project centered course focused on principles of planning, creating, and growing a technology venture. Topics include: identifying and analyzing opportunities created by technology paradigm shifts, designing innovative products, protecting intellectual property, engineering innovative business models.

COMS W4560 Introduction to Computer Applications in Health Care and Biomedicine. 3 points.
Lect: 3.

Prerequisites: Experience with computers and a passing familiarity with medicine and biology. Undergraduates in their senior or junior years may take this course only if they have adequate background in mathematics and receive the instructor’s permission.
An overview of the field of biomedical informatics, combining perspectives from medicine, computer science and social science. Use of computers and information in health care and the biomedical sciences, covering specific applications and general methods, current issues, capabilities and limitations of biomedical informatics. Biomedical Informatics studies the organization of medical information, the effective management of information using computer technology, and the impact of such technology on medical research, education, and patient care. The field explores techniques for assessing current information practices, determining the information needs of health care providers and patients, developing interventions using computer technology, and evaluating the impact of those interventions.
COMS W4701 Artificial Intelligence. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) and any course on probability. Prior knowledge of Python is recommended. Provides a broad understanding of the basic techniques for building intelligent computer systems. Topics include state-space problem representations, problem reduction and and-or graphs, game playing and heuristic search, predicate calculus, and resolution theorem proving, AI systems and languages for knowledge representation, machine learning and concept formation and other topics such as natural language processing may be included as time permits.

COMS W4705 Natural Language Processing. 3 points.
Lect: 3.

Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) or the instructor's permission.

Computational approaches to natural language generation and understanding. Topics include information extraction, summarization, machine translation, dialogue systems, and emotional speech. Particular attention is given to robust techniques that can handle understanding and generation for the large amounts of text on the Web or in other large corpora. Programming exercises in several of these areas.

COMS W4706 Spoken Language Processing. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) or the instructor's permission.

Computational approaches to speech generation and understanding. Topics include speech recognition and understanding, speech analysis for computational linguistics research, and speech synthesis. Speech applications including dialogue systems, data mining, summarization, and translation. Exercises involve data analysis and building a small text-to-speech system.

COMS W4725 Knowledge representation and reasoning. 3 points.

Prerequisites: (COMS W4701)

General aspects of knowledge representation (KR). The two fundamental paradigms (semantic networks and frames) and illustrative systems. Topics include hybrid systems, time, action/plans, defaults, abduction, and case-based reasoning. Throughout the course particular attention is paid to design trade-offs between language expressiveness and reasoning complexity, and issues relating to the use of KR systems in larger applications.

COMS W4731 Computer Vision. 3 points.
Lect: 3.

Prerequisites: Fundamentals of calculus, linear algebra, and C programming. Students without any of these prerequisites are advised to contact the instructor prior to taking the course.

Introductory course in computer vision. Topics include image formation and optics, image sensing, binary images, image processing and filtering, edge extraction and boundary detection, region growing and segmentation, pattern classification methods, brightness and reflectance, shape from shading and photometric stereo, texture, binocular stereo, optical flow and motion, 2D and 3D object representation, object recognition, vision systems and applications.
COMS W4733 Computational Aspects of Robotics. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: (COMS W3134 or COMS W3136COMS W3137) Introduction to robotics from a computer science perspective. Topics include coordinate frames and kinematics, computer architectures for robotics, integration and use of sensors, world modeling systems, design and use of robotic programming languages, and applications of artificial intelligence for planning, assembly, and manipulation.

Spring 2019: COMS W4733
<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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<td>001/74025</td>
<td>M W 4:10pm - 5:25pm 633 Seeley W. Mudd Building</td>
<td>Tony Dear</td>
<td>3</td>
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<td>COMS 4733</td>
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<td>M W 4:10pm - 5:25pm 633 Seeley W. Mudd Building</td>
<td>Tony Dear</td>
<td>3</td>
<td>4</td>
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COMS W4735 Visual Interfaces to Computers. 3 points.
Lect: 3.

Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) Visual input as data and for control of computer systems. Survey and analysis of architecture, algorithms, and underlying assumptions of commercial and research systems that recognize and interpret human gestures, analyze imagery such as fingerprint or iris patterns, generate natural language descriptions of medical or map imagery. Explores foundations in human psychophysics, cognitive science, and artificial intelligence.

COMS W4737 Biometrics. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: a background at the sophomore level in computer science, engineering, or like discipline.
In this course, we will explore the latest advances in biometrics as well as the machine learning techniques behind them. Students will learn how these technologies work and how they are sometimes defeated. Grading will be based on homework assignments and a final project. There will be no midterm or final exam. This course shares lectures with COMS E6737. Students taking COMS E6737 are required to complete additional homework problems and undertake a more rigorous final project. Students will only be allowed to earn credit for COMS W4737 or COMS E6737 and not both.

COMS W4771 Machine Learning. 3 points.
Lect: 3.

Prerequisites: Any introductory course in linear algebra and any introductory course in statistics are both required. Highly recommended: COMS W4701 or knowledge of Artificial Intelligence. Topics from generative and discriminative machine learning including least squares methods, support vector machines, kernel methods, neural networks, Gaussian distributions, linear classification, linear regression, maximum likelihood, exponential family distributions, Bayesian networks, Bayesian inference, mixture models, the EM algorithm, graphical models and hidden Markov models. Algorithms implemented in MATLAB.

COMS W4771 Machine Learning for Data Science. 3 points.
Lect: 3.

Prerequisites: Any introductory course in linear algebra and any introductory course in statistics are both required. Highly recommended: COMS W4701 or knowledge of Artificial Intelligence. Topics from generative and discriminative machine learning including least squares methods, support vector machines, kernel methods, neural networks, Gaussian distributions, linear classification, linear regression, maximum likelihood, exponential family distributions, Bayesian networks, Bayesian inference, mixture models, the EM algorithm, graphical models and hidden Markov models. Algorithms implemented in MATLAB.

COMS W4772 Advanced Machine Learning. 3 points.
Lect: 3.

Prerequisites: (COMS W4771) or instructor's permission; knowledge of linear algebra & introductory probability or statistics is required. An exploration of advanced machine learning tools for perception and behavior learning. How can machines perceive, learn from, and classify human activity computationally? Topics include appearance-based models, principal and independent components analysis, dimensionality reduction, kernel methods, manifold learning, latent models, regression, classification, Bayesian methods, maximum entropy methods, real-time tracking, extended Kalman filters, time series prediction, hidden Markov models, factorial HMMS, input-output HMMS, Markov random fields, variational methods, dynamic Bayesian networks, and Gaussian/Dirichlet processes. Links to cognitive science.

COMS W4776 Machine Learning for Data Science. 3 points.
Lect: 3.

Prerequisites: (STAT GU4001 or I EOR E4150) and linear algebra. Introduction to machine learning, emphasis on data science. Topics include least square methods, Gaussian distributions, linear classification, linear regression, maximum likelihood, exponential family distributions, Bayesian networks, Bayesian inference, mixture models, the EM algorithm, graphical models, hidden Markov models, support vector machines kernel methods. Emphasizes methods and problems relevant to big data. Students may not receive credit for both COMS W4771 and W4776.
COMS W4901 Projects in Computer Science. 1-3 points.
Prerequisites: Approval by a faculty member who agrees to supervise the work.
A second-level independent project involving laboratory work, computer programming, analytical investigation, or engineering design. May be repeated for credit, but not for a total of more than 3 points of degree credit. Consult the department for section assignment.

COMS W4910 Curricular Practical Training. 1 point.
Prerequisites: obtained internship and approval from faculty advisor.
Only for M.S. students in the Computer Science department who need relevant work experience as part of their program of study. Final report required. This course may not be taken for pass/fail credit or audited.

COMS W4995 Special topics in computer science, I. 3 points.
Lect: 3.
Prerequisites: Instructor's permission.
Special topics arranged as the need and availability arises. Topics are usually offered on a one-time basis. Since the content of this course changes each time it is offered, it may be repeated for credit. Consult the department for section assignment.

<table>
<thead>
<tr>
<th>Course Number</th>
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<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tr>
<td>COMS 4995</td>
<td>001/70948</td>
<td>T 6:10pm - 8:00pm 413 Kent Hall</td>
<td>Shruni Gandhi</td>
<td>3</td>
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<tr>
<td>COMS 4995</td>
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<td>T Th 8:40am - 9:55am 524 Seeley W. Mudd Building</td>
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<td>COMS 4995</td>
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<td>T Th 7:10pm - 8:20pm 517 Hamilton Hall</td>
<td>Iddo Drori</td>
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<tr>
<td>COMS 4995</td>
<td>005/20631</td>
<td>M W 1:10pm - 2:25pm 207 Mathematics Building</td>
<td>Andreas Mueller</td>
<td>3</td>
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<td>COMS 4995</td>
<td>006/89685</td>
<td>T 6:10pm - 8:00pm 963 Ext Schermerhorn Hall</td>
<td>Agnes Chang</td>
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<td>Joshua Gordon</td>
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<td>T Th 5:40pm - 6:55pm 253 Engineering Terrace</td>
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COMS W4996 Special topics in computer science, II. 3 points.
Lect: 3.
Not offered during 2019-20 academic year.

Prerequisites: Instructor's permission.
A continuation of COMS W4995 when the special topic extends over two terms.
Computer Science - English
Computer Science - Electrical Engineering

CSEE W3827 Fundamentals of Computer Systems. 3 points.

Lect: 3.

Prerequisites: an introductory programming course. Fundamentals of computer organization and digital logic. Boolean algebra, Karnaugh maps, basic gates and components, flipflops and latches, counters and state machines, basics of combinational and sequential digital design. Assembly language, instruction sets, ALU’s, single-cycle and multi-cycle processor design, introduction to pipelined processors, caches, and virtual memory.

<table>
<thead>
<tr>
<th>Spring 2019: CSEE W3827</th>
<th>Course Number</th>
<th>Section/Call Number</th>
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<td>Daniel Rubenstein</td>
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Fall 2019: CSEE W3827

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CSEE W4119 Computer Networks. 3 points.

Lect: 3.

Prerequisites: Corequisites: IOR E3658 or equivalent. Corequisites: IOR E3658
Introduction to computer networks and the technical foundations of the Internet, including applications, protocols, local area networks, algorithms for routing and congestion control, security, elementary performance evaluation. Several written and programming assignments required.

<table>
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<tr>
<th>Spring 2019: CSEE W4119</th>
<th>Course Number</th>
<th>Section/Call Number</th>
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<td>Javad Ghaderi Dehkordi</td>
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Fall 2019: CSEE W4119

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<td>M W 11:10pm - 2:25pm 207 Mathematics Building</td>
<td>Ethan Katz-Basset</td>
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CSEE W4140 Networking Laboratory. 3 points.

Lect: 3.

Prerequisites: (CSEE W4119) or equivalent.
In this course, students will learn how to put “principles into practice,” in a hands-on-networking lab course. The course will cover the technologies and protocols of the Internet using equipment currently available to large internet service providers such as CISCO routers and end systems. A set of laboratory experiments will provide hands-on experience with engineering wide-area networks and will familiarize students with the Internet Protocol (IP), Address Resolution Protocol (ARP), Internet Control Message Protocol (ICMP), User Datagram Protocol (UDP) and Transmission Control Protocol (TCP), the Domain Name System (DNS), routing protocols (RIP, OSPF, BGP), network management protocols (SNMP, and application-level protocols (FTP, TELNET, SMTP).

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<th>Course Number</th>
<th>Section/Call Number</th>
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Fall 2019: CSEE W4140

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CSEE W4823 Advanced Logic Design. 3 points.

Lect: 3.

Prerequisites: (CSEE W3827) or a half semester introduction to digital logic, or the equivalent. An introduction to modern digital system design. Advanced topics in digital logic: controller synthesis (Mealy and Moore machines); adders and multipliers; structured logic blocks (PLDs, PALs, ROMs); iterative circuits. Modern design methodology: register transfer level modelling (RTL); algorithmic state machines (ASMs); introduction to hardware description languages (VHDL or Verilog); system-level modelling and simulation; design examples.

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<th>Spring 2019: CSEE W4823</th>
<th>Course Number</th>
<th>Section/Call Number</th>
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Fall 2019: CSEE W4823

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<td>Sethumadhavan</td>
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CSEE W4824 Computer Architecture. 3 points.

Lect: 3.

CSEE W4840 Embedded Systems. 3 points.
Lect: 3.

Prerequisites: (CSEE W4823)
Embedded system design and implementation combining hardware and software. I/O, interfacing, and peripherals. Weekly laboratory sessions and term project on design of a microprocessor-based embedded system including at least one custom peripheral. Knowledge of C programming and digital logic required.

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<td>F 10:10am - 12:40pm</td>
<td>Stephen Edwards</td>
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CSEE W4868 System-on-chip platforms. 3 points.
Prerequisites: (COMS W3157) and (CSEE W3827)
Design and programming of System-on-Chip (SoC) platforms. Topics include: overview of technology and economic trends, methodologies and supporting CAD tools for system-level design, models of computation, the SystemC language, transaction-level modeling, software simulation and virtual platforms, hardware-software partitioning, high-level synthesis, system programming and device drivers, on-chip communication, memory organization, power management and optimization, integration of programmable processor cores and specialized accelerators. Case studies of modern SoC platforms for various classes of applications.

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<td>T Th 11:40am - 12:55pm</td>
<td>Luca Carloni</td>
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Computer Science - Biomedical Engineering

CBMF W4761 Computational Genomics. 3 points.
Lect: 3.

Prerequisites: Working knowledge of at least one programming language, and some background in probability and statistics.
Computational techniques for analyzing genomic data including DNA, RNA, protein and gene expression data. Basic concepts in molecular biology relevant to these analyses. Emphasis on techniques from artificial intelligence and machine learning. String-matching algorithms, dynamic programming, hidden Markov models, expectation-maximization, neural networks, clustering algorithms, support vector machines. Students with life sciences backgrounds who satisfy the prerequisites are encouraged to enroll.

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<tr>
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