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 Belhumeur
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 Erlikh
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
Ansal 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>Level</th>
<th>Course Name</th>
<th>Description</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</th>
<th>Description</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>Level</th>
<th>Course Name</th>
<th>Description</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>Sophomore Year</td>
<td>COMS W1007</td>
<td>Honors Introduction to Computer Science</td>
</tr>
<tr>
<td></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</th>
<th>Description</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</th>
<th>Description</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>
<tr>
<td>Course Code</td>
<td>Course Title</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>IEO E6614</td>
<td>Optimization, II</td>
</tr>
<tr>
<td>IEO E6711</td>
<td>Stochastic models, I</td>
</tr>
<tr>
<td>IEO 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.

<table>
<thead>
<tr>
<th>Required Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W4115</td>
</tr>
<tr>
<td>COMS W4118</td>
</tr>
<tr>
<td>CSEE W4119</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Track Electives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select 1 from:</td>
</tr>
<tr>
<td>Any COMS W41xx course</td>
</tr>
<tr>
<td>COMS W4444</td>
</tr>
<tr>
<td>Any COMS W48xx course</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 W4996 Special topics in computer science, II
- 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

**Intelligent Systems Track (15 points)**
For students interested in machine learning, robotics, and systems capable of exhibiting “human-like” intelligence.

<table>
<thead>
<tr>
<th>Required Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select two of the following courses:</td>
</tr>
<tr>
<td>COMS W4701</td>
</tr>
<tr>
<td>COMS W4705</td>
</tr>
<tr>
<td>COMS W4706</td>
</tr>
<tr>
<td>COMS W4731</td>
</tr>
<tr>
<td>COMS W4733</td>
</tr>
<tr>
<td>COMS W4771</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Track Electives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select 2 from:</td>
</tr>
<tr>
<td>COMS W4160</td>
</tr>
<tr>
<td>COMS W4167</td>
</tr>
<tr>
<td>COMS W4731</td>
</tr>
</tbody>
</table>

**Applications Track (15 points)**
For students interested in the implementation of interactive multimedia applications for the internet and wireless networks.

<table>
<thead>
<tr>
<th>Required Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W4115</td>
</tr>
<tr>
<td>COMS W4170</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Track Electives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select 2 from:</td>
</tr>
<tr>
<td>Any COMS W41xx course</td>
</tr>
<tr>
<td>Any COMS W47xx course</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
- 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 interested 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.

<table>
<thead>
<tr>
<th>Required Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select two of the following courses:</td>
</tr>
<tr>
<td>COMS W4160</td>
</tr>
<tr>
<td>COMS W4167</td>
</tr>
<tr>
<td>COMS W4731</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Track Electives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select 2 from:</td>
</tr>
<tr>
<td>COMS W4162</td>
</tr>
<tr>
<td>COMS W4170</td>
</tr>
<tr>
<td>COMS W4172</td>
</tr>
<tr>
<td>COMS W4701</td>
</tr>
<tr>
<td>COMS W4733</td>
</tr>
<tr>
<td>COMS W4735</td>
</tr>
<tr>
<td>COMS W4771</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
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.

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

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
COMS W1001 Introduction to Information Science
or COMS W1002 Computing in Context
COMS W1004 Introduction to Computer Science and Programming in Java
COMS W1007 Honors Introduction to Computer Science
COMS W3134 Data Structures in Java
STAT GU4001 Introduction to Probability and Statistics

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:
COMS W4111 Introduction to Databases
COMS W4170 User Interface Design
COMS W4701 Artificial Intelligence
COMS W3410 Computers and Society
SOCI UN3010 Methods for Social Research
SOCI UN3960 Law, Science, and Society

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:
COMS W4111 Introduction to Databases
COMS W4701 Artificial Intelligence
COMS W4771 Machine Learning
ECON UN3412 Introduction To Econometrics
ECON UN3025 Financial Economics
ECON UN3265 The Economics of Money and Banking

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:
COMS W4111 Introduction to Databases
COMS W4170 User Interface Design
COMS W4701 Artificial Intelligence
BINF G4001
BIOL W4037 Bioinformatics of Gene Expression
ECBM E3060/E4060 Introduction to genomic information science and technology

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)
MATH UN1101 Calculus I
MATH UN1102 Calculus II
MATH UN1201 Calculus III
MATH UN2010 Linear Algebra

Core Requirement
MATH UN2010 Linear Algebra
MATH UN3433 Calculus IV
MATH UN3952 Independent Work in Mathematics
MATH UN3953 Seminar in Mathematics
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
COMS W1007 Honors Introduction to Computer Science
COMS W3134 Data Structures in Java
COMS W3137 Honors Data Structures and Algorithms

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
Course Number 001/35954
Times/Location T Th 1:10pm - 2:25pm 451 Computer Science Bldg
Instructor Adam Cannon
Points 3
Enrollment 66/80

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
Course Number 001/35955
Times/Location T Th 2:40pm - 3:55pm 417 International Affairs Bldg
Instructor Adam Cannon
Points 4
Enrollment 247/300
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.

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS 1004</td>
<td>001/395930</td>
<td>M W 5:40pm - 6:55pm 417 International Affairs Bldg Paul Blaer</td>
<td>3</td>
<td>352/400</td>
<td></td>
</tr>
<tr>
<td>COMS 1004</td>
<td>001/12611</td>
<td>T Th 1:10pm - 2:25pm 309 Havemeyer Hall Adam Cannon</td>
<td>3</td>
<td>236/300</td>
<td></td>
</tr>
<tr>
<td>COMS 1004</td>
<td>002/12612</td>
<td>T Th 2:40pm - 3:55pm 309 Havemeyer Hall Adam Cannon</td>
<td>3</td>
<td>224/300</td>
<td></td>
</tr>
</tbody>
</table>

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: 1004 or 1005.

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.

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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tr>
<td>COMS 1007</td>
<td>001/395951</td>
<td>T Th 1:10pm - 2:25pm 633 Seeley W. Mudd Building John Kender</td>
<td>3</td>
<td>30/70</td>
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</tbody>
</table>

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.

<table>
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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tr>
<td>COMS 1404</td>
<td>001/16541</td>
<td>F 10:00am - 4:00pm 424 Kent Hall Adam Cannon</td>
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<td>COMS 1404</td>
<td>002/16542</td>
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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.

<table>
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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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<td>W 6:10pm - 8:00pm 603 Hamilton Hall Lawrence Stead</td>
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<td>COMS 3101</td>
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<td>Th 6:10pm - 8:00pm 480 Computer Science Bldg Ramana Isukapalli</td>
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</table>
COMS W3102 Development Technologies. 1-2 points.

Prerequisites: Fluency in at least one programming language.
Introduction to software development tools and environments. Each section devoted to a specific tool or environment. One-point sections meet for two hours each week for half a semester, and two point sections include an additional two-hour lab.

Fall 2019: COMS W3102
<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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Spring 2020: COMS W3102
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<td>Robert Coyne</td>
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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 only receive credit for either COMS W3134, W3136, or W3137.

COMS W3136 Data Structures with C/C++. 4 points.
Prerequisites: (COMS W1004) or (COMS W1005) or (COMS W1007) or (ENGI E1006)
A second programming course intended for nonmajors with at least one semester of introductory programming experience. Basic elements of programming in C and C++, arraybased 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 W3134, W3136, or 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 W3137 Honors 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 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 or COMS W4118 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.
Continuation of COMP S W4115, with broader and deeper investigation into compiler design, 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 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 W4119 Operating Systems.  3 points.
Lect: 3.
Prerequisites: (COMS W3136 or COMS W3137) and fluency in Java, or the instructor’s permission.
Operating systems, their role in computer systems, architecture, design, implementation, and performance. Topics include process management, protection and security, virtual memory, scheduling, file systems, interprocess communication, storage management, and distributed systems. Programming projects are 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, W3137, 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 W4146 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 W4156 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.

COMS W4160 Advanced Computer Graphics. 3 points.
Lect: 3.
Prerequisites: (COMS W3160) or (COMS W3160) or (COMS W3163) COMS W4160 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.

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.

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.

COMS W4180 Network Security. 3 points.
Lect. 3.

Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) and (CSEE W4119) or the 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 Hands-on analysis of malware. How hackers package and hide malware and viruses to evade analysis. Disassemblers, debuggers, and other tools for reverse engineering. Deep study of Windows Internals and x86 assembly.

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 W4242 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 W4261 Introduction to Cryptography. 3 points.
Lect: 2.5.

Prerequisites: Comfort with basic discrete math and probability. Recommended: COMS W3261 or CSOR W4231.
An introduction to modern cryptography, focusing on the complexity-theoretic foundations of secure computation and communication in adversarial environments; a rigorous approach, based on precise definitions and provably secure protocols. Topics include private and public key encryption schemes, digital signatures, authentication, pseudorandom generators and functions, one-way functions, trapdoor functions, number theory and computational hardness, identification and zero knowledge protocols.

COMS W4281 Introduction to Quantum Computing. 3 points.
Lect: 3.

Prerequisites: Knowledge of linear algebra. Prior knowledge of quantum mechanics is not required although helpful. Introduction to quantum computing. Shor’s factoring algorithm, Grover’s database search algorithm, the quantum summation algorithm. Relationship between classical and quantum computing. Potential power of quantum computers.

COMS W4419 Internet Technology, Economics, and Policy. 3 points.
Not offered during 2019-20 academic year.

Technology, economic and policy aspects of the Internet. Summarizes how the Internet works technically, including protocols, standards, radio spectrum, global infrastructure and interconnection. Microeconomics with a focus on media and telecommunications economic concerns, including competition and monopolies, platforms, and behavioral economics. US constitution, freedom of speech, administrative procedures act and regulatory process, universal service, role of FCC. Not a substitute for CSEE4119. Suitable for non-majors. May not be used as a track elective for the computer science major.

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.

Fall 2019: COMS W4460

<table>
<thead>
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<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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<td>COMS 4460</td>
<td>001/35914</td>
<td>F 10:10am - 12:40pm 602 Northwest Corner</td>
<td>William Reinisch</td>
<td>3</td>
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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.

Fall 2019: COMS W4701

<table>
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<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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Spring 2020: COMS W4701

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<td>Ansaf Salleb-Aouissi</td>
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<td>Ansaf Salleb-Aouissi</td>
<td>3</td>
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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. Recommended preparation: some previous or concurrent exposure to AI or Machine Learning. 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 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.

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 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 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 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 IEOR 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.

Fall 2019: COMS W4995

<table>
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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<td>Paul Blaer, Jason Cahill</td>
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<td>Stephen Edwards</td>
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Spring 2020: COMS W4995

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COMS W4996 Special topics in computer science, II. 3 points.

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: Instructor’s permission.
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.

Fall 2019: CSEE W3827

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Spring 2020: CSEE W3827

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<td>Simha Sethumadhavan</td>
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CSEE W4119 Computer Networks. 3 points.
Lect: 3.

Prerequisites: Corequisites: IEOR E3658 or equivalent.
Corequisites: IEOR 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.

Fall 2019: CSEE W4119

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<th>Instructor</th>
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<td>Ethan Katz-Bassett</td>
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Spring 2020: CSEE W4119

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<td>Javad Ghaderi Dehkordi</td>
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</table>
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).

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.

CSEE W4824 Computer Architecture. 3 points.
Lect: 3.
Prerequisites: (CSEE W3827) or equivalent.