DATA SCIENCE

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http://www.cs.columbia.edu/

Director of Undergraduate Studies: Dr. Jae Woo Lee, 715 CEPSR;
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Departmental Advisers:
For updated adviser information, see http://www.cs.columbia.edu/education/undergrad/advisors/.

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 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  
Julia Hirschberg  
Gail E. Kaiser  
John R. Kender  
Kathleen R. McKeown  
Vishal Misra  
Shree K. Nayar  
Jason Nieh  
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Gail E. Kaiser  
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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  
Mihalis Yannakakis

### 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  
Ansf 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>ENGI E1006</th>
<th>Introduction to Computing for Engineers and Applied Scientists (recommended but not required)</th>
</tr>
</thead>
</table>

First Year

<table>
<thead>
<tr>
<th>COMS W1004</th>
<th>Introduction to Computer Science and Programming in Java</th>
</tr>
</thead>
</table>

or COMS W1007 | Honors Introduction to Computer Science |

Sophomore Year

<table>
<thead>
<tr>
<th>COMS W3134</th>
<th>Data Structures in Java</th>
</tr>
</thead>
<tbody>
<tr>
<td>or COMS W3137</td>
<td>Honors Data Structures and Algorithms</td>
</tr>
</tbody>
</table>

or COMS W3157 | Advanced Programming |

or COMS W3203 | Discrete Mathematics: Introduction to Combinatorics and Graph Theory |

Junior and Senior Year

Select the remaining required core courses:

<table>
<thead>
<tr>
<th>COMS W3261</th>
<th>Computer Science Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSEE W3827</td>
<td>Fundamentals of Computer Systems</td>
</tr>
</tbody>
</table>

Select one of the following courses:

<table>
<thead>
<tr>
<th>MATH UN2010</th>
<th>Linear Algebra</th>
</tr>
</thead>
<tbody>
<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:

First Year

<table>
<thead>
<tr>
<th>COMS W1004</th>
<th>Introduction to Computer Science and Programming in Java</th>
</tr>
</thead>
</table>

Sophomore Year

<table>
<thead>
<tr>
<th>COMS W1007</th>
<th>Honors Introduction to Computer Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W3137</td>
<td>Honors Data Structures and Algorithms</td>
</tr>
<tr>
<td>COMS W3157</td>
<td>Advanced Programming</td>
</tr>
<tr>
<td>COMS W3203</td>
<td>Discrete Mathematics: Introduction to Combinatorics and Graph Theory</td>
</tr>
</tbody>
</table>

Junior and Senior Year

<table>
<thead>
<tr>
<th>COMS W3261</th>
<th>Computer Science Theory</th>
</tr>
</thead>
<tbody>
<tr>
<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>CSOR W4231</th>
<th>Analysis of Algorithms I</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W4236</td>
<td>Introduction to Computational Complexity</td>
</tr>
</tbody>
</table>

Track Electives

Select 2 from:

<table>
<thead>
<tr>
<th>MATH UN3020</th>
<th>Number Theory and Cryptography</th>
</tr>
</thead>
<tbody>
<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>INTRO MODERN ALGEBRA I</td>
</tr>
<tr>
<td>MATH GU4042</td>
<td>INTRO MODERN ALGEBRA II</td>
</tr>
<tr>
<td>MATH GU4061</td>
<td>INTRO 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></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>EEOE E6616</td>
<td>Convex optimization</td>
</tr>
<tr>
<td>IEOR E6613</td>
<td>Optimization, I</td>
</tr>
</tbody>
</table>
Data Science

IEOR E6614 Optimization, II
IEOR E6711 Stochastic models, I
IEOR E6712 Stochastic models, II
ELEN E6717 Information theory
ELEN E6718 Error Correcting Codes: Classical and Modern

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
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.

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

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
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
This introductory Statistics course:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT UN1201</td>
<td>Calculus-Based Introduction to Statistics</td>
</tr>
</tbody>
</table>

**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

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**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.

**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 2020: COMS W1002**

<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 1002</td>
<td>001/11682</td>
<td>T Th 2:40pm - 3:55pm</td>
<td>Adam Cannon</td>
<td>4</td>
<td>233/300</td>
</tr>
</tbody>
</table>

Room TBA
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 2020: COMS W1004
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 1004  001/12611  T Th 1:10pm - 2:25pm  309 Havemeyer Hall  Adam Cannon  3 166/300
COMS 1004  002/12612  T Th 2:40pm - 3:55pm  309 Havemeyer Hall  Adam Cannon  3 179/300

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.

Spring 2020: COMS W1007
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 1007  001/11692  T Th 4:10pm - 5:25pm  Room TBA  Adam Cannon  3 169/400

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.

Spring 2020: COMS W1404
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 1404  001/35447  F 12:15pm - 1:30pm  652 Schermerhorn Hall  Adam Cannon  1 6/15
COMS 1404  002/35448  F 1:45pm - 3:00pm  652 Schermerhorn Hall  Adam Cannon  1 4/15
COMS 1404  003/35449  F 1:15pm - 2:30pm  408a Philosophy Hall  Adam Cannon  1 2/15
COMS 1404  004/35450  F 2:45pm - 4:00pm  408a Philosophy Hall  Adam Cannon  1 4/15

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.

Spring 2020: COMS W3101
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 3101  001/20007  W 6:10pm - 8:00pm  644 Seeley W. Mudd Building  Lawrence Stead  1 35/40
COMS 3101  002/20135  M 6:10pm - 8:00pm  825 Seeley W. Mudd Building  Ramana Isukapalli  1 27/40

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.

Spring 2020: COMS W3102
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 3102  001/12613  F 2:10pm - 4:00pm  302 Fayerweather  Gary Zarnich  1/2 19/30
COMS 3102  002/12614  M 4:10pm - 6:00pm  337 Seeley W. Mudd Building  Bruno Scap  1/2 35/30
COMS 3102  003/19973  W 6:10pm - 8:00pm  303 Hamilton Hall  Robert Coyne  1/2 34/40
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.

Spring 2020: COMS W3134
Course Number: 3134
Section/Call Number: 001/12615
Times/Location: M W 5:40pm - 6:55pm 417 International Affairs Bldg
Instructor: Paul Blaer
Points: 3
Enrollment: 333/350

Fall 2020: COMS W3134
Course Number: 3134
Section/Call Number: 001/10066
Times/Location: M W 5:40pm - 6:55pm Room TBA
Instructor: Paul Blaer
Points: 3
Enrollment: 266/350

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++, 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 W3134, W3136, or W3137.

Fall 2020: COMS W3136
Course Number: 3136
Section/Call Number: 001/15273
Times/Location: T Th 5:40pm - 6:55pm Room TBA
Instructor: Timothy Paine
Points: 5/80

COMS W3137 Honors Data Structures and Algorithms. 4 points.
Prerequisites: (COMS W1004) or (COMS W1007)
Corequisites: COMS W2203
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.

Spring 2020: COMS W3137
Course Number: 3137
Section/Call Number: 001/12617
Times/Location: T Th 2:40pm - 3:55pm 503 Hamilton Hall
Instructor: Paul Blaer
Points: 4
Enrollment: 37/50

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.

Spring 2020: COMS W3157
Course Number: 3157
Section/Call Number: 001/12618
Times/Location: T Th 4:10pm - 5:25pm 301 Pupin Laboratories
Instructor: Jae Lee
Points: 4
Enrollment: 248/272

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).

Spring 2020: COMS W3203
Course Number: 3203
Section/Call Number: 001/1672
Times/Location: T Th 10:10am - 11:25am Room TBA
Instructor: Ansaf Salleb-Aouissi
Points: 3
Enrollment: 148/150

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

Spring 2020: COMS W3261

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<th>Instructor</th>
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<td>001/12622</td>
<td>T Th 10:10am - 11:25am 451 Computer Science Bldg</td>
<td>Mihalis Yannakakis</td>
<td>3</td>
<td>103/110</td>
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<tr>
<td>COMS 3261</td>
<td>002/12910</td>
<td>T Th 11:40am - 12:55pm 451 Computer Science Bldg</td>
<td>Mihalis Yannakakis</td>
<td>3</td>
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<td>COMS 3261</td>
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<td></td>
<td>Mihalis Yannakakis</td>
<td>3</td>
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</table>

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


Fall 2020: COMS W3410

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<td>COMS 3410</td>
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<td>T Th 8:40am - 9:55am Room TBA</td>
<td>Tal Malkin</td>
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<td>COMS 3410</td>
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<td>T Th 10:10am - 11:25am Room TBA</td>
<td>Tal Malkin</td>
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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.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: (COMS W3134) or (COMS W3137) or (COMS W3136) and (COMS W3134), (COMS W3136), or (COMS W3137), fluency in Java; or the instructor's permission.
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.

Spring 2020: COMS W4111

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<td>M W 1:10pm - 2:25pm 501 Northwest Corner</td>
<td>Kenneth Ross</td>
<td>3</td>
<td>115/164</td>
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<td>COMS 4111</td>
<td>002/13586</td>
<td>F 10:10am - 12:40pm 309 Haveneyer Hall</td>
<td>Donald Ferguson</td>
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<td>COMS 4111</td>
<td>003/19905</td>
<td>F 1:10pm - 3:40pm 451 Computer Science Bldg</td>
<td>Alexandros Biliris</td>
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Fall 2020: COMS W4111

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<td>T Th 1:10pm - 2:25pm Room TBA</td>
<td>Luis Gravano</td>
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<td>Donald Ferguson</td>
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<td>Alexandros Biliris</td>
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</table>

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 (CSEE W3827) 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 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.

Spring 2020: COMS W4156
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<th>Course Number</th>
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<tr>
<td>COMS 4156</td>
<td>001/16219</td>
<td>T 12:10pm - 2:00pm 411 International Affairs Bldg.</td>
<td>Junfeng Yang</td>
<td>3</td>
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</table>

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 2020: COMS W4160
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<th>Course Number</th>
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<td>COMS 4160</td>
<td>001/12627</td>
<td>T Th 5:40pm - 6:55pm 1127 Seeley W. Mudd Building</td>
<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).

Spring 2020: COMS W4167
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<th>Course Number</th>
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<td>COMS 4167</td>
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<td>Changxi Zheng</td>
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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 2020: COMS W4170
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<td>Lydia Chilton</td>
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<td>002/36445</td>
<td>F 10:10am - 12:40pm 451 Computer Science Bldg</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 2020: COMS W4172
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<td>COMS 4172</td>
<td>001/12629</td>
<td>T Th 1:10pm - 2:25pm 520 Mathematics Building</td>
<td>Steven Feiner</td>
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</table>
COMS W4180 Network Security. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: (COMS W3134 or COMS W3136 or COMS W3137) and (CSEE W4119) or COMS W3134, W3136, or W3137 and 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.
COMS W4181 Security I. 3 points.
Not offered during 2019-20 academic year.
Prerequisites: COMS W3157 or equivalent.

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COMS W4182 Security II. 3 points.
Not offered during 2019-20 academic year.
Prerequisites: COMS W4181, COMS W4118, COMS W4119

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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.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: (COMS W4118) COMS W4118, W4180 and/or W4119 recommended.

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COMS W4204 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 recurrences, 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.

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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 W2203 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.

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 any course on probability. Prior knowledge of Python is recommended.
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 W4450 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 W4460 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. 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 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 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 E4775 Causal Inference. 3 points.
Prerequisites: (COMS4711W) and Discrete Math, Calculus, Statistics (basic probability, modeling, experimental design), Some programming experience
Causal Inference theory and applications. The theoretical topics include the 3-layer causal hierarchy, causal bayesian networks, structural learning, the identification problem and the do-calculus, linear identifiability, bounding, and counterfactual analysis. The applied part includes intersection with statistics, the empirical-data sciences (social and health), and AI and ML.

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, 1. 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>Spring 2020: COMS W4995</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tr>
<td>COMS 4995 001/12639</td>
<td>M W 8:40am - 9:55am 417 Mathematics Building</td>
<td>Daniel Hsu</td>
<td>3</td>
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<td>COMS 4995 002/12640</td>
<td>T Th 2:40pm - 3:55pm 1024 Seeley W. Mudd Building</td>
<td>Alexandre Andoni</td>
<td>3</td>
<td>47/70</td>
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<tr>
<td>COMS 4995 003/12641</td>
<td>F 10:10am - 12:00pm 327 Seeley W. Mudd Building</td>
<td>Bjarni Stroustrup</td>
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<td>Th 6:10pm - 8:00pm 313 Fayerweather</td>
<td>Tristan Boutros</td>
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<td>50/50</td>
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<td>COMS 4995 005/12643</td>
<td>M W 4:10pm - 5:25pm 1127 Seeley W. Mudd Building</td>
<td>Iddo Drori</td>
<td>3</td>
<td>67/80</td>
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<td>Timothy Roughgarden</td>
<td>3</td>
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<tr>
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<td>F 1:10pm - 3:40pm 834 Seeley W. Mudd Building</td>
<td>Simandra Muresan, Isabelle Zaugg</td>
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<td>Th 7:00pm - 9:30pm 402 Chandler</td>
<td>Joshua Gordon</td>
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<tr>
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<th>Points</th>
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<td>Th 8:10pm - 10:00pm Room TBA</td>
<td>Tristan Boutros</td>
<td>3</td>
<td>0/50</td>
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</tbody>
</table>
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: 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.

CSEE 4119 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.

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 W4121 COMPUTER SYSTEMS FOR DATA SCIENCE. 3 points.
Prerequisites: Background in Computer System Organization and good working knowledge of C/C++. Corequisites: CSOR W4246 Algorithms for Data Science, STAT W4203 Probability Theory, or equivalent as approved by faculty advisor.

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.

CSEE W4119 001/16515
M W 1:10pm - 2:25pm
390 Havemeyer Hall
Javad Ghaderi
Dehkordi
3
124/150

CSEE W4119 001/13939
T Th 2:40pm - 3:55pm
Room TBA
Ethan Katz-Bassett
3
46/160

Fall 2020: CSEE W4119
Course Number Section/Call Number Times/Location Instructor Points Enrollment
CSEE 4119 001/16515 M W 1:10pm - 2:25pm 390 Havemeyer Hall Javad Ghaderi Dehkordi 3 124/150
CSEE 4119 001/13939 T Th 2:40pm - 3:55pm Room TBA Ethan Katz-Bassett 3 46/160

Spring 2020: CSEE W4140
Course Number Section/Call Number Times/Location Instructor Points Enrollment
CSEE 4140 001/16519 M W 10:10am - 11:25am 333 Seeley W. Mudd Building Gil Zussman 3 7/42
CSEE 4140 001/10602 M W 10:10am - 11:25am Room TBA Gil Zussman 3 8/40

Spring 2020: CSEE W4121
Course Number Section/Call Number Times/Location Instructor Points Enrollment
CSEE 4121 001/37174 M 4:10pm - 6:40pm Room TBA Asaf Cidon 3 0/155

Spring 2020: CSEE W4119
Course Number Section/Call Number Times/Location Instructor Points Enrollment
CSEE 4119 001/16515 M W 1:10pm - 2:25pm 390 Havemeyer Hall Javad Ghaderi Dehkordi 3 124/150
CSEE 4119 001/13939 T Th 2:40pm - 3:55pm Room TBA Ethan Katz-Bassett 3 46/160

Fall 2020: CSEE W4119
Course Number Section/Call Number Times/Location Instructor Points Enrollment
CSEE 4119 001/16515 M W 1:10pm - 2:25pm 390 Havemeyer Hall Javad Ghaderi Dehkordi 3 124/150
CSEE 4119 001/13939 T Th 2:40pm - 3:55pm Room TBA Ethan Katz-Bassett 3 46/160

Spring 2020: CSEE W4140
Course Number Section/Call Number Times/Location Instructor Points Enrollment
CSEE 4140 001/16519 M W 10:10am - 11:25am 333 Seeley W. Mudd Building Gil Zussman 3 7/42
CSEE 4140 001/10602 M W 10:10am - 11:25am Room TBA Gil Zussman 3 8/40

Spring 2020: CSEE W4121
Course Number Section/Call Number Times/Location Instructor Points Enrollment
CSEE 4121 001/37174 M 4:10pm - 6:40pm Room TBA Asaf Cidon 3 0/155

Spring 2020: CSEE W4119
Course Number Section/Call Number Times/Location Instructor Points Enrollment
CSEE 4119 001/16515 M W 1:10pm - 2:25pm 390 Havemeyer Hall Javad Ghaderi Dehkordi 3 124/150
CSEE 4119 001/13939 T Th 2:40pm - 3:55pm Room TBA Ethan Katz-Bassett 3 46/160
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.

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.

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.

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.

Spring 2020: CBMF W4761
Course Number Section/Call Number Times/Location Instructor Points Enrollment
CBMF 4761 001/12635 M W 4:10pm - 5:25pm 545 Seeley W. Mudd Building Itshack Pe’er 3 36/72
CBMF 4761 V01/25126 Itshack Pe’er 3 3/99