Computer Science

Departmental Office: 450 Computer Science Building; 212-939-7000
http://www.cs.columbia.edu/

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

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
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: ENG E1006 or COMS W1002.

ENG E1006 Introduction to Computing for Engineers and Applied
Scientist is a general introduction to computing for STEM students.
ENG 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. ENG 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.
Lecturer in Discipline
Daniel Bauer
Tony Dear
Ansa 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 (22-26 points). Adjustments were made to the course lists below in March 2022.

For students who declare in Spring 2014 and beyond:

<table>
<thead>
<tr>
<th>First Year</th>
<th>Sophomore Year</th>
<th>Junior and Senior Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGI E1006</td>
<td>COMS W1004</td>
<td>Select one of the following courses:</td>
</tr>
<tr>
<td>INTRO TO COMP FOR ENG/APP SCI</td>
<td>Introduction to Computer Science and Programming in Java</td>
<td>COMS W3251</td>
</tr>
<tr>
<td>(recommended but not required)</td>
<td>or COMS W1007</td>
<td>COMPUTATIONAL LINEAR ALGEBRA</td>
</tr>
<tr>
<td></td>
<td>Honors Introduction to Computer Science</td>
<td>(recommended)</td>
</tr>
<tr>
<td></td>
<td>COMS W3134</td>
<td>MATH UN2010</td>
</tr>
<tr>
<td></td>
<td>or COMS W3137</td>
<td>LINEAR ALGEBRA</td>
</tr>
<tr>
<td></td>
<td>COMS W3157</td>
<td>MATH UN2020</td>
</tr>
<tr>
<td></td>
<td>Advanced Programming</td>
<td>Honors Linear Algebra</td>
</tr>
<tr>
<td></td>
<td>COMS W3203</td>
<td>APMA E2101</td>
</tr>
<tr>
<td></td>
<td>DISCRETE MATHEMATICS</td>
<td>INTRO TO APPLIED MATHEMATICS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>APMA E3101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>APPLIED MATH I: LINEAR ALGEBRA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STAT GU4001</td>
</tr>
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<td></td>
<td></td>
<td>INTRODUCTION TO PROBABILITY AND STATISTICS</td>
</tr>
</tbody>
</table>

For students who declared prior to Spring 2014:

<table>
<thead>
<tr>
<th>First Year</th>
<th>Sophomore Year</th>
<th>Junior and Senior Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W1004</td>
<td>COMS W1007</td>
<td>Select one of the following courses:</td>
</tr>
<tr>
<td>Introduction to Computer Science and Programming in Java</td>
<td>Honors Introduction to Computer Science</td>
<td>COMS W3251</td>
</tr>
<tr>
<td></td>
<td>COMS W3137</td>
<td>COMPUTATIONAL LINEAR ALGEBRA</td>
</tr>
<tr>
<td></td>
<td>Honors Data Structures and Algorithms</td>
<td>(recommended)</td>
</tr>
<tr>
<td></td>
<td>COMS W3157</td>
<td>MATH UN2010</td>
</tr>
<tr>
<td></td>
<td>Advanced Programming</td>
<td>MATH UN2020</td>
</tr>
<tr>
<td></td>
<td>COMS W3203</td>
<td>APMA E2101</td>
</tr>
<tr>
<td></td>
<td>DISCRETE MATHEMATICS</td>
<td>APMA E3101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STAT GU4001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>INTRODUCTION TO PROBABILITY AND STATISTICS</td>
</tr>
</tbody>
</table>

In addition to the CS Core (22-26 points), all CS majors must complete the Calculus Requirement (3 points) and a Track Requirement (15 or 18 points). The CS major therefore requires 40-47 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
CSOR W4231 Analysis of Algorithms I
COMS W4236 INTRO-COMPUTATIONAL COMPLEXITY

Track Electives
Select 2 from:
MATH UN3020 Number Theory and Cryptography
MATH UN3025 Making, Breaking Codes
COMS W4203 Graph Theory
MATH GU4032 Fourier Analysis
MATH GU4041 INTRO MODERN ALGEBRA I
MATH GU4042 INTRO MODERN ALGEBRA II
MATH GU4061 INTRO MODERN ANALYSIS I
MATH GU4155 Probability Theory
COMS W4252 Introduction to Computational Learning Theory
COMS W4261 INTRO TO CRYPTOGRAPHY
APMA E4300 COMPUT MATH:INTRO-NUMERCL METH
IEOR E4407 GAME THEOR MODELS OF OPERATION
CSPH G4802 Math Logic II: Incompletness
COMS E6232 ANALYSIS OF ALGORITHMS II
MATH G6238 Enumerative Combinatorics
COMS E6253 ADV TPCS-COMPUT LEARNING THRY
COMS E6261 ADVANCED CRYPTOGRAPHY
EEOR E6616 CONVEX OPTIMIZATION
IEOR E6613 Optimization, I
IEOR E6614 OPTIMIZATION II
IEOR E6711 STOCHASTIC MODELING I
IEOR E6712 STOCHASTIC MODELING II
ELEN E6717 INFORMATION THEORY
ELEN E6718 ERROR CORRECTING CODES

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

Track Electives
Select 1 from:
Any COMS W41xx course
Any COMS W48xx course
COMS W3101 Programming Languages
COMS BC3930 Creative Embedded Systems
COMS W4444 Programming and Problem Solving

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

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 I: First Principles
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). Adjustments were made to the course lists below in March 2022.
For students interested in the implementation of interactive multimedia applications for the internet and wireless networks.

Required Courses
COMS W4111 INTRODUCTION TO DATABASES
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). Adjustments were made to the course lists below in March 2022.
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 I: First Principles

Track Electives
Select 2 from:
COMS W4162 Advanced Computer Graphics
COMS W4732 Computer Vision II: Learning
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

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. Adjustments were made to the course lists below in March 2022.

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 W3107  Clean Object-Oriented Design
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  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  Introduction To Computer Applications In Health Care and Biomedicine
BIOL W4037  Bioinformatics of Gene Expression
ECBM E3060/E4060  INTRO-GENOMIC INFO SCI # TECH

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.
### Computer Science

**Prerequisites (15 points)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH UN1101</td>
<td>CALCULUS I</td>
</tr>
<tr>
<td>MATH UN1102</td>
<td>CALCULUS II</td>
</tr>
<tr>
<td>MATH UN1201</td>
<td>Calculus III</td>
</tr>
<tr>
<td>MATH UN2010</td>
<td>LINEAR ALGEBRA</td>
</tr>
</tbody>
</table>

This introductory Statistics course:

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

**Statistics (12 points)**

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT GU4203</td>
<td>PROBABILITY THEORY</td>
</tr>
<tr>
<td>STAT GU4204</td>
<td>Statistical Inference</td>
</tr>
<tr>
<td>STAT GU4205</td>
<td>Linear Regression Models</td>
</tr>
<tr>
<td>STAT GU4241</td>
<td>Statistical Machine Learning or COMS W4771 Machine Learning</td>
</tr>
</tbody>
</table>

**Computer Science (12 points)**

Select one of the following courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W1004</td>
<td>Introduction to Computer Science and Programming in Java</td>
</tr>
<tr>
<td>COMS W1005</td>
<td>Introduction to Computer Science and Programming in MATLAB</td>
</tr>
<tr>
<td>COMS W1007</td>
<td>Honors Introduction to Computer Science</td>
</tr>
<tr>
<td>ENGI E1006</td>
<td>INTRO TO COMP FOR ENG/APP SCI</td>
</tr>
</tbody>
</table>

Select one of the following courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W3134</td>
<td>Data Structures in Java</td>
</tr>
<tr>
<td>COMS W3136</td>
<td>Data Structures with C/C++</td>
</tr>
<tr>
<td>COMS W3137</td>
<td>Honors Data Structures and Algorithms</td>
</tr>
</tbody>
</table>

Two required courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W3203</td>
<td>DISCRETE MATHEMATICS</td>
</tr>
<tr>
<td>CSOR W4231</td>
<td>Analysis of Algorithms I</td>
</tr>
</tbody>
</table>

**Electives (15 points)**

Select two of the following courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT UN3106</td>
<td>APPLIED MACHINE LEARNING</td>
</tr>
<tr>
<td>STAT GU4206</td>
<td>Statistical Computing and Introduction to Data Science</td>
</tr>
<tr>
<td>STAT GU4224</td>
<td>BAYESIAN STATISTICS</td>
</tr>
<tr>
<td>STAT GU4243</td>
<td>APPLIED DATA SCIENCE</td>
</tr>
<tr>
<td>STAT Q4242</td>
<td>Advanced Machine Learning</td>
</tr>
</tbody>
</table>

Select three of the following courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W3261</td>
<td>Computer Science Theory</td>
</tr>
<tr>
<td>COMS W4111</td>
<td>INTRODUCTION TO DATABASES</td>
</tr>
<tr>
<td>COMS W4130</td>
<td>Principles and Practice of Parallel Programming</td>
</tr>
<tr>
<td>COMS W4236</td>
<td>INTRO-COMPUTATIONAL COMPLEXITY</td>
</tr>
<tr>
<td>COMS W4252</td>
<td>Introduction to Computational Learning Theory</td>
</tr>
</tbody>
</table>

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. Adjustments were made to the course lists below in March 2022.

**For students who declare in Spring 2014 and beyond:**

The concentration in computer science requires a minimum of 22-24 points, as follows:

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W1004</td>
<td>Introduction to Computer Science and Programming in Java</td>
</tr>
<tr>
<td>or COMS W1007</td>
<td>Honors Introduction to Computer Science</td>
</tr>
<tr>
<td>COMS W3134</td>
<td>Data Structures in Java</td>
</tr>
<tr>
<td>or 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</td>
</tr>
<tr>
<td>COMS W3261</td>
<td>Computer Science Theory</td>
</tr>
<tr>
<td>CSEE W3827</td>
<td>Fundamentals of Computer Systems (or any 3 point 4000-level computer science course)</td>
</tr>
</tbody>
</table>

Select one of the following courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W3251</td>
<td>COMPUTATIONAL LINEAR ALGEBRA (recommended)</td>
</tr>
<tr>
<td>MATH UN2010</td>
<td>LINEAR ALGEBRA</td>
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<td>MATH V2020</td>
<td>Honors Linear Algebra</td>
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<tr>
<td>APMA E2101</td>
<td>INTRO TO APPLIED MATHEMATICS</td>
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<tr>
<td>APMA E3101</td>
<td>APPLIED MATH I: LINEAR ALGEBRA</td>
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<tr>
<td>STAT GU4001</td>
<td>INTRODUCTION TO PROBABILITY AND STATISTICS</td>
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<td>SIEO W3600</td>
<td>INTRO PROBABILITY/STATISTICS</td>
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</table>

**For students who declared prior to Spring 2014:**

The concentration requires a minimum of 23 points, as follows:

<table>
<thead>
<tr>
<th>Course</th>
<th>Subject</th>
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<tbody>
<tr>
<td>COMS W1004</td>
<td>Introduction to Computer Science and Programming in Java</td>
</tr>
<tr>
<td>COMS W1007</td>
<td>Honors Introduction to Computer Science</td>
</tr>
<tr>
<td>COMS W3137</td>
<td>Honors Data Structures and Algorithms</td>
</tr>
<tr>
<td>COMS W3157</td>
<td>Advanced Programming</td>
</tr>
<tr>
<td>COMS W3261</td>
<td>Computer Science Theory</td>
</tr>
<tr>
<td>CSEE W3827</td>
<td>Fundamentals of Computer Systems (or any 3-point 4000-level computer science course)</td>
</tr>
</tbody>
</table>

**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. 4.00 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.

COMS W1004 Introduction to Computer Science and Programming in MATLAB. 3 points.

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.

COMS W1007 Honors Introduction to Computer Science. 3 points.

Lect: 3.

Prerequisites: AP Computer Science with a grade of 4 or 5 or similar experience. An honors-level introduction to computer science, intended primarily for students considering a major in computer science. Computer science as a science of abstraction. Creating models for reasoning about and solving problems. The basic elements of computers and computer programs. Implementing abstractions using data structures and algorithms. Taught in Java.

COMS W1404 Emerging Scholars Program Seminar. 1 point.

Pass/Fail only.

Prerequisites: the instructor’s permission. Corequisites: COMS W1002 or COMS W1004 or COMS W1007.

COMS W3011 Programming Languages. 1 point.

Lect: 1.

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

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-half hour lab.

COMS W3107 Clean Object-Oriented Design. 3.00 points.
Prerequisites: Intro to Computer Science/Programming in Java (COMS W1004) or instructor’s permission. May not take for credit if already received credit for COMS W1007.

Prerequisites: see notes re: points
A course in designing, documenting, coding, and testing robust computer software, according to object-oriented design patterns and clean coding practices. Taught in Java. Object-oriented design principles include: use cases; CRC; UML; javadoc; patterns (adapter, builder, command, composite, decorator, facade, factory, iterator, lazy evaluation, observer, singleton, strategy, template, visitor); design by contract; loop invariants; interfaces and inheritance hierarchies; anonymous classes and null objects; graphical widgets; events and listeners; Java’s Object class; generic types; reflection; timers, threads, and locks.

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

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

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

Prerequisites: (COMS W3134) or (COMS W3137) C programming language and Unix systems programming. Also covers Git, Make, TCP/IP networking basics, C++ fundamentals.
COMS W3203 DISCRETE MATHEMATICS. 4.00 points.
Lect: 3.

Prerequisites: Any introductory course in computer programming.
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 2022: COMS W3203
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 3203  001/12422  T Th 10:10am - 11:25am  Ansaf Salleh-Aouissi  4.00  146/150
COMS 3203  002/12423  T Th 11:40am - 12:55pm  Ansaf Salleh-Aouissi  4.00  145/150

COMS W3210 Scientific Computation. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: two terms of calculus.
Introduction to computation on digital computers. Design and analysis
of numerical algorithms. Numerical solution of equations, integration,
recurrences, chaos, differential equations. Introduction to Monte
Carlo methods. Properties of floating point arithmetic. Applications to
weather prediction, computational finance, computational science, and
computational engineering.

COMS W3251 COMPUTATIONAL LINEAR ALGEBRA. 4.00 points.

Spring 2022: COMS W3251
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 3251  001/11907  M W 1:10pm - 2:25pm  Tony Dear  4.00  157/164

Fall 2022: COMS W3251
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 3251  001/11003  T Th 10:10am - 11:25am  Daniel Hsu  4.00  155/160

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

Prerequisites: (COMS W3203)
Corequisites: COMS W3134,COMS W3136,COMS W3137
Regular languages: deterministic and non-deterministic finite automata,
regular expressions. Context-free languages: context-free grammars,
push-down automata. Turing machines, the Chomsky hierarchy, and
the Church-Turing thesis. Introduction to Complexity Theory and NP-
Completeness.

Spring 2022: COMS W3261
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 3261  001/12424  T Th 1:10pm - 2:25pm  Mihalis Yannakakis  3  104/110
COMS 3261  002/12425  T Th 2:40pm - 3:55pm  Mihalis Yannakakis  3  103/110
COMS 3261  H01/20428  Mihalis Yannakakis  3  0/0
COMS 3261  H02/20438  Mihalis Yannakakis  3  36/65

Fall 2022: COMS W3261
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 3261  001/11004  M W 8:40am - 9:55am  Tal Malkin  3  164/164
COMS 3261  002/11005  M W 10:10am - 11:25am  Tal Malkin  3  164/164

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

Broader impact of computers. Social networks and privacy. Employment,
intellectual property, and the media. Science and engineering ethics.
Suitable for nonmajors.

Fall 2022: COMS W3410
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
COMS 3410  001/11006  W 4:10pm - 6:40pm  Ronald Baecker  3  65/65

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. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: COMS W3134, COMS W3136, or COMS W3137; or the instructor's permission.
Prerequisites: (COMS W3134) or (COMS W3136) or (COMS W3137) and fluency in Java; or the instructor’s permission. The fundamentals of database design and application development using databases: entity-relationship modeling, logical design of relational databases, relational data definition and manipulation languages, SQL, XML, query processing, physical database tuning, transaction processing, security. Programming projects are required.

COMS W4112 DATABASE SYSTEM IMPLEMENTATION. 3.00 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

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<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<td>001/12429</td>
<td>M W 1:10pm - 2:25pm 451 Computer Science Bldg</td>
<td>Kenneth Ross</td>
<td>3.00</td>
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</table>

COMS W4113 FUND-LARGE-SCALE DIST SYSTEMS. 3.00 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.

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Spring 2022: COMS W4111

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<td>F 1:10pm - 3:40pm 417 International Affairs Bldg</td>
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<td>COMS 4111</td>
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<td>Th 4:10pm - 6:40pm 402 Chandler</td>
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Fall 2022: COMS W4111

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<td>Luis Gravano</td>
<td>3.00</td>
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<td>COMS 4111</td>
<td>002/11008</td>
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</table>
COMS E4115 PROGRAMMING LANG # TRANSL. 3.00 points.
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 W4118 Operating Systems I. 3 points.
Lect: 3.

Prerequisites: (CSEE W3827) and knowledge of C and programming tools as covered in COMS W3136, W3157, or W3101, or the instructor’s permission.

Design and implementation of operating systems. Topics include process management, process synchronization and interprocess communication, memory management, virtual memory, interrupt handling, processor scheduling, device management, I/O, and file systems. Case study of the UNIX operating system. A programming project is required.

COMS W4119 COMPUTER NETWORKS. 3.00 points.
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
COMS W4162 Advanced Computer Graphics. 3 points.
Lect: 3.
Prerequisites: (COMS W4160) or equivalent, or the instructor's permission.
A second course in computer graphics covering more advanced topics including image and signal processing, geometric modeling with meshes, advanced image synthesis including ray tracing and global illumination, and other topics as time permits. Emphasis will be placed both on implementation of systems and important mathematical and geometric concepts such as Fourier analysis, mesh algorithms and subdivision, and Monte Carlo sampling for rendering. Note: Course will be taught every two years.

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

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

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 2022: COMS W4172
Course Number Section/Call Number Times/Location Instructor Points Enrollment
COMS 4172 001/12433 T Th 1:10pm - 2:25pm 644 Seeley W. Mudd Building Steven Feiner 3 42/40

COMS W4181 SECURITY I. 3.00 points.
Not offered during 2022-23 academic year.
Prerequisites: COMS W3157 or equivalent.
Introduction to security. Threat models. Operating system security features. Vulnerabilities and tools. Firewalls, virtual private networks, viruses. Mobile and app security. Usable security. Note: May not earn credit for both W4181 and W4180 or W4187

Fall 2022: COMS W4181
Course Number Section/Call Number Times/Location Instructor Points Enrollment
COMS 4181 001/11015 M W 1:10pm - 2:25pm Room TBA Suman Jana 3.00 0/90

COMS W4182 SECURITY II. 3.00 points.
Not offered during 2022-23 academic year.
Prerequisites: COMS W4181, COMS W4118, COMS W4119
Advanced security. Centralized, distributed, and cloud system security. Cryptographic protocol design choices. Hardware and software security techniques. Security testing and fuzzing. Blockchain. Human security issues. Note: May not earn credit for both W4182 and W4180 or W4187

Spring 2022: COMS W4182
Course Number Section/Call Number Times/Location Instructor Points Enrollment
COMS 4182 001/12434 T Th 1:10pm - 2:25pm 833 Seeley W. Mudd Building Steven Bellovin 3.00 32/100
COMS 4182 002/12434 T Th 1:10pm - 2:25pm 833 Seeley W. Mudd Building Steven Bellovin 3.00 4/99

COMS W4186 MALWARE ANALYSIS#REVERSE ENGINEERING. 3.00 points.
Not offered during 2022-23 academic year.
Prerequisites: COMS W3157 or equivalent. COMS W3827
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.
Lect: 3. Not offered during 2022-23 academic year.
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 W4232 Advanced Algorithms. 3.00 points.
Prerequisite: Analysis of Algorithms (COMS W4231).
Prerequisites: see notes re: points
Introduces classic and modern algorithmic ideas that are central to many areas of Computer Science. The focus is on most powerful paradigms and techniques of how to design algorithms, and how to measure their efficiency. The intent is to be broad, covering a diversity of algorithmic techniques, rather than be deep. The covered topics have all been implemented and are widely used in industry. Topics include: hashing, sketching/streaming, nearest neighbor search, graph algorithms, spectral graph theory, linear programming, models for large-scale computation, and other related topics

COMS W4236 Intro to Computational Complexity. 3.00 points.
Lect: 3.
Prerequisites: (COMS W3261) or (CSOR W4231). An introduction to computational hardness, identification and zero knowledge protocols. Topics include private and public key encryption schemes, computational hardness, digital signatures, authentication, pseudorandom generators and functions, one-way functions, trapdoor functions, number theory and computational hardness, identification and zero knowledge protocols

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) 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 Intro to Cryptography. 3.00 points.
Lect: 2.5.
Prerequisites: Comfort with basic discrete math and probability. Recommended: COMS W3261 or CSOR W4231.
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 W4419 Internet Technology, Economics, and Policy. 3 points. Not offered during 2022-23 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. Micro-economics with a focus on media and telecommunication 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.

Fall 2022: COMS W4419

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<th>Course Number</th>
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<th>Times/Location</th>
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<td>Henning Schulzrinne</td>
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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.

Fall 2022: COMS W4444

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<th>Course Number</th>
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<td>Kenneth Ross</td>
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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 2022: COMS W4460

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<td>William Reinisch</td>
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COMS W4560 INTRO-COMP APPL-HLTH CRE/BIOMD. 3.00 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. Undergraduates in their senior or junior years may take this course only if they have adequate background in mathematics and receive permission from the instructor. An overview of the field of biomedical informatics, combining perspectives from medicine, computer science, and social science. Use of computers and information in healthcare 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 healthcare 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.

Spring 2022: COMS W4701

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Fall 2022: COMS W4701

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<td>Ansal Salleb-Aouissi</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 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.
Lect: 3. Not offered during 2022-23 academic year.

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 I: First Principles. 3.00 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 W4762 Machine Learning for Functional Genomics. 3 points.
Prerequisites: Proficiency in a high-level programming language (Python/R/Julia). An introductory machine learning class (such as COMS 4771 Machine Learning) will be helpful but is not required.

Prerequisites: see notes re: points
This course will introduce modern probabilistic machine learning methods using applications in data analysis tasks from functional genomics, where massively-parallel sequencing is used to measure the state of cells: e.g. what genes are being expressed, what regions of DNA ("chromatin") are active ("open") or bound by specific proteins.

COMS E4762 Machine Learning for Functional Genomics. 3.00 points.
This course will introduce modern probabilistic machine learning methods using applications in data analysis tasks from functional genomics, where massively-parallel sequencing is used to measure the state of cells: e.g. what genes are being expressed, what regions of DNA ("chromatin") are active ("open") or bound by specific proteins

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 W4773 Machine Learning Theory. 3 points.
Prerequisites: Machine Learning (COMS W4771). Background in probability and statistics, linear algebra, and multivariate calculus. Ability to program in a high-level language, and familiarity with basic algorithm design and coding principles.

Prerequisites: see notes re: points
Core topics from unsupervised learning such as clustering, dimensionality reduction and density estimation will be studied in detail. Topics in clustering: k-means clustering, hierarchical clustering, spectral clustering, clustering with various forms of feedback, good initialization techniques and convergence analysis of various clustering procedures. Topics in dimensionality reduction: linear techniques such as PCA, ICA, Factor Analysis, Random Projections, non-linear techniques such as LLE, IsoMap, Laplacian Eigenmaps, TSNE, and study of embeddings of general metric spaces, what sorts of theoretical guarantees can one provide about such techniques. Miscellaneous topics: design and analysis of data structures for fast nearest neighbor search such as Cover Trees and LSH. Algorithms will be implemented in either Matlab or Python.
COMS E4773 Machine Learning Theory. 3.00 points.
Theoretical study of algorithms for machine learning and high-dimensional data analysis. Topics include high-dimensional probability, theory of generalization and statistical learning, online learning and optimization, spectral analysis.

COMS W4774 Unsupervised Learning. 3 points.
Prerequisites: Solid background in multivariate calculus, linear algebra, basic probability, and algorithms.

Prerequisites: see notes re: points
Theoretical study of algorithms for machine learning and high-dimensional data analysis. Topics include high-dimensional probability, theory of generalization and statistical learning, online learning and optimization, spectral analysis.

COMS W4775 Causal Inference. 3.00 points.
Prerequisites: Discrete Math, Calculus, Statistics (basic probability, modeling, experimental design), some programming experience.

Prerequisites: see notes re: points
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 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.

COMS W4996 Special topics in computer science, II. 3 points.
Lect: 3. Not offered during 2022-23 academic year.

Prerequisites: Instructor’s permission.
A continuation of COMS W4995 when the special topic extends over two terms.

COMS 4995 Special topics in computer science, I. 3 points.
Lect: 3.

Prerequisites: Instructor’s permission.
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.

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.

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.

Prerequisites: Instructor’s permission.
A continuation of COMS W4995 when the special topic extends over two terms.
CSEE W4140 NETWORKING LABORATORY. 3.00 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.

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.