Master's and Doctoral degrees

Why study Computer Science at the University of Denver?

DU's Department of Computer Science (CS) is creating the future of technology by providing a graduate education that emphasizes both multi-disciplinary and cross-disciplinary knowledge. The distinguished faculty are creating multi-disciplinary education programs that cover both depth and breadth, and research programs that incorporate and account for technological trends in research and development, along with industry. Graduate students join the faculty in conducting cutting-edge basic and applied research in emerging disciplines developing novel and unique solutions to old and new problems and opportunities. Additionally, students are not required to have a computer science background as we offer foundational courses to prepare students for the road ahead.

All laboratories in the Department contain state-of-the-art equipment and software to support research in algorithms, artificial intelligence, computational geometry, humane games, networks, programming languages, robotics, security and privacy, and software engineering, among other research areas. Small classes support our multi-disciplinary and real-time focus by providing close contact between students and faculty, which allows us to meet students’ individual career goals.

Denver is a first-rate location for business, government and laboratory partnerships, and technology employment. The Colorado Front Range is consistently rated as one of the top high-tech areas in the country, and DU is located just minutes from the Denver Technological Center, the site of many top technology companies. The Department of Computer Science is committed to active collaboration with these industry leaders. As a result, our students graduate with relevant research experience and a network of employment contacts in the technology sector that is second to none!

Degree Programs

We offer the following graduate computer science degrees:

- MS in Computer Science
- MS in Cybersecurity
- MS in Data Science
- PhD in Computer Science

Doctor of Philosophy in Computer Science

The PhD in Computer Science is, above all, a research degree. When the faculty award a PhD, they certify that the student has a broad foundation and awareness of core concepts in computer science, has advanced the field by performing significant original research and has reported that work in a scholarly fashion. Through this degree, students will be qualified to hold academic positions at universities across the world, to lead research groups in government or industry research laboratories, to be creators of new ideas and approaches in computer science through research, and to be leaders in technology. Our faculty are strong in research and particularly noted in software engineering, robotics, cybersecurity and privacy, and humane games.

Master of Science in Computer Science

The MS in Computer Science prepares students for advancement in academic or industrial careers. The program is designed to provide students with a breadth of advanced knowledge in computer science, while permitting them to achieve depth in areas of current interest within the computing field through electives, as well as the emerging technologies that will have great importance in the future. Students of this degree will be eminently qualified for more advanced careers using computer science given the ubiquitous nature of computing today in every single discipline. Students may also pursue a thesis option, enabling them to begin to perform research and be prepared for a PhD in Computer Science or related discipline.

Master of Science in Cybersecurity

The MS in Cybersecurity prepares students for advancement in professional careers. Network storage that holds sensitive information – from personal identities to financial records and national secrets – are increasingly vulnerable to malicious attacks. We are witnessing growing concerns and interests in cybersecurity in our globally interconnected society. The increasing dependence of our lives on information technology
infrastructures continues to stimulate strong support for this expertise. The program is designed to provide students with a breadth of knowledge in computer science, along with advanced domain knowledge in the field of information security.

**Master of Science in Data Science**

The MS in Data Science prepares students for advancement in professional careers. Data Scientists enable knowledge discovery in almost all of the subfields of science, social science, business, and policy. As businesses and government continue to turn to data-informed decision making, data scientists will become more necessary and influential within society as a whole. This program is designed to provide students with a breadth of knowledge in computer science, probability and statistics, data management and exploration, and machine learning, as well as the emerging technologies that will be gaining importance in the future.

**Doctor of Philosophy in Computer Science**

**Degree and GPA Requirements**

- Bachelor's degree: All graduate applicants must hold an earned baccalaureate from a regionally accredited college or university or the recognized equivalent from an international institution.

- Grade point average: The minimum undergraduate GPA for admission consideration for graduate study at the University of Denver is a cumulative 2.5 on a 4.0 scale or a 2.5 on a 4.0 scale for the last 60 semester credits or 90 quarter credits (approximately two years of work) for the baccalaureate degree. An earned master's degree or higher from a regionally accredited institution supersedes the minimum standards for the baccalaureate. For applicants with graduate coursework but who have not earned a master's degree or higher, the GPA from the graduate work may be used to meet the requirement. The minimum GPA is a cumulative 3.0 on a 4.0 scale for all graduate coursework undertaken.

- Program GPA requirement: The minimum undergraduate GPA for admission consideration for this program is a cumulative 2.5 on a 4.0 scale.

**Prerequisites:**

- Prerequisite courses for the PhD include: COMP 1671 Introduction to Computer Science I, COMP 1672 Introduction to Computer Science II, COMP 2673 Introduction to Computer Science III, COMP 2300 Discrete Structures in Computer Science, COMP 2370 Introduction to Algorithms & Data Structures, and COMP 2691 Introduction to Computer Organization (or equivalent).

**English Language Proficiency Test Score Requirements**

The minimum TOEFL/IELTS/C1 Advanced/Duolingo English Test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum IELTS Score: 6.5
- Minimum C1 Advanced Score: 176
- Minimum Duolingo English Test Score: 115

English Conditional Acceptance Offered: In cases where minimum TOEFL/IELTS/CAE scores were not achieved or no English proficiency test was taken, the program may offer English Conditional Admission (ECA) to academically qualified non-native English speakers.

**Master of Science in Computer Science**

**Degree and GPA Requirements**

- Bachelor's degree: All graduate applicants must hold an earned baccalaureate from a regionally accredited college or university or the recognized equivalent from an international institution.

- Grade point average: The minimum undergraduate GPA for admission consideration for graduate study at the University of Denver is a cumulative 2.5 on a 4.0 scale or a 2.5 on a 4.0 scale for the last 60 semester credits or 90 quarter credits (approximately two years of work) for the baccalaureate degree. An earned master's degree or higher from a regionally accredited institution supersedes the minimum standards for the baccalaureate. For applicants with graduate coursework but who have not earned a master's degree or higher, the GPA from the graduate work may be used to meet the requirement. The minimum GPA is a cumulative 3.0 on a 4.0 scale for all graduate coursework undertaken.

- Program GPA requirement: The minimum undergraduate GPA for admission consideration for this program is a cumulative 2.5 on a 4.0 scale.

**Prerequisites:**

- Prerequisite courses for the MS include: COMP 1671 Introduction to Computer Science I, COMP 1672 Introduction to Computer Science II, COMP 2673 Introduction to Computer Science III, COMP 2300 Discrete Structures in Computer Science, COMP 2370 Introduction to Algorithms & Data Structures, and COMP 2691 Introduction to Computer Organization (or equivalent).

**English Language Proficiency Test Score Requirements**

The minimum TOEFL/IELTS/C1 Advanced/Duolingo English Test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum IELTS Score: 6.5
Minimum C1 Advanced Score: 176
Minimum Duolingo English Test Score: 115

English Conditional Acceptance Offered: In cases where minimum TOEFL/IELTS/CAE scores were not achieved or no English proficiency test was taken, the program may offer English Conditional Admission (ECA) to academically qualified non-native English speakers.

Master of Science in Cybersecurity

Degree and GPA Requirements

- Bachelor’s degree: All graduate applicants must hold an earned baccalaureate from a regionally accredited college or university or the recognized equivalent from an international institution.
- Grade point average: The minimum undergraduate GPA for admission consideration for graduate study at the University of Denver is a cumulative 2.5 on a 4.0 scale or a 2.5 on a 4.0 scale for the last 60 semester credits or 90 quarter credits (approximately two years of work) for the baccalaureate degree. An earned master’s degree or higher from a regionally accredited institution supersedes the minimum standards for the baccalaureate. For applicants with graduate coursework but who have not earned a master’s degree or higher, the GPA from the graduate work may be used to meet the requirement. The minimum GPA is a cumulative 3.0 on a 4.0 scale for all graduate coursework undertaken.
- Program GPA requirement: The minimum undergraduate GPA for admission consideration for this program is a cumulative 2.5 on a 4.0 scale.

Prerequisites:

- Applicants must have the prerequisite knowledge equivalent to the following courses below and are required to pass a computer science placement exam prior to matriculation into the graduate program. Students with deficiencies will be eligible to complete the bridge courses prior to matriculation and are required to retake and pass the computer science placement exam prior to matriculation: COMP 1671 Introduction to Computer Science I, COMP 1672 Introduction to Computer Science II, COMP 2673 Introduction to Computer Science III, COMP 2300 Discrete Structures in Computer Science, COMP 2370 Introduction to Algorithms & Data Structures, and COMP 2691 Introduction to Computer Organization (or equivalent). Or students without the prerequisite knowledge may successfully complete the following four bridge courses and are required to pass a computer science placement exam prior to matriculation into the graduate program. Students with deficiencies will be required to demonstrate prerequisite knowledge equivalent to the courses listed above prior to matriculation and are required to retake and pass the computer science placement exam prior to matriculation. The bridge courses are COMP 2001 Bridge Course I: Computer Science Theory Basics, COMP 2002 Bridge Course II: Computer Science Theory Advanced, COMP 2003 Bridge Course III: Computer Science Systems Basics, and COMP 2004 Bridge Course IV: Computer Science Systems Advanced.

English Language Proficiency Test Score Requirements

The minimum TOEFL/IELTS/C1 Advanced/Duolingo English Test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum IELTS Score: 6.5
- Minimum C1 Advanced Score: 176
- Minimum Duolingo English Test Score: 115

Master of Science in Data Science

Degree and GPA Requirements

- Bachelor’s degree: All graduate applicants must hold an earned baccalaureate from a regionally accredited college or university or the recognized equivalent from an international institution.
- Grade point average: The minimum undergraduate GPA for admission consideration for graduate study at the University of Denver is a cumulative 2.5 on a 4.0 scale or a 2.5 on a 4.0 scale for the last 60 semester credits or 90 quarter credits (approximately two years of work) for the baccalaureate degree. An earned master’s degree or higher from a regionally accredited institution supersedes the minimum standards for the baccalaureate. For applicants with graduate coursework but who have not earned a master’s degree or higher, the GPA from the graduate work may be used to meet the requirement. The minimum GPA is a cumulative 3.0 on a 4.0 scale for all graduate coursework undertaken.
- Program GPA requirement: The minimum undergraduate GPA for admission consideration for this program is a cumulative 2.5 on a 4.0 scale.

English Language Proficiency Test Score Requirements

The minimum TOEFL/IELTS/C1 Advanced/Duolingo English Test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum IELTS Score: 6.5
• Minimum C1 Advanced Score: 176
• Minimum Duolingo English Test Score: 115

English Conditional Acceptance Offered: In cases where minimum TOEFL/IELTS/CAE scores were not achieved or no English proficiency test was taken, the program may offer English Conditional Admission (ECA) to academically qualified non-native English speakers.

**DOCTOR OF PHILOSOPHY IN COMPUTER SCIENCE**

**Degree Requirements**

**Coursework Requirements**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three quarters minimum of COMP 4600 : Seminar in Computer Science</td>
<td></td>
<td></td>
</tr>
<tr>
<td>At least 36 credits must be at the 4000-level courses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up to 24 credits may be taken in other relevant disciplines, as approved by the Computer Science Department Graduate Committee.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Courses should be chosen in consultation with, and are subject to the approval of, the student's advisor.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Credits</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>

Minimum credit hours required: 90 beyond BA or BS degree

**Additional degree requirements applicable to PhD students without a master's degree in Computer Science**

- Must complete the requirements of the Master of Science in Computer Science with a thesis at a reasonable pace to remain on pace to complete the PhD in Computer Science on the expected timeline established by the advisor.

**Additional Degree Requirements applicable to PhD Students with a 2-year master's degree in Computer Science or related field**

- May take a proficiency test in the four required courses for master's degree (COMP 3351 Programming Languages, COMP 3361 Operating Systems I, COMP 3371 Data Structures & Algorithms and COMP 3200 Discrete Structures). The test may be offered at a time other than the official final exam time of the term. A grade of B+ (B plus) or better must be obtained in the test.
- If the student chooses not to take the proficiency test, the student must register and attend classes for the four required courses (COMP 3351 Programming Languages, COMP 3361 Operating Systems I, COMP 3371 Data Structures & Algorithms and COMP 3200 Discrete Structures). A grade of B+ (B plus) or better must be obtained in the courses.

**Non-coursework Requirements:**

- Written dissertation and oral defense that makes a significant contribution to the research literature in computer sciences
- Tool requirement
- Qualifying examination
- Preliminary examination

**Qualifying & Dissertation Examinations**

**Qualifying Examination**

Every PhD student must pass the qualifying exam. It consists of two parts, the breadth requirement and the written and oral exam.

a. Breadth Requirement: To fulfill the breadth requirement the student must take 5 graded courses (20 quarter credits) at the 3000- and 4000-level (not including independent study, internship, or independent research). At most, two may be at the 3000-level. At least three must be at the 4000-level. The course work should cover at least three distinct areas. Five areas should include a sequence of 3000- and 4000-level courses. The GPA in these courses must be at least 3.7/4.0. No course with a grade below a B may be used to fulfill this requirement. Graduate Computer Science courses taken at another university and transferred for credit at DU may be applied to the breadth requirement up to a maximum of 2 courses (8 quarter credits).

b. Written and Oral Exam: Before being admitted to this exam, the student must have fulfilled the breadth requirement.

The student selects an area of examination from the list of areas in Table 1. The written part of the exam is a take-home exam. It is a handed out on a Friday and is due the following Tuesday. The oral exam is held the following Friday. The take-home exam consists of a set of research questions, a set of related papers and instructions. The student should prepare a written report of at least 10 but no more than 20 pages with answers to the questions. Study guides or other relevant material to prepare for the exam can be obtained from the chair of the examination committee. The oral portion of the exam is based on a student presentation in which the student explains and defends his/her answers. During the oral exam, questions in other areas of computer science may also be asked.

A failed exam may be retaken once (in the same or another area). Sufficiently prior to the exam date, the department chair will appoint an examination committee of three tenure-track faculty. One of the committee members must be in the area in which the examination will be held. The student's advisor is allowed to be on the committee. The committee creates the take home exam and grades it. After the oral exam, the committee makes
a recommendation to the Computer Science faculty on whether the student passes or fails. If the faculty agrees, the committee recommendation stands. If there is a disagreement, the faculty as a whole decides.

Preliminary Examination
Following successful completion of the Qualifying Examination, each student will prepare a dissertation proposal and take the preliminary examination. Passing this examination admits the student to Ph.D. candidacy. The dissertation proposal should be prepared in close consultation with the student’s advisor and should be available to all committee members at least two weeks prior to the examination. It should reflect an extensive critical literature survey, and contain an accurate assessment of the state-of-the-art in the area of research, a precise statement of the problem to be solved, motivation for pursuing the research, and evidence to the effect that there is a good likelihood the problem is solvable with reasonable effort.

For full-time students, the preliminary examination must be taken within 5 quarters of passing the qualifying examination. Successful completion of the preliminary examination results in agreement between the student and the committee as to what will constitute successful completion of the dissertation research. The committee may choose to reconvene the examination to allow the student to further research the problem, complete additional course work, or revise the dissertation proposal document.

The examining committee consists of at least three Computer Science faculty members, including the advisor. The preliminary exam is a one hour oral closed exam. If a student passed the preliminary exam, but subsequently switches advisor and hence topic, the preliminary exam must be repeated within one year to ensure capability of the student and feasibility of the project.

Dissertation Defense
After the dissertation has been completed, the student must defend it in a final examination, as specified by the Office of Graduate Studies.

Tool Requirement
It is strongly recommended that students satisfy their tool requirement by demonstrating proficiency in a modern computer typesetting system suitable for writing technical papers that include mathematical equations and graphics. The faculty advisor must approve the specific system used to satisfy this requirement. Other options include reading competency in two languages selected from French, German, and Russian; a series of outside courses in another discipline; or significant laboratory experience involving computer science.

Master of Science in Computer Science

Degree Requirements
Coursework Requirements
The Master of Science in Computer Science offers great flexibility in studying computer science beyond an undergraduate degree. Students without a background in computer science will typically begin with foundational courses that prepare them for more advanced work in computer science. An assessment is taken through the department that helps them determine where to begin.

Students are required to take 16 credits of required courses and 32 credits of electives. Of these 32 credits of elective computer science courses, 12 must be at the 4000-level, including 4 credits designated as "Theory". In addition, 8 of the 32 credits must be designated as advanced programming (and may also be 4000-level credits). Students wishing to pursue a thesis may apply up to 12 credits of Independent Research (COMP 4995) towards their 32 elective credits. Finally, students must take 3 quarters of Seminar in Computer Science (COMP 4600).

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Foundational Courses ¹</td>
<td>16</td>
</tr>
<tr>
<td>COMP 3003</td>
<td>Foundations in Computer Systems</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3004</td>
<td>Foundations in Discrete Structures &amp; Algorithms</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3005</td>
<td>Foundations in Python Programming</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Required Courses</td>
<td>16</td>
</tr>
<tr>
<td>COMP 3200</td>
<td>Discrete Structures</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3351</td>
<td>Programming Languages</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3361</td>
<td>Operating Systems I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3371</td>
<td>Data Structures &amp; Algorithms</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Electives</td>
<td>32</td>
</tr>
</tbody>
</table>

Students must complete graduate-level electives to satisfy the following requirements.

**4000-level requirement**
12 computer science elective credits at the 4000-level (excluding COMP 499X) are required, of which one must be designated as "Theory" (see below).

**Theory Requirement**
4 credits of COMP at the 4000-level designated as "Theory". The current pre-approved list of theory courses includes, but is not limited to:

- COMP 4705 Advanced Topics-Programming (Advanced Programming Languages, Performance Modeling & Analysis)
Advanced Programming Requirement

8 credits of COMP electives must include an advanced programming component. These courses must be approved by an advisor. The current pre-approved list includes but is not limited to:

- COMP 3352: Elements of Compiler Design
- COMP 3353: Compiler Construction
- COMP 3411: Web Programming II
- COMP 3432: Machine Learning
- COMP 3621: Computer Networking
- COMP 3801: Introduction Computer Graphics
- COMP 4510: Software for AI Robotics
- COMP 4621: Computer Networking

Seminar Attendance Requirement

- COMP 4600: Seminar in Computer Science

Non-Thesis Option

A maximum of 12 quarter hours may be earned in Independent Study (COMP 4991), provided the student can find an advisor for such independent study. No thesis is required. Not eligible for support (GTA, GRA).

Thesis Option

A maximum of 12 credits may be earned for thesis credits (COMP 4995 - Independent Research). A thesis of publishable quality and oral defense are required. A student receiving any support from the department (GTA, GRA) must complete the degree requirements as per the Thesis Option.

Total Credits

48-60

Foundation Courses serve to provide a mathematical and programming background for students without a computer science undergraduate degree. Foundation course needs are determined by pre-assessments. Students may test out of one or more Foundation courses.

Thesis-track students must complete three quarters of COMP 4600 - Seminar (0 credits).

GTA’s/GRA’s are required to attend all seminars.

Outside Coursework

A maximum of 8 quarter hours may be earned in approved courses outside the COMP designation, including transfer credits from another university. Such credit must be approved in writing by an advisor from the computer science faculty.

Students should follow the rules and regulations stated in the departmental Graduate Student Manual.

Non-Coursework Requirements

Thesis Option

- Thesis and Oral Defense

Non-Thesis Option

- None

Master of Science in Computer Science Systems Engineering

Degree requirements

Coursework requirements

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 3361</td>
<td>Operating Systems I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3381</td>
<td>Software Engineering I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3705</td>
<td>Topics in Computer Science</td>
<td>1-4</td>
</tr>
</tbody>
</table>

Application area core (pre-approval required)

The pre-approved application core:

- ENMT 4100: Systems Engineering
- ENMT 4000: Space Systems Design I
or ENMT 4010 Space Systems Design II

Theory Course (e.g., COMP 3702) 4
COMP 3702 Topics in Database

Capstone 2
Independent study 2
Computer science electives 12

Total Credits 45

Minimum credits required for degree: 45
Non-coursework Requirements
- Capstone

MASTER OF SCIENCE IN CYBERSECURITY

Degree Requirements
Coursework Requirements
Minimum credits required for degree: 48-60

<table>
<thead>
<tr>
<th>Code</th>
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<tbody>
<tr>
<td>COMP 3003</td>
<td>Foundations in Computer Systems</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3004</td>
<td>Foundations in Discrete Structures &amp; Algorithms</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3005</td>
<td>Foundations in Python Programming</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3006</td>
<td>Python Software Development</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3356</td>
<td>Introductory C/C++ Programming</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3361</td>
<td>Operating Systems I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3731</td>
<td>Computer Forensics</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4455</td>
<td>Shell Scripting and System Tools</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4384</td>
<td>Secure Software Engineering</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4621</td>
<td>Computer Networking</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4721</td>
<td>Computer Security</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4722</td>
<td>Network Security</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4723</td>
<td>Ethical Hacking</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4732</td>
<td>Human-Centered Data Security and Privacy</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4799</td>
<td>Capstone Project in Cybersecurity</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48-60</td>
</tr>
</tbody>
</table>

1 Foundational Courses serve to provide a computer science foundation for students without a computer science background. Foundational Course needs are determined by pre-assessment by the department. Students may test out of one or more Foundational Courses.

2 Capstone Project in Cybersecurity (COMP 4799) is required; however, with advisor approval, Internship/Co-Op in Computing (COMP 3904) may be substituted for the capstone.

No thesis is required.

Students should follow the rules and regulations stated in the departmental Graduate Student Manual.

GTA/GRA Support
Due to the intensive nature of this program, Cybersecurity students are not eligible for graduate teaching or research support.

Consult with Financial Aid at fnaid@du.edu or at 303-871-4020 to discuss financial aid options.

MASTER OF SCIENCE IN DATA SCIENCE

Degree Requirements
The MS in Data Science requires 48 credits. Students without prerequisite knowledge may take Foundations in Python Programming (COMP 3005) at DU prior to fully matriculating into the program.
Computer Science

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 3007</td>
<td>Foundations in Data Science Mathematics I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3008</td>
<td>Foundations in Data Science Mathematics II</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3006</td>
<td>Python Software Development</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3421</td>
<td>Database Organization &amp; Management I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4432</td>
<td>Machine Learning</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4433</td>
<td>Data Visualization</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4441</td>
<td>Introduction to Probability and Statistics for Data Science</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4442</td>
<td>Advanced Probability and Statistics for Data Science</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4531</td>
<td>Deep Learning: Model Design and Application</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4581</td>
<td>Algorithms for Data Science</td>
<td>4</td>
</tr>
</tbody>
</table>

**Elective Courses**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>COMP 4334</td>
<td>Parallel and Distributed Computing for Data Science</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4447</td>
<td>Data Science Tools 1</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4449</td>
<td>Data Science Capstone</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3904</td>
<td>Internship/Co-Op in Computing ¹</td>
<td>4</td>
</tr>
</tbody>
</table>

Total Credits: 48

¹ Only one for-credit Internship/Co-Op in Computing (COMP 3904) can be applied towards the graduation requirements.

**Master of science in data science (Online)**

**Degree Requirements**

The MS in Data Science (Online) requirements are identical to those listed in the Master of Science in Data Science listed above.

**4+1 Dual degree BS in Computer Science + MS in Computer Science**

The Department of Computer Science at the University of Denver offers a Dual Degree Bachelor of Science in Computer Science (http://bulletin.du.edu/undergraduate/majorsminorscoursedescriptions/traditionalbachelorsprogrammajorandminors/computerscience/#programofstudytext) and Master of Science in Computer Science (p. 5). The BS/MS combines the strong foundation of a BS in Computer Science and further depth and breadth in more advanced computer science topics through the MS in Computer Science.

**Total Credit Hours:** 183 at the undergraduate level (UG) for the Bachelor degree + 36 at the graduate level (GR) for the Master of Science degree = 219 credits

**Undergraduate Requirements**

Students who intend to obtain a BS/MS in Computer Science must satisfy all the requirements of the Bachelor of Science degree as outlined in the University of Denver Undergraduate Bulletin (http://bulletin.du.edu/undergraduate/), which includes completing two minors and all of the requirements for the Bachelor of Science in Computer Science (http://bulletin.du.edu/undergraduate/majorsminorscoursedescriptions/traditionalbachelorsprogrammajorandminors/computerscience/#programofstudytext) degree, including the Mathematics cognate requirements. In addition, 12 credits of the Breadth requirements for the BS in Computer Science are taken from the following list of required courses by the MS in Computer Science, but may be substituted for cross-listed COMP 3000-level undergraduate/graduate courses if these courses were taken prior to entry into the 4+1 program:

12 credits of the required MS in Computer Science courses that may be used for the Breadth requirement of the BS in Computer Science:

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<tr>
<th>Code</th>
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<tr>
<td>COMP 3200</td>
<td>Discrete Structures</td>
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<tr>
<td>COMP 3351</td>
<td>Programming Languages</td>
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<td>COMP 3361</td>
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<tr>
<td>COMP 3371</td>
<td>Data Structures &amp; Algorithms</td>
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**Graduate Requirements**

The student must complete 36 credit hours at the graduate level of required coursework for the MS. These 36 hours include the required courses for the MS in Computer Science (the 4 classes listed above), unless they were taken as part of the Breadth requirement for the BS in Computer Science. In this case, other graduate-level courses will be substituted for them to meet the 36 credit hour requirement of the degree. Internship/Co-Op in Computing (COMP 3904) may not be used to substitute for these requirements.
Advanced Programming, Theory, and 4000-level Elective Requirements
As with the MS in Computer Science, students are also required to satisfy the Advanced Programming, Theory, and 4000-level elective requirements of the MS in Computer Science (p. 5) in their 36 credit hours of graduate coursework.

All electives, especially the MATH and COMP electives, should be selected in close consultation with an academic advisor from the Computer Science Department.

Sample schedule
The following is a sample schedule for the BS in Computer Science + MS in Computer Science. Note that other MS requirements would replace the Theory and Adv. Programming requirements, instead coming from the requirements of those degrees.

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<th>First Year</th>
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Total Credits: 219

Faculty
Mohammed Mousa Ismail Albow, Teaching Associate Professor, MS, University of Denver
Sean L. Connin, Teaching Professor, PhD, Dartmouth College
Don A. Dalton, Visiting Teaching Assistant Professor, MBA, University of Colorado Boulder
Sanchari Das, Assistant Professor, PhD, Indiana University
Rinku Dewri, Associate Professor, PhD, Colorado State University
Catherine S. Durso, Teaching Professor, PhD, Massachusetts Institute of Technology
Courses

COMP 3001 C and C++ Programming Foundations for New Graduate Students (4 Credits)
This accelerated course covers the basics of discrete mathematics including functions, relations, counting, logic, proofs etc that is necessary to attend CS graduate school. In addition, it includes an introduction to programming and algorithm analysis. Enrollment restricted to graduate students.

COMP 3002 C and C++ Foundations II for New Graduate Students (4 Credits)
This accelerated course continues to build on the basics of discrete mathematics by covering material including advanced counting, recurrences, graphs, trees, traversals, automata etc. that is necessary to attend Computer Science graduate school. In addition, it includes an introduction to additional algorithms and data structures. Prerequisite: COMP 3001.

COMP 3003 Foundations in Computer Systems (4 Credits)
This course introduces computer systems, including instruction set architectures; memory hierarchies including registers, caching, virtual memory, paging, and segmentation; number representations; binary arithmetic and operations; assembly language instructions; and pipelining in the CPU.

COMP 3004 Foundations in Discrete Structures & Algorithms (4 Credits)
Both discrete mathematics and an understanding of algorithms along with their analysis form principle foundations in computer science. In this course, the fundamentals of discrete mathematics including functions, relations, counting, logic, proofs, counting, recurrences, and probability are covered. In addition, beginning data structures and algorithms are covered including linked-lists, graphs, hash-tables, sorting, and binary search. An analysis of these data structures and algorithms is also covered through big-O notation and proof methods.

COMP 3005 Foundations in Python Programming (4 Credits)
This accelerated course covers the basics of Python programming. By the end of the course students will be able to develop, design and implement Python programs, explain the differences between data types, learn to read from and write to files, understand and use data structures, understand and use recursion, and use Python packages.

COMP 3006 Python Software Development (4 Credits)
This accelerated course covers advanced Python programming for data scientists and cybersecurity professionals. Course Objectives: name and demonstrate proficiency using advanced Python programming techniques; analyze a programming task and create a development plan and high-level software design that accomplishes the task; relate common portions of the Python standard library to specific programming tasks; understand and apply aspects of the Python scientific programming ecosystem to achieve an analysis goal. Prerequisite: COMP 3005.

COMP 3007 Foundations in Data Science Mathematics I (4 Credits)
This course presents the elements of calculus essential for work in data science. Students will study differentiation and integration in the context of probability density and of optimization.
COMP 3008 Foundations in Data Science Mathematics II (4 Credits)
This course presents the elements of linear algebra and discrete math essential for subsequent coursework in data science.

COMP 3200 Discrete Structures (4 Credits)
Discrete mathematical structures and non-numerical algorithms; graph theory, elements of probability, propositional calculus, Boolean algebras; emphasis on applications to computer science. Cross-listed as MATH 3200. Prerequisites: (COMP 2300 or MATH 2200) and (COMP 2673 or COMP 1353).

COMP 3351 Programming Languages (4 Credits)
Learn the fundamentals of programming languages through functional programming through an in-depth understanding of syntax and semantics around program structures and how programming languages are parsed and interpreted. Understand recursion as a fundamental problem-solving paradigm and the important role that higher order types and kinds play in eliminating errors and simplifying software development. Prerequisites: COMP 2370 and ((COMP 2355, COMP 2691) or COMP 2362).

COMP 3352 Elements of Compiler Design (4 Credits)
Techniques required to design and implement a compiler; topics include lexical analysis, grammars and parsers, type-checking, storage allocation and code generation. Prerequisite: COMP 3351.

COMP 3353 Compiler Construction (4 Credits)
Design and implementation of a major piece of software relevant to compilers. Prerequisite: COMP 3352.

COMP 3356 Introductory C/C++ Programming (4 Credits)
This course introduces unmanaged programming language concepts to students whose primary programming experience is in a managed language (Java/Python, etc.). Concepts like type safety, manual memory management and “unsafe” library functions are covered. Common pitfalls in these languages from which most security issues arise are explained and students gain experience in understanding such code and evaluating it for program errors. Students will also be introduced to important compiled language concepts of static/dynamic linking, compilation and debugging. Prerequisites: COMP 3006.

COMP 3361 Operating Systems I (4 Credits)
Operating systems functions and concepts; processes, process communication, synchronization; processor allocation, memory management in multiprogramming, time sharing systems. Prerequisites: for undergraduates: (COMP 2355 and COMP 2691) or COMP 2361; COMP 2370; for graduate students: COMP 3003, 3004, and 3005.

COMP 3371 Data Structures & Algorithms (4 Credits)
Design and analysis of algorithms and data structures; asymptotic complexity, recurrence relations, lower bounds; algorithm design techniques such as incremental, divide-and-conquer, dynamic programming, iterative improvement, greedy algorithms; randomized data structures and algorithms. Prerequisites: COMP 2370 or equivalent and COMP 3200.

COMP 3372 Advanced Algorithms (4 Credits)
Advanced techniques for the design and analysis of algorithms and data structures; amortized complexity, self-adjusting data structures; randomized, online, and string algorithms; NP-completeness, approximation and exact exponential algorithms; flow networks.

COMP 3381 Software Engineering I (4 Credits)
An introduction to software engineering. Topics include software processes, requirements, design, development, validation and verification and project management. Cross-listed with COMP 4381. Prerequisites: COMP 3351; COMP 3361 or COMP 2362; or instructor permission.

COMP 3382 Software Engineering II (4 Credits)
Continuation of COMP 3381. Topics include component-based software engineering, model-driven architecture, and service-oriented architecture. Prerequisite: COMP 3381.

COMP 3400 Advanced Unix Tools (4 Credits)
Design principles for tools used in a UNIX environment. Students gain experience building tools by studying the public domain versions of standard UNIX tools and tool-building facilities. Prerequisites: COMP 2400 and knowledge of C and csh (or another shell), and familiarity with UNIX.

COMP 3411 Web Programming II (4 Credits)
In this course you will learn how to develop a full-stack web application that is capable of serving dynamic content from a database. Furthermore, you will learn the core design concepts and principles that will enable you to develop scalable and easy to maintain web applications - a set of skills that will serve you well in both your personal and professional projects in the future. Prerequisite: COMP 3410.

COMP 3412 Web Projects: Web Development III (4 Credits)
In this course you will learn how to develop, as a group, a full-stack web application that is capable of serving dynamic content from a database. We will use the MongoDB, ExpressJS, Angular, and Node.js (MEAN) software stack to work on a real-life problem presented to us by an external product owner. In the class we will use the Scrum framework for Agile development to work, as a software team, through several sprints of development. You will be peer reviewing each other throughout the course, and the product owner will also be reviewing your product through end-of-sprint demos as features are completed. The goal for this class is for it to be a fun, collaborative, and educational environment that demonstrates what it is like to work as a real software team. Prerequisite: COMP 3411.
COMP 3421 Database Organization & Management I (4 Credits)
An introductory class in database management systems covering both relational and non-relational databases with an emphasis on relational. Topics include database design, ER modeling, relational algebra, SQL, scripting, and embedded SQL. Each student will design, load, query and update a nontrivial database using a relational database management system (RDBMS). In addition, an introduction to a NoSQL database will be included. Graduate students will read one or two relevant technical papers and write a summary report. Prerequisites: for undergraduates: COMP 1353 or COMP 2673; for graduates: COMP 3005.

COMP 3424 NoSQL Databases (4 Credits)
In this course, students learn what NoSQL databases are, learn to identify the differences between them, and gain a fundamental understanding between SQL, relational databases, and NoSQL databases. Students further explore which type of NoSQL database is the correct one given a use-case, examining types, methods of communicating with it, contrasts to other NoSQL databases, performance and scalability. Prerequisites: for undergraduates, COMP 2355 or COMP 2361; for graduates: COMP 3005.

COMP 3431 Data Mining (4 Credits)
Data Mining is the process of extracting useful information implicitly hidden in large databases. Various techniques from statistics and artificial intelligence are used here to discover hidden patterns in massive collections of data. This course is an introduction to these techniques and their underlying mathematical principles. Topics covered include: basic data analysis, frequent pattern mining, clustering, classification, and model assessment. Prerequisites: COMP 2370.

COMP 3501 Introduction to Artificial Intelligence (4 Credits)
Introduces a variety of Artificial Intelligence concepts and techniques, relevant to a broad range of applications. Students survey multiple techniques including search, knowledge representation and reasoning, probabilistic inference, machine learning, and natural language processing. Examines concepts of constraint programming, evolutionary computation and non-standard computation. Prerequisites: COMP 2673 or COMP 1353.

COMP 3621 Computer Networking (4 Credits)
An introduction to computer networks with an emphasis on Internet protocols. Topics include: internet design, application layer protocols such as SMTP and HTTP, session layer protocols including TCP and UDP, the internet protocol (IP), link layer technology such as Ethernet, and security issues related to networking. Programming experience of client/server architectures using sockets and TCP/UDP through projects is emphasized. Prerequisites: for undergraduates: (COMP 2355 or COMP 2361) and COMP 2370; for graduates COMP 3004 and COMP 3006. Cross listed with COMP 4621.

COMP 3681 Networking for Games (4 Credits)
Implementing the networking code for multiplayer games is a complex task that requires an understanding of performance, security, game design, and advanced programming concepts. In this course, students are introduced to the networking stack and how this is connected to the Internet, learn how to write protocols for games, and implement several large games using a game engine that demonstrate the kind of networking and protocols required by different genres of games. In addition, tools are introduced that help understand and debug networking code, simplify the creation of protocols, and make the development of networking code easier.

COMP 3701 Topics in Computer Graphics (4 Credits)

COMP 3702 Topics in Database (4 Credits)

COMP 3703 Topics-Artificial Intelligence (4 Credits)

COMP 3704 Advanced Topics: Systems (4 Credits)

COMP 3705 Topics in Computer Science (1-4 Credits)

COMP 3731 Computer Forensics (4 Credits)
Computer Forensics involves the examination of information contained in digital media with the aim of recovering and analyzing latent evidence. This course will provide students an understanding of the basic concepts in preservation, identification, extraction and validation of forensic evidence in a computer system. The course covers many systems level concepts such as disk partitions, file systems, system artifacts in multiple operating systems, file formats, email transfers, and network layers, among others. Students work extensively on raw images of memory and disks, and in the process, build components commonly seen as features of commercial forensics tools (e.g. file system carver, memory analyzer, file carver, and steganalysis). Prerequisites: COMP 3361; COMP 2355 or 2361 for undergraduates; COMP 3006 for graduates.

COMP 3801 Introduction Computer Graphics (4 Credits)
Fundamentals of 3D rendering including the mathematics behind coordinate systems, projections, clipping, hidden surface removal, shadows, lighting models, shading models, and mapping techniques. Significant use of 3D APIs through shader programming is covered along with the basics of 3D model representation and animations. Satisfies "Advanced Programming" requirements for graduate students. Prerequisites: COMP 2370, MATH 1952 or 1962.

COMP 3821 Game Programming I (4 Credits)
Introduces the fundamentals of digital game programming that are essential as future game programmers or game designers. Students have the opportunity to learn game engine architecture, 2D and 3D linear algebra for graphics, sprites and animations, input handling, finite state machines, particle systems, user interfaces, game audio, and artificial intelligence for games. Prerequisites: COMP 2370 and COMP 2821.
COMP 4581. Classification and Regression. Techniques covered, at the discretion of the instructor, may include approaches such as linear and logistic regression.

This course will give an overview of machine learning techniques, their strengths and weaknesses, and the problems they are designed to solve. This course qualifies for the Computer Science "Advanced Programming" requirement. Prerequisite: COMP 3821. Suggested corequisite or prerequisite: COMP 3801.

COMP 3822 Game Programming II (4 Credits)
In this course, students learn how to work with a 3D game engine and build 3D games. Topics include algorithms, mathematics for 3D game engines, scene management, animations, 3D shaders, particle systems, physics for games, UIs, terrain systems, and working with higher-level scripting languages on top of the low-level implementation language. Prerequisites: COMP 3821. Suggested corequisite or prerequisite: COMP 3801.

COMP 3904 Internship/Co-Op in Computing (0-10 Credits)
Practical experience in designing, writing and/or maintaining substantial computer programs under supervision of staff of University Computing and Information Resources Center. Prerequisites: COMP 2370 and approval of internship committee (see department office).

COMP 3991 Independent Study (1-10 Credits)
Cannot be arranged for any course that appears in the regular course schedule for that particular year.

COMP 4100 Human-Computer Interaction (4 Credits)
Introduces students in computer science and other disciplines to principles of and research methods in human-computer interaction (HCI). HCI is an interdisciplinary area concerned with the study of interaction between humans and interactive computing systems. Research in HCI looks at cognitive and social phenomena surrounding human use of computers with the goal of understanding their impact and creating guidelines for the design and evaluation of software, interfaces, physical products, and services in industry. No prerequisites are required to take the course and students from all disciplines are welcome. Cross listed with COMP 3100.

COMP 4333 Parallel and Distributed Computing (4 Credits)
Current techniques for effective use of parallel processing and large scale distributed systems. Programming assignments will give students experience in the use of these techniques. Specific topics will vary from year to year to incorporate recent developments. This course qualifies for the Computer Science "Advanced Programming" requirement. Prerequisites: COMP2370 and COMP2355, or equivalent.

COMP 4334 Parallel and Distributed Computing for Data Science (4 Credits)
Current techniques for effective use of parallel processing and large-scale distributed systems for data science. Programming assignments will give students experience in the use of these techniques. Specific topics will vary from year to year to incorporate recent developments. This course is not to be used for the MS Computer Science. Prerequisite: COMP 4581.

COMP 4335 Advanced System Programming (4 Credits)
This course covers programming in a UNIX environment, including use of common command line utilities, scripting, source control via Git, and integration of POSIX system calls into C/C++ code. These features will be leveraged to solve practical problems cleanly and efficiently. More emphasis will be placed on using these features than on how those features work. Prerequisites: COMP 3001, 3002, 3003, and 3004.

COMP 4362 Operating Systems II (4 Credits)
Continuation of COMP 3361. Case studies of existing operating systems programming. Prerequisite: COMP 3621.

COMP 4370 Algorithmic Problem Solving (4 Credits)
The course is intended for students who are familiar with programming syntax but have not had much experience writing computer programs to solve a problem stated as a high-level description. The course will run through multiple such problem descriptions, discuss the design of programs to solve those problems using popular data structures, and have students implement those designs using a programming language. This course does not count for MS Computer Science requirements. Prerequisites: COMP 3001, 3002, 3003, and 3004.

COMP 4372 Advanced Algorithms (4 Credits)
Advanced techniques for the design and analysis of algorithms and data structures; amortized complexity, self-adjusting data structures; randomized, online, and string algorithms; NP-completeness, approximation and exact exponential algorithms; flow networks. Prerequisite: COMP 3371. Cross listed with COMP 3372.

COMP 4384 Secure Software Engineering (4 Credits)
This course is concerned with systematic approaches for the design and implementation of secure software. While topics such as cryptography, networking, network protocols and large scale software development are touched upon, this is not a course on those topics. Instead, this course is on identification of potential threats and vulnerabilities early in the design cycle. The emphasis in this course is on methodologies and paradigms for identifying and avoiding security vulnerabilities, formally establishing the absence of vulnerabilities, and ways to avoid security holes in new software. There are programming assignments designed to make students practice and experience secure software design and development. Prerequisites: COMP 3006, COMP 3361, COMP 3356.

COMP 4431 Data Mining (4 Credits)
Data Mining is the process of extracting useful information implicitly hidden in large databases. Various techniques from statistics and artificial intelligence are used here to discover hidden patterns in massive collections of data. This course is an introduction to these techniques and their underlying mathematical principles. Topics covered include: basic data analysis, frequent pattern mining, clustering, classification, and model assessment. Prerequisites: COMP 4441 and COMP 4581.

COMP 4432 Machine Learning (4 Credits)
This course will give an overview of machine learning techniques, their strengths and weaknesses, and the problems they are designed to solve. This will include the broad differences between supervised/unsupervised and reinforcement learning as well as associated learning problems such as classification and regression. Techniques covered, at the discretion of the instructor, may include approaches such as linear and logistic regression, neural networks, support vector machines, kNN, decision trees, random forests, Naïve Bayes, EM, k-Means, and PCA. After course completion, students will have a working knowledge of these approaches and experience applying them to learning problems. Enforced Prerequisites: COMP 4442 and COMP 4581.
COMP 4433 Data Visualization (4 Credits)
This course explores visualization techniques and theory. The course covers how to use visualization tools to effectively present data as part of quantitative statements within a publication/report and as an interactive system. Both design principles (color, layout, scale, and psychology of vision) as well as technical visualization tools/languages will be covered. Prerequisites: COMP 3006.

COMP 4441 Introduction to Probability and Statistics for Data Science (4 Credits)
The course introduces fundamentals of probability for data science. Students survey data visualization methods and summary statistics, develop models for data, and apply statistical techniques to assess the validity of the models. The techniques will include parametric and nonparametric methods for parameter estimation and hypothesis testing for a single sample mean and two sample means, for proportions, and for simple linear regression. Students will acquire sound theoretical footing for the methods where practical, and will apply them to real-world data, primarily using R. Prerequisites: COMP 1671, MATH 1951, MATH 1952; or Data Science Bridge Courses COMP 3005, 3007, and 3008.

COMP 4442 Advanced Probability and Statistics for Data Science (4 Credits)
This course builds on material in Probability and Statistics 1. Students will carry out model fitting and diagnostics for multiple regression, ANOVA, ANCOVA, and generalized linear models. Dimension reductions techniques such as PCA and Lasso are introduced, as are techniques for handling dependent data. The course introduces the principles of resampling and Bayesian Analysis. Students will acquire sound theoretical footing for the methods where practical, and will apply them to real-world data, primarily using R. Enforced Prerequisites: COMP 4441.

COMP 4447 Data Science Tools 1 (4 Credits)
Organizations are using data science to extract actionable insight from data. To highlight the hidden patterns in the data, this course equips students with essential skills for data collection, cleanup, transformation, feature engineering, summarization, and visualization. Students will do assignments and a final project. This is a hands-on course. Students will use Python libraries, Linux commands, and various data sets to perform these activities. Enforced Prerequisites: COMP 3006 and COMP 3008. Co-requisite: COMP 4441.

COMP 4448 Data Science Tools 2 (4 Credits)
Building a successful predictive model is a multi-faceted process. This course focuses on hypothesis testing and the development of predictive models. Students will also learn how to perform graph-based modeling and optimization. Students will do assignments and a final project. This is a hands-on course. Students will use Python libraries, Linux commands, and various data sets to perform these activities. Prerequisite: COMP 4447.

COMP 4449 Data Science Capstone (4 Credits)
Students identify and fill a demand for an innovative data science product, such as a data base tool, analytical software, or domain specific analysis. The product is defined, implemented, documented, tested, and presented by the student or student team with the instructor and other stakeholders acting as a project supervisors to verify that goals are met through the 10-week development process. Prerequisites: COMP 4442, COMP 4448, and COMP 4581.

COMP 4455 Shell Scripting and System Tools (4 Credits)
This course covers navigating and utilizing tools in a UNIX environment, including use of common command line utilities, Bash and Python shell scripting, source control via Git, pipes and I/O redirection, networking in Python and OS multi-processing/multi-threading. More emphasis will be placed on using these tools than on how those tools work. Prerequisite: COMP 3006.

COMP 4510 Software for AI Robotics (4 Credits)
This course provides an introduction to the key artificial intelligence issues involved in the development of intelligent robotics. We will examine a variety of algorithms for autonomous mobile robot behavior, exploring issues that include software control architectures, localization, navigation, sensing, planning, and uncertainty. We also introduce the Robot Operating System (ROS) middleware, which is popular in academic, industry, and government research. This course does not assume any prior knowledge of artificial intelligence or robotics. The course will be project focused. In the project assignments you will learn ROS and learn to implement algorithms essential for conducting AI robotics research. Prerequisites: COMP 3005 and proficiency in Python and Unix command-line tools.

COMP 4531 Deep Learning: Model Design and Application (4 Credits)
This course addresses the foundational concepts and components of Artificial Neural Networks (ANN), highlighting their capabilities, strengths, and weaknesses as a machine learning algorithm. Students taking this course will develop ANN models from scratch in Python as a basis for understanding their design as well as the underlying mechanics and calculations that shape their behavior. Key topics such as forward-backward propagation, loss function characteristics and optimization will be considered in relation to model design and computational efficiency as well as to problems such as exploding and vanishing gradients. Training strategies (e.g., dropout, initialization, batch normalization) will further enable students to assess trade-offs in model bias & variance. Coupled with hands-on assignments, these building blocks provide the knowledge and skills required to effectively design and implement ANN models that are ethically and technically sound. As well as foreground important architectures such as Convolutional ANNs, Recurrent ANNs, LSTMs, and Transformers as well as their applicability to modern problems. Student learning and proficiency will be assessed based on a combination of quizzes, coding assignments, exams, and a culminating project. Prerequisite: COMP 4432.

COMP 4581 Algorithms for Data Science (4 Credits)
This course introduces the design and analysis of algorithms within the context of data science. Topics include: asymptotic complexity and algorithm design techniques such as incremental, divide and conquer, dynamic programming, randomization, greedy algorithms, and advanced sorting techniques. Examples to illustrate techniques are drawn from multi-dimensional clustering (k-means and probabilistic), regression, decision trees, order statistics, data mining using apriori algorithms, and algorithms for generating combinatorial objects. Prerequisites: COMP 3006 and 3008.
COMP 4591 Computational Geometry (4 Credits)
This class deals with the design and implementation of efficient algorithms for problems defined over geometric objects, such as points, lines, polygons, surfaces, etc. The methods and algorithms covered find applications in many areas, including computer graphics (e.g., hidden surface removal), computer-aided design and manufacturing (e.g., 3D printing), machine learning (e.g., supervised and unsupervised classification), geographic information systems (e.g. terrain visibility), robotics (e.g., motion planning), data mining (e.g., dimensionality reduction), and computer vision (3D reconstruction), to name a few. Fundamental geometric problems such as partitioning, proximity, intersection, convexity, visibility, point location, and motion planning are focused on. Efficient data structures and algorithms for their solutions and design techniques germane to the field, such as divide-and-conquer, plane sweep, randomization, duality, etc. are discussed in detail. Practical methods for the robust implementation of geometric algorithms are also covered. Prerequisites: COMP 3006, COMP 3361 or advisor/instructor approval. Cross listed with COMP 3621.

COMP 4600 Seminar in Computer Science (0-4 Credits)
Preparation and presentation of lectures on some aspect of current research in computer science; topics not generally encountered in formal courses, may include robotics, pattern recognition, parallel processing, computer applications. 10- to 15- page paper with bibliography required.

COMP 4621 Computer Networking (4 Credits)
The Internet is arguably the most transformative invention in recent history and is at its core a massive global computer network (of networks). Students in this course learn how the Internet works, from the highest-level application layer to the lowest-level hardware layer. Topics covered include the OSI and TCP/IP reference models, physical transmission methods, error detection and correction, addressing, routing algorithms, congestion control and more. Prerequisites: COMP 3006, COMP 3361 (or instructor approval). Cross listed with COMP 3621.

COMP 4701 Special Tpcs-Computer Graphics (1-4 Credits)
COMP 4702 Advanced Topics-Database (3 Credits)
COMP 4703 Adv Topics-Artificial Intell (1-4 Credits)
COMP 4704 Advanced Topics-Systems (3-4 Credits)
COMP 4705 Advanced Topics-Programming (1-4 Credits)
COMP 4709 Special Tpcs-Computer Security (3 Credits)

COMP 4721 Computer Security (4 Credits)
This course gives students an overview of computer and system security along with some cryptography. Some network security concepts are also included. Other concepts include coverage of risks and vulnerabilities, policy formation, controls and protection methods, role-based access controls, database security, authentication technologies, host-based and network-based security issues. Prerequisites: 3006, COMP 3361 (or advisor/instructor approval).

COMP 4722 Network Security (4 Credits)
Network Security covers tools and techniques employed to protect data during transmission. It spans a broad range of topics including authentication systems, cryptography, key distribution, firewalls, secure protocols and standards, and overlaps with system security concepts as well. This course will provide an introduction to these topics, and supplement them with hands-on experience. In addition, students will perform an extensive analysis, or development of a security related product independently. Prerequisites: COMP 4721 or COMP 3001, 3002, 3003, and 3004.

COMP 4723 Ethical Hacking (4 Credits)
Ethical hacking is the process of probing computer systems for vulnerabilities and exposing their presence through proof-of-concept attacks. The results of such probes are then utilized in making the system more secure. This course will cover the basics of vulnerability research, foot printing targets, discovering systems and configurations on a network, sniffing protocols, firewall hacking, password attacks, privilege escalation, rootkits, social engineering attacks, web attacks, and wireless attacks, among others. Prerequisites: COMP 3361, or COMP 3001, 3002, 3003, and 3004.

COMP 4724 Systems Security Management (4 Credits)
This course covers basic system administration tasks on a Unix environment, with a special focus on command line navigation, file/process access control, setting up network configurations, and managing services related to networks and their security. Prerequisites: COMP 3001, 3002, 3003, and 3004.

COMP 4732 Human-Centered Data Security and Privacy (4 Credits)
With an increasing digital presence, it is critical to understand users’ needs and requirements in using technological equipment to secure interactions and adhere to privacy perceptions. Thus, it is essential to analyze the cognitive, social, organizational, commercial, and cultural factors in mind. This course will provide a socio-technical approach for analyzing critical user interaction with devices encountered in everyday life, including web, mobiles, and wearables. This course will help students develop an understanding of technological interactions from the perspectives of multiple stakeholders such as users, developers, system administrators, and others and build tools to protect user data.

COMP 4799 Capstone Project in Cybersecurity (1-8 Credits)
The purpose of the cybersecurity capstone project is to provide an integrative experience that ties together the learning outcomes from academic coursework undertakings and industry skills necessary to be productive in delivering an end product. Students will engage in one of many options available, such as involvement in a research project, a case study, a product development project, or an extensive survey paper. Capstone projects are presented at the end of the quarter in front of a representative group. Prerequisites: COMP 3001, 3002, 3003, and 3004.

COMP 4991 Independent Study (1-12 Credits)
Independent study on a particular topic supervised by a faculty member. Student must find a faculty member who will supervise work on the topic. Cannot be arranged for any course that appears in regular course schedule for that particular year.
COMP 4995 Independent Research (1-17 Credits)
Research projects undertaken in conjunction with a faculty member.

COMP 5991 Independent Study (1-17 Credits)

COMP 5995 Independent Research (1-17 Credits)