COMPUTER SCIENCE

Office: Department of Computer Science, ECS, Suite 379
Mail Code: 2155 E Wesley Avenue, Denver, CO 80208
Phone: 303-871-2458
Email: info@cs.du.edu
Web Site: Computer Science (http://www.du.edu/rsecs/departments/cs)

Why study Computer Science at the University of Denver?
The Department of Computer Science is based in the University of Denver’s Daniel Felix Ritchie School of Engineering and Computer Science. The school reflects two of the University’s strongest traditions: academic integrity and a commitment to meeting student needs with dynamic new programs. The Department of Computer Science offers cutting-edge and innovative graduate degree programs:

- MS in Computer Science
- MS in Cybersecurity
- MS in Data Science
- PhD in Computer Science
- Dual degree Undergraduate/Graduate (BS+MS) in Computer Science

We are strong in research and particularly noted in software engineering, information security and privacy, and humane gaming.

Some of our other outstanding advantages include:

- Small classes taught by faculty, not teaching assistants
- Research-active faculty members who publish regularly, land impressive grants and win teaching awards
- An up-to-date curriculum that includes classes in modern software engineering, web technology, multimedia, mobile computing, networks, databases, cyber security and computer game development
- Students who create a peer culture defined by high expectations
- A small yet vital PhD program that enhances the department’s intellectual atmosphere

At the University of Denver, you will find opportunities to research, study leading-edge technology and tools, and gain an integrated knowledge. We emphasize interdisciplinary programs, so you will be ready to meet career challenges around the office or, if you choose, around the world.

In addition, Denver is a first-rate location for internships and jobs, as well as business and government partnerships. The campus is just minutes from the Denver Technological Center — home to many top tech companies — and we enjoy sweeping views of the Rocky Mountains.

Doctor of Philosophy in Computer Science

The department currently has faculty to support PhD students in the following areas:

- Algorithms
- Artificial Intelligence
- Computational Geometry
- Humane Games
- Networks
- Programming Languages
- Robotics
- Security and Privacy
- Software Systems Engineering

Master of Science in Computer Science

The MS program 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, as well as the emerging technologies that will be gaining importance in the future.

Master of Science in Cybersecurity

The MS program in Cybersecurity prepares students for advancement in academic or industrial 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
advanced knowledge in computer science, along with domain knowledge in the field of information security.

Master of Science in Data Science
The MS program in Data Science prepares students for advancement in academic or industrial 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 advanced 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
- Bachelors 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 Introductio

Standardized Test Scores
- The Graduate Record Examination (GRE) is required. Competitive applicants typically score 156 or above on the quantitative section of the GRE.
  Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.
- This program has minimum GRE score requirements. The minimum quantitative score for the GRE is 152. The minimum written score for the GRE is 2.

English Language Proficiency Test Score Requirements
The minimum TOEFL/IELTS/CAE test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum TOEFL Score (Paper-based test): 550
- Minimum IELTS Score: 6.5
- Minimum CAE Score: 169

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

Doctor of Philosophy in Computer Science - Lockheed Employees Only
Degree and GPA Requirements
- Bachelors 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/CAE test score requirements for this degree program are:
• Minimum TOEFL Score (Internet-based test): 80
• Minimum TOEFL Score (Paper-based test): 550
• Minimum IELTS Score: 6.5
• Minimum CAE Score: 169

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

Master of Science in Computer Science or Computer Science Systems Engineering

Degree and GPA Requirements
• Bachelors 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

Standardized Test Scores
• The Graduate Record Examination (GRE) is required. Competitive applicants typically score 156 or above on the quantitative section of the GRE. Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.
• This program has minimum GRE score requirements. The minimum verbal score for the GRE is 146. The minimum quantitative score for the GRE is 156. The minimum written score for the GRE is 3.5.

English Language Proficiency Test Score Requirements
The minimum TOEFL/IELTS/CAE test score requirements for this degree program are:
• Minimum TOEFL Score (Internet-based test): 80
• Minimum TOEFL Score (Paper-based test): 550
• Minimum IELTS Score: 6.5
• Minimum CAE Score: 169

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

Master of Science in Computer Science or Computer Science Systems Engineering - Lockheed Employees Only

Degree and GPA Requirements
• Bachelors 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/CAE test score requirements for this degree program are:
• Minimum TOEFL Score (Internet-based test): 80
• Minimum TOEFL Score (Paper-based test): 550
Master of Science in Cybersecurity

Degree and GPA Requirements

- Bachelors 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.

Standardized Test Scores

- The Graduate Record Examination (GRE) is required. Competitive applicants typically score 156 or above on the quantitative section of the GRE. Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.
- This program has minimum GRE score requirements. The minimum verbal score for the GRE is 146. The minimum quantitative score for the GRE is 156. The minimum written score for the GRE is 3.5.

English Language Proficiency Test Score Requirements

The minimum TOEFL/IELTS/CAE test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum TOEFL Score (Paper-based test): 550
- Minimum IELTS Score: 6.5
- Minimum CAE Score: 169

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

Master of Science in Data Science

Degree and GPA Requirements

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

- The Graduate Record Examination (GRE) is required. Competitive applicants typically score 156 or above on the quantitative section of the GRE. Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.
- This program has minimum GRE score requirements. The minimum verbal score for the GRE is 146. The minimum quantitative score for the GRE is 156. The minimum written score for the GRE is 3.5.

English Language Proficiency Test Score Requirements

The minimum TOEFL/IELTS/CAE test score requirements for this degree program are:

- Minimum TOEFL Score (Internet-based test): 80
- Minimum TOEFL Score (Paper-based test): 550
- Minimum IELTS Score: 6.5
- Minimum CAE Score: 169

English Conditional Admission: In cases where minimum TOEFL/IELTS/CAE scores were not achieved or no English proficiency test was taken, the Data Science 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 Advanced 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 Advanced 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.

1. 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).
2. 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 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.

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**Master of Science in Computer Science**

**Degree Requirements**

**Coursework Requirements**

Minimum credits required for degree: 48-64

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Bridge Courses</strong></td>
<td>16</td>
</tr>
<tr>
<td>COMP 3001</td>
<td>Bridge Course: Theory Basics</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3002</td>
<td>Bridge Course: Theory Advanced</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3003</td>
<td>Bridge Course: Systems Basics</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3004</td>
<td>Bridge Course: Systems Advance</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><strong>Required Courses</strong></td>
<td>16</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>Advanced Data Structures &amp; Algorithms</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3200</td>
<td>Discrete Structures</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><strong>Electives</strong></td>
<td>20</td>
</tr>
</tbody>
</table>

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

**4000-level requirement**

3 computer science electives at the 4000-level (other than COMP 499X) are required of which at least one must be a designated "theory" class (see below).

**Theory requirement**
The current pre-approved list of 4000-level "theory" courses includes but is not limited to:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 4705</td>
<td>Advanced Topics-Programming (Computational Geometry)</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4372</td>
<td>Theory of Algorithms</td>
<td>4</td>
</tr>
</tbody>
</table>

**Advanced programming requirement**

Two 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:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 3353</td>
<td>Compiler Construction</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3621</td>
<td>Computer Networking</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4621</td>
<td>Computer Networking</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3801</td>
<td>Introduction Computer Graphics</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3705</td>
<td>Topics in Computer Science (Parallel &amp; Distributed Programming)</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4705</td>
<td>Advanced Topics-Programming (Parallel &amp; Distributed Programming)</td>
<td>4</td>
</tr>
</tbody>
</table>

**Seminar attendance requirement**

Students must complete three quarters of COMP 4600 - Seminar (0 credits). A passing grade is required for successful completion. In addition, graduate assistants (GTA/GRA) are required to attend all seminars.

**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). A thesis of publishable quality, and an 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**

48-64

1. Whether a student needs to take these four classes are dependent on placement exam results. The total number of degree credits is reduced by 4 times the number of bridge course exams passed.

**Outside Courses**

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**

- If the thesis option is chosen, a thesis and oral defense are required.

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**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:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENMT 4100</td>
<td>Systems Engineering</td>
<td>4</td>
</tr>
<tr>
<td>ENMT 4000</td>
<td>Space Systems Design I</td>
<td>4</td>
</tr>
<tr>
<td>ENMT 4010</td>
<td>Space Systems Design II</td>
<td>4</td>
</tr>
</tbody>
</table>

**Theory Course (e.g., COMP 3702)**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 3702</td>
<td>Topics in Database</td>
<td>4</td>
</tr>
</tbody>
</table>

**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: 48-64

<table>
<thead>
<tr>
<th>Code</th>
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<tr>
<td>COMP 3001</td>
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<tr>
<td>COMP 3003</td>
<td>Bridge Course: Systems Basics</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3004</td>
<td>Bridge Course: Systems Advance</td>
<td>4</td>
</tr>
</tbody>
</table>

Required Courses

COMP 3731  Computer Forensics  4
COMP 3361  Operating Systems I  4
COMP 4621  Computer Networking  4
COMP 4384  Secure Software Engineering  4
COMP 4721  Computer Security  4
COMP 4722  Network Security  4
COMP 4723  Ethical Hacking  4

Research/Project

COMP 4799  Capstone Project in Cybersecurity  4

In addition, any combination of the following courses can be used to meet the remaining 8 credit hours.

- COMP 3904  Internship/Co-Op in Computing  1-8
- COMP 4995  Independent Research  1-8
- COMP 4991  Independent Study  1-8

Electives

Students must choose and complete 8 credits of cybersecurity related electives. Elective credits need pre-approval from an advisor.

Total Credits  48-64

1 Whether a student needs to take these four classes are dependent on placement exam results. The total number of degree credits is reduced by 4 times the number of bridge course exams passed.

Capstone Project Course
The Cybersecurity master's degree is an intensely experiential program. Capstone project coursework will make up the culminating work in the degree. During the student's internship course, a capstone project will be selected and defined, relevant to the internship work. This individualized leaning will be planned with the student's advisor and internship/co-op instructor(s). 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 finaid@du.edu or at 303-871-4020 to discuss financial aid options.

Non-coursework Requirements
  • Capstone

MASTER OF SCIENCE IN DATA SCIENCE

Degree Requirements
Coursework Requirements
Minimum credits required for degree: 48-64

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 3005</td>
<td>Data Science Bridge Course 2: Computer Science Programming Basics</td>
<td>4</td>
</tr>
</tbody>
</table>

1 Whether a student needs to take these four classes are dependent on placement exam results. The total number of degree credits is reduced by 4 times the number of bridge course exams passed.
### Required Courses

<table>
<thead>
<tr>
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<tr>
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</tr>
<tr>
<td>COMP 3006</td>
<td>Data Science Bridge: Advanced Python</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3007</td>
<td>Data Science Bridge 3: Data Science Mathematics I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3008</td>
<td>Data Science Bridge 4: Data Science Mathematics II</td>
<td>4</td>
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</tbody>
</table>

### Research/Project

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 4447</td>
<td>Data Science Tools 1</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4448</td>
<td>Data Science Tools 2</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4449</td>
<td>Data Science Capstone</td>
<td>4</td>
</tr>
</tbody>
</table>

### Electives

Students must choose and complete two electives (with advisor approval). Examples include: Advanced Data Structures and Analysis, Bayesian Analysis, Computer Forensics, Introduction to Artificial Intelligence, Introduction to Non-Relational Database Management Systems, Programming Languages, Theory of Algorithms, and various special topics courses.

### Total Credits

48-64

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1 The first four courses, Bridge Courses 1-4, serve to provide a strong foundation for students without computer science backgrounds. All students are expected to have previously taken calculus, although a Bridge Course 4 provides a refresher of the most important concepts. Bridge Course needs are determined by pre-assessment. Based on pre-assessment results, students may test out of one or more bridge courses. The total number of degree credits is 48 credits plus 4 times the number of needed Bridge courses.

### Non-coursework Requirements

- **Capstone Project Course**

  The Data Science master's degree is an intensely experiential program. Capstone project coursework will make up the culminating work in the degree. During the student's internship course, a capstone project will be selected and defined, relevant to the internship work. This individualized leaning will be planned with the student’s advisor and internship/co-op instructor(s). No thesis is required.

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

### MASTER OF SCIENCE IN DATA SCIENCE (ONLINE)

<table>
<thead>
<tr>
<th>Code</th>
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<tbody>
<tr>
<td>COMP 3005</td>
<td>Data Science Bridge Course 2: Computer Science Programming Basics</td>
<td>4</td>
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<tr>
<td>COMP 3006</td>
<td>Data Science Bridge: Advanced Python</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3007</td>
<td>Data Science Bridge 3: Data Science Mathematics I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3008</td>
<td>Data Science Bridge 4: Data Science Mathematics II</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3421</td>
<td>Database Organization &amp; Management I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4333</td>
<td>Parallel and Distributed Computing</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4431</td>
<td>Machine Learning</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 4447</td>
<td>Data Science Tools 1</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4448</td>
<td>Data Science Tools 2</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4449</td>
<td>Data Science Capstone</td>
<td>4</td>
</tr>
<tr>
<td>COMP 4451</td>
<td>Algorithms for Data Science</td>
<td>4</td>
</tr>
</tbody>
</table>

Electives 8 hours.

Total degree 48-64
Non-coursework Requirements

- Capstone

Capstone Project Course
The Data Science master’s degree is an intensely experiential program. Capstone project coursework will make up the culminating work in the degree. During the student’s experiential course, a capstone project will be selected and defined, relevant to the experiential work. This individualized leaning will be planned with the student’s advisor and internship/co-op instructor(s). No thesis is required.

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

The course COMP 3007 & COMP 3008 is undergoing a title change.

Undergraduate + Graduate BS/MS
The Department of Computer Science at the University of Denver offers a Dual Degree Bachelor of Science and Masters in Computer Science. The BS/MS in Computer Science encompasses the theory and techniques by which information is encoded, stored, communicated, transformed, and analyzed. It is concerned with the theory of algorithms (that is, effective procedures or programs), with the structure of languages for the expression of algorithms, and with the design of algorithms for the solution of practical problems. A central concern is the study of the computer systems (hardware and software) for the automatic execution of these algorithms 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, as well as the emerging technologies that will be gaining importance in the future.

The degree is strongly based in mathematics and, in fact, a student will automatically acquire sufficient credits for a minor in mathematics. One additional minor is required. The second minor may be in any discipline other than mathematics or computer science.

Total Credit Hours: 183 at the undergraduate level (UG) for the Bachelor’s degree + 36 at the graduate level (GR) for the master’s of science degree

Required courses

<table>
<thead>
<tr>
<th>Course</th>
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<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 1671</td>
<td>Introduction to Computer Science I</td>
<td>4</td>
</tr>
<tr>
<td>COMP 1672</td>
<td>Introduction to Computer Science II</td>
<td>4</td>
</tr>
<tr>
<td>COMP 2300</td>
<td>Discrete Structures in Computer Science</td>
<td>1-4</td>
</tr>
<tr>
<td>COMP 2355</td>
<td>Intro to Systems Programming</td>
<td>4</td>
</tr>
<tr>
<td>COMP 2370</td>
<td>Introduction to Algorithms &amp; Data Structures</td>
<td>4</td>
</tr>
<tr>
<td>COMP 2673</td>
<td>Introduction to Computer Science III</td>
<td>4</td>
</tr>
<tr>
<td>COMP 2691</td>
<td>Introduction to Computer Organization</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>Advanced Data Structures &amp; Algorithms</td>
<td>4</td>
</tr>
<tr>
<td>COMP 3200</td>
<td>Discrete Structures</td>
<td>4</td>
</tr>
</tbody>
</table>

Other 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. One of the two minor areas required in the B.S. program must be in mathematics. The other minor may be in any field. Upon completion of the BS requirements, the student must satisfy the 36 hours at the graduate level of required coursework for the MS.

The eleven courses listed above total 44 quarter hours. An additional 28 hours of 3000-level computer science electives are required. COMP 2400 or COMP 2901, or COMP 2555 may be used to satisfy 8 credits of the required 3000-level elective credits, but COMP 3904 may not be used in this way. In addition there are 3 COMP courses at the 4000-level (other than COMP 4991) are required of which at least one must be a designated “theory” class and one must be a designated “Advanced Programming” course and completion of three quarters of COMP 4600 Seminar (0 credits).

Advanced Programming Requirement
Students must also choose and complete two courses that include an advanced programming component. These courses must be approved by an advisor. The current pre-approved list includes:

Math Minor Requirement
Minimum of 20 quarter hours in MATH courses numbered 1951 or higher. Discrete Structures in Computer Science (COMP 2300) may be counted toward the math minor. Courses not covered by the foregoing two sentences must be approved in writing by a mathematics faculty advisor.

For students entering DU Fall 2010 or later: At least 50% of the required credit hours for minor must be completed at the University of Denver
All electives, especially the MATH and COMP electives, should be selected in close consultation with an academic advisor from the Computer Science Department. The courses for the non-mathematics minor (see Minor courses above) should be selected in consultation with an academic advisor from the department in which the minor is administered.

Sample schedule

| First Year | Credits | | Credits | Credits |
|------------|---------|-----------------|---------|
| Fall       | Winter  | Spring          |         |
| COMP 1671  | 4 COMP 1672 | 4 COMP 2673    | 4       |
| MATH 1951  | 4 MATH 1952 | 4 COMP 2300    | 1-4     |
| FSEM       | WRIT 1122 | 4 WRIT 1133    | 4       |
| Foreign Language 1 | 4 Foreign Language 2 | 4 Foreign Language 3 | 4 |
|            | 12      | 16              | 13-16   |

| Second Year | Credits | | Credits | Credits |
|-------------|---------|-----------------|---------|
| Fall        | Winter  | Spring          |         |
| COMP 2370   | 4 COMP 2691 | 4 COMP Elective | 4       |
| MATH 2XXX/3XXX Elective | 4 COMP 2355 | 4 MATH 1953 | 4 |
| AI-Natural  | 4 AI-Society | 4 SI-Society | 4       |
| SI-Natural  | 4 SI-Natural | 4 SI-Natural | 4       |
|            | 16      | 16              | 16      |

| Third Year | Credits | | Credits | Credits |
|------------|---------|-----------------|---------|
| Fall       | Winter  | Spring          |         |
| COMP Elective | 4 COMP 3361 | 4 COMP Elective | 4       |
| COMP Elective | 4 ASEM | 4 Minor Course 3 | 4       |
| Minor Course 1 | 4 Minor Course 2 | 4 Elective | 4 |
| SI-Society  | 4 Elective | 4 Elective | 4       |
|            | 16      | 16              | 16      |

| Fourth Year | Credits | | Credits | Credits |
|-------------|---------|-----------------|---------|
| Fall        | Winter  | Spring          |         |
| COMP 3351   | 4 COMP 3200 | 4 COMP 3371    | 4       |
| COMP Elective | 4 Minor Course 5 | 4 COMP Elective | 4       |
| Minor Course 4 | 4 Elective | 4 Elective | 4       |
| Elective    | 4 Elective | 4 Elective | 4       |
|            | 16      | 16              | 16      |

| Fifth Year | Credits | | Credits | Credits |
|------------|---------|-----------------|---------|
| Fall       | Winter  | Spring          |         |
| COMP3XXX/4XXX Elective | 4 COMP3XXX/4XXX Adv Programming | 4 COMP3XXX/4XXX Elective | 4 |
| COMP 4XXX Theory | 4 COMP3XXX/4XXX Elective | 4 COMP3XXX/4XXX Elective | 4 |
| COMP 4600   | 4 COMP 4600 | 4 COMP 4600 | 4       |
|            | 12      | 12              | 12      |

Total Credits: 217-220

Courses

**COMP 3001 Bridge Course: Theory Basics (1-4 Credits)**

Bridge Course I: Computer Science Theory Basics 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. 4.000 Credit hours 4.000 Lecture hours.

**COMP 3002 Bridge Course: Theory Advanced (1-4 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. 4.000 Credit hours 4.000 Lecture hours.

**COMP 3003 Bridge Course: Systems Basics (1-4 Credits)**

This accelerated course covers the basics of computer systems including assembly language programming, addressing modes, logic design, etc. necessary to attend CS graduate school. In addition, it includes an introduction to C programming language. In particular, standard I/O, data manipulation, pointers, and dynamic memory management. 4.000 Credit hours 4.000 Lecture hours.

**COMP 3004 Bridge Course: Systems Advance (1-4 Credits)**

This accelerated course continues to build on the basics of computer systems by covering material including UNIX tools, version control, process creation, concurrent programming etc that is necessary to attend Computer Science graduate school. In addition, it includes an introduction to a scripting language. Prerequisites: COMP 3003. 4.000 Credit hours 4.000 Lecture hours.
COMP 3005 Data Science Bridge Course: Computer Science Programming Basics (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, appreciate the difference between data types, learn to read from and write to files, understand and use data structures, understand and use recursion.

COMP 3006 Python Software Development (4 Credits)
This accelerated course covers advanced Python programming for data scientists. Course Objectives: name and demonstrate proficiency using advanced Python programming techniques for data science; 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 a data-science analysis goal; collaborate with another data scientist to develop a software program that completes a given data-science task. Prerequisite: COMP 3005.

COMP 3007 Data Science Bridge: 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 Data Science Bridge: 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: MATH 2200 or COMP 2300 and COMP 1672 or COMP 1771.

COMP 3341 Multimedia Systems (4 Credits)
This course covers fundamental issues in design and implementation of multimedia applications. This course also covers technologies in multimedia systems such as multimedia data representation, compression, coding, networking, data management, and I/O technologies. Prerequisite: COMP 3361.

COMP 3351 Programming Languages (4 Credits)
Programming language as a component of software development environment; binding, scope, lifetime, value and type of a variable; run-time structure–static, stack-based and dynamic languages; parameter passing–call by reference, value, result, value-result and name; subprogram parameters; role played by side effects, dangling pointers, aliases and garbage; garbage collection; data abstraction - study of object-oriented, functional, and logic languages. Prerequisites: COMP 2370, COMP 2691, and COMP 2355.

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 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: COMP 2355, COMP 2370, and COMP 2691 or for MS Cybersecurity COMP 3001, 3002, 3003, 3004, COMP 4355, and COMP 4370.

COMP 3371 Advanced Data Structures & Algorithms (4 Credits)
Design and analysis of algorithms; asymptotic complexity, recurrence equations, lower bounds; algorithm design techniques such as incremental, divide and conquer, dynamic programming, randomization, greedy algorithms, etc. Prerequisites: COMP 2370, MATH 3200.

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 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 3410 World Wide Web Programming (4 Credits)
Creating WWW pages with HTML, accessing user-written programs via CGI scripts, creating forms, imagemaps and tables, and Java programming principles and techniques. Prerequisite: COMP 2355.

COMP 3421 Database Organization & Management I (4 Credits)
An introductory class in databases explaining what a database is and how to use one. Topics include database design, ER modeling, database normalization, relational algebra, SQL, and B trees. Each student will design, load, query and update a nontrivial database using a relational database management system (RDBMS). An introduction to a NoSQL database will be included. Prerequisite: COMP 3006. Co-requisite: COMP 3007.
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)
Programming in LISP and Prolog with applications to artificial intelligence; fundamental concepts of artificial intelligence; emphasis on general problem-solving techniques including state-space representation, production systems, and search techniques. Prerequisites: MATH 2200, COMP 2370.

COMP 3621 Computer Networking (4 Credits)
An introduction to computer networks with an emphasis on Internet protocols. Topics include; network topologies, routing, Ethernet, Internet protocol, sockets, operating system impact and client/server implementations. Prerequisites: COMP 2355 and COMP 2370.

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 2355 or for MS Cybersecurity COMP 3001, 3002, 3003, and 3004.

COMP 3801 Introduction Computer Graphics (4 Credits)
Fundamentals of graphics hardware, scan conversion algorithms, 2D and 3D viewing transformations, windows, viewports, clipping algorithms, mathematics for computer graphics, graphics programming using a standard API. Prerequisites: COMP 2370, MATH 1952 or 1962, and MATH 2060.

COMP 3821 Game Programming I (4 Credits)
An introduction to computer game programming. Use of a game engine to create 3D computer games. Topics to include game scripting, simple 3D asset creation, incorporation of assets, keyboard/mouse event handling, animation, game phases and score keeping. Prerequisite: COMP 2370.

COMP 3822 Game Programming II (4 Credits)
An introduction to computer game engine programming. Major class goal is to understand how game engines are created by building subsets of a game engine. Non-exhaustive set of topics include how terrains are generated, how animations are supported, how particle systems are implemented, how physics systems are coded, and how support is provided for higher level scripting languages. All coding will be done in low-level graphics languages. Prerequisites: COMP 3801 and COMP 3821.

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 3992 Directed Study (1-10 Credits)
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 4355 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 Theory of Algorithms (4 Credits)
NP-completeness; lower bound theory; approximation algorithms; amortized complexity and data structures, randomized algorithms. Assorted topics such as string algorithms, graph algorithms, linear programming, computational geometry. Prerequisite: COMP 3371.

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 3001, 3002, 3003, and 3004.

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, Naive 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.

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 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 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 3001, 3002, 3003, and 3004.

COMP 4701 Special Topics-Computer Graphics (1-4 Credits)

COMP 4702 Advanced Topics-Database (3 Credits)

COMP 4703 Adv Topics-Artificial Intelligence (1-4 Credits)

COMP 4704 Advanced Topics-Systems (3-4 Credits)

COMP 4705 Advanced Topics-Programming (1-4 Credits)

COMP 4708 Special Topics-VLSI (3 Credits)

COMP 4709 Special Topics-Computer Security (3 Credits)

COMP 4720 Applied Cryptography (4 Credits)
Block ciphers, one-way hashes, symmetric and asymmetric encryption, public-key infrastructure, digital signatures, security protocols, anonymity, and digital cash.

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: COMP 3001, 3002, 3003, and 3004.

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. Prerequisites: COMP3361 or Permission of Instructor.

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 4799 Capstone Project in Cybersecurity (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 (1-10 Credits)
Cannot be arranged for any course that appears in regular course schedule for that particular year.
COMP 4992 Directed Study (1-10 Credits)

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)