The following requirements are for students entering Fall 2019.

Curriculum - B.S. in Computer Science

The following requirements are for students entering Fall 2019.

Computer Science

Computer Science Core (all of the following):

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>07-128</td>
<td>First Year Immigration Course</td>
<td>1</td>
</tr>
</tbody>
</table>

Computer Science Program

Srinivasan Seshan, Department Head, Computer Science Department
Location: GHC 7019

Thomas Cortina, Program Director, Assistant Dean for Undergraduate Education
Location: GHC 4117

Mary Widom, Program Coordinator, CS Undergraduate Office
Location: GHC 4115
www.csd.cs.cmu.edu (http://www.csd.cs.cmu.edu)

The B.S. program in Computer Science combines a solid core of Computer Science courses with the ability to gain additional depth through a required minor in a second subject or a concentration in a computing area. In addition, the curriculum provides breadth through numerous choices for science, engineering, humanities and fine arts courses. As computing is a discipline with strong links to many fields, this provides students with unparalleled flexibility to pursue allied (or non-allied) interests.

Students apply to, and are directly admitted into, the School of Computer Science. Admitted students may choose to pursue an undergraduate degree in Computer Science and, upon successful completion, are awarded a Bachelor of Science in Computer Science. SCS offers additional majors in Computer Science Intelligence major, the Computational Biology major and the Computer Computational Biology and a Bachelor's Degree in Computer Science courses, culminating in the preparation of a senior research thesis.

Students in the B.S. program in Computer Science are expected to acquire the following skills upon graduation:

- Identify, use, design, develop and analyze appropriate abstractions and algorithms to solve problems while being able to prove the algorithm’s performance and correctness across a variety of metrics (e.g., time, space, parallel vs. sequential implementation, computability).
- Implement solutions to problems in domains such as artificial intelligence, graphics and sound, software engineering, and human-computer interaction, by applying the fundamentals of those areas to create solutions to current problems while being exposed to research developments that will enable them to adapt as the technology changes.
- Reason about and implement programs in various programming languages and paradigms
- Describe, specify, and develop large-scale, open-ended software systems subject to constraints such as performance and/or resource issues
- Communicate technical material effectively to technical and non-technical audiences
- Work both individually and in teams
- Recognize the social impact of computing and the attendant responsibility to consider the legal, moral and ethical implications of computing technologies.

Due to the tremendous number of ongoing research projects within the School, many students obtain part-time or summer jobs, or receive independent study credit, working on research while pursuing their undergraduate degree. Students seeking a research/graduate school career may pursue an intensive course of research, equivalent to four classroom courses, culminating in the preparation of a senior research thesis.

SCS also offers a B.S. degree in Artificial Intelligence, a B.S. degree in Computational Biology and a Bachelor’s Degree in Computer Science and the Arts (jointly with the College of Fine Arts). More detail about the Artificial Intelligence major, the Computational Biology major and the Computer Science and the Arts program is available in separate sections of the Undergraduate Catalog. SCS offers additional majors in Computer Science (for non-CS majors), Human-Computer Interaction, and Robotics, and minors in Computational Biology, Computer Science (for non-CS majors), Human-Computer Interaction, Language Technologies, Machine Learning, Neural Computation, Robotics, and Software Engineering. Information about additional majors and minors in SCS besides those in Computer Science are listed in a separate section in the Undergraduate Catalog.

Mathematics

All of the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-151</td>
<td>Mathematical Foundations for Computer Science</td>
<td>10</td>
</tr>
</tbody>
</table>
### Computer Science Program

**Double Counting.**

Rules as well. Consult with a CS undergraduate advisor and an advisor from minors. Additional majors and minors have their own double counting.

In general, students may double count at most 5 of the 12 core.

CS major is strictly limited and depends on the chosen minor (or additional major). In general, students may double count at most 5 of the 12 core CS major is strictly limited and depends on the chosen minor (or additional major).

In general, students may double count at most 5 of the 12 core courses outside of the Computer Science and Mathematics requirements. Double counting toward Computer Science and Mathematics courses in the specific areas of research important to SCS. SCS concentrations are areas of research important to SCS. SCS concentrations are significant core knowledge in Computer Science including 15-210, 15-213 and 15-251. See the SCS Concentrations section for a list of available concentrations and their requirements. Completion of an additional major (or dual degree) also satisfies this requirement. Students should consult with their academic advisor to plan for their desired minor or concentration starting in the sophomore year.

### Technical Communication

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Technical Communications course</td>
<td></td>
</tr>
<tr>
<td>15-300 Research and Innovation in Computer Science</td>
<td>9</td>
</tr>
<tr>
<td>17-200 Ethics and Policy Issues in Computing</td>
<td>9</td>
</tr>
<tr>
<td>76-270 Writing for the Professions</td>
<td>9</td>
</tr>
</tbody>
</table>

### Science and Engineering

All candidates for the bachelor's degree in Computer Science must complete a minimum of 36 units offered by the Mellon College of Science and/or the College of Engineering (CIT). These courses offer students an opportunity to explore scientific and engineering domains that can influence their effectiveness as computer scientists upon graduation.

Requirements for this component of the degree are listed under the SCS main page under General Education Requirements (http://coursecatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#genedtext).

### Humanities and Arts

All candidates for the bachelor's degree in Computer Science must complete a minimum of 63 units offered by the College of Humanities & Social Sciences and/or the College of Fine Arts. Some courses from the Tepper School of Business also qualify for this requirement. These courses offer students breadth in their education and perspectives and provide students with a better appreciation of social, artistic, cultural, political and economic issues that can influence their effectiveness as computer scientists upon graduation.

Requirements for this component of the degree are listed under the SCS main page under General Education Requirements (http://coursecatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#genedtext).

### Required Minor or Concentration

Students completing the bachelor's degree in Computer Science must complete either a minor outside of SCS or a concentration within SCS. A minor is a sequence of (typically 5-6) courses within a particular department to give students a core of a specific discipline but not an entire major of study. Refer to the sections for other CMU colleges for details about available non-SCS minors. An SCS concentration is a sequence of (typically 4-5) courses within an SCS department to give students further depth in specific areas of research important to SCS. SCS concentrations are available only to SCS students and assume that these students have a significant core knowledge in Computer Science including 15-210, 15-213 and 15-251. See the SCS Concentrations section for a list of available concentrations and their requirements. Completion of an additional major (or dual degree) also satisfies this requirement. Students should consult with their academic advisor to plan for their desired minor or concentration starting in the sophomore year.

### Double Counting

In general, courses taken in satisfaction of the minor or additional major may also count toward any general education category in the CS major (i.e. courses outside of the Computer Science and Mathematics requirements). Double counting toward Computer Science and Mathematics courses in the specific areas of research important to SCS. SCS concentrations are significant core knowledge in Computer Science including 15-210, 15-213 and 15-251. See the SCS Concentrations section for a list of available concentrations and their requirements. Completion of an additional major (or dual degree) also satisfies this requirement. Students should consult with their academic advisor to plan for their desired minor or concentration starting in the sophomore year.

### Computing @ Carnegie Mellon (1 course)

The following course is required of all students to familiarize them with the campus computing environment:

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>99-101 Computing @ Carnegie Mellon</td>
<td>3</td>
</tr>
</tbody>
</table>

### Free Electives

A free elective is any Carnegie Mellon course. However, a maximum of nine (9) units of Physical Education and/or Military Science (ROTC) and/or Student-Led (StuCo) courses may be used toward fulfilling graduation requirements.

### Summary of Degree Requirements:

<table>
<thead>
<tr>
<th>Area</th>
<th>Courses</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer Science (core courses, constrained electives, and SCS electives)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematics</td>
<td>5</td>
<td>48</td>
</tr>
<tr>
<td>Technical Communication</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Science/Engineering</td>
<td>4</td>
<td>36</td>
</tr>
<tr>
<td>Humanities/Arts</td>
<td>7</td>
<td>63</td>
</tr>
<tr>
<td>Minor or Concentration Requirement/Free electives</td>
<td>Varies</td>
<td>75</td>
</tr>
<tr>
<td>Computing @ Carnegie Mellon</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>First Year Seminar</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>360</td>
</tr>
</tbody>
</table>

### Sample Course Sequence

The sample given below is for a student who already has credit for introductory programming and one semester of calculus. Students with credit for two semesters of calculus may start with a more advanced math class (e.g. 21-241) in their first year. Students with no credit for introductory programming and/or one semester of calculus will take 15-112 and/or 21-120 in their first semester and shift a few courses to later semesters after consulting with their academic advisor; these students should still be able to complete their degree in four years. It is recommended that students keep their academic load lighter for their Senior Fall semester to account for visits to graduate schools.

**Freshman Year:**

**Fall**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>07-128 First Year Immigration Course</td>
<td>1</td>
</tr>
<tr>
<td>07-131 Great Practical Ideas for Computer Scientists (optional, not required for CS major)</td>
<td>2</td>
</tr>
<tr>
<td>15-122 Principles of Imperative Computation</td>
<td>10</td>
</tr>
<tr>
<td>15-151 Mathematical Foundations for Computer Science (if not offered, substitute 21-127)</td>
<td>10</td>
</tr>
<tr>
<td>21-122 Integration and Approximation</td>
<td>10</td>
</tr>
<tr>
<td>76-101 Interpretation and Argument</td>
<td>9</td>
</tr>
<tr>
<td>99-101 Computing @ Carnegie Mellon</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>45</td>
</tr>
</tbody>
</table>

**Spring**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-150 Principles of Functional Programming</td>
<td>10</td>
</tr>
<tr>
<td>15-213 Introduction to Computer Systems</td>
<td>12</td>
</tr>
<tr>
<td>21-259 Calculus in Three Dimensions</td>
<td>9</td>
</tr>
<tr>
<td>xx-xxx Science/Engineering Course</td>
<td>9</td>
</tr>
<tr>
<td>xx-xxx Humanities and Arts Elective</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>49</td>
</tr>
</tbody>
</table>

**Sophomore Year:**

**Fall**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-210 Parallel and Sequential Data Structures and Algorithms</td>
<td>12</td>
</tr>
<tr>
<td>21-241 Matrices and Linear Transformations</td>
<td>10</td>
</tr>
<tr>
<td>xx-xxx Science/Engineering Course</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
</tbody>
</table>
For more information about the SCS Honors Research Thesis, refer to the SCS Honors Research Thesis (http://coursescatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#scshonorsresearchthesis) section for learning objectives, application requirements and expected outcomes.

Dual Degree in Computer Science

Students wishing to pursue a Dual Degree in Computer Science are required to apply in the same way as students wishing to transfer into the Computer Science major. Details are given in the SCS Policies section. Besides the student’s primary degree requirements, a student accepted for Dual Degree in CS is required to complete at least 450 units in total and meet all requirements for the CS major including all general education requirements (humanities/arts and science/engineering). Dual degree students do not need to complete 15-128, and these students will replace 15-151 with either 21-127 or 21-128. Since the CS major requires at least a minor or concentration in another area, the student’s primary major will substitute for this requirement. Note that the primary major must be completed prior to or at the same time as the dual degree in CS to satisfy the minor requirement; a dual degree in CS cannot be certified if the primary degree is not completed. Students should consult with the Assistant Dean in the CS Undergraduate Office and/or their CS academic advisor to review all requirements, once approved.

Double-Counting Restriction

Students pursuing a Dual Degree in Computer Science must complete all requirements for the CS primary major (except 15-128 which is not required and 15-151 which will be replaced with 21-127 or 21-128). In addition, at most 5 of the 12 computer science requirements can double count with all other declared majors and minors. Students, especially from interdisciplinary majors or with multiple majors or minors, are urged to consult with the Assistant Dean or Undergraduate Program Coordinator in the CS Undergraduate Office to determine double-counting restrictions specific to their own situations.

Computer Science Additional Major

Students interested in pursuing an additional major in Computer Science should first consult with an advisor in the CS Undergraduate Office. Students are expected to complete the requirements for the CS minor first before continuing on to the additional major. Completion of the CS additional major requires 12 computer science courses (not including 15-110 and 15-112 if needed), 5 mathematics courses, and 1 technical communication course. Students are expected to complete all courses for the additional major with an average QPA of 3.0 or higher.

Declaration for the additional major is allowed only after all math requirements are completed or in progress, and at least 9 of the 12 CS requirements, once approved.

For course requirements, please consult the most current catalog or the Computer Science Program section.

Undergraduate Research Thesis

CS majors may use the SCS Honors Research Thesis as part of their degree. The SCS Honors Undergraduate Research Thesis (07-599) typically starts in the fall semester of the senior year, and spans the entire senior year. Students receive a total of 36 units of academic credit for the thesis work. 16 units per semester. Up to 18 units can be counted toward CS elective requirements (9 per semester for 2 semesters maximum). Students interested in research may also consider using Research and Innovation in Computer Science (15-300, 9 units) as their technical communications requirement in their junior year since this course will introduce students to various research projects going on in the School of Computer Science that may lead to a senior thesis. This course leads to a subsequent Research Practicum in Computer Science (15-400, 12 units) that allows students to complete a small-scale research study or experiment and present a research poster. Students who use 15-400 to start their senior thesis can use these units toward the required 36 units.

For more information about the SCS Honors Research Thesis, refer to the SCS Honors Research Thesis (http://coursescatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#scshonorsresearchthesis) section for learning objectives, application requirements and expected outcomes.

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Declaration for the additional major is allowed only after all math requirements are completed or in progress, and at least 9 of the 12 CS requirements, once approved.

For more information about the SCS Honors Research Thesis, refer to the SCS Honors Research Thesis (http://coursescatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#scshonorsresearchthesis) section for learning objectives, application requirements and expected outcomes.

Dual Degree in Computer Science

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Double-Counting Restriction

Students pursuing a Dual Degree in Computer Science must complete all requirements for the CS primary major (except 15-128 which is not required and 15-151 which will be replaced with 21-127 or 21-128). In addition, at most 5 of the 12 computer science requirements can double count with all other declared majors and minors. Students, especially from interdisciplinary majors or with multiple majors or minors, are urged to consult with the Assistant Dean or Undergraduate Program Coordinator in the CS Undergraduate Office to determine double-counting restrictions specific to their own situations.

Computer Science Additional Major

Students interested in pursuing an additional major in Computer Science should first consult with an advisor in the CS Undergraduate Office. Students are expected to complete the requirements for the CS minor first before continuing on to the additional major. Completion of the CS additional major requires 12 computer science courses (not including 15-110 and 15-112 if needed), 5 mathematics courses, and 1 technical communication course. Students are expected to complete all courses for the additional major with an average QPA of 3.0 or higher.

Declaration for the additional major is allowed only after all math requirements are completed or in progress, and at least 9 of the 12 CS requirements, once approved.

For more information about the SCS Honors Research Thesis, refer to the SCS Honors Research Thesis (http://coursescatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#scshonorsresearchthesis) section for learning objectives, application requirements and expected outcomes.

Dual Degree in Computer Science

Students wishing to pursue a Dual Degree in Computer Science are required to apply in the same way as students wishing to transfer into the Computer Science major. Details are given in the SCS Policies section. Besides the student’s primary degree requirements, a student accepted for Dual Degree in CS is required to complete at least 450 units in total and meet all requirements for the CS major including all general education requirements (humanities/arts and science/engineering). Dual degree students do not need to complete 15-128, and these students will replace 15-151 with either 21-127 or 21-128. Since the CS major requires at least a minor or concentration in another area, the student’s primary major will substitute for this requirement. Note that the primary major must be completed prior to or at the same time as the dual degree in CS to satisfy the minor requirement; a dual degree in CS cannot be certified if the primary degree is not completed. Students should consult with the Assistant Dean in the CS Undergraduate Office and/or their CS academic advisor to review all requirements, once approved.

Double-Counting Restriction

Students pursuing a Dual Degree in Computer Science must complete all requirements for the CS primary major (except 15-128 which is not required and 15-151 which will be replaced with 21-127 or 21-128). In addition, at most 5 of the 12 computer science requirements can double count with all other declared majors and minors. Students, especially from interdisciplinary majors or with multiple majors or minors, are urged to consult with the Assistant Dean or Undergraduate Program Coordinator in the CS Undergraduate Office to determine double-counting restrictions specific to their own situations.

Computer Science Additional Major

Students interested in pursuing an additional major in Computer Science should first consult with an advisor in the CS Undergraduate Office. Students are expected to complete the requirements for the CS minor first before continuing on to the additional major. Completion of the CS additional major requires 12 computer science courses (not including 15-110 and 15-112 if needed), 5 mathematics courses, and 1 technical communication course. Students are expected to complete all courses for the additional major with an average QPA of 3.0 or higher.

Declaration for the additional major is allowed only after all math requirements are completed or in progress, and at least 9 of the 12 CS requirements, once approved.

For more information about the SCS Honors Research Thesis, refer to the SCS Honors Research Thesis (http://coursescatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#scshonorsresearchthesis) section for learning objectives, application requirements and expected outcomes.
80-413  Category Theory  9
others as designated by the CS Undergraduate Program

One Systems elective (minimum 12 units):  Units
15-410  Operating System Design and Implementation  15
15-411  Compiler Design  15
15-418  Parallel Computer Architecture and Programming  12
15-440  Distributed Systems  12
15-441  Networking and the Internet  12
15-445  Database Systems  12

One Artificial Intelligence elective (minimum 9 units):  Units
10-315  Introduction to Machine Learning (SCS Majors)  12
(or 10-301 by permission)
11-411  Natural Language Processing  12
11-485  Introduction to Deep Learning  9
15-281  Artificial Intelligence: Representation and Problem Solving  12
15-386  Neural Computation  9
16-384  Robot Kinematics and Dynamics  12
16-385  Computer Vision  12

One Domains elective (minimum 9 units):  Units
02-251  Great Ideas in Computational Biology  12
05-391  Designing Human Centered Software  12
15-322  Introduction to Computer Music  9
15-330  Introduction to Computer Security  12
15-455  Undergraduate Complexity Theory  9
15-462  Computer Graphics  12
17-313  Foundations of Software Engineering  12

Two Computer Science electives (minimum 18 units):  Units
These electives can be from any SCS department; 200-level or above, at least 9 units each (see exceptions below):
Computer Science [15-], Computational Biology [02-], Human Computer Interaction [05-], Machine Learning [10-], Language Technologies [11-], Robotics [16-], and Software Engineering [17-]. (NOTE: The following undergraduate courses do NOT count as Computer Science electives: 02-201, 02-223, 02-250, 02-261, 15-351, 16-223, 17-200, 17-333, 17-356. Some IDEATE courses and SCS graduate courses might not be allowed. Consult with a CS undergraduate advisor before registration to determine eligibility for this requirement.)

Math requirements (minimum 5 courses):  Units
All of the following courses:
21-122  Integration and Approximation  10
21-259  Calculus in Three Dimensions  9
21-127  Concepts of Mathematics  10
or 21-128  Mathematical Concepts and Proofs  10
21-241  Matrices and Linear Transformations  10
or 21-242  Matrix Theory  10

Plus one of the following:
15-259  Probability and Computing  12
21-325  Probability  9
36-218  Probability Theory for Computer Scientists  9
36-226  Introduction to Statistical Inference  9

Technical Communication requirement (1 course):  Units
One Technical Communications course:
15-300  Research and Innovation in Computer Science  9
(seating limited, by permission of instructor only)
17-200  Ethics and Policy Issues in Computing  9
76-270  Writing for the Professions  9

Double-Counting Restriction

Students pursuing an Additional Major in Computer Science must complete all requirements listed above. In addition, at most 5 of the 12 computer

Science requirements can be double counted toward all other declared majors and minors. The mathematics and technical communication requirements can be double counted without restriction. Students, especially from interdisciplinary majors or with multiple majors or minors, are urged to consult with the Assistant Dean or Undergraduate Program Coordinator in the CS Undergraduate Office to determine double-counting restrictions specific to their own situations.

Computer Science Minor

FOR STUDENTS ENTERING CMU IN FALL 2018

Students interested in pursuing a minor in Computer Science should first consult with an advisor in the CS Undergraduate Office after completion of the prerequisites, 15-122, 15-150 and with at least one of the 200-level required courses in progress. Students are expected to complete all courses for the minor with a C or higher (for a minor average QPA of 2.0 or higher).

The following courses are required for the Minor in Computer Science:

<table>
<thead>
<tr>
<th>Prerequisites</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-112</td>
<td>Fundamentals of Programming and Computer Science</td>
</tr>
<tr>
<td>(some students may need to take 15-110 prior to 15-112 for additional preparation)</td>
<td></td>
</tr>
<tr>
<td>or 21-127</td>
<td>Concepts of Mathematics</td>
</tr>
<tr>
<td>or 21-128</td>
<td>Mathematical Concepts and Proofs</td>
</tr>
<tr>
<td>15-122</td>
<td>Principles of Imperative Computation</td>
</tr>
<tr>
<td>15-150</td>
<td>Principles of Functional Programming</td>
</tr>
<tr>
<td>15-210</td>
<td>Parallel and Sequential Data Structures and Algorithms</td>
</tr>
</tbody>
</table>

One of the following Computer Science core courses:

| 15-213  | Introduction to Computer Systems |
| 15-251  | Great Ideas in Theoretical Computer Science |

Two additional Computer Science electives, of at least 9 units each:

CS elective courses must be 15-213 or higher, at least 9-units each. 15-221 and 15-351 cannot be used. One course can be from any other SCS department besides the Computer Science Department, with prior approval. Note: Students who take 15-213/18-213 or 15-251 as part of another degree are required to replace that CS minor requirement with another CS elective (15-xxx) as defined above, for a total of 3 additional CS electives.

Double-Counting Restriction

Students may double-count a maximum of 2 courses for the CS minor (not including the prerequisites) toward all other majors and minors. Students, especially from computing-related majors, interdisciplinary majors or with multiple majors or minors, are urged to consult with the Assistant Dean or Undergraduate Program Coordinator in the CS Undergraduate Office to review double-counting restrictions specific to their own situations.