Computer Science Program

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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. Suitably prepared students from other Carnegie Mellon colleges are eligible to apply for internal transfer to the School of Computer Science and will be considered for transfer if grades in core courses are sufficiently high and space is available.

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 subjects, culminating in the preparation of a senior research thesis.

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 subjects, 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.

Curriculum - B.S. in Computer Science

The following requirements are for students entering Fall 2019.

**Computer Science**

Computer Science Core (all of the following): 18
- 07-128 Freshman Immigration Course 1
- 07-122 Principles of Imperative Computation (students without credit or a waiver for 15-112, Fundamentals of Programming and Computer Science, must take 15-112 before 15-122) 10
- 15-150 Principles of Functional Programming 10
- 15-210 Parallel and Sequential Data Structures and Algorithms 12
- 15-213 Introduction to Computer Systems 12
- 15-251 Great Ideas in Theoretical Computer Science 12
- 15-451 Algorithm Design and Analysis 12

One Logics/Languages elective (min. 9 units): 9
- 15-312 Foundations of Programming Languages 9
- 15-314 Programming Language Semantics 9
- 15-316 Software Foundations of Security and Privacy 9
- 15-317 Constructive Logic 9
- 15-414 Bug Catching: Automated Program Verification 9
- 15-424 Logical Foundations of Cyber-Physical Systems 12
- 17-355 Program Analysis 12
- 80-413 Category Theory 9
- others as designated by the CS Undergraduate Program

One Software Systems elective (min. 12 units): 12
- 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 Computer Networks 12
- 15-445 Database Systems 12
- others as designated by the CS Undergraduate Program

One Artificial Intelligence elective (min. 9 units): 9
- 10-315 Introduction to Machine Learning (Undergrad) 12
- 11-411 Natural Language Processing 12
- 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
- others as designated by the CS Undergraduate Program

One Domains elective (min. 9 units): 9
- 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
- 17-313 Foundations of Software Engineering 12
- others as designated by the CS Undergraduate Program

Two Computer Science electives: 18

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, 17-562. Some IDEATE courses and some SCS undergraduate and graduate courses might not be allowed based on course content. Consult with a CS undergraduate advisor before registration to determine eligibility for this requirement.)

**Mathematics**

All of the following courses:
- 15-151 Mathematical Foundations for Computer Science (if not offered, substitute 21-127 or 21-128) 10
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 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 Computer Science requirements toward all other declared additional majors and minors. Additional majors and minors have their own double counting rules as well. Consult with a CS undergraduate advisor and an advisor from the department of the minor (or additional major) for specific restrictions on double counting.

Computing @ Carnegie Mellon (1 course)

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

99-101 Computing @ Carnegie Mellon 3

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>Computing (core courses, constrained electives, and SCS electives)</td>
<td>Mathematics</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Technical Communication</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Science/Engineering</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Humanities/Arts</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Minor or Concentration Requirement/Free electives</td>
<td>Varies</td>
</tr>
<tr>
<td></td>
<td>Computing @ Carnegie Mellon</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>First Year Seminar</td>
<td>1</td>
</tr>
<tr>
<td>Total</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 offsite job interviews or for their Senior Spring semester to account for visits to graduate schools.

Freshman Year:

<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
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</thead>
<tbody>
<tr>
<td>Fall</td>
<td>07-128</td>
</tr>
<tr>
<td></td>
<td>07-131</td>
</tr>
<tr>
<td></td>
<td>15-122</td>
</tr>
<tr>
<td></td>
<td>15-151</td>
</tr>
<tr>
<td></td>
<td>21-122</td>
</tr>
<tr>
<td></td>
<td>76-101</td>
</tr>
<tr>
<td></td>
<td>99-101</td>
</tr>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>15-150</td>
</tr>
<tr>
<td></td>
<td>15-213</td>
</tr>
<tr>
<td></td>
<td>21-259</td>
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<tr>
<td></td>
<td>xx-xxx</td>
</tr>
<tr>
<td></td>
<td>xx-xxx</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

Sophomore Year:

<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>15-210</td>
</tr>
<tr>
<td></td>
<td>21-241</td>
</tr>
<tr>
<td></td>
<td>xx-xxx</td>
</tr>
<tr>
<td>Fall</td>
<td>Spring</td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
</tr>
<tr>
<td>15-451: Algorithm Design and Analysis</td>
<td>15-xxx: Computer Science: Systems Elective*</td>
</tr>
<tr>
<td>9 units</td>
<td>12 units</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minor Requirement / Free Elective</th>
<th>Minor Requirement / Free Elective</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 units</td>
<td>9 units</td>
</tr>
</tbody>
</table>

**Minimum number of units required for the degree:** 360

*The flexibility in the curriculum allows many different schedules, of which the above is only one possibility. Some elective courses are offered only once per year (Fall or Spring). Constrained electives (probability, logic/ languages, software systems, artificial intelligence and domains) may be taken in any order and in any semester if prerequisites are met and seats are available. Constrained electives are shown in the specific semesters in the schedule above as an example only. Students should consult with their academic advisor to determine the best elective options depending on course availability, their academic interests and their career goals.

## 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, 15 units per semester. Up to 38 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 presents 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://coursecatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#scshonorsresearchthesistext) 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 GPA 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 course requirements, once approved.

Students should plan to be flexible in selecting constrained and general electives. Acceptance to complete a Computer Science additional major is not guaranteed and depends on student performance and seat availability.

The following courses are required for the Additional Major in Computer Science:

## Computer Science requirements (12 courses):

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-122</td>
<td>Principles of Imperative Computation</td>
<td>10</td>
</tr>
<tr>
<td>15-150</td>
<td>Principles of Functional Programming</td>
<td>10</td>
</tr>
<tr>
<td>15-210</td>
<td>Parallel and Sequential Data Structures and Algorithms</td>
<td>12</td>
</tr>
<tr>
<td>15-213</td>
<td>Introduction to Computer Systems</td>
<td>12</td>
</tr>
<tr>
<td>15-251</td>
<td>Great Ideas in Theoretical Computer Science</td>
<td>12</td>
</tr>
<tr>
<td>15-451</td>
<td>Algorithm Design and Analysis</td>
<td>12</td>
</tr>
<tr>
<td>15-312</td>
<td>Foundations of Programming Languages</td>
<td>12</td>
</tr>
<tr>
<td>15-314</td>
<td>Programming Language Semantics</td>
<td>12</td>
</tr>
<tr>
<td>15-316</td>
<td>Software Foundations of Security and Privacy</td>
<td>9</td>
</tr>
<tr>
<td>15-317</td>
<td>Constructive Logic</td>
<td>9</td>
</tr>
<tr>
<td>15-414</td>
<td>Bug Catching: Automated Program Verification</td>
<td>9</td>
</tr>
<tr>
<td>15-424</td>
<td>Logical Foundations of Cyber-Physical Systems</td>
<td>12</td>
</tr>
<tr>
<td>17-355</td>
<td>Program Analysis</td>
<td>12</td>
</tr>
</tbody>
</table>
Computer Science Program

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 Computer Networks 12
15-445 Database Systems 12

others as designated by the CS Undergraduate Program

One Artificial Intelligence elective (minimum 9 units): Units
10-315 Introduction to Machine Learning (Undergrad) (or 10-301 by permission) 12
11-411 Natural Language Processing 12
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

others as designated by the CS Undergraduate Program

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

others as designated by the CS Undergraduate Program

Two Computer Science electives (minimum 18 units): 18
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, 17-562. 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):

All of the following courses: Units
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
21-241 Matrices and Linear Transformations 10
or 21-242 Matrix Theory

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 (for students already taking 36-217 or 36-225) 9

Technical Communication requirement (1 course):

One Technical Communications course: Units
15-300 Research and Innovation in Computer Science (seating limited, by permission of instructor only) 9
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:

Prerequisites: Units
15-112 Fundamentals of Programming and Computer Science (some students may need to take 15-110 prior to 15-112 for additional preparation) 12
21-127 Concepts of Mathematics or 21-128 Mathematical Concepts and Proofs 10-12

Computer Science core courses:

15-122 Principles of Imperative Computation 10
15-150 Principles of Functional Programming 10
15-210 Parallel and Sequential Data Structures and Algorithms 12

One of the following Computer Science core courses:

15-213 Introduction to Computer Systems 12
15-251 Great Ideas in Theoretical Computer Science 12

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.