Computer Science Program

Srinivasan Seshan, Department Head, Computer Science
Location: GHC 4115
Mark Stehlik, Program Director, Assistant Dean for Outreach
Location: GHC 6205
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. 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 CS requirements 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 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, a B.S. degree in Human-Computer Interaction, 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, a Bachelor’s Degree in Computer Science and the Arts (jointly with the College of Fine Arts), 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, 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): Units

07-128 First Year Immigration Course 1

15-122 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 Artificial Intelligence elective (min. 9 units):
10-315 Introduction to Machine Learning (SCS Majors) 12
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
others as designated by the CS Undergraduate Program

One Domains elective (min. 9 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

One Logics/Languages elective (min. 9 units):
15-312 Foundations of Programming Languages 12
15-314 Programming Language Semantics 12
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):
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
others as designated by the CS Undergraduate Program

Two Computer Science electives: Units

These electives can be from any SCS department; 200-level or above, at least 9 units each (see exceptions below):

Mathematics

All of the following Mathematics courses:
15-151 Mathematical Foundations for Computer Science (if not offered, substitute 21-127 or 21-128) 10
21-122 Integration and Approximation 10
(Students without credit or a waiver for 21-120, Differential and Integral Calculus, must take 21-120 before 21-122.)
21-241 Matrices and Linear Transformations 10 or 21-242 Matrix Theory
21-259 Calculus in Three Dimensions 9
Plus one of the following four Probability choices:
15-259 Probability and Computing 12
21-325 Probability 9
36-218 Probability Theory for Computer Scientists 9
36-225-36-226 Introduction to Probability Theory - Introduction to Statistical Inference 18
(must take both courses in this sequence to satisfy requirement)

Technical Communications
One Technical Communications course: Units
15-300 Research and Innovation in Computer Science 9
17-200 Ethics and Policy Issues in Computing 9
76-270 Writing for the Professions 9

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 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>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>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:

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

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

Sophomore Year:

Fall
15-210 Parallel and Sequential Data Structures and Algorithms 12
21-241 Matrices and Linear Transformations 10
xx-xxx Science/Engineering Course 9
<table>
<thead>
<tr>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
</tr>
</tbody>
</table>
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. 18 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.

### 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.

### 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 the Program Coordinator 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 (core and electives) are completed or in progress. Due to high demand, seats in upper-level CS courses are not guaranteed for additional majors so 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 Name</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>10-315</td>
<td>Introduction to Machine Learning (SCS Majors)</td>
<td>12</td>
</tr>
<tr>
<td>11-411</td>
<td>Natural Language Processing</td>
<td>12</td>
</tr>
<tr>
<td>15-485</td>
<td>Introduction to Deep Learning</td>
<td>9</td>
</tr>
<tr>
<td>15-281</td>
<td>Artificial Intelligence: Representation and Problem Solving</td>
<td>12</td>
</tr>
<tr>
<td>15-386</td>
<td>Neural Computation</td>
<td>9</td>
</tr>
<tr>
<td>16-384</td>
<td>Robot Kinematics and Dynamics</td>
<td>12</td>
</tr>
</tbody>
</table>
### Computer Science Program

**Math requirements (minimum 5 courses):**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>21-122 Integration and Approximation</td>
<td>10</td>
</tr>
<tr>
<td>21-259 Calculus in Three Dimensions</td>
<td>9</td>
</tr>
<tr>
<td>21-127 Concepts of Mathematics</td>
<td>10</td>
</tr>
<tr>
<td>or 21-128 Mathematical Concepts and Proofs</td>
<td></td>
</tr>
<tr>
<td>21-241 Matrices and Linear Transformations</td>
<td>10</td>
</tr>
<tr>
<td>or 21-242 Matrix Theory</td>
<td></td>
</tr>
<tr>
<td>36-218 Probability Theory for Computer Scientists</td>
<td>9</td>
</tr>
<tr>
<td>36-226 Introduction to Statistical Inference</td>
<td>9</td>
</tr>
<tr>
<td>(for students already taking 36-219 or 36-225)</td>
<td></td>
</tr>
</tbody>
</table>

**Technical Communication requirement (1 course):**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-300 Research and Innovation in Computer Science (seating limited, by permission of instructor only)</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>

**Computer Science Minor**

Students interested in pursuing a minor in Computer Science should first consult with the Program Coordinator 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:**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-112 Fundamentals of Programming and Computer Science</td>
<td>12</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>21-127 or 21-128 Mathematical Concepts and Proofs</td>
<td>10-12</td>
</tr>
</tbody>
</table>

**Computer Science core courses:**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-122 Principles of Imperative Computation</td>
<td>10</td>
</tr>
<tr>
<td>15-150 Principles of Functional Programming</td>
<td>10</td>
</tr>
<tr>
<td>15-210 Parallel and Sequential Data Structures and Algorithms</td>
<td>12</td>
</tr>
</tbody>
</table>

**One of the following Computer Science core courses:**

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-213 Introduction to Computer Systems</td>
<td>12</td>
</tr>
<tr>
<td>15-251 Great Ideas in Theoretical Computer Science</td>
<td>12</td>
</tr>
</tbody>
</table>

**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 Computer Science Program Director or the Undergraduate Program Coordinator in the CS Undergraduate Office to determine double-counting restrictions specific to their own situations.

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### Math requirements (minimum 5 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: 9
  - 21-241 Matrices and Linear Transformations: 10
  - or 21-242 Matrix Theory: 9
  - 36-218 Probability Theory for Computer Scientists: 9
  - 36-226 Introduction to Statistical Inference: 9 (for students already taking 36-219 or 36-225)

### Technical Communication requirement (1 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