Undergraduate Computational Biology Program

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Assistant Dept. Head for Education: Phillip Compeau, PhD (GHC 7403)
Academic Program Manager: Nicole Steinger (GHC 7414)
http://cbd.cmu.edu

Bachelor of Science in Computational Biology

Program Director: Dr. Phillip Compeau
Program Manager: Samantha Mudrinich

Success in computational biology requires significant technical knowledge of fundamental computer science as well as a broad biological intuition and general understanding of experimental biology. However, most importantly, it requires students who can integrate their knowledge by making connections between the two fields.

There is significant industry demand for excellent computational biology students, in biotech firms, biomedical research, as well as in pharmaceutical research. Both established companies and startups struggle to find employees with the correct skillset, and our students will be able to take advantage of the fact that an undergraduate computational biology major has the rigorous training required to handle the challenges of modern research that is not provided by any of our peer institutions.

Students completing the undergraduate program in computational biology will also be ideally prepared for Ph.D. programs in any of a range of biomedical areas, including Computational Biology, Systems Biology, or Quantitative Biology. Students who complete pre-medical requirements will be very well-prepared to attend medical school; after all, the next generation of physicians will need to better understand the computational approaches needed for automated medical testing, automated medical imaging, and the coming personalized medicine revolution.

Degree Requirements (students entering Fall 2018)

Students completing the Bachelor of Science in Computational Biology follow certain policies that apply to all SCS students; please consult the SCS policies page (http://coursecatalog.web.cmu.edu/schoolofcomputerscience/#policies) for a complete listing of these expectations.

Students must complete a minimum of 360 units for the degree in computational biology.

For Mellon College of Sciences students interested in computational biology who matriculated at Carnegie Mellon before Fall 2017, please go to Previous Catalogs (http://coursecatalog.web.cmu.edu/previous) for degree requirements.

Mathematics/Statistics Core

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>21-120</td>
<td>Differential and Integral Calculus</td>
<td>10</td>
</tr>
<tr>
<td>21-122</td>
<td>Integration and Approximation</td>
<td>10</td>
</tr>
<tr>
<td>15-151</td>
<td>Mathematical Foundations for Computer Science (or 21-127 if not offered)</td>
<td>10</td>
</tr>
<tr>
<td>36-218</td>
<td>Probability Theory for Computer Scientists (Students taking 15-359 should take 36-326 instead.)</td>
<td>9</td>
</tr>
<tr>
<td>or 36-226</td>
<td>Introduction to Statistical Inference</td>
<td></td>
</tr>
<tr>
<td>or 36-326</td>
<td>Mathematical Statistics (Honors)</td>
<td>10</td>
</tr>
<tr>
<td>21-241</td>
<td>Matrices and Linear Transformations</td>
<td>10</td>
</tr>
<tr>
<td>or 21-242</td>
<td>Matrix Theory</td>
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</table>

Total Units: 49

General Science Core

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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<tbody>
<tr>
<td>09-105</td>
<td>Introduction to Modern Chemistry I</td>
<td>10</td>
</tr>
<tr>
<td>or 09-107</td>
<td>Honors Chemistry: Fundamentals, Concepts and Applications</td>
<td></td>
</tr>
<tr>
<td>33-121</td>
<td>Physics I for Science Students</td>
<td>12</td>
</tr>
<tr>
<td>or 33-141</td>
<td>Physics I for Engineering Students</td>
<td></td>
</tr>
</tbody>
</table>

Total Units: 22

Biological Core

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>03-121</td>
<td>Modern Biology</td>
<td>9</td>
</tr>
<tr>
<td>03-221</td>
<td>Genomes, Evolution, and Disease: Introduction to Quantitative Genetic Analysis (or 03-220 if not offered)</td>
<td>9</td>
</tr>
<tr>
<td>03-232</td>
<td>Biochemistry I (Students taking 03-231, including pre-med students, will take organic chemistry as a prerequisite, which will satisfy a biology elective requirement.)</td>
<td>9</td>
</tr>
<tr>
<td>or 03-231</td>
<td>Honors Biochemistry</td>
<td></td>
</tr>
<tr>
<td>03-320</td>
<td>Cell Biology</td>
<td>9</td>
</tr>
</tbody>
</table>

Total Units: 36

Computer Science Core

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>07-128</td>
<td>Freshman Immigration Course</td>
<td>1</td>
</tr>
</tbody>
</table>

<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>15-251</td>
<td>Great Ideas in Theoretical Computer Science</td>
<td>12</td>
</tr>
<tr>
<td>15-351</td>
<td>Algorithms and Advanced Data Structures (Students taking 15-150 and 15-210 as prerequisites for 15-451 may apply these courses as CS electives.)</td>
<td>12</td>
</tr>
<tr>
<td>or 15-451</td>
<td>Algorithm Design and Analysis</td>
<td></td>
</tr>
<tr>
<td>10-401</td>
<td>Introduction to Machine Learning (Undergrad)</td>
<td>12</td>
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</tbody>
</table>

Total Units: 47

Computational Biology Core

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>02-251</td>
<td>Great Ideas in Computational Biology</td>
<td>12</td>
</tr>
<tr>
<td>02-261</td>
<td>Quantitative Cell and Molecular Biology Laboratory</td>
<td>12</td>
</tr>
<tr>
<td>or 03-343</td>
<td>Experimental Techniques in Molecular Biology</td>
<td></td>
</tr>
<tr>
<td>02-402</td>
<td>Computational Biology Seminar</td>
<td>3</td>
</tr>
<tr>
<td>02-510</td>
<td>Computational Genomics</td>
<td>12</td>
</tr>
<tr>
<td>02-512</td>
<td>Computational Methods for Biological Modeling and Simulation</td>
<td>9-12</td>
</tr>
<tr>
<td>or 02-530</td>
<td>Cell and Systems Modeling</td>
<td></td>
</tr>
</tbody>
</table>

Total Units: 48-51

Major Electives

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>02-3xx</td>
<td>Computational Biology Electives at 300 level or above (Includes a few courses outside of 02-xxx, such as 03-500 if research is computational; list of acceptable courses updated annually)</td>
<td>18-24</td>
</tr>
<tr>
<td>03-xxx</td>
<td>Biology Electives at 300 level or above (03-217 also counts as a biology elective)</td>
<td>9-12</td>
</tr>
<tr>
<td>15-xxx</td>
<td>Computer Science or 10-xxx Machine Learning Electives</td>
<td>18-24</td>
</tr>
</tbody>
</table>

Total Units: 45-60

Humanities & 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. 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/schoolofcomputerscience/#genedtext).
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>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math/Stats Core</td>
<td>49</td>
</tr>
<tr>
<td>General Science Core</td>
<td>22</td>
</tr>
<tr>
<td>Biological Core</td>
<td>36</td>
</tr>
<tr>
<td>Computer Science Core</td>
<td>50</td>
</tr>
<tr>
<td>Computational Biology Core</td>
<td>48-51</td>
</tr>
<tr>
<td>Major Electives</td>
<td>45-60</td>
</tr>
<tr>
<td>General Education (Humanities &amp; Arts)</td>
<td>63</td>
</tr>
<tr>
<td>Remaining Units</td>
<td>29-47</td>
</tr>
<tr>
<td>Total Units</td>
<td>360</td>
</tr>
</tbody>
</table>

Sample Course Sequence

The sample given below assumes a student has credit for an introductory programming course, but no credit for calculus. The course sequence below is simply a suggested guide to which courses may be appropriate for students completing the undergraduate program in computational biology in each term. Individual students will have individual paths based on their backgrounds and needs.

### Fall 2023

#### Freshman

- 07-128 freshman immigration course
- 21-128 Principles of imperative computation
- 15-131 Great practical ideas for computer scientists
- 15-151 Mathematical foundations for computer science
- 21-120 Differential and integral calculus
- 36-101 interpretation and argument
- 99-101 computing @ Carnegie Mellon

#### Sophomore

- 02-251 Great ideas in computational biology
- 03-121 modern biology
- 09-105 introduction to modern chemistry
- 21-122 integration and approximation
- xx-xxx humanities and arts elective
- xx-xxx humanities and arts elective

### Spring 2024

#### Freshman

- 02-252 Quantitative cell and molecular biology laboratory
- 03-211 Genomes, evolution, and disease: introduction to quantitative genetic analysis
- 15-351 algorithms and advanced data structures
- 21-241 matrices and linear transformations
- xx-xxx humanities and arts elective
- xx-xxx humanities and arts elective

#### Sophomore

- 02-261 Quantitative cell and molecular biology laboratory
- 03-212 Genomes, evolution, and disease: introduction to quantitative genetic analysis
- 15-351 algorithms and advanced data structures
- 21-241 matrices and linear transformations
- xx-xxx humanities and arts elective
- xx-xxx humanities and arts elective

### Prerequisite Courses

- 02-250 Introduction to Computational Biology 12
- 02-251 Great Ideas in Computational Biology 12
- 03-121 Modern Biology 9
- 03-151 Honors Modern Biology 9
- 15-122 Principles of Imperative Computation 10
- 15-151 Mathematical foundations for Computer Science 10
- 21-127 Concepts of Mathematics 9
- 21-128 Mathematical concepts and proofs 9
- 21-120 Differential and Integral Calculus 10
- 21-122 Integration and approximation 10

### Total Units

- 360

### Additional Major in Computational Biology

The Additional Major in Computational Biology is designed for undergraduate students wishing to study computational biology as a second field of study at Carnegie Mellon University in addition to their primary major.

To prevent double-counting, students must complete at least seven courses of at least 9 units each as part of the additional major in computational biology (not including prerequisites) that are unique to the additional major.

Students interested in the Additional Major in Computational Biology should contact the Computational Biology Undergrad Program Director.

### Prerequisite Courses

- 02-250 Introduction to Computational Biology 12
- or 02-251 Great Ideas in Computational Biology 12
- 03-121 Modern Biology 9
- or 03-151 Honors Modern Biology 9
- 15-122 Principles of Imperative Computation 10
- 15-151 Mathematical foundations for Computer Science 10
- or 21-127 Concepts of Mathematics 9
- or 21-128 Mathematical concepts and proofs 9
- 21-120 Differential and Integral Calculus 10
- 21-122 Integration and approximation 10

### Total Units

- 61

### Mathematics/Statistics Core

- 36-218 Probability theory for Computer Scientists 9
- or 36-226 Introduction to Statistical Inference 9
- or 36-226 Mathematical Statistics (Honors) 9
- 21-241 Matrices and Linear Transformations 10
- or 21-242 Matrix Theory 10

### Total Units

- 19

### General Science Core

- 09-105 Introduction to Modern Chemistry I 10
- or 09-107 Honors Chemistry: Fundamentals, Concepts and Applications 10
- 33-121 Physics I for Science Students 12
- or 33-141 Physics I for Engineering Students 12

### Total Units

- 22

### Biological Core

- 03-221 Genomes, Evolution, and Disease: Introduction to Quantitative Genetic Analysis 9
- or 03-220 Genetics 9
- 03-232 Biochemistry I 9
- (Students taking 03-231, including pre-med students, will take organic chemistry as a prerequisite, which will satisfy a biology elective requirement.)
- or 03-231 Honors Biochemistry 9
- 03-320 Cell Biology 9

### Total Units

- 27
Computational Biology is a growing field not only in academia, but also in industry. Major players in computation and medicine have invested heavily in biological systems, and to use them to devise methods of prevent or treat disease. Computational Biologists inhabit and expand the interface of computation and biology, making them integral to the future of biology and medicine.

Why Minor in Computational Biology?
Computational Biology is concerned with solving biological and biomedical problems using mathematical and computational methods. It is recognized as an essential element in modern biological and biomedical research. There have been fundamental changes in biology and medicine over the past two decades due to spectacular advances in high throughput data collection for genomics, proteomics and biomedical imaging. The resulting availability of unprecedented amounts of biological data demands the application of advanced computational tools to build integrated models of biological systems, and to use them to devise methods of prevent or treat disease. Computational Biologists inhabit and expand the interface of computation and biology, making them integral to the future of biology and medicine.

Computational Biology is a growing field not only in academia, but also in industry. Major players in computation and medicine have invested heavily in computational biology, including Google, Microsoft, Roche and Merck.

### Undergraduate Computational Biology Program

#### Curriculum Overview
The minor in computational biology requires a total of five courses: 3 core courses, 1 biology elective, and 1 computational biology elective, for a total of at least 45 units.

#### Prerequisites
Students must take both of the following courses as prerequisites:
- 03-121 Modern Biology
- 03-151 Honors Modern Biology
- 15-122 Principles of Imperative Computation

#### Core Classes
Students must take both of the following courses:
- 02-250 Introduction to Computational Biology
- 02-251 Great Ideas in Computational Biology
- 02-261 Quantitative Cell and Molecular Biology Laboratory
- 03-263 Experimental Techniques in Molecular Biology
- 03-343 Experimental Techniques in Molecular Biology may be substituted for 02-261 with permission of the minor advisor; 03-115 and 03-116 may be used to replace 02-261 if and only if the latter is not offered

#### Biology Elective
Please select one of the following courses:
- 03-220 Genetics
- 03-221 Genomes, Evolution, and Disease: Introduction to Quantitative Genetic Analysis
- 03-231 Honors Biochemistry
- 03-322 Biochemistry I
- 03-320 Cell Biology
- 03-327 Phylogenetics
- 03-362 Cellular Neuroscience
- 03-363 Systems Neuroscience
- 03-364 Developmental Neuroscience
- 03-439 Introduction to Biophysics
- 03-442 Molecular Biology
- 03-534 Biological Imaging and Fluorescence Spectroscopy
- 42-202 Physiology

#### Computational Biology Elective
Please select one of the following courses:
- 02-xxx Any 02-xxx listed course 02-300 or above
- 09-560 Computational Chemistry
- 15-386 Neural Computation
- 15-883 Computational Models of Neural Systems
- 16-725 Medical Image Analysis
- 42-640/24-658 Image-Based Computational Modeling and Analysis

### Why Minor in Computational Biology?
The minor in computational biology requires a total of five courses: 3 core courses, 1 biology elective, and 1 computational biology elective, for a total of at least 45 units.

#### Prerequisites
Students must take both of the following courses as prerequisites:
- 03-121 Modern Biology
- 03-151 Honors Modern Biology
- 15-122 Principles of Imperative Computation

#### Core Classes
Students must take both of the following courses:
- 02-250 Introduction to Computational Biology
- 02-251 Great Ideas in Computational Biology
- 02-261 Quantitative Cell and Molecular Biology Laboratory
- 03-263 Experimental Techniques in Molecular Biology
- 03-343 Experimental Techniques in Molecular Biology may be substituted for 02-261 with permission of the minor advisor; 03-115 and 03-116 may be used to replace 02-261 if and only if the latter is not offered

Students must take one of the following courses:
- 02-510 Computational Genomics
- 02-512 Computational Methods for Biological Modeling and Simulation
- 02-530 Cell and Systems Modeling

#### Biology Elective
Please select one of the following courses:
- 03-220 Genetics
- 03-221 Genomes, Evolution, and Disease: Introduction to Quantitative Genetic Analysis
- 03-231 Honors Biochemistry
- 03-322 Biochemistry I
- 03-320 Cell Biology
- 03-327 Phylogenetics
- 03-362 Cellular Neuroscience
- 03-363 Systems Neuroscience
- 03-364 Developmental Neuroscience
- 03-439 Introduction to Biophysics
- 03-442 Molecular Biology
- 03-534 Biological Imaging and Fluorescence Spectroscopy
- 42-202 Physiology

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Please select one of the following courses:
- 02-xxx Any 02-xxx listed course 02-300 or above
- 09-560 Computational Chemistry
- 15-386 Neural Computation
- 15-883 Computational Models of Neural Systems
- 16-725 Medical Image Analysis
- 42-640/24-658 Image-Based Computational Modeling and Analysis

#### Policy on Double Counting
No more than two courses may be double counted with your major's core requirements. Courses in the minor may not be counted towards another SCS minor. Consult the minor advisor for more information.