COMPUTATIONAL AND SYSTEMS BIOLOGY

The field of computational and systems biology represents a synthesis of ideas and approaches from the life sciences, physical sciences, computer science, and engineering. Recent advances in biology, including the human genome project and massively parallel approaches to probing biological samples, have created new opportunities to understand biological problems from a systems perspective. Systems modeling and design are well established in engineering disciplines but are newer in biology. Advances in computational and systems biology require multidisciplinary teams with skill in applying principles and tools from engineering and computer science to solve problems in biology and medicine. To provide education in this emerging field, the Computational and Systems Biology (CSB) program integrates MIT's world-renowned disciplines in biology, engineering, mathematics, and computer science. Graduates of the program are uniquely prepared to make novel discoveries, develop new methods, and establish new paradigms. They are also well-positioned to assume critical leadership roles in both academia and industry, where this field is becoming increasingly important.

Computational and systems biology, as practiced at MIT, is organized around "the 3 Ds" of description, distillation, and design. In many research programs, systematic data collection is used to create detailed molecular- or cellular-level descriptions of a system in one or more defined states. Given the complexity of biological systems and the number of interacting components and parameters, system modeling is often conducted with the aim of distilling the essential or most important subsystems, components, and parameters, and of obtaining simplified models that retain the ability to accurately predict system behavior under a wide range of conditions. Distillation of the system can increase the interpretability of the models in relation to evolutionary and engineering principles such as robustness, modularity, and evolvability. The resulting models may also serve to facilitate rational design of perturbations to test understanding of the system or to change system behavior (e.g., for therapeutic intervention), as well as efforts to design related systems or systems composed of similar biological components.

More than 70 faculty members at the Institute participate in MIT's Computational and Systems Biology Initiative (CSBi). These investigators span nearly all departments in the School of Science and the School of Engineering, providing CSB students the opportunity to pursue thesis research in a wide variety of different MIT laboratories. It is also possible for students to arrange collaborative thesis projects with joint supervision by faculty members with different areas of expertise. Areas of active research include behavioral genetics and genomics; bioengineering and neuroengineering; biological networks and machine learning;cancer systems biology; cellular biophysics; chemical biology and metabolomics; epigenomics; evolutionary and computational biology; microbiology and systems ecology; molecular biophysics and structural biology; precision medicine and medical genomics; quantitative imaging; regulatory genomics and proteomics; single cell manipulations and measurement; stem cell and developmental systems biology; and synthetic biology and biological design.

The CSB PhD program is an Institute-wide program that has been jointly developed by the Departments of Biology, Biological Engineering, and Electrical Engineering and Computer Science. The program integrates biology, engineering, and computation to address complex problems in biological systems, and CSB PhD students have the opportunity to work with CSBi faculty from across the Institute. The curriculum has a strong emphasis on foundational material to encourage students to become creators of future tools and technologies, rather than merely practitioners of current approaches. Applicants must have an undergraduate degree in biology (or a related field), bioinformatics, chemistry, computer science, mathematics, statistics, physics, or an engineering discipline, with dual-emphasis degrees encouraged.

All students pursue a core curriculum that includes classes in biology and computational biology, along with a class in computational and systems biology based on the scientific literature. Advanced electives in science and engineering enhance both the breadth and depth of each student's education. During their first year, in addition to coursework, students carry out rotations in multiple research groups to gain a broader exposure to work at the frontier of this field, and to identify a suitable laboratory in which to conduct thesis research. CSB students also serve as teaching assistants during one semester in the second year to further develop their teaching and communication skills and facilitate their interactions across disciplines. Students also participate in training in the responsible conduct of research to prepare them for the complexities and demands of modern scientific research. The total length of the program, including classwork, qualifying examinations, thesis research, and preparation of the thesis is roughly five years.

Curriculum

The CSB curriculum has two components. The first is a core that provides foundational knowledge of both biology and computational biology. The second is a customized program of electives that is selected by each student in consultation with members of the CSB graduate committee. The goal is to allow students broad latitude in defining their individual area of interest, while at the same time providing oversight and guidance to ensure that training is rigorous and thorough.

Core Curriculum

The core curriculum consists of three classroom subjects plus a set of three research rotations in different research groups. The classroom subjects fall into three areas described below.

Modern Biology

One subject in biochemistry, genetics, cell biology, molecular biology, or neurobiology, determined consultation with graduate committee members.		12
Computational Biology		
20.490	Foundations of Computational and Systems Biology	12
or 6.878[J]	Advanced Computational Biology: Genomes, Networks, Evolution	
Computational and Systems Biology		
CSB.110	Research Rotations in Computational and Systems Biology	12
Research Group Rotations		
Students participate in three research rotations of one to two months' duration during their first year to expose them to a range of research activities in computation and systems biology, and to assist them in choosing a lab. Students are encouraged to gain experience in experimental and computational approaches taken across different disciplines at MIT.		

Advanced Electives

To develop breadth and depth, add to the base of the diversified core, and contribute strength in areas related to their interest and research direction, students must take four advanced electives. Each student designs a program of advanced electives that satisfies the distribution and area requirements in close consultation with members of the graduate committee.

Two subjects in the student's research area or department
One subject in engineering
One subject in science

Additional Subjects

CSB PhD students may take classes beyond the required diversified core and advanced electives described above. These additional subjects can be used to add breadth or depth to the proposed curriculum, and might be useful to explore advanced topics relevant to the student's thesis research in later years. The CSB Graduate Committee works with each graduate student to develop a path through the curriculum appropriate for his or her background and research interests.

Training in the Responsible Conduct of Research

Throughout the program, students will be expected to attend workshops and other activities that provide training in the ethical conduct of research. This is particularly important in interdisciplinary fields such as computational and systems biology, where different disciplines often have very different philosophies and conventions. By the end of the fourth year, students will have had about 16 hours of training in the responsible conduct of research.

Qualifying Exams

In addition to coursework and a research thesis, each student must pass a written and an oral qualifying examination at the end of the second year or the beginning of the third year. The written examination involves preparing a research proposal based on the student's thesis research, and presenting the proposal to the examination committee. This process provides a strong foundation for the thesis research, incorporating new research ideas and refinement of the scope of the research project. The oral examination is based on the coursework taken and on related published literature. The qualifying exams are designed to develop and demonstrate depth in a selected area (the area of the thesis research) as well as breadth of knowledge across the field of computational and systems biology.

Thesis Research

Research will be performed under the supervision of a CSBi faculty member, culminating in the submission of a written thesis and its oral defense before the community and thesis defense committee. By the second year, a student will have formed a thesis advisory committee that they will meet with on an annual basis.