

Boston University

Graduate Program in Bioinformatics

Handbook

2022-23

<http://www.bu.edu/bioinformatics>

Department of Biochemistry (School of Medicine)
Department of Biology (College of Arts and Sciences)
Department of Biostatistics (School of Public Health)
Biomedical Engineering Department (College of Engineering)
Department of Chemistry (College of Arts and Sciences)
Department of Computational Biomedicine (School of Medicine)
Department of Computer Science (College of Arts and Sciences)
Computing & Data Sciences (CDS)
Electrical and Computer Engineering Department (College of Engineering)
Genetics and Genomics Department (School of Medicine)
Department of Mathematics and Statistics (College of Arts and Sciences)
Department of Mechanical Engineering (College of Engineering)
Department of Medicine (School of Medicine)
Department of Microbiology (School of Medicine)
Pharmacology & Experimental Therapeutics (School of Medicine)
Department of Physics (College of Arts and Sciences)
Pulmonary Medicine (School of Medicine)
Systems Engineering Division (College of Engineering)
Center for Computational Science
Center for Advanced Biotechnology
Center for Advanced Genomic Technology

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Department of Electrical and Computer Engineering (ENG)

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Department of Pharmacology & Experimental Therapeutics (BUSM)

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Staff

Mary Ellen Gipson-Fitzpatrick, Systems Administrator
David King, Graduate Program Coordinator
Caroline Lyman, Assistant Director
Johanna Vasquez, Administrative Coordinator

Overview

The graduate program in bioinformatics at Boston University provides interdisciplinary training for students of exceptional motivation. The program includes some 50 active faculties from five Colleges: Engineering, Arts and Sciences, Dentistry, Medicine and Public Health, and focuses on the molecular biology and physics of the cell, emphasizing the use of advanced mathematics and computation. Because we are educating future leaders, the program also includes training designed to sensitize students to the social impact of technology, including ethical and legal implications of emerging technologies.

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The Bioinformatics Ph.D. Program

I. Degree Requirements

The Ph.D. requires a total of **64** credits, consisting of the 34 required credits listed below, or their equivalents, and additional elective lecture, laboratory, seminar and/or research credits. The precise course of study will be determined in consultation with the student's academic advisor, and will reflect the student's background and interests. In order to be admitted to Ph.D. candidacy students must demonstrate mastery of the core subject matter (no lower than a 'B' in each of the core courses) and successfully complete a qualifying examination (see below).

Core Course Requirements:

Course#	Course Name	Credits	Offered
BE 562	Computational Biology: Genomes, Networks, Evolution	4	Fall
MA 681	Accelerated Intro to Stat Methods	4	Fall
BF 820	Research Opportunities in Bioinformatics	1	Fall
BF 690	BF Challenge Project Class	2 each; 4 total	Spring & Fall
BF 768	Biological Database Systems	4	Spring
	or		
BF 571	Dynamics & Evolution of Bio Networks	4	Spring
	or		
CS 542	Machine Learning	4	Spring & Fall
	or		
MA 770	Math & Stat Methods of Bioinformatics	4	Spring
BF 752	Legal & Ethical Issues of Science & Tech	4	Spring
BI 565	Functional Genomics	4	Spring
	or		
BF 751	Molecular Biology & Biochem for Bioinformatics	4	Fall
BF 821	Bioinformatics Graduate Seminar	2	Fall
BF 810	Lab Rotation	1 each rotation; 3 total	Summer, Spring & Fall
	Elective	4	Spring & Fall

Fulfillment of core course **equivalents** will be determined based on documented previous academic and/or work experience. The student and his or her advisors will petition the curriculum committee for such equivalencies. When either past work or an alternate course has been accepted as a core equivalent, the student's advisors will recommend another course to fulfill the 30 core credit hours. **Advanced elective courses should be taken in place of any waived course requirements.**

Students are also required to complete Boston University's Program in Advanced Responsible Conduct of Research (RCR). The goal of the Advanced RCR program is to achieve RCR Certification of every doctoral and postdoctoral trainee in scientific research, whether in the physical, social and behavioral, clinical or other basic or applied sciences at Boston University and Boston Medical Center. The program orients both trainees and faculty discussion facilitators to the complex ethical and regulatory context of research today. Participants develop the skills needed to make appropriate ethical decisions to survive in this challenging context.

Award of a Certificate of Completion of the Advanced RCR Program requires completion of the online preparation component (which must be completed within 30 days of enrollment in the PhD program) and all four live sessions in any sequence, over a two-year period. Recertification is required four years after completing the initial Advanced RCR program. Recertification is obtained by successful retaking the online preparation components and each of the four live sessions. Additional information on the Advanced RCR program, including session dates and locations can be found at the Research at Boston University website: <http://www.bu.edu/research/>.

Electives:

In addition to the core courses listed above, students are required to complete at least **one** additional elective course (i.e., non-research). The remainder of the 64 credits may be satisfied by research/thesis credits (BF 900 and/or BF 901). A minimum of 2 research credits is required.

Approved Elective Courses

ENG BE 560: Biomolecular Architecture
 ENG BE 564: Biophysics of Large Molecules
 ENG BE 565: Molecular Biotechnology
 ENG BE 566: DNA Structure and Function
 ENG BE 568: Systems Biology of Human Disease
 ENG BE 569: Next Generation Sequencing: Technology, Data Analysis & Biomedical Applications
 ENG BE 605: Molecular Bioengineering
 ENG BE 700/GRS PY 895: Methods and Logic in Quantitative Biology
 ENG BE 777: Computational Genomics
 ENG BF 831: Translational Bioinformatics Seminar
 CAS BI/CH 527: Biochemistry Laboratory I
 CAS BI/CH 528: Biochemistry Laboratory II
 CAS BI 502: Topics in the Theory of Biological Networks
 CAS BI 504: Advanced Evolutionary Analysis
 CAS BI 549: Molecular Phylogenetics and Evolution
 CAS BI 553: Molecular Biology II
 CAS BI 556: Drug Discovery in Neuroscience
 CAS BI 560: Systems Biology
 CAS BI 565: Functional Genomics
 CAS BI 572: Advanced Genetics
 GRS BI 610: Developmental Biology
 GRS BI 611: Microbiome: Our Intimate Relationship with Microorganisms
 GRS BI 735: Advanced Cell Biology
 GRS BI 753: Advanced Molecular Biology
 GRS BI 755: Cellular and Systems Neuroscience
 CAS BB 522: Molecular Biology Laboratory
 CAS CH 525: Physical Biochemistry
 GRS CH 626: Epigenetics: Protein, DNA & RNA Modifications & their Roles in Biological Processes
 GRS CH 751: Advanced Topics in Physical Chemistry
 GRS CH 752: Advanced Topics and Chemical Physics
 CAS CS 506: Computational Tools for Data Science
 CAS CS 542: Machine Learning
 CAS CS 543: Algorithmic Techniques for Taming Big Data
 CAS CS 549: Pattern Matching and Detection with Applications in Biological Sequence Analysis
 CAS CS 565: Algorithmic Data Mining
 SPH BS 730: Introduction to R: Software for Statistical Computing
 SPH BS 831: Genomics Data Mining and Statistics
 SPH BS 845: Applied Statistical Modeling and Programming in R

SPH BS 849: Bayesian Modeling for Biomedical Research & Public Health
 SPH BS 858: Statistical Genetics I
 SPH BS 859: Applied Genetic Analysis
 SPH BS 860: Statistical Genetics II
 CAS MA 555: Numerical Analysis I
 CAS MA 565: Mathematical Models in the Life Sciences
 CAS MA 575: Linear Models
 CAS MA 576: Generalized Linear Models
 CAS MA 579: Numerical Methods for Biological Sciences
 CAS MA 581: Probability
 CAS MA 582: Mathematical Statistics
 CAS MA 583: Introduction to Stochastic Processes
 CAS MA 584: Multivariate Statistical Analysis
 GRS MA 614: Statistical Methods II
 GRS MA 615: Data Science in R
 GRS MA 684: Applied Multiple Regression and Multivariable Methods
 GRS MA 770: Mathematical and Statistical Methods of Bioinformatics
 GRS MA 881: Statistics Seminar I
 GRS MA 882: Statistics Seminar II
 GRS MB 721: Graduate Level Biochemistry
 GRS MB 722: Advanced Biochemistry
 GRS PY 771: Systems Biology for Physical Scientists and Engineers
 GMS GE 701: Principles of Genetics and Genomics
 ENG EC 533: Advanced Discrete Mathematics
 ENG EC 534: Discrete Stochastic Models
 ENG EC 730: Information-Theoretical Design of Algorithms

† The core, elective and research/seminar courses are grouped by department.

Colleges:

ENG = College of Engineering
SPH = School of Public Health

GRS = Graduate School of Arts and Sciences
GMS = Graduate Medical Sciences

CAS = College of Arts and Sciences

Departments:

BE = Biomedical Engineering

BF = Bioinformatics

BI = Biology

BS = Biostatistics

CH = Chemistry

CS = Computer Science

EC = Electrical and Computer Engineering

MA = Mathematics

MB = Molecular Biology, Cell Biology and Biochemistry (MCBB)

PA = Pathology

PY = Physics

Lab Rotation Requirements:

Three lab rotations (BF810) are required during a Ph.D. student's first year. Students can only do rotations with faculty members who are currently appointed in Bioinformatics Program. One rotation must be experimental, one computational, and the third can be either.

In order to select a lab, students should visit faculty websites and narrow their choices to about 6 labs, then make appointments with faculty members to discuss their research. It is also recommended that students meet with other employees of the lab to discuss their experience there. Selection of laboratories is aided by enrolling in BF820, which is completed by mid-November of the first year. In this course, faculty with projects available for bioinformatics graduate students introduce their research topics.

Rotations typically last for a minimum of nine weeks and it is expected that the student will participate in the lab full time except for time spent on classes and class work. Students report on each rotation by completing a **Lab Rotation Approval Form** before the start of the rotation and a **Lab Rotation Report Form** at the end of the rotation. The report form must include a report of work completed; be signed by the immediate laboratory supervisor and academic advisor; and

submitted to the Graduate Program Coordinator. Students are required to begin their first rotation in early-July (wet-lab project) and submit their first rotation report by September 15th. The second rotation must start by October 15th and submit the second rotation report by December 15th. The third rotation will begin by January 15th and the report must be submitted by March 15th. Rotations will only be credited if reports are received by the due dates. Rotation forms can be found on the Bioinformatics website <http://www.bu.edu/bioinformatics/student-services>.

Teaching Requirement

It is a requirement for all students enrolled in the Bioinformatics PhD program to complete one semester of teaching. This requirement is to be completed in year 3 and is expected to be fulfilled by serving as a Teaching Fellow (TF) for a Bioinformatics course. If a student would like to satisfy this requirement by serving as a TF for a non-Bioinformatics class they or their research advisor will need to submit a petition to request it.

Details on the Bioinformatics teaching requirement are as follows:

- 1) The Bioinformatics teaching requirement consist of 15-20 hours of work per week for 1 semester.
- 2) Since a semester of teaching is a degree requirement, students are not funded as TFs from the Bioinformatics Program during their teaching semester but will continue to receive their normal Research Assistantship stipend via their lab.
- 3) In order to maintain consistency, the teaching of computational or BRITE REU workshops offered by the Bioinformatics Program will not fulfill the PhD teaching requirement. Instead, students teaching these workshops will be paid an hourly rate to compensate for their time.
- 4) Students who have already fulfilled their teaching requirement but would like to continue to serve as a TF for Bioinformatics classes will receive a TF stipend paid by the Bioinformatics Program.

Below is a breakdown of the Bioinformatics courses with teaching opportunities each semester and the number of TFs usually needed for each:

Fall

BF527: Bioinformatics Applications (2 TFs)

BF550: Foundations of Programming, Data Analytics & Machine Learning in Python (2 TFs)

BF751: Molecular Biology & Biochemistry for Bioinformatics (1 TF)

Spring

BF527: Bioinformatics Applications (1 TF)

BF528/591¹: Translation Bioinformatics Applications (5 TFs)

BF768: Biological Database Systems (2 TFs)

¹ = since the Teaching Fellow responsibilities for each of these courses are less than 10 hours per week, students will need to serve as a TF for both courses in order to fulfill their teaching requirement.

Internships

The Bioinformatics Program understands the professional development benefits of completing an industrial internship, but since it is not a requirement for the PhD program, students must request permission in order to complete one. Students will only be approved to complete one internship during their enrollment in the PhD program and will request permission by submitting the PhD Internship Approval form.

In order to receive approval, all of the following criteria must be met:

- Student must be member of a Bioinformatics research lab.
- Student's research advisor(s) approves of student taking time off from the lab to complete the internship.
- Student understands that the PhD Qualifying Exam must be completed following the completion of the 2nd year of study (by June 30th) and that the internship will not cause a delay in fulfilling this requirement.
- The work completed during the internship is relevant to the student's thesis research and must be explained in detail below.
- A job description must be reviewed and approved by both the research advisor and internship supervisor.

II. Ph.D. Advising System

Academic Advisor

Upon entry into the Bioinformatics Program, each student will be appointed an Academic Advisor from the Bioinformatics faculty. The advisor will act as the student's primary academic advisor until the student selects a research advisor(s) (see below).

Research Advisor(s)

The Ph.D. thesis is expected to have both computational and experimental components and will ideally, involve collaboration between experimental and computational labs. Therefore, the Bioinformatics Program strongly encourages the selection of two research advisors, one primarily computational and one primarily experimental. However, the nature of the Ph.D. thesis may be such that only a single advisor is appropriate. In this case, the advisor must be primarily computational (see below section). In either case, **one research advisor must be a faculty member of the Boston University Program in Bioinformatics**. If two advisors are selected and one is from outside Boston University, the other advisor must be a member of the Bioinformatics faculty. Students typically identify potential research advisers based upon published research, academic advising, teaching, research lab meetings and laboratory rotations. Research advisors are selected by mutual agreement with the student and replace the academic advisor. Students must identify their research advisor(s) at the end of their first year in the program (by June 1st). Once identified, students must submit a Research Advisor Election/Change Form to the Graduate Program Coordinator.

Computational Co-Advisor Requirement

The primary goal of the Boston University Bioinformatics Program is to train Ph.D. students to develop innovative computational and/or mathematical approaches to biological problems. This goal is not satisfied if the Ph.D. student primarily applies existing computational pipelines to experimental datasets. A significant feature of each Bioinformatics Ph.D. dissertation will be the development of a novel computational, mathematical, or statistical method that can be used to elucidate some aspect of a biological system.

Because nearly half of the Bioinformatics faculty focus primarily on wet-lab experiments in their research, there was concern that students working in these labs might not be receiving sufficient training in computational and mathematical innovation. Therefore, the following policy was established:

- A Bioinformatics Ph.D. student who chooses to join an experimental research group must have a computational co-advisor. The 'Faculty' page on the Bioinformatics Program

- website identifies whether each affiliated member is considered an experimental or computational mentor.
- It is the duty of the experimental advisor to identify a computational co-advisor who is willing to be involved in the training of the student.
 - After a student submits his/her advisor selection form at the end of the first year, the Bioinformatics Program will send a reminder to the experimental advisor that a computational co-advisor will be necessary.
 - The computational advisor and his/her role in the student's project must be in place by December 1 of year 2. At this time the student will provide an overview of the computational innovation that will be a part of their project.
 - The computational co-advisor must agree to meet regularly with the student. This can be accomplished in a variety of ways, including regular participation by the Bioinformatics student in the computational co-advisor's lab group meetings.
 - The computational co-advisor will be a member of the student's second-year oral exam, thesis advisory, and dissertation committees.
 - Each Bioinformatics student's dissertation will include a section or chapter that describes the computational innovation that has emerged from the research project.

III. Requirements for Admission to Ph.D. Candidacy

With successful completion of all course requirements and the qualifying examination, the student is admitted to Ph.D. candidacy. The student will receive formal notification of Ph.D. candidacy from the Bioinformatics Graduate Program Office. Once entered, Ph.D. candidacy will expire on its fifth anniversary. In unusual circumstances, the student may petition the Director of Graduate Studies (DGS) for an extension. The DGS will review the petition and the student will be advised in writing of the outcome. No student will be allowed to defend a completed Ph.D. dissertation if he/she is not a Ph.D. candidate.

Qualifying Examination

All Boston University graduate students must pass a qualifying exam in order to advance to the level of PhD Candidacy. In the Bioinformatics Program, this exam takes the form of an oral qualifying exam. The goal of the exam is for the student to demonstrate his or her general proficiency in bioinformatics, as well as command of the area(s) in which he or she intends to conduct research. Each student in the Bioinformatics Program will select a Qualifying Committee (QC) of 4 faculty members in the program (including his or her primary adviser), typically by sometime during the first semester of their second year. It is strongly encouraged that the QC include both faculty members with biological/experimental expertise and faculty members with computational expertise. The Director of Graduate Studies (DGS) must approve the committee membership and will be an ex officio member of the committee. In order to help avoid issues with committee membership students are required to submit the name of 6 potential committee members, the topic of their research project, and an overview of their computational innovation by December 1st of their second year. Students must schedule their Qualifying Exam by March 31 of their second year, and must take the exam by June 30. Students who fail to pass the exam on their first try are allowed a second attempt, to be scheduled and completed by the end of the first semester of their third year.

The oral qualifying exam will generally last approximately 2 hours, during which time members of the QC will ask questions focused on topics relating to the general topic area(s) chosen from the list below. At least one topic area should be agreed upon by the student and his/her QC prior to scheduling the exam. At that time, the student will also work with the QC to identify a list of specific representative resources (e.g., books, chapters, articles, etc.) around which the oral

exam questioning can be expected largely to focus. Questions should probe the student's knowledge of both biological and computational aspects of the chosen topic areas. Ideally, the examination questions will not only test general background knowledge, but also those aspects that pertain specifically to the student's intended area of research. Towards this end, students are expected to make a brief (20-30 min) oral presentation on their current research to the committee at the start of the exam. At least 2 weeks prior to the exam, the committee should be supplied with a brief written description of 10-12 pages (but not more than 15) of the student's current and planned research, organized in the manner of a grant proposal.

Approved general topic areas (each with a sample of illustrative sub-topic areas) are given below. Approval for a topic area(s) outside of those listed must be obtained from the Bioinformatics Curriculum Committee.

- **Biochemistry and Molecular Biology**
Enzyme catalysis; regulation; metabolomics; macromolecular metabolism; biochemical pathways; molecular evolution.
- **Databases and Computing**
Algorithms and complexity; database design; SQL; query optimization; web interface design; visualization.
- **Genetics and Genomics**
Gene expression analysis; transcriptional regulation; epigenetics; proteomics; sequence analysis.
- **Statistics and Machine Learning**
Data mining; learning algorithms; probabilistic modeling; statistical methods and modeling; statistical genetics.
- **Structural Biology and Biophysics**
Methods of macromolecular structure determination; spectroscopic probes; energy transduction; bioenergetics.
- **Systems Biology / Synthetic Biology**
Network modeling (metabolic, regulatory, etc.); non-linear dynamics; reverse engineering.

Following successful completion of the Qualifying Exam, and filing of the appropriate paperwork with the Bioinformatics Program office (which transmits it to the Graduate School of Arts and Sciences), the student passes to PhD Candidacy.

Immediately following the examination, the Report of Examinations form must be submitted to the Graduate Program Coordinator along with a copy of the oral proposal.

Examination Committee

The Qualifying Examination Committee consists of the student's research advisor(s) and two or three additional scientists, for a total of four members. At least two members should serve on the faculty of the Bioinformatics Program at Boston University. Inclusion of scientists (Ph.D.-level) from outside academic institutions or companies is encouraged. Outside members require a special service appointment. A "Special Service Appointment Form" along with the C.V. of the outside member should be submitted to the Graduate Program Coordinator. The chair of the committee, who must be a Bioinformatics faculty member and not a research advisor, will submit the Report of Examinations Form which documents the student's performance, to the Graduate Program Office immediately after the examination. The student's Qualifying Examination Committee is responsible for grading the exam. It is left to the committee's discretion how to remedy any unsatisfactory performance. A student who fails the examination has one opportunity to re-take it after three months have elapsed. Failure on the second attempt constitutes grounds for automatic dismissal from the Ph.D. program and loss of any further financial aid. In such an event, the student may still be eligible for the M.S. degree provided the degree requirements have been met. Upon successful completion of the examination, the Qualifying Examination Committee generally continues to serve as a student's Thesis Committee.

Students must have their examination committee as well as the date/time of their examination approved via a Committee Approval Form. This form must be submitted to the Graduate Program

Coordinator at least one month in advance of the oral examination. The oral examination **cannot** be scheduled any less than a month from when the Committee Approval Form is submitted.

IV. Preparation and Submission of a Ph.D. Dissertation

Some of the forms mentioned below require the signature of the Director. In these cases, the forms should be submitted to the Graduate Program Coordinator who will obtain the signatures. Once the forms are complete, students will be contacted so they may hand the forms in at the GRS Records Office in person.

1. Thesis Advisory Committee. A student must have a Thesis Advisory Committee, which is normally the same as the student's Qualifying Examination Committee (see above). The composition criteria of both committees are the same. The Thesis Advisory Committee meets annually to review the Ph.D. candidate's progress and make suggestions. The procedures for these meetings are as follows:

1. At least 1 week prior to the meeting the student will provide each committee member with the following documents:
 - a. Completed **Pre-TAC Meeting Update Form** (attached). This form will provide brief updates since the last committee meetings in each of the following areas:
 - i. Progress made in each Research Aim
 - ii. Listing of new publications and presentations
 - iii. Any collaborations or collaborative projects worked on outside of the main thesis project
 - iv. Any problems encountered that have impacted thesis work
 - b. Unofficial copy of their current BU transcript
2. The meeting will consist of the following:
 - a. The student will be asked to leave the room and the committee will hear initial input from the thesis advisor(s) on the student's progress.
 - b. The student will make a brief presentation (30-40 minutes) summarizing their research project. Committee members will ask questions during and/or after the presentation.
 - c. The student will be asked to leave the room and the committee will discuss the student's progress. In consultation with the other committee members, the committee chair will complete the **Bioinformatics Program Thesis Advisory Committee Report Form A** (attached). This form is used by the committee to evaluate the student in a variety of areas including: skills & achievements, acceptable progress of research project, computational innovation, recommendations, etc.
 - d. With the student back in the room, the committee will provide feedback to the student about the progress of the project, address any areas of concern and suggestions/recommendations for next steps.
 - e. The thesis advisor(s) will be asked to leave the room and the committee will hear input from the student regarding the mentoring they are receiving from their thesis advisor(s). In consultation with the other committee members (excluding the research advisors), the chair will complete the **Bioinformatics Program Thesis Advisory Committee Report Form B** (attached). This form is used to evaluate the effectiveness of the mentoring the student is receiving from their advisor(s) and summarizes any areas of concern and recommendations from the committee.
3. Following the meeting, the committee chair will provide a completed copy of the **Bioinformatics Program Thesis Advisory Committee Report Form A** to the student, research advisor(s), and the Bioinformatics Program Coordinator. The chair will also provide a completed copy of the **Bioinformatics Program Thesis Advisory Committee**

Report Form B to the student, and the Bioinformatics Program Coordinator, but not to the research advisor(s).

2. Thesis/Dissertation Committee. The Thesis/Dissertation Committee is very similar to the Thesis Advisory Committee and consists of the student's research advisor(s) and two or three additional scientists, for a total of four members. At least three members must be Boston University faculty and of those, two members should serve on the faculty of the Bioinformatics Program. Inclusion of scientists (Ph.D.-level) from outside academic institutions or companies is encouraged. Outside members require a special service appointment (this does not apply to adjunct faculty). A "Special Service Appointment Form" along with the C.V. of the outside member should be submitted to the Graduate Program Coordinator.

Two members of the committee are designated the First and Second Readers of the thesis. If the student has one research advisor, that member will be the First Reader. If the student has two research advisors, one will be the First Reader and the other the Second Reader. A third member of the committee, who must be a Bioinformatics faculty member, will serve as Chairman of the Dissertation Defense. A student cannot change the members of the dissertation committee after submission of the dissertation prospectus to the Graduate School of Arts and Sciences. All members must attend the Dissertation Defense.

3. Dissertation Prospectus (Dissertation Prospectus Approval Page). Approximately six months prior to the proposed graduation date, a formal Dissertation Prospectus must be submitted to the GRS Records Office along with the Dissertation Prospectus Approval Page. The dissertation prospectus should be prepared in consultation, and with approval of, the student's research advisors (First and Second Readers). An additional requirement for the Bioinformatics Program is that each member of the student's Thesis Defense Committee must review and approve the prospectus. Committee approval is documented by completion of the *Bioinformatics Dissertation Prospectus Approval* form (this is in addition to the approval form required by GRS). The Director of Graduate Studies and the Director of the Bioinformatics Program must also approve the prospectus. The Dissertation Prospectus provides an outline of the major chapters and subheadings to be included in the Ph.D. thesis, as well as a section on the computational innovation that has been developed as part of the research project.

4. Statement of Progress. The Bioinformatics Program expects its PhD students to finish their dissertation and defense within five years of joining the program or shortly thereafter. To help ensure that students are on track to complete within that timeframe, a Statement of Progress is required by September 1st of the 5th year in the PhD program. This statement should include an estimate of the dissertation defense date (month and year), the status of the selection of a defense committee, the titles and completion status of the major sections of the dissertation, and a summary of publications based on the dissertation research, broken down into the categories (a) already published, (b) submitted, and (c) in preparation or planned. Students are required to complete this statement in consultation with their research advisors and to jointly sign the statement.

5. Intent to Graduate Form. At least three months prior to the proposed graduation date, an Intent to Graduate form must be submitted to GRS Records Office.

6. Ph.D. Dissertation Defense Abstract. At least three weeks prior to the defense of dissertation, this abstract must be submitted to the GRS Records Office. This abstract must be read and approved by the student's research advisors (First and Second Readers), the Director of Graduate Studies, and the Director of the Bioinformatics Program before being submitted to the Graduate School of Arts and Sciences.

7. Distribution of Dissertation. At least two weeks prior to the defense of the dissertation, the student will distribute a copy of the dissertation to the members of the Thesis/Dissertation

committee. The student must anticipate that the committee will make numerous suggestions and required changes in the proposed thesis. In some cases the committee may require additional data analyses or even additional experimental work, which must be completed prior to scheduling the final thesis defense.

8. Ph.D. Thesis/Dissertation Defense.

It is expected of all Ph.D. students to defend significance, originality and methodologies employed in their thesis research. This defense consists of two parts.

A. The first is the public seminar open to the University community and based on the work by the student. Generally in consultation with the student's thesis committee, the time and date for this seminar will be submitted to the Graduate School of Arts and Sciences for publication.

B. The second is an oral defense of the work, which usually follows the public seminar, and is done privately before the student's Thesis Committee. The committee members ensure that the research is complete and understood by the candidate. At this time they can voice any concerns over the data or the preparation of the dissertation document. Depending on how well the thesis experiments are designed, performed, and defended, and how well the thesis is prepared, the committee will vote whether or not the thesis is complete and satisfactory. More than one committee member voting negatively will require either another Dissertation Defense or a decision about whether the Ph.D. degree is offered. Because the signatures of both Readers are required on the thesis, a Reader who votes negatively automatically necessitates another Dissertation Defense. A positive vote on the Dissertation Defense usually involves several suggested modifications of the thesis. An agreement is reached, in consultation with the Readers, for the incorporation of any written comments from committee members for the final version of the thesis, which is the version submitted to the Graduate School of Arts and Sciences. **Students must pay attention to published deadlines for submission of this final version of the signed thesis. These are hard deadlines and late submission will delay graduation.** Upon satisfactory completion of revisions, the First and Second Readers approve and sign several copies of a final version of the thesis. the required dates prior to graduation. The student must give final copies to the First and Second Readers (and when requested, other members of the thesis committee), and should retain at least one final copy for him/herself.

A set of rules/guidelines concerning page sizes, page numbering etc. for the thesis is available at the Graduate School Records Office webpage entitled Guide for the Writers of Theses and Dissertations. The Graduate School rules must be strictly followed. It is a requirement for the student to submit a draft copy to the Graduate School Records Officer (grsrec@bu.edu) at least 3 weeks prior to the defense to ensure that specific stylistic guidelines are being followed.

Highlights of the Bioinformatics Program

Seminar Series

The Bioinformatics Program invites seminar speakers both from academic and industrial settings to discuss an aspect of their research. Bioinformatics students are encouraged to attend all seminars and are expected to attend the Bioinformatics-related seminars. Students are asked to join the guest speaker at an informal luncheon following the speaker's presentations. Formal dinners may be planned as well. Students will be notified of these seminars as they are scheduled.

Facilities

The program in Bioinformatics spans the Colleges of Arts and Sciences, Engineering, Dentistry, Medicine, and Public Health. Research areas are numerous and include biological information management, genomic sequence mining, drug design and targeting, protein and nucleic acid structure, and cellular regulatory networks. Students in the program have access to state-of-the-art computational facilities, including Boston University's Shared Computing Cluster (SCC). The SCC consists of over 21,000 CPU cores, 330 GPUs, and more than 8 petabytes of storage. All the project storage spaces can be offered with NIH dbGaP compliance for storing human genomics data. The experimental facilities include pulse-field apparatus, high-speed sequencers, for microarrays an Axon 400B scanner with GenePixPro, a MALDI mass spectrometer, and various NMR spectrometers, fluorescence-activated cell cytometer and sorter, real-time quantitative PCR instrument, oligonucleotide synthesizer and automated DNA sequencing facility, confocal and electron microscopes, arrayed for generation of microarrays, two-dimensional fluorescence imager and robot spot picker.

With over fifty faculty currently contributing to the program, the resources in centers and labs and students is comparable to the number of faculty participating. The University also has a number of libraries and offices that are available to the students. You can review the faculty pages at our web site (<http://www.bu.edu/bioinformatics>) to learn more about these facilities and what projects they are currently involved in.

The following are some of the on-campus resources:

Biomedical Data-Acquisition Laboratory	DNA Sequencing Core Facility
Biomolecular Engineering Research Center	Center for Biodynamic
Cellular and Subcellular Mechanics Laboratories	Center for Advanced Biotechnology
Computer Modeling and Simulation Laboratory	Center for Computational Science
Biomolecular System Laboratory	Science and Engineering Library

Graduate School of Arts and Sciences General Guidelines

Time Limits

The Ph.D. program must be completed within seven years after the first registration for doctoral study.

Residency Requirement

Each student must satisfy a residency requirement of a minimum of two consecutive regular semesters of full-time graduate study at Boston University. Full-time study in this context is full-time commitment to the discipline as determined by the department. Without necessarily implying full-time course enrollment, this commitment permits access to libraries, laboratories, instructional staff, and other academic facilities of the University, including the department of concentration.

Doctoral students holding appointments as teaching fellows or research assistants are considered full-time students for purposes of the residency requirement provided that the time beyond that required by their appointments is devoted fully to their graduate program. In order to graduate, students must be registered part- or full time in the semester or summer term in which they complete degree requirements, as well as in the preceding semester.

Transfer of Credit

Graduate-level courses in other accredited graduate schools or in other Schools or Colleges of Boston University not used toward the awarding of any other degree may be transferred on recommendation of the major advisor and the Director of the department with the approval of the Graduate School. Credit for work to be taken concurrently with studies in the Graduate School of Arts and Sciences must be approved before registration for such courses; all such courses must have been taken for a letter grade (not pass/fail). No transfer of credit for courses taken before the senior year of college or from correspondence or extension schools will be accepted. Petitions for credits for transfer are available in the GRS Records Office.

Registration

An officially registered student is one who has selected courses by web registration (WebReg), on a registration form and who has paid or settled all charges.

Candidates for admission may not register until they receive a formal statement of acceptance. Registration is conducted under the direction of the Office of the University Registrar. Graduate students should consult the BF Graduate Program Coordinator for detailed instruction concerning the procedure to be followed during the announced registration period. Students must be registered for any regular semester or Summer Term during which a degree requirement is completed or University facilities are used.

Students must be registered every semester or be granted an official leave of absence. Failure to register without having been granted an authorized leave of absence may result in termination of degree status.

Registration Deadlines

A student in the Graduate School of Arts and Sciences should complete the course selection process by May for the fall semester and December for the spring semester. The deadline for payment/settlement of a student's account appears in The Guide published by the Office of Student Accounting Services. A new graduate student usually completes registration during the week prior to the beginning of classes. Late fees are charged to students who do not register or settle their tuition account during the official period. Students may not register later than 2 weeks after the start of classes. Students who are not registered by the deadline will have their financial assistance offers revoked.

Adding or Dropping a Course

Students wishing to change their courses must complete a Class Adjustment Form, obtain their advisor's signature, and return the completed form to the Graduate Program Coordinator. A request for late registration in courses cannot ordinarily be granted after the first 2 full weeks of classes.

No course may be added after the first two weeks of class. A course dropped during the first five weeks of class will not appear on the student's permanent record. After the first five weeks, a dropped course will appear on the student's record as W, and the student will be charged for the course. No course may be dropped after the eighth week of class. Graduate School financial aid will not cover the cost of a course from which a student has officially withdrawn. Students who register for any course are held responsible for its completion unless they officially withdraw by the deadline date or change to the status of auditor within the first five weeks of class.

Full-Time Students

By enrollment— A student enrolled in three to four-and-a-half courses (12 to 18 credits) will be considered full-time and will be charged full tuition and fees. A student may register for more than four courses (16 credits) only with approval of the Graduate School's Committee on Academic Standards.

By certification— a student registered for fewer than three courses or 12 credits (a minimum of one course must be taken until all coursework requirements have been completed) but engaged otherwise in full-time study, research, or teaching pertinent to the completion of degree requirements or to gaining competence in the field of study, may be certified as a full-time student. Such a student must pay tuition on a per-course basis and full-time fees. A student desiring full-time certification must submit to the Graduate Program Coordinator, during the official registration period, a completed full-time certification form approved by the advisor.

As teaching fellows and research assistants— Students holding regular appointments as teaching fellows or research assistants are considered full-time if they are enrolled in two or more courses. Teaching fellows or research assistants taking fewer than two courses may, if appropriate, be designated as full-time by certification.

Part-Time Students

All part-time students who are candidates for degrees must register each regular semester for no less than one semester course until all departmental course requirements are completed. Continuing students (see below) may register for less than one 4-credit course.

Continuing Student Status

Ph.D. candidates who have completed all departmental course requirements must register each subsequent regular semester for continuing student status until all requirements for the degree have been completed. Payment of the Continuing Student Fee each semester entitles the student to appropriate access to and use of the libraries, research laboratories, academic staff, and other academic facilities of the University for the purpose of completing such requirements as examinations, research, and thesis or dissertation work. Continuing students who are Ph.D. candidates are entitled to officially audit one course each semester without further tuition charge. Graduate courses at the 900 level, language and physical education courses, studio courses and courses with laboratories may not be audited.

Registering and payment of regular tuition and fees for at least one course exempts the student from the Continuing Student Fee. Continuing students may also qualify as full time according to the above regulations.

Incomplete Coursework and Grade Changes

When the work of a course has not been completed within the semester of registration, the grade of I is used. This automatically becomes a permanent I (unsatisfactory grade) unless the coursework is completed within the following calendar year. Grades of I and C+ or lower are

interpreted as failures. A student receiving such grades in more than two semester courses (or more than a total of 8 credit hours) is terminated. Grades, including incompletes, may not be changed after a period of one year from the time the original grade is recorded.

Graduation

PhD degrees are awarded in August, January, and May. Commencement exercises are held in May only. Students planning to receive their degrees at the May commencement must submit diploma applications by January 25th. Students must submit the Intent to Graduate form by May 27th for August graduation and by September 23rd for January graduation. The Intent to Graduate is valid only for the graduation date specified; a new form must be filed if the student does not graduate as planned. The Intent to Graduate form and the Graduate School of Arts and Sciences regulations on the preparation of theses and dissertations are available on the GRS Records Office website <https://www.bu.edu/cas/academics/phd-and-mfa-academics/graduation-information/>.

Transcripts

Requests for official transcripts must be made in writing, either by letter or by completing a Transcript Request form available online at Office of the University Registrar or at the Office of the University Registrar. Please include the following information: full name, including any former names; signature; Boston University ID number or Social Security number; Schools attended and dates; degrees awarded; and complete address of transcript destinations. The transcript fee is \$5 per copy, and payment must accompany the request. Processing time for transcript requests received by mail is three to five business days. The Registrar's Office does not accept faxed transcript requests. Transcripts can be sent by the USPS for an additional \$10 per destination to locations within the continental United States. For other destinations, please contact the Transcript Department for the cost. Unofficial transcripts can be obtained in person at the Registrar's Office during regular business hours. There is no charge for unofficial transcripts. A valid photo ID is required to obtain unofficial and official transcripts if the request is done in person at the Registrar's Office. Please note that the Registrar's Office does not mail unofficial transcripts.

Suspension or Dismissal

Boston University, through its various faculties or appropriate committees, may suspend or dismiss any student from the University for reasons of scholarship, aptitude, or conduct.

Leave of Absence and Withdrawal

Normally, students must register for each regular semester until completion of all degree requirements. Upon written request to the Graduate School of Arts and Sciences, a student will be allowed up to two semesters of leave of absence without committee consideration. Leaves of absence beyond two semesters may be granted in cases of substantiated illness, one-semester maternity or paternity leave, or military service. In exceptional cases, the student should petition the Associate Dean of the Graduate School of Arts and Sciences with approval of the chairman of the department or division of concentration.

A student who files for a leave of absence from the University before classes start is eligible to receive full credit of tuition and fees. Students should refer to "Withdrawals and Refunds" in the GRS Bulletin for the refund schedule after the beginning of classes. A student who is on leave and who has borrowed federal and/or private loans may be required to begin repayment while on leave. If leave is granted, a certificate of authorized leave of absence is issued and a copy included in the student's record.

The period of authorized leave of absence is counted as a part of the time allowed for completion of degree requirements. Students may not complete any degree requirements in a semester for which they have been granted leave of absence. Students must be registered in the semester in which the degree requirements are completed, as well as in the preceding semester.

Students who wish to withdraw or take a leave of absence from the University must submit their requests in writing to the GRS Records Office, Suite 112, 705 Commonwealth Avenue, Boston, MA 02215. The Graduate School will be responsible for notifying the student's major department. A request for a withdrawal or leave of absence is effective on the day it is received in the appropriate office; charges are canceled in accordance with the University's published refund schedule, based on the effective date of the student's leave of absence or withdrawal. Mere absence from class does not reduce financial obligations or guarantee that final grades will not be recorded.

Readmission to a Degree Program

Students applying for readmission to the Graduate School of Arts and Sciences will be subject to the following regulations: a minimum of two years must elapse from the time of withdrawal or termination until enrollment; reapplication must be accompanied by an application fee; if readmitted, the student may be asked to retake examinations or demonstrate knowledge in current issues in the field of specialization; readmitted students will be subject to the rules and regulations set forth in the Graduate School of Arts and Sciences Bulletin at the time of readmission; students who have outstanding financial obligations to the University at the time of withdrawal or termination will be required to meet those obligations as a condition of readmission; at the time of readmission, the student must provide a detailed schedule of plans for completing the remaining degree requirements within specific time limits.

Identification Cards and Numbers

Terrier cards are issued by the Terrier Card Office and the Office of the University Registrar. Students are assigned an ID number by the University.

A student is entitled to a new card only when there are changes to the information on the card. A fee is charged for replacing a lost card. Replacement cards are issued at the Terrier Card Office and the Office of the University Registrar.

** For more information about the GRS General Guidelines please see their bulletin either in print format or online at <http://www.bu.edu/bulletins/grs>.

Course Descriptions

CORE COURSES

ENG BE 562: Computational Biology: Genomes, Networks, Evolution

Prereq: Fundamentals of programming and algorithm design (EK 127 or equivalent), basic molecular biology (BE 209 or equivalent), statistics and probability (BE 200 or equivalent), or consent of instructor. The algorithmic and machine learning foundations of computational biology, combining theory with practice are covered. Principles of algorithm design and core methods in computational biology, and an introduction of important problems in computational biology. Hands on experience analyzing large-scale biological data sets. 4 cr. *Professor Galagan*

GRS MA 681: Accelerated Introduction to Statistical Methods for Quantitative Research

Prereq: CAS MA225 & CAS MA242 or their equivalents. Introduction to statistical methods relevant to research in the computational sciences. Core topics include probability theory, estimation theory, hypothesis testing, linear models, GLMs, and experimental design. Emphasis on developing a firm conceptual understanding of the statistical paradigm through data analyses.

CAS CS 542: Machine Learning

Prereq: CAS CS365. Introduction to modern machine learning concepts, techniques, and algorithms. Topics include regression, kernels, support vector machines, feature selection, boosting, clustering, hidden Markov models, and Bayesian networks. Programming assignments emphasize taking theory into practice, through applications on real-world data sets.

ENG BF 768: Biological Database Analysis

Prereq: CS 112 or CS 113, graduate standing, or consent of instructor. Background knowledge of biochemistry and genetics. Describes relational data models and database management systems. Teaches the theories and techniques of constructing relational databases with emphasis on those aspects needed for various biological data, including sequences, structures, genetic linkages and maps, and signal pathways. Introduces relational database query language SQL. Summarizes currently existing biological databases and the Web-based programming tools for their access. Object-oriented modeling is introduced primarily as a design aid for dealing with the particular complexities of biological information in standard RDB design. Emphasis will be on those problems associated with dealing with data whose nomenclature and interrelationships are undergoing rapid change. 4 cr. *Professor Benson*

GRS MA 770: Mathematical and Statistical Methods of Bioinformatics

Prereq: graduate standing. Mathematical and statistical bases of bioinformatics methods and their applications. Hidden Markov models, kernel methods, mathematics of machine learning approaches, probabilistic sequence alignment, Markov chain Monte Carlo and Gibbs sampling, mathematics of phylogenetic trees, and statistical methods in microarray analysis.

ENG BF 571 Dynamics and Evolution of Biological Networks

Prereq: MA 226 & MA 242, EK102 can be used in lieu of the MA242 pre-req. Familiarity with differential equations and linear algebra at equivalent levels and the consent of instructor can be used in lieu of both pre-reqs. The course focuses on mathematical models for exploring the organization, dynamics, and evolution of biochemical and genetic networks. Topics include: introductions to metabolic and genetic networks, deterministic and stochastic kinetics of biochemical pathways; genome-scale models of metabolic reaction fluxes; models of regulatory networks; modular architecture of biological networks. 4 cr. Professors Segre & Korolev

CAS BI 565: Functional Genomics

Prereq: CAS BI552 or consent of instructor. This paper- and problem-based course focuses on functional genomics topics such as genetic variation, genome organization, and mechanisms of transcriptional and post-transcriptional gene regulation. Up-to-date methods include NGS,

genome editing, ChIP-seq, chromatin accessibility assays, transcriptomics, and proteomics. Effective Fall 2020, this course fulfills a single unit in each of the following BU Hub areas: Oral and/or Signed Communication, Writing-Intensive Course, Critical Thinking.

ENG BF 751: Molecular Biology and Biochemistry for Bioinformatics

Prereq: MS or PhD program standing in Bioinformatics. Modern research in the life sciences is an increasingly interdisciplinary endeavor where new fields of study have developed at the interfaces of biology, chemistry, physics, mathematics, and computer science. In many instances, the development of these new fields goes hand in hand with development of new experimental approaches to surveying the content of the cell. While, traditional molecular cell biology and biochemistry courses often focus on the basic details of cell physiology and macromolecular (DNA, lipid, protein) structures, they too often neglect the quantitative aspects of number, scale, forces, etc. that are crucial to providing a larger context within living systems. This course aims at reframing the basic concepts of cell and molecular biology in a quantitative context and providing a basic overview of some of the key approaches used to develop a quantitative framework inside the cell. How this detailed information can then be applied to bioinformatics research problems will also be explored.

ENG BF 690: Bioinformatics Challenge Project

The Challenge Project consists of complex open-ended biological problems which can best be addressed by a combination of bioinformatics and wet-lab approaches. The Project will extend over both semesters in the first year. The problems involve bioinformatics as a key element, typically requiring the use of large data sets and computational analyses to make predictions about molecular function, molecular interactions, regulation, networks, etc. *Professor Benson*

ENG BF 810: PhD Laboratory Rotation System

This course is for Ph.D. students to take part in a laboratory rotation system. Students will become familiar with research activity in Bioinformatics labs. These rotations will help students identify the laboratory in which they will perform their Dissertation research. Post-Bachelor Ph.D. students must complete one 9-week rotation in their first semester of matriculation and two in their second semester. Ph.D. standing, 1 cr. per rotation; 3 total.

ENG BF 820: Research Opportunities in Bioinformatics

Required for entering Bioinformatics Ph.D. students. The course will consist of a series of presentations by Bioinformatics faculty that focuses on research projects being investigated in their laboratories. Emphasis is placed on the description of collaborative projects involving experimental and computational approaches to Bioinformatics research problems. 1 cr.

ENG BF 821: Bioinformatics Graduate Seminar

In this course the students present advanced papers in Computational Biology and Bioinformatics. The papers are chosen to cover recent breakthroughs in genomics, computational biology, high-throughput biology, analysis methods, computational modeling, databases, theory and bioinformatics. 2 cr. *Professor Segre*

BIOINFORMATICS COURSES

ENG BF 541: Internship in Bioinformatics

This course allows M.S. and Ph.D. students in bioinformatics to take part in an industrial internship. Students will be required to present a report on their training and/or make a presentation and poster as a part of participating in the University's Science Day program (annual in March). Variable credits

ENG BF 501, 502: Master's Project

For MS students in bioinformatics. Participation in a research project under the direction of two faculty advisors. Variable credits

ENG BF 900: Pre-candidacy Research in Bioinformatics

For Ph.D. students prior to candidacy. Participation in a research project under the direction of two faculty advisors. Requires the development of a brief document outlining the proposed research leading to either a Ph.D. prospectus (for Ph.D. students). Variable credits

ENG BF 901, 902: Post-candidacy Thesis/Research in Bioinformatics

For Ph.D. students post-candidacy. Participation in a research project under the direction of two faculty advisors. Variable credits

Please visit the links below to view...

BIOMEDICAL ENGINEERING COURSES

<http://www.bu.edu/academics/eng/programs/biomedical-engineering/>

BIOLOGY COURSES

<http://www.bu.edu/bulletins/grs/item14.html#anchor05>

CHEMISTRY COURSES

<http://www.bu.edu/bulletins/grs/item17.html#anchor04>

COMPUTER ENGINEERING COURSES

<http://www.bu.edu/academics/eng/programs/computer-engineering/>

COMPUTER SCIENCE

<http://www.bu.edu/bulletins/grs/item20.html#anchor04>

ELECTRICAL ENGINEERING COURSES

<http://www.bu.edu/academics/eng/programs/electrical-engineering/>

MATHEMATICS AND STATISTICS COURSES

<http://www.bu.edu/bulletins/grs/item29.html#anchor06>

MOLECULAR BIOLOGY, CELL BIOLOGY & BIOCHEMISTRY COURSES (MCBB)

<http://www.bu.edu/academics/grs/programs/molecular-biology-cell-biology-biochemistry/>

