Foundations in Quantitative Biosciences (BIOL 6750/PHYS 6750)

Course Syllabus – Fall 2020

Instructors: Prof. Joshua Weitz

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Office hours: M 2-3pm

Lectures: T/Th 8:00-9:15AM, Virtual (may be shifted to in person if/when conditions warrant)
Computational lab: Fri 12:10-2:50pm, Virtual
TA: Alexander (Bo) Lee
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Office Hours online, 2x a week, 1.5 hrs each, TBD

Sources:
Special readings to be posted on http://canvas.gatech.edu/

Course Topics: Quantitative methods key to foundational advances in the bioscience spanning distinct scales of organization from molecules, cells, organisms, populations to ecosystems. The course is organized into three major themes: (i) molecular and cellular biosciences; (ii) organismal behavior and physiology; (iii) ecology & earth systems.

Prerequisites:
(i) Enrollment in the PhD with a Major in Quantitative Biosciences, Biology or Physics; or
(ii) Permission of instructor, contingent upon demonstration of prior coursework in mathematical methods including differential equations.

Overview
The class is organized around the understanding of key advances in the biosciences, one organizing unit at a time, in which the advances depended critically on quantitative methods and reasoning. Both foundational advances and recent challenges will be discussed. Each week, students will be exposed to:

- *methods* for developing and analyzing quantitative models;
- *logic* for how to reason given uncertainty in the biosciences;
- *computational skills* to implement and support a thorough understanding of stochastic and dynamic modeling at the interface between mathematical formalism and biological data.

The overall objective of the course is to teach graduate students how to reason quantitatively in the biosciences given uncertainty in mechanisms, rates and reliability of measurements.

Course format

Three hours each week are scheduled for the class lecture. Class time will be divided among traditional lectures and group problem-solving exercises or discussions. A component of the course will involve formulating and solving problems in small cooperative groups of three to four members.

The reading listed for each week should be done *prior* to the first lecture of the week. These papers will be the basis for in-class discussion.

In addition, a two-to-three hour recitation section will be held each week involving computational work that will serve as a prelude to problem sets.

Software: Implementation of homework requires use of (i) mathematical analysis; and (ii) MATLAB/Python. Python is available as a free computing language. MATLAB is available for use by all students enrolled at GT without charge. Refer to the OIT website for more details on access: http://software.oit.gatech.edu.

Grading Scheme:
60% homework
15% final presentation
15% final paper
10% class participation

Final project: Final project proposals will be handed in the mid-term (date to be announced). Final presentations will take place during the last week of classes, in lieu of a final exam. Final papers will be due on the date of the final exam. More information will be available later in the term.

Homework: The following rules apply to homework:

1. You are encouraged to work individually or in small groups (up to 3 students per group) to discuss concepts and approaches to solving problem sets.
2. If you use any sources other than class notes or your own original ideas, you must cite the source(s).
3. Every student must write/type their own homework solutions and associated computational code based on their own understanding of the problems.

Violation of these guidelines is a violation of the GT Honor Code.

Learning outcomes: Students will gain experience in (i) reading primary literature & presenting and interpreting data; (ii) developing standalone computational code to represent multi-scale biological dynamics; (iii) connecting theoretical principles with experimental data.

Attendance: Regular attendance in lectures is required – most lectures will include some component of group work and problem solving. Exceptions will be accepted for valid, documented reasons only, including medical or other emergencies.

Academic Integrity: Students are reminded of the obligations and expectations associated with

the Georgia Tech Academic Honor Code and Student Code of Conduct, available online at:
http://www.deanofstudents.gatech.edu/integrity/policies/honor_code.php
http://www.deanofstudents.gatech.edu/codeofconduct.
Any violations will be reported directly to the Dean of Students.

Additional Resources:

- Office of Disability Services – http://disabilityservices.gatech.edu/
- Canvas — http://canvas.gatech.edu

Updates: This syllabus is subject to modification. Any changes will be announced in class and posted on the course website.

Schedule of Topics

Introduction

Module 1: Introduction
Quantitative Models and the Biosciences (in-class discussion)
Intro to MATLAB (and Intro to Python)
August 18, 20, 21

Unit 1: Molecular and cellular biology

Module 2: Analysis of Fluctuations I – the nature of mutations
Aug 25, 27, 28
HW 1 out 8/28, due 9/4
Recitation material: probability distributions

Module 3: Bistability and gene regulation
Sep 1,3,4
HW 2 out 9/4 due 9/11
Recitation material: stability analysis

Module 4: Analysis of Fluctuations II- noise and gene expression
Sep 8,10,11
HW3 out 9/11 due 9/18
Recitation material: Gillespie algorithm

Module 5: Neutral theory of molecular evolution
Sep 15,17,18
HW 4 out 9/18, due 9/25
Recitation material: Markov chains

Unit 2: Organismal behavior and physiology

Module 6: Robustness and homeostasis – examples from chemotaxis
Sep 22,24,25
HW 5 out 9/25, due 10/6
Recitation material: Enzyme kinetics

Module 7 & 8: Spikes from Hodgkins and Huxley and beyond
Sep 29, Oct 1,2
Recitation material: Fast-slow dynamics

Module 7 & 8: Pacing and synchronization in the beating heart
Oct 6,8,9
HW 6 out 10/9, due 10/16
Recitation material: Limit cycles

Module 9: Principles of locomotion
Oct 13,15,16
Recitation material: time series analysis

Unit 3: Populations and Communities
Module 10: Predator-prey dynamics from Lotka-Volterra to the present day
Oct 20,22, 23
HW7 out 10/23, due 10/30
Recitation material: Adaptive dynamics

Module 11: Outbreaks: forecasting, control, and prevention
Oct 27,29,30
HW 8 out 10/30, due 11/6
Abstract statement out 10/30; due November 10 (comments by November 13)
Recitation material: Stochastic model-data fitting

Module 12: Cooperation and conflict in groups
November 3,5,6 (note November 3 is election day; in-person participation optional)
Recitation material: Nash equilibria

Module 13: Spatial groups and flocks
Nov 10,12,13
Recitation material: Statistical mechanics of flocks

Module 14: Climate and catastrophes
Nov 17,19,20
Recitation material: Project support

Unit 4: Final Projects and Beyond
Module 15: Final presentation prep (note non-consecutive dates)
11/24 Work on in-class preparation for final projects

Final presentations in lieu of final exam