CMPB 5001
Dynamic Models in Biology

Course Director: Trine Krogh-Madsen, PhD, trk2002@med.cornell.edu

Course Description: This course covers fundamental concepts and techniques used for mathematical modeling of biological systems. Course topics include basic theoretical analysis of nonlinear ordinary differential equations as well as numerical simulation of different classes of models. Students will also learn approaches for model development, model validation, parameter identification, and determining parameter sensitivity. Techniques and methods covered in lectures will be implemented and demonstrated in computer labs. Models demonstrated in class will originate from various biological systems, including electrophysiology, gene networks, and immunology.

Learning Objectives:
On completion of this course:
1. students will be able to formulate, implement, analyze, and numerically simulate models consisting of ordinary differential equations.
2. students will be able to perform numerical simulations of stochastic models and spatial models.
3. students will be able to analyze simulated data.

Semester: Fall (Aug 24 - Dec 9, 2022)

Course Format: The course consists of twice-weekly lectures and a weekly computer lab. Lectures and lab will be in-person.

Time: Lectures: Wednesdays and Fridays 11am-12:15pm.
Lab: Fridays 12:15-1:15pm

Location: Varies. First class will be in WGC-B + WGC-C (1305 York, 2nd Floor).

Prerequisites: calculus, linear algebra, computer programming proficiency.

Textbook: Steven Strogatz: *Nonlinear Dynamics and Chaos*

Software: Computer labs will use MATLAB. Prior knowledge of MATLAB is not required. Weill Cornell students can download a free student version of MATLAB here: https://www.mathworks.com/academia/tah-portal/weill-cornell-medical-college-40598044.html

Credits: 4

TAs: Zi-Ning Choo, zic2001@med.cornell.edu
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Assignments and Exam:

- Weekly homework assignments
- Weekly computer lab reports
- Mid-term exam
- Final take-home exam

Assessment and Grading:

Grades will depend on the homework assignments, the mid-term, and the final exam with the following weights: final (30%), mid-term (20%), homework (50%). All students will receive a letter grade (A-F).

Course Calendar:

Weeks 1-6: Introduction to dynamical systems and mathematical modeling

<u>Week 1 Introduction and one-dimensional systems</u>

Aug 24 Course introduction, dynamic models, ODEs, numerical integration
Aug 26 Fixed points, stability, bifurcations, the lac switch
Lab: Numerical integration of ODEs in Matlab

<u>Week 2 One- and two-dimensional systems</u>

Aug 31 Population biology models
Sept 2 Two-dimensional linear systems, fixed points
Lab: Vector fields and phase space trajectories
HW #1 due

<u>Week 3 Linear and nonlinear systems</u>

Sept 7 Examples of linear systems: pharmacokinetics and chemical reactions
Sept 9 Nonlinear systems, phase plane analysis
Lab: Infectious disease model
HW #2 due

<u>*Break*</u>

Sept 14 No class
Sept 16 No class

<u>Week 4 Modeling biological oscillations</u>

Sept 21 Limit cycles, relaxation oscillations
Sept 23 Time delay systems: respiratory control of CO_2
Lab: Oscillatory gene expression – p53 model
HW #3 due

<u>Week 5 Bifurcations involving fixed points and limit cycles</u>

Sept 28 Bifurcations of fixed points
Sept 30 Bifurcations of limit cycles
Lab: Bifurcation analysis
HW #4 due

Week 6 Dynamical systems analysis
Oct 5 Chaos
Oct 7 Dynamics of excitable cells
Lab: FitzHugh-Nagumo model
HW #5 due

Weeks 7-9: Building dynamic models

Week 7 Model formulation
Oct 12 Developing model equations
Oct 14 Parameter estimation I: Least squares and maximum likelihood
Lab: Parameter fitting: Tumor growth data and model
HW #6 due

Week 8 Model development and evaluation
Oct 19 Sensitivity analysis
Oct 21 Journal club: Paper TBD
Lab: Model sensitivity analysis
HW #7 due

Week 9 Model development and evaluation
Oct 26 Parameter estimation II: Global search heuristics
Oct 28 Journal club: Paper TBD
Lab: Student presentations of HW #7
No HW due

Weeks 10-11: Modeling stochastic processes

Week 10 Introduction to random processes
Nov 2 Random processes, Langevin equation
Nov 4 Single channel noise: Markov process, Gillespie's algorithm
Lab: Stochastic crossbridge dynamics
Mid-term exam due

Week 11 Noise in gene regulatory networks
Nov 9 Gene regulatory networks
Nov 11 Chemical Master equation, Gillespie's algorithm
Lab: Transcription model
HW #8 due

Weeks 12-13: Spatial dynamic models

Week 12 Spatial modeling
Nov 16 Spatial modeling intro, random walks, diffusion equation
Nov 18 Reaction-diffusion, numerical simulation of PDEs
Lab: Action potential propagation
HW #9 due

Thanksgiving break

Nov 23 Thanksgiving week – no class
Nov 25 Thanksgiving week – no class

Week 13 Biological pattern formation

Nov 30 0 → 3D spatial modeling, Turing instability
Dec 2 Turing patterns; Journal club: Paper TBD
Lab: no lab
HW #10 due

Week 14: Final exam (take home)

Dec 9 *Final exam due*