Modeling and Control of Biomolecular Machines
EGM 4585 Section 9013
Spring 2026, M W F, 6th Period, 12:50 PM – 1:40 PM
LAR 0239

Modifications to this syllabus may be required during the semester. Any changes that are made will be reflected in a posted version of the syllabus and announced in class.

Instructor

Associate Professor **Amor A. Menezes**, Ph.D. (min-AY-zis)
Department of Mechanical and Aerospace Engineering
University of Florida, Gainesville, FL 32611-6250
WERT 489
Please contact through the Canvas website https://elearning.ufl.edu
Any emails to ufl email address must include EGM 4585 in the subject line

Office Hours

- M W, 2:00 PM – 3:00 PM, WERT 489
- Or via confirmed written appointment

Course Description

Course Catalog: "Overview of biomolecular systems engineering. Introduction to cell processes, biochemical kinetics, models of biological macromolecules, analyses of biomolecular dynamics, simulation of stochastic behaviors, common gene regulatory network motifs, and the design of synthetic biology circuits." (Credits: 3)

Course Pre-Requisites

MAP 2302 (Elementary Differential Equations) with a minimum grade of C, or instructor permission.

Course Objectives

By the end of this course, you should be able to do the following:

- Describe biomolecular machine behaviors using kinetic and thermodynamic concepts;
- Construct phenomenological and mechanistic models of these behaviors and machine interactions;
- Predict the dynamics of biomolecular and cellular networks using analysis and design tools from dynamical systems theory and control; and
- Deploy models, analysis, and design tools from dynamical systems theory and control to alter the predicted dynamics of biomolecular and cellular networks, in simulation.

Materials and Supply Fees

None.

Professional Component (ABET)

This course contributes to enhancing the student's knowledge of advanced mathematics through multivariable calculus, differential equations, and linear algebra. This course also contributes to the student's ability to work professionally in mechanical and aerospace systems areas including the design and analysis of such systems. The course supports several program outcomes enumerated by the Department of Mechanical and Aerospace Engineering. The content of this course is approximately 30% engineering design, 30% mathematics, and 40% engineering science.

<u>Relation to Program Outcomes (ABET)</u>

Outcome	**Coverage**
1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	High

2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	Medium
3. An ability to communicate effectively with a range of audiences	
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	Low
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies	Medium

Coverage is given as high, medium, or low. An empty box indicates that this outcome is not covered or assessed in the course.

Recommended Textbooks, Software, and Hardware

- Brian P. Ingalls, "Mathematical Modelling in Systems Biology: An Introduction," MIT Press, 1st Ed., ISBN: 9780262545822, 2022
- MATLAB (MathWorks), any recent release.
- Various handout materials provided digitally on Canvas.
- Scientific calculator (not your phone).
- It is important that you have your own laptop/mobile computer. Details are provided at: https://www.eng.ufl.edu/students/advising/fall-semester-checklist/computer-requirements/ https://mae.ufl.edu/academics/undergraduate/computer-requirements/

Alternate (Reference) Textbooks

- Uri Alon, *An Introduction to Systems Biology: Design Principles of Biological Circuits*, 2nd Ed., 2020
- Geoff Baldwin et al., *Synthetic Biology - A Primer (Revised Edition)*, 2016
- Carlo Cosentino and Declan Bates, *An Introduction to Feedback Control in Systems Biology*, 2012
- Domitilla Del Vecchio and Richard M. Murray, *Biomolecular Feedback Systems*, 2015
- Leah Edelstein-Keshet, *Mathematical Models in Biology*, 2005
- Terrell Hill, *Free Energy Transduction and Biochemical Cycle Kinetics*, 2004
- Pablo Iglesias and Brian Ingalls, *Control Theory and Systems Biology*, 2010
- Eric Klavins, *BioCircuits: A Systems Approach to Synthetic Biology*, 2019
- John Kuriyan et al., *The Molecules of Life: Physical and Chemical Principles*, 2013
- J. D. Murray, *Mathematical Biology*, Vols. I and II, 3rd Ed., 2007
- Rob Phillips et al., *Physical Biology of the Cell*, 2nd Ed., 2013
- Steven Strogatz, *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering*, 2nd Ed., 2015

Important Dates

- Classes Begin: Jan 12 (Monday)
- Holidays/Reading Days: Jan 19 (Monday), Mar 16 – 20 (Monday – Friday), Apr 23, 24 (Thursday, Friday)
- Classes End: Apr 22 (Wednesday)
- Classes Canceled: Mar 27 (Friday)
- Project Presentations to Attend: Apr 30 (Thursday)
- Homework, reading assignment, and project attendance dates stated in this syllabus will be confirmed in class

Requirements for class attendance, make-up exams, assignments, and other work in this course are consistent with university academic policies: https://go.ufl.edu/syllabuspolicies

Attendance Policy

- Students are expected to attend all lectures and final project presentations.
- **Make-up Policy:** Homework / reading assignment / project presentation absences may be excused with appropriate documentation. See https://care.dso.ufl.edu/instructor-notifications. Note that "Instructors have the right to accept or reject the Instructor Notification."

Class Expectations

- The student is solely responsible for their education. The instructor is the guide to their understanding of the field.
- Cell phones, laptops, etc.: **under no circumstances will disruptions from electronic devices be tolerated. Students are expected to take either handwritten notes with pen/pencil and paper, or electronic notes with stylus and tablet.**
- **Electronic notes must be printed out if used as reference material on examinations.**

- **No Artificial Intelligence (AI):** The learning that takes place in this course requires your unique perspective and human experience. Use of AI would make it harder to evaluate your work. It is not permitted to use any generative AI tools in this course, and the use of AI will be treated as an academic integrity issue.

- Respect and disruption: the instructor and students will be always respectful. Classroom disruption of any kind will not be tolerated.
- **The principles of the Honor Code must be always adhered to.** Individual effort is required on homework assignments, quizzes, and exams. Groups will be treated as individuals for projects. Students are bound by the Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code." On all work submitted for credit, the following statement is either required or implied:

  On my honor, I have neither given nor received unauthorized aid in doing this homework/quiz/report/exam.

  The Conduct Code (https://sccr.dso.ufl.edu/process/student-conduct-code/) specifies behaviors that are in violation of this code and the possible sanctions. You are obligated to report any academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TA.

  Course Zero-Tolerance Policy: *Any* violation or suspected violation of the Honor Code by a student may result in that student receiving a grade of E for the course.

Homework

The purpose of homework is to learn and understand the material. **Students are responsible for performing and understanding the homework problems and solutions on their own.**

Software and Copyrighted Material Use

All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing the use of software and the use of copyrighted material. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

Exams

Honorlock: Consistent with UF policy, Honorlock may be used for course assessments and will be confirmed by the instructor in advance. Please see https://distance.ufl.edu/proctoring/ for more information.

Students Requiring Accommodations

Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the Disability Resource Center (https://disability.ufl.edu/students/get-started/). Students should share their accommodation letter with their instructor and discuss their access needs as early as possible in the semester.

Commitment to a Positive Learning Environment

The Herbert Wertheim College of Engineering values varied perspectives and lived experiences within our community and is committed to supporting the University's core values.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:

- Your academic advisor or Graduate Coordinator
- HWCOE Human Resources, 352-392-0904, student-support-hr@eng.ufl.edu
- Professor Pam Dickrell, Associate Dean of Student Affairs, 352-392-2177, pld@ ufl.edu

Evaluation of Grades and Grading Policy

Evaluation Mechanism on a Percent Basis

Homeworks (6)	30%
Reading Assignments (8)	40%
Project Attendance	30%

Homework

Students will submit solutions of the homework problems only via the course website. Students who turn in homework before the due date and time will have their homework graded. Not all homework problems may be graded, and a selection of problems may be randomly chosen for grading after the homework due date and time. Submitted homework that is partially- or fully-missing solutions to these chosen problems will not be eligible for full or partial credit for those problems, respectively, even if other non-chosen homework problems were completed. **Grading may be on completeness or on correctness.** However, it is the student's responsibility to check their solutions against posted homework solutions.

Reading Assignment

For each assignment, students will submit a document that includes the signed Honor Code, a list of the assigned papers that they attest to have finished reading, and for each of these papers, a few bullet points that summarize the paper's key results / methodological advance / significance / errors (if any). **Grading may be on completeness or on correctness.**

Project

All students are expected to attend graduate student final project presentations in the assigned timeslot. If a student is unable to attend in this timeslot for unforeseeable reasons, then the other assignments will count toward the percentage of the grade that makes up the exam if an appropriate DSO instructor notification is accepted.

Final Grade

Final grades may be calculated by the following table. For example, if a student earns 86.60% (Percent Grade Earned %GE = 86.60) then their grade point will be 3.33 (B+). %GE are rounded to the hundredths decimal place. For example, if a student earns 77.995% (Percent Grade Earned %GE = 77.995) it will be rounded up to 78.00%, and their grade point will be 2.67 (B-). Shifts in the grading table are at the discretion of the instructor.

Table 1. Grading Table. *%GE = Percent Grade Earned.*

Percentage Range	Grade Point
92.00 $\leq$ %GE $<$ 100.00 $\Longrightarrow$ A	4.00
88.00 $\leq$ %GE $<$ 92.00 $\Longrightarrow$ A-	3.67
85.00 $\leq$ %GE $<$ 88.00 $\Longrightarrow$ B+	3.33
81.00 $\leq$ %GE $<$ 85.00 $\Longrightarrow$ B	3.00
78.00 $\leq$ %GE $<$ 81.00 $\Longrightarrow$ B-	2.67
74.00 $\leq$ %GE $<$ 78.00 $\Longrightarrow$ C+	2.33
71.00 $\leq$ %GE $<$ 74.00 $\Longrightarrow$ C	2.00
67.00 $\leq$ %GE $<$ 71.00 $\Longrightarrow$ C-	1.67
64.00 $\leq$ %GE $<$ 67.00 $\Longrightarrow$ D+	1.33
61.00 $\leq$ %GE $<$ 64.00 $\Longrightarrow$ D	1.00
60.00 $\leq$ %GE $<$ 61.00 $\Longrightarrow$ D-	0.67
00.00 $\leq$ %GE $<$ 60.00 $\Longrightarrow$ E	0.00

Grade Corrections

Grade corrections should be submitted promptly in writing within three business days of the grade posting. Include a concise statement of why you believe that there has been an error. The instructor has the final determination in the assigned grade; if a grade change is made, the grade may be lower or higher.

Course Schedule

The course content is approximately:

Lectures 02-15	Deterministic modeling of biomolecular machines (14 lectures)
Lectures 16-21	Stochastic modeling of biomolecular machines (6 lectures)
Lectures 22-28	Dynamical systems theory to control biomolecular machines (7 lectures)
Lectures 29-39	Control of biomolecular machines (11 lectures)

Course Schedule, Approximately by Lecture Number (1/2 Modeling, 1/2 Control)

1	Jan 12	Systems Biology and Synthetic Biology
2	Jan 14	Biomolecular Systems Modeling
3	Jan 16	Cell Processes
4	Jan 21	Cell Processes for Synthetic Biology
5	Jan 23	Passive and Active Transport, Biological Macromolecules
Reading Assignment 1 Due Jan 23 (Friday), 11:59 PM		
6	Jan 26	Strong and Weak Forces
Approximate End of Coverage for Homework 1		
7	Jan 28	Ligand-Receptor Binding, Intro to Chemical Reaction Networks (CRNs)
8	Jan 30	CRNs: Conversion, Binding
Homework 1 Due Jan 30 (Friday), 11:59 PM		
9	Feb 2	Binding Isotherm
10	Feb 4	CRNs: (Non-)Exponential Decay, Stoichiometry
11	Feb 6	CRNs: Cooperative Binding and Allostery
Reading Assignment 2 Due Feb 6 (Friday), 11:59 PM		
12	Feb 9	CRNs: Feedback Inhibition, Competitive Binding
Approximate End of Coverage for Homework 2		
13	Feb 11	CRNs: Enzyme Kinetics, Michaelis-Menten
14	Feb 13	CRNs: Quasi-steady-state, Briggs-Haldane, Post-Translational Regulation
Homework 2 Due Feb 13 (Friday), 11:59 PM		
15	Feb 16	Linear Transforms, Monod Kinetics, Statistical Mechanics
16	Feb 18	Microstates, Macrostates, Boltzmann Distribution

17	Feb 20	Thermodynamic Entropy, Gibbs Entropy, Free Energy

Reading Assignment 3 Due Feb 20 (Friday), 11:59 PM

18	Feb 23	Stochastic Behavior, Chemical Master Equation
19	Feb 25	Stochastic Modeling, Fokker-Planck Equation
20	Feb 27	Langevin Equation, Monte Carlo Methods

Reading Assignment 4 Due Feb 27 (Friday), 11:59 PM

21	Mar 2	Gillespie Algorithm, Flux Balance Analysis

Approximate End of Coverage for Homework 3

22	Mar 4	Glycolysis, Limit Cycles, Stability
23	Mar 6	Phase Portraits, Negative Autoregulation

Homework 3 Due Mar 6 (Friday), 11:59 PM

24	Mar 9	Linearization, Nonlinear System Equilibria

Approximate End of Coverage for Homework 4

25	Mar 11	Repressilator, Dulac's Criterion, Poincaré-Bendixson Theorem
26	Mar 13	Cyclic Feedback Systems, Glycolytic Oscillations

Homework 4 Due Mar 13 (Friday), 11:59 PM

27	Mar 23	Bifurcations
28	Mar 25	Hopf Bifurcation, Glycolytic Oscillations, Positive Systems Theory

Approximate End of Coverage for Homework 5
Reading Assignment 5 Due Mar 27 (Friday), 11:59 PM

29	Mar 30	Genetic Circuit Design, Negative Autoregulation
30	Apr 1	Sequestration, Subtraction, Quorum Sensing, Ultrasensitivity

Homework 5 Due Apr 1 (Wednesday), 11:59 PM

31	Apr 3	Digital vs. Analog Genetic Circuits, Positive Autoregulation, Genetic Toggle Switch
32	Apr 6	Review of Classical Control, Integral Control, Disturbance Rejection

Reading Assignment 6 Due Apr 6 (Monday), 11:59 PM

33	Apr 8	Bacterial Chemotaxis, Adaptation
34	Apr 10	Biomolecular Network Motifs, Relationship to Control
35	Apr 13	Biomolecular Integral Control, Plasmid Copy Number Control

Reading Assignment 7 Due Apr 13 (Monday), 11:59 PM

36	Apr 15	Activator-Repressor Clock
37	Apr 17	Hasty Oscillator, Oscillator-Based Control

Approximate End of Coverage for Homework 6

38	Apr 20	Turing Patterns, Oscillator-Driven Turing Patterns

Reading Assignment 8 Due Apr 20 (Monday), 11:59 PM

39	Apr 22	Optogenetics, Model Predictive Control

Homework 6 Due Apr 22 (Wednesday), 11:59 PM
Project Presentations on Apr 30 (Thursday), 10:00 AM