Dynamical modeling in biology: Deterministic models
BI 399, University of Oregon

- Syllabus -

Stilianos Louca

Winter 2022

Contents

Note: This syllabus accounts for the current regulations and restrictions associated with the COVID-19 pandemic, as of October 27, 2021. Some aspects may be subject to change on short notice as the COVID-19 situation continues to evolve.

1 Course description

This course covers deterministic dynamical models in biology, i.e., mathematical models that describe the behavior of a system over time as a result of internal feedback loops and external forcings. Such models tend to be more realistic and powerful than static regression models, especially when a mechanistic understanding is sought for a biological phenomenon. The course's focus will be on deterministic continuous-time models (differential equations) and deterministic discrete-time models (iterative maps), including stability analysis, periodicity, numerical simulations and fitting models to multivariate data. Examples will cover a broad spectrum of topics, such as neuroscience, physiology, cell biology, epidemiology, population dynamics, ecosystems, conservation and species invasion. Exercises will include mathematical calculations as well as scientific programming. As most concepts covered are rather fundamental to mathematical modeling, students from other quantitative fields such as physics or data sciences will likely also find great use in them.

The course will consist of two in-person lectures per week, one computer lab, and weekly homework assignments. The lectures will cover mostly theoretical/mathematical material, as well as general approaches in scientific programming. The homework assignments will include mathematical questions as well as scientific programming tasks, where students will practice using a programming language to solve modeling questions. The computer lab will provide opportunities to discuss the weekly assignments, to cover additional grounds on the programming side, and to help students resolve programming questions for example related to their assignments. In addition, the GE and the lead instructor will each host 1 online or in-person office hour per week.

2 Instructors

Lead instructor: Stilianos Louca, PhD, Assistant Professor.
Email address can be found at www.loucalab.com.
In-person office hours: Tuesdays at 15:30–16:30, in Onyx Bridge 282.

Teaching assistant: Danny Burnham
Email address: dburnham (the squiggly thing) uoregon.edu
In-person office hours: To be determined (will be posted on Canvas)

3 Schedule

In-person lecture: Tuesdays and Thursdays, 14:00–15:20, in Peterson Hall 101.
First lecture is on Tuesday, January 4, 2022. Last lecture is on Thursday, March 10, 2022.

In-person computer lab: Wednesdays, 14:00-15:50, in Huestis Hall 112.
Access to the lab is via the hallway.
First lab is on Wednesday, January 5, 2022. Last lab is on Wednesday, March 9, 2022.

Mid-term exam: In-person written examination during one of the regular lecture or lab hours, in the week of February 7–11, 2022. If in-person exams are not possible (e.g., due to COVID-19 restrictions), exams may be held orally and individually over zoom, in which case dates/times will be scheduled individually for each student.

Final exam: In-person written examination during week of March 14-18, 2022. If in-person exams are not possible (e.g., due to COVID-19 restrictions), exams may be held orally and individually over zoom, in which case dates/times will be scheduled individually for each student.

Holidays observed: None.

4 Zoom instructions

Unless mentioned otherwise, all lectures, computer labs, exams and office hours will be held in person. However, as the COVID-19 pandemic continues to evolve, situations might arise where any of these sessions is moved to a remote Zoom meeting (for example, if the lead instructor is forced to self-isolate). Hence, students are encouraged to familiarize themselves with Zoom prior to the course. Instructions for installing Zoom and joining a Zoom meeting can be found at:
https://service.uoregon.edu/TDClient/2030/Portal/KB/ArticleDet?ID=101392

Please join all online lectures and computer labs with video turned on and audio turned off by default. If you'd like to ask a question during the lecture and lab, please behave as in a normal class – either raise your hand and/or discretely draw the instructor's attention by voice (remember, everyone in the meeting can hear you). Please avoid using the Zoom text-chat function during the lecture and lab, since it distracts from the main conversation and may escape the attention of the instructor.

5 Target audience

The course targets junior and senior undergraduate students in biology with a strong interest in mathematical methods and students in data sciences with an interest in biology, but could also be of interest to students in physics, mathematics, computer science and environmental sciences. Indeed, students from other disciplines will find that many of the mathematical techniques taught are also applicable to problems in their own field.

6 Course contents

The following topics will be covered, roughly in this order and as time permits.

- Differential equation models and introduction to dynamical systems: Formulation, steady states, periodic trajectories, coordinate transformations, linearization theorem.
- Numerically simulating differential equation models in forward time.
- Numerically fitting differential equation models to data, for example using weighted least squares.

- Linear differential equations: Eigenvalues, normal modes, matrix-exponential representation of solutions, diagonalization and Jordan normal form, asymptotic stability concepts.
- Forced linear systems, impulse response function, transfer function, Fourier transform of input (forcing) and output (response).
- Fourier analysis of models and time series.
- Linear stability theory for differential equation models.
- Epidemiological models (e.g., SIR), basic reproduction ratio.
- Discrete-time models (iterative maps), including stability concepts, simulations and fitting.

To some students the math may appear to be somewhat abstract. For example, most of the theory is formulated for n-dimensional systems, thus allowing application to a wide range of realistic problems. Mathematical proofs as well as programming tasks are common components of the course. Application of the theory will be demonstrated using examples from across the field of biology. Population genetics models are not discussed in this course.

A lot of the material is presented along with mathematical proofs, a practice that some students may not necessarily be familiar with. Providing a "proof" simply means that a rigorous justification is given for a particular statement. This has a two-fold educational rationale. First, seeing the *reason* for a specific mathematical statement facilitates its apprehension, as the task shifts from that of *memorization* to one of *understanding*. Second, a central aspect of modeling is to make quantitative predictions through deductive reasoning that can then be tested experimentally. When an experiment contradicts the prediction of a model it is essential to know whether the experiment really contradicts the model, or whether the model itself is accurate but the prediction itself was erroneously deducted through sloppy (aka. "hand-wavy") arguments. Being accustomed to the art of mathematical proof (that is, clear deductive reasoning) is a skill that any serious modeler must have.

Examples will be drawn from a broad spectrum of topics, including neuroscience, physiology, cell biology, microbiology, epidemiology, population dynamics, ecosystems, conservation and species invasions.

7 Prerequisites

Highly recommended prerequisites for this course are:

- Familiarity with multivariate calculus (multivariate integrals, partial derivatives, basic differential equations).
- Basic linear algebra (matrixes, eigenvectors, systems of linear equations).
- Basic probability and statistics (common distributions in biology, especially normal and Poisson, conditional probabilities, density and cumulative distribution function).

- Some familiarity with complex numbers.
- Experience with computer programming (any language).
- Basic knowledge of biology (e.g., entry college level).

Students lacking some of this background might still succeed in this course with (potentially considerable) additional effort. Students lacking most of this background will probably find this course to be very challenging. Formal course prerequisites listed on the university website may be waived upon instructor approval.

8 Materials and equipment

Canvas: Unless otherwise mentioned, material (reading assignments, homework assignments, announcements etc) will be posted on the UO Canvas course page. Students should check for announcements and assignments posted on Canvas at least every 2-3 days; students may also choose to set up automated email notifications in Canvas.

Textbook: The full reading material for this course will be provided for free as a textbook on Canvas. Students should download the latest version of this document from Canvas at least once a week, since material might be added or modified throughout the course. A not-regularly updated version of the textbook can also be found here, and students are free to start reading it prior to the course. Students lacking some of the prerequisites mentioned earlier will need to look into catching up on that material prior to the course, e.g. through wikipedia, books etc., although some brief introductions are also provided as appendixes in the textbook.

Software: The course includes examples and homework assignments in MATLAB, a widely used commercial software for scientific computations. The provided code examples assume MATLAB 2019b or later. Macs at the Price Science Commons & Research Library have MATLAB installed, and students can use those to work on their homework assignments depending on current UO restrictions due to COVID-19. Students will also have access to computers with a MATLAB installation during the weekly computer labs, however note that the lab time will almost certainly not be enough to finish the homework assignments. Students are thus strongly encouraged to install MATLAB on their own computers. It is also recommended to bring a small USB thumb drive to the labs for backing up your work at the end of each session (the lab computers have USB-A ports). Students are free to use their own laptops during the weekly computer labs, instead of those provided in the lab. The University of Oregon provides MATLAB licenses for students at: software.uoregon.edu. During installation, make sure to include the "Optimization", "Econometrics" and "Curve fitting" toolboxes (other toolboxes might also be useful if you have space).

Students may in principle choose to use an alternative software to MATLAB for their homework assignments (e.g., R or python), however this is discouraged and no advice/instructions will be provided specific to that alternative software. There is also no guarantee that the provided lab computers will have any of those other programming languages installed. In past years most students that chose to use an alternative programming language tended to have more difficulties with the homework than their peers.

Copyright and privacy protection: Do not share or post online any of the course material, including lecture notes, assignments and official solutions, exams, or recordings of online Zoom meetings.

9 Reading assignments

Students will be expected to complete weekly reading assignments from the freely available textbook mentioned in Section 8. These assignments will be posted on the course's Canvas webpage prior to the week in which they are supposed to be completed. Reading assignments will largely overlap with the material subsequently discussed in class, and serve primarily as a preparation for the lectures. By being exposed to the lecture material beforehand, students will be better prepared to ask questions and participate in discussions during the lectures.

10 Exercise assignments

Students will be expected to complete weekly exercise assignments, which will generally include mathematical calculations or proofs as well as scientific programming tasks (such as simulating a model and visualizing the outcomes). Exercises will be based on previously covered material and will be graded. Weekly exercise assignments will be posted on Canvas and will be **due on the Monday of the following week at noon**. Solutions must be uploaded to Canvas in PDF file format prior to the deadline. Only PDF files will be accepted; please do not upload your assignments in Word document format. Solutions in paper format will not be accepted. Students are encouraged to learn and use LaTeX for their assignments, a free and widely used software for writing scientific (especially mathematical) documents. Alternatively, students may choose to complete their assignments on paper and upload scanned PDFs to Canvas, provided that these are clearly legible and combined into a single PDF.

Students are expected to complete most of the assignments on their own. Consultation and collaboration with peers is permitted, but every student should fully understand the solutions produced and must individually write up their computer code and report. Assignment solutions are graded individually. Solutions must be clearly legible and must adhere to common professional standards (e.g., proper axes labeling, thorough reasoning, proper writing, reasonable structure, legibility, etc). Solutions to selected exercises will be subsequently discussed in class during the weekly computer session. Computer code itself will generally not be graded nor evaluated - only the results of the computer code will be evaluated.

11 Estimated student workload

Students will be expected to complete weekly reading assignments from a textbook (details in Section 8) and weekly exercise assignments (details in Section 10). A summary of the typical workload needed to succeed in this course is given below:

Lectures: 20 lectures $\times$ 1.5 hours = 30 hours

Computer lab (including discussions): 10 labs $\times$ 2 hours = 20 hours

Assignments: 10 weeks $\times$ 7 hours per week (on average) = 70 hours

Total hours: 120

12 Grading

All homework and exam scores are counted on a percentage scale. The final grade G will be calculated on a percentage scale using the following formula: $G = 0.2 \cdot H + 0.8 \cdot E$, where H is the average score from the homework assignments (averaged over all assignments) and E is determined by the mid-term and final examination scores, as follows. If the final exam score is greater than the mid-term exam score, then E is equal to the final exam score. If the final exam score is equal to or less than the mid-term exam score, then E is equal to a weighted average of the two exam scores, with the mid-term exam weighting 30% and the final exam weighting 70%. There will be no opportunities for extra credit, no grade bumps and no grading on a curve.

Letter grade: The following rubric will be used to convert the final grade G from a percentage scale to a letter scale.

Percentage (P)	Letter
$97\% \leq P \leq 100\%$	A+
$93\% \leq P < 97\%$	A
$90\% \leq P < 93\%$	A-
$87\% \leq P < 90\%$	B+
$83\% \leq P < 87\%$	B
$80\% \leq P < 83\%$	B-
$77\% \leq P < 80\%$	C+
$73\% \leq P < 77\%$	C
$70\% \leq P < 73\%$	C-
$67\% \leq P < 70\%$	D+
$63\% \leq P < 67\%$	D
$60\% \leq P < 63\%$	D-
$0\% \leq P < 60\%$	F

13 Course policies

Students are strongly encouraged to attend all lectures and computer labs. However, attendance will not be taken into account for the grade. It is ultimately the student's responsibility to stay up to date with the material taught and homework assignments. Students that miss a class will be able to download the covered course materials from Canvas, as part of the freely provided textbook. Assignment solutions and all important announcements will also be posted on Canvas.

Late delivery of solutions to exercise assignments will not be accepted in the absence of adequate justification. If you anticipate a delay in your solution delivery and in the presence of adequate justification please contact the lead instructor as early as possible (preferably well ahead of the deadline) to discuss options. Adequate justification may include, for example, a serious illness or natural disaster. Having too much academic workload (e.g., term papers for other courses) does not constitute adequate justification. Students are responsible for checking notifications and assignments posted on Canvas in time.

Students may share their personal lecture notes and may discuss their homework assignments with each other. However, students **must not** share exams, exam solutions, or solutions to the weekly exercise assignments online (including through Canvas). Students must not share audio or video recordings of the lectures, computer labs or office hours without prior permission from the head instructor.

14 Disabilities and other issues

If there are aspects of this course that result in unfair barriers to your participation, please let us know as early as possible. You may also contact Accessible Education Services in 164 Oregon Hall, by phone at 541-346-1155 or via email at uoaec@uoregon.edu.

Students may request to borrow a Chromebook laptop from the University of Oregon, as described here:
https://service.uoregon.edu/TDClient/2030/Portal/Requests/ServiceDet?ID=42589

Students may also access the UO virtual computer lab, which provides various Windows software, including MATLAB, remotely:
https://service.uoregon.edu/TDClient/2030/Portal/Requests/ServiceDet?ID=42572

Students having trouble installing MATLAB on their computer should contact CASIT as soon as possible (https://casit.uoregon.edu).

15 COVID-19 specific rules

Students are expected to follow all University of Oregon regulations regarding COVID-19. Official information on expectations and policies is available at the following websites:

- https://provost.uoregon.edu/covid-containment-plan-classes
- https://coronavirus.uoregon.edu/covid-19-regulations

A selection of expectations (current as of October 27, 2021) is copied below:

- Students should introduce themselves to their classroom neighbors at the start of each class, as this greatly facilitates contact tracing, should it be needed in specific classes.
- Instructors are required to notify the Corona Corps if a student informs them that they have tested positive for COVID-19, have been identified as a close contact, or if a student is evidently symptomatic.
- Students should conduct daily symptom self-checks and not come to class if they have symptoms. See Sections 13 regarding missing classes.
- Face masks are required in class for all students. A fully vaccinated instructor can teach without a mask, provided that everyone else in the room is masked and at least 6 feet away from the instructor.
- Physical distancing is no longer required.