CEE 498: Modeling Plants from Genes to Ecosystems

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COURSE INFORMATION

CEE 498 – Modeling Plants from Genes to Ecosystems
Department of Civil and Environmental Engineering
Spring semester 2025, 4 credits

Class meeting: Tuesdays and Thursdays 9:30-10:50am
Location 2310 Newmark Civil Engineering Lab

Office hours: TBD

Course website: https://canvas.illinois.edu

Synopsis

Computational models are a useful tool for studying how plants and crops respond to a changing climate, and for exploring approaches for engineering plants to better respond to these changes and to meet the needs of a growing population. The aim of this course is to introduce how we quantitatively study plants and their interactions with their surrounding environment. In this course, we will study different levels of biological organization that govern plant behavior, focusing on gene regulation, metabolism, and physiology. Students will learn and apply mathematical, statistical, and computational approaches to gain insight into the structure and behavior of complex systems. Analysis tools will include, but are not limited to, the simulation and analysis of nonlinear ordinary differential equations, network analysis, constraint-based optimization modeling, and machine learning/data-driven modeling. While this course will focus on biological systems, the approaches studied are broadly applicable to other types of systems. It is expected that students will already be familiar with the fundamentals of differential equations and linear algebra and have prior experience with python (or similar programming language). A background in biology is not required.

Pre-requisites
None

Texts
There is no textbook for this course. Reading materials required for the course will be available online and on the class Canvas site. A list of readings is provided at the end of this syllabus.

LEARNING OBJECTIVES

1. Learn and understand concepts of how plants function and interact with their environment from a systems perspective.
2. Learn and understand key biological processes from biological, mathematical, and computational perspectives.
3. Apply the methodology in hands-on projects with data and networks for the purpose of solidifying understanding of concepts.
4. Learn and understand strengths and weaknesses of different modeling and computational approaches and how to decide which approach to use for different problems.
5. Become proficient in reading relevant primary literature and connecting the key concepts to lecture content and hands-on projects.
6. Assess the current state of the field and identify open questions that relate to problems facing the global community and other CEE areas.
7. Communicate your methods to the scientific community (your peers and instructor) in the form of a written report and oral presentation.

COURSE POLICIES

Academic integrity. Each student is expected to complete their own work. Academic dishonesty, including cheating, plagiarism, and/or copyright infringement of any kind, will not be tolerated and will be reported to the appropriate administration. Academic dishonesty may result in a failing grade. Every student is expected to review and abide by the Academic Integrity Policy: https://studentcode.illinois.edu/article1/part4/1-401/. Ignorance is not an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding. Ask the instructor if you are in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

Mental Health. Significant stress, mood changes, excessive worry, substance/alcohol misuse or interferences in eating or sleep can have an impact on academic performance, social development, and emotional wellbeing. The University of Illinois offers a variety of confidential services including individual and group counseling, crisis intervention, psychiatric services, and specialized screenings which are covered through the Student Health Fee. If you or someone you know experiences any of the above mental health concerns, it is strongly encouraged to contact or visit any of the University's resources provided below. Getting help is a smart and courageous thing to do for yourself and for those who care about you.

- Counseling Center (217) 333-3704
- McKinley Health Center (217) 333-2700
- National Suicide Prevention Lifeline (800) 273-8255
- Rosecrance Crisis Line (217) 359-4141 (available 24/7, 365 days a year)

If you are in immediate danger, call 911.

COVID. If you feel ill or are unable to come to class or complete class assignments due to issues related to COVID-19, including but not limited to testing positive yourself, feeling ill, caring for a family member with COVID-19, or having unexpected child-care obligations, you should contact your instructor immediately, and you are encouraged to copy your academic advisor.

Emergency response recommendations. Emergency response recommendations and campus building floor plans can be found at the following website: https://police.illinois.edu/em/run-hide-fight/. I encourage you to review this website within the first 10 days of class.

Disability-related accommodations. To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor as soon as possible and provide the instructor with a Letter of Academic Accommodations from Disability Resources and Educational Services (DRES). To ensure that disability-related concerns are properly addressed from the beginning, students with disabilities who require assistance to participate in this class should apply for services with DRES and see the instructor as soon as possible. If you need accommodations for any sort of disability, please speak to me after class, or make an appointment to see me or see me during my office hours. DRES provides students with academic accommodations, access, and support services. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 217-333-1970, e-mail disability@illinois.edu or visit the DRES website at http://www.disability.illinois.edu/. Here is the direct link to apply for services at DRES, https://www.disability.illinois.edu/applying-services.

Family Educational Rights and Privacy Act (FERPA). Any student who has suppressed their directory information pursuant to Family Educational Rights and Privacy Act (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See https://registrar.illinois.edu/academic-records/ferpa/ for more information on FERPA.

Anti-racism and inclusivity. The Grainger College of Engineering is committed to the creation of an anti-racist, inclusive community that welcomes diversity along a number of dimensions, including, but not limited to, race, ethnicity and national origins, gender and gender identity, sexuality, disability status, class, age, or religious beliefs. The College recognizes that we are learning together in the midst of the Black Lives Matter movement, that Black, Hispanic, and Indigenous voices and contributions have largely either been excluded from, or not recognized in, science and engineering, and that both overt racism and micro-aggressions threaten the well-being of our students and our university community.

The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the course instructor if you feel comfortable. You can also report these behaviors to the Bias Assessment and Response Team (BART) at https://bart.illinois.edu/. Based on your report, BART members will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action.

Religious observances. Illinois law requires the University to reasonably accommodate its students' religious beliefs, observances, and practices in regard to admissions, class attendance, and the scheduling of examinations and work requirements. Students should complete the Request for Accommodation for Religious Observances form should any instructors require an absence letter in order to manage the absence. In order to best facilitate planning and communication between students and faculty, students should make requests for absence letters as early as possible in the semester in which the request applies.

Sexual misconduct reporting obligation. The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University's Title IX and Disability Office. In turn, an individual with the Title IX and Disability Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options.

A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: wecare.illinois.edu/resources/students/#confidential.

Other information about resources and reporting is available here: wecare.illinois.edu.

LATE WORK POLICY

Late assignments. Late assignments will be accepted up to 24 hours after the due date without penalty.

Late exams. Late or make-up exams are not allowed, except under extreme circumstances approved by the instructor in advance.

ASSIGNMENTS

Computational assignments: Several class sessions will focus on developing computer simulations of gene networks and metabolic pathways, using programming languages such as python and/or R. Homework assignments will require you to extend these simulation models to explore new network types and behaviors.

Homework assignments: Students are expected to submit all homework assignments in a neat and presentable manner. Using word processing or typesetting tools (e.g., LaTeX) are encouraged. All supplemental information (code, plots, derivations) should be included as necessary.

Project: Students will work in small groups (2-3 people) and identify a course-related topic of interest that they can develop a research question or applied project around. Groups will be responsible for submitting a written report describing the merit and broader impact of the chosen project and a proposed research or project plan using knowledge gained throughout the class. Groups will also be responsible for a 10-minute oral presentation of their project.

GRADING

Homework assignments	25%
In-class assignments/discussions	10%
Project report and presentation	15%
Midterm exams	30% (15% each)
Final exam	20%
	100%

Letter grades will be assigned using a plus/minus system, as below:

A	93.0-100.0%
A-	90.0-92.9%
B+	87.0-89.9%
B	83.0-86.9%
B-	80.0-82.9%
C+	77.0-79.9%
C	73.0-76.9%
C-	70.0-72.9%
D+	67.0-69.9%
D	63.0-66.9%
D-	60.0-62.9%
F	59.9% and below

MAJOR COURSE TOPICS

- Introduction – Systems Overview
- Plant Biology Basics
- Gene Regulation
    - Biological concepts
    - Modeling
    - Data Collection
- Nonlinear systems analysis
- Gene Regulatory Network Inference
- Metabolism
    - Biological concepts
    - Mechanistic modeling
    - Constraint-based modeling (Flux Balance Analysis)
- Photosynthesis
    - Biological concepts
    - Photosynthesis models
- Physiology and Crop Models
- Multiscale models of plants
- Omic and Multiomic data and analyses
- Plant responses to environmental stress (e.g., drought, heat, etc.)
- Plants as part of biogeochemical cycles; agriculture and environmental sustainability
- Plants and ecosystem dynamics (eddy covariance flux towers, remote sensing, ecosystem models)

Required readings (more may be added):

Burba G. Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications: A Field Book on Measuring Ecosystem Gas Exchange and Areal Emission Rates. LI-COR Biosciences; 2013. 345 p. (Part One only)

Huynh-Thu VA, Sanguinetti G. Gene Regulatory Network Inference: An Introductory Survey. In: Sanguinetti G, Huynh-Thu VA, editors. Gene Regulatory Networks: Methods and Protocols. New York, NY: Springer; 2019. p. 1–23. (Methods in Molecular Biology).

Karlebach G, Shamir R. Modelling and analysis of gene regulatory networks. Nat Rev Mol Cell Biol. 2008 Oct;9(10):770–80.

Marbach D, Costello JC, Küffner R, Vega NM, Prill RJ, Camacho DM, et al. Wisdom of crowds for robust gene network inference. Nat Methods. 2012 Aug;9(8):796–804.

Moore CE, Meacham-Hensold K, Lemonnier P, Slattery RA, Benjamin C, Bernacchi CJ, et al. The effect of increasing temperature on crop photosynthesis: from enzymes to ecosystems. Journal of Experimental Botany. 2021 Apr 2;72(8):2822–44.

Orth JD, Thiele I, Palsson BØ. What is flux balance analysis? Nat Biotechnol. 2010 Mar;28(3):245–8.

Van den Broeck L, Gordon M, Inzé D, Williams C, Sozzani R. Gene Regulatory Network Inference: Connecting Plant Biology and Mathematical Modeling. Frontiers in Genetics. 2020;11.

Optional readings/resources (more may be added):

Hecker M, Lambeck S, Toepfer S, van Someren E, Guthke R. Gene regulatory network inference: Data integration in dynamic models—A review. Biosystems. 2009 Apr 1;96(1):86–103.

Kong Q, Siauw T, Bayen A. Python Programming and Numerical Methods: A Guide for Engineers and Scientists. Academic Press; 2020. 482 p. ISBN: 978-0-12-819550-5 (online version available for free: https://pythonnumericalmethods.berkeley.edu/notebooks/Index.html)

Linde J, Schulze S, Henkel SG, Guthke R. Data- and knowledge-based modeling of gene regulatory networks: an update. EXCLI journal. 2015;14:346–78.

Strogatz SH. Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering. CRC Press; 2018. 533 p., ISBN: 978-0-429-97219-5

Wang YXR, Huang H. Review on statistical methods for gene network reconstruction using expression data. Journal of Theoretical Biology. 2014 Dec 7;362:53–61.