MATH 243: Evolutionary Dynamics

Course Instructor: Martin Nowak

Teaching Fellows: David Brewster, Caitlin Hauser, Bright Liu, Anthony Rodriguez-Miranda

Location: SC 309, T/Th 12:00-1:15 PM

Course ID: 119511

Course Description:

Research seminar on evolutionary dynamics, spanning mathematical and computational models of evolution in biological and social systems. Students attend a weekly lecture and conduct an original research project. Lecture topics this year include epidemiology, virus dynamics, cancer evolution, origins of life, eusociality, population genetics, and evolutionary economics.

Logistics

Meetings

The class will meet Tuesday/Thursdays from 12:00 to 1:15 PM. Tuesday will consist of a lecture on the scheduled topic while Thursday will be made up of student presentations and group work.

Prerequisites

There are no formal prerequisites for the course. Lectures may assume some familiarity with dynamical systems, probability theory, linear algebra, game theory, or basic biology. Some students find programming helpful for their project, although this is not required.

Assignments

There are neither problem sets nor exams in this course. Instead, you will be asked to submit project progress reports throughout the semester and a final project report at the end of the semester. Guidelines for the report format are provided.

Grading

- Attendance and participation (20%)
    - Please email the TFs if you have a valid reason for being absent (e.g., illness, etc.)
    - Participation entails active listening and asking questions during lectures/student presentations, as well as filling out Google Forms at the end of class
- Milestone 1: presentation & research question (5%)
- Milestone 2: presentation & proposal (10%)
- Milestone 3: presentation & draft (15%)
- Final presentation & report (25% each)

Office Hours

Professor Nowak's office hours are by appointment. Office hours of the course assistants will be listed below soon. Please reach out to the course staff by email with any questions or concerns you may have.

Research Project

This course is meant to act as an incubator/seminar for an original research project of your choosing. The project should be related to something discussed in the class/evolutionary dynamics generally. You may work with the course staff to come up with a project idea, or you may choose to define your own project. You are also free to work on an ongoing research project from outside the class if it relates to the course material. For your project, you may choose to use some combination of analytic derivation, formal proof, computer simulation, machine learning, statistical analysis, or any other appropriate methods.

Schedule

Tuesday Classes

The **tentative** schedule for Tuesday lectures with some associated readings is given below:

1. Toward global cooperation
    - Hauser, Rand, Peysakhovich, Nowak, Cooperating with the future, Nature;
    - Download Hauser, Rand, Peysakhovich, Nowak, Cooperating with the future, Nature;
    - Hauser, Hilbe, Chatterjee, Nowak, Social dilemmas among unequals, Nature;
    - Download Hauser, Hilbe, Chatterjee, Nowak, Social dilemmas among unequals, Nature;
    - Hauser, Hilbe, Chatterjee, Nowak, Social dilemmas among unequals, Nature (Supplementary Information);
    - Download Hauser, Hilbe, Chatterjee, Nowak, Social dilemmas among unequals, Nature (Supplementary Information);
2. Evolutionary dynamics - review
    - Nowak, Evolutionary Dynamics, Harvard University Press;
    - Allen, Lippner, Chen, et. al., Evolutionary dynamics on any population structure, Nature;
    - Download Allen, Lippner, Chen, et. al., Evolutionary dynamics on any population structure, Nature;
    - Allen, Lippner, Chen, et. al., Evolutionary dynamics on any population structure, Nature (Supplementary Information);
    - Download Allen, Lippner, Chen, et. al., Evolutionary dynamics on any population structure, Nature (Supplementary Information);
    - Hilbe, Simsa, Chatterjee, Nowak, Evolution of cooperation in stochastic games, Nature;
    - Download Hilbe, Simsa, Chatterjee, Nowak, Evolution of cooperation in stochastic games, Nature;
    - Hilbe, Simsa, Chatterjee, Nowak, Evolution of cooperation in stochastic games, Nature (Supplementary Information);

- Download Hilbe, Simsa, Chatterjee, Nowak, Evolution of cooperation in stochastic games, Nature (Supplementary Information);

3. Cancer
    - Nowak, Komarova, Sengupta, et. al., The role of chromosomal instability in tumor initiation, PNAS;
    - Download Nowak, Komarova, Sengupta, et. al., The role of chromosomal instability in tumor initiation, PNAS;
    - Michor, Hughes, Iwasa, Branford, et. al., Dynamics of chronic myeloid leukemia, Nature;
    - Download Michor, Hughes, Iwasa, Branford, et. al., Dynamics of chronic myeloid leukemia, Nature;
    - Bozic, Reiter, Allen, Antal, et. al., Evolutionary dynamics of cancer in response to targeted combination therapy, eLife;
    - Download Bozic, Reiter, Allen, Antal, et. al., Evolutionary dynamics of cancer in response to targeted combination therapy, eLife;
    - Bozic, Antal, Ohtsuki, Carter, et. al., Accumulation of driver and passenger mutations during tumor progression, PNAS;
    - Download Bozic, Antal, Ohtsuki, Carter, et. al., Accumulation of driver and passenger mutations during tumor progression, PNAS;
    - Waclaw, Bozic, Pittman, Hruban, et. al., A spatial model predicts that dispersal and cell turnover limit intratumour heterogeneity, Nature;
    - Download Waclaw, Bozic, Pittman, Hruban, et. al., A spatial model predicts that dispersal and cell turnover limit intratumour heterogeneity, Nature;
    - Reiter, Makohon-Moore, Gerold, Heyde, et. al., Minimal functional driver gene heterogeneity among untreated metastases, Science;
    - Download Reiter, Makohon-Moore, Gerold, Heyde, et. al., Minimal functional driver gene heterogeneity among untreated metastases, Science;
4. Prelife
    - Nowak and Ohtsuki, Prevolutionary dynamics and the origin of evolution, PNAS;
    - Download Nowak and Ohtsuki, Prevolutionary dynamics and the origin of evolution, PNAS;
5. Evolution of Eusociality I
    - Nowak, Tarnita, E. O. Wilson, The evolution of eusociality, Nature;
    - Download Nowak, Tarnita, E. O. Wilson, The evolution of eusociality, Nature;
6. Evolution of Eusociality II

- Nowak, Tarnita, E. O. Wilson, The evolution of eusociality, Nature;
- Download Nowak, Tarnita, E. O. Wilson, The evolution of eusociality, Nature;

7. Hamilton's rule
    - Nowak, McAvoy, Allen, E.O. Wilson, the general form of Hamilton's rule makes no predictions and cannot be tested empirically, PNAS;
    - Download Nowak, McAvoy, Allen, E.O. Wilson, the general form of Hamilton's rule makes no predictions and cannot be tested empirically, PNAS;
8. Language I
    - Nowak, Komarova, Niyogi, Computational and evolutionary aspects of language, Nature;
    - Download Nowak, Komarova, Niyogi, Computational and evolutionary aspects of language, Nature;
    - Nowak, Komarova, Niyogi, Evolution of Universal Grammar, Science;
    - Download Nowak, Komarova, Niyogi, Evolution of Universal Grammar, Science;
    -
9. Language II
    - Nowak, Komarova, Niyogi, Computational and evolutionary aspects of language, Nature;
    - Download Nowak, Komarova, Niyogi, Computational and evolutionary aspects of language, Nature;
    - Nowak, Komarova, Niyogi, Evolution of Universal Grammar, Science;
    - Download Nowak, Komarova, Niyogi, Evolution of Universal Grammar, Science;
    -
10. Time (to evolve)
    - Knoll and Nowak, The timetable of evolution, Science Magazine;
    - Download Knoll and Nowak, The timetable of evolution, Science Magazine;

Thursday Classes

Expectations for milestone presentations and the final presentation can be found below.

Weeks 1- 4: Milestone 1

- Week 1: (Jan 25): Form groups
- Week 2 (Feb 1): Brainstorm project ideas
- Week 3 (Feb 8): Milestone 1 presentations
- Week 4 (Feb 15): Milestone 1 presentations

Weeks 5-7: Milestone 2

- Week 5 (Feb 22): Group work
- Week 6 (Feb 29): Milestone 2 presentations
- Week 7 (Mar 7): Milestone 2 presentations

Week 8: Spring Break (no class)

Weeks 9-12: Milestone 3

- Week 9 (Mar 21): Group work
- Week 10 (Mar 28): Group work
- Week 11 (Apr 4): Milestone 3 presentations
- Week 12 (Apr 11): Milestone 3 presentations

Weeks 13-14: Final Presentations

- Week 13 (*Tuesday*, Apr 16): Final presentations
- Week 13 (Apr 18): Final presentations
- Week 14 (*Tuesday*, Apr 23): Final presentations

Milestone Presentations

Your group will have *three* opportunities to present your project's progress over the course of the semester, before the final presentation. The purpose of the Milestone Presentations is to facilitate an informal research seminar discussion and present your progress to your peers. This means that groups will present on either a set of papers, an idea, or the current progress of their project, and we can have a longer form discussion about the materials and ideas presented. The point is to allow for a deeper level of discussion and allow you to integrate feedback from the class and the course staff into your research throughout the semester. **Note:** we will randomly assign presentation orders but your group can contact the course assistants if there are outstanding conflicts.

Milestone 1 (Weeks 1-4):

- 5-minute presentation + 5 minutes Q&A/discussion
- Introduce the idea(s) you're considering for your final project and your tentative research question
- DUE on Feb 15th: Tentative research question (this *can* be changed later on)
- *Ideas: discuss research papers of interest, present past research you've conducted on the topic, explain your motivation, how it relates to lectures/textbook, etc.*

Please upload a single PDF of your research question to Canvas by **11:59pm on Thursday, February 15th, 2024** (only one member needs to submit the pdf, but all group members' names must be listed).

Milestone 2 (Weeks 5-7):

- 5-minute presentation + 5 minutes Q&A/discussion
- Present your project proposal
- DUE on Mar 7th: Project proposal (provide an outline of your proposed final project)

Your final project should both:

Pose a question in evolutionary dynamics and use the mathematical tools and principles developed throughout the course to address the chosen question (perhaps through a new mathematical model/principle within evolutionary dynamics or an application of an existing model/principle to a relevant topic of your choice).

Your project proposal should include:

- A proposed question that your final project will address,
- A brief literature review (2-5 sources),
- A proposed approach (model or algorithm)

Note that as you continue to research your final project after you submit your proposal, you may adjust your research question and approach (this is common in research!).

Please upload a single PDF of your 2-3 page proposal to Canvas by **11:59pm on Thursday, March 7th, 2024.** You may use any formatting or organization that you feel is appropriate, including any reasonable choice of columns, line spacing, and margin size.

We suggest the following structure (not required):

- Group members: Only one member needs to submit the proposal, but all group members' names must be listed.
- An informed introduction (~1 page): Use your introduction section to concisely inform the reader about your research question of interest, which should be in some way connected to the course material. Summarize the current state of the literature by discussing and referencing around 2-5 published papers on your topic (including at least 2 mathematical papers if possible), and identify a specific question that remains unresolved.
- Your proposed approach (~1 page): Present the model equations or algorithm you propose to study. Your model may be deterministic, stochastic, algorithmic, statistical, computational, game theoretical, or anything else. It may be your own original model or a meaningful modification of an existing model. Be sure to identify the variables and notation, clearly explain each of the model equations, and identify any assumptions underlying the formulation of the model.
- References: Please cite the papers or materials that you discussed in your proposal. You may use whatever bibliographic format you prefer. For each reference, please also include in-text citations.

Milestone 3:

- 5-minute presentation + 5 minutes Q&A/discussion
- Present your project draft, including all the progress you've made since the previous presentation as well as next steps
- DUE on April 11th: Final Project Draft

Please submit a minimum length 6-8 page paper with relevant references and figures by **11:59pm on April 11th, 2024**. Submit the file as a PDF and feel free to submit code if you feel it could be helpful to the readers.

Below is a possible structure for your paper:

- Abstract (~100-200 words)
- Introduction (~1 page)
- Model/Methods (~2 pages)
- Results (~2 pages)
- Discussion (~1 page)
- References (~10-20 citations)

Group members: Only one member needs to submit the draft, but all group members' names must be listed.

References: Please cite the papers or materials that you discussed in your draft. You may use whatever bibliographic format you prefer. For each reference, please also include in-text citations.

Final project:

Taking into account the TFs' feedback, submit the updated version of the final draft, which is tentatively due on the last day of reading period, at **11:59pm on May 1st, 2024**.

Please submit a minimum length 6-8 page paper with relevant references and figures. Submit the file as a PDF and feel free to submit code if you feel it could be helpful to the readers.

Group members: Only one member needs to submit the draft, but all group members' names must be listed.

References: Please cite the papers or materials that you discussed in your paper. You may use whatever bibliographic format you prefer. For each reference, please also include in-text citations.

Final Presentation: You will have a maximum of 10 minutes to present your final report and 5 minutes of Q&A.