HONR 3310: Limits on Scientific Knowledge:
Chaos, Complexity and Computability

Syllabus

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CONTENT

The principle of determinism - the belief that future behavior can be known and determined from an analysis of current conditions - has shaped contemporary scientific knowledge in physics, chemistry, mathematics, and other areas. This seminar begins with an exploration of this principle, and then focuses on four important conceptual challenges that were discovered during the 20th century and which reduce the applicability of determinism: chaos, complexity, uncertainty, and noncomputability.

These ideas have had a dramatic effect on scientific disciplines as diverse as biology, computer science, economics, sociology, and engineering, and on applications such as weather prediction, genome sequencing, and cell phone routing. In understanding these challenges, we will discuss their practical implications for scientists. Throughout the seminar students will get hands-on experience using software packages.

PREREQUISITES

The seminar is self-contained and the only prerequisites are the ability to think critically and to carefully read non-technical descriptions of the ideas being discussed. The emphasis is on the broad ideas and not on the technical details. The speed and depth of lectures will depend on students' background.

STRUCTURE AND REQUIREMENTS

In class we will have lectures, group discussions, demonstrations, and student presentations. Lectures will cover the details behind the different scientific limitations. Class discussions will focus on the often surprising and counter-intuitive implications of the topics we study. It is important that you come to class fully prepared. You should be ready to ask questions and engage the material. I will often use computer tools to demonstrate key points during class and you may also be experimenting with these tools yourselves during class.

Regularly doing the assigned reading is an important class requirement. Weekly reading assignments will be listed on the class website.

A one-page response to the previous week's reading is due before the first lecture every week. This informal response can be a description of the main points in part of the reading, things you did not understand, things you disagree with, a description of how the reading relates to the main themes of the class, or something else. This response should show that you have done the reading and thought about it carefully.

Each of you will give a 20-minute, non-technical presentation on a topic related to the class material. Possible topics include: how a specific application area copes with a scientific limitation, a discussion of the philosophical implications of a limitation, or a more detailed description of the research that led to the discovery of the limitation.

The class' online discussion group is a forum for the class community, including your classmates, the teaching assistants, and the instructor, to share and discuss ideas related to course material. You should post at least two entries to the discussion group every week. Your first post can be anything related to the course that the community might find interesting. It could be a summary of one of your recent written responses, questions about lecture or reading material, a link to a relevant news article with your comments, a link to a relevant website with your comments, something you liked or disagree with from a recent lecture, questions about a classmate's presentation, etc. Your second post should be a response to one of your classmates' postings.

There will be a final project due toward the end of the semester. More information about the project will be given later. There will be no tests or exams.

Your final grade for the class will be based on the following breakdown: 15% attendance and participation, 10% weekly reading and written responses, 5% discussion group participation, 35% homework, 15% presentation and 20% final project. A satisfactory score in each area is required to pass the class.

POLICIES

Homework is due by the beginning of class on the due date. No late homework will be accepted.

Class attendance is required. If you miss a lecture, you are responsible for all material that was covered, announcements that were made and handouts that were distributed in class.

All requirements must be completed during the semester. No incompletes will be given.

All students must adhere to Northeastern University's Policy on Academic Integrity. Students are encouraged to work together on homework assignments, but copying someone else's work and presenting it as your own is not allowed.

Exceptions to any course policy may be made if you have a personal emergency that prevents you from participating in the course. In this case you must make arrangements with me as soon as possible, preferably within 24 hours.

OUTLINE

Foundations:	Determinism, Laplace's demon, Newton's laws and approach to empiricism, layers of determinism: differential dynamics, unique evolution, total predictability.
Chaotic systems:	Predictive hopelessness, sensitive dependence on initial conditions, implications, Lorenz's experiment. Dynamical systems: orbits, fixed points, periodic points, logistic maps, bifurcation diagrams, sensitive dependence on initial conditions, Poincare maps, forced damped pendulum model, sinks, sources, saddles, Henon map, chaotic attractors. Fractals: Cantor sets, probabilistic constructions, deterministic systems, basin boundaries, Julia sets, Mandelbrot set.
Computational Complexity:	Introduction to algorithms and problems, complexity of algorithms, big-O notation, polynomial vs exponential runtime, assumptions, tractable and intractable problems, provably intractable problems. NP-completeness: NP, P vs NP, reductions, NP-completeness. Implications of NP-completeness: what does it mean, responses to intractability, exhaustive algorithms, heuristics.
Computability:	Computable and uncomputable problems, Turing's Halting problem, Godel's result, implications of uncomputability.
Special relativity and Uncertainty:	Fundamentals of relativity, effect of relativity on simultaneity, Einstein, limits on movement of information, fundamentals of quantum mechanics, Heisenberg's uncertainty principle, Schrodinger's wave equations, implications of uncertainty.

READING

All assigned reading is either in the coursepack or on reserve in the library.

Foundations/Determinism

S. Hook, “Determinism and Freedom in the Age of Modern Science”, NY University Press, 1958.

P. Laplace, “Philosophical Essay on Probabilities”, Springer-Verlag, 1995.

J. Lucas, “The Freedom of the Will”, Clarendon Press, 1970.

K. Popper, “The Open Universe: An Argument for Indeterminism”, Rowman and Littlefield, 1982.

Classical Science

E. Andrade, “Sir Isaac Newton”, Greenwood, 1979.

I. Cohen, “The Newtonian Revolution”, Cambridge University Press, 1980.

B. J. Dobbs and M. Jacob, “Newton and the Culture of Newtonianism”, Humanities Press, 1995.

J. Fauvel, R. Flood, M. Shortland, and R. Wilson, “Let Newton Be!”, Oxford Univ. Press, 1988.

J. Pitt, “Galileo, Human Knowledge and the Book of Nature”, Kluwer, 1992.

Chaos and Complexity

K. Alligood, T. Sauer and J. Yorke, “Chaos: An Introduction to Dynamical Systems”, Springer, 1997.

S. Kellert, “In the Wake of Chaos: Unpredictable Order in Dynamical Systems”, The University of Chicago Press, 1993.

Computational Complexity and Computability

G. Brassard and P. Bratley, “Fundamentals of Algorithmics”, Prentice-Hall, 1996.

D. Harel, “Algorithmics: The Spirit of Computing”, Addison Wesley, 1987.

M. Garey and D. Johnson, “Computers and Intractability: A Guide to the Theory of NP-Completeness”, Freeman, 1979.

J. Jintikka, “On Godel”, Wadsworth, 2000.

H. Lewis and C. Papadimitriou, “Elements of the Theory of Computation”, Prentice-Hall, 1981.

J. Prager, “On Turing”, Wadsworth, 2001.

Relativity and Quantum Mechanics

A. Kompaneyets, “Basic Concepts in Quantum Mechanics”, Reinhold Publishing, 1966.

D. Mook and T. Vargish, “Inside Relativity”, Princeton University Press, 1987.

R. Resnick, “Basic Concepts in Relativity and Early Quantum Theory”, Wiley, 1972.

L. Sartori, “Understanding Relativity”, University of California Press, 1996.

P. Tipler, “Physics”, Worth Publishers, 1976.

POLICY ON ACADEMIC INTEGRITY

Northeastern University is committed to the principles of intellectual honesty and integrity. All members of the Northeastern community are expected to maintain complete honesty in all academic work, presenting only that which is their own work in tests and all other assignments. If you have any questions regarding proper attribution of the work of others, please contact me prior to submitting the work for evaluation.

Academic integrity is important for two reasons. First, independent and original scholarship ensures that students derive the most from their educational experience and the pursuit of knowledge. Second, academic dishonesty violates the most fundamental values of an intellectual community and depreciates the achievements of the entire university community.

Accordingly, Northeastern University views academic dishonesty as one of the most serious offenses that a student can commit while in college. The following is a broad overview of what constitutes academic dishonesty, but is not meant to be an all-encompassing definition.

Cheating: Intentionally using or attempting to use unauthorized materials, information or study aids in any academic exercise.

Plagiarism: Intentionally or knowingly representing the words or ideas of another as ones own in any academic exercise without providing proper documentation of source by way of a footnote, endnote, or intertextual note.

Unauthorized Collaboration: This refers to instances when students, each claiming sole authorship, submit separate reports which are substantially similar to one another. While several students may have the same source material (as in case write-ups), the analysis, interpretation, and reporting of the data must be each individuals.

All members of the Northeastern University community, students, faculty, and staff share the responsibility to bring forward known acts of apparent academic dishonesty. Any member of the academic community who witnesses an act of academic dishonesty should report it to the appropriate faculty member or to the Director of Judicial Affairs. The charge will be investigated and if sufficient evidence is presented, the case will be referred to Northeastern University Student Judicial Hearing Board. If found responsible of an academic dishonesty violation, a minimum sanction of probation will follow. (adapted from NU's Academic Honesty and Integrity Policy)