COMPLEX ADAPTIVE SYSTEMS

UNM CS 523

Fall Term, 2015
Mon, Wed 12:30 - 1:15 pm
Mechanical Engineering, Rm. 220

Professor: Stephanie Forrest

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Textbook:

Complexity: A Guided Tour M. Mitchell, Oxford. Hardcopy, 2009; Paperback 2011. This is not a textbook, but we will use it as a guide, supplemented with more in-depth readings each week.

Recommended: *How the Immune System Works* by Lauren Sompayrac. Blackwell Science, 1999.

Selected Readings.

Course Description:

A graduate introduction to selected topics in the field of complex adaptive systems, including: definitions of complexity, cellular automata, dynamical systems, genetic algorithms, computer immune systems, and artificial life. The course will emphasize computational tools to measure, simulate and analyze complexity in exemplar complex systems. Because New Mexico is a center of research in complex adaptive systems, there may be guest speakers throughout the semester. Programming and mathematical maturity or permission of instructor required.

Course Assignments and Grading:

Expect to spend a significant amount of time each week reading and preparing the assigned papers (plan on one or two scientific papers per week). You are expected to have completed the assigned reading when you come to class, contribute to discussions, and be prepared for quizzes on the material.

Grades will be based on programming assignments and exercises ($\approx 50\%$), exams and quizzes ($\approx 30\%$), and class participation ($\approx 20\%$).

Collaboration, online help and academic honesty

Programming is often a collaborative endeavor, but in this class you are expected to develop code for assignments independently and hand in only your own work, unless explicitly directed otherwise. Students are encouraged to help each other with concepts from class and to discuss the assigned readings ahead of time, but they are not allowed to copy any part of another students' code. In other words, students may help each other by communicating in English, but not by communicating computer programs or snippets of computer programs. You are strongly encouraged to seek help from the instructor to clarify assignments, algorithm design and tips on writing up reports, although you are expected to debug your own code. You are responsible for documenting and citing the sources for all code that you do not write yourself, for example, open source code that you use in one of your assignments. Any code, images, or text that is obtained online and modified, must be cited. The original code and web address must be provided in the program comments and project report when it is turned in. If you end up collaborating with another student, the details of the collaboration must be documented in program comments and lab reports. Any student caught copying code from any source and presenting it as his or her own will, at least, be failed and reported to the University for cheating. Any student who is unclear whether something is 'cheating' should ask the instructor.

Course Topics

I. Introduction (2 weeks)

Lecture: Course Overview
Lecture: Dynamics and the Logistic Map (read Mitchell Chs. 1-2, Flake Ch. 10)
Lecture: Measuring complexity and information theory (read Mitchell Chs. 3, 7; Schneider)
Lecture/Discussion: What is a model? Modeling paradigms
(read Mitchell Ch. 4, Holland)

Supplemental Readings:

G. Flake *The Computational Beauty of Nature* Chapter 10, 2000.
J. Holland *Hidden Order*, Ch. 1
T.D. Schneider "Information Theory Primer" (2000)

II. Evolution and genetic algorithms (3 weeks)

Biological underpinnings
Lecture: Introduction to genetics (read Mitchell Chs. 5-6)
Computational tools and applications
Lectures: Genetic algorithms I and II (read Mitchell Ch. 8-9; Flake, Ch. 20)
Lecture: Applications (read Le Goues, 2012; Schulte, 2015)
Discussion: Neutral landscapes (read Wagner; Schulte, 2014)
Discussion: The myth of the objective (read Woolley and Stanley)

Supplemental Readings:

Computational Beauty of Nature by G. Flake (Ch. 20)
C. Le Goues et al. "A systematic study of automated program repair:
Fixing 55 out of 105 bugs for $8.00 each" (2012)
E. Schulte et al. "Repairing COTS router firmware without access to source code
or test suites: A case study in evolutionary software repair" (2015)
A. Wagner "The role of robustness in phenotypic adaptation and innovation" (2012)

E. Schulte, et al. "Software mutational robustness" (2014)
Woolley and Stanley "A novel human-computer collaboration: Combining novelty search with interactive evolution" (2014)
K. O. Stanley and R. Miikkulainen. "Evolving neural networks through augmenting topologies." GECCO 2002.

IV. Cellular automata and agent-based modeling (2 weeks)

Cellular Automata and artificial life:

Lecture: Cellular automata and the game of life (read Mitchell Ch. 10-11, Wolfram)
Lecture (D. Levin): Modeling ants (read Gordon, Dorigo)
Lecture: Modeling cancer (read Abbott et al., Gerety et al.)
Discussion: Models for social science (read Holme and Liljeros)

Supplemental Readings:

S. Wolfram "Cellular Automata as models of complexity" *Nature* (1984)
M. Dorigo et al. "Ant colony optimization artificial ants as a computational intelligence technique" *IEEE Computational Intelligence Mag.* Nov. 2006
D. Gordon *Ant Encounters* Ch. 1-2, Princeton Univ. Press
R. Abbott et al. "Simulating the hallmarks of cancer." *Journal of Artificial Life* Vol. 12, No. 4: 617-634 (2006)
R. Gerety et al. "Modeling somatic evolution in tumorigenesis." *PLOS* (2006)
Holme and Liljeros "Mechanistic models in computational social science" (arXiv, 2015

III. Modeling Complex Adaptive Systems (3 weeks)

Lecture: What is a model? Homomorphic theory of modeling
Lecture: Non-zero sum games and the iterated Prisoner's Dilemma (read Mitchell Ch. 14, Axelrod 1980)
Lecture (Edwards): The Responsibility game
Lecture: Continuous vs. Individual-based models (read Flake Ch. 12, Axelrod)
Discussion (Levin): SIR models
Discussion: The importance of being discrete

Supplemental Readings:

R. Axelrod *The Evolution of Cooperation* Chs. 1, 2, and 9, 1981
R. Durrett and S. Levin "The importance of being discrete (and spatial)" *Theoretical Population Biology* 46:3 (1994)
R. Axelrod "Agent-based modeling as a bridge between disciplines"
M. Nowak and R. May "The basic model of virus dynamics"

V. Computational Immunology: (3 weeks)

Introduction

Discussion: Information processing in living systems (Ch. 12)

Biological underpinnings

Lecture: Overview of the adaptive immune system (read Sompayrac)

Applications:

Student presentation: Shape Space (Perelson and Oster; Smith et al.)
Student presentation: How much does it cost to have an immune system?
Student presentations: Negative Selection (Forrest, Groat, Textor)
Lecture: Computer security applications (read Hofmeyr and Forrest)
Lecture (Moses): Scaling in the immune system

Supplemental Readings:

Recommended: Sompayrac *How the Immune System Works*

A. Perelson and G. Oster "Theoretical studies of clonal selection: Minimal antibody size repertoire and reliability of self- non-self discrimination"

D. Smith et al. "Variable efficacy of repeated annual influenza vaccination" PNAS (1999)

A. Read and J. Allen "The economics of Immunity"

Y. Moret and P. Schmid-Hempel "Survival for Immunity: The price of immune system (activation for bumblebee workers. *Science* 1166 (2000).

F. Wiegel and A. Perelson "Some Scaling Principles for the Immune System *Immunology and Cell Biology* 82(2) (2004).

Hofmeyr and Forrest "Architecture for an artificial immune system"

M. Groat, et al. "Enhancing Privacy in Participatory Sensing Applications with Multidimensional Data"

Elberfeld and Textor "Efficient Algorithms for String-Based Negative Selection"

IV. Scaling, Power Laws, and Complex Networks (3 weeks)

Discussion: Introduction to complex networks and power laws (read Mitchell Ch. 15-16, Barabasi and Albert)

Lecture: Power laws and how to detect them (read Newman, Clauset)

Discussion: Allometric scaling in biology (read Michell, Ch. 17, Brown et al.)

Student Presentations : Power laws in computer networks (student selected readings)

Supplemental Readings:

M. Newman *Networks*, Ch. 17 pp. 627-641

"The Larger Context for Moores Law: Superexponential long-term trends in information Technology" Nagy et al.

A. Barabasi and R. Albert "Emergence of scaling in random networks" *Science* (1999)

G. West and J. Brown "Life's universal scaling laws" *Physics Today* (2004)

M. Moses et al. "Scaling theory for information networks." (2008)

S. Frank "The common patterns of nature"

V. Complexity Revisited (1 weeks

Discussion (read Mitchell Ch. 19, Simon)

Student presentations

TBA

Supplemental Readings

H. Simon *The Architecture of Complexity, Ch. 7*