

# **Nonlinear Systems: Agent-Based and Computer Intensive Modeling**

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The nonlinear dynamics exhibited by complex social systems often pose difficult problems for modelers of those systems. The problems are especially challenging when modelers want to capture the way actors in these systems adapt to their environment, which usually includes other adaptive agents. Humans can be assumed to adapt their behavior in light of feedback from other individuals or from collective actions of individuals, but until recently it has been difficult to model this kind of adaptive behavior in formal models. The growing availability of computers has led to a recent proliferation of bottom-up, agent-based models of complex adaptive systems. These models consist of a number of interacting agents. Each agent's behavior is governed by a small set of simple rules, though it is typically assumed that the agents do not know or cannot calculate the aggregate patterns resulting from all agents' actions. Despite the simplicity of the individual agents' cognitive and behavioral capabilities, the interaction of the agents can produce complex emergent structures and dynamical behaviors of individuals and groups. These lectures will give an introduction to recent approaches in computer modeling of complex social systems, comparing them to more traditional mathematical (analytical) approaches and to the previous generation of computer simulations in the social sciences. In addition to describing the methods and techniques of this modeling approach, a number of social science applications will be reviewed and analyzed. Students also will be able to run and carry out experiments with implementations of several of the models discussed in the lectures. Additional optional sessions will be available for those students who wish to learn how to modify those models, or write their own models, using the Swarm simulation library.

## **Class Schedule**

### **Week One -- Scott Page**

**July 24:** Introduction to Complex Adaptive Systems, Comparison of Modeling Strategies

*Note: We will also self-organize the evening hands-on computer sessions at this time*

Page, Scott. 1999. "Computational models from A to Z."

Complexity, vol 5 (1), pp35-41.

John Holland. 1992. "Complex Adaptive Systems."

Daedalus 121:17-30.

John Holland. 1992. "Genetic Algorithms."  
Scientific American. July. pp. 66-72.

**July 25:** "Emergence?" Micro to Macro Transitions

Page, S. 1999. "On the Emergence of Cities."

Journal of Urban Economics, 45, pp 184--208.

Thomas Schelling. 1978, Micromotives and Macrobehavior.

Norton, New York, 1978. Selected chapters TBA.

Forrest, S. 1990. "Emergent Computation: Self-Organizing,  
Collective, and Cooperative Phenomena in Natural and Artificial  
Computing Networks." Physica D, Vol 42, pp1--11.

Crutchfield, James, Melanie Mitchell, and Rajarshi Das. 1999.

"The Evolutionary Design of Collective Computation in Cellular Automata."

Paper under submission, available from:

<http://www.santafe.edu/projects/evca/evabstracts.html#EvDens>

**July 26:** Self Organized Critically

Per Bak. 1997. How Nature Works.

Selected Chapters TBA.

Ishii, Page and Wang. 1999. "A Day at the Beach."

Forthcoming in Journal of Complex Systems.

**July 27:** Representation of the World Complexity

Page, S. 1996. "Two Measures of Difficulty."

Economic Theory, 8, pp. 321--346.

**July 28:** Diversity and Optimality

Johnson, Norman. 1999. "Diversity and Robustness: Collective Problem Solving: Functionality  
beyond the individual." Submitted for publication.

Online at [http://ishi.lanl.gov/Documents/NLJsims\\_AB\\_v11.pdf](http://ishi.lanl.gov/Documents/NLJsims_AB_v11.pdf)

Hong, L, and S. Page. 1999.

"Problem Solving by Heterogeneous Agents." Journal of Economic Theory (forthcoming).

**Week Two -- Rick Riolo**

**July 31:** Modeling Complex Adaptive Systems

Bankes, Steve (1993) "Exploratory Modeling for Policy Analysis."

Operations Research, 41(3), 435-449.

Casti, John (1997)

Would-Be Worlds: How Simulation is Changing the Frontiers of Science.  
Wiley, NY. Pp 12-31.

Parunak, H. Van Dyke, Savit, Robert and Riolo, Rick. (1998)

"Agent-Based Modeling vs. Equation-Based Modeling: A Case Study and Users' Guide."  
Proc. of Workshop on Multi-agent systems and Agent-based Simulation (MABS'98), Springer.  
Online at <http://www.erim.org/~van/mabs98.pdf>.

### **August 1:** Simulating Societies

Epstein, Joshua M. and Axtell, Robert L. (1996)

Growing Artificial Societies: Social Science from the Bottom-Up.  
The MIT Press. Selected Chapters TBA.

### **August 2:** Who Interacts with Whom?

Epstein, Joshua (1997) "Zones of Cooperation."

Santa Fe Institute Working Paper SFI-97-12-094.

Michael D. Cohen, Rick L. Riolo and Robert Axelrod (1999)

"The Emergence of Social Organization in the Prisoners' Dilemma: How Context-Preservation  
and other Factors Promote Cooperation."

Santa Fe Institute Working Paper SFI-99-01-002.

### **August 3:** Emergence: Co-Adaptation and Perpetual Novelty

Arthur, Brian W. (1994)

"Inductive Reasoning and Bounded Rationality."  
Amer. Econ. Assoc. Papers and Proc. 84:406-411.

Casti, John L. (1996)

"Seeing the Light at the El Farol."  
Complexity, 1: pp7-10.

D. Challet and Y.-C. Zhang (1997)

"Emergence of Cooperation and Organization in an Evolutionary Game."  
Physica A 246, p407. Online at: <http://xxx.sissa.it/abs/adap-org/9708006>

Bruce Edmonds (1999)

"Gossip, Sexual Recombination and the El Farol Bar: Modeling the Emergence of  
Heterogeneity." J Artificial Societies and Social Simulation (JASSS) vol 2, no 3.  
<http://www.soc.surrey.ac.uk/JASSS/2/3/2.html>

Optional:

Lindgren, Kristian and Nordahl, Mats G. (1994)

"Cooperation and community Structure in Artificial Ecosystems." Artificial Life, 1, pp15-37.

#### **August 4:** Things That Go Bump in the Night: Verification, Validation and Related Issues

Axtell, Robert L. and Epstein, Joshua M. (1994)

"Agent-Based Modeling: Understanding Our Creations."

The Bulletin of the Santa Fe Institute, Winter, 1994, p28-32.

Miller, John. (1996)

"Active Nonlinear Tests (ANTs) of Complex Simulation Models."

Sante Fe Institute Working Paper 96-03-011.

Axtell, Robert, Axelrod, Robert, Epstein, Joshua, and Cohen, Michael (1995)

Aligning Simulation Models: A Case Study and Results

Santa Fe Institute Working Paper 95-07-065.

Nowak, Martin and May, R.M. (1992)

"Evolutionary games and spatial chaos."

Nature, 359, pp826-929.

Huberman, Bernardo A. and Glance, Natalie S. (1993)

"Evolutionary Games and Computer Simulations."

Proc. Natl. Acad. Sciences (USA), 90, 7716-18.

Optional:

Nowak, Martin, Bonhoeffer, S. and May, R.M. (1994)

"Spatial games and the maintenance of cooperation."

PNAS (USA), v91, pp4877-4881.

Ferrenberg, Alan M., Landau, D.P., and Wong, Y. Joanna (1992)

"Monte Carlo Simulations: Hidden Errors from 'Good' Random Number Generators."

Physical Review Letters 69(23).

See also News and Views in Nature Vol 372, 1 Dec 1994.

#### **Week Three -- Ken Kollman**

##### **August 7:** Learning, Strategies

Robert Axelrod. 1997. The Complexity of Cooperation. New York: Basic.

Introduction, Chapter 1.

John H. Miller. 1996. "The Coevolution of Automata in the Repeated Prisoner's Dilemma."

Journal of Economic Behavior and Organization 29:1.

##### **August 8:** Models of Markets

W. Brian Arthur, John H. Holland, Blake LeBaron, Richard Palmer, and Paul Taylor. 1997.

"Asset Pricing Under Endogenous Expectations in an Artificial Stock Market."

In W. Brian Arthur, Steven N. Durlauf, and David A. Lane (Eds).

The Economy as a Complex System II. Reading, Massachusetts: Addison-Wesley. Pp. 15-44.

Leigh Tesfatsion. 1997

"How Economists Can Get A Life, " in W. Brian Arthur, Steven Durlauf, and David Lange, eds.

The Economy as an Evolving Complex System II. Reading, MA: Addison-Wesley.

**August 9:** Models of Culture and Norms

Robert Axelrod. 1997. *The Complexity of Cooperation*.  
New York: Basic. Chapters 3,7.

**August 10:** Models of Domestic Political Competition

Ken Kollman, John Miller, and Scott Page. 1992.

"Adaptive Parties and Spatial Elections."

*American Political Science Review*. 86:929-937.

Ken Kollman, John Miller, and Scott Page. 1998.

"Political Parties and Electoral Landscapes."

*British Journal of Political Science*. 28:139-58.

Ken Kollman, John Miller, and Scott Page. 1997.

"Political Institutions and Sorting in a Tiebout Model."

*American Economic Review*. 87:977-92.

**August 11:** Models of International Relations

Robert Axelrod. 1997. *The Complexity of Cooperation*.

New York: Basic. Chapters 4,6.

Lars-Erik Cederman. 1997. *Emergent Actors in World Politics*.

Princeton: Princeton University Press.

Selected chapters, TBA.

