SOC 537– Modeling Emergence: Social Simulation

Mon, 5:30-6:30pm – Savery Hall, Room 137 (Lab)
Thurs, 3:30-5:20pm – Mary Gates Hall, Room 242
Office Hours- Friday 10:00am-12:00pm

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Social scientists are increasingly using computer simulation to investigate the dynamics and emergent properties of social systems. Recent projects have modeled macro-phenomena, from technology standards in industry to military alliances between nations, as well as micro-phenomena, from neighborhood segregation to conformity in peer groups. As we survey a set of case studies in social simulation, we will scrutinize the design of computational experiments. We will focus primarily on agent-based simulation, with a brief introduction to some more traditional modeling approaches (including closed-form analytic solutions and system-level simulation). Students must share an interest in abstract theory, but do not need any specialized training in mathematics or computer science for this course.

SEMINAR REQUIREMENTS

- **Read all of the assigned articles and chapters**

- **Choose one class (or more) when you will serve as "lead discussant":**
  Prepare a brief orientation for the class, including discussion questions relevant to our learning goals. You may choose to address some points from colleagues' "reflections" below.

- **Each week (when you are not lead discussant) write "reflections" on the reading:**
  Write an informal one-page single-spaced response, grappling with some model(s) in the reading. E-submit by *Noon* on *Wednesday*. You may also submit a replication or implementation (e.g. a computer program, an awfully good diagram) as your "reflections."

- **Lab meeting (required):**
  Our Monday labs include approximately one hour of structured activities (analyzing source code, replicating simulations, etc.) followed by open exploration.

- **Seminar project:**
  All students will work on seminar projects. You may write a conventional term paper, such as a synthetic/critical review essay, but I strongly encourage you to work on a project that will lead to publication. Unless you have previous simulation experience, this should probably be a replication or extension of an existing simulation model related to your interests. In any case, collaboration (with other students) or double-dipping (with other seminars) will be fine, if this contributes to a publishable product.

BOOKS

- Schelling, Thomas C. 1978. *Micromotives and Macrobehavior*.
- Axelrod, Robert. 1997. *The Complexity of Cooperation.*
- Epstein, Joshua M. and Robert Axtell. 1996. *Growing Artificial Societies.* (optional)
- Gilbert, Nigel and Klaus G. Troitzsch. 2002. *Simulation for the Social Scientist*. (optional)

EVALUATION: 65% Participation (including discussions & reflections); *35%* Final Project.

COURSE SCHEDULE

We begin by discussing a variety of motivations for simulation in the social sciences. Prognostic simulation uses data-driven ("realistic") models to forecast future trends and events. Methodologists use simulation to generate surrogate datasets for the purpose of validating or calibrating their analytical tools. Planners use simulation to aid in decision-making. Increasingly, social scientists are using simulation as a virtual laboratory for conducting "computational experiments" to investigate basic theoretical questions. We will focus on the latter use of simulation as a flexible tool for inventing and refining theory.

MARCH 28: Orientation – Meet in Savery 137

MARCH 31: Introduction

Schelling and Axelrod motivate the use of "bottom-up" (agent-based) formal models to understand the emergence of nonobvious macro-level patterns from micro-level behavioral regularities.

BACKGROUND READING (required for this first class):

Schelling, Thomas C. 1978. Chapters 1-2; pp 11-80. *Micromotives and Macrobehavior*. New York: Norton. *78 pgs*

Axelrod, Robert. 1997. "Introduction." pp. 1-8. *The Complexity of Cooperation*. Princeton, NJ: Princeton University Press.

FURTHER READING (optional)

Gilbert, G. Nigel and Klaus G. Troitzsch. 2002. Chapters 1-2, pp 1-26. *Simulation for the Social Scientist*. Philadelphia, PA: Open University Press.

APRIL 4 -- LAB 1

(can be downloaded from electronic syllabus during lab meeting)

APRIL 7: System Dynamics and Simulation as a Theory-Building Tool

Hanneman et al and Leik & Meeker demonstrate "top-down" (system-level) simulation as a method for developing and refining theory in Sociology. They differentiate the goals of computational experiments from the goals of empirical research and from alternative methods of formalization (logic and mathematics).

Hanneman, Robert A., Randall Collins, and Gabriele Mordt. 1995. "Discovering Theory Dynamics by Computer Simulation: Experiments on State Legitimacy and Imperialist Capitalism" *Sociological Methodology* 25:1-46. *66 pgs*

Leik, Robert K. and Barbara F. Meeker. 1995. "Computer Simulation for Exploring Theories: Models of Interpersonal Cooperation and Competition." *Sociological Perspectives* 38:463-482.

FURTHER READING

[Discrete system dynamics]

Mooney, Douglas and Randall Swift. 1999. "Discrete Dynamical Systems." Chapter 1, pp 9-37, in *A Course in Mathematical Modeling*. Mathematical Association of America.

Huckfeldt, R. Robert, Kohfeld, C. W., and Thomas W. Likens. 1982. *Dynamic Modeling: An Introduction.* Newbury Park, CA: Sage Publications.

[Continuous system dynamics; requires familiarity with Differential Calculus]

Mooney, Douglas and Randall Swift. 1999. "Continuous Models." Chapter 5, pp 239-305 in *A Course in Mathematical Modeling*. New York: The Mathematical Association of America.

Gintis, Herbert. 2000. "Dynamical Systems and Differential Equations." Chapter 8, pp 164-187 in *Game Theory Evolving*. Princeton, NJ: Princeton.

Turchin, Peter. 2003. "Geopolitics." Chapter 2, pp 9-28. *Historical Dynamics: Why States Rise and Fail*.

Simon, Herbert A. 1952. "A Formal Theory of Interaction in Social Groups." *American Sociological Review* 17:202-211.

APRIL 11 – LAB 2

(can be downloaded from electronic syllabus during lab meeting)

APRIL 14: Studying Cooperation and Competition with Agent-Based Simulation

Axelrod's iterated prisoner's dilemma tournament in *Evolution of Cooperation* remains one of the most influential implementations of agent-based modeling, earning thousands of citations across the natural sciences and social sciences. This week's readings – looking at extensions of Axelrod's study – illustrate two perennial debates in social simulation. Kollock's criticism of Axelrod (as well as Reeves & Pitts' criticism of Kollock) raises the question of model sensitivity and the robustness of conclusions from simulation. Bendor, Kramer, and Swistak's criticism of Kollock (as well as Binmore's criticism of Axelrod) raises questions about the strengths and limitations of simulation as an alternative to mathematical proof.

Kollock, Peter. 1993. "'An Eye for an Eye Leaves Everyone Blind': Cooperation and Accounting Systems." *American Sociological Review* 58:768-786.

69 pgs

Bendor, Jonathan, Roderick Kramer, and Piotr Swistak. 1996. "Cooperation Under Uncertainty: What is New, What is True, and What is Important." *American Sociological Review* 61:333-338.

Reeves, Edward B. and Timothy C. Pitts. 1996. "Cooperative Strategies in Low-Noise Environments." *American Sociological Review* 61:338-341.

Kollock, Peter. 1996. "The Logic and Practice of Generosity." *American Sociological Review* 61:341-346.

Axelrod, Robert. 1997. "Coping With Noise: How to Cope With Noise in the Iterated Prisoner's Dilemma." Chapter 3, pp. 30-39. *The Complexity of Cooperation*. Princeton, NJ: Princeton University Press.

Binmore, Ken. 1998. Review of Axelrod's *The Complexity of Cooperation* in the *Journal of Artificial Societies and Social Simulation* 1(1).

FURTHER READING

Axelrod, Robert. 1981. "The Emergence of Cooperation among Egoists." *American Political Science Review* 75:306-318.

Bendor, Jonathan. 1987. "In Good Times and Bad: Reciprocity in an Uncertain World." *American Journal of Political Science* 31:531-558.

Bendor, Jonathan and Piotr Swistak. 1997. "The Evolutionary Stability of Cooperation." *American Political Science Review* 91:290-307.

APRIL 18 -- LAB 3

APRIL 21: Evolutionary Dynamics I: System-Level Deterministic Models

This week we maintain our interest in the emergence of cooperation in the iterated prisoner's dilemma. However, we look at work that recasts this problem with an ecological lens. Here, we examine the "fitness" of strategies and examine their propagation over time in an ecology of other strategies. Although we may describe these abstract models as depicting births and deaths in biological generations, they may also represent proliferation of strategies through social learning. Our readings demonstrate the use of deterministic system-level models of population dynamics as alternatives to the stochastic agent-based models used by Axelrod and Kollock. This gives us an opportunity to discuss the analytical strengths of system-level models – including mathematical and graphical stability analysis – along with the simplifying assumptions that may be required to make such models tractable.

Hirshleifer, Jack and Juan Carlos Martinez Coll. 1988. "What Strategies Can Support the Evolutionary Emergence of Cooperation?" *Journal of Conflict Resolution* 32:367-398. *48 pgs*

Gilbert, G. Nigel and Klaus G. Troitzsch. 2002. "System Dynamics and World Models." Chapter 3, pp 27-43. *Simulation for the Social Scientist.*

FURTHER READING

Mark, Noah P. 2002. "Cultural Transmission, Disproportionate Prior Exposure, and the Evolution of Cooperation." *American Sociological Review* 67:323-344.

Heckathorn, Douglas D. 1996. "The Dynamics and Dilemmas of Collective Action." *American Sociological Review* 61:250-277.

Hofbauer, Josef and Karl Sigmund. 1998. Chapters 7-10, pp 67-112. *Evolutionary Games and Population Dynamics*.

Weibull, Jörgen W. 1995. "Multipopulation models" Chapter 5, pp. 163-228. *Evolutionary Game Theory*. Cambridge, MA: MIT Press.

Gintis, Herbert. 2003. "Solving the Puzzle of Prosociality." *Rationality and Society* 15:155-187.

Lotem, Arnon, Michael A. Fishman, and Lewi Stone. 2003. "From Reciprocity to Unconditional Altruism Through Signalling Benefits." *Proceedings: Biological Sciences* 270:199-205.

Bendor, Jonathan and Piotr Swistak. 2001. "The Evolution of Norms." *American Journal of Sociology* 106:1493-1545.

APRIL 25 -- LAB 4

APRIL 28: Evolutionary Dynamics II: Agent-Based Stochastic Models

The ecological models considered an important form of interdependence: The fitness of strategies depends on the distribution of other strategies in the population, and the proliferation of strategies in the population depends on their fitness. The model thus describes population trajectories given a replicator dynamic and an initial distribution of strategies. This week we consider evolutionary models, which allow for mutation (or innovation) along with selection (or social learning), and thus the emergence of strategies not present in the initial population.

70 pgs

Axelrod, Robert. 1997. "Promoting Norms: An Evolutionary Approach to Norms." Chapter 4, pp. 40-66. *The Complexity of Cooperation*. Princeton, NJ: Princeton University Press.

Macy, Michael W. and John Skvoretz. 1998. "Trust and Cooperation between Strangers." *American Sociological Review*. 63: 638-660.

Takahashi, Nobuyuki. 2000. "The Emergence of Generalized Exchange." *American Journal of Sociology* 105:1105-1034.

FURTHER READING

Allison, Paul. 1992. "The Cultural Evolution of Beneficent Norms." *Social Forces*. 71(2): 279-301.

Macy, Michael W. 1996. "Natural Selection and Social Learning in Prisoner's Dilemma: Coadaptation with Genetic Algorithms and Artificial Neural Networks." *Sociological Methods and Research* 25:103-137.

Gilbert, G. Nigel and Klaus G. Troitzsch. 2002. "Genetic Algorithms." Chapter 9, pp 218-237. *Simulation for the Social Scientist*.

Boyd, Robert, Herbert Gintis, Samuel Bowles, and Peter J. Richerson. 2003. "The Evolution of Altruistic Punishment." *Proceedings of the National Academy of Sciences* 100:3531-3535.

Nowak, Martin A. and Karl Sigmund. 1998. "Evolution of Indirect Reciprocity by Image Scoring." *Nature* 393:573.

Brandt, Hannelore and Karl Sigmund. 2005. "Indirect Reciprocity, Image Scoring, and Moral Hazard." *Proceedings of the National Academy of Sciences* 102:2666-2670.

MAY 2 -- LAB 5

MAY 5: Critical Mass and System-Level Threshold Models of Collective Behavior

Critical mass theory incorporates another form of interdependence in individuals' choices: Agents' propensity to engage in a behavior may depend on the frequency of other agents who are engaging in that behavior. We now consider a class of models that describe heterogeneous propensities to join as a distribution of individuals' thresholds, and then derive a macro-level function for the dynamic behavior of the population resulting from that distribution: The overall level of collective action (such as participation in a riot or seminar) at a given time is a function of the previous level of participation. In these models, both the interdependence of actors' choices and heterogeneity among actors can be characterized and analyzed as a function for the behavior of the aggregate.

Schelling, Thomas C. 1978. "Thermostats, Lemons, and Other Families of Models." Chapter 3, pp. 83-87, **87-110**, 115-133. *Micromotives and Macrobehavior*. *82 pgs*

Granovetter, Mark S. 1978. "Threshold Models of Collective Behavior." *American Journal of Sociology* 83:1420-1443.

Oliver, Pamela E. and Gerald Marwell. 1988. "The Paradox of Group Size in Collective Action: A Theory of Critical Mass II." *American Sociological Review* 53:1-8.

FURTHER READING

Heckathorn, Douglas D. 1993. "Collective Action and Group Heterogeneity: Voluntary Provision versus Selective Incentives." *American Sociological Review* 58:329-350.

Strang, David and Michael W Macy. 2001. "In Search of Excellence: Fads, Success Stories, and Adaptive Emulation." *American Journal of Sociology* 107:147-182.

Bicchieri, Cristina and Yoshitaka Fukui. 1999. "The Great Illusion: Ignorance, Informational Cascades, and the Persistence of Unpopular Norms." *Business Ethics Quarterly* 9:127-155.

Oliver, Pamela E. and Gerald Marwell. 2001. "Whatever Happened to Critical Mass Theory? A Retrospective and Assessment." *Sociological Theory* 19:292-311.

Edwards, Margaret, Huet, Sylvie, Goreaud, Francois, and Guillaume Deffuant. 2003. Comparing an Individual-Based Model of Behaviour Diffusion with Its Mean Field Aggregate Approximation Journal of Artificial Societies and Social Simulation 6 (4).

MAY 9 -- LAB 6

MAY 12: Structural Models of Collective Action

In this week we consider structural models, which allow for direct interdependence in agents' choices that is not reducible (for practical purposes) to a function for macro-level behavior. Agents make autonomous choices, but are influenced by the behaviors of other agents in their network neighborhood.

Marwell, Gerald, Pamela E. Oliver, and Ralph Prahl. 1988. "Social Networks and Collective Action: A Theory of the Critical Mass, III." *American Journal of Sociology* 94:502-534. *74 pgs*

Macy, Michael W. 1991. "Chains of Cooperation: Threshold Effects in Collective Action." *American Sociological Review* 55:730-747.

Kim, Hyojoung and Peter S. Bearman. 1997. "The Structure and Dynamics of Movement Participation." *American Sociological Review* 62:70-93.

FURTHER READING

Gould, Roger V. 1993. "Collective Action and Network Structure." *American Sociological Review* 58:182-196.

Chwe, Michael Suk-Young. 1999. "Structure and Strategy in Collective Action." *American Journal of Sociology* 105:128-156.)

Macy, Michael W. and Robb Willer. 2002. "From Factors to Actors: Computational Sociology and Agent-Based Modeling." *Annual Review of Sociology* 28:143-166.

Karoly, Takacs. 2001. "Structural Embeddedness and Intergroup Conflict." *Journal of Conflict Resolution* 45:743-769.

Bonacich, Phillip. 2003. "Cellular Automata for the Network Researcher." *Journal of Mathematical Sociology* 27: 263-278.

MAY 16 -- LAB 7

MAY 19: Spatial and Network Models of Convergence and Differentiation

We consider a few basic models of the proliferation of ideas, practices, or behaviors across populations. All of these models can be taken to represent dynamic networks driven by homophily, where individuals preferentially interact with others who share "culture" with them. Latané and Axelrod include an explicit representation of space (2-D cellular automata), while Mark allows the network to emerge purely as a function of cultural familiarity.

Latané, Bibb. 2000. "Pressures to Uniformity and the Evolution of Cultural Norms." pp. 189-215 in *Computational Modeling of Behavior in Organizations: The Third Scientific Discipline*, edited by D. R. Ilgen and C. L. Hulin. *76 pgs*

Axelrod, Robert. 1997. "The Dissemination of Culture: A Model With Local Convergence and Global Polarization." Chapter 7, pp. 145-174. *The Complexity of Cooperation*. Princeton, NJ: Princeton University Press.

Mark, Noah. 1998. "Beyond Individual Differences: Social Differentiation from First Principles." *American Sociological Review* 63:309-330.

FURTHER READING

Carley, Kathleen. 1991. "A Theory of Group Stability." *American Sociological Review* 56:331-54.

Epstein, Joshua M. and Robert Axtell. 1996. *Growing Artificial Societies: Social Science from the Bottom Up*. Cambridge, MA: MIT Press.

Harrison, J. Richard and Glenn R. Carroll. 1991. "Keeping the Faith: A Model of Cultural Transmission in Formal Organizations." *Administrative Science Quarterly* 36:552-582.

Macy, Michael W., James A. Kitts, Andreas Flache, and Steve Benard. 2003. "Polarization in Dynamic Networks: A Hopfield Model of Emergent Structure." Pp. 162-173 in *Dynamic Social Network Modeling and Analysis*. Washington, DC: National Academies Press.

Gilbert, G. Nigel and Klaus G. Troitzsch. 2002. "Cellular Automata." Chapter 7, pp 121-157. *Simulation for the Social Scientist*.

Lomi, Alessandro and Erik R. Larsen. 1996. "Interacting Locally and Evolving Globally: A Computational Approach to the Dynamics of Organizational Populations." *Academy of Management Journal* 39:1287-1321.

MAY 23 -- LAB 8

MAY 26: Sociometric Models of Aggregation and Fragmentation

This week we consider models of aggregation, depicting the processes by which agents align with one another (and against others) to generate coherent macrolevel patterns – such as military alliances between nations and coalitions of firms in setting technological standards. Our readings also address the challenge (shared with most sociological scholarship) of confronting models with 'real-world' data. Axelrod uses empirical observations to set parameters and initial conditions for simulation and then uses the resulting model trajectories to predict real-world events and configurations.

Axelrod, Robert. 1997. "Choosing Sides: A Landscape Theory of Aggregation." Chapter 4, pp. 69-94. *The Complexity of Cooperation*. Princeton, NJ: Princeton University Press. *48 pgs*

Axelrod, Robert. 1997. "Setting Standards: Coalition Formation in Standard-Setting Alliances." Chapter 5, pp. 95-118. *The Complexity of Cooperation*. Princeton, NJ: Princeton University Press.

FURTHER READING

Gilbert, G. Nigel and Klaus G. Troitzsch. 1999. "Neural Networks." Chapter 9, pp 195-218. *Simulation for the Social Scientist*.

Bainbridge, William Sims. 1995. "Neural Network Models of Religious Belief." *Sociological Perspectives* 38:483-496.

Orbell, John, Langche Zeng, and Matthew Mulford. 1996. "Individual Experience and the Fragmentation of Societies." *American Sociological Review* 61:1018-1032.

MAY 30 -- Open Lab Session for Group Projects

JUNE 10: To Be Determined

I will leave the last week flexible until I determine how to best advance the research programs of the seminar participants. We will spend at least part of this time focusing on seminar projects, including presentations and peer review.

The readings on the syllabus do not require a background in college mathematics. However, I strongly recommend that students have a foundation in mathematics to conduct serious research in dynamic modeling (or Statistics, for that matter). See a few recommendations below.

STEP 1: MATHEMATICAL FOUNDATIONS (Undergrad textbooks)

Calculus for Biology and Medicine (Neuhauser) **–** This is an excellent accelerated textbook, mostly applied to population dynamics. It surveys differential and integral calculus, providing an accessible introduction to differential equations, linear algebra, and dynamical systems.

Mathematics for Economics and Finance: Methods and Modeling (Anthony & Biggs) **–**This is an accelerated review textbook in mathematical foundations of Economics. It abbreviates basic principles of calculus and linear algebra, including optimization and dynamical systems. It is much less comprehensive than Neuhauser, and more appropriate for a student who only needs a refresher in calculus and/or is looking for applications in Economics.

STEP 2: MODELING SYSTEM DYNAMICS (Undergrad textbooks)

A Course in Mathematical Modeling (Mooney & Swift) **–** This is an accessible undergraduate textbook in math modeling, using mostly applications to population dynamics. It surveys differential and difference equations, including deterministic and stochastic versions. It works through examples in *Mathematica*, and also discusses fitting models to data.

A First Course in Discrete Dynamical Systems (Holmgren) **–** This is a focused theoretical treatment of deterministic/discrete-time models, with examples in *Mathematica* code.

STEP 3: EXTENSIONS

Mathematical Biology (Brauer & Castillo-Chavez) **–**Applied textbook in dynamical systems, including ecology and epidemiology, with examples in *Mathematica*. It covers some math preliminaries in an appendix, but requires a modest background in differential equations.

Matrix Population Models (Caswell) **–** General text in matrix models of population dynamics (of particular interest to demographers and ecologists), in both continuous and discrete time. It works through examples in *Matlab* and includes a review of matrix algebra.

Game Theory Evolving (Gintis) **–** This is an accelerated introduction to evolutionary game theory, and also includes a brief review of differential equations and dynamical systems theory. It's a delightful introduction, and should be read before Hofbauer & Sigmund below.

Evolutionary Games and Replicator Dynamics (Hofbauer & Sigmund) **–** This is a graduate-level text, requiring a solid background in differential equations. It discusses discrete and continuous time dynamical systems, with application to selection dynamics.