

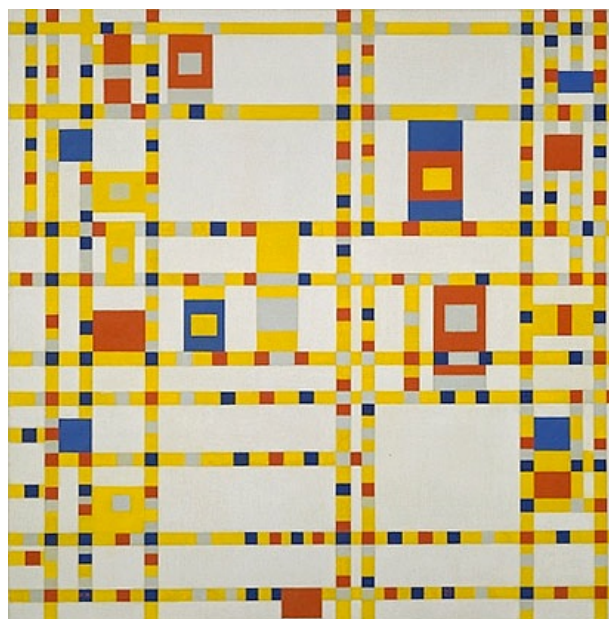
## Motivation for the Course

Interactions between people are the main subjects studied in the social sciences. Agent computing is a relatively new methodology for modeling such interactions. In *agent-based models (ABM)* a population of data structures/objects representing individuals is instantiated, given rules of interaction (object methods), and then allowed to interact. One then looks for systematic regularities to emerge at the macro-level. The shorthand for this is that aggregate structures “grow” from the bottom-up. No (explicit) equations govern the macrostructure in multi-agent modeling; if any equations are present, they are used by individual agents for decision-making. This new methodology is particularly useful for modeling (1) heterogeneous agents having (2) bounded rationality who (3) interact directly with one another (social interactions) through networks (4) out of equilibrium.

*Multi-agent systems (MAS)* are an emerging paradigm within computer science: for artificial intelligence (*AI*), distributed computation, and electronic commerce, among others. Increasingly, computer systems are being designed not from the ‘top down,’ in which each state is conceived and tested in advance, but rather from the ‘bottom up’ in which component behaviors are specified and the overall system is treated as *emergent*. New tools for the creation of agent systems in software are becoming more powerful and user-friendly.

In the field of ecology, agent models are known as *individual-based models (IBMs)* and have been used mostly to model animal groups (e.g., bird flocks) and mammal populations. At the fringes of biology so-called *artificial life (ALife)* models make use of *ABM* ideas.

In this course we will build a wide range of agent-based models of social and economic phenomena, including market processes, the evolution of social norms, customs, conventions, and institutions (e.g., residential segregation), the formation of multi-agent groups and organizations (e.g., firms), and the long-run evolution of whole societies. The methodological issues to be examined across models include the role of randomness (e.g., random number generation, variance reduction techniques), path-dependence (e.g., information content of single realizations), emergence (including self-organization and spontaneous order), the production and control of computational artifacts, estimation, verification and validation, and graphical representation/visualization of *ABM* output. This is a project-oriented course in which students will learn how to create *ABMs* in software.



**Rob Axtell** Department of Computational and Data Sciences  
 College of Science  
 375 Research Hall  
 Fairfax, VA 22030  
 (703)-993-9302  
[rax222@gmu.edu](mailto:rax222@gmu.edu)

External Professor  
 Santa Fe Institute  
 1399 Hyde Park Road  
 Santa Fe, NM 87501

**Meets** Wednesdays, 7:20-10:00 PM

223 Innovation Hall

**Website** <https://www.dropbox.com/home/CSS%20610-ECON%20895%20Spring%202021>

**Office hours** I have an ‘open door’ policy – if my door is open you are welcome to stop in. I will be on campus each Wednesday this semester, assuming satisfactory completion of COVID-19 protocols. Karen Underwood knows my schedule. The best time to see me is in the afternoon.

## Texts

There is no satisfactory graduate-level textbook for this material, thus we will work from several books. Some sections from my textbook manuscript (*Foundations of Agent Computing*) will be distributed via the website as reading assignments some weeks. We will read Schelling (1978) and go through most of *Growing Artificial Societies* (weeks 1, 2, 9 and 10). If you have never done any agent modeling then Wilensky and Rand will be useful. It has good discussions and working code but is not very technical. It is based on NetLogo, which is fine to use for the homework assignments and the term project. If you are not using NetLogo there is no need to buy their book.

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

*Micromotives and Macrobehavior*. Thomas C. Schelling, Norton (N.Y., N.Y., 1978). Classical pre-ABM treatment of a variety of problems in which there is a clear distinction between the agent and social levels. This book has proven to be very fertile for research topics that have subsequently been implemented with agents.

*An Introduction to Agent-Based Modeling: Modeling Natural, Social, and Engineered Complex Systems with NetLogo*, Uri Wilensky and William Rand, MIT Press (Cambridge, Mass., 2015). NetLogo-based introduction to agent computing; somewhat introductory, provides code, while giving only heuristic treatment of many topics we will go into in detail. *Optional*: recommended for those using NetLogo.

Beyond these, the following volumes may prove useful, depending on your background/field/discipline:

*Discrete-Event Simulation: A First Course*, Lawrence Leemis and Steve Park. Several editions available; there is a link to an e-version of this on the course website. Covers classical material on conventional simulation methodology, useful primarily if you have never built a simulation model before.

*Agent-Based Models of Geographical Systems*. Alison J. Heppenstall, Andrew T. Crooks, Linda M. See and Michael Batty, eds. Springer (Netherlands, 2012). Good reference for geographers. More closely related to CSS 645: Spatial ABMs, but the first dozen or so chapters are a good introduction to agent-based modeling.

*Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations*. Yoav Shoham and Kevin Leyton-Brown, Cambridge University Press (N.Y., 2008). Textbook by computer scientists, focused on bringing game theoretic ideas to MAS. Too formal for our purposes and misses much of the point of ABMs for the social sciences, e.g., heterogeneous agents, bounded rationality, networks. An electronic version of the book is available at [www.masfoundations.org](http://www.masfoundations.org). It is a good reference for computer scientists and game theorists interested in computational/algorithmic issues.

*Networks, Crowds, and Markets*. David Easley and Jon Kleinberg. Cambridge U. Press (N.Y., N.Y., 2011). Recent interdisciplinary approach to the disparate social phenomena in the title; surprisingly little computing.

## Prerequisites

Students should have good working knowledge of at least one programming language (e.g., C/C++, Java, Python, Lisp/Scheme, Pascal/Delphi, BASIC, FORTRAN, Ruby, Swift,...), preferably one having some object orientation (agents are naturally coded as objects) but this is not essential. Solid knowledge of a mathematical or statistics package (e.g., MatLab, Mathematica, R, Stata, Gauss, possibly Excel) can substitute, as would learning a high-level agent programming system (e.g., NetLogo, AnyLogic, or AgentSheets). Less common languages (e.g., Clojure, Erlang, Go, Haskell, Julia, Rust, Scala) are also perfectly satisfactory but I won't be able to provide much feedback if your code doesn't work. CSS 600 and 605 are recommended as prerequisites but not strictly required. Also helpful is some background in basic probability and statistics, as well as introductory economics or game theory. I am not a stickler for prerequisites, however, and enthusiasm can substitute for preparation.

For those working on Apple machines the Xcode development environment is perfectly good for writing code in Objective C, C/C++ and Swift. Microsoft Studio works well for those with PCs. Eclipse and NetBeans have long been solid cross-platform integrated development environments (IDEs) supporting multiple languages. Specialized compilers are available that integrate with various IDEs (e.g., Intel's Parallel Studio) and are often available for free for educational use.

## Pedagogical Goals

We will be building representations of individual people in software, giving them plausible or empirically-grounded motivations and behavior, things to trade, data-gathering abilities, and cognitive capabilities. We will then let these software objects interact directly with one another, i.e., in social environments, and study what happens. When we build such agent models in the context of known models we are, in essence, ‘agentizing’ standard models. When we build agent models without conventional counterparts then we are relaxing more than one of the traditional assumptions – e.g., rationality, equilibrium – at once. Both kinds of models can yield interesting results and we will study each kind this semester. It is my belief that the agent modeling approach is sufficiently new and capable that each student should be able to apply it to some domain and make a significant contribution *this semester*.

## Workload, Assignments and Grading

*Homework:* All homework assignments consist of both a computational part and an interpretative discussion. Please submit PDFs online in advance of class. The code is to be submitted to your online folder and must include the following as comments at the beginning: (1) your name, (2) hardware platform employed, (3) the operating system used, (4) the software development environment (including version information), and (5) any special information needed in order to satisfactorily compile and run it, e.g. ‘Must open an X window under Linux.’ Additionally I expect extensive comments throughout your code – 50% of keystrokes as comments is a good objective, although I won’t be counting precisely. Failure to meet these requirements will reduce your grade. **8 homework assignments @ 5 pts each = 40 pts max**, graded as follows: 1 pt for on-time submission, 1 pt if the code compiles and runs and does something relevant to the problem, 1 pt for sufficient code comments (half of symbols), 1 pt for coherent write-up, 1 pt for the right answer; each week a homework assignment is late costs 1 pt; some students will be asked to present their homework to class, let me know if you want to present.

*Presentation of an agent-based model:* The agent field has grown to such an extent that models exist in essentially every one of the social sciences. Pick one such model, read the corresponding paper, run the model (if you can), and then do a ten minute presentation in class, preferably with a demo. The presentation will **count for up to 10 pts of your grade**, for both slides (5 pts) and competent manipulation of the model illustrating the main results (5 pts). Afterwards, deposit the slides online.

*Book review:* Suggestions for books to review are listed below in the weekly schedule. If there is a book you really want to review that is not mentioned below, you are welcome to propose it to me along with a presentation date. Before your presentation either email your review to everyone or add it to the website. Each book review should be written in a format comparable to a published book review in a professional journal, conveying the key messages of the book and providing appropriate critical analysis. If you are unfamiliar with book reviews, consult journals (e.g., the *Journal of Artificial Societies and Social Simulation*). In general, a review should have an introductory paragraph with an overall assessment, followed by a very brief summary of the book’s key arguments, an evaluation of the book’s strength and weaknesses, placement of the book within the larger literature, and summary comments. Your review should be 2-3 pages long with the in-class presentation lasting about ten minutes. It will be **worth 10 pts**, graded based on presentation (5 pts) and written review (5 pts).

*Team project:* Team sizes of 2-3 are recommended. Larger teams will be permitted for ambitious projects if a clear role for each participant is indicated. Each team member will receive the same grade on the project unless there is compelling reason to do otherwise. Singleton ‘teams’ are permitted. A sample project paper will be distributed in April. Projects that have been worked on in previous semesters can be extended in this class if you furnish me the original work so that the exact nature of the extension(s) is clear. Projects that you are working on in other classes *cannot* be used for this class without my consent. Submit a 20 pp research paper in the style of a scientific journal article; counts for **40 pts of final grade**: form team (2 pts), pick topic (3 pts), write an early draft (5 pts), make in-class presentation (10 pts), final paper (15 pts), and code (5 pts).

*Grading:* 40 pts + 10 pts + 10 pts + 40 pts = 100 pts

**Typical Class**

7:20-9:00	Lecture, model demonstrations, and discussion
9:00-9:05	Break
9:05-9:20	Student presentation of previous HW assignment
9:20-9:40	Student book review or model demonstration
9:40-10:00	Student book review of model demonstration
10:00 PM	Brief discussion of next week's assignment(s)

With ~15+ students, ~2 student presentations/week

**SPIRIT of the Course**

Agent-based computational modeling is a new field within the social sciences. In many (most?) respects, the full scale and scope of the field is still emerging. Therefore, this course is designed to both codify what we presently know and give direction for future development, while identifying important lacuna.

The material to be covered in the course falls broadly into two main categories: methodology and applications. In the first group are topics having to do with the structure and function of successful agent-based computational models. In the second are areas of the social sciences where this approach has been fruitfully employed.

Everyone in the class is a graduate student (aside from the occasional precocious high schooler from TJ!) and therefore each of you is transitioning from being a 'student' to becoming an 'expert'. Specifically, Certificate and Master's degree students are expected to become capable of leveraging their knowledge of particular academic domains in order to build novel agent models in software. Ph.D. students and post-docs, in the process of gaining a distinctive 'voice' as a scholar, are further expected to develop a broad knowledge of agent models in their field.

**Departmental Compute Resources**

In the Computational Social Science Program/Center for Social Complexity there exist the following hardware resources and operating systems:

1. Ganesha: 2 x 8 core CPUs (32 logical cores), 256GB RAM, NVIDIA GTX 680, 2 x 30" displays, Centex Linux
2. Brahma: 2 x 6 core CPUs (hyperthreaded, 24 logical cores) 64 GB RAM, 3 x 30" displays, MacOS
3. Vishnu: 4 core CPU (hyperthreaded, 8 logical cores), 32 GB RAM, GTX 280/680, 30" display, MacOS
4. Oxford: 2 x 4 core CPUs (hyperthreaded, 16 logical cores), 128 GB, ATI Radeon 5770, 30" display, MacOS
5. Cambridge: 2 x 4 core CPUs (hyperthreaded, 16 logical cores), 64 GB RAM, 30" display, MacOS
6. Dusk: 2 x 4 core CPUs, 32 GB RAM, 30" display, MacOS
7. Dawn: 4 core CPU, 16 GB RAM, 24" display, MacOS

**Weekly Schedule and Assignments**

**Week 1** (January 27<sup>th</sup>): **Introduction** to the course – background material on cellular automata, distributed AI and multi-agent systems; autonomous agents; complex adaptive systems; object-oriented programming;

**Read:** Schelling (1978), chapters 1 and 2, Simon (1996) chapter 7, Axtell (2000), Rauch (2002) and Epstein and Axtell (1996) chapter 1;

**Deeper reading:** Wilensky and Rand (2015), chapters 0, 1 and appendix; graduate students in the social sciences should read Axelrod (2003); economists, read Tesfatsion (1997) and Axtell (2007); natural scientists should read Laughlin and Pines (2000) who argue that 21<sup>st</sup> C science will be all about *emergence*;

**Demo:** Quick passes through various agent models;

**Homework #0:** Sign-up for book to review or model to demo by February 3<sup>rd</sup>;

**Homework #1:** Basic computing skills, due February 3<sup>rd</sup>.

**Week 2** (February 3<sup>rd</sup>): Application of agents to **economics**: in-class market experiment and demonstration of an artificial computational market reproducing simple supply and demand concepts; ‘invisible hand’ and the philosophy of emergence; sources of randomness in agent models and the importance of making multiple realizations; path-dependence; *agentization*;

Read: Gode and Sunder (1993); Wilensky and Rand (2015), chapters 4 and 5 if using Net Logo; economists read Epstein and Axtell (1996) chapter 4;

Deeper reading: Graduate students in economics should read Plott (1986), Gode and Sunder (1997), and Axtell (2005) and skim Cliff and Bruten (1997; 1997); on the mathematical expediency of equilibrium assumptions see Kaldor (1972; 1985); Anderson, Arrow and Pines (1988) is a somewhat dated overview of complexity economics; on adaptive vs. rational foundations for economic science, Leijonhufvud (1999); importance of heterogeneity, Kirman (1992); rationality as an ‘ideal type’ (Simon 1955; 1956; 1978); role of direct agent-agent interactions, Kirman (1997); Kohn (2004) was the motivation for Axtell (2007) and most of the papers in that issue of the *Review of Austrian Economics*; a non agent take on economic complexity is due to Krugman (1996);

Demo: ZI agents;

Homework #2: ZI traders, due February 10<sup>th</sup>;

Books/suites of papers to review: Friedman and Rust (1994) and Clearwater (1996); anyone interested in financial economics is invited to review the papers of Arthur *et al.* (1997), Lux (1998; 1999) and LeBaron (2000; 2001; 2001; 2001; 2001; 2002) as a group, the papers of Farmer and co-authors as a group (1999; 2005; 2009; Forthcoming), or one of the following books: Mandelbrot (1997), Abu-Mostafa *et al.* (2000), Levy *et al.* (2000), Sornette (2003), Johnson *et al.* (2003), Beinhocker (2005) or Taleb (2007).

**Week 3** (February 10<sup>th</sup>): Rational choice **game theory**: two person, two strategy games of full information, normal and extensive forms, pure and mixed strategies, solution concepts, repeated games, the ‘folk’ theorem; games played in populations; evolutionary game theory; implementation using agents; social norms and conventions;

Read: Schelling (1978) chapters 6 and 7; excerpt on Axelrod’s prisoner’s dilemma tournament (Axelrod 1984);

Deeper reading: Wilensky and Rand (2015), chapter 3, pp 141-151; many good texts on this subject exist, at the upper undergraduate level (e.g., Binmore 1992; 2007) through advanced graduate level (e.g., Fudenberg and Tirole 1991; Osborne and Rubinstein 1994); computer science students should read Shoham and Leyton-Brown (2009), chapters 3 and 4; students using evolutionary game in their research should familiarize themselves with Friedman (1991) and Gintis (2000);

Demo: games of coordination and assurance; the ‘El Farol’ (bar) problem (Arthur 1994);

Homework #3: Games played in a population of agents, due February 17<sup>th</sup>;

Books to review: Luce and Raiffa (1957), Dresher (1961), Axelrod (1984), Rosenschein and Zlotkin (1994), Green and Shapiro (1994), Rubinstein (1998), Fudenberg and Levine (1998), and Gintis (2000).

**Week 4** (February 17<sup>th</sup>): **Agent activation** regimes (aka scheduling) including serial vs. parallel activation, deterministic vs. random activation, and synchronous vs asynchronous activation; single vs multi-threading; random number generation and avoiding the production of computational artifacts;

Read: Nowak and May (1992), Huberman and Glance (1993) and Axtell (2001);

Deeper reading: There is a large literature in numerical analysis that differentiates synchronous, partially asynchronous and fully asynchronous parallel updating (e.g., Bertsekas and Tsitsiklis 1993) and I have tried to interpret these results for agents (Axtell 2003); furthermore, there is a growing literature in so-called *interacting particle systems* and game theory that attempts to discriminate between those models for which the agent activation order matters from those in which it does not (e.g., Gacs 1997; Chen and Micali 2013);

Demo: Java version of Huberman and Glance (code by Steve Scott);

Homework #4: Activation effects, due February 23<sup>rd</sup>;

Books to review: Resnick (1994), Casti (1994; 1997), Holland (1995; 1998; 2012) and Miller and Page (2007).

- Week 5** (February 23<sup>rd</sup>): Behavioral, computational and ‘low rationality’ **game theory**: games of incomplete information, ‘fictitious play,’ ‘best reply’ strategies and adaptive dynamics; learning; behavioral game theory;  
Read: Schelling (1978), chapter 3; Axtell, Epstein and Young (2001);  
Deeper reading: Economics students should familiarize themselves with Camerer (2003); computational science students should read Shoham and Layton-Brown (2009), chapters 5, 6 and 8 along with section 7.7;  
Demo: Spontaneous emergence of classes in a bargaining model (Axtell, Epstein and Young 2001);  
Homework #5: Perturbed games, including noisy games, due March 3<sup>rd</sup>;  
Books to review: Bicchieri *et al.* (1993; 2006), Weibull (1997), Young (1998), Parsons and Gmytrasiewicz (2002), Bowles (2003), Camerer (2003), Gintis *et al.* (2004), Skyrms (2004), and Vega-Redondo (1996).
- Week 6** (March 3<sup>rd</sup>): Social network theory and practice for agent models; regular and random graphs, including ‘small world,’ Erdős-Renyi and ‘scale free’ (power law) graphs, along with strategies for making agents mobile in networks; digression on power laws and social complexity;  
Read: Watts and Strogatz (1998), Barabasi and Albert (1999), and Axtell and Epstein (1999);  
Deeper reading: Students wishing to become expert in this area should study Barabasi and co-authors (1999; 2002), Watts (1999; 2002), and Newman and colleagues (2001; 2002; 2006); economists should become familiar with Bala and Goyal (2000), Morris (2000), Wilhite (2001), Vega-Redondo (2007), Jackson (2008), and Acemoglu *et al.* (2012); those interested in disease processes on networks should study Morris (1997), Liljeros *et al.* (2001), Pastor-Satorras and Vespignani (2001), Deszo and Barabasi (2002), and Eubank *et al.* (2004); diffusion on networks is relevant to marketing and opinion dynamics and good work includes Valente (1996) and Young (1999); Wilensky and Rand (2015), chapter 6;  
Demo: Social norms of retirement (Axtell and Epstein 1999);  
Homework #6: Game on graphs, due March 10<sup>th</sup>;  
Books to review: Scott (1991), Wasserman and Faust (1994), Valente (1995), Watts (1999), Barabasi (2002), Goyal (2007), Dorogovtsey and Mendes (2003), Vega-Redondo (2007), Jackson (2008), Barrat *et al.* (2010), Easley and Kleinberg (2010), and Newman (2010).
- Week 7** (March 10<sup>th</sup>): Application of agents to **sociology**: neighborhood formation via sorting and Schelling segregation; cultural tags; programming mobile agents on landscapes; crime as a social and spatial process;  
Read: Schelling (1978) chapter 4 and 5, Macy and Willer (2002), Hegemann *et al.* (2011);  
Deeper reading: Schelling (1971); Wilensky and Rand (2005), chapter 3, pp 128-141; Hedstrom’s (2005) book is important for sociology students interested in agents; extensions of Schelling’s basic models include Zhang (2001; 2004; 2004; 2011), Vinkovic and Kirman (2006), Benard and Willer (2007), Panes and Vriend (2007), Dall’Asta *et al.* (2008), and Gerhold *et al.* (2008); Glaeser, Sacerdote and Scheinkman (1996) study models capable of producing excess variance of violent crime across cities, as is found empirically;  
Demo: Schelling segregation;  
Homework #7: Variations on Schelling segregation, due March 17<sup>th</sup>;  
Project week #0: Form project teams, select project, and email me your team and tentative subject by March 17<sup>th</sup>;  
Books to review: Gilbert and Conte (1995), Troitzsch *et al.* (1996), Gaylord and D’Andria (1998), Gilbert and Troitzsch (1999), and Hedstrom (2005).
- Week 8** (March 17<sup>th</sup>): Agent-based software frameworks, focusing on NetLogo and MASON/RePast/FLAME;  
Read: Luke *et al.* (2005), North *et al.* (2006); skim Scott and Koehler (on website) and Scott (handout/website);  
Deeper reading: Ascape is an older framework (Parker 2001; Centola 2002);  
Demo: Various NetLogo and MASON models;  
Project week #1: Each project team submit 1 page description of what you will work on, due March 24<sup>th</sup>;  
Books to review: O’Hare and Jennings (1996), Wooldridge and Jennings (1995) + Wooldridge and Mueller (1996), Wooldridge (2002), and North and Macal (2007).

- Week 9** (March 24<sup>th</sup>): Application of agents to **human ecology** (demography, environment, urban systems, ecology); brief digression on the relation of agent systems to evolutionary computation;  
**Read:** Epstein and Axtell (1996) chapters 2-3; economists read chapter 4 if you have not already;  
**Deeper reading:** Wilensky and Rand (2015), chapter 2; Lawson and Park (2000) on the agent activation scheme in Sugarscape; Elsaway *et al.* (2020) advocate for *ABMs* in coupled socio-environmental systems; Parker *et al.* (2003) review *ABMs* in land use and cover change (*LUCC*); Axtell *et al.* (2002) argue for *ABMs* in *industrial ecology*;  
**Demo:** Sugarscape;  
**Project week #2:** Get going!  
**Books to review:** Jacobs (1970; 1992), Ostrom (1990; 1994), Kohler (2001), Gimblett (2002), Grimm and Railsback (2005), Batty (2005), Heppenstall, Crooks, See and Batty (2012).
- Week 10** (March 31<sup>st</sup>): Application of agents to **disease processes** generally and **epidemiology/epidemics/pandemics**; initial discussion of empirical calibration of agent models;  
**Read:** Ferguson *et al.* (2020); Epstein and Axtell (1996), chapter 5;  
**Deeper reading:** Halloran *et al.* (2008), Ferguson *et al.* (2006), Gemann *et al.* (2006), Longini *et al.* (2005), Ferguson *et al.* (2003);  
**Demo:** Various NetLogo models;  
**Project week #3:** Some code written or at least sketched, some literature review done;  
**Books to review:** McNeill (1976), Anderson and May (1991), Daley and Gani (1999), Vynnycky and White (2010), Bjornstad (2018).
- Week 11** (April 7<sup>th</sup>): Application of agents to **anthropology and archaeology**; further discussion of empirical ABMs  
**Read:** Axtell *et al.* (2002), Diamond (2002) and Kohler *et al.* (2005);  
**Deeper reading:** Dean *et al.* (2000), Kohler *et al.* (1999), Reynolds (1999), Kuznar (2006);  
**Demo:** Artificial Anasazi model;  
**Project week #4:** Assemble a ms (3-5 pages) of text, code and any preliminary output, due April 14<sup>th</sup>;  
**Books to review:** Taintner (1988), Gilbert and Doran (1994), Kohler and Gumerman (2000), Diamond (2004), Beekman and Baden (2005), Schwartz and Nichols (2006) and McAnany and Yoffe (2010).
- Week 12** (April 14<sup>th</sup>): Application of agents to **organization science**; group formation via team production and multi-agent firms; further digression on power laws; more discussion of empirical calibration of agent models;  
**Read:** Axtell (2016) and Axtell (2018);  
**Deeper reading:** Firm sizes (Simon 1955; Simon and Bonini 1958; Axtell 2001; de Wit 2005), ages (Coad 2010), growth (Ijiri and Simon 1964; 1967; Evans 1987; 1987; Hall 1987; Sutton 1997; Bottazzi and Secchi 2006; Perline, Axtell and Teitelbaum 2006; Coad 2008), and dynamics (Kwasnicki 1998; Axtell 2002; Luttmmer 2011);  
**Demo:** FIRMS model;  
**Project week #5:** Keep moving!  
**Books to review:** Cyert and March (1963), Steindl (1965), Ijiri and Simon (1977), Carley and Prietula (1994), Prietula *et al.* (1998), Lomi and Larsen (2001), Ormerod (2005) and Saichev *et al.* (2010).
- Week 13** (April 21<sup>st</sup>): **Identification** (calibration and estimation) of agent models; ‘docking’ models; design of computational experiments; significance testing model output; verification and validation of agent models;  
**Read:** Axtell and Epstein (1994), Axtell *et al.* (1996) and Grimm *et al.* (2005);  
**Deeper reading:** Wilensky and Rand (2015), chapter 7; estimation by simulation is standard practice in econometrics (cf. McFadden and Ruud 1994); identifying agent models is made trickier due to their multi-level character, e.g., Alfarano *et al.* (forthcoming).  
**Demo:** Axelrod culture model in Sugarscape;  
**Project week #6:** Draft ms: describe problem (2 pp), literature (2 pp), your model (2 pp) w/placeholders for results;  
**Books/suites of papers to review:** Box and Draper (1998), Box, Hunter and Hunter (2005), and Mitzenmacher (2004) + Perline (2005) + Clauset *et al.* (2009).

**Week 14** (April 28<sup>th</sup>): Application of agents to **politics**; Axelrod culture model; models of group identity, political party formation, and civil conflict; country-specific models;

Read: Axelrod (1997), Castellano *et al.* (2000) and Lustick *et al.* (2004);

Deeper reading: Cederman (2001) on international relations; Epstein on civil conflict; Cioffi on the evolution of political complexity; computer scientists should read Shoham and Layton-Brown (2009) chapters 9 and 10;

Demo: Axelrod culture model;

Project week #7: Draw conclusions and work on your presentation;

Books to review: Axelrod (1997), Cederman (1997), the suite of papers by Kollman, Miller and Page (1992; 1997; 1997), and de Marchi (2005).

**Week 15** (May 5<sup>th</sup>): Project presentations; we will use an online poll to sign up for presentation slots.

### Summary of Homework assignments

Homework #0: Propose book to review or model to demo by February 3<sup>rd</sup>;

Homework #1: Basic computing skills, due February 3<sup>rd</sup>.

Homework #2: ZI traders, due February 10<sup>th</sup>;

Homework #3: Games played in a population of agents, due February 17<sup>th</sup>;

Homework #4: Activation effects, due February 24<sup>th</sup>;

Homework #5: Perturbed games, including noisy games, due March 3<sup>rd</sup>;

Homework #6: Game on graphs, due March 10<sup>th</sup>;

Homework #7: Schelling variations, due March 17<sup>th</sup>;

### Suggestions for Projects and Models (those with \* are feasible class demos)

Background for the course:

0. Make 'Artificial Social Life' video Part II (Ch III), Part III (Ch IV), Part IV (Ch V) or Part V (Ch VI).

Anthropology and Archaeology (5)

1. Collapse or rebirth of a small-scale society (Diamond 2002; 2004).
2. Can a model inform the debate between the theorists of collapse (Tainter 1988; Diamond 2004) and the nay-sayers (Schwartz and Nichols 2006; McAnany and Yoffee 2010)?
3. Societal transition from competing tribes to chiefdoms and simple states (Griffin and Stanish 2007).
4. The Iroquois (Haudenosaunee) League/Confederacy was governed by a Grand Council which the ethnographer Morgan mistakenly interpreted as a central government (Morgan 1851). B. Franklin's early attempt to unite the 13 British colonies in his 1754 Albany Plan for Union may have derived from the workings of the League and gave rise to his well-known admonition to the Constitutional Congress that if the Iroquois could form a union then American colonists could too. Build a model of Iroquois governance.
5. Modify the rules in the Anasazi model to improve the spatial distribution of population (Axtell *et al.* 2002).

Biology and Artificial Life (15)

6. \*Bird flocking: fluid dynamics and bioenergetics (Reynolds 1987; Smale 2007).
7. \*Starling flocks are famously complex and have been modeled in detail (Hemelrijk and Hildenbrandt 2011);
8. \*Ant colony dynamics (Bonabeau, Dorigo and Theraulaz 1999; Couzin and Franks 2003).
9. \*Predator avoidance by fish schools (Couzin 2007).
10. \*Emergence of leaders in animal groups (Couzin *et al.* 2005).
11. Disease agent propagation in 3D tissue (cellular automata) model; many models of this in biology.
12. Reimplement Nowak and May (1992).
13. Reimplement Fontana's 'algorithmic chemistry' (Langton *et al.* 1991).
14. \*Build the 'Game of Life' (e.g., Gardner 1970) using RePast or MASON or analyze the NetLogo version.
15. Reimplement 'self-reproducing automata' of von Neumann and Burks (1966) using agent technology.
16. Comb *Artificial Life* for social science models and reimplement one of them, e.g., Padgett (1997).



17. Locust swarms and the recent efforts to genetically modify certain species (Buhl et al. 2006).
18. Fish school size distributions are heavy-tailed (Bonabeau, Dorigo and Theraulaz 1999). Model this.
19. \*The mathematical equations of fishery dynamics typically abstract from spatial processes, minor species, even fishermen as individuals, in favor of a ‘fishing fleet’ as harvester model (Clark 2005). Agent models have begun to appear, including several in MASON. Survey these and extend them in some direction.
20. \*Marine protected areas (MPA) are a common fisheries management policy. ‘Fishing the line’ is the phenomenon of fishers operating their boats right along the MPA boundary. Model this with agents and focus on why this is very hard to model mathematically (Scott 2016).

## Demography (5)

21. Build a model of local social norms of fertility (Kohler 2001).
22. Compare the Leslie matrix (well-mixed) version of demography with spatially or network-based view.
23. Take the ‘life tables’ view of demography and agentize it, then critique the extreme methodologically-individualist approach to agent lifetimes and enrich your agent model to include such factors as serial correlation in spousal death probabilities and local fertility norms (see #21 above).
24. Emigration and immigration between two countries having disparate wage levels; Ben Clemens of Census has worked on this, see me for his draft paper(s).
25. According to a famous essay by Amartya Sen (1990), 100 million women are ‘missing’. Model this!

## Economics (25)

26. Emergence of ‘middlemen’ in 2 good economy (Feldman 1973).
27. Extend my model of  $k$ -lateral exchange (Axtell 2005) to CES preferences or parallel execution.
28. Take my model of firm dynamics and study the lifecycle of firms (Nelson 2006).
29. Study the network of job-to-job changing in my model of firm dynamics, the ‘labor flow network’ (Guerrero and Axtell 2013).
30. Friedman famously argued (1953) that inefficient firms would go extinct in competition with efficient firms. Later this was shown to be naive by various authors, including Blume and Easley (2002). Build a model to inform this debate.
31. \*Redo Padget’s (1997) model of goods production via complementary skills.
32. \*Money (Menger 1892; Kiyotaki and Wright 1989; Marimon, McGrattan and Sargent 1990; Howitt and Clower 2000).
33. \*Modify the model of local store pricing in Howitt and Clower (2000) and study the effect on the emergence of money.
34. Create a model of monetary transmission into the real economy and investigate Cantillon effects (Veetil 2016).
35. Study inflation using agents (see me for a recent working paper by Howitt).
36. \*Circulation of bank-issued currency (e.g., 18th C Scotland; see McBride (2010)).
37. Agentize Akerlof’s famous ‘market for lemons’ (Akerlof 1970) extending (Tilles et al. 2011).
38. Reimplement Gintis’s macroeconomic model having explicit microeconomic foundations (2007).
39. Build a simple Keynesian macroeconomic model (Bruun 1999).
40. Consumption theory is normally rendered in terms of a single agent. Palmer (2015) has recently written a dissertation agonizing the theory of consumption. Review his dissertation and extend his model.
41. Review and extend recent ideas on heterogeneous agent macroeconomics (Guvenen 2011).
42. ‘Agentize’ the ‘dynamic stochastic general equilibrium’ (DSGE) macro model (Colander et al. 2008).
43. Extend the Parker and Filatova models of housing markets (2007; 2009; 2009).
44. \*Extend the Resources for the Future model of housing markets (Magliocca et al. 2011).
45. \*Model a housing market bubble (Geanakoplos et al. 2012).
46. \*International trade with country-specific labor and mobile capital; see Guden (2004) dissertation.
47. Agentize the Melitz (2003) model of international trade, grounded in firm behavior.

48. Build an agent model of open source software development, e.g., extending Madey (2008).
49. \*Create a model in which technology evolves (see me for references, prototypes).
50. Build a model of market-based regulation in the context of heterogeneous firms.

## Finance (10)

51. Re-implement Lux's (1998) financial market; study how results depend on the number of agents.
52. Convert one of LeBaron's MatLab-based financial market models into MASON or some other framework.
53. Redo the Cont (2006) model which reproduces many of the statistics of real financial markets.
54. Model order book flows in a financial market (e.g., Farmer, Patelli and Zovko 2005).
55. Model the way the Treasury Department auctions U.S. bonds (Koesrindartoto 2004).
56. According to Kindelberger (2005) there are just a few 'types' of financial crises; model one of these.
57. Most financial crises are, before the onset of crisis, believed to be different from previous crises (Reinhart and Rogoff 2009); build a model in which people who have experienced crises in immune to them but people who have not are vulnerable.
58. Build a model of the Panic of 1907 JP Morgan intervenes to 'save' the financial system and bank clearinghouses are born (Bruner and Carr 2007).
59. Create a simple agent model of the Great Depression and compare it to Bernanke and Gertler (2004).
60. \*The CRISIS project is an EU funded effort on-going at several European universities. Take some of their models and experiment with them (Aymanns and Farmer 2015; Aymanns et al. 2016).

## Environmental Science and Policy including Energy and Sustainability issues (20)

61. \*Take a CA-type forest fire model with fire breaks, other policies (Doyle and Carlson 2000) and agentize it.
62. \*Build a model of the 'tragedy of the commons' type dilemmas (Ostrom 1990); see me for a prototype.
63. Agentize the Hahn and Axtell (1995) model in which there is uncertainty in compliance and enforcement.
64. Build a model of cap-and-trade policies and compare with Pigouvian taxes, e.g., agentize Weitzman (1974).
65. Build a coalition formation model for climate change, starting from the work of Scott Barrett (1994).
66. Compare auction mechanisms when goods can be resold (Hailu and Schilizzi 2005).
67. \*International environmental negotiations are often spear-headed by parties with large stakes in the outcomes, coalitions led by 'norm entrepreneurs'. A recent CSS Ph.D. dissertation by Rouleau develops this idea. Read his work and extend his model (you will need to ask him for his code).
68. Agent models are used in the field of *industrial ecology*. Survey this area (Andrews 2001; Axtell, Andrews and Small 2002) and build something relevant.
69. \*Individual-based models (IBMs) are common in ecology (Grimm and Railsback 2005). Go to a relevant journal (e.g., *Ecological Modeling*), find a policy relevant IBM and extend it.
70. ABMs are being increasingly used in climate change research. Survey the literature, assess the various uses (e.g., sea level rise, energy infrastructure) and extend one of them (e.g., Farmer et al. 2015).
71. \*Integrated assessment models are historically *not* agent-based. Survey these and focus on the few attempts to add agency to them. Try to get your hands on one of these and agentize it.
72. \*Solar photovoltaic technology is in a period of rapid evolution. What can agent modeling teach us about it? (There are a variety of examples in recent years from the Department of Energy.)
73. Wearable technologies are limited by energy sources. Recent technology promises use of body heat to fuel such devices. Build agent models of people wearing devices that interact with one another. How might these be used for detecting environmental pathogens or in other ways?
74. For many technologies, including some energy technologies, unit costs fall with increasing production, a phenomenon known as Wright's law or industrial 'experience curves' (McNerney, Farmer and Trancik 2011). Build agent models of this phenomena.
75. Fisheries regulations, like individual traceable quotas (ITQs) and effort limitations (TAC), can be modeled at either the fleet or individual vessel level (Gordon 1954; Rosser 2002). Build an ABM that compares these.
76. Scott (2016) has modeled the Chesapeake Bay. Familiarize yourself with his work and extend it.

77. A recent paper in this broad area mentions 8 grand challenges (Elsaway et al. 2020). Build a related model.
78. Build an ABM of forestry management (e.g., Bone and Dragicevic 2010; e.g., Spies et al. 2017).
79. NEON is a new NSF-funded data acquisition technology for ecosystems. How might it be relevant to ABMs.
80. ABMs are increasingly used in agricultural research. Review and extend some of this work (Bert et al. 2011).

#### Game Theory (10)

81. Redo Axelrod's prisoner's dilemma tournament (Axelrod 1984).
82. Reimplement the emergence of classes model or extend it to include agents having class preferences.
83. \*Reimplement the retirement model (Axtell and Epstein 1999).
84. Reimplement Kristian Lindgren's evolutionary prisoner's dilemma model (Lindgren 1992).
85. Implement Skyrms' model for the emergence of meaning through signaling (Skyrms 2010).
86. Prisoner's dilemma with tags (Riolo, Axelrod *et al.* (2001)).
87. Explore the 'cost allocation' problem: a boss ('principal') writes contracts for many agents for joint use of a facility, and wants the contract to be incentive compatible (agents tell the truth), individually rational (it is in agents' best interest to use the facility), and Pareto optimal (no better contract exists). Only 2 of these 3 criteria can be achieved (Young 1985)!
88. \*Reimplement the 'El Farol' (aka bar) problem – emergence of mixed strategies (Arthur 1994).
89. Study 'anti-coordination' games (see me for a dissertation on this topic).
90. Build a game theoretic model in which rationality is tempered by one or more emotions (active topic within MAS – see recent years in the *AAMAS* conferences on this topic – as well as Epstein (2013)).

#### Geography, including Traffic (15)

91. Re-implement Simon's city formation model using agents (Ijiri and Simon 1964; 1967; 1977).
92. Focus the above to reproduce the Zipf distribution of city sizes (Axtell and Florida 2006; Waters 2019).
93. Extend the nighttime lights work of Gulden and Florida ('The World is Spiky').
94. \*Compare stop signs, traffic circles and stop lights in an agent- model of traffic (CSS qualifying exam question from a few years ago).
95. \*Emergence of social driving norms at a one lane bridge (see me for the Reston bridge example).
96. \*Pedestrian traffic flow on the Millenium Bridge leading to instability (Strogatz 2003).
97. Crowd dynamics in an emergency egress setting (e.g., Helbing, Farkas and Vicsek 2000; Ha and Lykotafitis 2012).
98. Debottlenecking pedestrian traffic Mecca and Medina (various people have worked on this).
99. TRANSIMS was built at Los Alamos for Albuquerque, Portland and Dallas (Barrett and Beckman 1995; Beckman 1997). Learn about it, survey related models, and write a review paper of the state of the field while prototyping your own traffic simulator.
100. Capture geographically-tagged Twitter feeds on some topic and build an agent model to explain the spatial structure of the data (Stefanidis, Crooks and Radzikowski 2013).
101. Wise (2014) built an emergency egress model based on fire risk; review and extend her work.
102. Geographically accurate models of segregation in Boston (Vandell and Harrison 1978) and Baltimore were built in the 1970s . Compare these and discuss what makes them more or less scientifically-interesting than the abstract Schelling model. How would you build a model of Washington, D.C.?
103. Review ABMs of slum formation and operation (Mahabir et al. 2016) and extend the state-of-the-art.
104. A variety of models exist of The Station nightclub fire in 2003. Review this work and build an ABM.
105. Combining ABM with GIS is the speciality of Professor Andrew Crooks in the Computational Social Science Program ([www.gisagents.org](http://www.gisagents.org)). Review research in this broad area and build a model of this type.

#### History (5)

106. Pre-industrial town markets for agricultural goods were believed to dampen weather-related production shocks, but it has recently been argued they do the opposite. Build a model to test these hypotheses.

107. The English Civil Wars of the 17th C were essentially conflict between the monarchy and Parliament, culminating in the Glorious Revolution and the structural reduction in kingly power. Can an agent model teach us anything about this era?
108. The American, French and subsequent revolutions through 1848 have much in common. Build an abstract model of the general forces that led to these events.
109. Why did the Industrial Revolution happen where and when it did (Mokyr 1998; 2009), and did it even happen (Mokyr 1987; 1990)? Build a model of some of these issues, perhaps starting with (Allen 2009)
110. Model Napoleon's failed attack on Russia – no one has tried this, proceed at your own risk and see me before embarking!

#### International Security and Military Operations (5)

111. \*Infantry combat (pick your era: Revolutionary War, 2-3 shots/min w/muskets; Civil War, 3-10 shots/min w/cartridges; WWI, trench warfare, up to 100 shots/min w/machine guns); Ilachinski is best source on simple models of this kind (2004).
112. Prototype an agent model of Gettysburg (analogs exist there).
113. Submarine warfare against supply convoys during WWII (McCue 2006).
114. Model counterinsurgency (COIN) dynamics (Johnson et al. 2011).
115. Terrorist networks: formation, evolution and disruption (MacKerrow 2003).

#### Marketing (10)

116. Agentize the Bass diffusion model (Bass 1969).
117. Viral marketing is a data-intensive, bottom up approach to marketing, as compared to top-down advertising (Goodin 2000). Build a model of the uptake of a consumer good with both kinds of advertising.
118. A game theoretic version of adoption dynamics is due to Young (1999). Build this model with agents.
119. Technology standards are characterized by network externalities, e.g., VHS vs Betamax (Economides 1996). Build an agent-based marketing model in the presence of network externalities. In such environments some amount of piracy may even be useful. Model this phenomenon.
120. Read a book on high-tech marketing (Moore 1991; Mohr, Sengupta and Slater 2009). How is marketing different in this arena and what can be learned by building agent models in this domain?
121. Read CSS Ph.D. student Wyn Farrell's "How Hits Happen" and build a relevant agent model.
122. Build an information cascade model and contrast the perspectives of Watts (2002) and Gladwell.
123. Build bottom up marketing models and compare the effects of alternative interaction topologies.
124. Product placement is important in actual marketing. Build a spatial agent model where this matters.
125. Companies claim to be able to turn cash register receipt data into targeted marketing; model this.

#### Methodology of Agent Computation and Simulation (10)

126. \*Use of GPU technology for agent models (D'Souza, Lysenko and Rahmani 2007).
127. Investigate alternative activation regimes in Sugarscape (Lawson and Park 2000).
128. Investigate parallel activation regimes (see me for references).
129. Investigate parallel languages for agent modeling (e.g., Erlang, Scala, Go, Haskell); see me for a paper.
130. Investigate shared memory machines vs clouds for agent modeling (see me for a white paper).
131. Emotional agents are an active topic in MAS. Leverage some of those formulations for social models.
132. Agents that talk directly to one another is another active area of MAS; extend Tesfatsion (2001).
133. What would an agent-oriented operating system look like? See me for some references.
134. Compare agent learning in CS vs economics; see special issue of *AI Journal* (Vohra and Wellman 2007).
135. Build large-scale models and study how to efficiently execute them or glean data from them.

#### Operations Research and Business Management (5)

136. \*Take the Axtell and Kimbrough (see me) model of bipartite matching with aspirations, convert it to Java (possibly MASON), and study the role of matchmakers.

137. \*Information flow in an organization through formal organizations and informal networks (there exist a variety of extant models in the org theory literature).
138. \*Airline ‘free flight’: pilots pick their own routes (see me for a recent Mason dissertation).
139. Study leaderless organizations (see me for a recent GWU dissertation).
140. Compare mathematical programming solutions to agents for a well-known OR problem.

#### Politics (10)

141. Societal transition from simple states to feudalism (Engels 1972 (1884)); model it.
142. Societal transition from feudalism to capitalism and its recent incarnation in the ‘Brenner debate’ (Dobb 1963; Brenner 1976; 1978; Aston and Philpin 1987); model the essential elements.
143. Write a Tiebout model – agents ‘vote with their feet’ to satisfy preferences (Kollman, Miller and Page 1997).
144. Build a voting model (a la Nate Silver, [www.538.com](http://www.538.com)) that uses polling data.
145. The formation of political parties by politicians to attract a majority of votes; possibly focus on reproducing theoretical cycling results (Kollman, Miller and Page 1992).
146. Cross-border flows and refugee camp formation as a response to civil violence (Groen 2016).
147. \*Extend the party competition model of Laver and Sergenti (2011).
148. Agentize a model of local/city government.
149. Agentize an informal model of federalism (Bednar, Eskridge and Ferejohn 2001; Bednar 2011).
150. \*Build a new model of civil violence that does not use global variables like legitimacy (Epstein 2002).

#### Public Health (15)

151. Compare distinct approaches (Luke and Stamatakis 2012).
152. \*Build a disease propagation ABM (SIS, SIR, or SIER) on a graph. Compare critical fractions of populations that need to be vaccinated to stop disease spread as a function of the  $R_0$  parameter; see (Pastor-Satorras and Vespignani 2001).
153. Build a spatial or network model of disease propagation among agents and compare it with a system dynamics model of the same process; Sterman (2000) for references..
154. \*Spread of addictive behavior, such as drug ‘epidemics’ (Agar and Wilson 2002).
155. Extant epidemiological models do not alter behavior once agents are sick. Try this (see me for a paper).
156. Experiment with a policy-relevant model for flu to study policy options (Gemann et al. 2006).
157. Build an ABM of cardiovascular health (Li et al. 2018).
158. Build an ABM of the obesity epidemic (Shoham et al. 2015).
159. Spread of flu in emergency rooms (Laskowski et al. 2011).
160. Validation of models in this area is a problem. Build such a model and review alternative V&V approaches.
161. ABMs have been used to study of STDs (Rutherford, Friesen and McLeod 2012); review and extend.
162. RFID tracking systems are used in hospital settings and modeled with ABMs (Laskowski et al. 2010).
163. Review and extend ABMs of the opioid epidemic (e.g., Bobashev et al. 2018; Keane, Egan and Hawk 2018).
164. ABMs can also be used to study diabetes and other noncommunicable diseases (Li et al. 2016).
165. Tobacco use ABMs have a reasonably long history (Wallace, Geller and Ogawa 2015; Luke et al. 2017).

#### Sociology and Crime (10)

166. Investigate non-lattice topologies in Schelling segregation (Flache and Hegselmann 2001).
167. \*Evolution of opinions within social networks; huge literature here so pick some specific topic (Deffaut et al. 2002).
168. \*Adoption of smoking behavior among adolescents in social networks (see me for a paper).
169. Compare alternative personnel promotion systems (e.g., tenure vs seniority-based systems; see me for a recent computational paper).
170. Investigate emergence from the perspective of Parsons’ theories (Parsons 1937; 1937); build a model.
171. Build an agent model relevant to “Coleman’s boat” (1964) and interpretations of emergence that result.
172. Build a model of crime as a socially-interactive process (e.g., Glaeser, Sacerdote and Scheinkman 1996).

173. Build a model of crime as occurring in ‘hot spots’ and/or on the boundaries of gang ‘territories’ (Brantingham et al. 2012).
174. Extend Redfish’s model of the UK justice system (see me for slide deck).
175. Build a model for the interaction between drugs and gun violence (see me for prototype).

## Sports and Entertainment (25)

176. \*RoboSoccer (review state-of-the-art; modify and existing team or design your own team).
177. Bicycle racing: peloton formation, paceline dynamics (see UC-Irvine dissertation on this topic).
178. Auto racing on an oval track, in particular the social dynamics of ‘drafting’ (are there no models?).
179. Build a computational model of drag racing. If cars + drivers can be absolutely ranked in terms of their performance (mean + variance), what fraction of the time do the top 16 actually qualify for eliminations? How often do the top eight all win the first round and the best 4 reach the semi-finals? Is it rare or common for the two best vehicles to make it to the finals? Does the best vehicle usually win? How are any of these modified by 4 lane racing (e.g., Charlotte)? Are there better ways to arrange eliminations?
180. Model ‘relegation’ in the English Premier League (Soccer/football in England).
181. Model league division formation from undifferentiated teams (e.g., youth soccer leagues).
182. Study the mathematics of ranking system and build an agent model to better understand their dynamics.
183. Exactly how extraordinary was Joe DiMaggio’s 57 game hitting streak? Build a model to explore this.
184. Study the empirics of ‘streak’ behavior in sports and build a general purpose agent model to study these.
185. Model football play-calling using machine learning (e.g., genetic algorithms).
186. \*Why did it take 15-20 years for hockey helmets in hockey to go from being rare to common? Model it.
187. \*Dynamics of a so-called ‘stadium wave’ (Farkas, Helbing and Vicsek 2002).
188. \*Formation and evolution of a standing ovation in an audience (CSS qualifying exam problem).
189. Recreate *Lord of the Rings*-type battle scenes (There many popular accounts of how this was done).
190. \*Movie profitability is notoriously hard to predict, for reasons well-described by De Vany (2004). Build a model the ‘grows’ some of the empirical regularities in Professor De Vany’s book.
191. Get the MASON version of Monopoly, created in CSS 605 in Fall 2014, and develop effective strategies.
192. Built a model of *Risk* or some other classic board game (this was done in CSS 605 several years ago).
193. Make a dynamic *Broadway Boogie Woogie* (Mondrian; see p1 above), maybe by morphing Sugarscape code.
194. Build a model of how Intel prices their chips, particularly focusing on strategic pricing at the high end.
195. Build a model of the lifecycle of a computer game, from introduction to peak popularity and decline.
196. A recent paper (Gabel and Redner 2012) convincingly demonstrates that basketball score differentials follow a random walk, with slight deviations just before halftimes and games ending. They propose a model but it is purely mathematical, with any behavioral or social science content. Propose such a model.
197. In the context of the above, Clauset *et al.* (2015) attempt to determine what constitutes a ‘safe lead’. Once again, their formal model is devoid of any social phenomena. Build a model that remedies this deficiency.
198. Football simulation games are essentially agent-based but have very simple algorithms. Explore the guts.
199. Ditto for basketball games. Can these be used vis-a-vis the Redner (Gabel and Redner 2012) papers?
200. Are football teams too conservative, i.e., punt too much on 4<sup>th</sup> down (Romer 2006)? Model this with agents.

## Academic Integrity

The integrity of the University community is affected by the individual choices made by each of us. Mason has an Honor Code with clear guidelines regarding academic integrity. Three fundamental and rather simple principles to follow at all times are that: (1) all work submitted be your own; (2) when using the work or ideas of others, including fellow students, give full credit through accurate citations; and (3) if you are uncertain about the ground rules on a particular assignment, ask for clarification. No grade is important enough to justify academic misconduct.

Plagiarism means using the exact words, opinions, or factual information from another person without giving the person credit. Writers give credit through accepted documentation styles, such as parenthetical citation, footnotes, or endnotes. Paraphrased material must also be cited, using MLA or APA format. A simple listing of books or articles is not sufficient. Plagiarism is the equivalent of intellectual robbery and cannot be tolerated in our class. If you have any doubts about what constitutes plagiarism, please see me.

## Disability Accommodations

If you have a disability and need academic accommodations, please see me and contact the Office of Disability Services (ODS) at (703) 993-2474, ods.gmu.edu. All academic accommodations are to be arranged through the ODS.

## Diversity

George Mason promotes a living and learning environment for intellectual growth and research productivity, through its curriculum, programs, policies, procedures, services and resources. Emphasis upon diversity and inclusion throughout the campus community is essential to achieve these goals. Diversity is broadly defined to include such characteristics as, but not limited to, race, ethnicity, gender, religion, age, disability, and sexual orientation. Diversity also entails different viewpoints, philosophies, and perspectives. Attention to these aspects of diversity helps promote a culture of inclusion and belonging, and an environment where diverse opinions, backgrounds and practices have the opportunity to be voiced, heard and respected. Mason's commitment to diversity and inclusion goes beyond policies and procedures to focus on behavior at the individual, group and organizational level. This commitment to diversity and inclusion can be found in all settings, including individual work units, student organizations, and classroom settings; it is also found in the delivery of services and activities, including, but not limited to, curriculum, teaching, events, advising, research, service, and community outreach. The attainment of diversity and inclusion are dynamic and continuous processes, evolving over time, Mason seeks to continuously improve its environment and to this end, the University promotes continuous monitoring and self-assessment regarding diversity. The aim is to incorporate diversity and inclusion within the philosophies and actions of the individual, group and organization, and to make improvements as needed.

## Bibliography

- Abu-Mostafa, Y. S., B. LeBaron, A. W. Lo and A. S. Weigend, Eds. (2000). Computational Finance 1999. Cambridge, Mass., MIT Press.
- Acemoglu, D., V. M. Carvalho, A. Ozdaglar and A. Tahbaz-Salehi (2012). "The Network Origins of Aggregate Fluctuations." Econometrica **80**(5): 1977-2016.
- Agar, M. and D. Wilson (2002). "Drugmart: Heroin Epidemics as Complex Systems." Complexity **7**(5): 44-52.
- Akerlof, G. (1970). "The Market for 'Lemons': Quality Uncertainty and the Market Mechanism." Quarterly Journal of Economics **LXXXIV**(3): 488-500.
- Albert, R. and A.-L. Barabasi (2002). "Statistical Mechanics of Complex Networks." Reviews of Modern Physics **74**: 47-97.
- Albert, R., H. Jeong and A.-L. Barabasi (1999). "Diameter of the World Wide Web." Nature **401**: 130-131.
- Alfarano, S., F. Wagner and T. Lux (forthcoming). "Estimation of Agent-Based Models: The Case of an Asymmetric Herding Model." Computational Economics.
- Allen, R. C. (2009). "Engels' pause: Technical change, capital accumulation, and inequality in the British industrial revolution." Explorations in Economic History **46**(4): 418-435.
- Anderson, P. W., K. J. Arrow and D. Pines, Eds. (1988). The Economy as an Evolving Complex System. Santa Fe Institute Studies in the Sciences of Complexity, Proceedings Volume V.
- Anderson, R. M. and R. M. May (1991). Infectious Diseases of Humans: Dynamics and Control. New York, N.Y., Oxford University Press.
- Andrews, C. J. (2001). "Building a Micro Foundation for Industrial Ecology." Journal of Industrial Ecology **4**(3): 35-51.
- Arthur, W. B. (1994). "Inductive Reasoning and Bounded Rationality." American Economic Review **84**(2): 406-411.
- Arthur, W. B., J. H. Holland, B. LeBaron, R. Palmer and P. Tayler (1997). Asset Pricing Under Endogenous Expectations in an Artificial Stock Market. The Economy as an Evolving Complex System II. W. B. Arthur, S. N. Durlauf and D. A. Lane. Reading, Mass., Addison-Wesley.
- Aston, T. H. and C. H. E. Philpin, Eds. (1987). The Brenner Debate: Agrarian Class Structure and Economic Development in Pre-Industrial Europe. New York, N.Y., Cambridge University Press.
- Axelrod, R. (1984). The Evolution of Cooperation. New York, N.Y., Basic Books.
- (1997). The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration. Princeton, N.J., Princeton University Press.
- (1997). "The Dissemination of Culture: A Model with Local Convergence and Global Polarization." Journal of Conflict Resolution **41**: 203-226.
- (2003). "Advancing the Art of Simulation in the Social Sciences." Journal of the Japanese Society for Management Information Systems **12**(3).
- Axtell, R. and R. Florida (2006). Emergent Cities: Micro-Foundations of Zipf's Law. Working paper. The Martin Prosperity Institute. Toronto, Canada.
- Axtell, R. L. (2000). Why Agents? On the Varied Motivations for Agent Computing in the Social Sciences. Proceedings of the Workshop on Agent Simulation: Applications, Models, and Tools. C. M. Macal and D. Sallach. Chicago, Illinois, Argonne National Laboratory: 3-24.
- (2001). Effects of Interaction Topology and Activation Regime in Several Multi-Agent Systems. Multi-Agent-Based Simulation. S. Moss and P. Davidsson. Heidelberg, Germany, Springer Verlag. 1979: 33-48.
- (2001). "Zipf Distribution of U.S. Firm Sizes." Science **293**(5536): 1818-1820.
- (2002). Non-Cooperative Dynamics of Multi-Agent Teams. Proceedings of the First International Joint Conference on Autonomous Agents and Multiagent Systems. C. Castelfranchi and W. L. Johnson. Bologna, Italy, ACM Press. Part 3: 1082-1089.



- (2003). Economics as Distributed Computation. Meeting the Challenge of Social Problems via Agent-Based Simulation. T. Terano, H. Deguchi and K. Takadama. Tokyo, Springer-Verlag: 3-23.
- (2005). "The Complexity of Exchange." Economic Journal **115**: F193-210.
- (2007). "What economic agents do: How cognition and interaction lead to emergence and complexity." Review of Austrian Economics **20**: 105-122.
- (2007). "What economic agents do: How cognition and interaction lead to emergence and complexity." Review of Austrian Economics **20**(2-3): 105-122.
- (2016). 120 Million Agents Self-Organize into 6 Million Firms: A Model of the U.S. Private Sector. Proceedings of the 15th International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS2016). J. Thangarah, K. Tuyls, C. Jonker and S. Marsella. Singapore, International Foundation for Autonomous Agents and Multiagent Systems.
- (2018). Endogenous Firm Dynamics and Labor Flows with Heterogeneous Agents. Handbook of Computational Economics. C. Hommes and B. LeBaron. Amsterdam, North-Holland. **IV: Heterogeneous Agent Modeling**.
- Axtell, R. L., C. J. Andrews and M. J. Small (2002). "Agent-Based Modeling and Industrial Ecology." Journal of Industrial Ecology **5**(4): 10-13.
- Axtell, R. L., R. Axelrod, J. M. Epstein and M. D. Cohen (1996). "Aligning Simulation Models: A Case Study and Results." Computational and Mathematical Organization Theory **1**(2): 123-141.
- Axtell, R. L. and J. M. Epstein (1994). "Agent-Based Models: Understanding Our Creations." Bulletin of the Santa Fe Institute.
- (1999). Coordination in Transient Social Networks: An Agent-Based Computational Model of the Timing of Retirement. Behavioral Dimensions of Retirement Economics. H. J. Aaron. Washington, D.C., The Brookings Institution Press: 161-183.
- Axtell, R. L., J. M. Epstein, J. S. Dean, G. J. Gumerman, A. C. Swedlund, J. Harburger, S. Chakravarty, R. Hammond, J. Parker and M. T. Parker (2002). "Population Growth and Collapse in a Multiagent Model of the Kayenta Anasazi in Long House Valley." Proc Natl Acad Sci U S A **99**(supplement 3): 7275-7279.
- Axtell, R. L., J. M. Epstein and H. P. Young (2001). The Emergence of Classes in a Multi-Agent Bargaining Model. Social Dynamics. S. N. Durlauf and H. P. Young. Cambridge, Mass./Washington, D.C., MIT Press/Brookings Institution Press: 191-211.
- Aymanns, C., F. Caccioli, J. D. Farmer and V.W. C. Tan (2016). "Taming the Basel leverage cycle." Journal of Financial Stability **27**: 263-277.
- Aymanns, C. and J. D. Farmer (2015). "The dynamics of the leverage cycle." Journal of Economic Dynamics and Control **50**: 155-179.
- Bala, V. and S. Goyal (2000). "A Non-Cooperative Theory of Network Formation." Econometrica **68**(1181-1229).
- Barabasi, A.-L. (2002). Linked: The New Science of Networks. Boston, Perseus.
- Barabasi, A.-L. and R. Albert (1999). "Emergence of Scaling in Random Networks." Science **286**: 509-512.
- Barrat, A., M. Barthelemy and A. Vespignani (2010). Dynamical Processes on Complex Networks. New York, N.Y., Cambridge University Press.
- Barrett, C. and R. Beckman (1995). TRANSIMS - Portland Case Study Report, Volume I: Introduction and Overview. Technical Report. Los Alamos, N.M., Los Alamos National Laboratory.
- Barrett, S. (1994). "Self-Enforcing International Environmental Agreements." Oxford Economic Papers, New Series **46**: 878-894.
- Bass, F. (1969). "A New Product Growth Model for Consumer Durables." Management Science **15**: 215-227.
- Batty, M. (2005). Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals. Cambridge, Mass., MIT Press.
- Beckman, R. (1997). TRANSIMS-Release 1.0 - The Dallas-Ft. Worth Case Study. Technical Report. Los Alamos, N.M., Los Alamos National Laboratory.
- Bednar, J. (2011). "The Political Science of Federalism." Annual Review of Law and Social Science **7**: 269-288.

- Bednar, J., J. Eskridge, William N. and J. Ferejohn (2001). A Political Theory of Federalism. Constitutional Culture and Democratic Rule. J. Ferejohn, J. N. Rakove and J. Riley. New York, N.Y., Cambridge University Press: 223-267.
- Beekman, c. S. and W. W. Baden (2005). Nonlinear Models in Archaeology and Anthropology, Ashgate Publishing.
- Beinhocker, E. (2005). The Origin of Wealth: How Evolution Creates Novelty, Knowledge, and Growth in the Economy. Cambridge, Mass., Harvard Business School Press.
- Benard, S. and R. Wiler (2007). "A wealth and status-based model of residential segregation." Journal of Mathematical Sociology 31: 149-174.
- Bernanke, B. S. (2004). Essays on the Great Depression. Princeton, New Jersey, Princeton University Press.
- Bert, F. E., G. P. Podestá, S. L. Rovere, Á. N. Menéndez, M. J. North, E. Tatara, C. E. Laciana, E. Weber and F. R. Toranzo (2011). "An agent based model to simulation structural and land use changes in agricultural systems of the Argentine Pampas." Ecological Modelling 222(19): 3486-3499.
- Bertsekas, D. and J. Tsitsiklis (1993). Parallel and Distributed Computation: Numerical Methods. Englewood Cliffs, N.J., Prentice-Hall.
- Bicchieri, C. (1993). Rationality and Coordination. New York, N.Y., Cambridge University Press.
- (2006). The Grammar of Society: The Nature and Dynamics of Social Norms. New York, N.Y., Cambridge University Press.
- Binmore, K. G. (1992). Fun and Games: A Text on Game Theory. Lexington, Mass., D.C. Heath and Company.
- (2007). Playing for Real: A Text on Game Theory. New York, N.Y., Oxford University Press.
- Bjornstad, O. (2018). Epidemics: Models and Data using R. Cham, Switzerland, Springer Nature Switzerland AG.
- Blume, L. E. and D. Easley (2002). "Optimality and Natural Selection in Markets." Journal of Economic Theory 107(1): 95-135.
- Bobashev, G., S. Goree, J. Frank and W. Zule (2018). Pain Town, an Agent-Based Model of Opioid Use Trajectories in a Small Community. International Conference on Social Computing, Behavioral-Cultural Modeling and Prediction and Behavior Representation in Modeling and Simulation (SBP-BRiMS). R. Thomson, C. Dancy, A. Hyder and H. Bisgin. Washington, D.C., Springer Lectures Notes in Computer Science (LNCS). 10899: 274-285.
- Bonabeau, E., M. Dorigo and G. Theraulaz (1999). Swarm Intelligence: From Natural to Artificial Systems. New York, N.Y., Oxford University Press.
- Bone, C. and S. Dragicevic (2010). "Simulation and validation of a reinforcement learning agent-based model for multi-stakeholder forest management." Computers, Environment and Urban Systems 34(2): 162-174.
- Bottazzi, G. and A. Secchi (2006). "Explaining the distribution of firm growth rates." Rand Journal of Economics 37(2): 235-256.
- Bowles, S. (2003). Microeconomics: Behavior, Institutions, and Evolution. Princeton, N.J., Princeton University Press.
- Box, G. E. P., J. S. Hunter and W. G. Hunter (2005). Statistics for Experimenters: Design, Innovation, and Discovery. New York, N.Y., Wiley.
- Brantingham, P. J., G. E. Tita, M. B. Short and S. Reid (2012). "The Ecology of Gang Territorial Boundaries." Criminology 30: 851-885.
- Brenner, R. (1976). "Agrarian Class Structure and Economic Development in Pre-Industrial Europe." Past & Present 70: 30-75.
- (1978). "Dobb on the transition from feudalism to capitalism." Cambridge Journal of Economics 2: 121-140.
- Bruner, R. F. and S. D. Carr (2007). The Panic of 1907: Lessons Learned from the Market's Perfect Storm. Hoboken, New Jersey, John Wiley & Sons, Inc.
- Bruun, C. (1999). Agent-based Keynesian Economics: Simulating a Monetary Production System Bottom Up. Denmark, Aalborg University.
- Buhl, J., D. J. T. Sumpter, I. D. Couzin, J. J. Hale, E. Desplane, E. R. Miller and S. J. Simpson (2006). "From disorder to order in marching locusts." Science 312: 1402-1406.

- Camerer, C. (2003). Behavioral Game Theory. Princeton, N.J., Princeton University Press.
- Carley, K. M. and M. J. Prietula (1994). Computational Organization Theory. Hillsdale, N.J., Lawrence Erlbaum Associates.
- Castellano, C., M. Marsili and A. Vespignani (2000). "Nonequilibrium Phase Transition in a Model for Social Influence." Physical Review Letters **85**(16): 3536-3539.
- Casti, J. L. (1994). Complexification: Explaining a Paradoxical World through the Science of Surprise. New York, N.Y., HarperCollins Publishers.
- (1997). Would-Be Worlds: How Simulation is Changing the Frontiers of Science. New York, N.Y., John Wiley & Sons.
- Cederman, L.-E. (1997). Emergent Actors and World Politics: How States and Nations Develop and Dissolve. Princeton, N.J., Princeton University Press.
- (2001). "Modeling the Democratic Peace as a Kantian Selection Process." Journal of Conflict Resolution **45**: 470-502.
- Centola, D. (2002). The Ascape Manual. Washington, D.C., The Brookings Institution.
- Chen, J. and S. Micali (2013). "The order independence of iterated dominance in extensive games." Theoretical Economics **8**: 125-163.
- Clark, C. W. (2005). Mathematical Bioeconomics: The Optimal Management of Renewable Resources. New York, N.Y., Wiley Inter-science.
- Clauset, A., M. Kogan and S. Redner (2015). "Safe Leads, A and Lead Changes in Competitive Team Sports." Physical Review E **91**(6): 11.
- Clauset, A., C. R. Shalizi and M. E. J. Newman (2009). "Power-Law Distributions in Empirical Data." SIAM Review **51**(4): 661-703.
- Clearwater, S. H., Ed. (1996). Market-Based Control, World Scientific.
- Cliff, D. and J. Bruton (1997). Less Than Human: Simple Adaptive Trading Agents for CDA Markets. Bristol, UK, Hewlett-Packard Laboratories.
- (1997). Minimal-Intelligence Agents for Bargaining Behaviors in Market-Based Environments. Bristol, UK, Hewlett-Packard Laboratories.
- Coad, A. (2008). "Firm growth and scaling of growth rate variance in multiplant firms." Economics Bulletin **12**(9): 1-15.
- (2010). "The Exponential Age Distribution and the Pareto Firm Size Distribution." Journal of Industrial Competition and Trade **10**: 389-395.
- Colander, D. C., P. Howitt, A. Kirman, A. Leijonhufvud and P. Mehrling (2008). "Beyond DSGE Models: Toward and Empirically Based Macroeconomics." American Economic Review, Papers and Proceedings **98**(2): 236-240.
- Coleman, J. S. (1964). Introduction to Mathematical Sociology. Glencoe, Ill., Free Press.
- Cont, R. (2006). Volatility clustering in financial markets: Empirical facts and agent-based models. Long Memory in Economics. A. P. Kirman and G. Teyssiere. New York, N.Y., Springer.
- Couzin, I. D. (2007). "Collective Minds." Nature **445**: 715.
- Couzin, I. D. and N. R. Franks (2003). "Self-organized lane formation and optimized traffic flow in army ants." Proceedings of the Royal Society B **270**: 139-146.
- Couzin, I. D., J. Krause, N. R. Franks and S. A. Levin (2005). "Effective leadership and decision-making in animal groups on the move." Nature **433**: 513-516.
- Cyert, R. M. and J. G. March (1963). A Behavioral Theory of the Firm. Englewood Cliffs, N.J., Prentice-Hall.
- D'Souza, R. M., M. Lysenko and K. Rahmani (2007). Sugarscape on Steroids: Simulation over a Million Agents at Interactive Rates, Michigan Technological University.
- Daley, D. J. and J. Gani (1999). Epidemic Modelling: An Introduction. New York, N.Y., Cambridge University Press.
- Dall'Asta, L., C. Castellano and M. Marsili (2008). "Statistical physics of the Schelling model of segregation." Journal of Statistical Mechanics: Theory and Experiment.

- de Marchi, S. (2005). *Computational and Mathematical Modeling in the Social Sciences*. New York, N.Y., Cambridge University Press.
- De Vany, A. (2004). *Hollywood Economics: How Extreme Uncertainty Shapes the Film Industry*. New York, N.Y., Routledge.
- de Wit, G. (2005). "Firm Size Distributions: An Overview of Steady-State Distributions Resulting from Firm Dynamics Models." *International Journal of Industrial Organization* 23: 423-450.
- Dean, J. S., G. J. Gumerman, J. M. Epstein, R. L. Axtell, A. C. Swedlund, M. T. Parker and S. McCarroll (2000). *Understanding Anasazi Culture Change Through Agent-Based Modeling: Dynamics in Human and Primate Societies: Agent-Based Modeling of Social and Spatial Processes*. T. A. Kohler and G. J. Gumerman. New York, N.Y., Oxford University Press.
- Deffaunt, G., F. Amblard, G. Weisbuch and T. Faure (2002). "How Can Extremism Prevail? A Study Based on the Relative Agreement Interaction Model." *Journal of Artificial Societies and Social Simulation* 5(4).
- Dezso, Z. and A.-L. Barabasi (2002). "Halting Viruses in Scale-Free Networks." *Physical Review E* 65.
- Diamond, J. M. (2002). "Life with the Artificial Anasazi." *Nature* 419: 567-569.
- (2004). *Collapse: How Societies Choose to Fail or Succeed*. New York, N.Y., Viking.
- Dobb, M. (1963). *Studies in the Development of Capitalism*. London, England, Routledge & Kegan Paul.
- Dorogovtsev, S. N. and J. F. F. Mendes (2003). *Evolution of Networks: From Biological Nets to the Internet and WWW*. New York, N.Y., Oxford University Press.
- Doyle, J. and J. M. Carlson (2000). "Power Laws, Highly Optimized Tolerance, and Generalized Source Coding." *Physical Review Letters* 84(24): 5656-5659.
- Draper, B. a. (1998). *Evolutionary Operation: A Statistical Method for Process Improvement*. New York, N.Y., Wiley-Interscience.
- Dresher, M. (1961). *The Mathematics of Games of Strategy: Theory and Applications*. Santa Monica, Calif., Rand Corporation.
- Easley, D. and J. Kleinberg (2010). *Networks, Crowds, and Markets: Reasoning About a Highly Connected World*. New York, N.Y., Cambridge University Press.
- Economides, N. (1996). "The Economics of Networks." *International Journal of Industrial Organization* 16(4): 673-699.
- Elsaway, S., T. Filatova, A. J. Jakeman, A. J. Kettner, M. L. Zellner, I. N. Athansiadis, S. H. Hamilton, R. L. Axtell, D. G. Brown, J. M. Gilligan, M. A. Janssen, D. T. Robinson, J. Rozenberg, I. I. T. Ullah and S. J. Lade (2020). "Eight Grand Challenges in Socio-Environmental Systems Modeling." *Socio-Environmental System Modeling* 2.
- Engels, F. (1972 (1884)). *The Origin of the Family, Private Property and the State*. New York, N.Y., Pathfinder Press.
- Epstein, J. M. (2002). "Modeling civil violence: An agent-based computational approach." *Proc Natl Acad Sci U S A* 99(Suppl 3): 7243-7250.
- Epstein, J. M. (2013). *Agent\_Zero: Toward Neurocognitive Foundations for Generative Social Science*. Princeton, N.J., Princeton University Press.
- Epstein, J. M. and R. Axtell (1996). *Growing Artificial Societies : Social Science from the Bottom Up*. Washington, D.C./Cambridge, Mass., Brookings Institution Press/MIT Press.
- Eubank, S., H. Guclu, V. S. A. Kumar, M. V. Marathe, A. Srinivasan, Z. Toroczkai and N. Wang (2004). "Modelling Disease Outbreaks in Realistic Urban Social Networks." *Nature* 429: 180-184.
- Evans, D. S. (1987). "The Relationship Between Firm Growth, Size, and Age: Estimates for 100 Manufacturing Industries." *Journal of Industrial Economics* 35: 567-581.
- (1987). "Tests of Alternative Theories of Firm Growth." *Journal of Political Economy* 95(4): 657-674.
- Farkas, I. J., D. Helbing and T. Vicsek (2002). "Mexican waves in an excitable medium." *Nature* 419: 131-132.
- Farmer, J. D. and D. Foley (2009). "Computer Age Economic Modeling." *Nature*.
- Farmer, J. D., C. Hepburn, P. Mealy and A. Teytelboym (2015). "A Third Wave in the Economics of Climate Change." *Environmental and Resource Economics* 62: 329-357.

- Farmer, J. D. and A. W. Lo (1999). "Frontiers of Finance: Evolution and Efficient Markets." Proc Natl Acad Sci U S A **96**(18): 9991-9992.
- Farmer, J. D., P. Patelli and I. I. Zovko (2005). "The Predictive Power of Zero Intelligence in Financial Markets." Proc Natl Acad Sci U S A **102**(6): 2254-2259.
- Feldman, A. (1973). "Bilateral Trading Processes, Pairwise Optimality, and Pareto Optimality." Review of Economic Studies **XL**(4): 463-473.
- Ferguson, N. M., D. A. T. Cummings, C. Fraser, J. C. Cajka, P. Cooley and D. S. Burke (2006). "Strategies for mitigating and influenza pandemic." Nature **442**(27): 448-452.
- Ferguson, N. M., M. J. Keeling, W. J. Edmunds, R. Gani, B. T. Grenfell, R. M. Anderson and S. Leach (2003). "Planning for Smallpox Outbreaks." Nature **425**: 681-685.
- Ferguson, N. M., D. Laydon, G. Nedjati-Giliani, N. Imai, K. Ainslie, M. Maguelin, S. Bhatia, A. Boonyasiri, Z. Cucunubá, G. Cuomo-Dannenburg, A. Dighe, I. Dorigatti, H. Fu, K. Gaythorpe, W. Green, A. Hamlet, W. Hinsley, L. C. Okell, S. v. Eslsand, H. Thompson, R. Verity, E. Volz, H. Wang, Y. Want, P. G. T. Walker, P. Winskill, C. Wahittaker, C. A. Donnelly, S. Riley and A. C. Ghani (2020). Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand. Imperial College COVID-19 Response. London, U.K.: 20.
- Filatova, T. V. (2009). Land Markets from the Bottom Up: Micro-macro links in economics and implications for coastal risk management Ph.D., University of Twente.
- Filatova, T. V., D. C. Parker and A. van der Veen (2007). Agent-based land markets: Heterogeneous agents, land prices, and urban land use change. Proceedings of the 4th Conference of the European Social Simulation Association (ESSA '07). Toulouse, France.
- (2009). "Agent-based Urban Land Markets: Agent's Pricing Behavior, Land Prices and Urban Land Use Change." Journal of Artificial Societies and Social Simulation **12**(13).
- Flache, A. and R. Hegselmann (2001). "Do Irregular Grids Make a Difference? Relaxing the Spatial Regularity Assumption in Cellular Models of Socila Dynamics." Journal of Artificial Societies and Social Simulation **4**(4).
- Friedman, D. (1991). "Evolutionary Games in Econmics." Econometrica **59**: 637-666.
- Friedman, D. and J. Rust, Eds. (1994). The Double Auction Market: Institutions, Theories, and Evidence. Santa Fe Institute Studies in the Sciences of Complexity. Reading, Mass., Addison-Wesley Publishing.
- Friedman, M. (1953). Essays in Positive Economics. Chicago, Ill., University of Chicago Press.
- Fudenberg, D. and D. Levine (1998). The Theory of Learning in Games. Cambridge, Mass., MIT Press.
- Fudenberg, D. and J. Tirole (1991). Game Theory. Cambridge, Mass., MIT Press.
- Gabel, A. and S. Redner (2012). "Random Walk Picture of Basketball Scoring." Journal of Quantitative Analysis in Sports.
- Gacs, P. (1997). Deterministic Computations Whose History is Independent of the Order of Asynchronous Updating. Department of Computer Science working paper. Boston, Mass., Boston University.
- Gardner, M. (1970). "The Fantastical Combinations of John Conways New Solitaire Game "Life". " Scientific American **223**(4-6): 120, 114, 118.
- Gaylord, R. J. and L. J. D'Andria (1998). Simulating Society: A Mathematica Toolkit for Modeling Socioeconomic Behavior. New York, N.Y., Telos (Springer-Verlag).
- Geanakoplos, J., R. L. Axtell, J. D. Farmer, P. Howitt, B. Conlee, J. Goldstein, M. Hendrey, N. M. Palmer and C.-Y. Yang (2012). "Getting at Systemic Risk via an Agent-Based Model of the Housing Market." American Economic Review: Papers and Proceedings **102**(3): 53-58.
- Gemann, T. C., K. Kadau, I. M. Longini Jr. and C. A. Macken (2006). "Mitigation strategies for pandemic influenza in the United States." Proc Natl Acad Sci U S A **103**(15): 5935-5940.
- Gerhold, S., L. Glebsky, C. Schneider and H. Weiss (2008). "Limit states for one-dimensional Schelling segregation models." Communications in Nonlinear Science and Numerical Simulation **13**(10): 2236-2245.

- Gilbert, N. and R. Conte, Eds. (1995). *Artificial Societies: The Computer Simulation of Social Life*. London, UCL Press.
- Gilbert, N. and J. Doran, Eds. (1994). *Simulating Societies: The Computer Simulation of Social Phenomena*. London, UCL Press.
- Gilbert, N. and K. G. Troitzsch (1999). *Simulation for the Social Scientist*. Buckingham, United Kingdom, Open University Press.
- Gimblett, H. R., Ed. (2002). *Integrating Geographic Information Systems and Agent-Based Modeling Techniques for Simulating Social and Ecological Processes*. Santa Fe Institute Studies in the Sciences of Complexity. New York, N.Y., Oxford University Press.
- Gintis, H. (2000). *Game Theory Evolving: A Problem-Centered Introduction to Modeling Strategic Interaction*. Princeton, N.J., Princeton University Press.
- (2007). "The Dynamics of General Equilibrium." *Economic Journal* 117(523): 1280-1309.
- Gintis, H., S. Bowles, R. Boyd and E. Fehr, Eds. (2004). *Moral Sentiments and Material Interests: On the Foundations of Cooperation in Economic Life*. Cambridge, Mass., MIT Press.
- Glaeser, E. L., B. Sacerdote and J. A. Scheinkman (1996). "Crime and Social Interactions." *Quarterly Journal of Economics* CXI(2): 507-548.
- Gode, D. K. and S. Sunder (1993). "Allocative Efficiency of Markets with Zero Intelligence (ZI) Traders: Market as a Partial Substitute for Individual Rationality." *Journal of Political Economy* CI: 119-137.
- (1997). "What Makes Markets Allocationally Efficient?" *Quarterly Journal of Economics* 112(2): 603-630.
- Goodin, S. (2000). *Unleashing the Ideavirus*. New York, N.Y., Hyperion.
- Gordon, H. S. (1954). "The Economic Theory of a Common-Property Resource: The Fishery." *Journal of Political Economy* 62(2): 124-142.
- Goyal, S. (2007). *Connections: An Introduction to the Economics of Networks*. Princeton, N.J., Princeton University Press.
- Green, D. P. and I. Shapiro (1994). *Pathologies of Rational Choice Theory: A Critique of Applications in Political Science*. New Haven, Conn., Yale University Press.
- Griffin, A. F. and C. Stanish (2007). "An Agent-based Model of Prehistoric Settlement Patterns and Political Consolidation in the Lake Titicaca Basin of Peru and Bolivia." *Structure and Dynamics: eJournal of Anthropological and Related Sciences* 2(2).
- Grimm, V. and S. F. Railsback (2005). *Individual-based Modeling and Ecology*. Princeton, N.J., Princeton University Press.
- Grimm, V., E. Revilla, U. Berger, F. Jeltsch, W. M. Mooij, S. F. Reilsback, H.-H. Thulke, J. Weiner, T. Wiegand and D. L. DeAngelis (2005). "Pattern-Oriented Modeling of Agent-Based Complex Systems: Lessons from Ecology." *Science* 310: 987-991.
- Groen, D. (2016). *Simulating Refugee Movements: Where would you go?* *Procedia Computer Science, International Conference on Computational Science (ICCS 2016)*. San Diego, CA, Elsevier: 2251-2255.
- Guerrero, O. A. and R. L. Axtell (2013). "Employment Growth through Labor Flow Networks." *PLoS ONE* 8(5): e60808.
- Gulden, T. (2004). *Adaptive Agent Modelling in a Policy Context* Ph.D., University of Maryland.
- Guvenen, F. (2011). *Macroeconomics with Heterogeneity: A Practical Guide*. *NBER Working Paper Series*. Cambridge, Mass.
- Ha, V. and G. Lykotafitis (2012). "Agent-based modeling of a multi-room multi-floor building emergency evacuation." *Physica A: Statistical Mechanics and its Applications* 391(8): 2740-2751.
- Hahn, R. W. and R. L. Axtell (1995). "Reevaluating the Relationship between Transferable Property Rights and Command-and-Control Regulation." *Journal of Regulatory Economics* 8(2): 125-148.

- Hailu, A. and S. Schilizzi (2005). Learning in a "Basket of Crabs": An Agent-Based Computational Model of Repeated Conservation Auctions. Nonlinear Dynamics and Heterogeneous Interacting Agents. T. Lux, S. Reitz and E. Samanidou. New York, N.Y., Springer. 550: 27-39.
- Hall, B.W. (1987). "The Relationship Between Firm Size and Firm Growth in the U.S. Manufacturing Sector." Journal of Industrial Economics 35: 583-606.
- Halloran, M. E., N. M. Ferguson, S. Eubank, I. M. Longini Jr., D. A. T. Cummings, B. Lewis, S. Xu, C. Fraser, A. Vullikanti, T. C. Germann, D. Wagener, R. Beckman, K. Kadau, C. Barrett, C. A. Macken, D. S. Burke and P. Cooley (2008). "Modeling targeted layered containment of an influenza pandemic in the United States." Proc Natl Acad Sci U S A 105(12): 4639-4644.
- Hedstrom, P. (2005). Dissecting the Social: On the Principles of Analytical Sociology. New York, N.Y., Cambridge University Press.
- Hegemann, R. A., L. M. Smith, A. B. T. Barbaro, A. L. Bertozzi, S. E. Reid and G. E. Tita (2011). "Geographical influences of an emerging network of gang rivalries." Physica A 390: 3894-3914.
- Helbing, D., I. J. Farkas and T. Vicsek (2000). "Simulating Dynamical Features of Escape Panic." Nature 407: 487-490.
- Hemelrijk, C. K. and H. Hildenbrandt (2011). "Some Causes of the Variable Shape of Flocks of Birds." PLOS One.
- Heppenstall, A. J., A. T. Crooks, L. M. See and M. Batty, Eds. (2012). Agent-Based Models of Geographical Systems. Netherlands, Springer.
- Holland, J. H. (1995). Hidden Order: How Adaptation Builds Complexity. New York, N.Y., Perseus Press.
- (1998). Emergence: From Chaos to Order. Reading, Mass., Perseus.
- (2012). Signals and Boundaries: Building Blocks for Complex Adaptive Systems. Cambridge, Mass., MIT Press.
- Howitt, P. and R. Clower (2000). "The Emergence of Economic Organization." Journal of Economic Behavior and Organization 41(1): 55-84.
- Huberman, B. A. and N. S. Glance (1993). "Evolutionary Games and Computer Simulations." Proc Natl Acad Sci U S A 90: 7716-7718.
- Ijiri, Y. and H. A. Simon (1964). "Business Firm Growth and Size." American Economic Review 54: 77-89.
- (1967). "A Model of Business Firm Growth." Econometrica 35(2): 348-355.
- (1977). Skew Distributions and the Sizes of Business Firms. New York, N.Y., North-Holland.
- Ilchinski, A. (2004). Artificial War: Multiagent-Based Simulation of Combat. Singapore, World Scientific Publishing.
- Jackson, M. O. (2008). Social and Economic Networks. Princeton, N.J., Princeton University Press.
- Jacobs, J. (1970). The Economy of Cities. New York, N.Y., Vintage Books.
- (1992). The Death and Life of Great American Cities. New York, N.Y., Vintage Books.
- Jin, E. M., M. Girvan and M. E. J. Newman (2001). "The Structure of Growing Social Networks." Physical Review E 64.
- Johnson, N. F., S. Carran, J. Botner, K. Fontaine, N. Laxague, P. Nuetzel, J. Turnley and B. Tivnan (2011). "Pattern in Escalations in Insurgent and Terrorist Activity." Science 333(6038): 81-84.
- Johnson, N. F., P. Jefferies and P. M. Hui (2003). Financial Market Complexity: What Physics Can Tell Us About Market Behavior. New York, N.Y., Oxford University Press.
- Kaldor, N. (1972). "The Irrelevance of Equilibrium Economics." Economic Journal 82(328): 1237-1255.
- (1985). Economics without Equilibrium. Cardiff, U.K., University College Cardiff Press.
- Keane, C., J. E. Egan and M. Hawk (2018). "Effects of naloxone distribution to likely bystanders: Results of an agent-based model." International Journal of Drug Policy 55: 61-69.
- Kindleberger, C. P. (2005). Manias, Panics and Crashes: A History of Financial Crises. New York, New York, John Wiley & Sons, Inc.
- Kirman, A. P. (1992). "Whom or What Does the Representative Individual Represent?" Journal of Economic Perspectives 6(2): 117-136.

- Kirman, A. P. (1997). The Economy as an Interactive System. The Economy as an Evolving Complex System II. W. B. Arthur, S. N. Durlauf and D. A. Lane. Reading, Mass., Addison-Wesley.
- Kiyotaki, N. and R. Wright (1989). "On Money as a Medium of Exchange." Journal of Political Economy 97(4): 927-954.
- Koesrindartoto, D. (2004). Treasury Auctions, Uniform or Discriminatory?: An Agent-Based Approach. Iowa State University, Department of Economics Working Paper Series. Ames, Iowa.
- Kohler, H.-P. (2001). Fertility and Social Interactions. New York, N.Y., Oxford University Press.
- Kohler, T. A. and G. J. Gumerman, Eds. (2000). Dynamics in Human and Primate Societies: Agent-Based Modeling of Social and Spatial Processes. Santa Fe Institute Studies in the Sciences of Complexity. New York, N.Y., Oxford University Press.
- Kohler, T. A., G. J. Gumerman and R. G. Reynolds (2005). Simulating Ancient Societies. Scientific American: 76-84.
- Kohler, T. A., J. Kresl, C. R. Van West, E. Carr and R. H. Wilshusen (1999). Be There Then: A Modeling Approach to Settlement Determinants and Spatial Efficiency Among Late Ancestral Pueblo Populations of the Mesa Verde Region, U.S. Southwest. Dynamics in Human and Primate Societies. T. A. Kohler and G. J. Gumerman. New York, N.Y., Oxford University Press.
- Kohn, M. (2004). "Value and Exchange." The Cato Journal 24(3): 303-339.
- Kollman, K., J. H. Miller and S. E. Page (1992). "Adaptive Parties in Spatial Elections." American Political Science Review 86: 929-937.
- (1997). Computational Political Economy. The Economy as an Evolving Complex System II. W. B. Arthur, S. N. Durlauf and D. A. Lane. Reading, Mass., Addison-Wesley.
- (1997). "Political Institutions and Sorting in a Tiebout Model." American Economic Review 87(5): 977-992.
- Krugman, P. (1996). The Self-Organizing Economy. New York, N.Y., Blackwell.
- Kuznar, L. A. (2006). "High-Fidelity Computational Social Science in Anthropology." Social Science Computer Review 24(1): 15-29.
- Kwasnicki, W. (1998). "Skewed Distribution of Firm Sizes--An Evolutionary Perspective." Structural Change and Economic Dynamics 9: 135-158.
- Langton, C. G., C. Taylor, J. D. Farmer and S. Rasmussen, Eds. (1991). Artificial Life II. Santa Fe Institute Studies in the Sciences of Complexity, Proceedings Volume X. Reading, Mass., Addison-Wesley Publishing.
- Laskowski, M., B. Demianyk, M. R. Friesen and R. D. McLeod (2010). Uncertainties inherent in RFID tracking systems in an emergency department. Workshop on Health Care Management. Venice, Italy, IEEE.
- Laskowski, M., B. C. P. Demianyk, J. Witt, S. N. Mukhi, M. R. Friesen and R. D. McLeod (2011). "Agent-Based Modeling of the Spread of Influenza-Like Illness in an Emergency Department: A Simulation Study." IEEE Transactions on Information Technology in Biomedicine 15(6): 877-889.
- Laughlin, R. B. and D. Pines (2000). "The Theory of Everything." Proc Natl Acad Sci U S A 97(1): 28-31.
- Laver, M. and E. Sergenti (2011). Party Competition: An Agent-Based Model. Princeton, NJ, Princeton University Press.
- Lawson, B. G. and S. Park (2000). "Asynchronous Time Evolution in an Artificial Society Model." Journal of Artificial Societies and Social Simulation 3(1).
- LeBaron, B. (2000). "Agent-Based Computational Finance: Suggested Readings and Early Research." Journal of Economic Dynamics and Control 24: 324-338.
- (2001). "A Builder's Guide to Agent-Based Financial Markets." Quantitative Finance 1: 254-261.
- (2001). "Empirical Regularities from Interacting Long and Short Memory Investors in an Agent-Based Stock Market." IEEE Transactions on Evolutionary Computation 5: 442-455.
- (2001). "Evolution and Time Horizons in an Agent-Based Stock Market." Macroeconomic Dynamics 5: 225-254.
- (2001). Financial Market Efficiency in a Coevolutionary Environment. Agents 2000: The Simulation of Social Agents: Architectures and Institutions, Chicago, Ill., Argonne National Laboratory.



- (2001). "Stochastic Volatility as a Simple Generator of Apparent financial Power Laws and Long Memory." Quantitative Finance 1: 621-631.
- (2002). "Short-Memory Traders and Their Impact on Group Learning in Financial Markets." Proc Natl Acad Sci U S A 99(suppl 3): 7201-7206.
- Leijonhufvud, A. (1999). Microfoundations: Adaptive or Optimizing? Money, Markets and Method: Essays in Honour of Robert W. Clower. P. Howitt, E. De Antoni and A. Leijonhufvud. Northampton, Mass., Edward Elgar Publishing.
- Levy, H., M. Levy and S. Solomon (2000). Microscopic Simulation of Financial Markets: From Investor behavior to Market Phenomena. New York, N.Y., Academic Press.
- Li, Y., N. Kong, M. A. Lawley and J. A. Pagán (2018). An Agent-Based Model for Ideal Cardiovascular Health. Decision Analytics and Optimization in Disease Prevention and Treatment. N. King and S. Zhang. Hoboken, NJ, Wiley.
- Li, Y., M. A. Lawley, D. S. Siscovick, D. Zhand and J. A. Pagán (2016). "Agent-Based Modeling of Chronic Diseases: A Narrative Review and Future Research Directions." Preventing Chronic Disease: Public Health Research, Practice, and Policy 13(150561).
- Liljeros, F., C. R. Edling, L. A. N. Amaral, H. E. Stanley and Y. Abert (2001). "The Web of Human Sexual Contracts." Nature 411: 907-908.
- Lindgren, K. (1992). Evolutionary Phenomena in Simple Dynamics. Artificial Life II. C. G. Langton, C. Taylor, J. D. Farmer and S. Rasmussen. Redwood City, Calif. Addison-Wesley.
- Lomi, A. and E. R. Larsen, Eds. (2001). Dynamics of Organizations: Computational Modeling and Organization Theories. Cambridge, Mass., MIT Press.
- Longini Jr., I. M., A. Nizam, S. Xu, K. Ungchusak, W. Hanshaoworakui, D. A. T. Cummings and M. E. Halloran (2005). "Containing Pandemic Influenza at the Source." Science 309: 1083-1087.
- Luce, R. D. and H. Raiffa (1957). Games and Decisions: Introduction and Critical Survey. New York, N.Y., John Wiley & Sons.
- Luke, D. A., R. A. Hammond, T. Combs, A. Sorg, M. Kasman, A. Mack-Crane, K. M. Ribisl and L. Henriksen (2017). "Tobacco Town: Computational Modeling of Policy Options to Reduce Tobacco Retailer Density." American Journal of Public Health 107(5): 740-746.
- Luke, D. A. and K. A. Stamatakis (2012). "Systems Science Methods in Public Health: Dynamics, Networks, and Agents." Annual Review of Public Health 33: 357-376.
- Luke, S., C. Cioffi-Revilla, L. Panait, K. Sullivan and G. Balan (2005). "MASON: A Multiagent Simulation Environment." SIMULATION 81(7): 517-527.
- Lustick, I. S., D. Miodownik and R. J. Eidelson (2004). "Secessionism in Multicultural States: Does Sharing Power Prevent or Encourage It?" American Political Science Review 98(2): 209-229.
- Luttmer, E. G. J. (2011). "On the Mechanics of Firm Growth." Review of Economic Studies 78(3): 1042-1068.
- Lux, T. (1998). "The Socioeconomic Dynamics of Speculative Markets: Interacting Agents, Chaos and the Fat Tails of Return Distributions." Journal of Economic Behavior and Organization 33: 143-165.
- Lux, T. and M. Marchesi (1999). "Scaling and Criticality in a Stochastic Multi-Agent Model of a Financial Market." Nature 397: 498-500.
- MacKerrow, E. P. (2003). "Understanding Why -- Dissecting Islamist terrorism with Agent-Based Simulation." Los Alamos Science 28.
- Macy, M. W. and R. Willer (2002). "From Factors to Actors: Computational Sociology and Agent-Based Modeling." Annual Review of Sociology 28: 143-166.
- Madey, G. (2008). The SourceForge Research Data Archive, University of Notre Dame.
- Magliocca, N., E. Safirova, V. McConnell and M. Walls (2011). "An economic agent-based model of coupled housing and land markets (CHALMS)." Computers, Environment and Urban Systems 35: 183-191.

- Mahabir, R., A. T. Crooks, A. Croitoru and P. Agouris (2016). "The study of slums as social and physical constructs: challenges and emerging research opportunities." Regional Studies, Regional Science 3(1): 399-419.
- Mandelbrot, B. (1997). *Fractals and Scaling in Finance: Discontinuity, Concentration and Risk*. New York, N.Y., Springer-Verlag.
- Marimon, R., E. McGrattan and T. J. Sargent (1990). "Money as a Medium of Exchange in an Economy with Artificially Intelligent Agents." Journal of Economic Dynamics and Control 14: 329-373.
- McAnany, P. A. and N. Yoffee, Eds. (2010). *Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire*. New York, N.Y., Cambridge University Press.
- McBride, W. A. (2010). *Banking and Asset Bubbles: Testing the Theory of Free Banking using Agent-Based Computer Simulation and Laboratory Experiments* Ph.D., George Mason University.
- McCue, B. (2006). *U-Boats in the Bay of Biscay*. Alidade Press: Newport, Rhode Island.
- McFadden, D. and P. A. Ruud (1994). "Estimation by Simulation." The Review of Economics and Statistics LXXVI(4): 591.
- McNeill, W. H. (1976). *Plagues and Peoples*. New York, N.Y., Anchor Press/Doubleday.
- McNerney, J., J. D. Farmer and J. E. Trancik (2011). "Role of design complexity in technology improvement." Proc Natl Acad Sci U S A 108(22): 9008-9013.
- Melitz, M. J. (2003). "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." Econometrica 71(6): 1695-1725.
- Menger, C. (1892). "On the Origin of Money." Economic Journal 2: 239-255.
- Miller, J. H. and S. E. Page (2007). *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. Princeton, N.J., Princeton University Press.
- Mitzenmacher, M. (2004). "A Brief History of Generative Models for Power Law and Lognormal Distributions." Internet Mathematics 1(2): 226-251.
- Mohr, J. J., S. Sengupta and S. Slater (2009). *Marketing of High-Technology Products and Innovations*, Prentice Hall.
- Mokyr, J. (1987). "Has the Industrial Revolution Been Crowded Out? Some Reflections on Crafts and Williamson." Explorations in Economic History 24(3): 293-319.
- (1990). *Was there a British Industrial Revolution? The Vital One: Essays Presented to Jonathan R.T. Hughes*. J. Mokyr. Greenwich, Conn., JAI Press: 253-286.
- , Ed. (1998). *The British Industrial Revolution: An Economic Perspective*. Boulder, Colorado, Westview Press.
- (2009). *The Enlightened Economy: An Economic History of Britain 1700-1850*. New Haven, Conn., Yale University Press.
- Moore, G. A. (1991). *Crossing the Chasm*. New York, N.Y., Harper Business Essentials.
- Morgan, L. H. (1851). *The League of the Ho-de-no-sau-nee or Iroquois*. Rochester, NY, Sage and Brothers.
- Morris, M. (1997). "Sexual Networks and HIV." AIDS 11: S209-S216.
- Morris, S. (2000). "Contagion." Review of Economic Studies 67(1): 57-78.
- Nelson, A. (2006). *Self-Organising Skew Distributions in an Agent-Based Model with Applications to Gibrat's Law* Ph.D., University of Dublin, Trinity College.
- Newman, M. E. J. (2010). *Networks: An Introduction*. New York, N.Y., Oxford University Press.
- Newman, M. E. J., A.-L. Barabasi and D. J. Watts (2006). *The Structure and Dynamics of Networks*. Princeton, N.J., Princeton University Press.
- Newman, M. E. J., D. J. Watts and S. H. Strogatz (2002). "Random Graph Models of Social Networks." Proc Natl Acad Sci U S A 99(suppl. 1): 2566-2572.
- North, M. J., N. T. Collier and J. R. Vos (2006). "Experiences Creating Three Implementations of the Repast Agent Modeling Toolkit." ACM Transactions on Modeling and Computer Simulation 16(1): 1-25.
- North, M. J. and C. M. Macal (2007). *Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation*. New York, N.Y., Oxford University Press.

- Nowak, M. A. and R. M. May (1992). "Evolutionary Games and Spatial Chaos." Nature 359: 827-829.
- O'Hare, G. M. P. and N. R. Jennings (1996). *Foundations of Distributed Artificial Intelligence*. New York, N.Y., Wiley.
- Ormerod, P. (2005). *Why Most Things Fail: Evolution, Extinction and Economics*. London, U.K., Faber & Faber.
- Osborne, M. J. and A. Rubinstein (1994). A Course in Game Theory. Cambridge, Mass., MIT Press.
- Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. New York, N.Y., Cambridge University Press.
- Ostrom, E., R. Gardner and J. Walker, Eds. (1994). Rules, Games, and Common Pool Resources. Ann Arbor, Michigan, University of Michigan Press.
- Padgett, J. (1997). *The Emergence of Simple Ecologies of Skill: A Hypercycle Approach to Economic Organization. The Economy as an Evolving Complex System II*. W. B. Arthur, S. N. Durlauf and D. A. Lane, Westview Press.
- Palmer, N. M. (2015). *Individual and Social Learning: An Implementation of Bounded Rationality from First Principles* Ph.D., Computational Social Science, George Mason University.
- Pancs, R. and N. J. Vriend (2007). "Schellings's spatial proximity model of segregation revisited." Journal of Public Economics 91(1-2): 1-24.
- Parker, D., S. Manson, M. Janssen, M. Hoffman and P. Deadman (2003). "Multi-Agent Systems for the Simulation of Land Use and Land Cover Change: A Review." Annals of the Association of American Geographers 93(2): 314-337.
- Parker, M. T. (2001). "What is Ascape and Why Should You Care?" Journal of Artificial Societies and Social Simulation 4(1).
- Parsons, S., P. J. Gmytrasiewicz and M. Wooldridge, Eds. (2002). Game Theory and Decision Theory in Agent-Based Systems. Boston, Mass., Kluwer Academic Publishers.
- Parsons, T. (1937). *The Structure of Social Action, Volume I: Marshall, Pareto, Durkheim*. New York, N.Y., McGraw-Hill Book Company, Inc.
- (1937). *The Structure of Social Action, Volume II: Weber*. New York, N.Y., McGraw-Hill Book Company, Inc.
- Pastor-Satorras, R. and A. Vespignani (2001). "Immunication of Complex Networks." Physical Review Letters 86: 3200-3203.
- Perline, R. (2005). "Strong, Weak and False Inverse Power Laws." Statistical Science 20(1): 68-88.
- Perline, R., R. Axtell and D. Teitelbaum (2006). *Volatility and Asymmetry of Small Firm Growth Rates Over Increasing Time Frames*. SBA Research Reports. Washington, D.C.
- Plott, C. (1986). *Rational Choice in Experimental Markets*. Rational Choice: The Contrast between Economics and Psychology. R. M. Hogarth and M. W. Reder. Chicago, Ill., University of Chicago Press.
- Prietula, M. J., K. M. Carley and L. Gasser, Eds. (1998). *Simulating Organizations: Computational Models of Institutions and Groups*. Cambridge, Mass., MIT Press.
- Rauch, J. (2002). *Seeing Around Corners*. The Atlantic Monthly. 289: 35-48.
- Reinhart, C. M. and K. S. Rogoff (2009). *This Time is Different: Eight Centuries of Financial Folly*. Princeton, N.J., Princeton University Press.
- Resnick, M. (1994). *Turtles, Termites and Traffic Jams: Explorations in Massively Parallel Microworlds*. Cambridge, Mass., MIT Press.
- Reynolds, C. W. (1987). "Flocks, Herds, and Schools: A Distributed Behavioral Model." Computer Graphics 21(4): 25-34.
- Reynolds, R. G. (1999). *The Impact of Raiding on Settlement Patterns in the Northern Valley of Oaxaca: An Approach Using Decision Trees*. Dynamics in Human and Primate Societies. T. A. Kohler and G. J. Gumerman. New York, N.Y., Oxford University Press.
- Riolo, R. L., R. Axelrod and M. D. Cohen (2001). "Evolution of Cooperation without Reciprocity." Nature 414: 441-443.
- Romer, D. (2006). "Do Firms Maximize? Evidence from Professional Football." Journal of Political Economy 114(2): 340-365.

- Rosenschein, J. S. and G. Zlotkin (1994). *Rules of Encounter: Designing Conventions for Automated Negotiation among Computers*. Cambridge, Mass., MIT Press.
- Rosser, J., J. Barkley (2002). "Implications for Fisheries Policy of Complex Ecologic-Economic Dynamics." *Nonlinear Dynamics, Psychology, and Life Sciences* 6(2): 103-120.
- Rubinstein, A. (1998). *Modeling Bounded Rationality*. Cambridge, Mass., MIT Press.
- Rutherford, G., M. R. Friesen and R. D. McLeod (2012). "An Agent Based Model for Simulating the Spread of Sexually Transmitted Infections." *Online Journal of Public Health Informatics* 4(3).
- Saichev, A., Y. Malevergne and D. Sornette (2010). *Theory of Zipf's Law and Beyond*. New York, N.Y., Springer-Verlag.
- Schelling, T. C. (1971). "Dynamic Models of Segregation." *Journal of Mathematical Sociology* 1: 143-186.
- (1978). *Micromotives and Macrobehavior*. New York, N.Y., Norton.
- Schwartz, G. M. and J. J. Nichols, Eds. (2006). *After Collapse: The Regeneration of Complex Societies*. Tucson, Arizona, The University of Arizona Press.
- Scott, J. (1991). *Social Network Analysis: A Handbook*. Thousand Oaks, Calif., Sage Publications.
- Scott, S. L. (2016). *Computational Modeling for Marine Resource Management* Ph.D., Computational Social Science, George Mason University.
- Sen, A. K. (1990). "More Than 100 Million Women are Missing." *The New York Review of Books*.
- Shoham, D. A., R. Hammond, H. Rahmandad, Y. Wang and P. Hovmand (2015). "Modeling Social Norms and Social Influence in Obesity." *Current Epidemiology Reports* 2: 71-79.
- Shoham, Y. and K. Layton-Brown (2009). *Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations*. New York, N.Y., Cambridge University Press.
- Simon, H. A. (1955). "A Behavioral Model of Rational Choice." *Quarterly Journal of Economics* 69(1): 99-118.
- (1955). "On a Class of Skew Distribution Functions." *Biometrika* 42: 425-440.
- (1956). "Rational Choice and the Structure of the Environment." *Psychological Review* 63(2): 129-138.
- (1978). "Rationality as Process and as Product of Thought." *American Economic Review, Papers and Proceedings* 68(2): 1-16.
- (1996). *The Sciences of the Artificial*. Cambridge, Mass., MIT Press.
- Simon, H. A. and C. Bonini (1958). "The Size Distribution of Business Firms." *American Economic Review* 48(4): 607-617.
- Skyrms, B. (2004). *The Stag Hunt and the Evolution of Social Structure*. Cambridge, U.K., Cambridge University Press.
- (2010). *Signals: Evolution, Learning, and Information*. New York, N.Y., Oxford University Press.
- Smale, S. (2007). "The Mathematics of Emergence." *Japanese Journal of Mathematics* 2(1): 197-227.
- Sornette, D. (2003). *Why Stock Markets Crash? Critical Events in Complex Financial Systems*. Princeton, N.J., Princeton University Press.
- Spies, T. A., E. White, A. Ager, J. D. Kline, J. P. Bolte, E. K. Platt, K. A. Olsen, R. J. Pabst, A. M. G. Barros, J. D. Bailey, S. Charnley, A. T. Morzillo, J. Koch, M. M. Steen-Adams, P. H. Singleton, J. Sulzman, C. Schwartz and B. Csuti (2017). "Using an agent-based model to examine forest management outcomes in a fire-prone landscape in Oregon, USA." *Ecology and Society* 22(1): 25.
- Stefanidis, A., A. T. Crooks and J. Radzikowski (2013). "Harvesting ambient geospatial information from social media feeds." *GeoJournal* 78(2): 319-338.
- Steindl, J. (1965). *Random Processes and the Growth of Firms*. New York, N.Y., Hafner Publishing Company.
- Sterman, J. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. New York, N.Y., McGraw-Hill.
- Strogatz, S. H. (2003). *Sync: The Emerging Science of Spontaneous Order*. New York, N.Y., Theia.
- Sutton, J. (1997). "Gibrat's Legacy." *Journal of Economic Literature* XXXV(1): 40-59.
- Taintner, J. A. (1988). *The Collapse of Complex Societies*. Cambridge, U.K., Cambridge University Press.

- Taleb, N. N. (2007). The Black Swan. New York, N.Y., Random House.
- Tesfatsion, L. (1997). How Economists Can Get A Life. The Economy as an Evolving Complex System, Volume II. W. B. Arthur, S. Durlauf and D. A. Lane. Menlo Park, Calif., Addison-Wesley.
- (2001). "Structure, Behavior, and Market Power in an Evolutionary Labor Market with Adaptive Search." Journal of Economic Dynamics and Control 25: 419-457.
- Thurner, S., J. D. Farmer and J. Geanakoplos (Forthcoming). "The Regulation of Risk and the Risk of Regulation." American Economic Review.
- Tilles, P. F. C., F. F. Ferreira, G. Francisco, C. d. B. P. Pereira and F. M. Sarti (2011). "A Markovian model market Akerlof's lmons and the asymmetry of information." Physica A 390: 2562-2570.
- Troitzsch, K. G., U. Mueller, G. N. Gilbert and J. E. Doran, Eds. (1996). Social Science Microsimulation. New York, N.Y., Springer-Verlag.
- Valente, T. (1995). Network Models of the Diffusion of Innovations. Cresskill, N.J., Hampton Press.
- (1996). "Social Network Thresholds in the Diffusion of Innovations." Social Networks 18: 69-89.
- Vandell, K. D. and B. Harrison (1978). "Racial Transition among Neighborhoods: A Simulation Model Incorporating Institutional Parameters." Journal of Urban Economics 5: 441-470.
- Veetil, V. P. (2016). Network-based Macroeconomics: A Preliminary Investigation Ph.D., George Mason University.
- Vega-Redondo, F. (1996). Evolution, Games, and Economic Behavior. New York, N.Y., Oxford University Press.
- (2007). Complex Social Networks. New York, N.Y., Cambridge University Press.
- Vinkovic, D. and A. P. Kirman (2006). "A physical analogue of the Schelling model." Proc Natl Acad Sci U S A 103(51): 19261-19265.
- Vohra, R. V. and M. P. Wellman (2007). "Foundations of multi-agent learning: Introduction to the special issue." Artificial Intelligence 171: 363-364.
- von Neumann, J. and A. W. Burks (1966). Theory of Self-Reproducing Automata. Urbana, Ill., University of Illinois Press.
- Vynnycky, E. and R. G. White (2010). An Introduction to Infectious Disease Modelling. New York, N.Y., Oxford University Press.
- Wallace, R., A. Geller and V. A. Ogawa, Eds. (2015). Assessing the Use of Agent-Based Models for Tobacco Regulation. Washington, D.C., The National Academies Press.
- Wasserman, S. and K. Faust (1994). Social Network Analysis: Methods and Applications. New York, N.Y., Cambridge University Press.
- Waters, K. (2019). Firm Formation and Regional Labor Allocation Ph.D., George Mason University.
- Watts, D. (1999). Small Worlds: The Dynamics of Networks between Order and Randomness. Princeton, N.J., Princeton University Press.
- Watts, D. J. (1999). "Networks, Dynamics and the Small-World Phenomenon." American Journal of Sociology 105: 493-527.
- (2002). "A Simple Model of Global Cascades on Random Networks." Proc Natl Acad Sci U S A 99(9): 5766-5771.
- Watts, D. J. and S. H. Strogatz (1998). "Collective Dynamics of Small-World Networks." Nature 393: 440-442.
- Weibull, J. (1997). Evolutionary Game Theory. Cambridge, Mass., MIT Press.
- Weitzman, M. L. (1974). "Prices vs. Quantities." Review of Economic Studies 41: 477-491.
- Wilensky, U. and W. Rand (2015). An Introduction to Agent-Based Modeling: Modeling Natural, Social, and Engineered Complex Systems with NetLogo. Cambridge, Mass., MIT Press.
- Wilhite, A. (2001). "Bilateral Trade and 'Small-World' Networks." Computational Economics 18(1): 49-64.
- Wise, S. (2014). Humanitarian Agent-Based Modeling for Crisis Response Ph.D., Computational Social Science, George Mason University.
- Wooldridge, M. (2002). An Introduction to Multi-Agent Systems. West Sussex, England, John Wiley & Sons.
- Wooldridge, M., J.-P. Muller and M. Tambe, Eds. (1996). Intelligent Agents II: Agent Theories, Architectures and Languages. Lecture Notes in Artificial Intelligence. Berlin, Springer-Verlag.

- Wooldridge, M. J. and N. R. Jennings, Eds. (1995). Intelligent Agents. Lecture Notes in Artificial Intelligence. Berlin, Springer-Verlag.
- Young, H. P., Ed. (1985). Cost Allocation Methods, Principles and Applications. New York, N.Y., North Holland Publishing Company.
- (1998). Individual Strategy and Social Structure. Princeton, N.J., Princeton University Press.
- (1999). Diffusion in Social Networks. Center on Social and Economic Dynamics working paper. Washington, D.C., Brookings Institution.
- Zhang, J. (2001). An Evolutionary Approach to Residential Segregation, Johns Hopkins University.
- (2004). "A Dynamic Model of Residential Segregation." Journal of Mathematical Sociology 28: 147-170.
- (2004). "Residential Segregation in an All-Integrationist World." Journal of Economic Behavior and Organization 54(4): 533-550.
- (2011). "Tipping and Residential Segregation." Journal of Regional Science 51: 167-193.