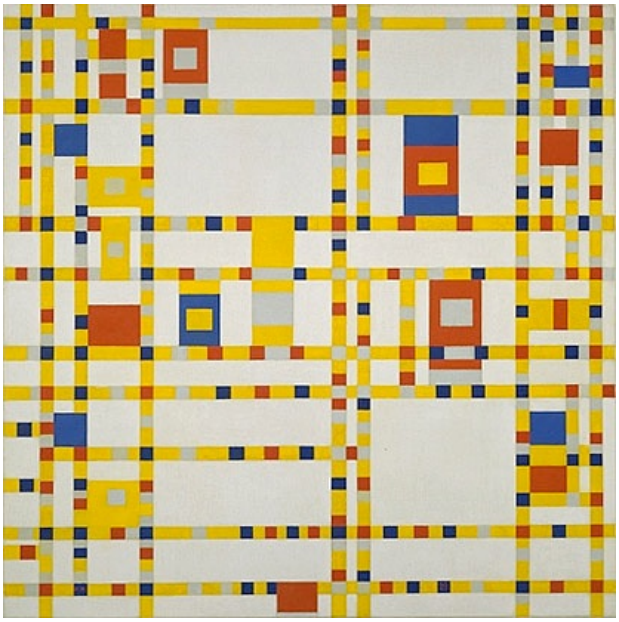
CSS 610: Agent-Based Modeling and Simulation

Spring 2015

Motivation for the Course

The social sciences concern interactions between purposively-behaving actors. 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, 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 also 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 low level protocols are specified and the overall behavior of the 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 social insects and mammal populations. At the fringes of biology so-called *artificial life* 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 agent models in software.

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Website css610.wikispaces.com **userid**: registered students will be invited to join
Doodle scheduler for model demos and book reviews: doodle.com/k45g7e4vssygedai

Office hours I have an 'open door' policy if my door is open you are welcome to stop in. If I am not my office ask Karen Underwood about my schedule. Fridays are the easiest time to find me.

Texts

There is not really a textbook for this class. Sections from my textbook manuscript will be distributed via the website. We will use Railsback and Grimm as background. It has good discussions but is not very technical. It is based on NetLogo, which is fine to use for the homework assignments and term project but some of you will probably want to use Java, MASON, or RePast instead. We will also read most of Schelling (1978) and go through most of my Sugarscape model (week 10).

Agent-Based and Individual-Based Modeling: A Practical Introduction, Steven F. Railsback and Volker Grimm, Princeton University Press (Princeton, N.J., 2011). NetLogo-based introduction to agent computing; somewhat introductory, rather informal, abstracts from details and provides only heuristic treatment of many topics we will go into in detail.

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 level and aggregate behavior. This book has proven to be very fertile for research topics that have subsequently been implemented with agents.

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

Beyond this, the following volumes should prove useful, depending on your field/discipline:

Discrete-Event Simulation: A First Course, Lawrence Leemis and Steve Park. Several editions available; I own the December 2004 version and there is a link to this on the course website. Covers classical material on conventional simulation methodology, useful primarily if you have never built a simulation 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 and simulation.

Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations. Yoav Shoham and Kevin Layton-Brown, Cambridge University Press (N.Y., 2008). Recent MAS volume 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`. It is a good reference for computer scientists and game theorists interested in computational/algorithmic issues.

Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence. Gerhard Weiss, editor. MIT Press (Cambridge, Massachusetts, 1999). Early cross-section of work in MAS. Increasingly archaic.

Prerequisites

Students should have working knowledge of at least one computer programming language (e.g., C/C++, Java, Python/Julia, Objective-C, Lisp/Scheme, Pascal/Delphi, BASIC, FORTRAN, Ruby,,…), preferably one having some object orientation (e.g., C++, Java, Python) but this is not essential. Solid knowledge of a mathematical or statistics package (e.g., MatLab, Mathematica, Maple, Macsyma, R, Stata, Gauss, possibly Excel) may substitute, as would a commitment to learning a high-level agent programming system (e.g., NetLogo , StarLogoT or AgentSheets). CSS 600 is recommended as a prerequisite 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 is often a substitute for preparation.

Pedagogical Goals

We will be building representations of individual people in software, giving them plausible motivations and behavior, things to trade, data-gathering abilities, and cognitive capabilities. We will then let these software objects interact directly in social environments and study what happens. When we build such agent models in the context of known models we are in essence 'agentizing' the standard models. When we build agent models without conventional counterparts then we are normally 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 provide me the text part in hardcopy. The text and code is to be submitted to the online folder I set up for you, and must include the following as comments at the beginning of the code: (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 be basis for a reduced grade. **10 homework assignments @ 5% each = 50%**, 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 (50% of keystrokes), 1 pt for coherent write-up, 1 pt for the right answer; homework is to be deposited into your folder by midnight on the Monday before class; each week or fraction of a week that a homework assignment is late costs 1 pt; each week one student will be asked to present their homework to class; some weeks significantly harder homework assignments may be made available, worth double or triple credit.

Presentation of an agent-based model: The agent field has grown to such an extent that models exist in essentially every social science. 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 as 5% of your grade**, for both model description and competent manipulation of the model illustrating the main results.

Book review: Suggestions for books to review are listed below in the weekly schedule. These will also be allocated on a first-come, first-served basis. If possible, do not pick a book to review that you have already read the goal here is to get you to build on what you already know. (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.) 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 written with in-class presentation lasting no more than ten minutes. It will be **worth 5%,** graded equally on the basis of presentation and written review.

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 possible in certain cases. 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 extensions 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% of final grade**, based on the paper (25%), an early draft (5%) and in-class presentation (10%).

Typical Class

4:30-6:00	Lecture, model demonstration, and discussion
6:00-6:05	Break
6:05-6:15	Student presentation of previous HW assignment
6:15-6:30	Student book review or model demonstration
6:30-6:45	Student book review or model demonstration
6:45-7:00	Student book review or model demonstration
7:00-7:10	Handout of next week's homework assignment

With ~20 students, 40 book reviews and model demos means ~3/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 to 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 groups 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.

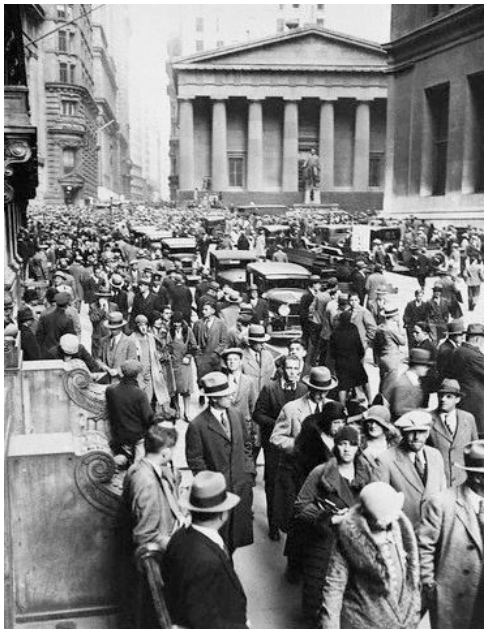
Everyone in the class is a graduate student (aside from the occasional precocious high schooler from TJ!) and therefore each of you is transitioning from being a 'student' to becoming an 'expert'. Specifically, Certificate and Master's degree students are expected to become capable of leveraging their 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 Department of Computational Social Sciences/Center for Social Complexity there exist the following hardware and operating systems:

1. Ganesha: 2 x 8 core CPUs (32 logical cores), 256GB RAM, NVIDIA GTX 680, 2 x 30" displays, Fedora 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, 30" display, MacOS
4. Oxford: 2 x 4 core CPUs (hyperthreaded, 16 logical cores), 32 GB, ATI Radeon 5770, 30" display, MacOS
5. Cambridge: 2 x 4 core CPUs (hyperthreaded, 16 logical cores), 32 GB RAM, 30" display, MacOS
6. Dusk: 2 x 4 core CPUs, 32 GB RAM, 30" display, MacOS
7. Dawn: 2 x 4 core CPUs, 32 GB RAM, 24" display, MacOS

Weekly Schedule and Assignments



Week 1 (January 20th): **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) and Rauch (2002);
Deeper reading: Graduate students in the social sciences should read Axelrod (2003), economists should read Tesfatsion (1997) and Axtell (2007); Laughlin and Pines argue that 21st C science will be about *emergence* (Laughlin and Pines 2000);
Demo: Quick passes through various agent models;
Homework #0 (solo): Propose book to review and model to demo, due Jan 26th;
Homework #1 (solo): Basic computing skills, due January 26th.

Week 2 (January 27th): 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; concept of *agentization*;
Read: Gode and Sunder (1993);
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 (solo): ZI traders, due February 2nd;
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 (2001; 2001; 2001; 2001; 2002; 2001; 2000) as a group, the papers of Farmer and co-authors as a group (2009; 1999; 2005; 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 3rd; Dr. Ken Comer, guest lecturer): **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 #3 (group): Activation effects, due February 9th;
Books to review: Resnick (1994), Casti (1994; 1997), Holland (1998; 1995; 2012) and Miller and Page (2007).

Week 4 (February 10th): 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; establishment of social norms and conventions;

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

Deeper reading: Many good texts on this subject exist, at the upper undergraduate level (e.g., Binmore 1992; 2007) through advanced graduate level (e.g., Osborne and Rubinstein 1994; Fudenberg and Tirole 1991); computer science students should read Shoham and Layton-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 #4 (solo): Games played in a population of agents, due February 16th;

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 5 (February 17th): No class, University closed;

Homework #5 (solo): Extend homework #4, due Feb 23rd;

Week 6 (February 24th): Behavioral, computational and 'low rationality' **game theory**: games of incomplete information, 'fictitious play,' 'best reply' strategies and adaptive dynamics; behavioral game theory;

Read: Schelling (1978) chapter 3, Axtell, Epstein and Young (2001);

Deeper reading: Economics students should familiarize themselves with Camerer (2003); computer 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 #6 (group): Perturbed games, including noisy games, due March 2nd;

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 7 (March 3rd): Social network theory and practice for agent models; regular and random graphs, including 'small world,' Erdös-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 (2002; 1999), Watts (1999; 2002), and Newman and colleagues (2006; 2002; 2001); economists should look at 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);

Demo: Social norms of retirement (Axtell and Epstein 1999);

Homework #7 (solo): Game on graphs, due March 16th;

Homework #8 (group): Form project teams, select project, and email me your team composition and tentative subject over Spring Break;

Books to review: Scott (1991), Wasserman and Faust (1994), Valente (1995), Watts (1999), Barabasi (2002), Goyal (2007), Dorogovtsev and Mendes (2003), Vega-Redondo (2007), Jackson (2008), Barrat *et al.* (2010), Easley and Kleinberg (2010), and Newman (2010).

Spring Break (March 10th): No class.

Week 8 (March 17th): 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), Hedstrom's (2005) book is important for sociology students interested in agents; extensions of Schelling's basic models include Zhang (2004; 2004; 2001; 2011), Vinkovic and Kirman (2006), Benard and Willer (2007), Pancs 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 #9 (solo): Variations on Schelling segregation, due March 23rd;
Homework #10 (group): Each project team submit 1 page description of what you will work on, due March 23rd;
Books to review: Gilbert and Conte (1995), Troitzsch *et al.* (1996), Gaylord and D'Andria (1998), Gilbert and Troitzsch (1999), and Hedstrom (2005).

Week 9 (March 24th; guest lecturer): Agent-based software frameworks, focusing on **NetLogo** and **MASON**;
Read: Luke *et al.* (2005), North *et al.* (2006); skim Scott and Koehler (on website) and Scott;
Deeper reading: Ascape is an older framework (Parker 2001; Centola 2002);
Demo: Various NetLogo and MASON models;
Homework: Project week #1;
Books to review: O'Hare and Jennings (1996), Wooldridge and Jennings (1995) + Wooldridge and Mueller (1996), Wooldridge (2002), and North and Macal (2007).

Week 10 (March 31st): Application of agents to **organization science**; group formation via team production and multi-agent firms; further digression on power laws; discussion of empirical calibration of agent models;
Read: Axtell (2012), on website;
Deeper reading: Firm sizes (Axtell 2001; de Wit 2005; Simon 1955; Simon and Bonini 1958), ages (Coad 2010), growth (Bottazzi and Secchi 2006; Evans 1987; 1987; Hall 1987; Ijiri and Simon 1964; 1967; Perline, Axtell and Teitelbaum 2006; Sutton 1997; Coad 2008), and dynamics (Axtell 2002; Luttmer 2011; Kwasnicki 1998);
Demo: FIRMS model;
Homework: Project week #2;
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 11 (April 7th): 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 1-3; economists chapter 4; for disease models chapter 5;
Deeper reading: Lawson and Park (2000) demonstrated that the agent activation scheme in the Sugarscape model matters for population dynamics; Parker *et al.* (2003) review applications of agents to land use and cover change; Axtell *et al.* (2002) argue for the utility of agents in industrial ecology;
Demo: Sugarscape;
Homework: Project week #3;
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 12 (April 14th): 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;
Homework: Project week #4 submit draft paper with 5 pages of text and 5 pages of code + output;
Books to review: Axelrod (1997), Cederman (1997), the suite of papers by Kollman, Miller and Page (1997; 1997; 1992), and de Marchi (2005).

Week 13 (April 21st): **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: 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;
Homework: Project week #5;
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 28th): Application of agents to **anthropology** and **archaeology**; further discussion of empirical calibration of agent models;
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;
Homework: Project week #6;
Books to review: Taintner (1988), Gilbert and Doran (1994), Kohler and Gumerman (2000), Diamond (2004), Beekman and Baden (2005) and McAnany and Yoffe (2010).

Week 15 (May 5th): **Advanced topics** from among auctions, agents + GIS, agent-based traffic models, parallel execution (multi-threaded ABMs and concurrency, parallel activation regimes), large-scale models, data gathering (journalist and statistician) agents, narrative agents, epidemiology models, artificial life (ALife), ant colony (optimization), military combat models, 'swarm' optimization methods, and commercial applications of agent technology; implications of agents for public policy; 'participatory simulation';

Read: *TBD*;
Deeper reading: *TBD*
Demo: Various;
Homework: Project week #7;
Books/papers to review: Nagel and Barrett (1997; 1998; 1995; 1994), Bonabeau *et al.* (1999), Johnson (2001), Kennedy (2001), Schweitzer (2003; 2002), Longini and co-authors (2006; 2002; 2005), Ball (2004), Dorigo (2004), and Ilachinski (2004).

Final Exam Week (May 12th): Presentation of student project models; all **reports** due in hardcopy with code sent electronically by the start of class (4:30 PM).

Summary of Homework assignments

Homework #0 (solo): Propose book to review and model to demo, due January 27th;
Homework #1 (solo): Basic computing skills, due January 26th.
Homework #2 (solo): ZI traders, due February 2nd;
Homework #3 (group): Activation effects, due February 9th;
Homework #4 (solo): Games played in a population of agents, due February 16th;
Homework #5 (solo): Extend homework #4, due February 23rd;
Homework #6 (group): Perturbed games, including noisy games, due March 2nd;
Homework #7 (solo): Game on graphs, due March 16th;
Homework #8 (group): Form project teams, select project, and email me your team's composition and tentative subject over Spring Break;
Homework #9 (solo): Variations on Schelling segregation, due March 23rd;
Homework #10 (group): Each project team send 1 page description of what you will be working on by March 23rd.

Suggestions for Projects (those with * are feasible class demos)

Background for the course:

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

Anthropology and Archaeology (5)

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

Biology and Artificial Life (10)

6. *Bird flocking: fluid dynamics and bioenergetics (Reynolds 1987; Smale 2007).
7. *Ant colony dynamics (Bonabeau, Dorigo and Theraulaz 1999; Couzin and Franks 2003).
8. Fish schooling: predator avoidance (Couzin 2007).
9. *Emergence of leaders in animal groups (Couzin et al. 2005).
10. Disease agent propagation in 3D tissue (cellular automata) model; many models of this in biology.
11. Reimplement Nowak and May (1992).
12. Reimplement Fontana's 'algorithmic chemistry' (Langton et al. 1991).
13. Build the 'Game of Life' (e.g., Gardner 1970) using RePast or MASON.
14. Explore non-spatial 'self-reproducing automata' in the sense of von Neumann and Burks (1966) using agents.
15. Comb the *Artificial Life* volumes for social science models and reimplement one of them, e.g., Padgett (1997).

Demography (5)

16. Build a model of local social norms of fertility (Kohler 2001).
17. Compare the Leslie matrix (well-mixed) version of demography with a spatially-extended or network-based view; Ph.D. student Steve Scott has worked on this.
18. Take the 'life tables' view of demography and agentize it, then critique the extreme methodologically-individualist approach to agent lifetime and enrich your agent model to include such factors as serial correlation in spousal death probabilities, local fertility norms (see #11 above), and conditional distributions.
19. Emigration and immigration between two countries having disparate wage levels; Ben Clemens of Census has worked on this but not sure if he has published anything.
20. According to a famous essay by Amartya Sen (NYRoB), 100 million women are 'missing'. Model this!

Economics (20)

21. Emergence of 'middlemen' in two good economy (Feldman 1973).
22. Extend my model of *k*-lateral exchange (Axtell 2005) to CES preferences.
23. Take my model of firm dynamics and study the lifecycle of firms (there is a dissertation on this subject from University College, Dublin).
24. Study the network of job-to-job changing in my model of firm dynamics (Omar Guerrero has done this in his dissertation).
25. Friedman argued in the 1950s 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.
26. *Redo Padget's (1997) model of goods production via complementary skills.
27. Emergence of money (Kiyotaki and Wright 1989; Marimon, McGrattan and Sargent 1990; Menger 1892; Howitt and Clower 2000).
28. *Modify the model of local store pricing in Howitt and Clower (2000) and study the effect on the emergence of money.
29. Create a model of monetary transmission into the real economy and find parameterizations that yield monetarist phenomena and then relax these.
30. Study inflation using agents (see me for a recent working paper by Howitt).
31. *Free banking in a country without government-issued currency (e.g., 18th C Scotland; see me for a recent GMU dissertation on this topic).
32. Reimplement Gintis's macroeconomic model having explicit microeconomic foundations (2007).
33. Build a simple Keynesian macroeconomic model (one of our Ph.D. students worked on this briefly).
34. *Take the MASs macro model of macroeconomics and add exogenous shocks (see me for code).
35. Extend the Parker and Filatova models of housing markets (2009; 2007; 2009).
36. *Extend the RFF model of housing markets (Magliocca et al. 2011).
37. *Model a housing market bubble (see me for references, prototype models).
38. *International trade with country-specific labor and mobile capital (Gulden 2004); published c 2013.
39. Build an agent model of open source software development (see me for papers).
40. Create a model in which technology evolves (see me for references, prototypes).

Finance (10)

41. Re-implement Lux's (1998) financial market; study how results depend on the number of agents.
42. Convert one of LeBaron's MatLab-based financial market models into MASON or some other framework.
43. Redo the Cont model (Cont 2006).
44. Model order book flows (see me for working papers).
45. Model the way Treasury auctions U.S. bonds (see me for paper).
46. According to Kindelberger (2005) there are just a few 'types' of financial crises; model one of these.
47. 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.
48. 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).
49. Create a simple agent model of the Great Depression and compare it to Bernanke and Gertler (2004).
50. The CRISIS project is an EU funded effort on-going at several European universities. Take some of their models and experiment with them (see me for details).

Environmental Science and Policy (10)

51. *Forest fire model with fire breaks, other policies (Doyle and Carlson 2000).
52. *Build a model of the 'tragedy of the commons' type dilemmas (Ostrom 1990); see me for a prototype.
53. Agentize the model of Hahn and Axtell in which there is un-certainty in compliance and enforcement (Hahn and Axtell 1995).
54. Build a model of cap-and-trade policies and compare with Pigouvian taxes, e.g., agentize Weitzman (1974).
55. Build a coalition formation model for alternative climate change mitigation schemes (see me for a paper).
56. Compare auction mechanisms when goods can be resold (see me for a paper on applications in environmental conservation policy).
57. 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 studies this. Acquire the model of Mark Rouleau and develop it further.
58. Agent models are used in the field of *industrial ecology*. Survey this area and extend one of these.
59. Individual-based models (IBMs) are common in ecology. Go to the journal *Ecological Modeling* and find a policy relevant IBM and extend it.
60. ABMs have been little used in climate change research to date. Survey the literature, assess whether this is true, propose various models that might be relevant, and prototype one.

Game Theory (10)

61. Redo Axelrod's prisoner's dilemma tournament (Axelrod 1984).
62. Reimplement the emergence of classes model or extend it to include agents having class preferences.
63. Reimplement the retirement model (Axtell and Epstein 1999).
64. Reimplement Kristian Lindgren's evolutionary prisoner's dilemma model (Lindgren 1992).
65. Implement Skyrmes' model for the emergence of meaning through signaling (Skyrms 2010).
66. Prisoner's dilemma with tags (Riolo, Axelrod *et al.* (2001)).
67. Explore the 'cost allocation' problem: a boss ('principal') writes contracts for many agents for imperfectly monitored joint use of a facility, and wants the contract to be incentive compatible (agents tell the truth about their use), individually rational (agents use the facility instead of going elsewhere), and Pareto optimal (no other contracts out-perform it). Only 2 of these 3 criteria can be achieved; cf. Young (1985)).
68. *The 'El Farol' (aka bar) problem emergence of mixed strategies (Arthur 1994).
69. Study 'anti-coordination' games (see me for a dissertation on this topic).
70. Build a game theoretic model in which rationality is tempered by one or more emotions (active topic within MAS there are a variety of papers in recent years in the *AAMAS* conferences on this topic).

Geography, including Traffic (10)

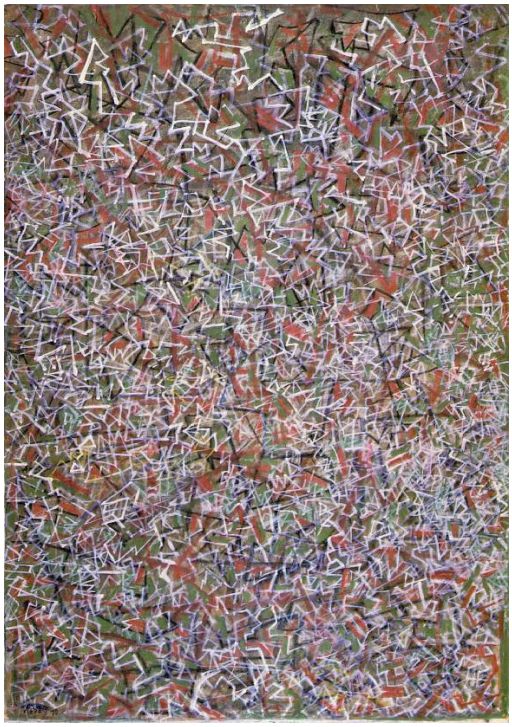
71. Re-implement Simon's city formation model using agents (Ijiri and Simon 1964; 1967).
72. Extend the nighttime lights work of Gulden and Florida (see me for references).
73. *Compare stop signs, traffic circles and stop lights in an agent- model of traffic (CSS qualifying exam question from a few years ago).
74. *Emergence of social driving norms at a one lane bridge (see me for Reston bridge example).
75. *Pedestrian traffic flow on the Millenium Bridge (see me for references).
76. Crowd dynamics in an emergency egress setting (Helbing, Farkas and Vicsek 2000).
77. Debottlenecking pedestrian traffic Mecca and Medina (various people have worked on this).
78. 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.
79. Capture geographically-tagged Twitter feeds on some topic and build an agent model to explain the spatial structure of the data; see recent work of A Crooks and S Wise.
80. Geographically accurate models of segregation in Boston 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.? (See me for these hard to find references.)

History (5)

81. 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 competing hypotheses.
82. 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?
83. 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.
84. Why did the Industrial Revolution happen where and when it did (Mokyr 2009; 1998), and did it even happen (Mokyr 1990; 1987)? Build a simple model of some of these issues.
85. 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)

86. *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 modeling (2004).
87. Prototype a model of Gettysburg (analog exist!).
88. Submarine warfare against supply convoys during WWII (McCue 2006).
89. Model counterinsurgency (COIN) dynamics (see me for recent efforts in this direction).
90. *Terrorist networks: formation, evolution and disruption (MacKerrow 2003).



Marketing (5)

91. Agentize the Bass diffusion model (Bass 1969).
92. 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 viral and traditional advertising.
93. A game theoretic version of adoption dynamics is due to Young (1999). Build this model with agents.
94. 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.
95. 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?

Methodology of Agent Computation and Simulation (5)

96. *Use of GPU technology for agent models (D'Souza, Lysenko and Rahmani 2007).
97. Investigate alternative activation regimes in Sugarscape (Lawson and Park 2000).
98. Investigate parallel activation regimes (see me for references).
99. Investigate parallel languages for agent modeling (e.g., Erlang, Scala, Go, Haskel).
100. Investigate shared memory machines vs clouds for agent modeling (see me for a white paper).

Operations Research and Business Management (5)

101. Take the Axtell and Kimbrough (forthcoming, see me) model of bipartite matching with aspirations, convert it to Java (possibly MASON), and study the role of matchmakers.
102. Information flow in an organization through formal organizations and informal networks.
103. *Airline 'free flight': pilots pick their own routes (see me for a recent GMU dissertation).
104. Study leaderless organizations (see me for a recent GWU dissertation).
105. Compare mathematical programing solutions to agents for a common problem.

Politics (10)

106. Societal transition from simple states to feudalism (Engels 1972 (1884)); model it.
107. Societal transition from feudalism to capitalism and its recent incarnation in the 'Brenner debate' (Aston and Philpin 1987; Brenner 1976; 1978; Dobb 1963); model the essential elements.
108. Write a Tiebout model agents 'vote with their feet' to satisfy preferences (Kollman, Miller and Page 1997).
109. 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).
110. Cross-border flows and refugee camp formation as a response to civil violence (work of A Crooks).
111. Build a voting model (N. Silver) that uses polling data.
112. Reimplement a party competition model.
113. Agentize a model of municipal government (city hall) .
114. Reimplement a model of international norms .
115. Build a model of civil wars .

Public Health (5)

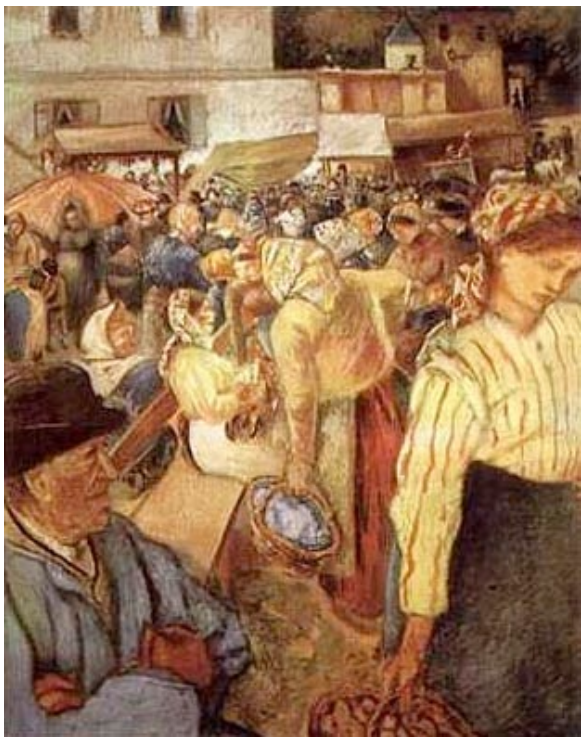
116. *Build a disease propagation model (SIS, SIR, or SIER) on small world and scale-free graphs; compare and contrast critical fractions of populations that need to be vaccinated to stop disease spread as a function of the R_0 parameter; what does R_0 mean in an agent model? (See me for references.)
117. Build a spatial or network model of disease propagation among agents and compare it with a system dynamics model of the same process; see me for refs.
118. *Spread of addictive behavior, such as drug 'epidemics' (Agar and Wilson 2002).
119. Extant epidemiological models do not alter behavior once agents are sick. Try this (see me for a paper).
120. Build a policy-relevant model for avian flu to study the efficacy of shutting down interstate trucking in the wake of an outbreak (Gemann et al. 2006).

Sociology and Crime (10)

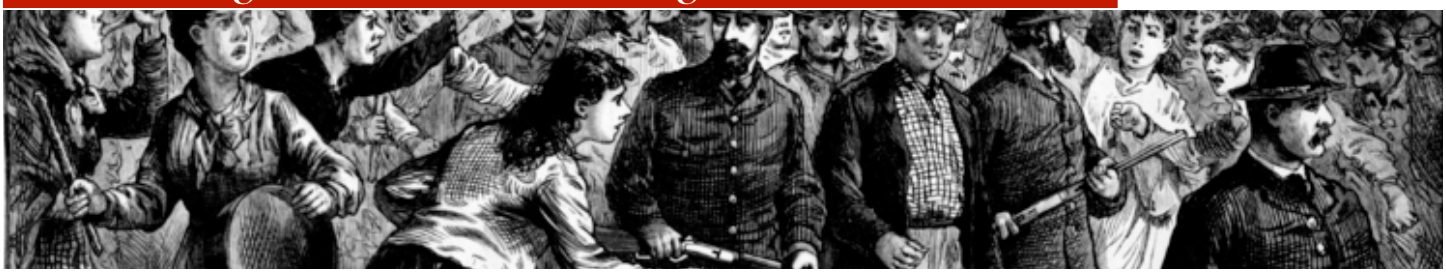
121. Investigate non-lattice topologies in Schelling segregation (Flache and Hegselmann 2001).
122. *Evolution of opinions within social networks; huge literature here so pick some specific topic (Deffaunt et al. 2002).
123. *Adoption of smoking behavior among adolescents in social networks (see me for a paper).
124. Compare alternative personnel promotion systems (e.g., tenure vs seniority-based systems; see me for a recent computational paper).
125. Investigate emergence from the perspective of Talcott Parsons theories of these (Parsons 1937; 1937); build a model.
126. Build an agent model relevant to "Coleman's boat" and the interpretation of emergence that results from it (Coleman 1964).
127. Build a model of crime as a socially-interactive process (Glaeser, Sacerdote and Scheinkman 1996).
128. Build a model of crime as occurring in 'hot spots' and/or on the boundaries of gang 'territories' (Brantingham et al. 2012).
129. Extend Redfish's model of the UK justice system (see me for slide deck).
130. Build a model for the interaction between drugs and gun violence (see me for prototype).

Sports and Entertainment (20)

131. *RoboSoccer (review state-of-the-art; design your own team).
132. Bicycle racing: peleton formation, paceline dynamics (see UC-Irvine dissertation).
133. Auto racing on an oval track, in particular the social dynamics of 'drafting' (are there no models?).
134. Build a computational model of drag racing. Let's say that cars + drivers can be absolutely ranked in terms of their performance (mean + variance). For x vehicles showing up, what fraction of the time do the top 16 actually qualify for eliminations? How often do the top eight all win the first round? What fraction of time do 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)? Can you figure out a better way to arrange eliminations? In what sense is your way better? Now relax all of the above to give distinct performance RVs to car and driver.
135. Model 'relegation' in the English Premier League (Soccer/football in England).
136. Model league division formation from undifferentiated teams (e.g., WAGS).
137. Study the mathematics of ranking system and then build agent models to better understand their dynamics.
138. Exactly how extraordinary was Joe DiMaggio's 57 game hitting streak? Build a model to explore this.
139. Study the empirics of 'streak' behavior in sports and build a general purpose agent model to study these.
140. Model football play-calling using machine learning (e.g., genetic algorithms).



141. Why did it take 15-20 years for hockey helmets in hockey to go from bering rare to common? Build a model to base your answer off (see me for previous work on this).
142. *Dynamics of a so-called 'stadium wave' (Farkas, Helbing and Vicsek 2002).
143. *Formation and evolution of a standing ovation in an audience (CSS qualifying exam problem).
144. Recreate *Lord of the Rings*-type battle scenes (There is a *Popular Mechanics* story on how this was done).
145. 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.
146. Get the MASON version of Monopoly, created in CSS 605 in Fall 2014, and invent a strategy that outperforms extant ones.
147. Built a model of *Risk* or some other classic board game.
148. Make a dynamic *Broadway Boogie-Woogie* (Mondrian; see p1 of this syllabus), possibly by morphing a Sugarscape code.
149. Build a model of how Intel prices their chips, particularly focusing on strategic pricing of those relevant to computer gaming.
150. Build a model of the lifecycle of a popular computer game, from introduction through peak popularity and fade from glory.



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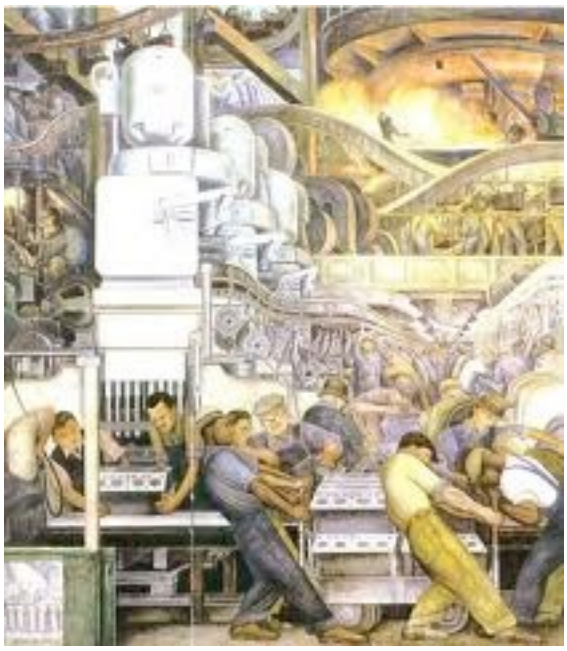

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