Agent-Based Modeling

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SFI short course on Complexity
May 24, 2011
Goals

- Introducing the rationale for and the capabilities of agent-based modeling (with lots of demos)

- Teaching you to build agent-based models

- Making the argument for treating agent-based modeling as a new form of literacy for the public at large.
Nature is filled with beautiful patterns, from flocks of birds in flight to delicate flowers to crystalline snowflake crystals. Human behavior and institutions also exhibit characteristic patterns. Why is there such a variety and consistency of pattern in the world? How do such patterns arise?
Why This Pattern?
Large-scale patterns are usually the result of the interaction and accumulation of large numbers of smaller components, each with its characteristic behavior.
**Emergent Phenomena**

Structure (Rules) at Micro-level leads to pattern at Macro-level
Order without Design
No leader or orchestrator of pattern
Probabilistic, decentralized control
Self-organization
Emergence is hard

• If you know the micro, difficult to predict the macro

• If you know the macro, difficult to find the micro structure that generates it
Agents start on a circle, facing around it

At each clock tick:
Agents move forward a little and turn a little, each forming a circle of the same radius

Question: if we change the radius of the circle each turtle is making -- how will the global pattern change?
Two kinds of agents: heroes and cowards.

Each agent picks out a friend and an enemy agent.

Heroes move so as to “stand” between their friend and enemy – protecting their friend.

Cowards move so as to have their friends “stand” between them and their enemies.
Tendency to see pattern as orchestrated by a leader or designer
Resistance to distributed explanations or methodology

Tendency to see order as a result of a deterministic procedure
Resistance to the role of randomness in creating order
How does a flock of geese form?

Minnie: *I think the leader of them is the mother so this is her right here, then behind her and then it always ends up that there is about two or one at the back.*

Ed: *How do you think they know how to get in that order?*

Minnie: *I think they just follow their mother. I think that’s how it ends up being.*

Alan: *By size, the biggest one in front. Again it could be, and so OK they find out that the V formation is more efficient than no formation, so then they find that when the birds are arranged this way with the biggest in front and the smallest at the two ends of the V.*
THAT’S LIFE by Mike Twohy

Maybe they draw straws.
With the aid of new computer-based modeling languages, we can simulate complex patterns and understand more about how they arise in nature and society.

Computers can simulate (thousands of) individual system elements (“agents”) allowing new, accessible (and playful) ways to study complex phenomena -- simulate to understand
What is a Model?

An abstracted description of a process, object, or event
Exaggerates certain aspects at the expense of others

“Essentially, all models are wrong, but some are useful”
(George Box, 1987)
What is Agent-Based Modeling?

An *agent* is an autonomous individual element with properties and actions in a computer simulation.

*Agent-Based Modeling (ABM)* starts with the idea that the world can be modeled by using a multiplicity of distributed agents, each following simple rules of behavior.
The secret to understanding much of the world’s complexity is to model that complexity as the result of many distributed individuals (agents) following a few simple rules.

To model a macro-level pattern you observe, find appropriate units of analysis at the micro-level (the agents) and how they behave and interact (the rules).
Agent-Based Modeling (aka multi-agent modeling)

Give rules to thousands of agents
Effective parallelism
Spatial model / easy to model local action
Designed for modeling complex systems/emergent phenomena
Rapidly infiltrating research, education and policy

E.g., NetLogo, Repast, Swarm, Ascape, Mason, Breve
Agent-based modeling language (aka multi-agent)
Integrated Modeling Environment
Bundled Models Library (over 300 models)
Uses syntax from Logo programming language, inherits also from StarLogo and (earlier) StarLisp
Thousands of “turtles”
Grid of “patches” - pieces of the world
Designed for modeling complex systems & emergent phenomena
Most widely used ABM toolkit – in both research and in education
Developed at the CCL with NSF support
NetLogo Demo
Natural, Social and Engineered phenomena comprised of a number of component elements that interact with each other and with the environment.

(Image courtesy of 2008 NSF workshop report on complex systems)
Demo: Sample Models
The birds ("boids") follow three rules: "alignment", "separation", and "cohesion".

"Alignment" means that a bird tends to turn so that it is moving in the same direction that nearby birds are moving.

"Separation" means that a bird will turn to avoid another bird which gets too close.

"Cohesion" means that a bird will move towards other nearby birds (unless another bird is too close).

The three rules affect only the bird's heading. Each bird always moves forward at the same constant speed.
Create modeling literacy for all Researchers to “read/write” and publish models University courses to include model-based inquiry Pre-collegiate curriculum includes complex systems and modeling News and Media to include models as evidence for arguments Narrow/eliminate gap between scientist, model designer and programmer
NetLogo in Education

• Hundreds of university courses use NetLogo (computer science, economics, biology, chemistry, physics, psychology, sociology, linguistics, business, medicine, etc)

• Middle and High school activities and curricula (thousands of schools worldwide)

• International Modeling Competitions
Research with Agent-based models

Molecular (Troisi et al, 2005; Stieff et al, 2008)
Ecology (Grimm & Railsback, 2005; Stonedahl et al, 2010)
Evolution (Bryson, 2011; Centola et al, 2000)
Geographic/Urban (Batty, 2007; Dean et al, 2000; Lechner et al, 2006, Thorp et al, 2006)
Sociology (Macy, 2007; Gilbert, 2005)
Social Policy (Maroulis et al, 2010; Epstein, 2009)
Cognition (Blikstein et al, 2009; Levin et al, 2010)
Economics (Axtell, 2006; LeBaron, 2005)
Medicine (An et al, 2009; Chavali et al, 2009; Woods, 2006)
Political Science (Axelrod, 2006; Lustick, 2000)
Imagine a country where everyone uses Roman numerals. The scientists, business leaders and educators in this country are very concerned with problems of numeracy amongst the citizens.

- Some focused on numerical misconceptions
  - If CX is ten more than C, then CIX must be ten more than CI
- Some wrote computer-programs to enable students to practice Roman arithmetic
- Some constructed wooden blocks with X, I, V, C
Imagine the educators had invented Hindu-Arabic numerals.

Before: the learning gap in arithmetic was immense - only a small number of trained people could do multiplication.

After: multiplication became part of what we can expect everyone to learn.
Structurations -- the encoding of the knowledge in a domain as a function of the representational infrastructure used to express the knowledge

Restructurations -- A change from one structuration of a domain to another resulting from a change in representational infrastructure (Wilensky & Papert 2006;2010; Wilensky, Papert, Sherin, diSessa, Kay, Turkle, Noss & Hoyles, 2005)
Agent-Based Restructurations

With the invention of computer-based representations such as agent-based modeling, we are now poised to create restructurations of complex systems that will allow us to more powerfully understand complex phenomena and make them accessible to the public at large.
Describing systems evolving over time

Traditionally use language of algebra, calculus, differential equations

Agent modeling has some advantages

- Easier entry
- Model individual behavior, not average/population
- Much easier to extend, modify
- Spatial affordances
- Can model local mechanisms
- Network topologies
The printing press was the dominant force that transformed the Middle Ages into our scientific society...The printing press didn’t do it just by making books more available, it did it by changing the thought patterns of those who learned to read.

McLuhan - Understanding Media
Equations for Fire Spread

Reynolds Equation

\[
\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho} \frac{\partial P}{\partial x_i} + \nu \frac{\partial^2 U_i}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_j} \left( u'_i u'_j \right)
\]

Heat Equation

\[
\frac{\partial H(x,t)}{\partial t} = \theta \frac{\partial^2 H(x,t)}{\partial x^2}
\]
Fire model Rules

SETUP
The patches have trees set by DENSITY
Each leftmost patch has fire

GO
At each clock tick:
Each red patch “talks to” its 4 cardinal neighbors and “asks”
If any of you are are trees (green), burn (turn red)
Lotka Volterra Equations

\[
dN_1/dt = b_1 N_1 - k_1 N_1 N_2 \\
dN_2/dt = k_2 N_1 N_2 - d_2 N_2
\]

\[N_1 = \text{prey} \quad b_1 = \text{prey birth rate} \]
\[N_2 = \text{predators} \quad d_2 = \text{predator death rate}\]
at each clock-tick, the wolves:

1. move randomly to an adjacent patch and decrease energy
2. if on the same patch as one or more sheep, then eat a sheep and increase energy
3. if energy ≤ 0 then die
4. with fixed probability, reproduce
Features of ABM

Agents enable focus on individuals

Highlights connection between micro and macro
Includes Spatial dimension
Foregrounds mechanisms and locality
More easily accommodates Stochastic
Reduces problems of “mean field” averaging
Greater sensitivity of systems
Calculus

Integration - accumulation of small changes over time

Differentiation - finding the behavior of a function in a small time interval
Need to create basic literacy in reading, writing, analyzing and critiquing ABM.

Join in.

Learn to build ABMs after the break.
NetLogo is a multi-agent programmable modeling environment. It is used by tens of thousands of students, teachers and researchers worldwide. It also powers HubNet participatory simulations. It is authored by Uri Wilensky and developed at the CCL. You can download it free of charge.

What can you do with NetLogo? Read more here. Click here to watch videos.

Join mailing lists here.

Download

NetLogo comes with a large library of sample models. Click on some examples below.

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Break

See you at 3:00
Participatory Simulations

- Can enable modelers to do more than give rules to agents.

- They can be the agents in the simulation, interacting with other human agents and simulated agents, seeing how the “accumulation” of the behaviors results in some groupwide pattern.

- The mix of human and simulated agents has great potential for social science & business research (e.g., Goldstone, 2011; Bonabeau, 2002)
Building an ABM
Start Simple!

"The supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience."

– Albert Einstein

“Do not multiply entities unnecessarily.”

– William of Ockham
Demo: Build a model
Advantages of simplicity:

• Confirms that all agents and mechanisms are necessary
• Is easier to understand
• Facilitates verification
• Allows you to more easily examine components
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Growing Cities

[Lechner et al., 2006]
NetLogo 3D
Middle school students discussing "gridlock"

[Wilensky & Stroup 1999, 2000]
System Dynamics Modeler

(cf. STELLA [Richmond 1985])
Thanks for coming!

- We’re interested in seeing your models. Consider sending it to info@ccl.northwestern.edu

- Consider signing up for the NetLogo users group on Yahoo groups (netlogo-users)

- Report bugs to bugs@ccl.northwestern.edu

- Give feedback to feedback@ccl.northwestern.edu
Stay local!