An Introduction to Agent-Based Modeling

Unit 1: What is ABM and Why Should You Use It?

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The Boids Model
(Craig W. Reynolds, SIGGRAPH, 1987)

• How do birds flock?
  • Is there a central leader?
  • Do they know exactly where to be at all times?
  • Is it a deterministic process?
  • Can they act based on local information?
Three Rules of Boids

• Cohere
  • Move toward the center of your flockmates

• Align
  • Move in the same direction as your flockmates

• Avoid
  • Do not get too close to any of your flockmates
Course Structure

1. What is Agent-Based Modeling and Why Should You Use It?
2. Beginning with Simple Models
3. Extending Models
4. A Full Model
5. The Architecture of an Agent-Based Model
6. Analyzing Agent-Based Models
7. Verification, Validation, and Replication
8. Application and History of ABM
9. Advanced ABM
Course Instructors

William (Bill) Rand - Lead Instructor

Anamaria Berea - Assistant Instructor
Contacting Us

- Email: abm@complexityexplorer.org
- Twitter: @intro2abm or @billrand
- Google Hangouts:
  - Weekly on Tuesday from 11-12 EST
  - Links will be posted
Assignments

• Quizzes - Interspersed through the units
  • Typically 2-3 questions
• Tests - At the end of every unit
  • Longer than quizzes
  • May require some model running or programming
• Final Project - Due at the end of the course
  • Checkpoints along the way
  • Developed over the entire course
Software

• NetLogo
  • http://ccl.northwestern.edu/netlogo
  • Go through the tutorial

• R
  • http://www.r-project.org/
  • Many Tutorials Available
Recommended Book

• An Introduction to Agent-Based Modeling
  • Uri Wilensky and William Rand
  • Available at MIT Press and Amazon

https://mitpress.mit.edu/books/introduction-agent-based-modeling

http://www.intro-to-abm.com/
Your First Assignment

• Participant Poll
• We want to find out who you are and what your background is so we can tailor this course
• Different from the survey that Complexity Explorer will be sending out
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 an Agent-Based Model?

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

**Agent-Based Modeling (ABM)** is the idea that the world can be modeled using agents, an environment, and a description of agent-agent and agent-environment interactions.
Toolkits for ABM
Why are we using NetLogo?

NetLogo is a premier agent-based modeling language and development environment, designed by Uri Wilensky at Northwestern University.

It is the most widely used ABM environment.

It’s the easiest to learn.
The NetLogo Design Principle

- Low threshold
  - Novices can build simple models at first use
  - Pre-collegiate curriculum includes complex systems and modeling
  - University courses to include model-based inquiry
  - News and Media to include models as evidence for arguments
- High ceiling
  - Language should be expressive enough to enable high end complex models
  - Researchers to “read/write” and publish models
  - Narrow/eliminate gap between modeler and programmer
  - Enable interactive development and research
  - Easy to share models
  - Easy to verify and/or challenge models
The Birth of the Turtle

Logo was first developed in ~1969 by Seymour Papert and colleagues
How Big / Advanced Can it Get?

• Tens of Thousands of Agents and Patches
• Complex Decision Makers
• Many Agent Types
• Models of Whole Cities
• Additional Tools Allow for Integration with other Software
Redfish Group
Growing Cities

[Lechner et al., 2006]
Viral Marketing

Image Credit: Forrest Stonedahl

with Forrest Stonedahl and Uri Wilensky, 2010
Visualization Courtesy of Forrest Stonedahl
Inferring Social Networks

with Michael Trusov and Yogesh Joshi, 2010
Decision Support Systems

Who should I incentivize and why?

with Manuel Chica, 2016
Network Visualizations by Jared Sylvester
What is Complex Systems?

• A system composed of many interacting parts in which the **emergent** outcome of the system is a product of the interactions between the parts and the **feedbacks** between that emergent outcome and individual decisions.

http://ccl.northwestern.edu/netlogo/models/TrafficBasic

NOMAD - http://www.flickr.com/photos/lingaraj/2415084235/sizes/l/ CC BY 2.0
Emergence

- Emergence = ‘the action of the whole is more than the sum of the parts’  (Holland, 2014)
Feedbacks

- The effect of the emergent result on the decisions of the individuals

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How do you understand Complex Systems?

• Complex Systems can be difficult to predict, control and manage, which in many ways is the goal of public policy

• Agent-Based Modeling and Complex Systems analysis is to provide a ‘flight simulator’ rather than a perfect prediction  (Holland, 1996; Sterman, 2000)
Leverage Points

• Leverage points are places where the complex system can potentially be shifted from one regime to another with the least effort (Bankes, 1993)

• Related to:
  – Tipping Points: places where a small change in an input can dramatically affect the outcome (Scheffer, 2010)

• Complex Systems analysis often gives you the most when it tells you the least

http://ccl.northwestern.edu/netlogo/models/Fire
Path Dependence

Path Dependence is when the current possibilities are limited by past choices

Brown et al., 2005, IJGIS
Sensitivity to Initial Conditions

— Sensitivity to Initial Conditions (The Butterfly Effect): in its strong form a condition of chaos which says that every starting point is arbitrarily close to another starting point with a significantly different future (Lorenz, 1972)

• Chaos: when the present determines the future, but the approximate present does not approximately determine the future. — Lorenz

— Weak Version - Where you start matters significantly

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Non-Linearity and Dynamics

• Inputs do not necessarily affect outputs in a linear manner

• Interactions between various inputs mean that you cannot just solve problems by breaking them down one-by-one

http://ccl.northwestern.edu/netlogo/models/GiantComponent
Robustness

- Robustness is when a system maintains its characteristic behavior even after perturbation (Bankes, 2002)
Diversity and Heterogeneity

• Individuals in Complex Systems are often significantly diverse and heterogeneous (Page, 2010)

• Most traditional modeling approaches fail to accurately capture the heterogeneity of individuals
Interconnectedness and Interactions

• Individuals are connected and affect each other’s decision
Representation

- Representation is the key to understanding any phenomenon.
- As an example, imagine writing the Flocking model as a series of equations that describe where the birds are and how they affect each other.
- In many cases, agent-based representations are appropriate.
Benefits of Appropriate Representation

• New representations can help us solve problems we could not solve before
• Changing representations can help us ask new questions
• Agent-based representations can help us to communicate our results
Representation of Complex Systems

• Complex systems are composed of many interacting parts
• Those parts are often connected in complex ways
• Agent-based modeling provides a powerful way to represent those connections
A Third Way of Doing Science
(Axelrod, 1997)

• Two traditional ways of doing science
  • Induction - inferring from particular data a general theory
  • Deduction - reasoning from first principles to a general theory

• Third Way
  • Generative - using first principles to generate a particular set of data that can create a general theory
Integrative Understanding

• If one knows the first principled rules, can you determine the aggregate pattern
• This is often difficult, and ABM provides us a way to understand this
Differential Understanding

• What if the aggregate pattern is known and you want to figure out the individual-level rules?
• This is similar to the flocking model exercise we previously explored
• We can propose rules and see if they generate the phenomenon we observe
When to use ABM?

- Medium Numbers
- Heterogeneity
- Complex but Local Interactions
- Rich Environments
- Time
- Adaptation
Medium Numbers
Casti, 1996

- Too few agents and the simple may be too simple
  - Game theory and ethnography work well
- Too many agents and means may describe the system well
  - Mean-field approaches and statistical descriptions
- The key is that the number of agents that can affect the outcome of the system be a medium number
Heterogeneity

• Agents can be as heterogeneous as they need to be
• Many other approaches assume homogeneity over individuals
Complex but Local Interactions

• ABM can model complex interactions
  • History dependent
  • Property dependent
• The assumption is that these are local
  • No global knowledge
Rich Environments

• The environment the agents interact in can be extremely rich
• Social Networks
• Geographical systems
• The environment can even have its own agent-like rules
Time

- Almost all agent-based models feature time
- ABM is a model of process
- Nearly necessary
- There are exceptions
  - Solving complex equilibrium problems
Adaptation

• Adaptation is when an agent’s actions are contingent on their past history
• An agent may take different actions depending on its own past experience
• Usually sufficient
• Very few modeling approaches besides ABM feature adaptive individuals
Agent-Based Modeling (ABM) vs. Equation-Based Modeling (EBM)

• Many EBM make the assumption of homogeneity
• EBM are often continuous and not discrete
  • The nano-wolf problem (Wilson, 1998)
• EBM require aggregate knowledge in many cases
• Ontology of EBM is at a global level
• EBM do not provide local detail
• EBM are Top-Down, ABM are Bottom-Up
• EBM are generalizable, but restricted
• ABM can be built from analytical models, and can complement EBM
ABM and Statistical Modeling

- Hard to link to first principles and behavioral theory
- Need to have the right kind of data
- ABM can complement by building from first principles to statistical results
ABM vs. Lab Experiments

- Lab experiments can generate theory
- Lab experiments are rarely scaled up
- ABM can be created from lab experiments
  - ABM can explore macro-implications of lab experiments
  - ABM can generate new hypotheses
  - ABM can determine sensitivity of results
  - ABM can compare generative principles
ABM vs. Aggregate Computer Modeling

• System Dynamics Modeling embraces a system-level approach to thinking about the world
• However, it often lacks the individual-level representation
• Hybrid models are possible
Limitations

• High Computational Cost
  – Benefit of more insight and data to intermediate stages
• Many Free Parameters
  – Simply exposing parameters that other models assume
• May Require Individual-Level Behavioral Knowledge
  – Provides better insight
Why the Resistance?

• Lack of Education about Complex Systems
• The Drunk, The Keys and The Streetlight
  – People want to search for solutions where it is easy
• Centralized and Deterministic Mindset (Resnick and Wilensky, 1993)
  – People expect their to be a central leader
  – People expect that everything happens for a “cause” and negate the possibility of chance
Uses of ABM

• Description
• Explanation
• Experimentation
• Analogy

• Education
• Touchstone
• Thought Experiments
• Prediction
Description

• An ABM is a description of a real-world system
• A simplified description but still a description
• Models that are not simplified are useless
• “Make your model as simple as possible but no simpler.” - Albert Einstein
Explanation

• An ABM provides an explanation of potential underlying phenomenon that control a system
• They are a proof-of-concept that something is possible
• They illuminate the power of emergence
Experimentation

• ABMs can be run repeatedly under slightly different conditions to observe the resultant changes
• We can change the model and see what happens
• We can then go back to the real-world and validate these experiments
Analogy

• ABMs help us to understand other system with similar patterns of behavior
• For instance, the model of flocking birds can help us understand fish and even locusts
• They can even help us understand engineered systems, e.g., drones
Education / Communication

- ABMs help us communicate our results to others
- They encapsulate knowledge in a way that is easily transferrable
- They encourage exploration about different theories
Touchstone

• ABMs create a focal object
  • Papert (1980) calls them an object to think with
• They give us a common language to describe a phenomenon and to argue about its causes
• They turn complex systems into a set of simple rules
Thought Experiments

• ABMs can explore things that may not even exist in the real world, or are very idealized examples of the real world
• ABM gives us the power to say what will happen if we assume a few basic rules
Prediction

- ABM is often used to think about possible future scenarios
- But the validity of a prediction is determined by how well the model has been validated
- It is difficult to assess the validity of any model for an event that has not yet occurred
- Prediction can often be reduced to description and explanation
Complex Systems, Agent-Based Modeling and Psychohistory

• Psychohistory is a fictional science used by Isaac Asimov’s character, Hari Seldon, in the Foundation series.

• Psychohistory combines history, sociology, and mathematics to make approximate predictions about the future behavior of large groups of people.

• Complex Systems has the potential to help us understand how large groups of individuals and organizations will react to future events, potentially paving the way for a real psychohistory.

• However, the goal is not to make specific predictions, but can help us to embrace uncertainty.
Thank You

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