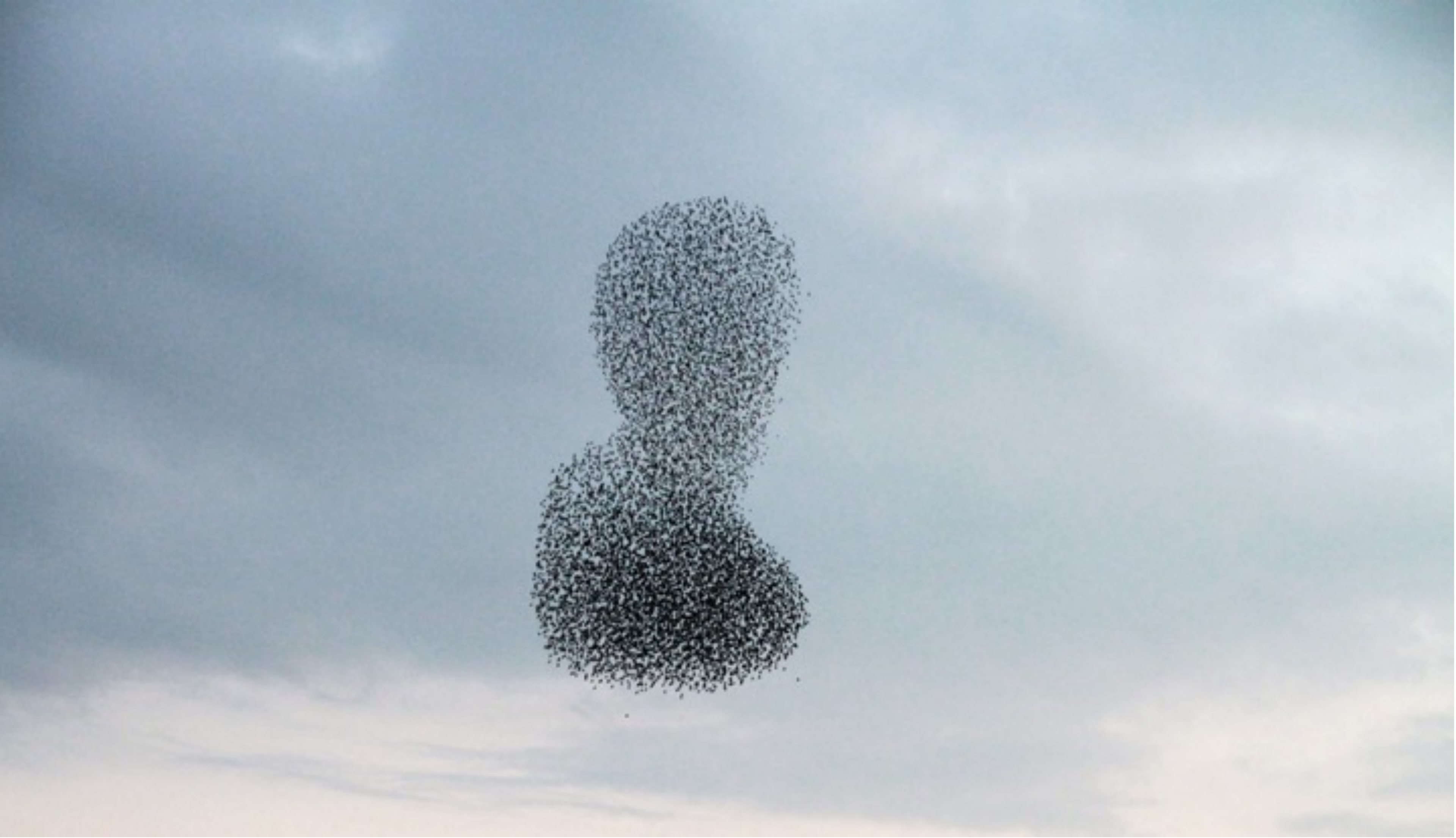
An Introduction to Agent-Based Modeling

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

Bill Rand
Assistant Professor of Business Management
Poole College of Management
North Carolina State University



Picture by Milo Bostock (https://www.flickr.com/photos/milesmilo/25121357602)

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

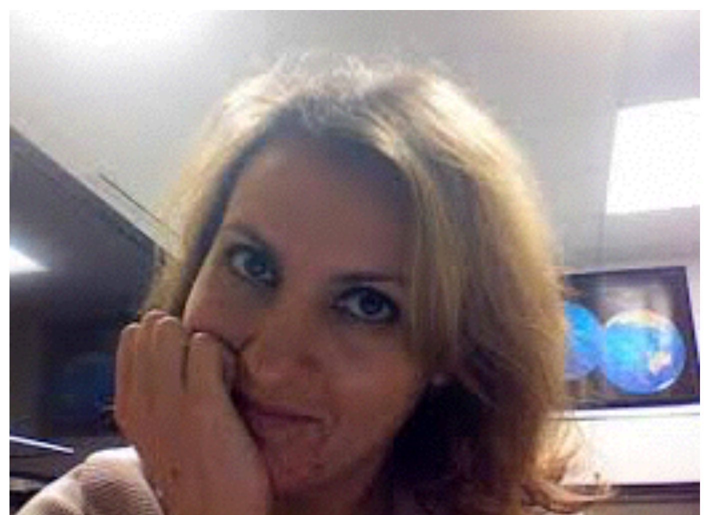
Course Structure

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

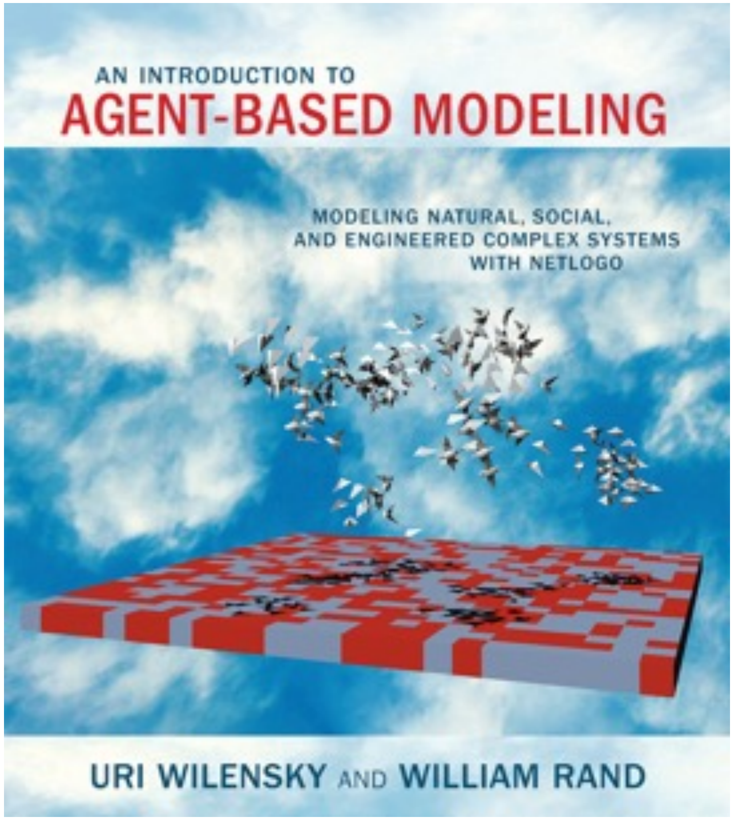
- Quizzes - Interspersed through the units
  - Typically 2-3 questions
- Tests - At the end of every unit
  - Longer than quizzes
  - May require some model running or programming
- Final Project - Due at the end of the course
  - Checkpoints along the way
  - Developed over the entire course

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

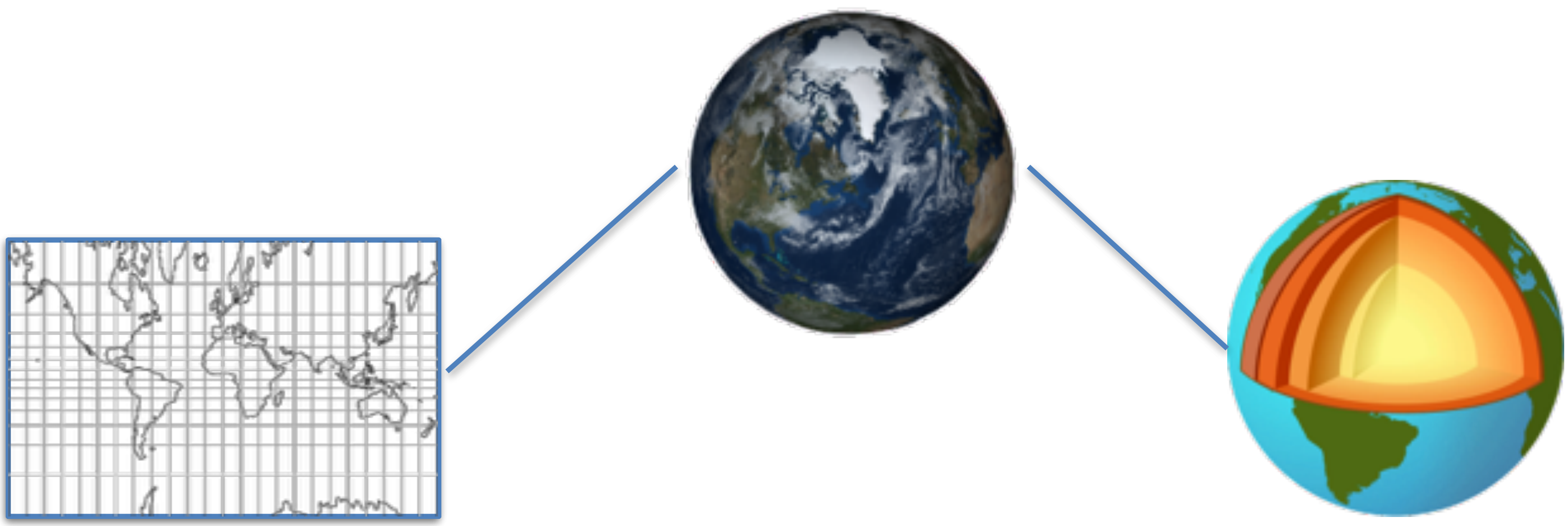
http://www.intro-to-abm.com/

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

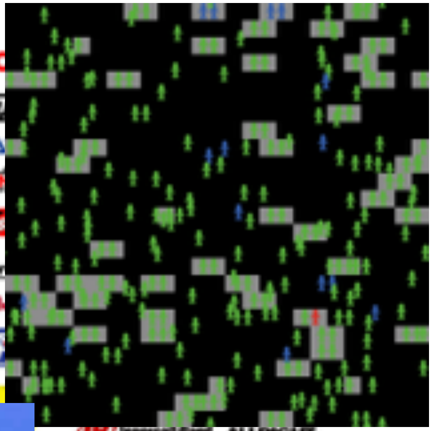


"Essentially, all models are wrong, but some are useful"
(George Box, 1987)

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

SWARM

Repast
Recursive Porous Agent Simulation Toolkit

ASCAPE

MASON

mass
Multi-Agent Simulation Suite

breve: a 3d Simulation Environment for Multi-Agent Simulations and Artificial Life

NetLogo

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.

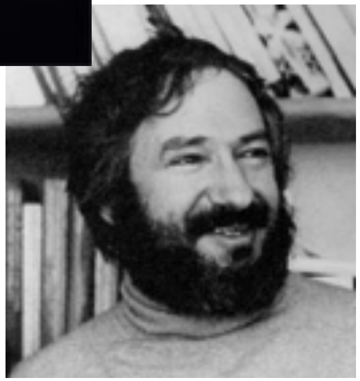
It's the easiest to learn.

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

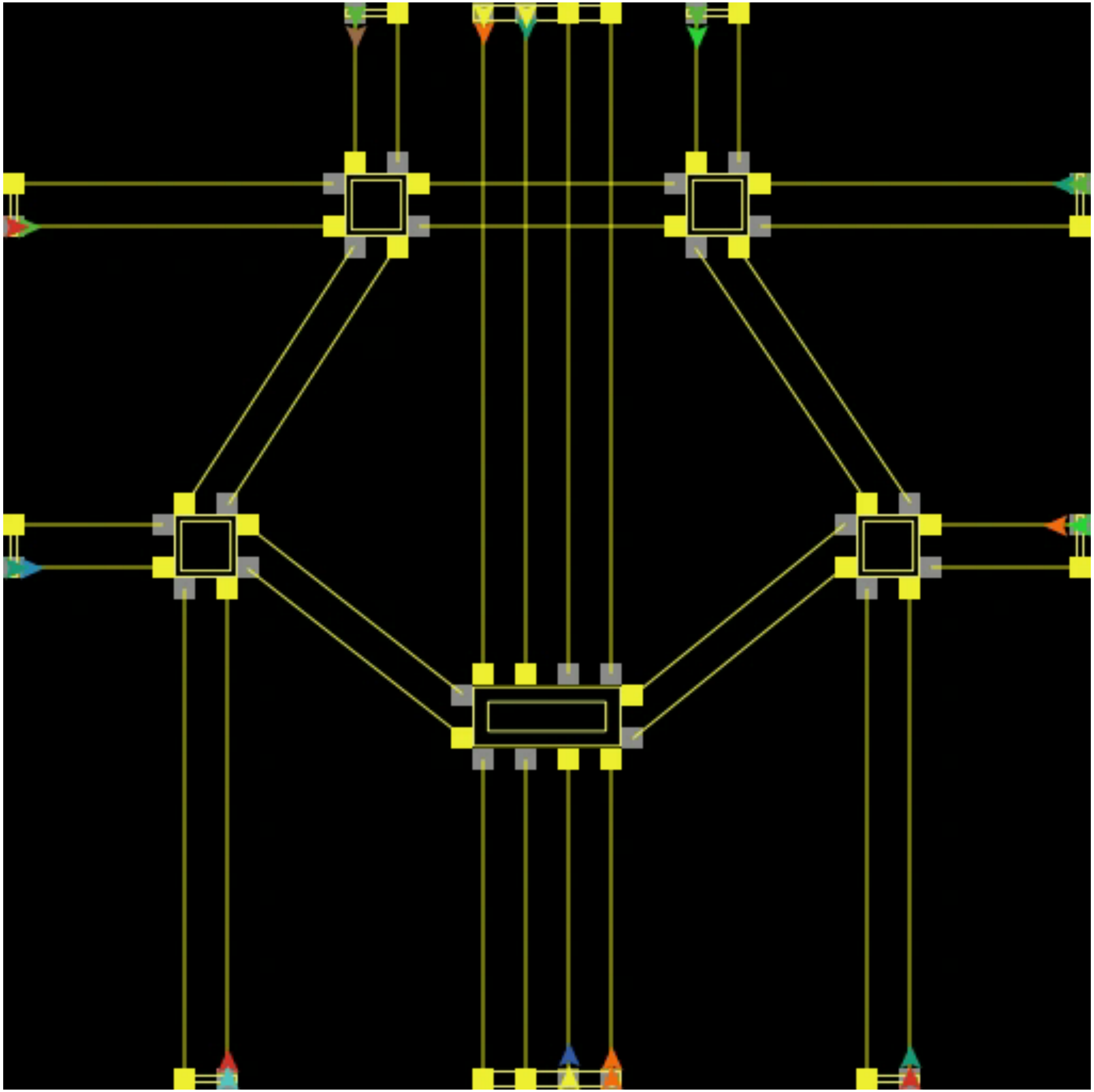
The Birth of the Turtle

Logo was first developed in ~1969 by Seymour Papert and colleagues

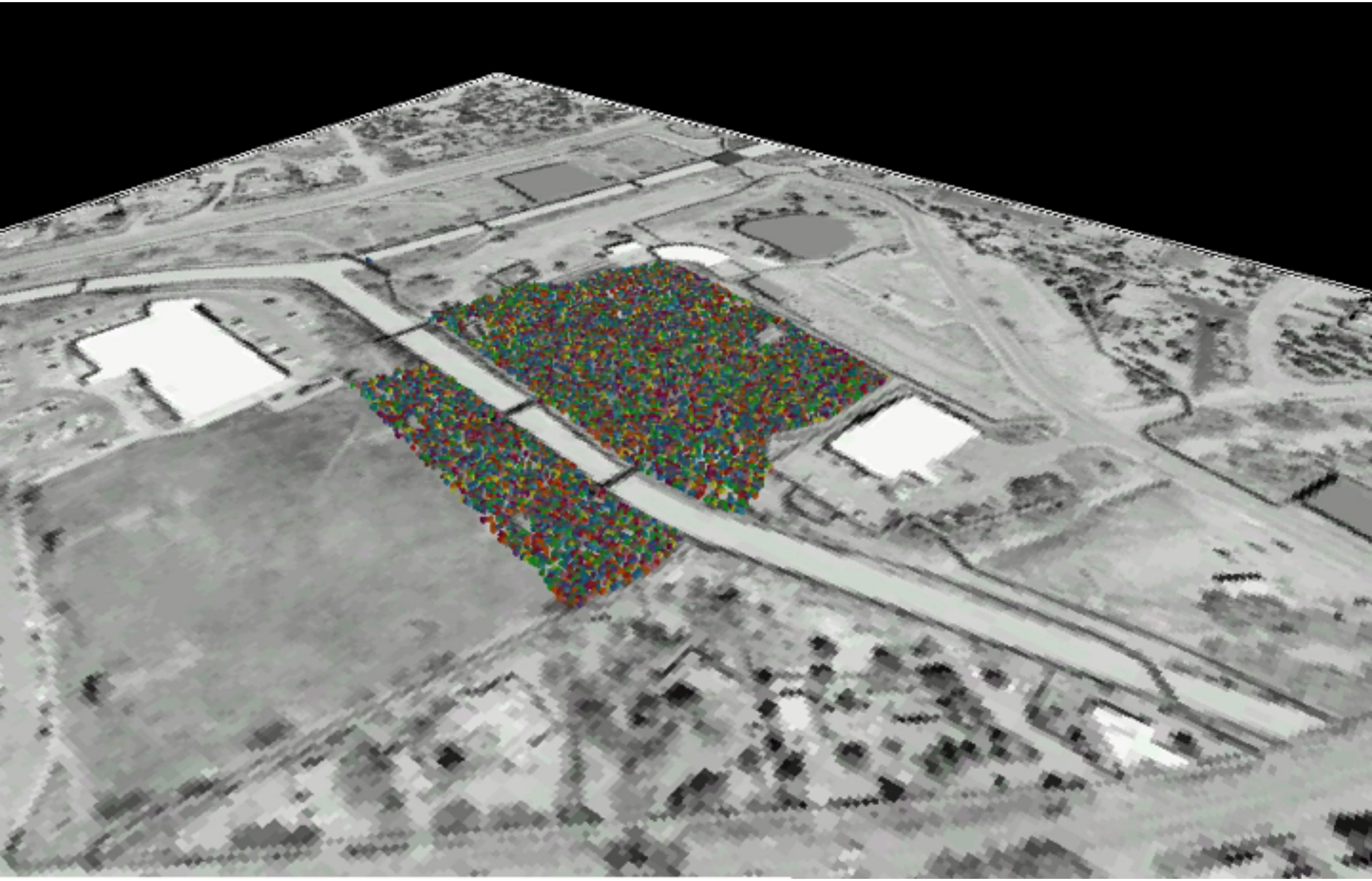


How Big / Advanced Can it Get?

- 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

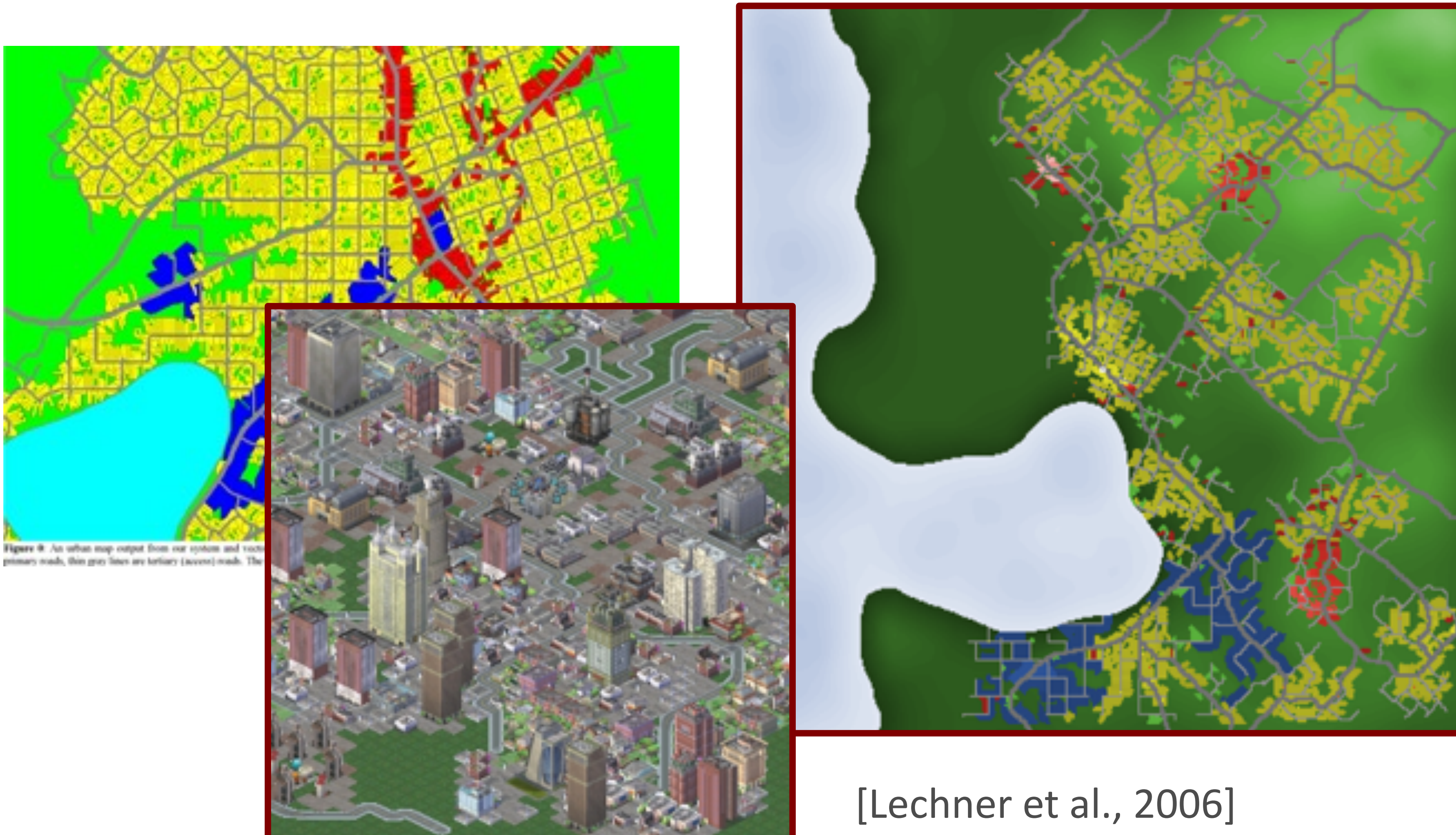


Redfish
Group



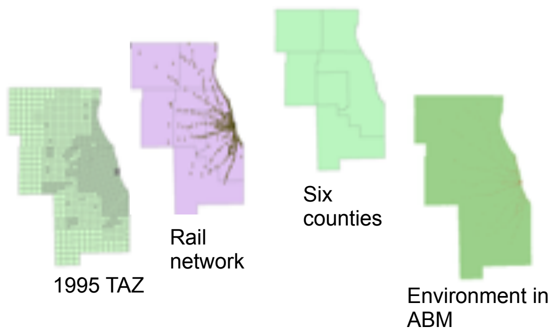
Redfish Group

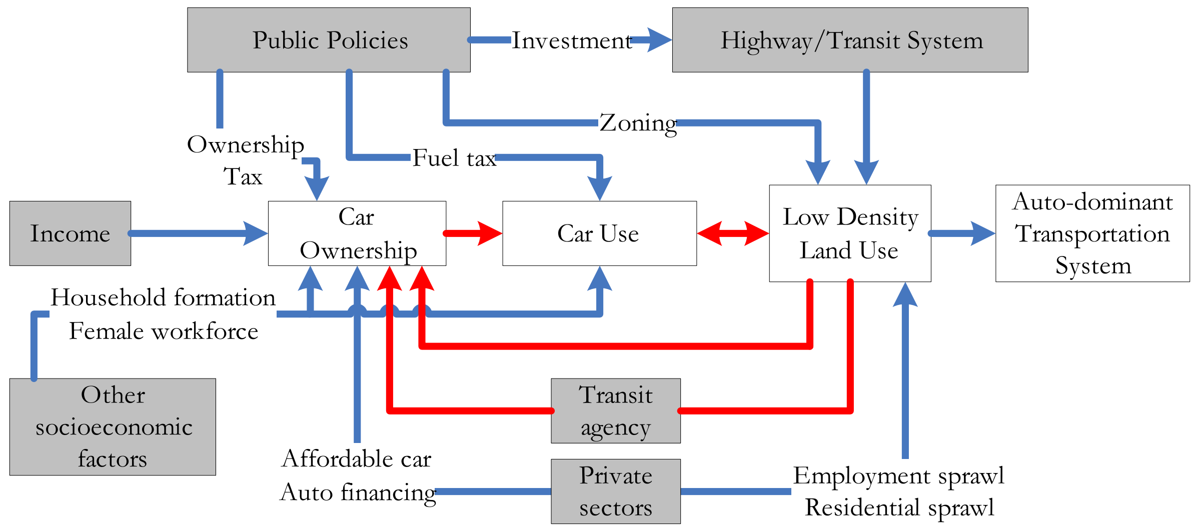
Growing Cities

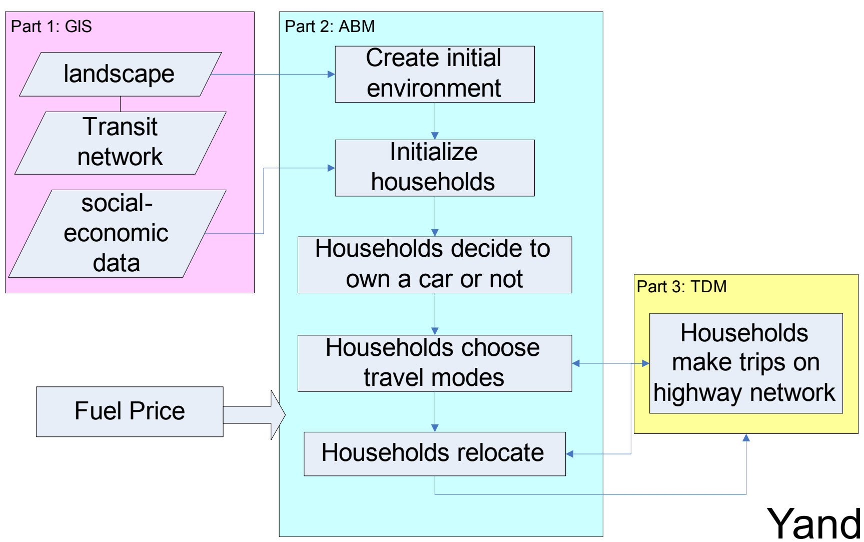


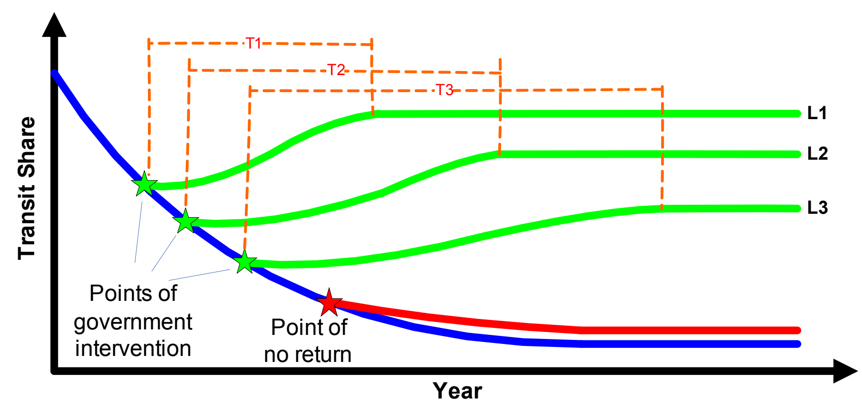
[Lechner et al., 2006]

Policy Analysis



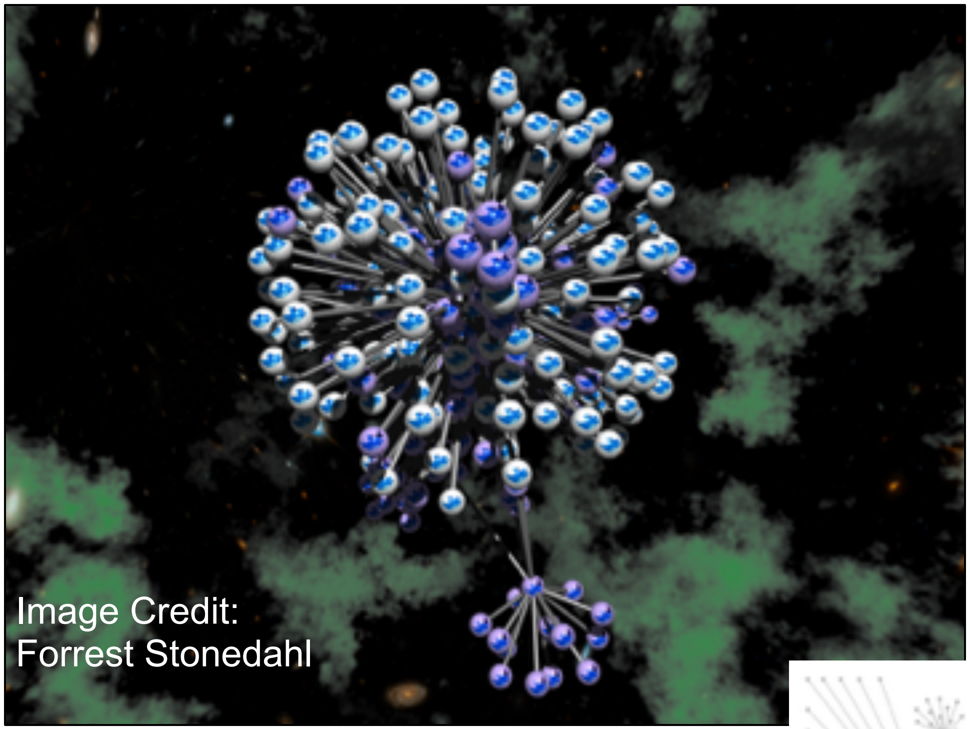


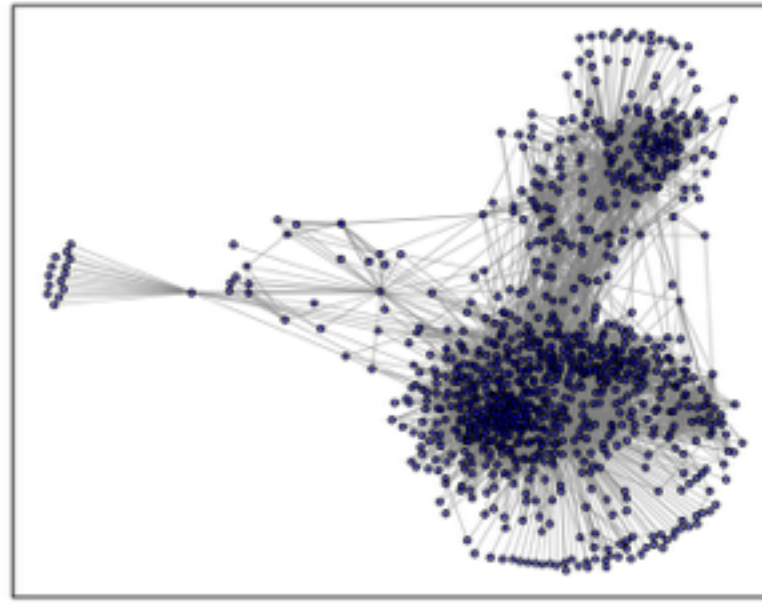


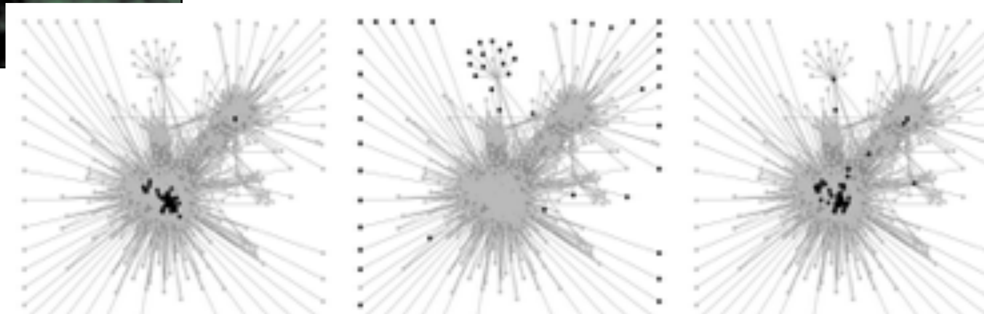


Yandan Lu, 2009

Viral Marketing





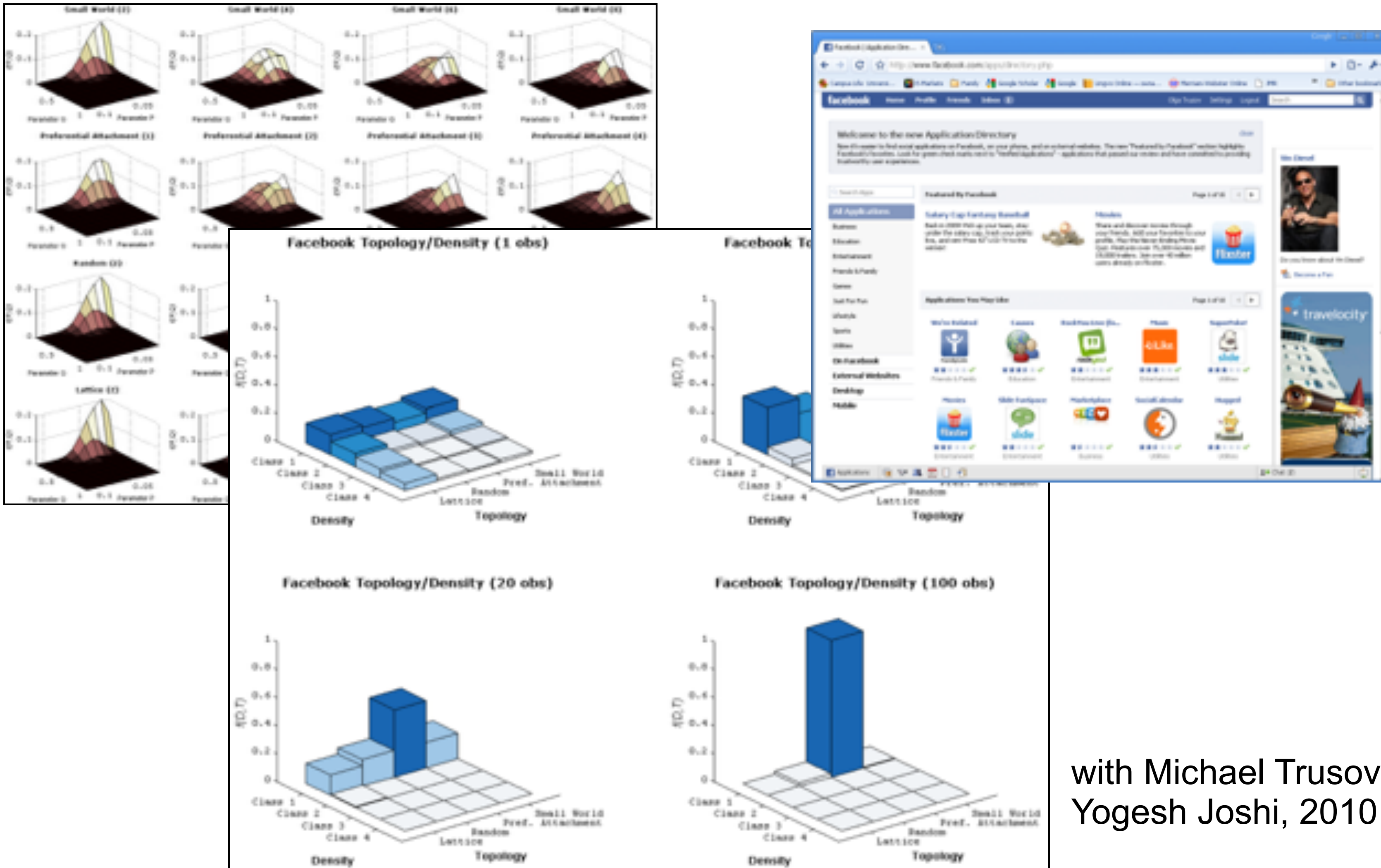


a) pure degree   b) pure cc   c) GA's best strategy

with Forrest Stonedahl
and Uri Wilensky, 2010

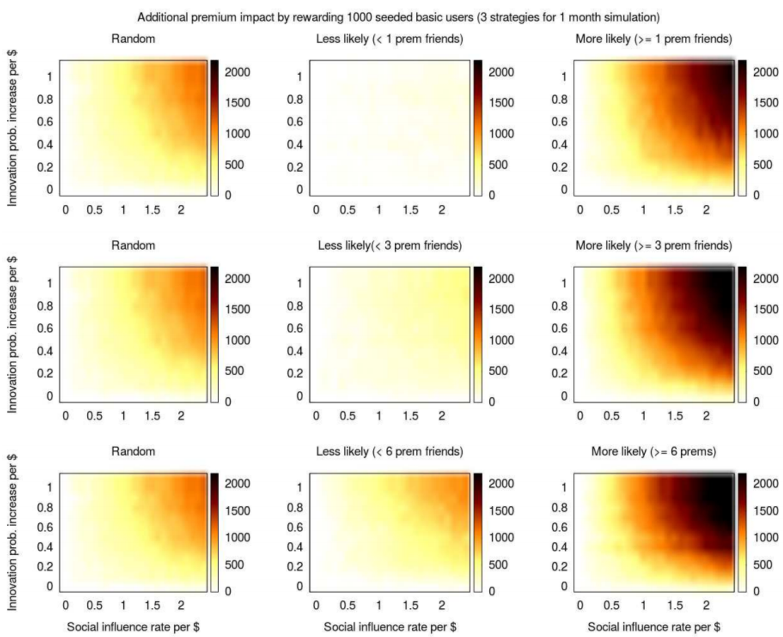
Visualization Courtesy of Forrest Stonedahl

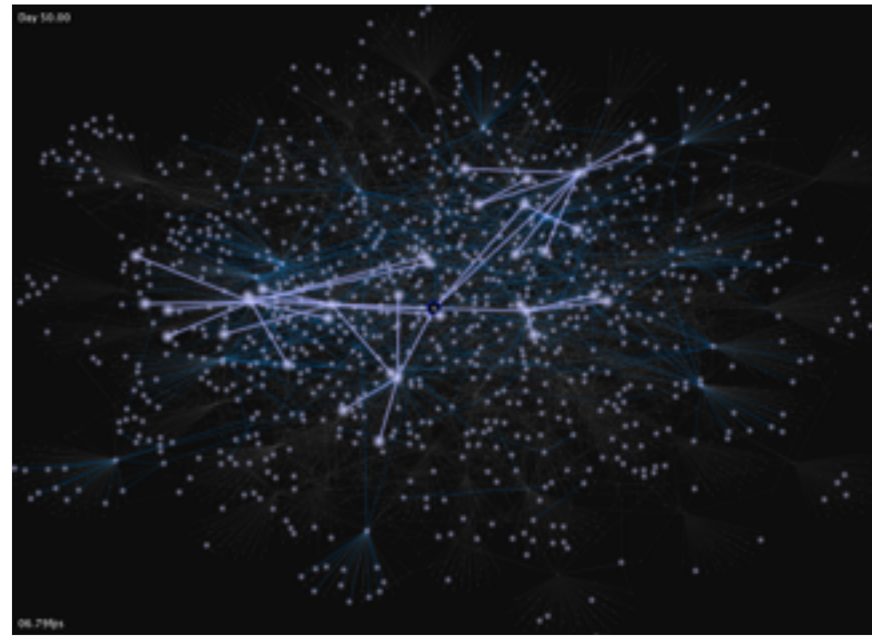
Inferring Social Networks



with Michael Trusov and Yogesh Joshi, 2010

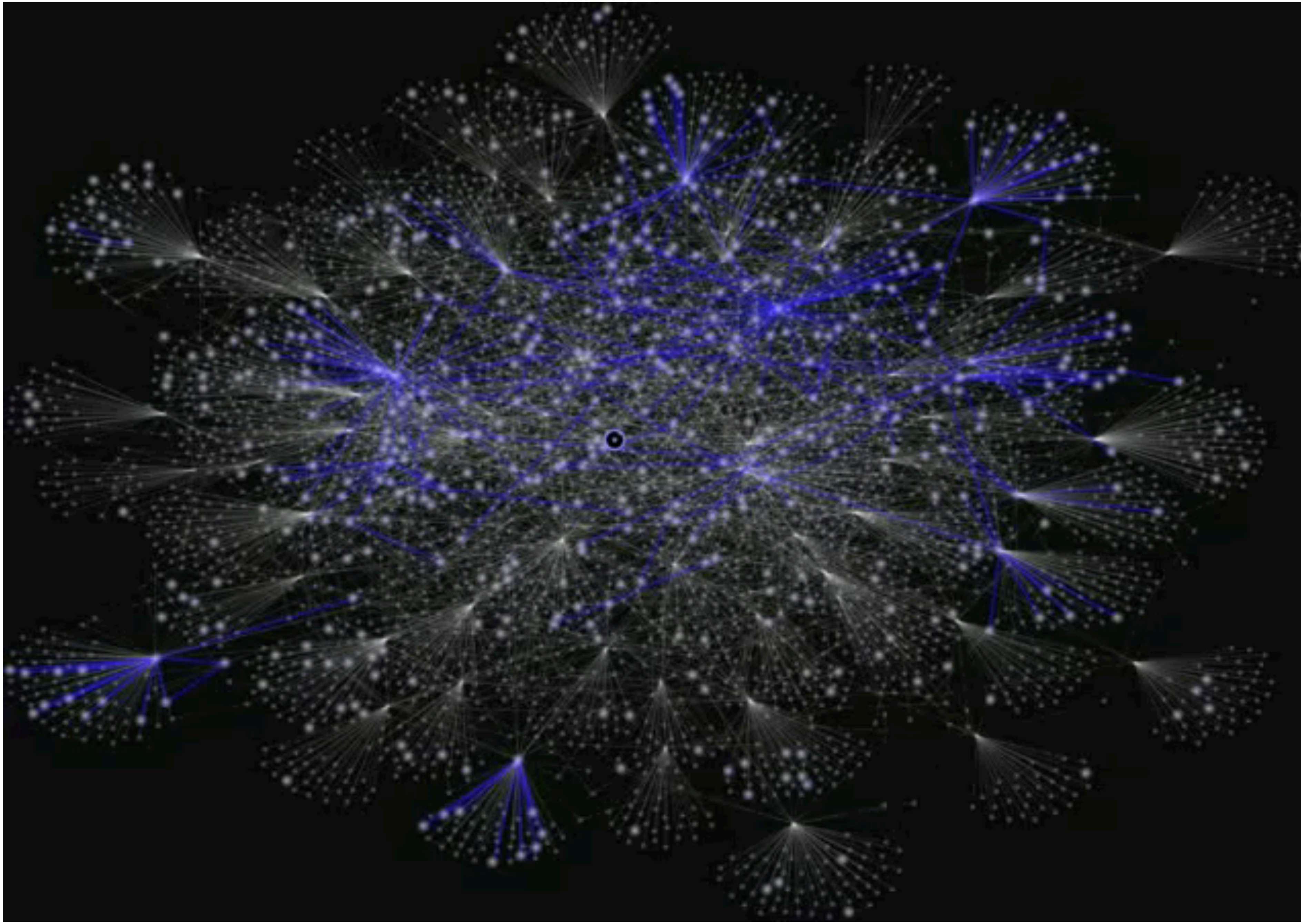
Decision Support Systems





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

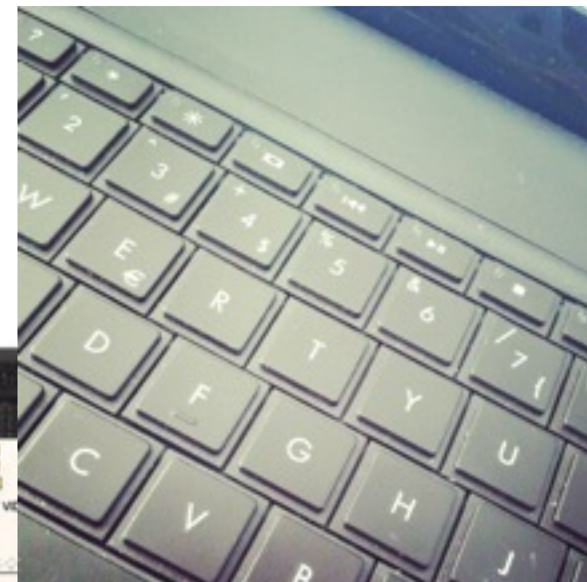
NOMAD - http://www.flickr.com/photos/lingaraj/2415084235/sizes/l/

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



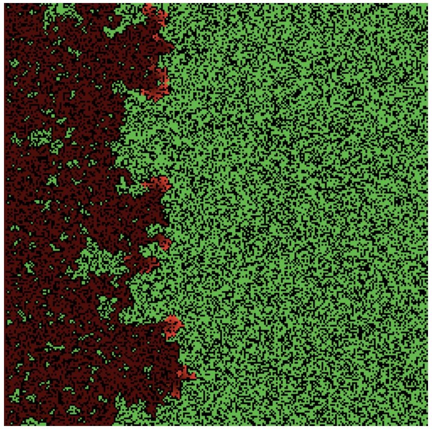
https://www.flickr.com/photos/thefrankfurtschool/1313097473/

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

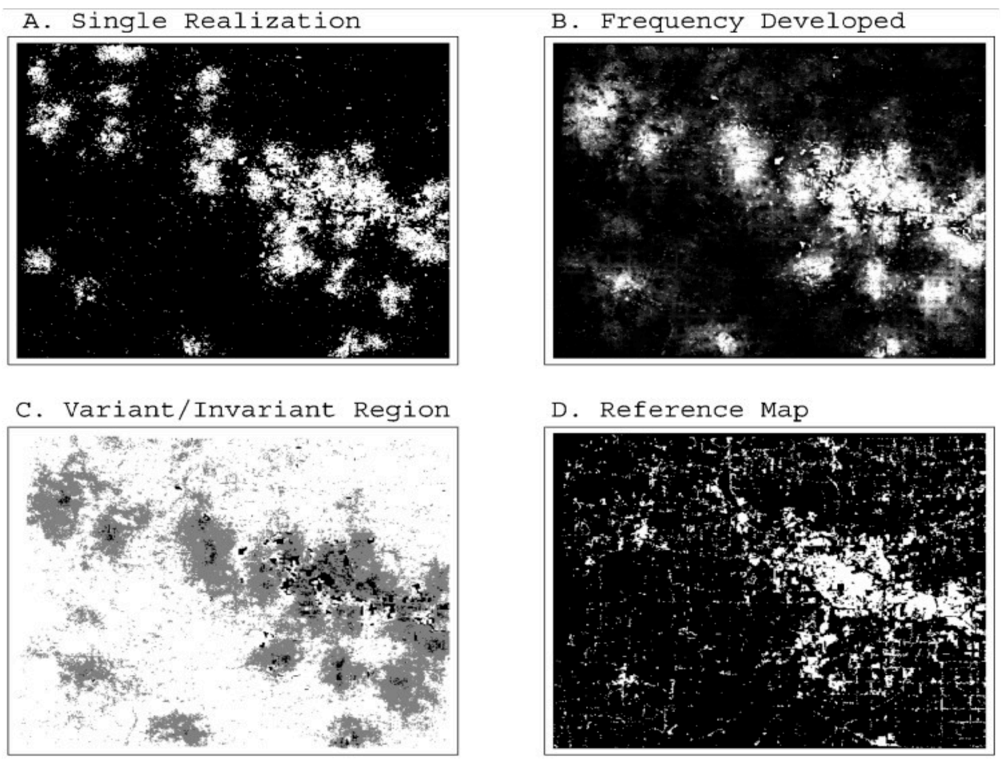
- Leverage points are places where the complex system can potentially be shifted from one regime to another with the least effort (Bankes, 1993)
- Related to:
  - Tipping Points: places where a small change in an input can dramatically affect the outcome (Scheffer, 2010)
- Complex Systems analysis often 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

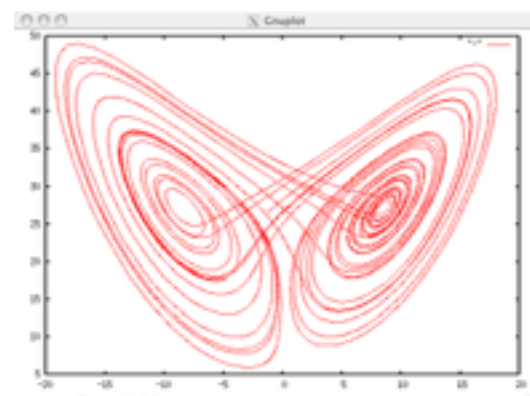


Brown et al., 2005, IJGIS

Sensitivity to Initial Conditions

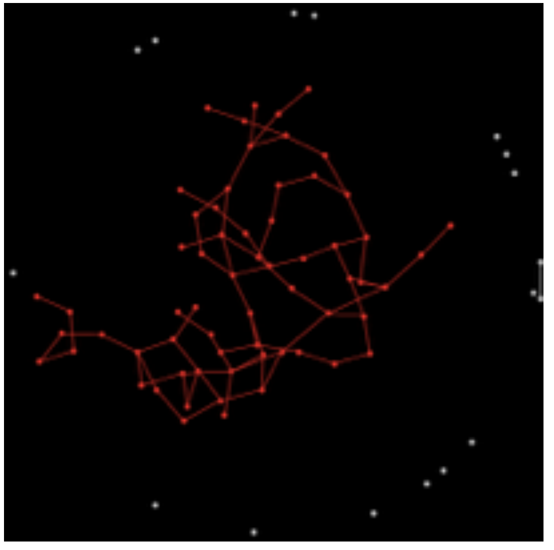
– Sensitivity to Initial Conditions (The Butterfly Effect): in its strong form a condition of chaos which says that every starting point is arbitrarily close to another starting point with a significantly different future (Lorenz, 1972)
  - Chaos: when the present determines the future, but the approximate present does not approximately determine the future. — Lorenz

– Weak Version - Where you start matters significantly



Non-Linearity and Dynamics

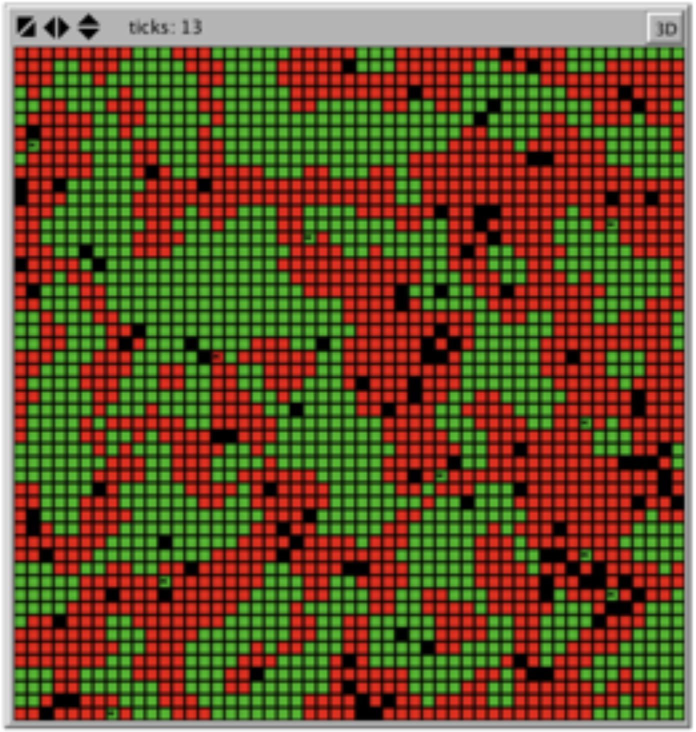
- Inputs do not necessarily affect outputs in a linear manner
- Interactions between various inputs mean that you can not just solve problems by breaking them down one-by-one



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

Robustness

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



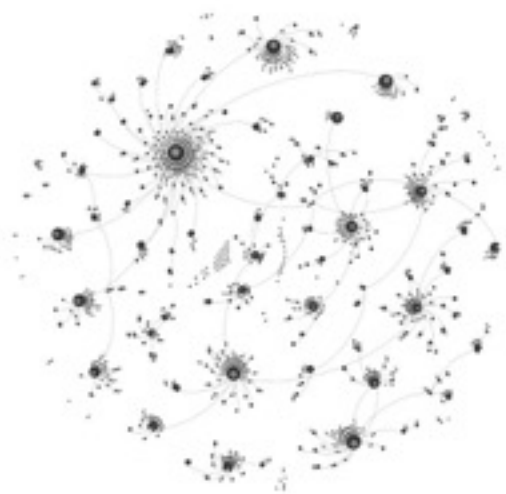
NetLogo Segregation Model

Diversity and Heterogeneity

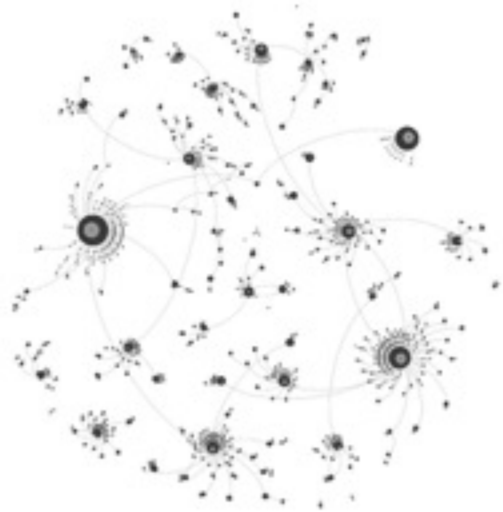
- Individuals in Complex Systems are often significantly diverse and heterogeneous (Page, 2010)
- Most traditional modeling approaches fail to accurately capture the heterogeneity of individuals

Interconnectedness and Interactions

- Individuals are connected and affect each other's decision



Bin Laden Retweet Network



Hurricane Sandy
Retweet Network

US 2012 Election
Retweet Network

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

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

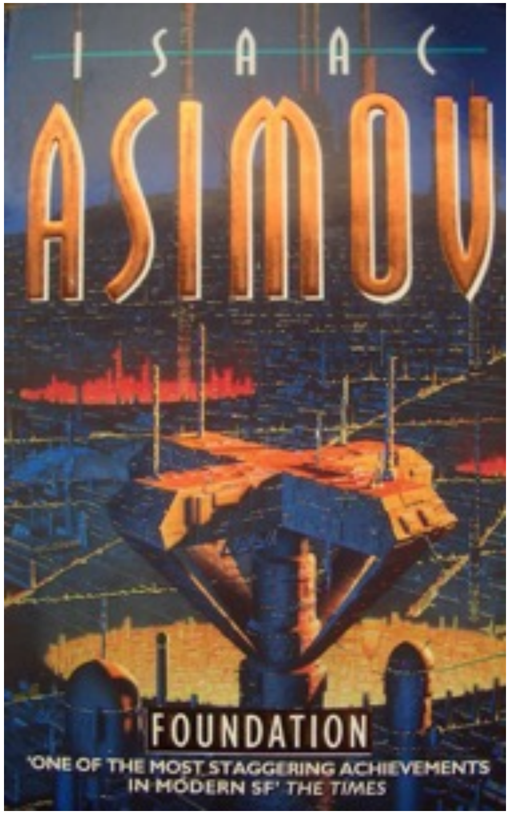
- ABMs can explore things that may not even exist in the real world, or are very idealized examples of the real world
- ABM gives us the power to say what will happen if we assume a few basic rules

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



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Thank You

Several of these slides benefited from significant contributions from Forrest Stonedahl, Uri Wilensky, and others.