Agent-based Models, Networks & Social Influence

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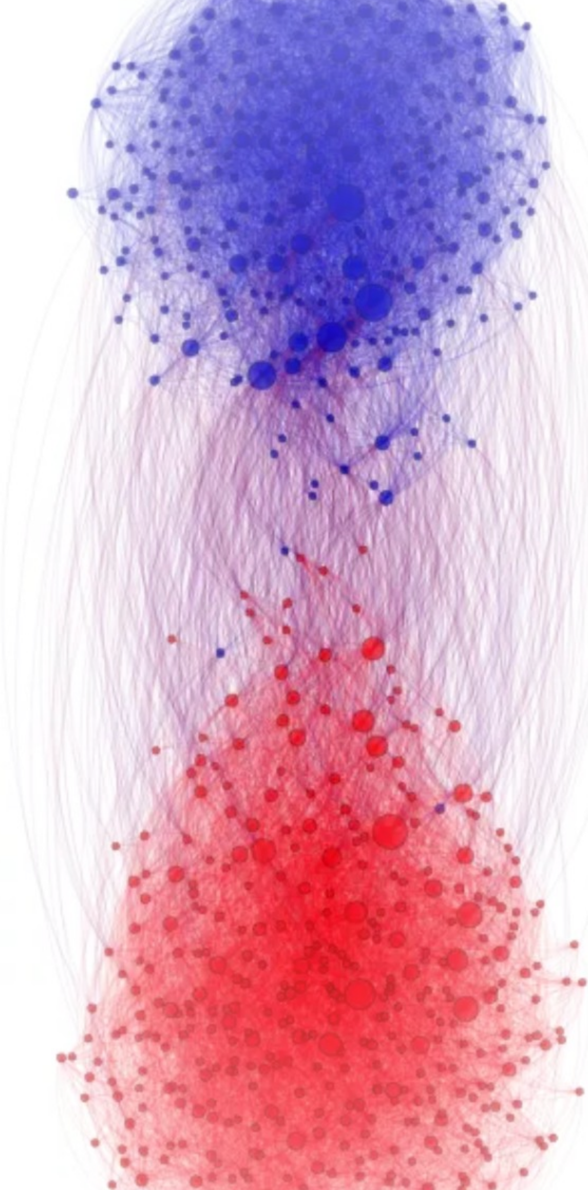
Brussels, 31 Oct 2018



Where to Find these Slides

github.com/cluhmann/ABM-workshop

Who am I?

- B.S. in Computer Science
- Ph.D. in Psychology
- Stony Brook University
- Decision-making, learning, methods (stats & “cognitive modeling”)

Who are you?

Goals of this Workshop

- Learn about the **hows** and **whys** of agent-based modeling (but mostly the whys)
- Familiarity with the **ingredients**
- Familiarity with some **conventions**
- Ability to make **informed design decisions**

Non-Goals of this Workshop

- Ability to immediately create arbitrary models

- Exhaustive knowledge of modeling software

Outline

1. Overview
2. ABM
3. Networks
4. Influence
5. Looking Forward

Agent-Based Models

What

- Agent-based models go by many different names
  - Agent-based modeling and simulation (ABMS)
  - Individual based model (IBM)
  - Multi-agent simulation (MAS)
- Used in a wide variety of disciplines
  - Ecology
  - Economics
  - Sociology
  - Political Science

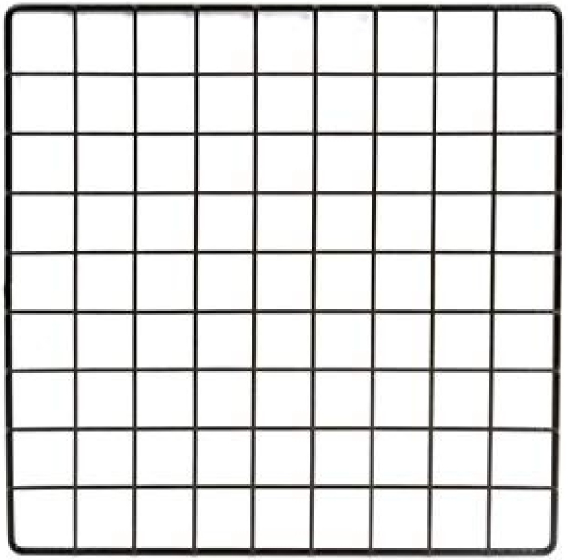
What

- Less prevalent in psychology
- Perhaps due to...
  - General distaste for computational methods/models
  - General focus on individual-level explanations

What

- ABMs typically consists of three major components
    1) **Agents**
    2) **Interaction**
    3) **Environment**
- With these components in place, we specify **initial conditions**...
- ...and run it!

Conway's Game of Life



- Agents (cells)
  - Alive or dead
- Environment
  - 2D grid
- Interaction
  - More than 3 or less than 2 neighbors kills live agents
  - Dead agents with exactly 3 live neighbors come to life
- Initial conditions
  - A random 20% of cells selected to start off as "alive"

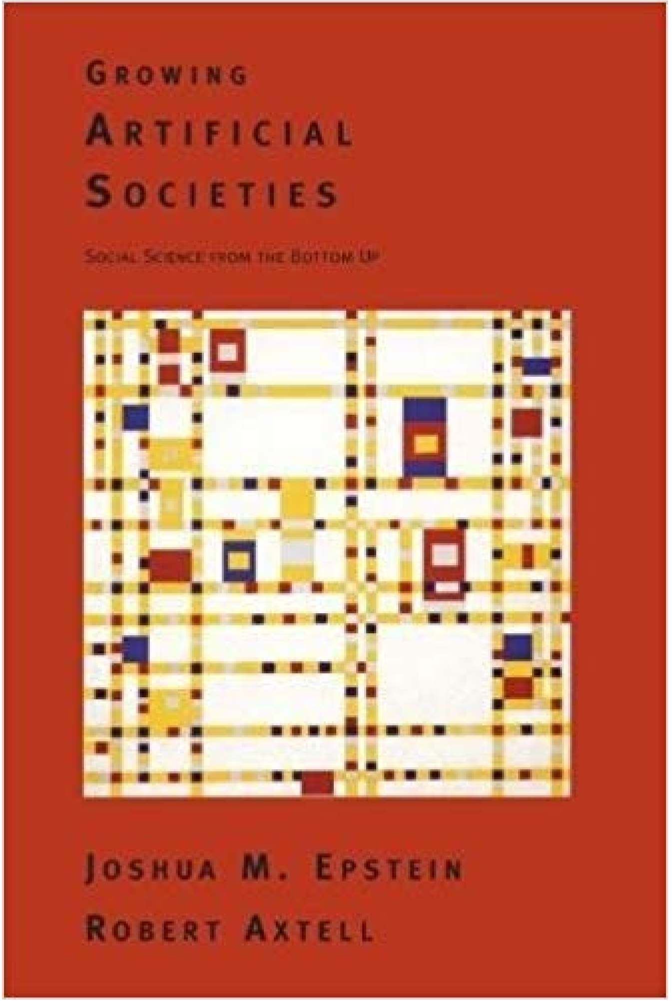
Conway's Game of Life

Demo

Conway's Game of Life

- The Game of Life model specifies **individual-level** rules
- The animation depicts **group-level** patterns of behavior
- ABMs are particularly useful for examining **micro-macro** relationships
- Some group-level behavior is unexpected: **emergent phenomena**

Emergent Phenomena



“Every time we build one of these things, **it does some shocking thing**,” Epstein told me. “You can make it as simple as you want, and it will **do something surprising, almost certainly**.”

Rauch, J. (2002, April). Seeing around corners. *The Atlantic*.

Micro-Macro Theories

Macro

Micro

Micro-Macro Theories

- Economists can simulate markets
  - Existing markets to test theories of status quo
  - Counterfactuals such as changes in policy or conditions
- Political scientists can study consequences of candidate positions and intra-electorate persuasion processes
- Sociologists can evaluate large-scale behavioral trends
  - Beneficial (e.g., exercise, Centola, 2010, *Science*)
  - Undesirable (e.g., segregation, Schelling, 1971, *J. of Math. Sociology*)

Goals of an ABM

Axelrod and Tesfatsion (2006) distinguish among 3 goals:

- Empirical
- Normative
- Heuristic

Empirical

- Figuring out the **hows** and **whys** associated with empirically observed phenomena

- Typically seeking micro explanations for macro behavior
  - ex. People are often generous despite personal costs. Why?
  - Prisoner's dilemma (Axelrod, 1997) as a stylized interaction

Normative

- What interventions will achieve particular objectives?
- Economics: what policies encourage personally costly but publicly beneficial behavior?
- Epidemiology: how can we minimize the spread of disease?
- Sociology: are there relatively neutral ways to reduce segregation?

Heuristic

- What are the **general principles** and **fundamental factors** that underlie collective patterns of behavior?
- Heuristic goals **do not require** the ABM to be absolutely **correct in its details**
- Schelling's classic model (Schelling, 1971) demonstrated that residential segregation can arise without either
  - Centralized control (e.g., governmental policies)
  - Strong local intent (e.g., overly malicious preferences about mixing)
- In this case, segregation was **emergent**

Schelling Demo

Heuristic

- Schelling's model does not attempt to represent the true richness of actual racism
  - e.g., **why** do agents have the mixing preferences they do?
  - Schelling's model has nothing to say
- Instead, Schelling demonstrated the fallibility of intuitions about the micro implications (racism) of macro observations (segregation)

Heuristic

- Gray, Rand, Ert, Lewis, Hershman, & Norton, (2014). The emergence of "us and them" in 80 lines of code: Modeling group genesis in homogeneous populations. *Psychological Science*.
- Can "groups" emerge out of...
  - **Reciprocity** (Generous to generous others)
  - **Transitivity** (Liking one's friends' friends)
- Agents like those that cooperate with them
- Mutual cooperators influence each other's view of everyone else

Heuristic

Demo

http://www.mpmlab.org/groups/

Optimize

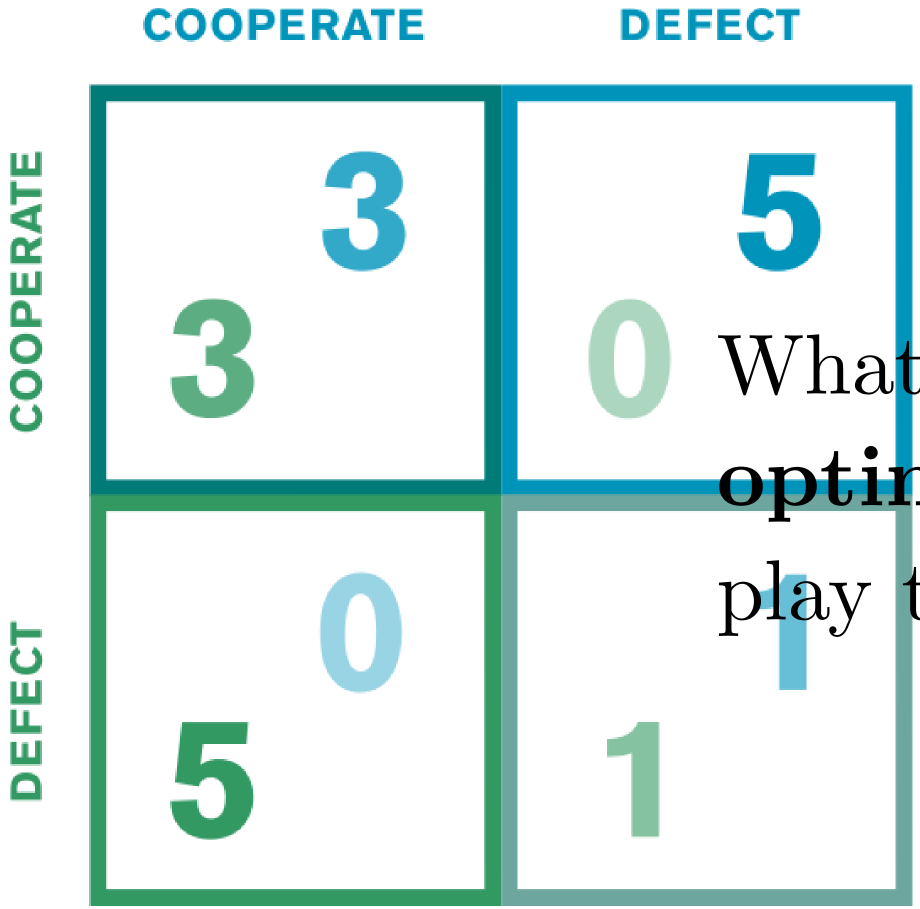
- Another goal may be to explore “optimal” behavior

- Claims of optimality are often presented without good evidence
  - e.g., altruism (costly pro-social behavior) is not rational/optimal

- Proofs of optimality are particularly challenging in complex systems (e.g., social systems)

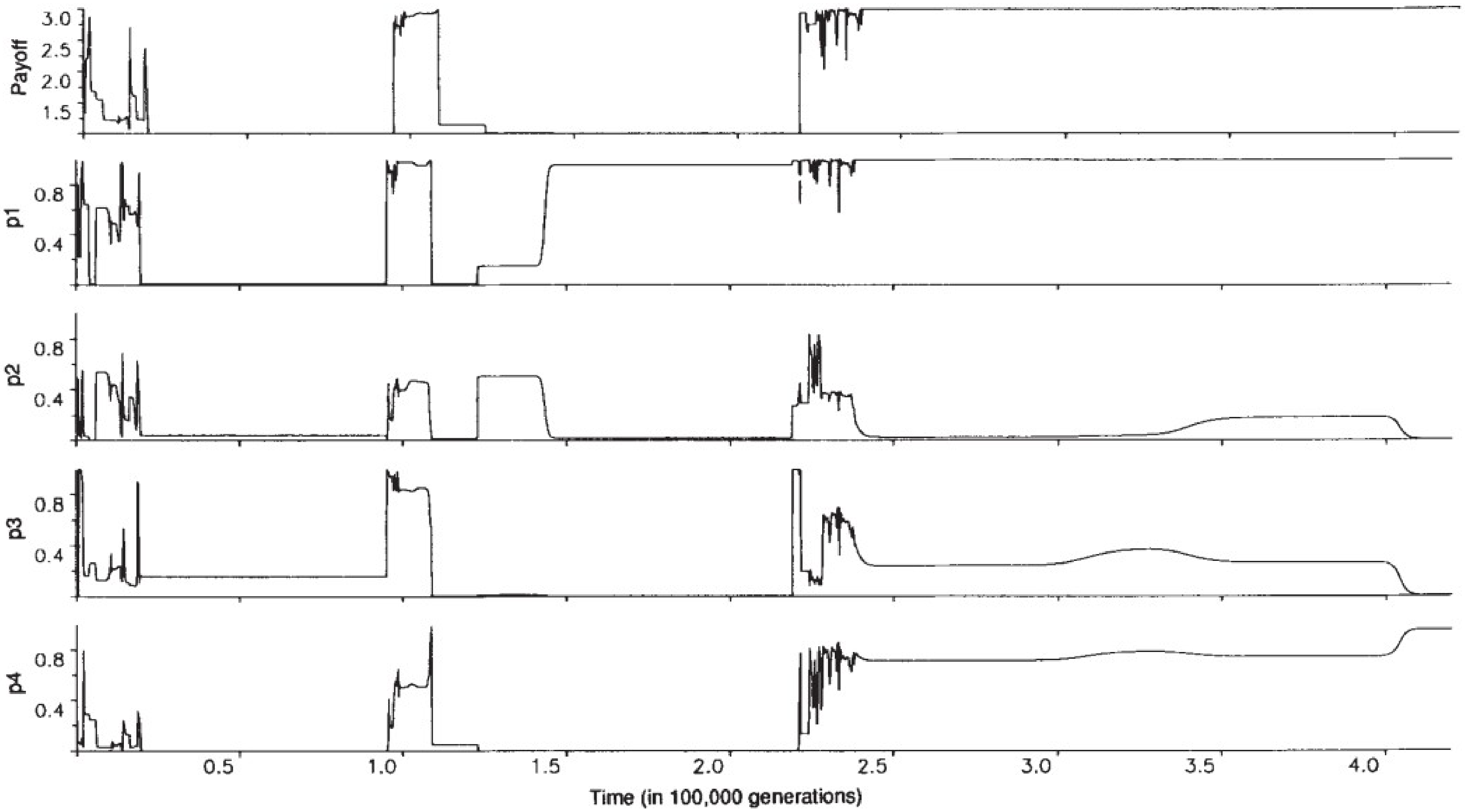
- ABM with learning/evolution can address such claims directly

Prisoner's Dilemma

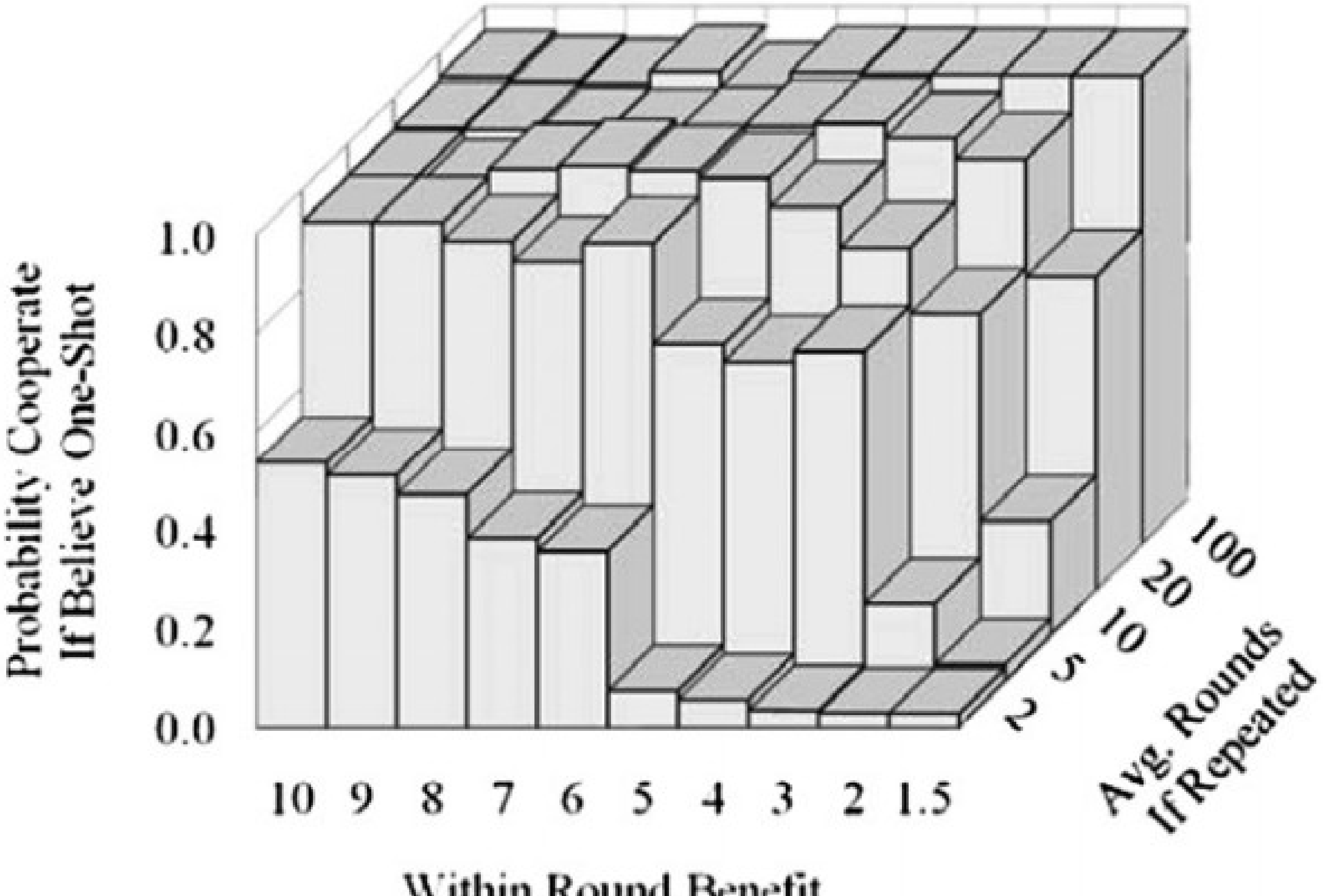


What is the **optimal** way to play this game?

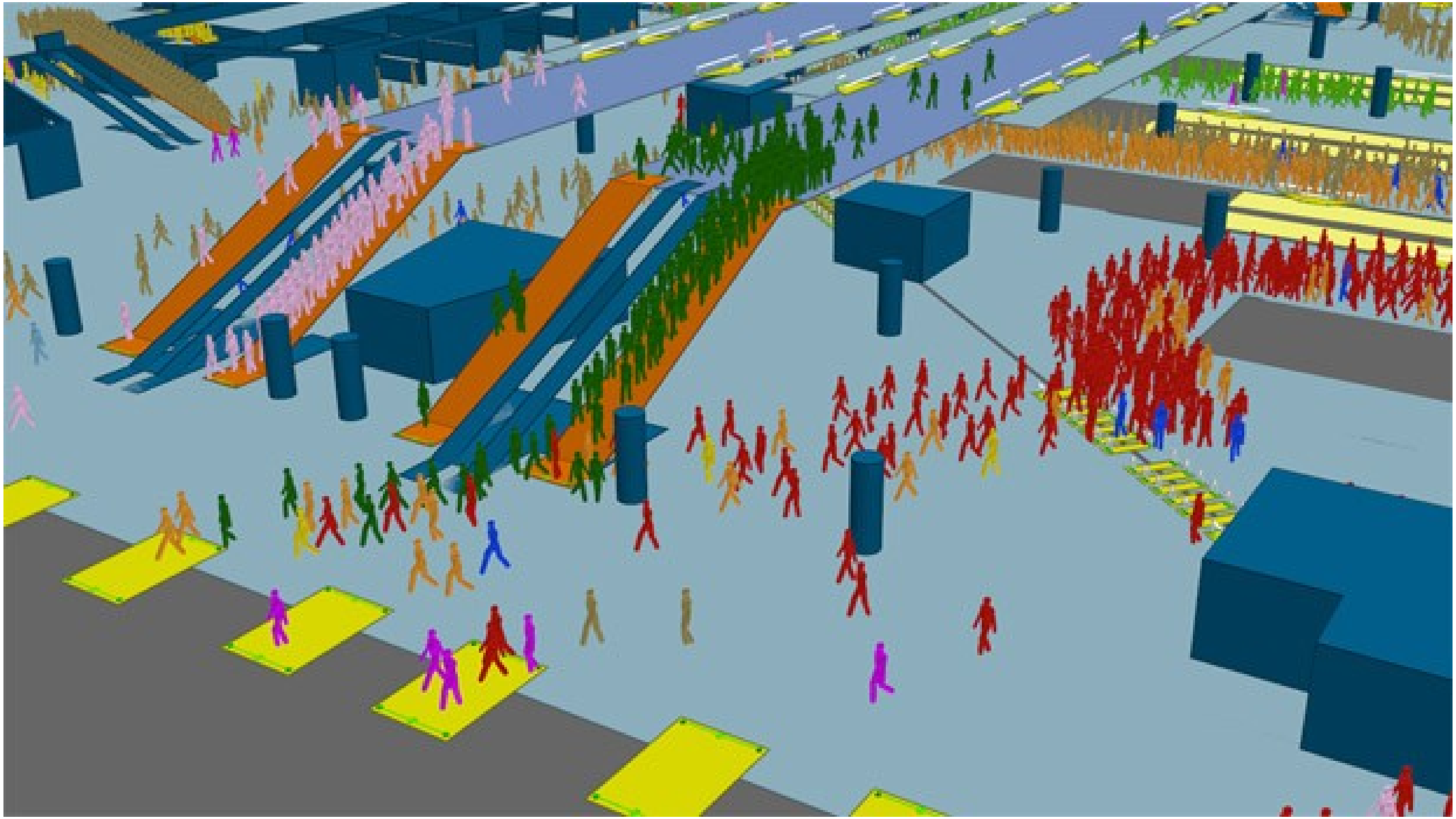
Nowak & Sigmund (1993, Nature)



Delton, Krasnow, Cosmides, & Tooby (2011, PNAS)



ABM in the "Real World"



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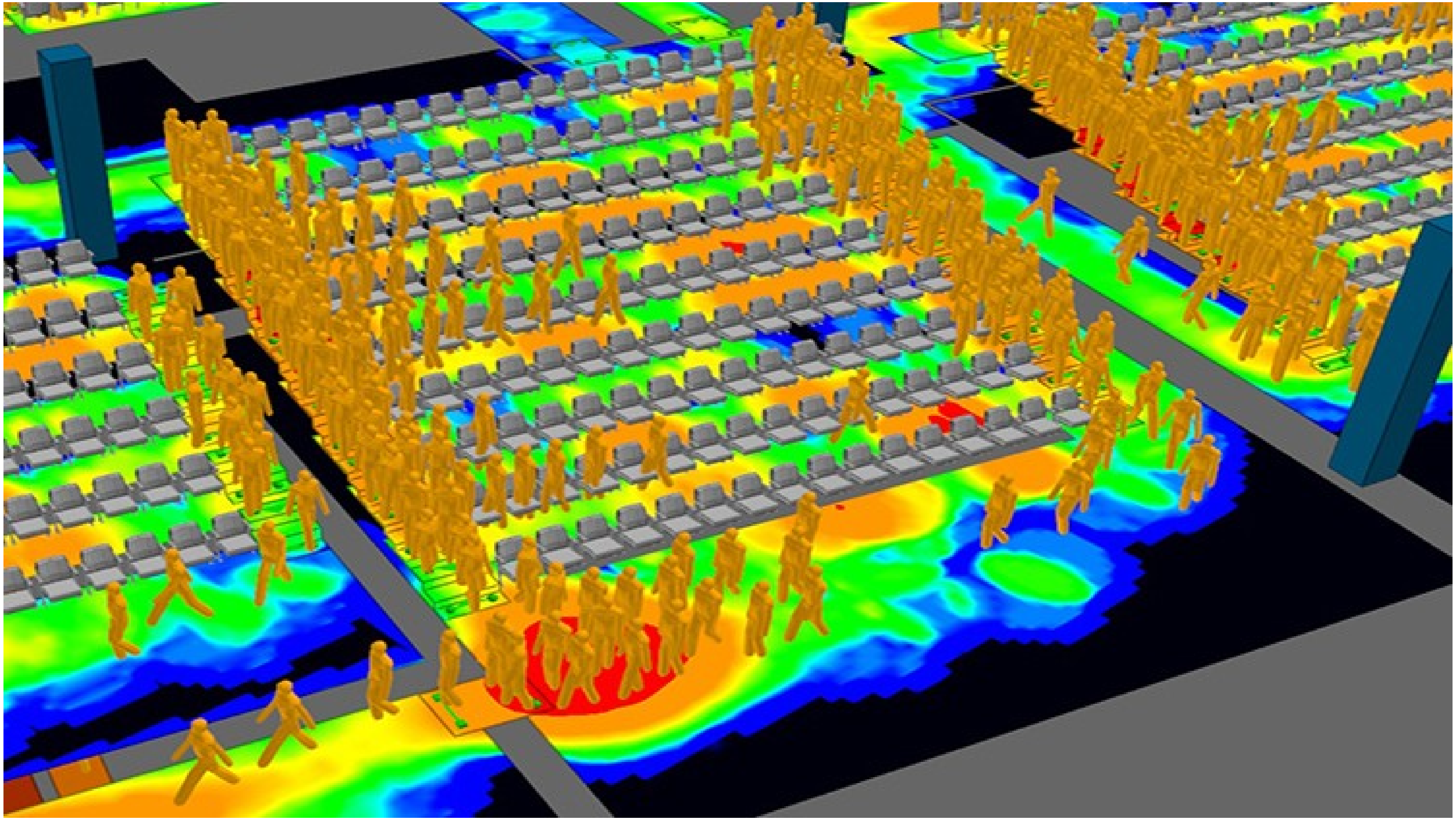

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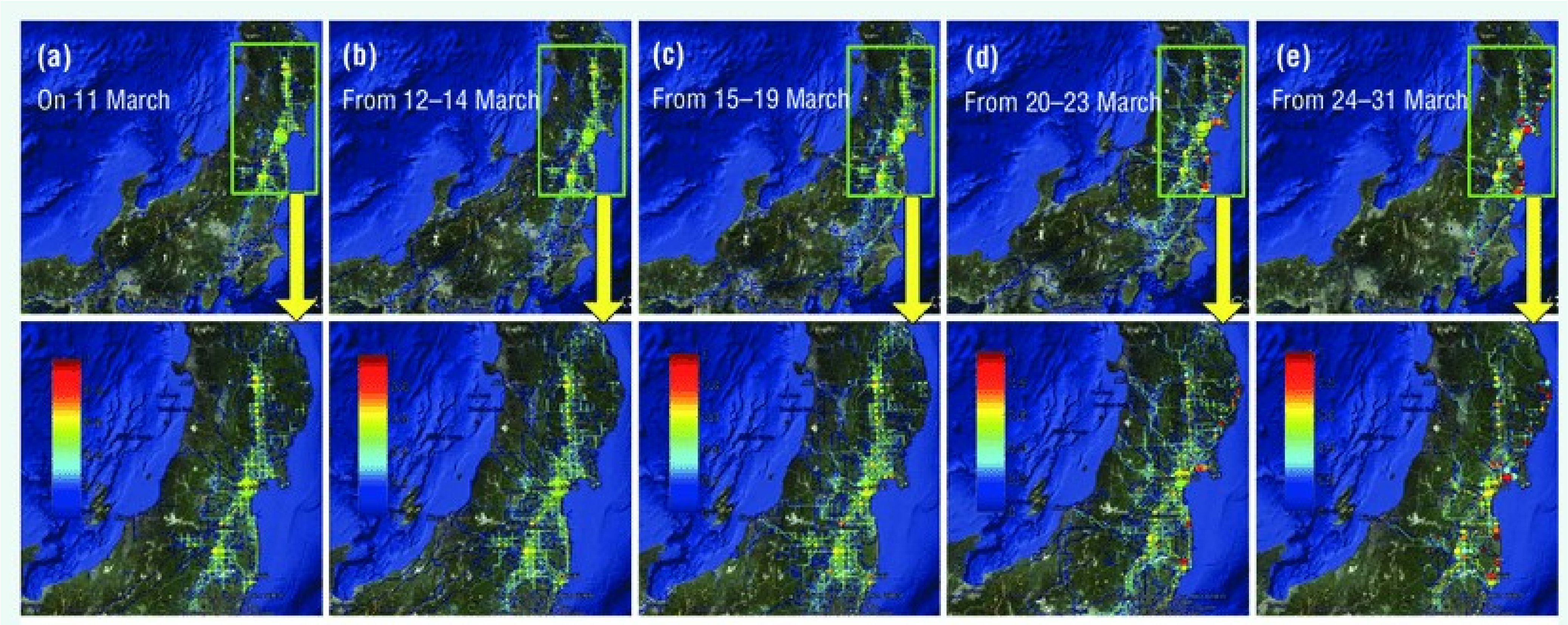

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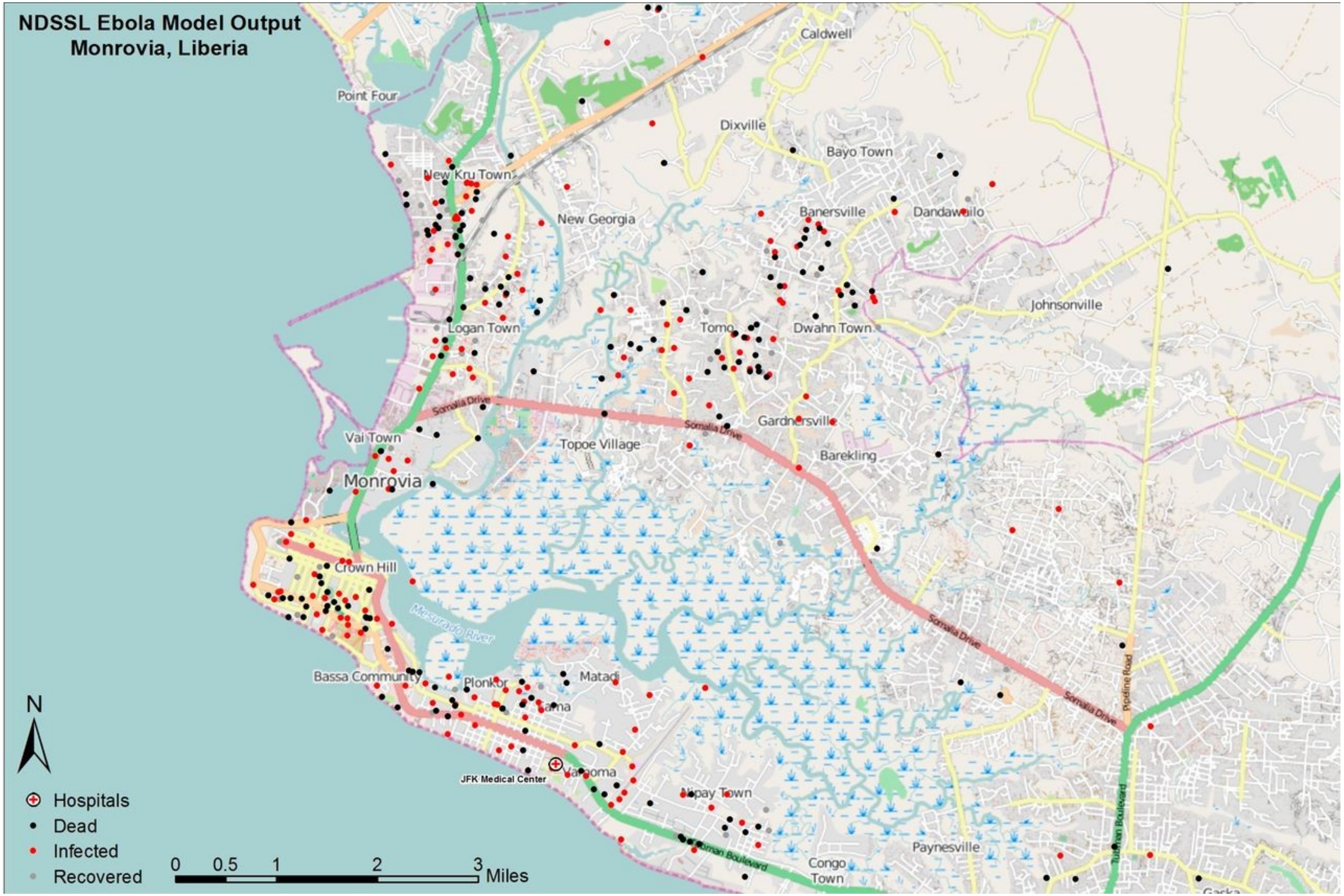


ABM

- Agents
- Interaction
- Environment

Agents

- This is your "micro" model
- Behavior is guided by rules you define
- Rules are typically sensitive to
  - Environment
  - Other agents
  - State (e.g., hungry)
  - Past experiences (learning)

Agents

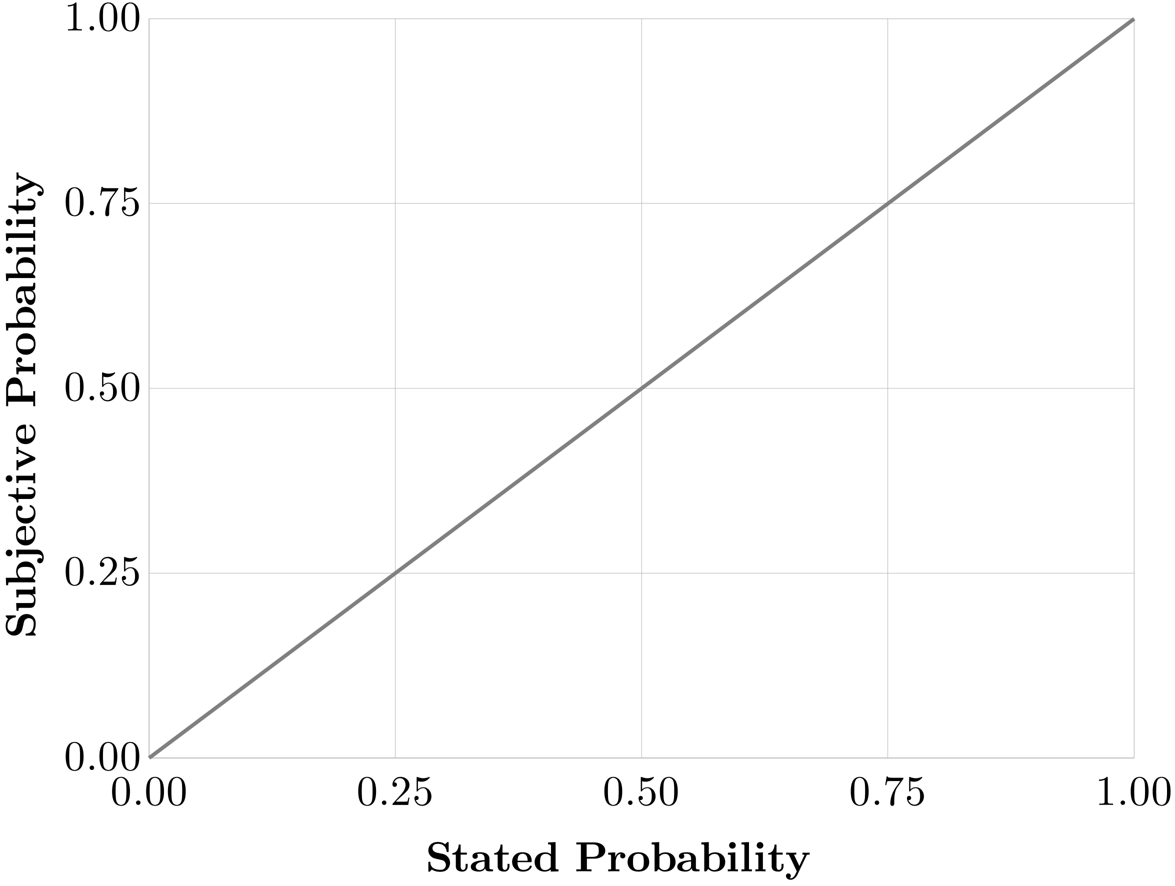
- Memory
- Beliefs
  - Model of the environment
  - Models of other agents
- Emotions
- Preferences/behavioral tendencies
- ...and much more

Schelling (1971)

0% 100%

Minimum proportion of same-race neighbors required to not move

Johnson & Luhmann (submitted)



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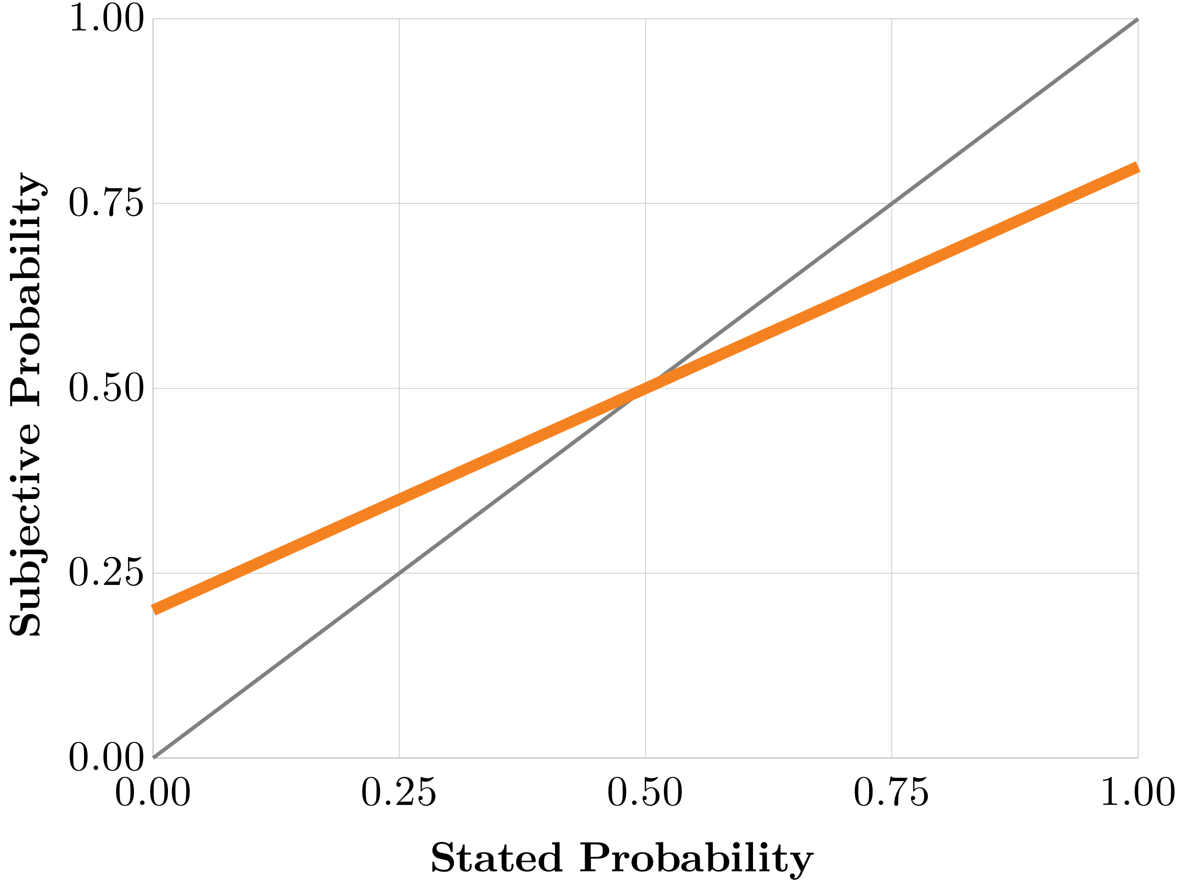
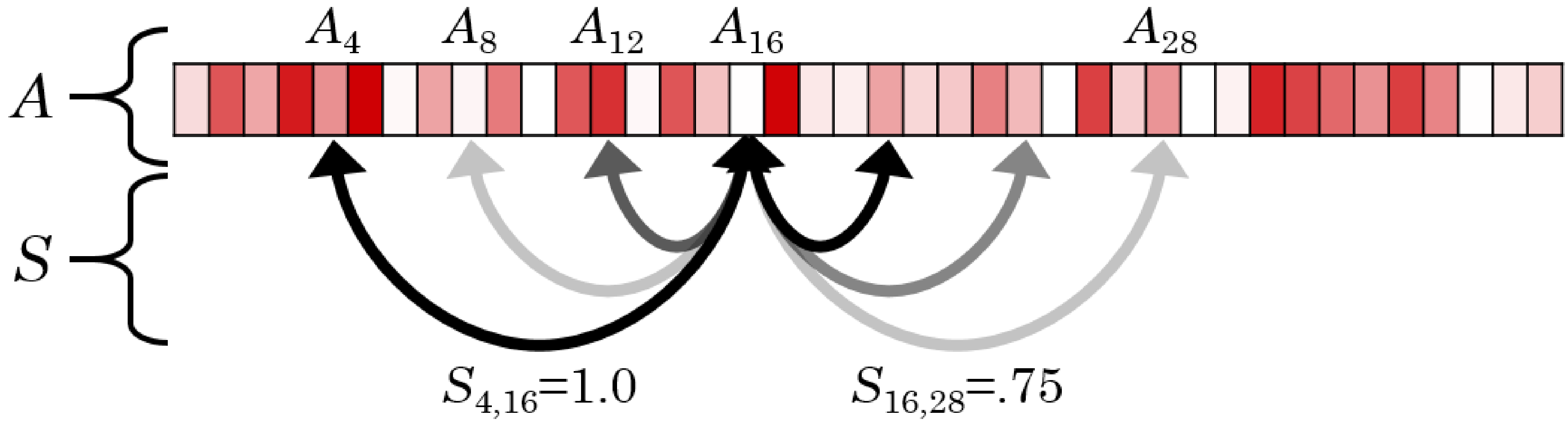


Luhmann & Rajaram (2015, Psych. Sci.)



Agents

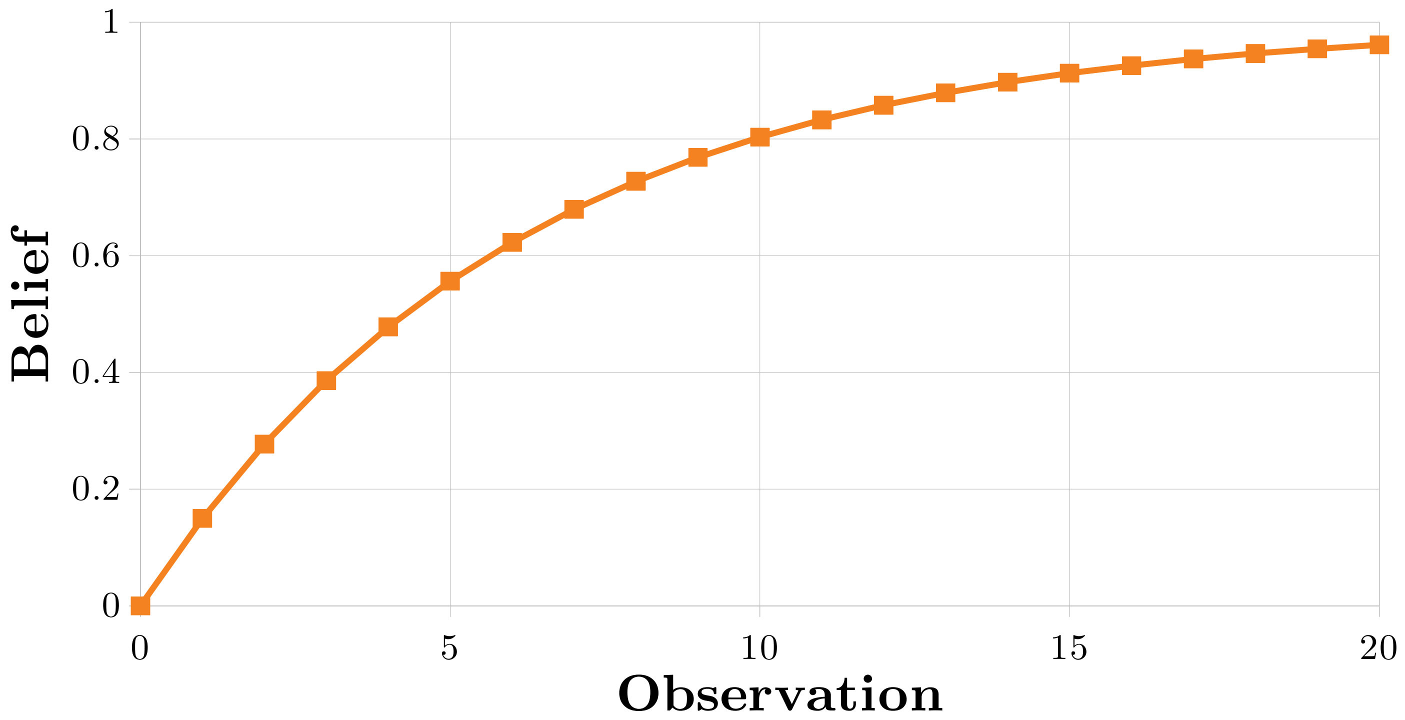
- Types of agents?
  - Wolf & sheep
  - Caucasian & African-American
  - Management & employees
  - Political affiliation
- Parametric variation?
  - Generosity
  - Prejudice
  - Political ideology

Agents

- Are agents static or can they change?
- Learning
  - Rules sensitive to past interactions with other agents/environment
  - e.g., Delton et al. from earlier
- Evolution
  - Agents reproduce/die off according to their fitness
  - Obviates strong justification of updating rules
  - Nowak & Sigmund (1993) from earlier

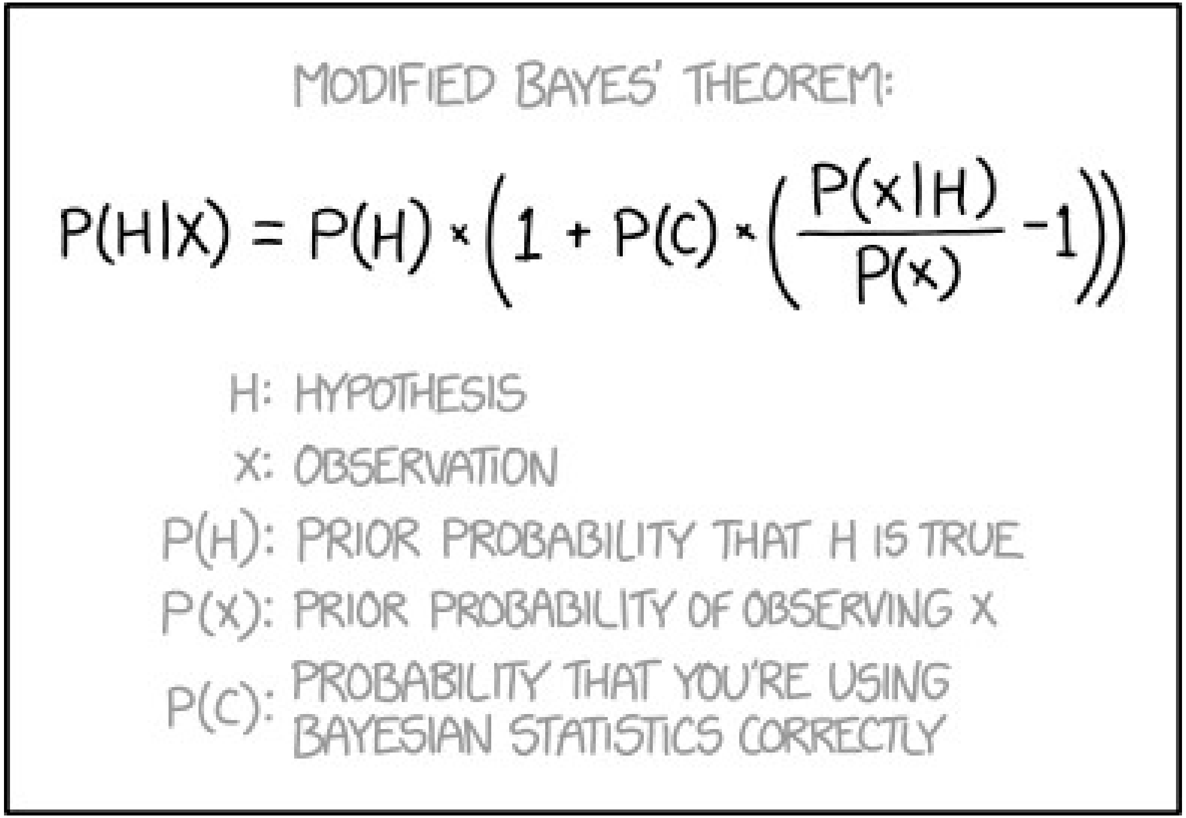
Learning

- Can be simple and heuristic
  - e.g., new belief = old belief + [learning rate * (old belief – observation)]



Learning

- Can be complex and “rational”



xkcd.com/2059/

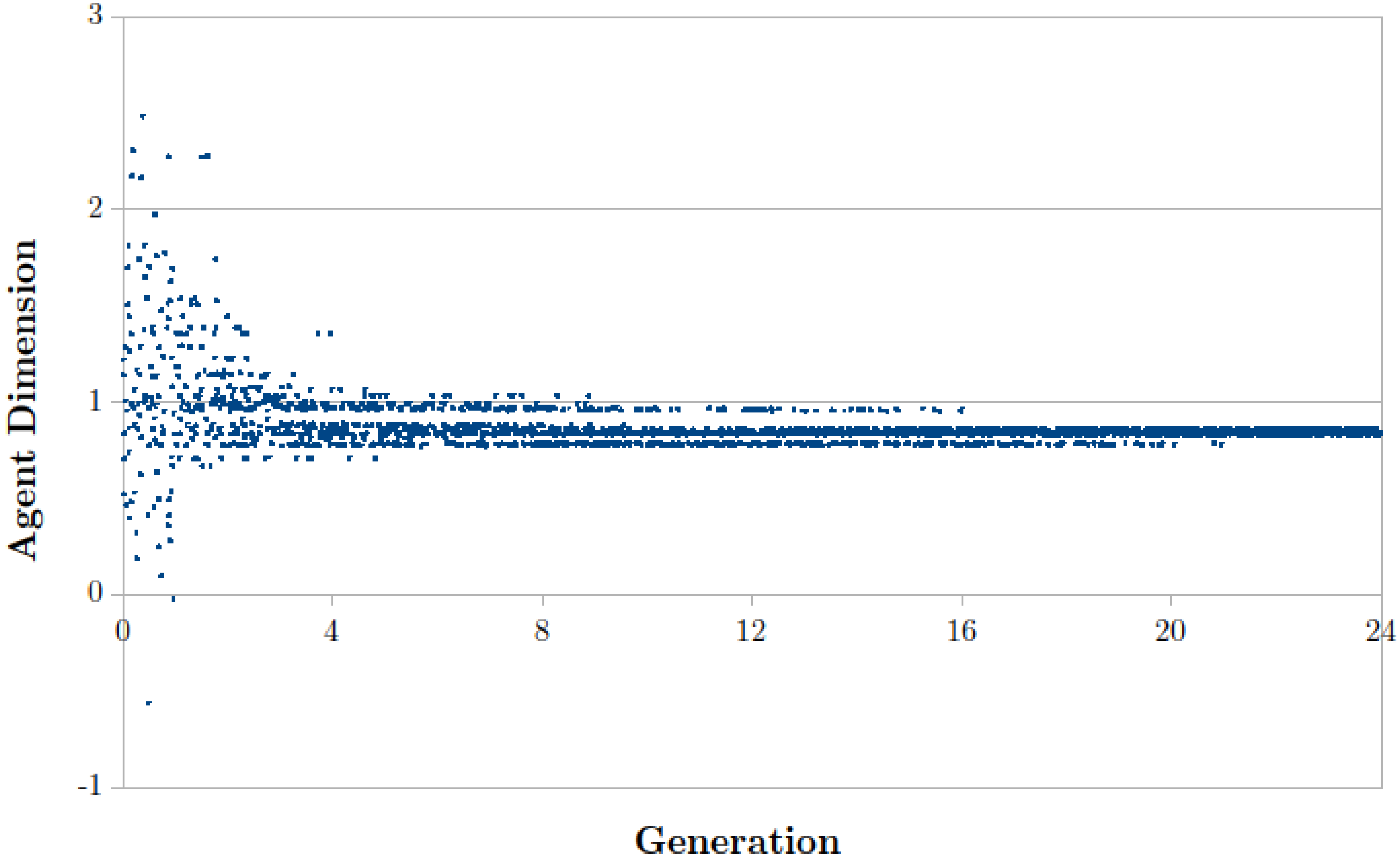
Evolution

- Initial conditions
- Reproduction scheme
- Death

Evolution

- Initial conditions:
  - 1000 agents initialized so that their generosity is distributed as $U(0,1)$
- At the end of each generation (after a series of interactions), agents reproduce
  - Reproduction is asexual
  - Number of offspring is proportional to fitness (fitter produce more)
- All agents die at the end of each generation

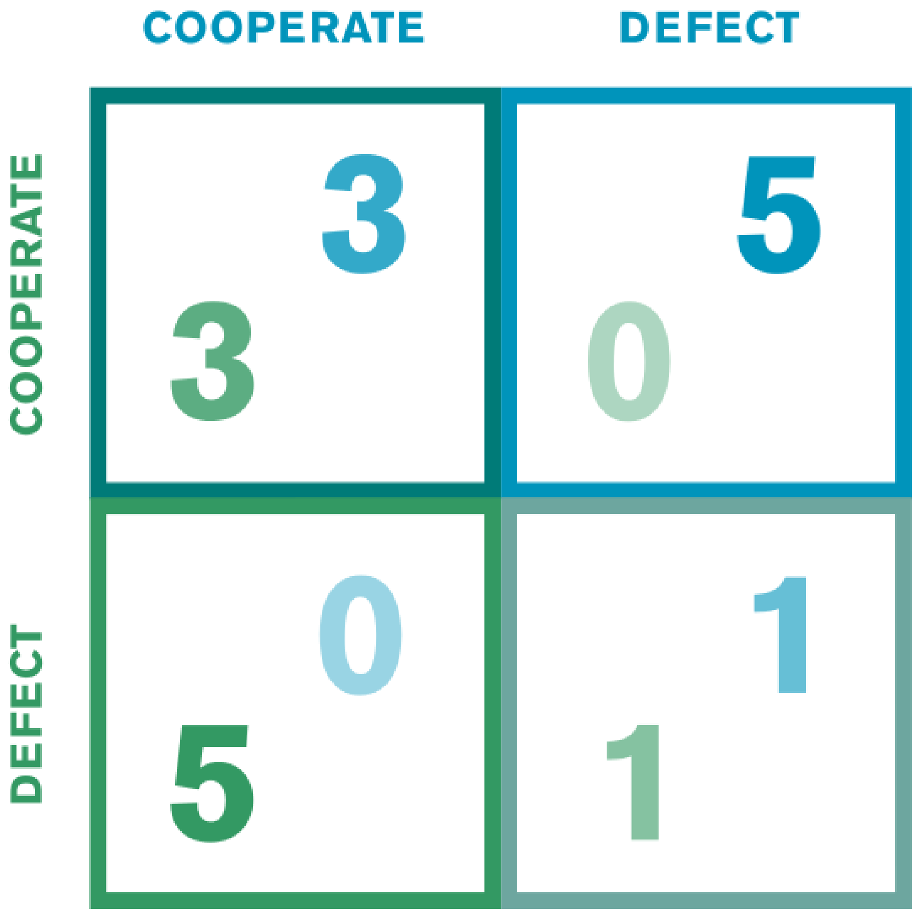
Evolution



Interaction

- When two (or more) agents come in contact, what do they do?
  - Fight?
  - Discuss?
  - Negotiate?
  - Barter?
  - Physically bump into each other?
- Typically, this will determined by the scenario/behavior you are attempting to model

Game Theory



Matching Pennies

	Heads	Tails
Tails	-1 1	1 -1
Heads	1 -1	-1 1

Matching Pennies

Coordination Game

	Left	Right
Right	1, 1	-1, -1
Left	-1, -1	1, 1

Coordination Game

Coordination Game

Battle of the Sexes

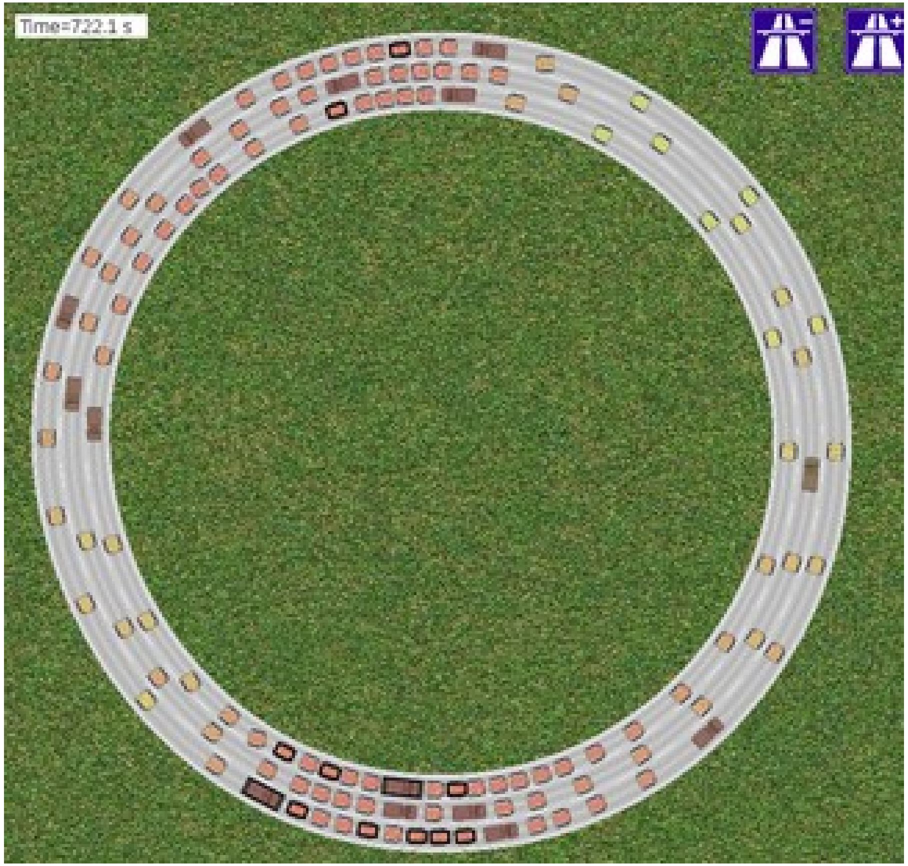
	Football	Opera
Opera	0, 0	2, 4
Football	4, 2	0, 0

Chicken

	Straight	Swerve
Straight	-10 -10	-1 1
Swerve	1 -1	0 0

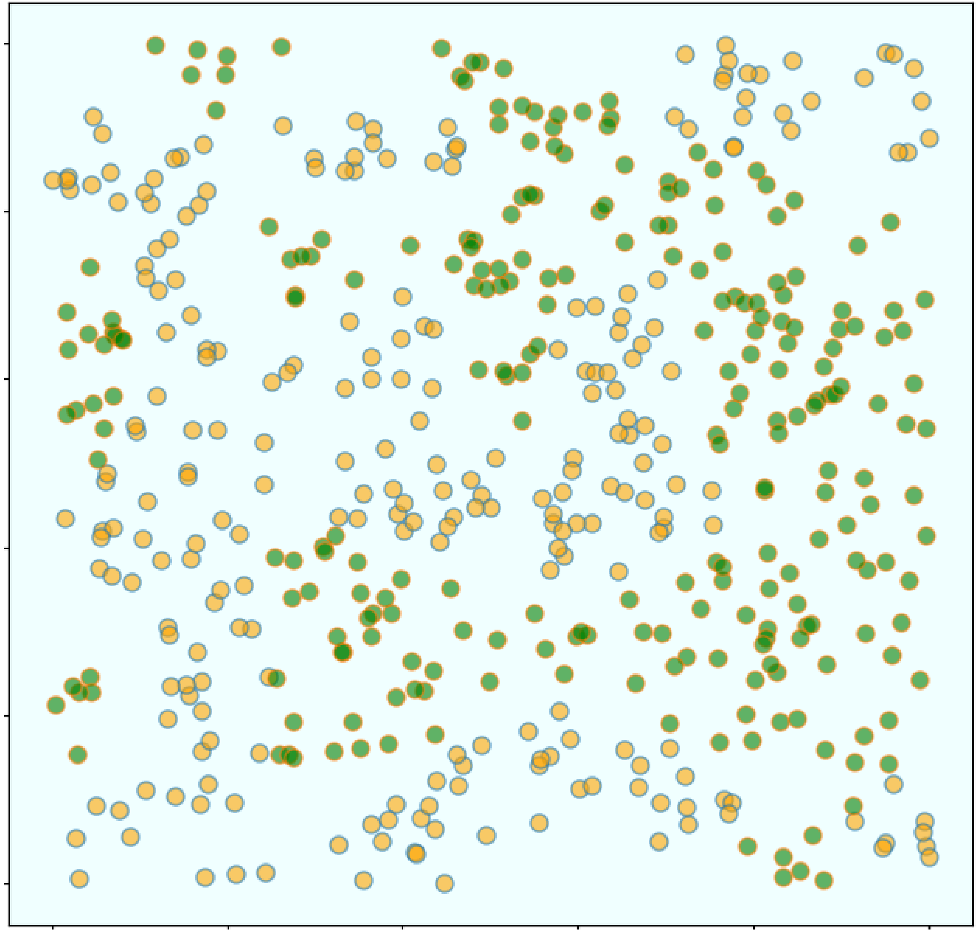
Chicken

Traffic



Interaction is simple and intuitive (don't collide with others)

Schelling

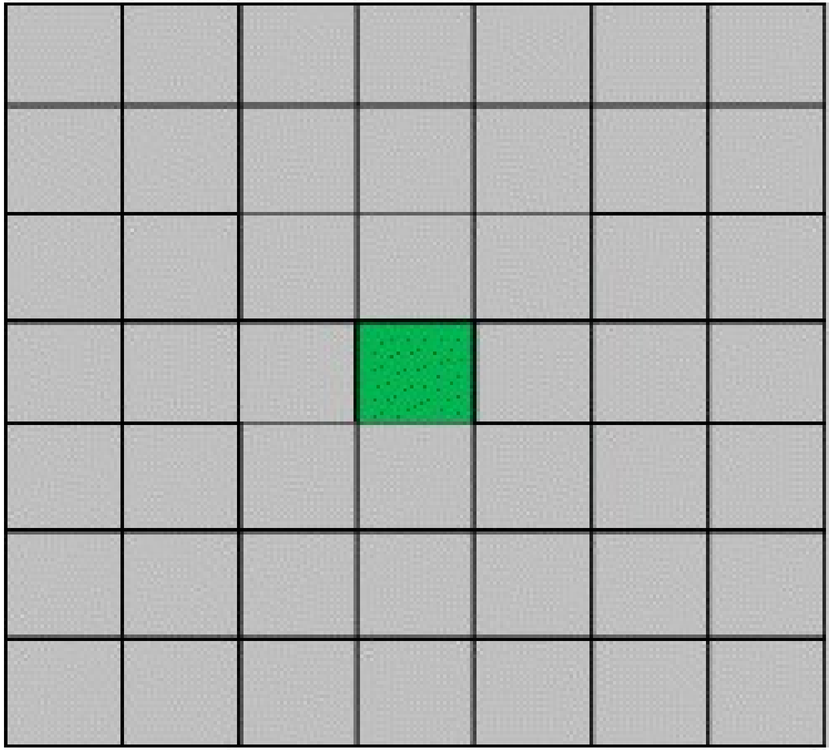


Agents are essentially treated as part of the environment

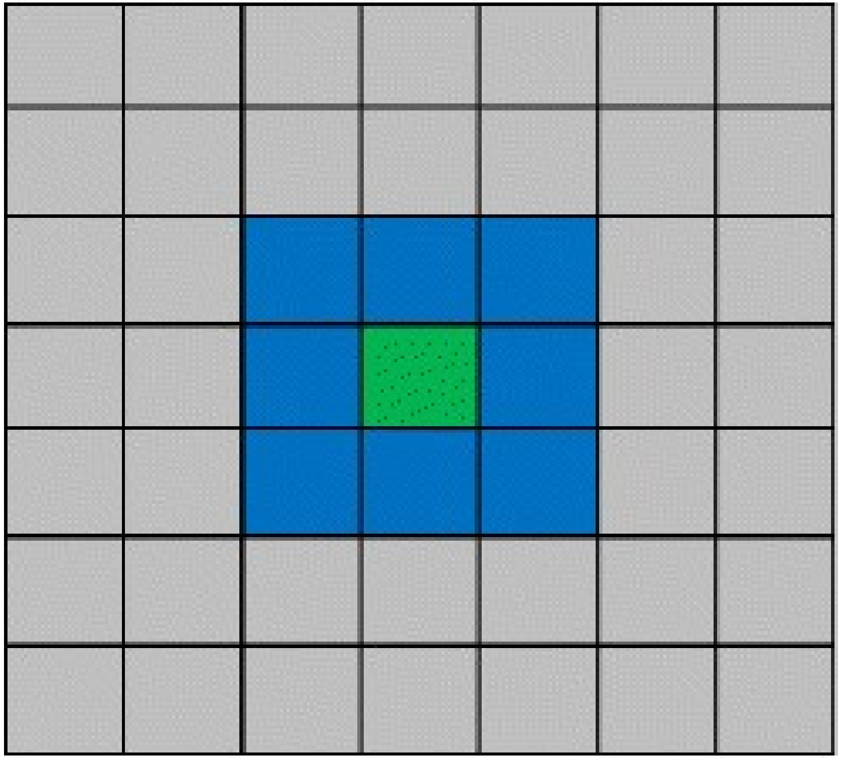
Environment

- Environments can simply be constraints on agents
  - Where can/can't agents go
  - Which agents are near which other agents
- Or they can also rich sources of influence on agents
  - Food or other resources
  - Institutions (e.g., the government via taxes, police via punishment)

Lattice

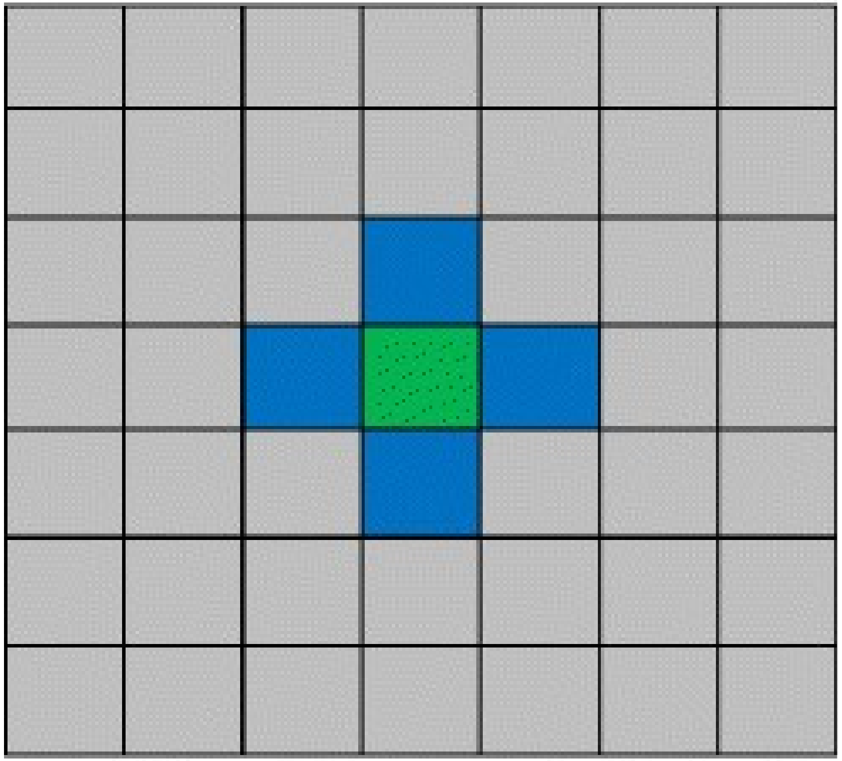


Lattice



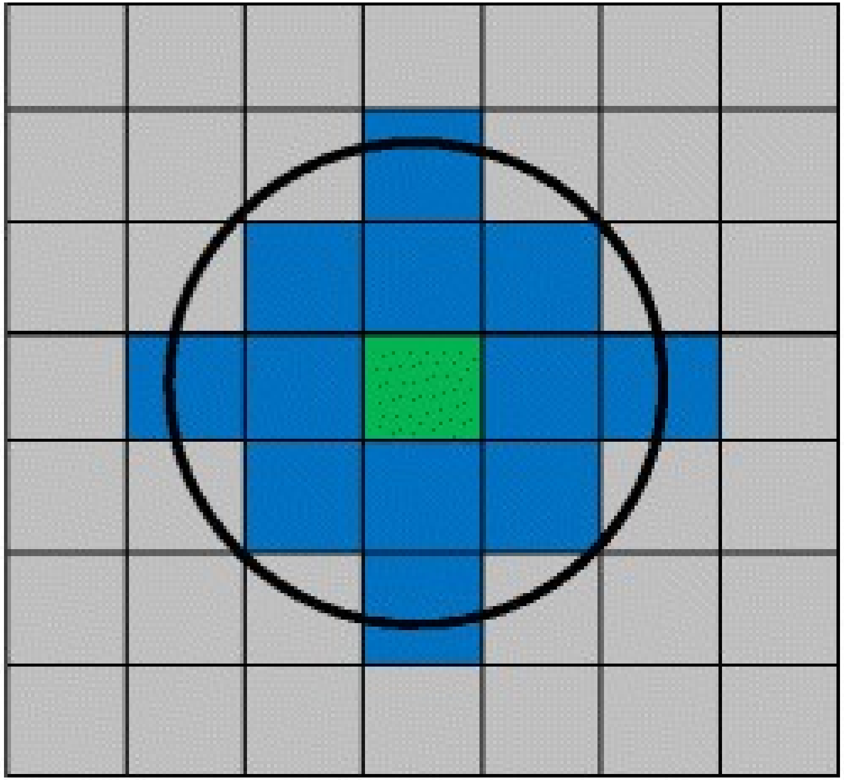
(b) Moore neighborhood

Lattice



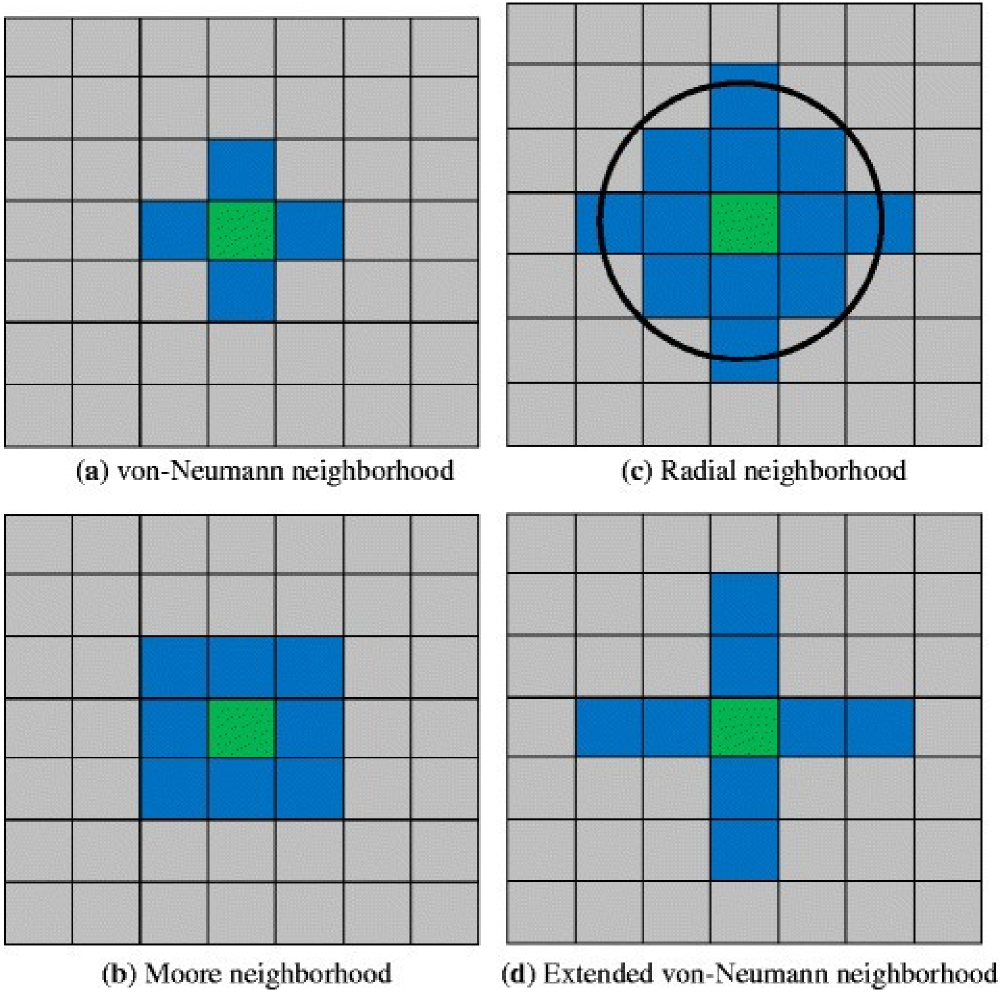
(a) von-Neumann neighborhood

Lattice

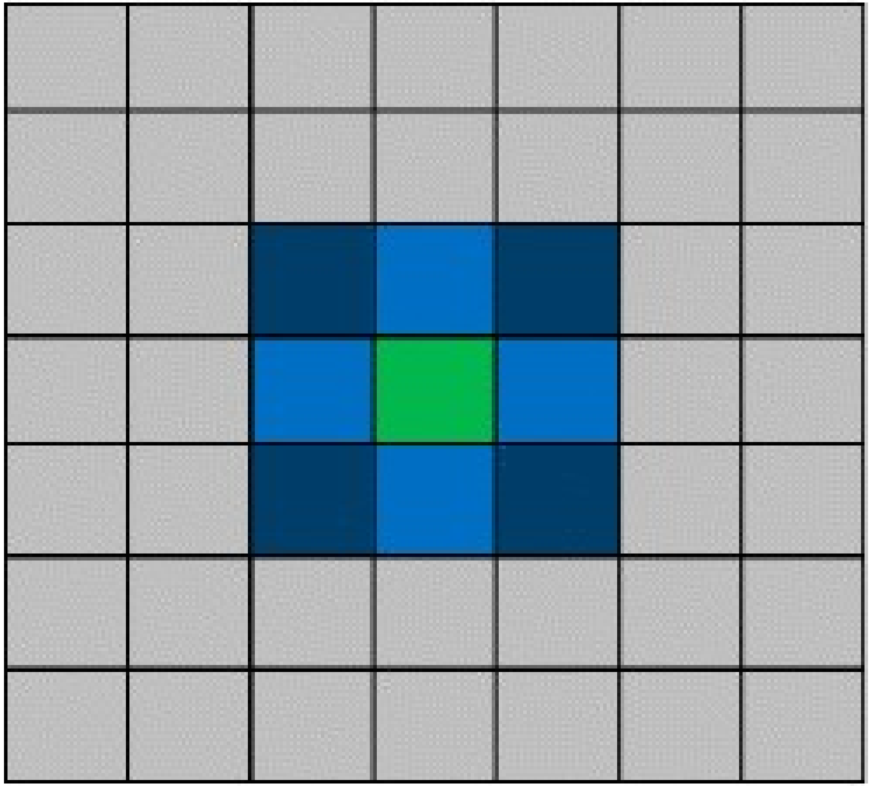


(c) Radial neighborhood

Lattice

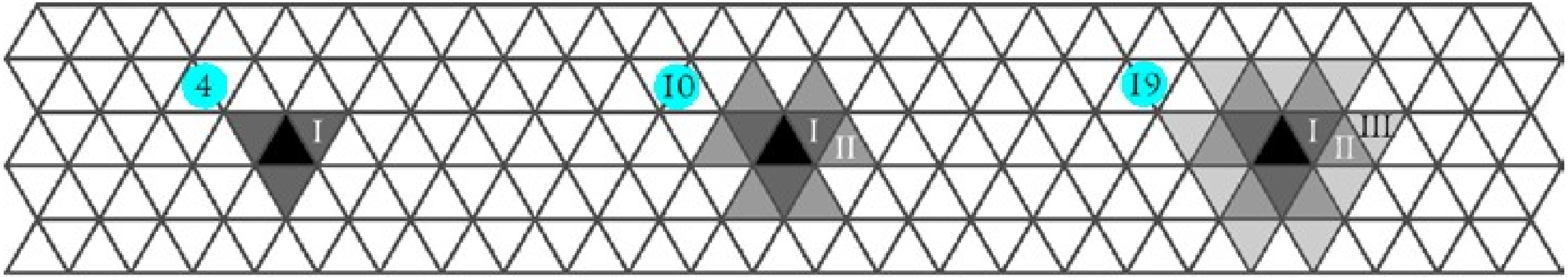

(a) von-Neumann neighborhood
(c) Radial neighborhood
(b) Moore neighborhood
(d) Extended von-Neumann neighborhood

Why Square?

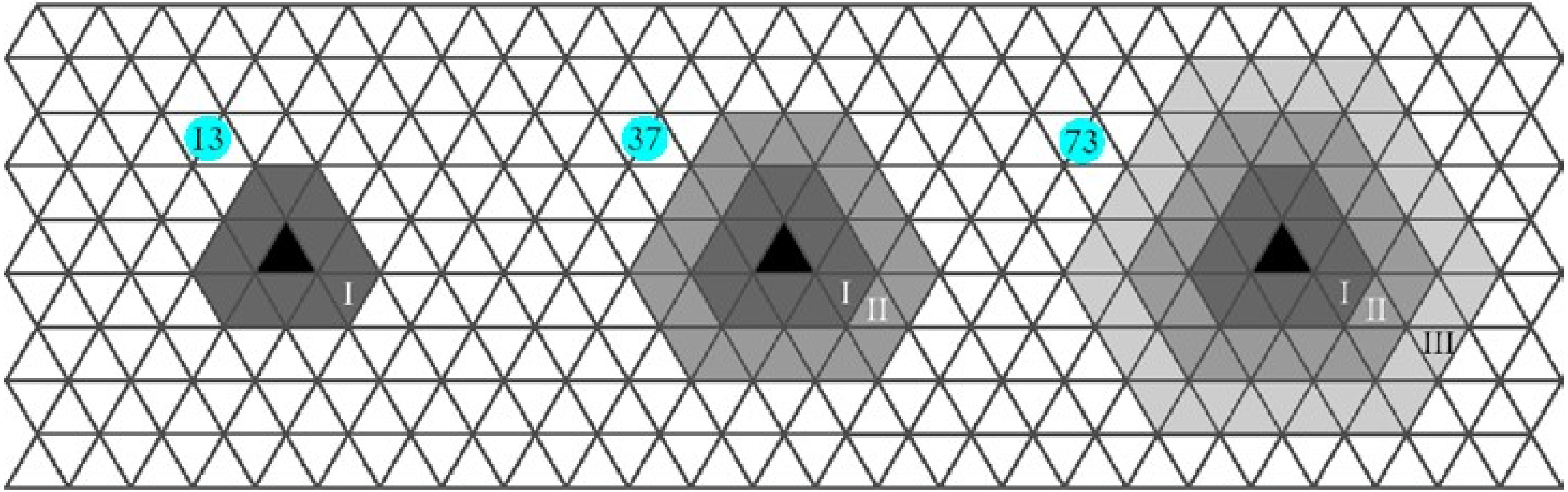


Triangular Lattice

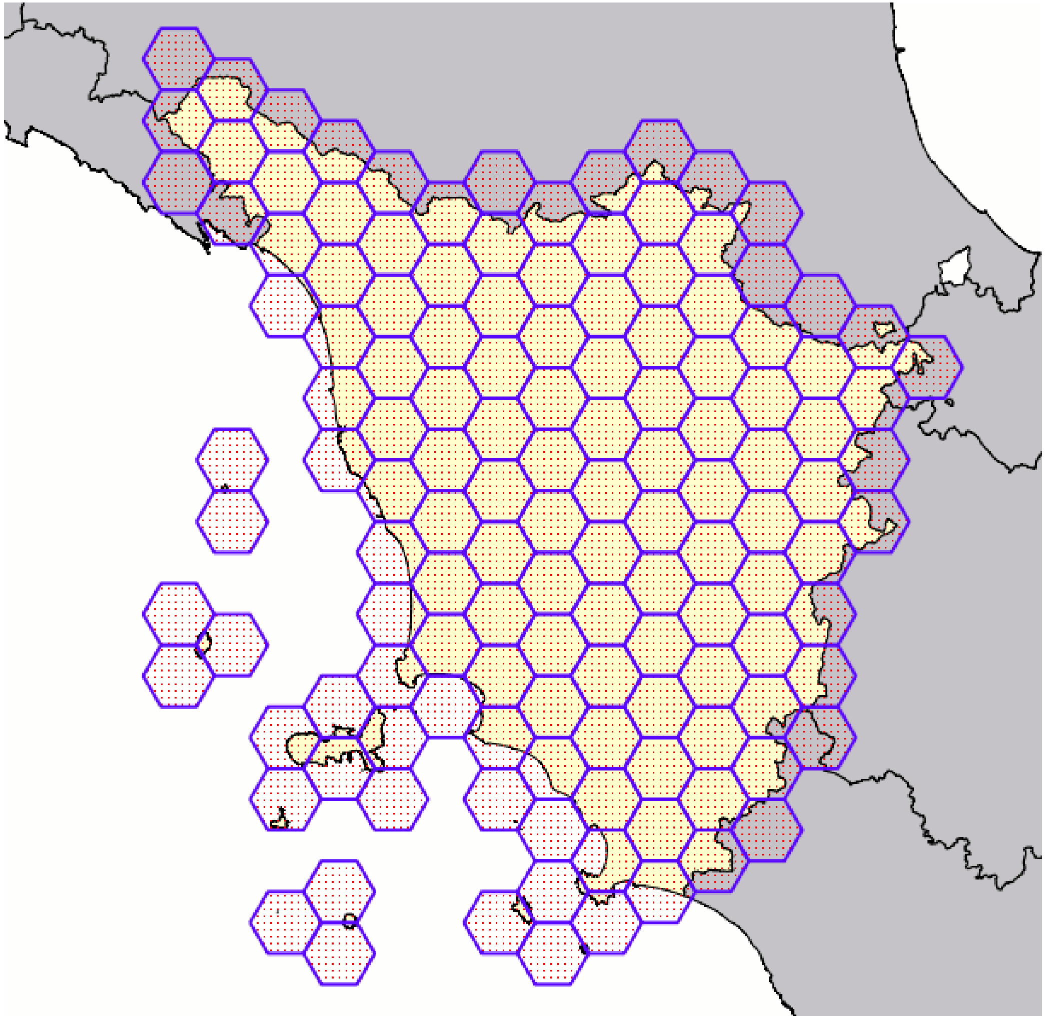
von Neumann



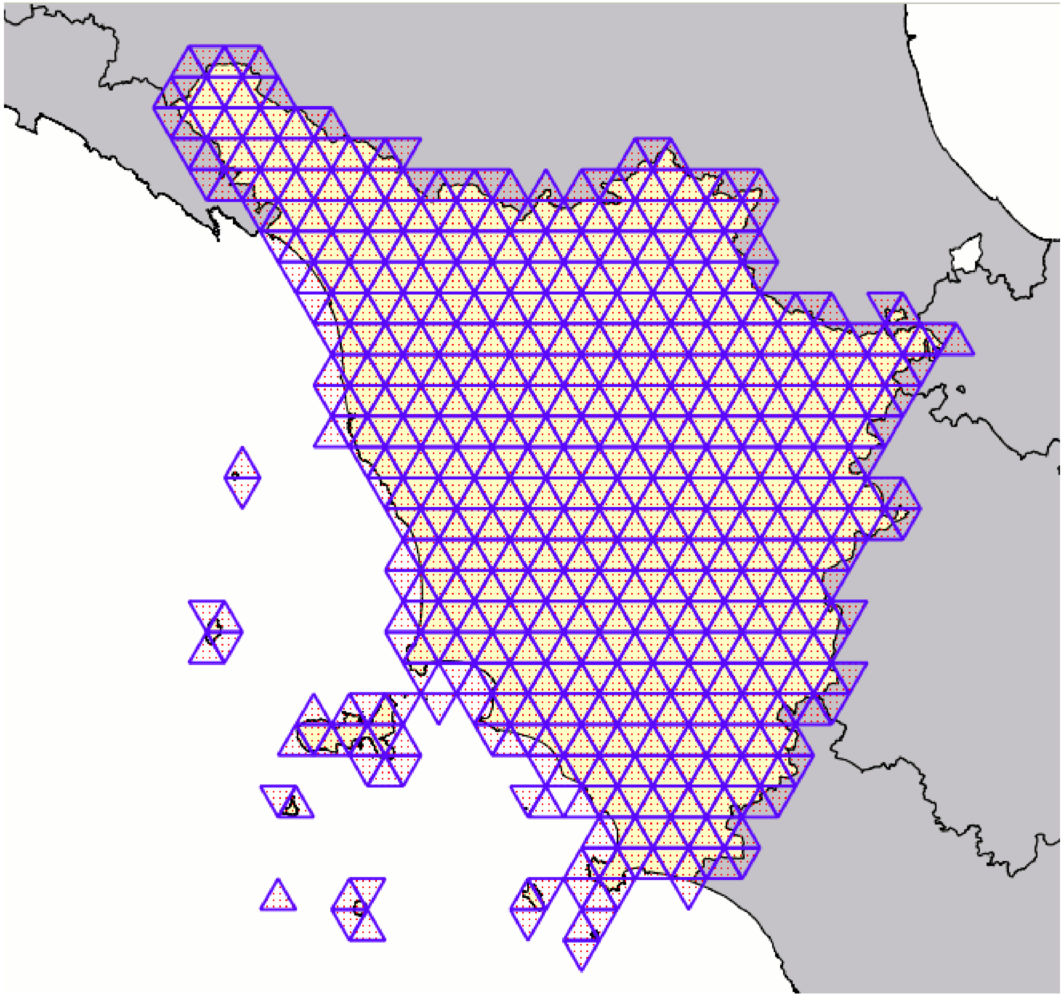
Moore



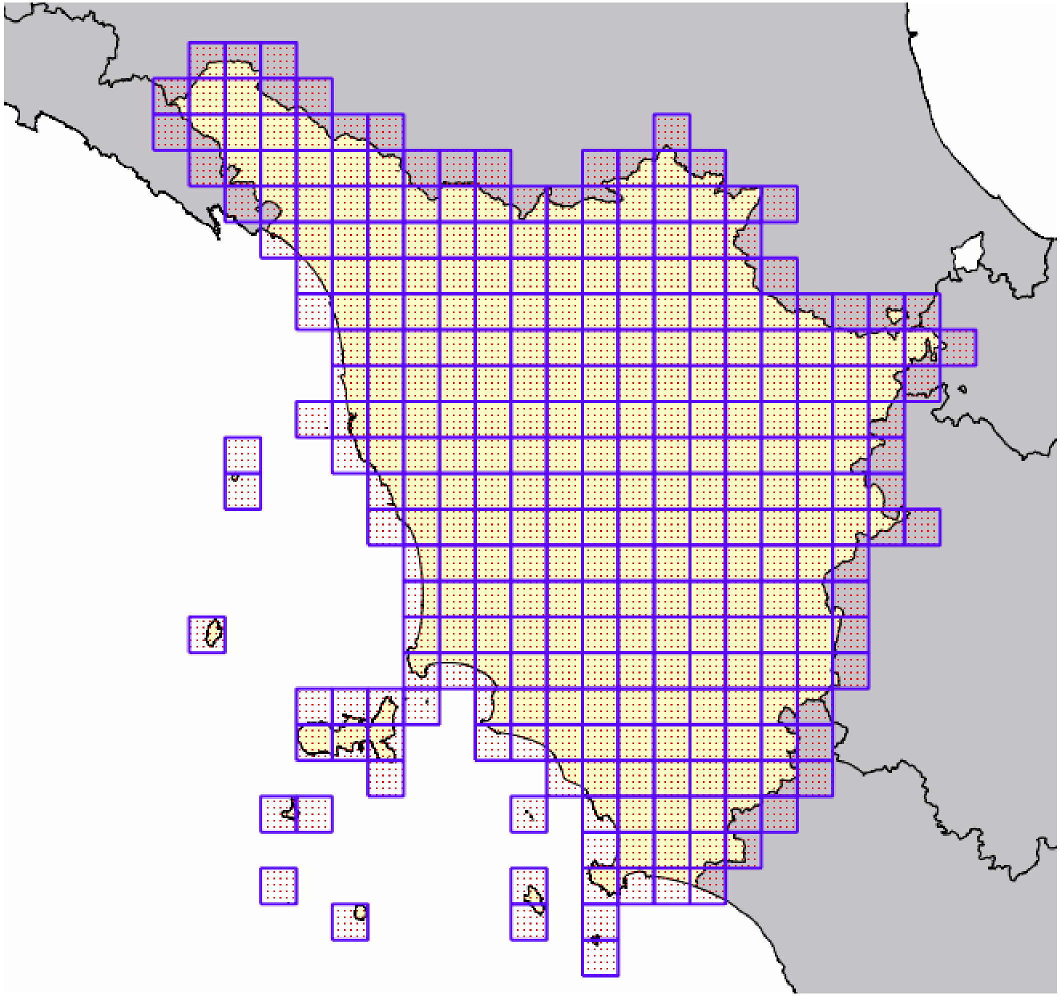
Hexagonal Lattice



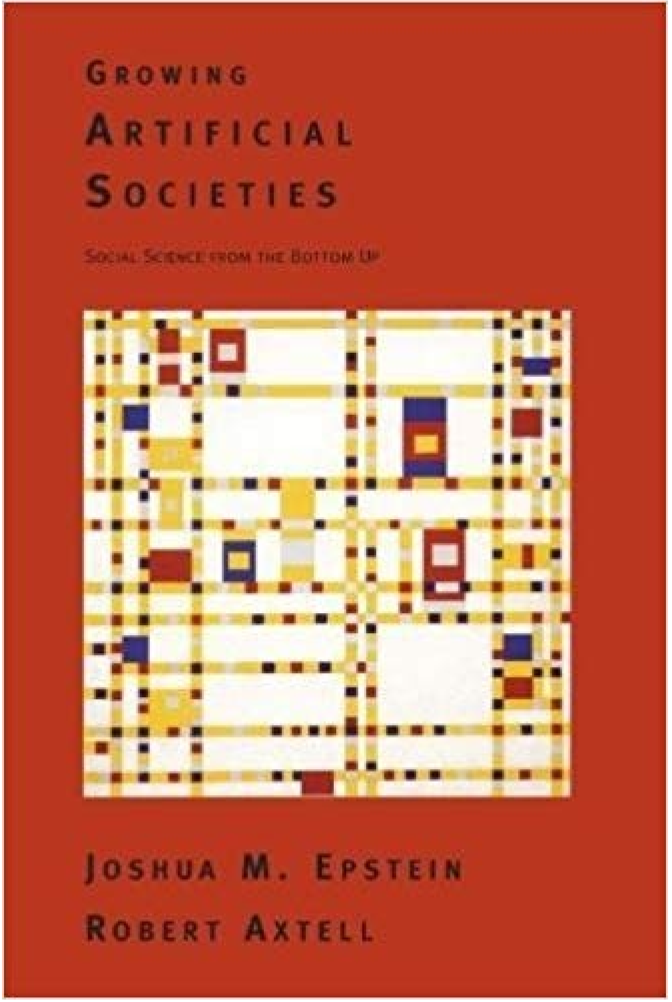
Triangular Lattice



Square Lattice



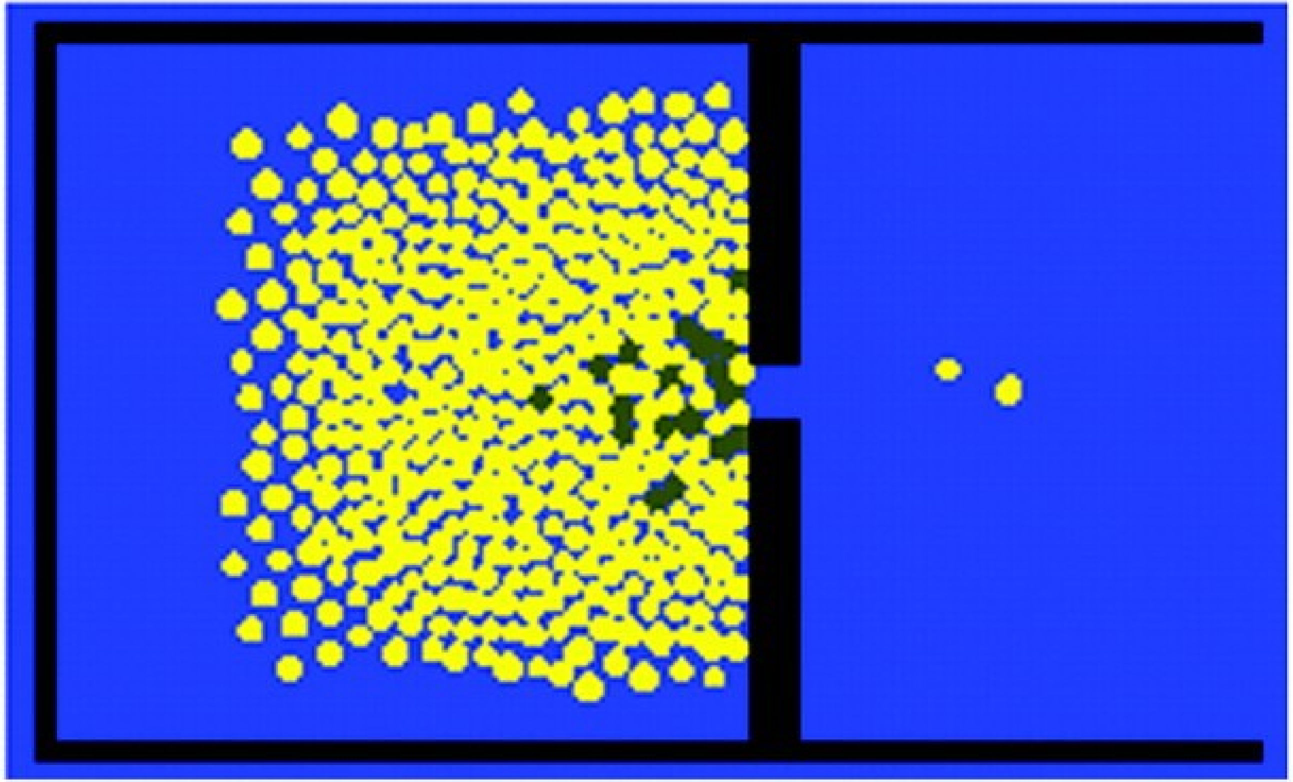
Environment



Environment

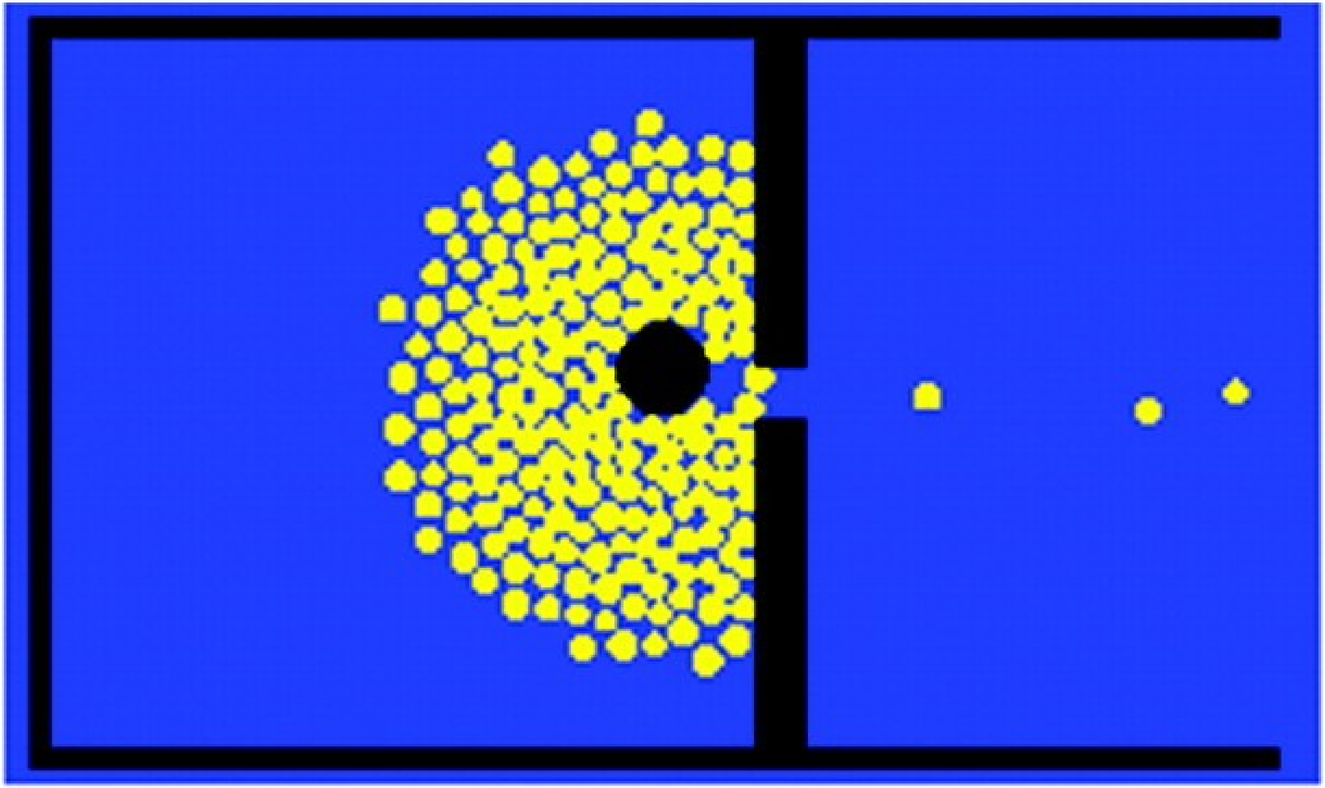
Sugarscape Demo

Environment



Bonabeau (2002, PNAS)

Environment



Bonabeau (2002, PNAS)

Software

- NetLogo (ccl.northwestern.edu/netlogo)
- JADE (jade.tilab.com)
- Repast (repast.github.io)
- Swarm (swarm.org)
- Generic programming environments
  - Python
  - Java
  - R
  - Matlab

Abar, S., Theodoropoulos, G. K., Lemarinier, P., & O'Hare, G. M. (2017). Agent based modelling and simulation tools: A review of the state-of-art software. *Computer Science Review*, 24, 13-33.

NetLogo

- System
  - Free, open source
  - Cross-platform: Windows, Mac, Linux, etc.
- Programming
  - Fully programmable
  - Approachable syntax
  - Language is Logo dialect extended to support agents
  - Mobile agents (turtles) move over a grid of stationary agents (patches)
  - Link agents connect turtles to make networks, graphs, and aggregates
  - Large vocabulary of built-in language primitives

NetLogo

- Environment
  - Command center for on-the-fly interaction
  - Interface builder w/ buttons, sliders, switches, choosers, monitors, text boxes, notes, output area
  - Agent monitors for inspecting and controlling agents
  - Export and import functions (export data, save and restore state of model, make a movies

NetLogo demo

ccl.northwestern.edu/netlogo

Software

- Python
  - Mesa (github.com/projectmesa/mesa)
  - AB-CE (github.com/AB-CE/abce)
- R
  - SpaDES (cran.r-project.org/web/packages/SpaDES.core)
  - RNetLogo (cran.r-project.org/web/packages/RNetLogo)

CoMSES Net

- International network of people seeking to develop, share, and use agent based modeling in the social and ecological sciences
  - comses.net

- The model library is a useful starting point
  - comses.net/codebases

Outline

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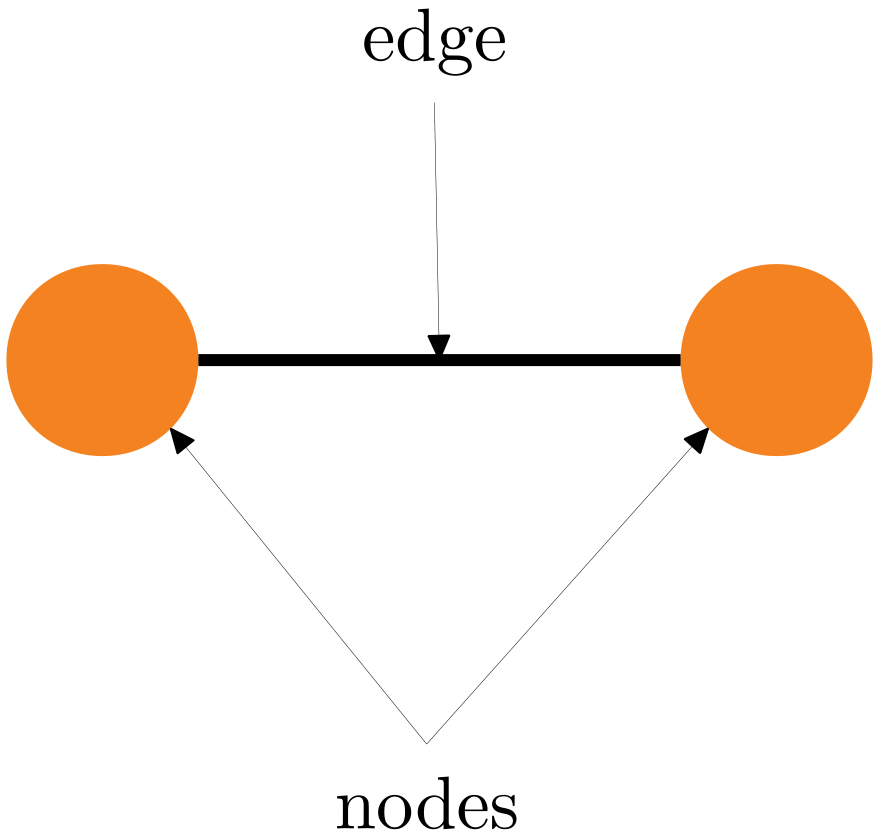
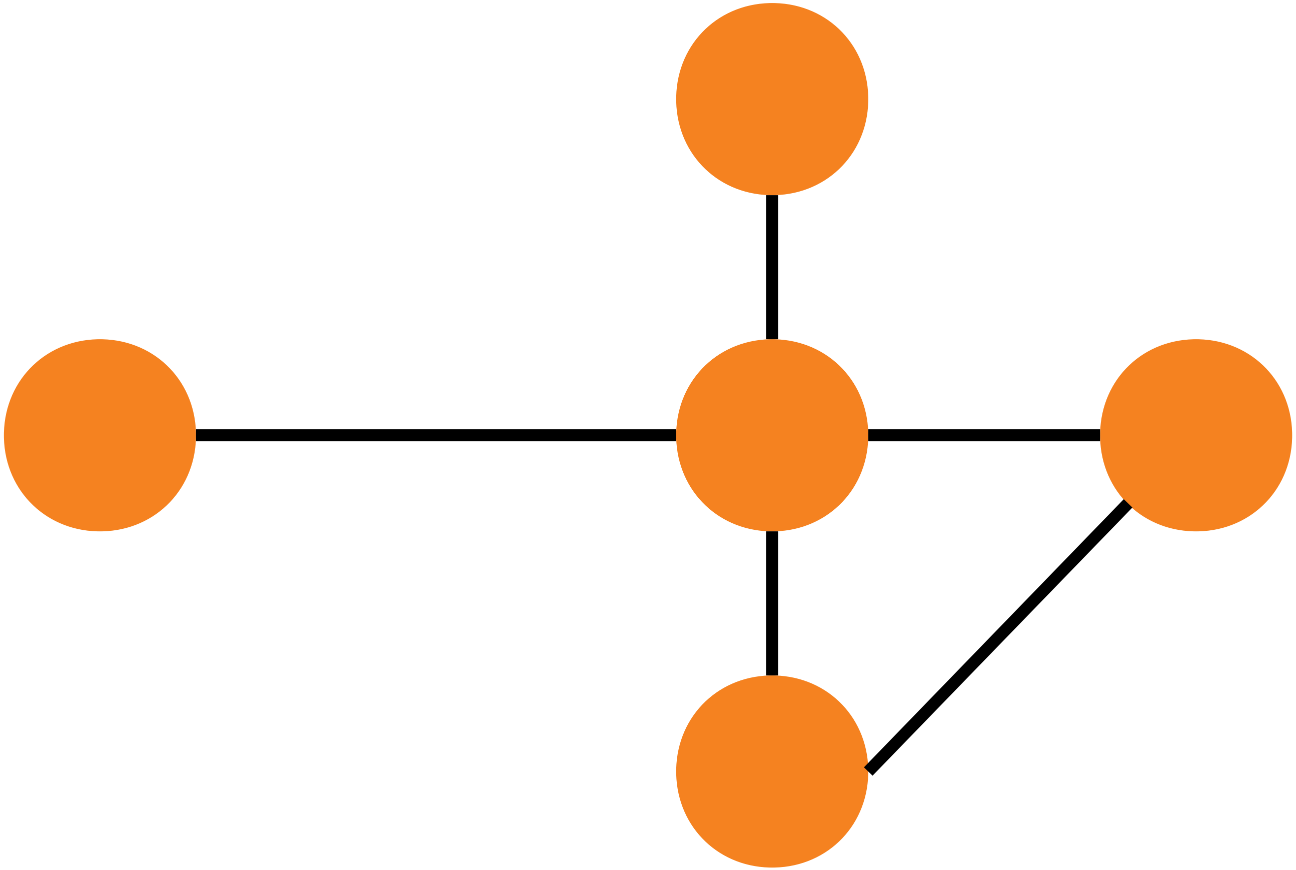
2. ABM
3. **Networks**
4. Influence
5. Looking Forward

Networks

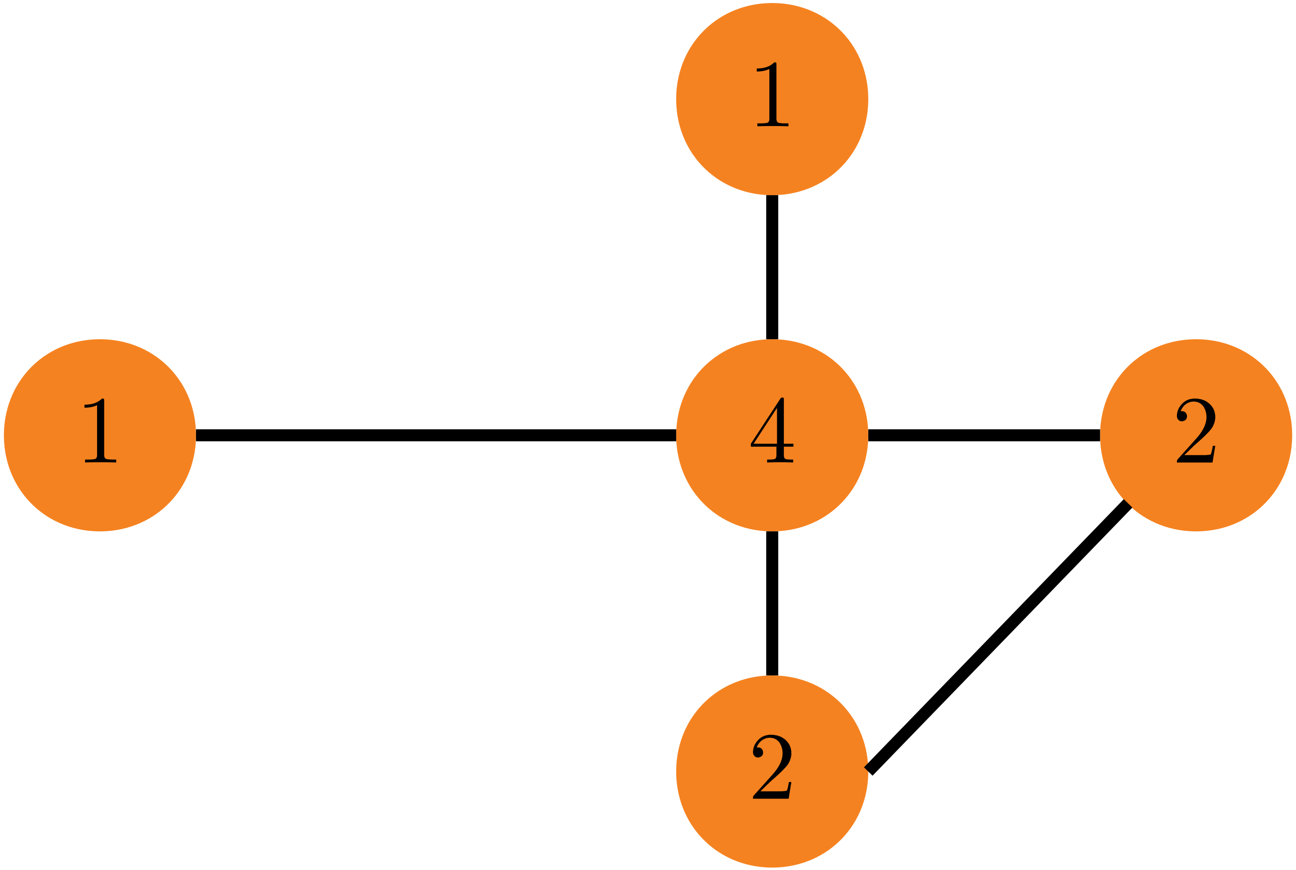
Networks



Degree



Degree



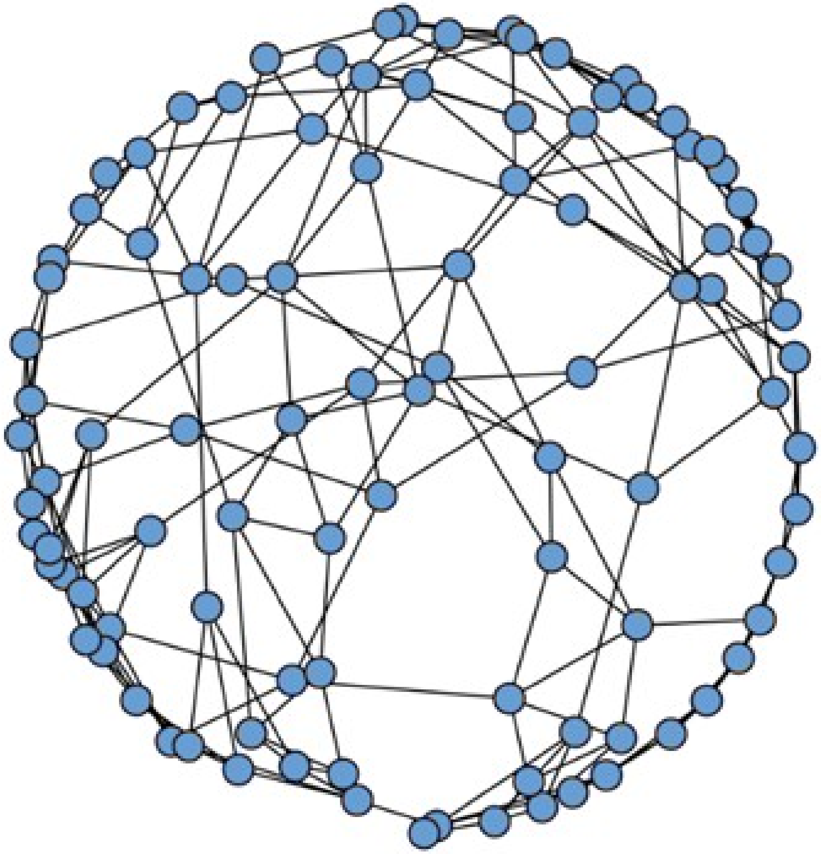
Networks

- Random graphs
  - Algorithmically generated networks
  - Small # of parameters
  - Guarantees on characteristics of the resulting network
  - Permits creation of large number of similar, but not identical networks
- Empirical networks
  - Unambiguously "realistic"
  - Static (might be ok)
  - Subject to measurement error (e.g., nomination methods)

Small-World

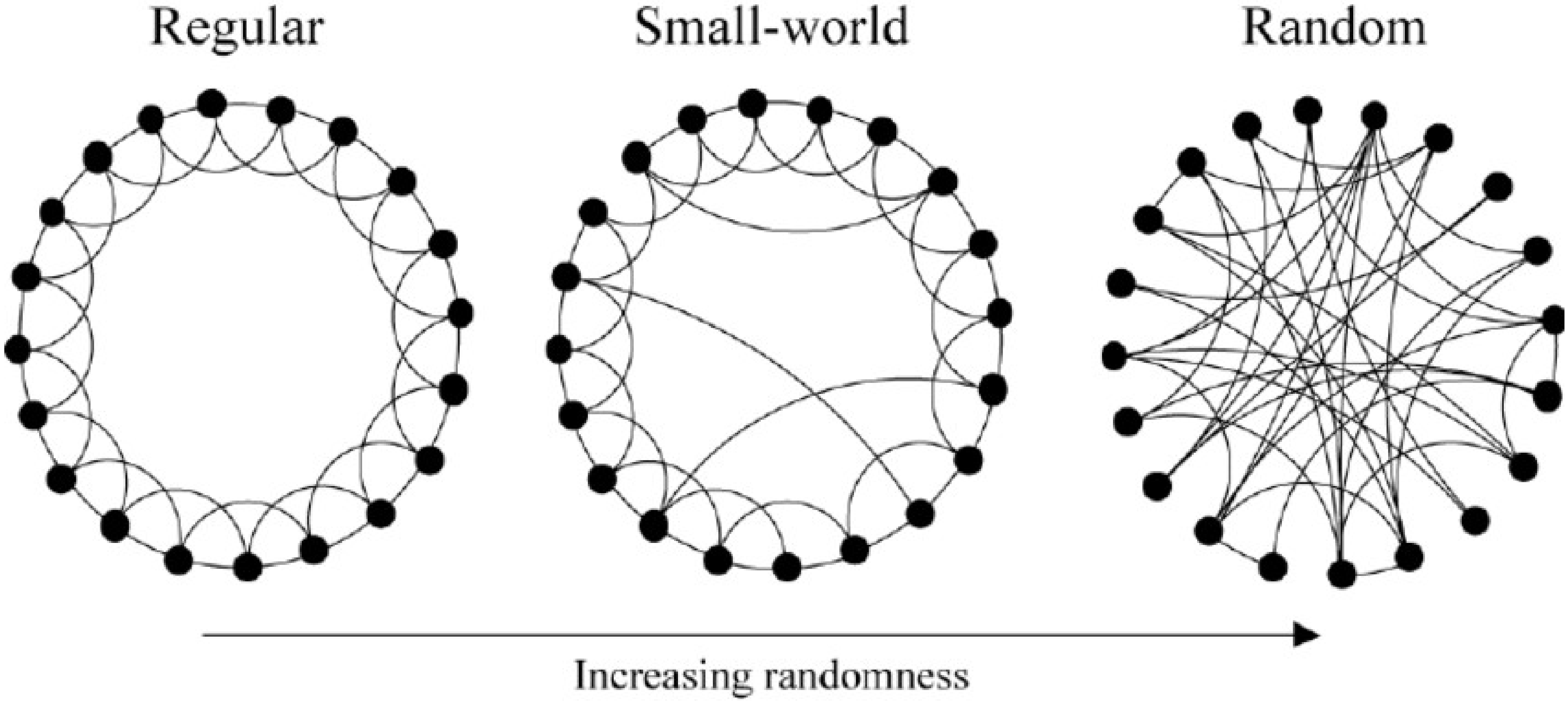
- Short average path length
- High clustering (triangles)
- Unrealistic degree distribution

- Parameters:
  - \# of nodes
  - Average degree
  - Rewiring probability



Watts & Strogatz (1998, *Nature*)

Small-World

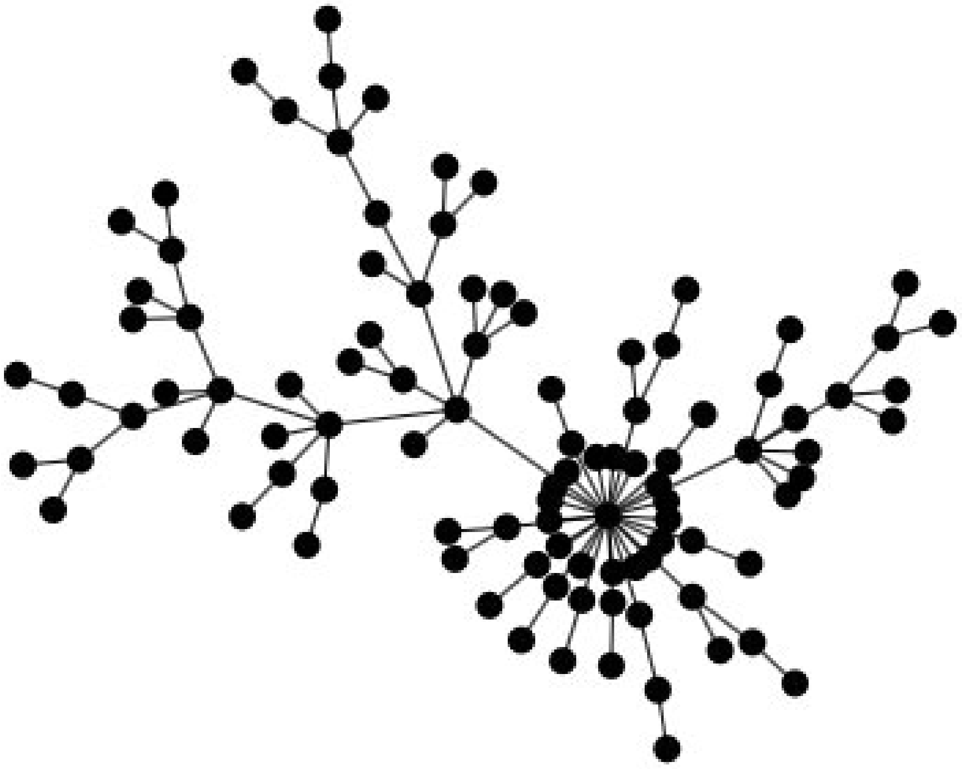


Watts & Strogatz (1998, *Nature*)

Scale-Free

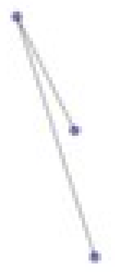
- Short average path length
- Clustering is unrealistic
- Realistic degree distribution

- Parameters:
  - \# of nodes
  - \# of edges for new nodes



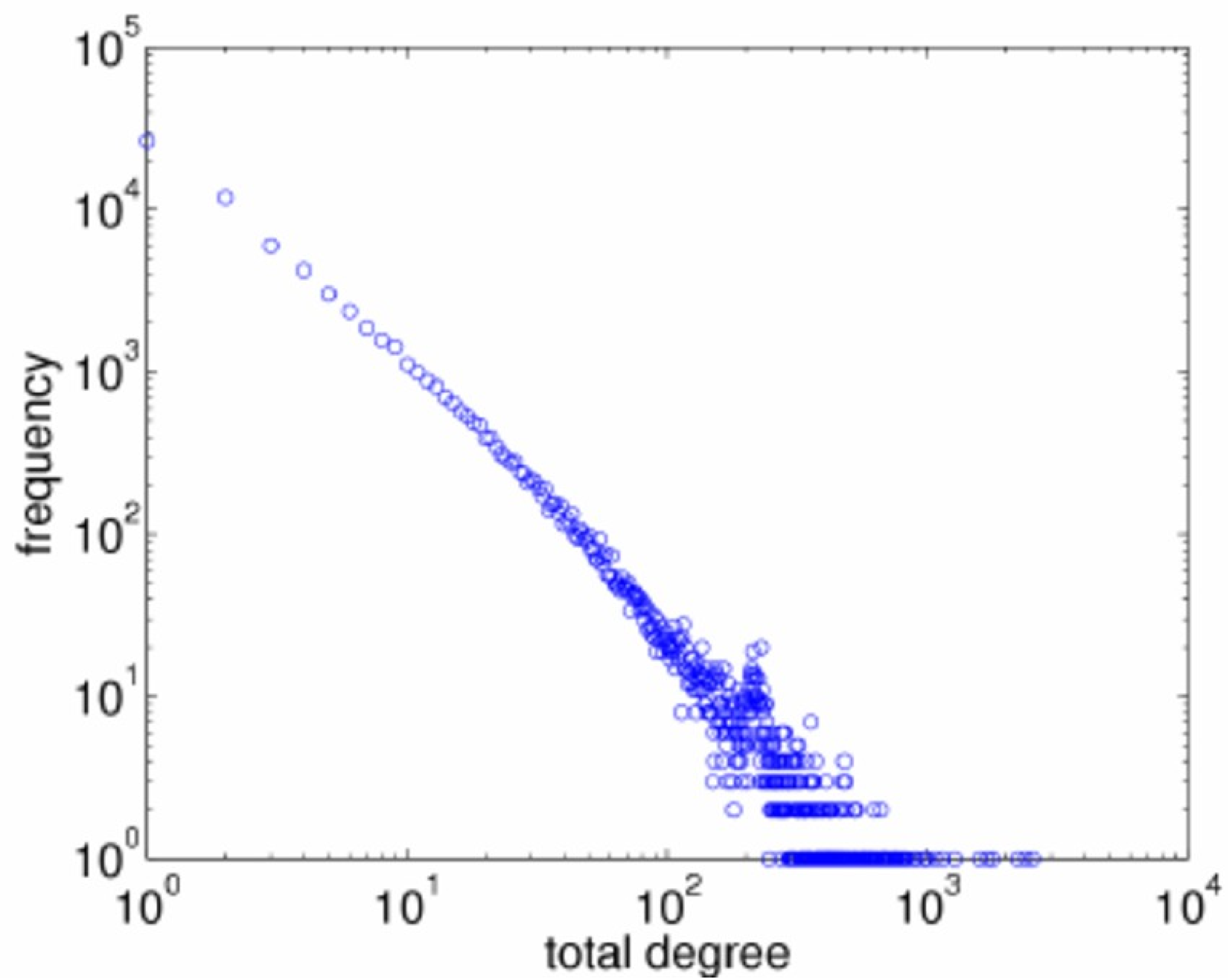
Barabasi & Albert (1999, *Science*)

Preferential Attachment

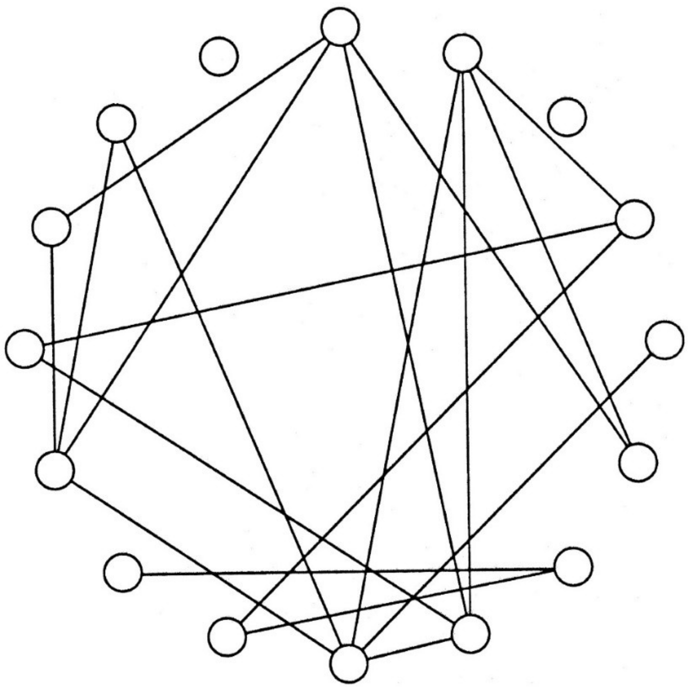


Barabasi & Albert (1999, *Science*)

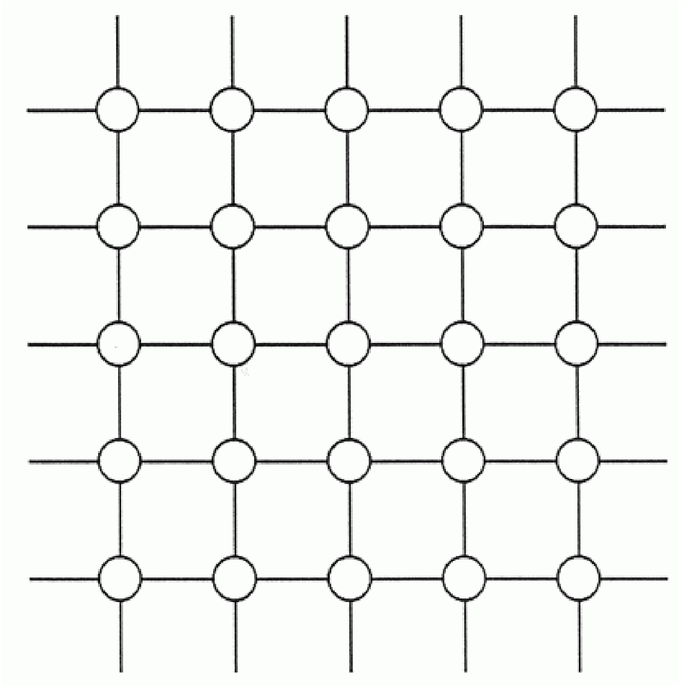
Power Law Degree Distribution



Other Networks



Erdős-Rényi



Lattice

Chung-Lu Networks

- Parameters:
  - $k_1, k_2, k_3, \ldots, k_n$
  - k_i is the degree of node i
  - n is the number of nodes
- The degree distribution is exactly what you ask for
- No other guarantees (random)

Aiello, Chung, & Lu, (2001)

RMAT Networks

- Parameters: a, b, c, d, n
- A and D partitions represent separate **communities** (e.g., doctors & engineers)
- B and C partitions represent **cross-links** between the A and D communities
- Recursiveness yields **sub-communities**

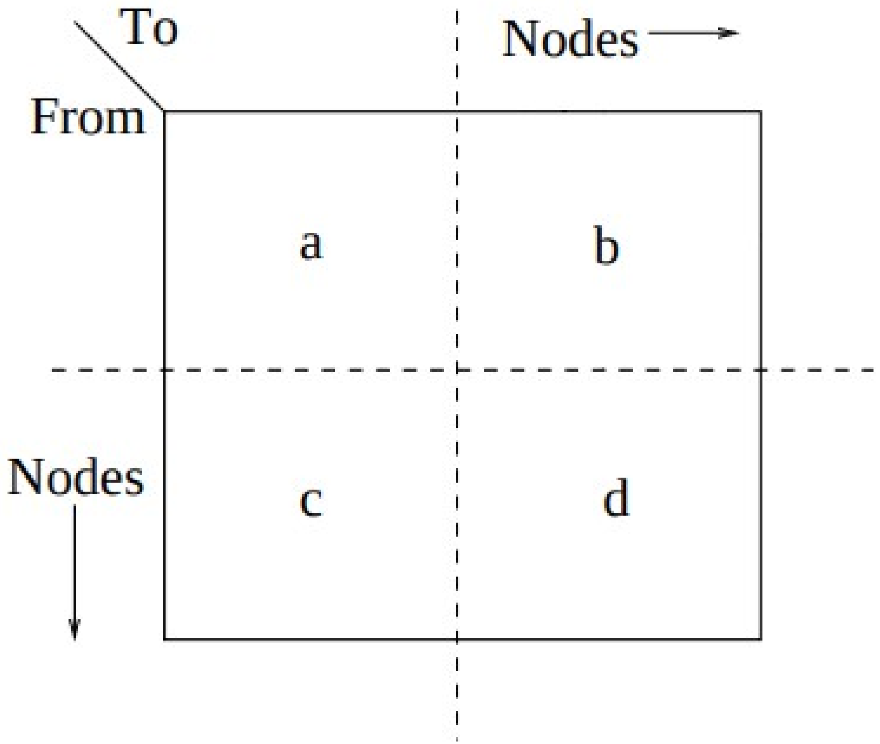
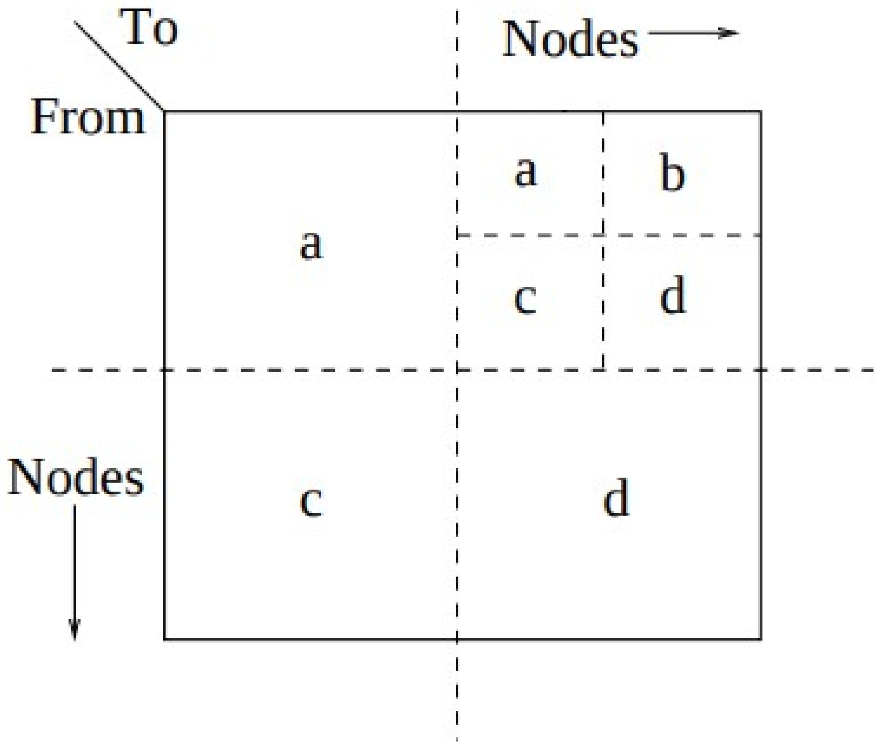


Figure 1: The **R-MAT** model

RMAT Networks

- Parameters: a, b, c, d, n
- A and D partitions represent separate **communities** (e.g., doctors & engineers)
- B and C partitions represent **cross-links** between the A and D communities
- Recursiveness yields **sub-communities**



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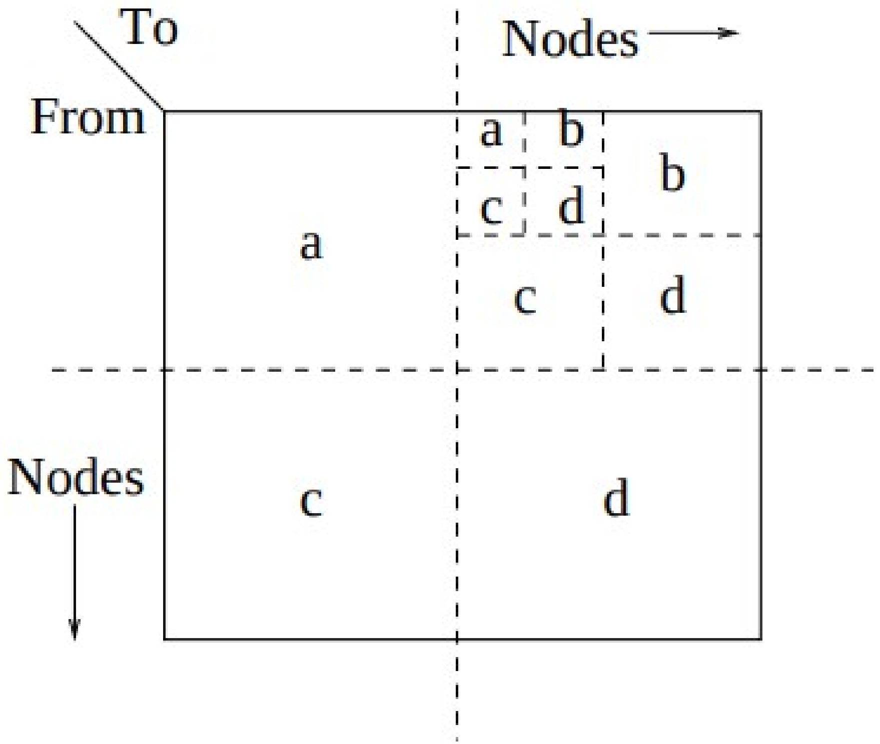
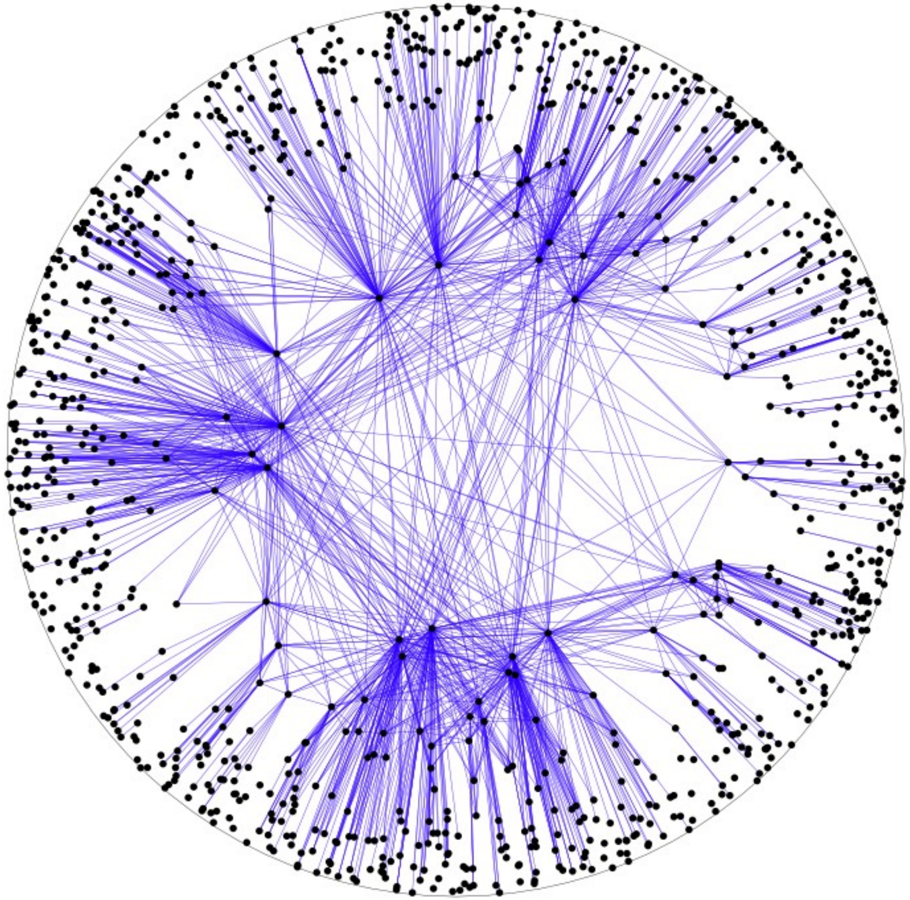


Figure 1: The **R-MAT** model

Hyperbolic Geometric Networks

- Parameters: n, α, ν
  - α controls power law exponent
  - ν controls degree
- Power law degree distribution
- Realistic clustering



Krioukov et al. (2010, *Physical Review*)

Empirical Networks

- Social
  - Online: Digg, Slashdot, Live Journal
  - Offline: Friendships in schools and other organizations
- Collaboration
  - Nodes: scientists, edges: co-authorship
- Communication
  - Enron (email)
  - Offline (coworkers)

Empirical Networks

- Stanford Network Analysis Project
  - Datasets: http://snap.stanford.edu/data/index.html
- CMU's Computational Analysis of Social and Organizational Systems
  - http://www.casos.cs.cmu.edu/tools/data2.php
- Pajek
  - http://mrvar.fdv.uni-lj.si/pajek/
- Mark Newman
  - http://www-personal.umich.edu/~mejn/netdata/
- UCI
  - https://networkdata.ics.uci.edu/resources.php
- Network Repository
  - http://networkrepository.com/

Realistic Social Networks

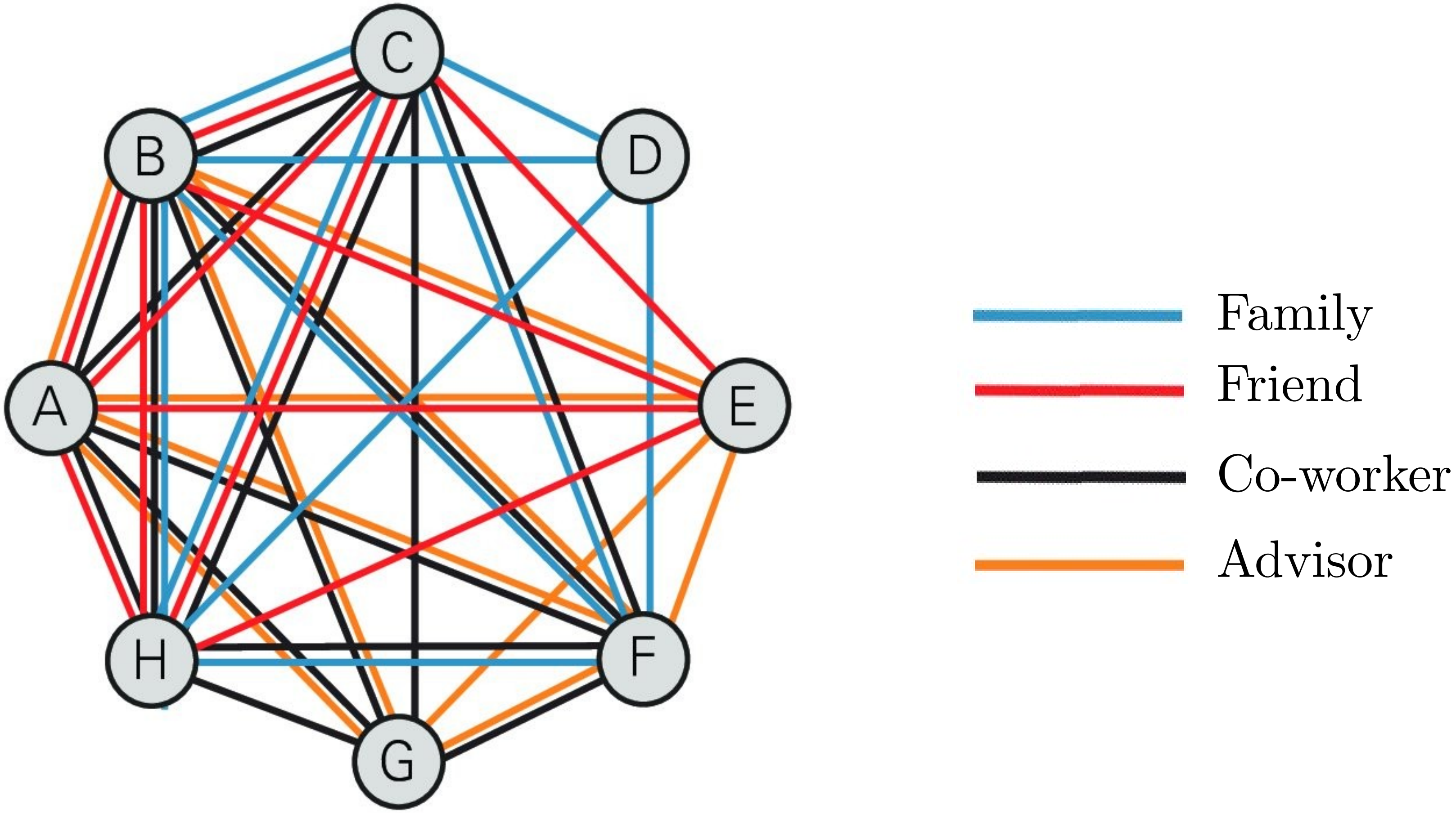
- Static, undirected, unweighted networks are frequently used because they are **simple**

- Real social networks are
  - Weighted (e.g., some friends are better friends than others)
  - Directed (e.g., I seek advice from you more than you from me)
  - Dynamic (e.g., I met a new friend or we used aren't friends anymore)

Multiplex Networks

- Real social networks are also multidimensional
  - aka, multiplex, multilayer, multilevel, multirelational
- There are qualitatively different kinds of social ties:
  - Family
  - Friends
  - Co-worker
  - Advisory
- Each type of edge can be weight, directed, etc.

Multiplex Networks



Outline

1. Overview
2. ABM
3. Networks
4. **Influence**
5. Looking Forward

Influence

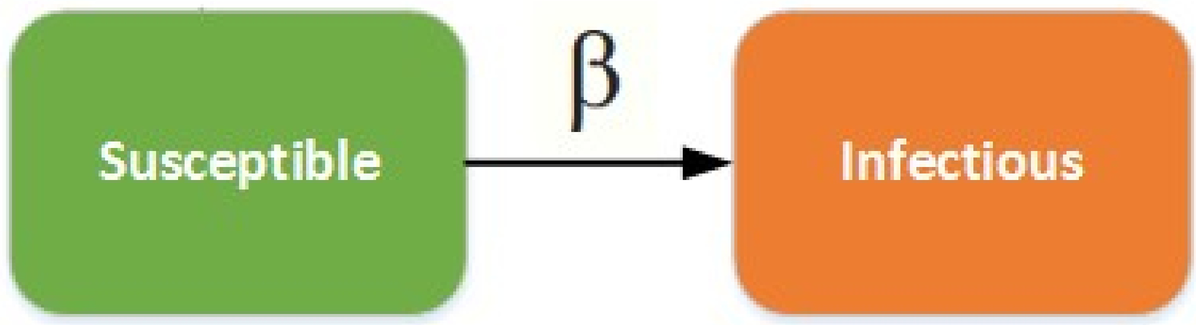
Influence

- In psychology, work on influence tends to focus on content, presentation, source, etc.
  - Milgram
  - Stanford Prison Experiment
  - Cialdini
  - Lord, Ross, & Lepper (1979)
- In sociology, there has been more theoretical (computational) work on how influence works
  - Models are simple (at the micro level) so that they scale

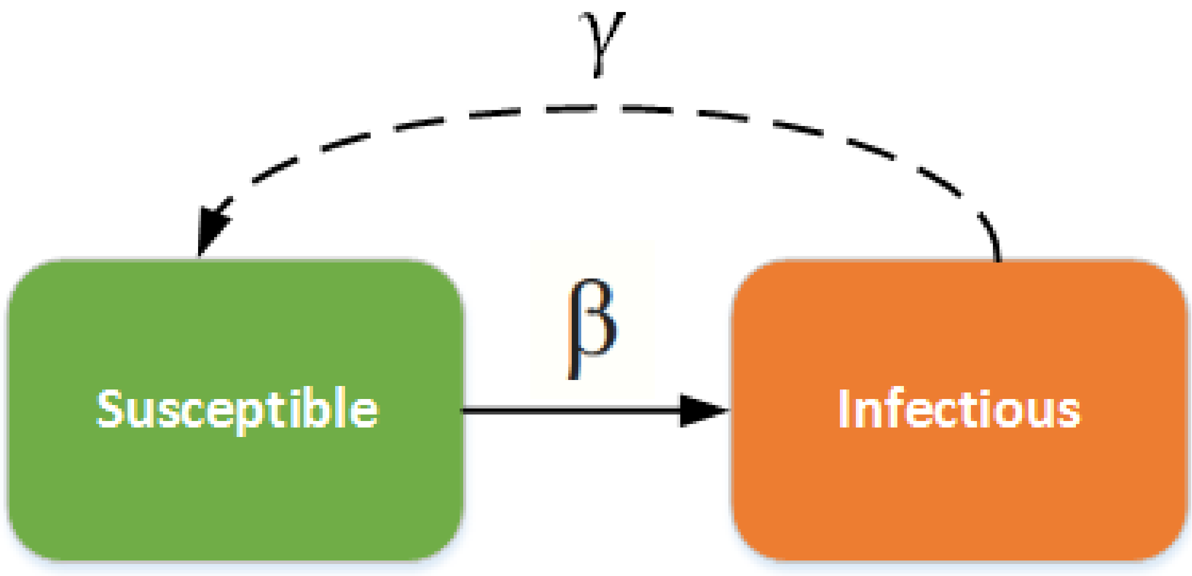
Epidemiological Models

- Sometimes referred to as compartment models
- Designed to model transmission of infectious biological disease
- Proven useful in predicting various aspects of actual outbreaks (e.g., # of fatalities)

SI Model

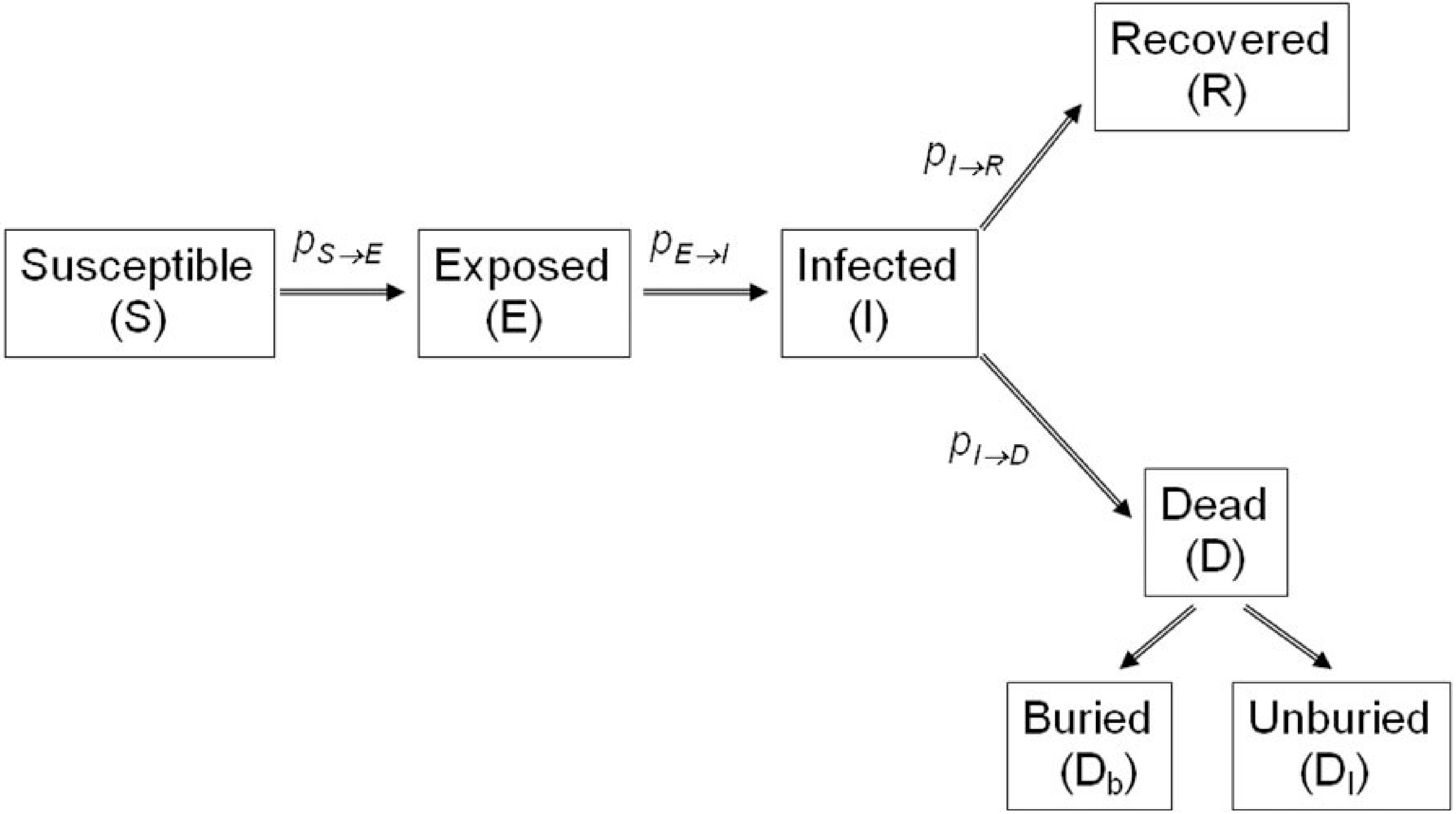


SIS Model



SIR Model

More Complicated



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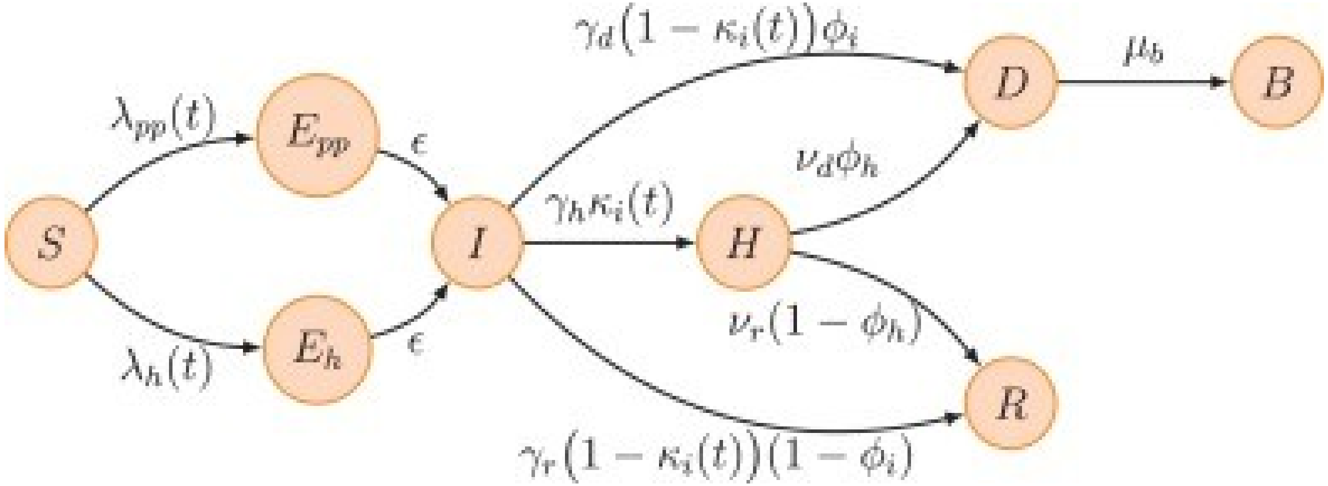

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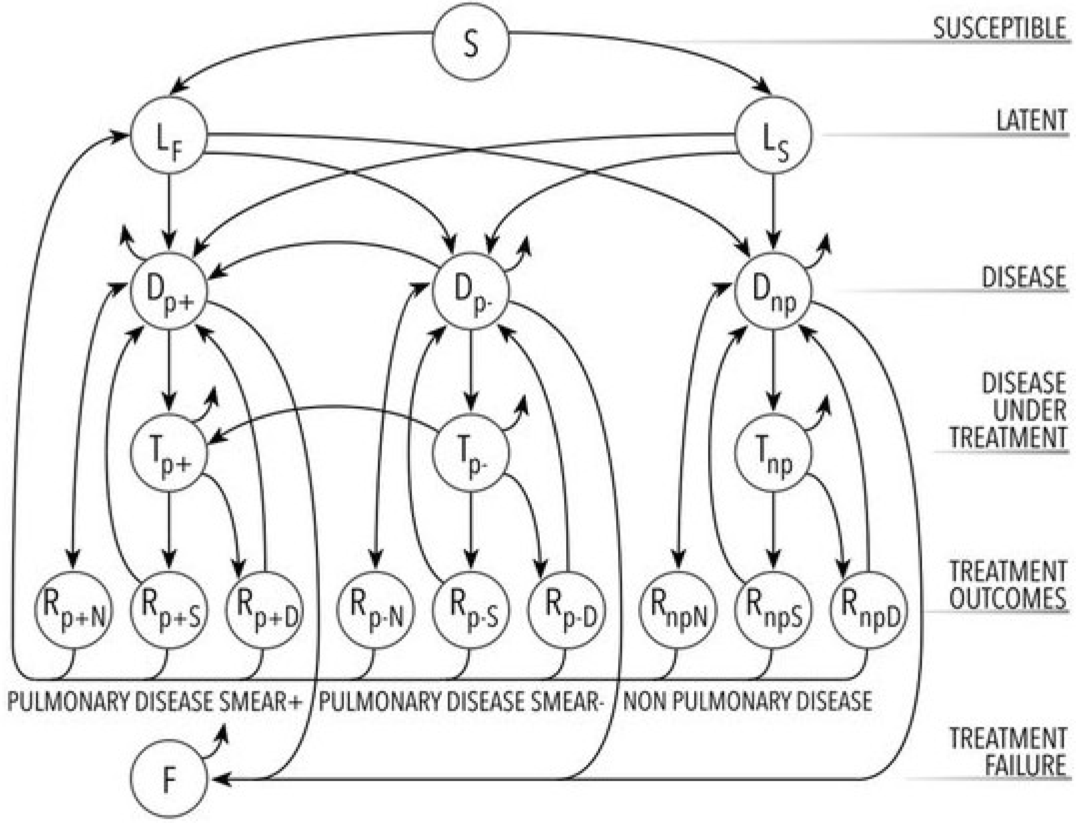
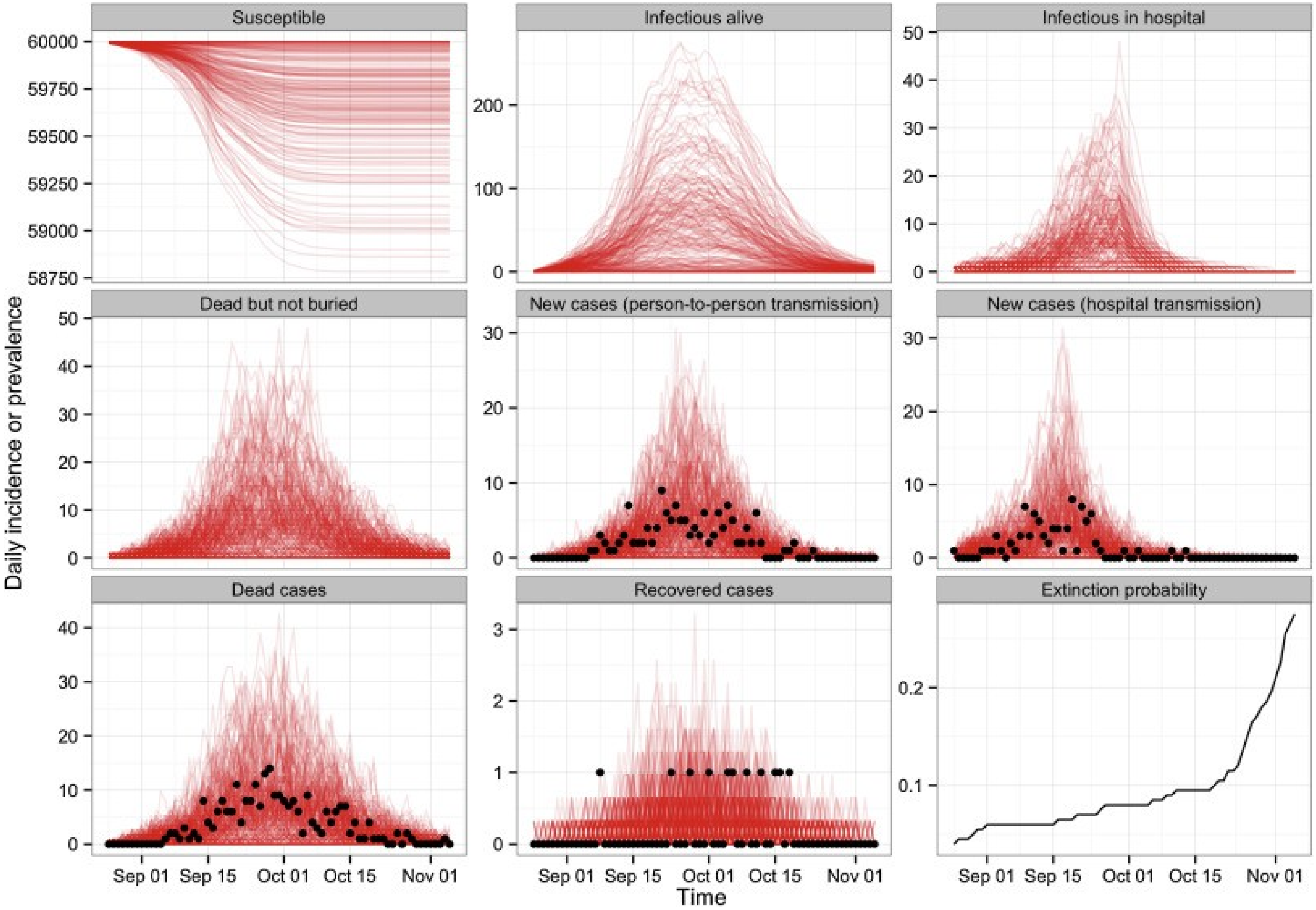
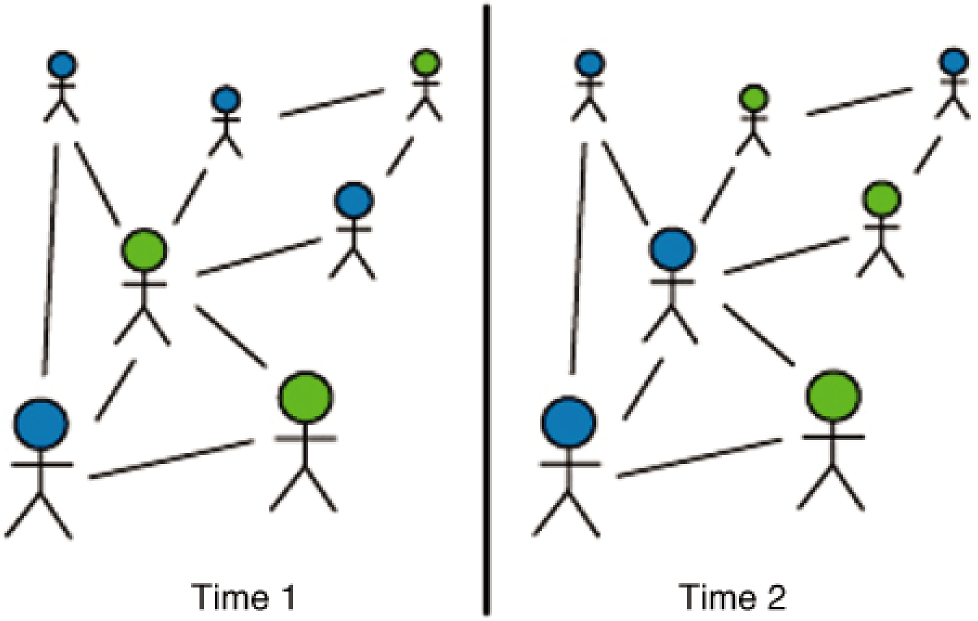


Epidemiological Models



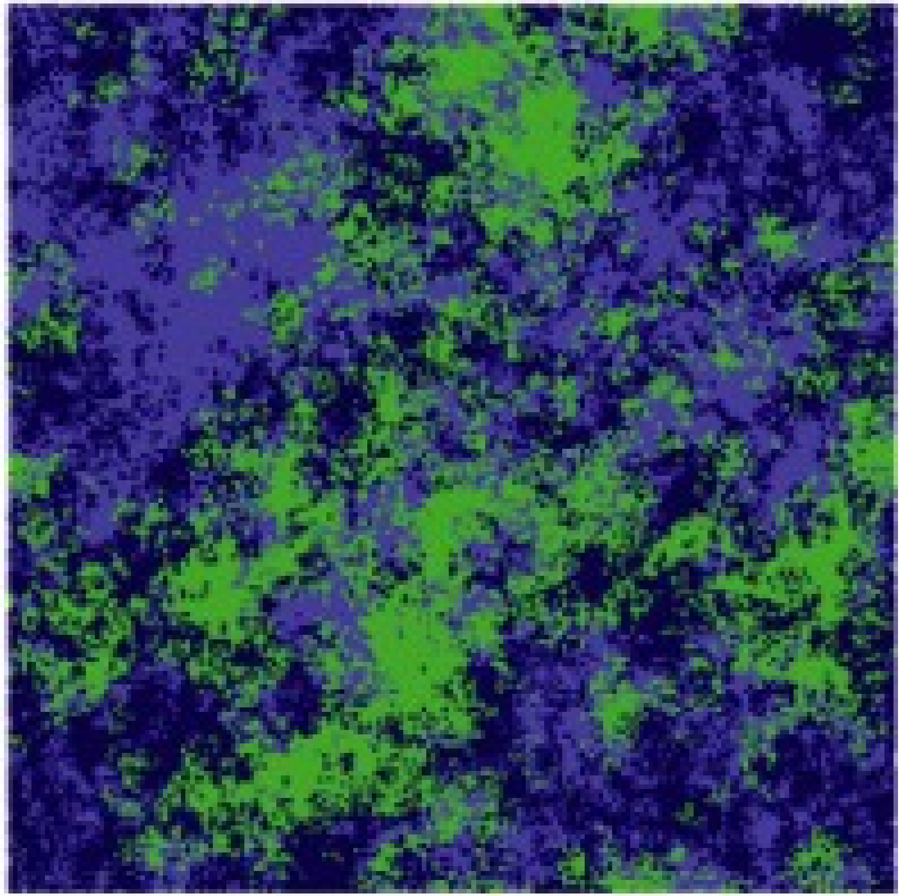
Bahr et al. (2009, *Obesity*)

- Agents are in one of N states
- Influenced by those "around" them via simple majority-style rules



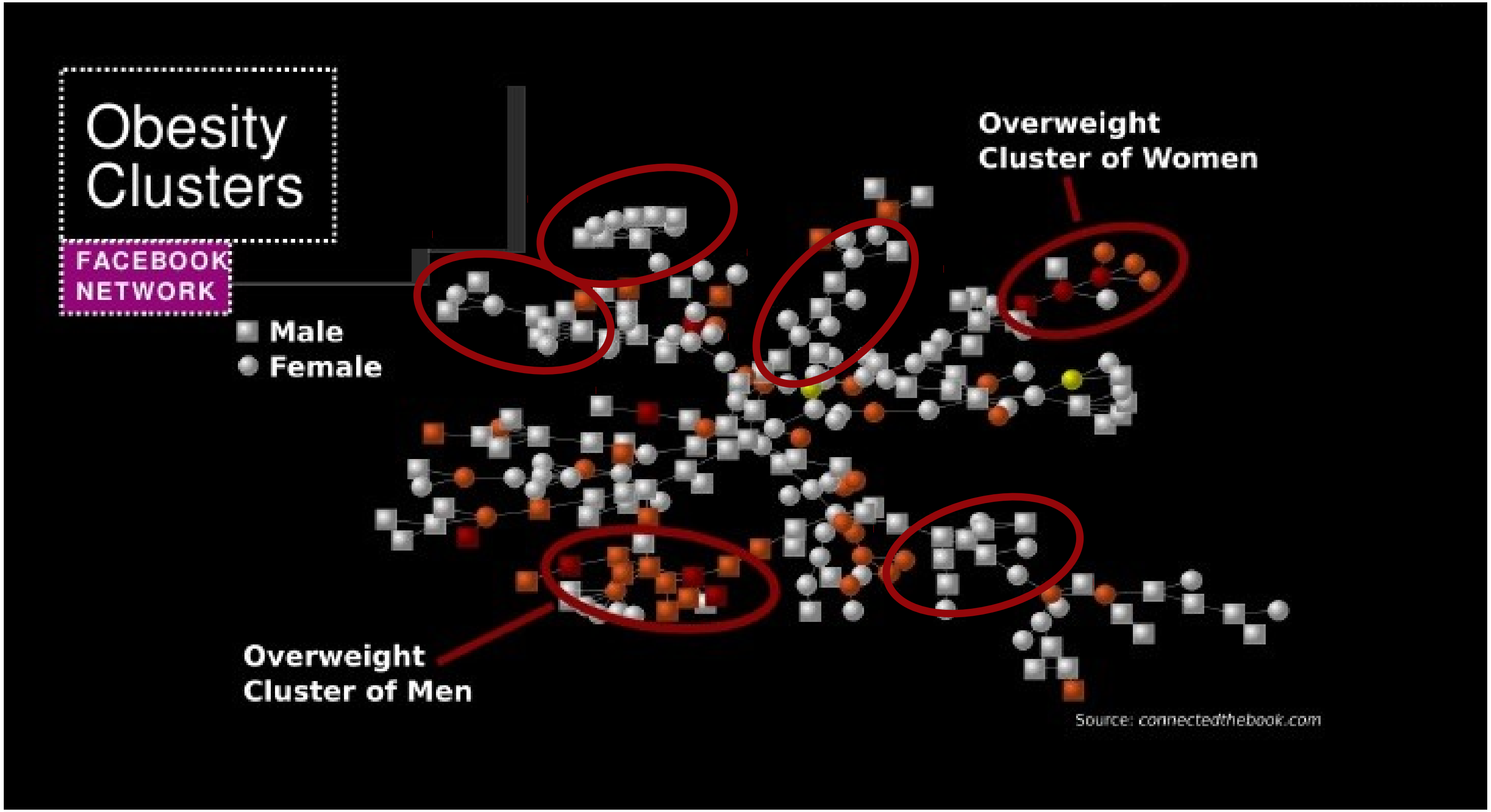
Clustering

Less volatility



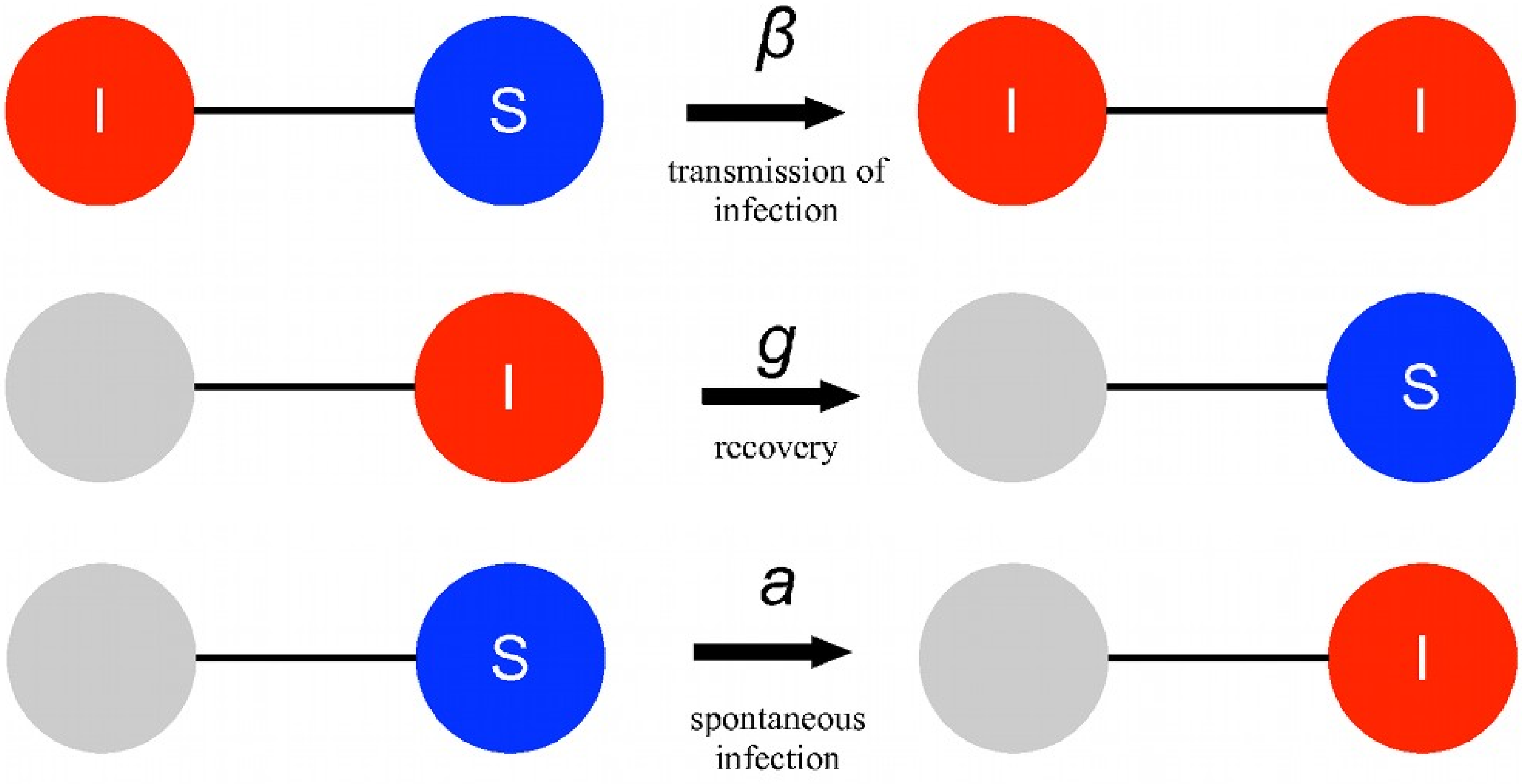
More volatility

Clustering



Lewis, Kaufman, Gonzolez, Wimmer, & Christakis (2007)

Hill et al. (2010)



SISa model

Opinion Dynamics

- Rich history of studying how individuals' opinions interact
- Opinions/preferences/beliefs govern behavior
- So the study of dynamics of opinions is the study of collective behavior

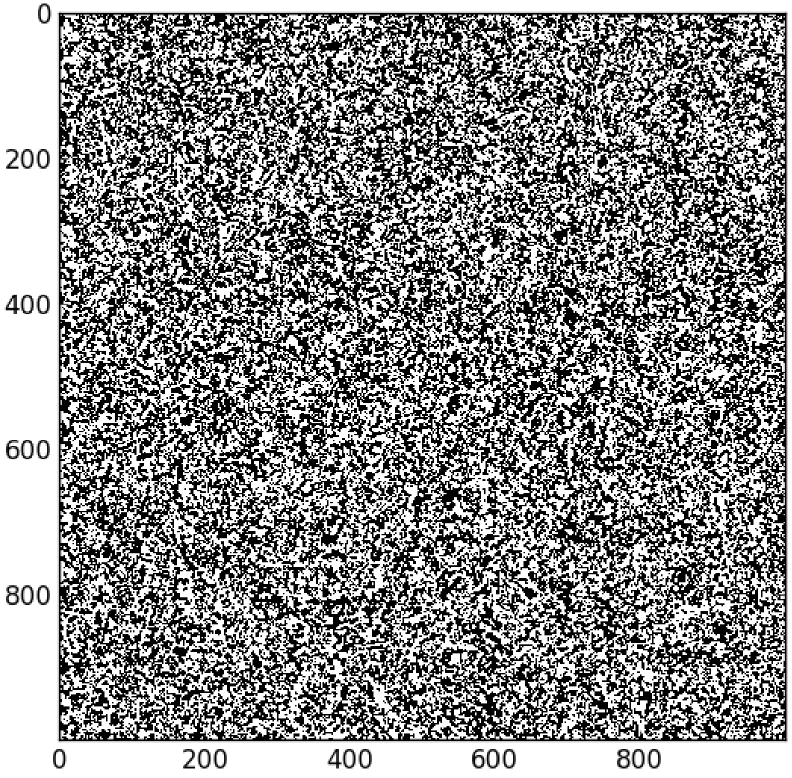
Ising Model

- Each agent (cell) adopts the majority opinion of its neighbors

- Agents may randomly “flip” (volatility)

- Agents influence may be stochastic (majority...ish)

Ising Model



Classical Influence Model

- Model of the opinions or attitudes

$$x(t+1) = Ax(t)$$

- A is a fixed matrix of influence weights and $x(t)$ the vector of opinions at time t
- Has been proposed and employed to assess opinion pooling by a dialogue among experts (De Groot, 1974)

FJ Model

- Friedkin & Johnsen (1990, 1999)
- Assumes that agent i adheres to his initial opinion to a certain degree g_i and by a susceptibility of 1 - g_i the agent is socially influenced by the other agents according to a classical model

$$x(t+1) = G\,x(0) + (I - G)\,A\,x(t)$$

Bounded Confidence Model

- An agent i is only influenced by agents j, whose opinions differ from her own by not more than a certain confidence level ε_i

$$x_i(t+1) = \left| I(i, x(t)) \right|^{-1} \sum_{j \in I(i, x(t))} x_j(t)$$

$$I(i, x) = \left\{ 1 \leq j \leq n \mid \left| x_i - x_j \right| \leq \varepsilon_i \right\}$$

Bounded Confidence Model

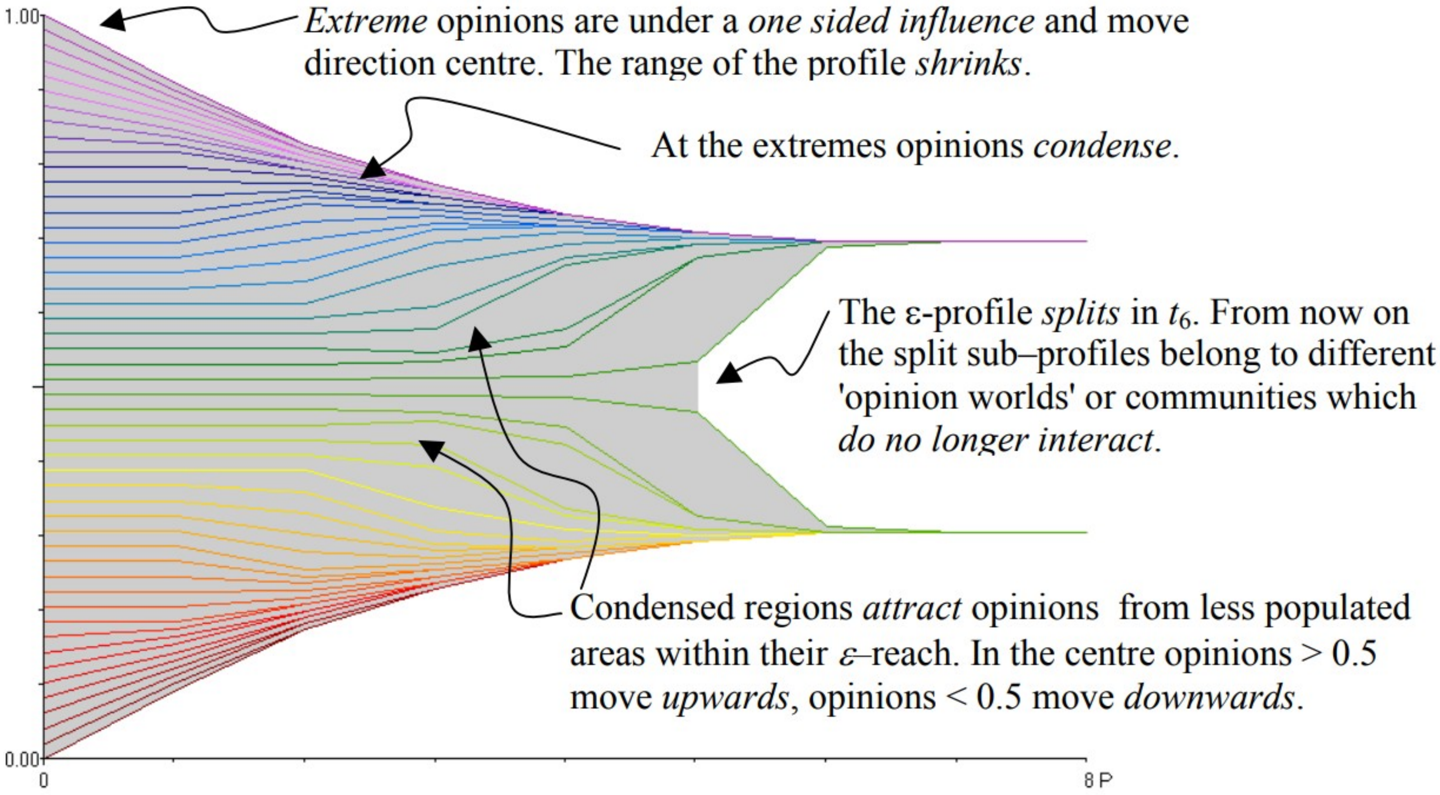
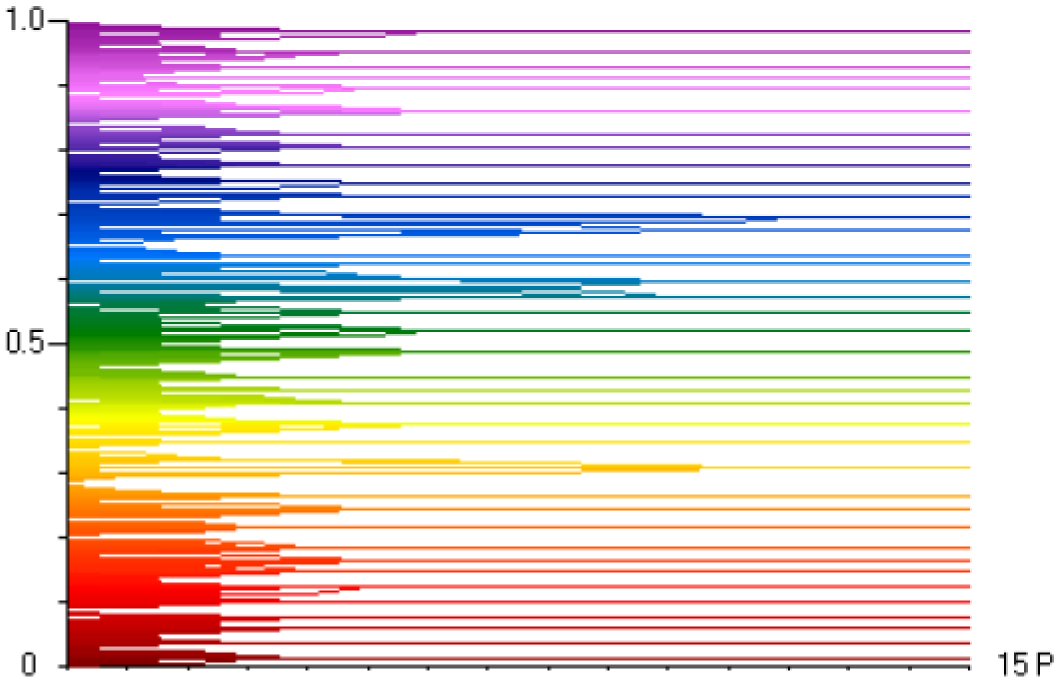


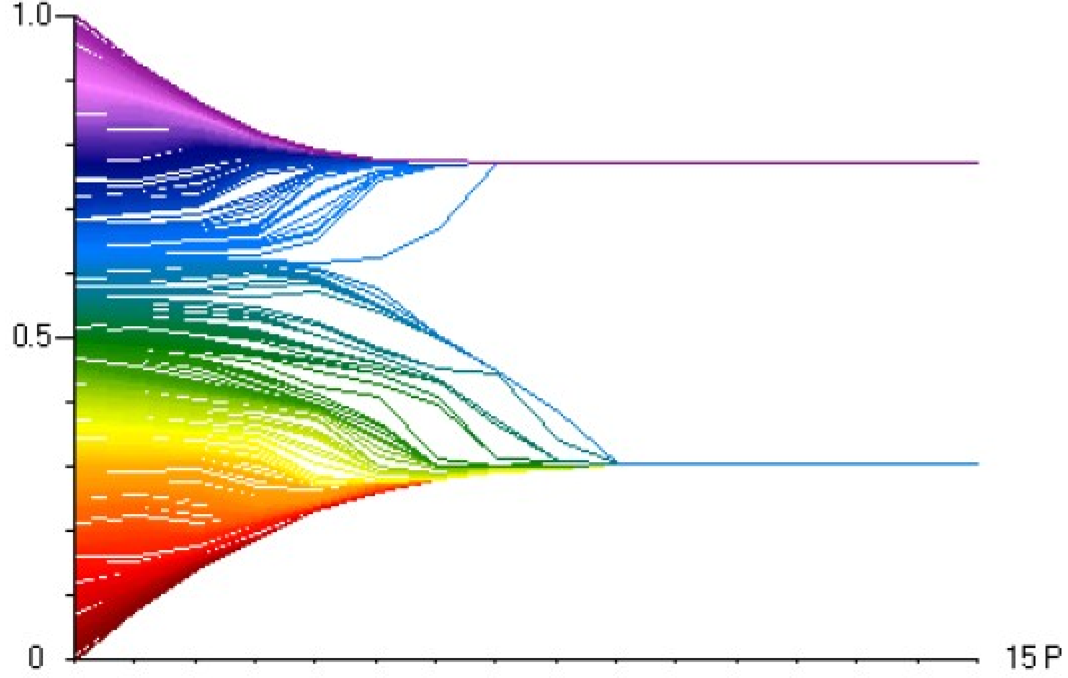
Figure 4: Regular start profile, $\varepsilon_l = \varepsilon_r = 0.2$.

Bounded Confidence Model



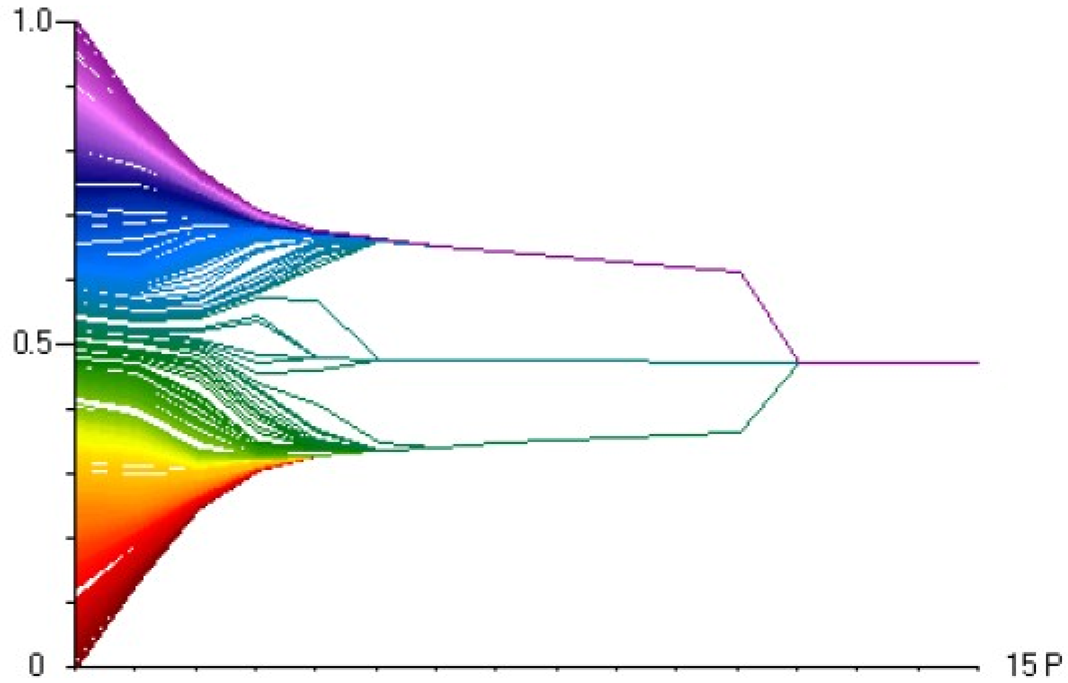
(a) $\varepsilon_l = \varepsilon_r = 0.01$

Bounded Confidence Model



$(b)\ \varepsilon_l = \varepsilon_r = 0.15$

Bounded Confidence Model

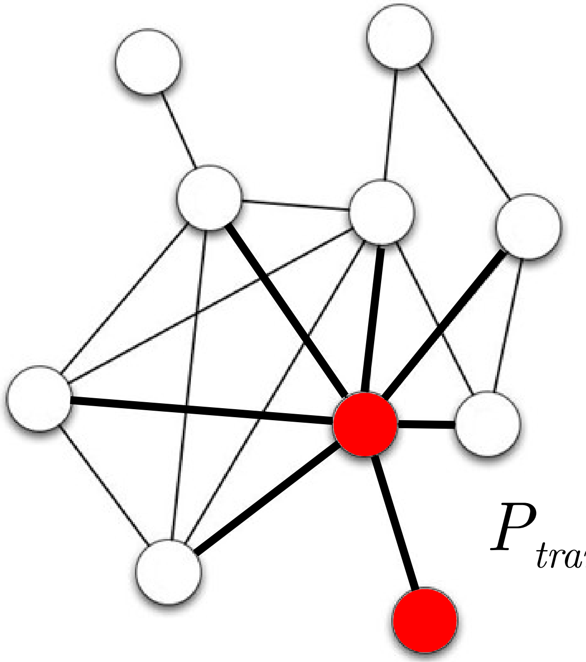


(c) $\varepsilon_l = \varepsilon_r = 0.25$

Simple Contagion

- Each node (e.g., person) is in one of two states, active or inactive
- Active nodes infect each of their inactive neighbors with some probability
- Once infected, nodes are infected forever

Simple Contagion



$$P_{transmit} = .5$$

Complex Contagion

- Complex contagion proposed as an alternative mechanism
  - Centola & Macy (2007, Amer. J. Sociology)
- Demonstrate that complex and simple contagion yield very different macro-level phenomena

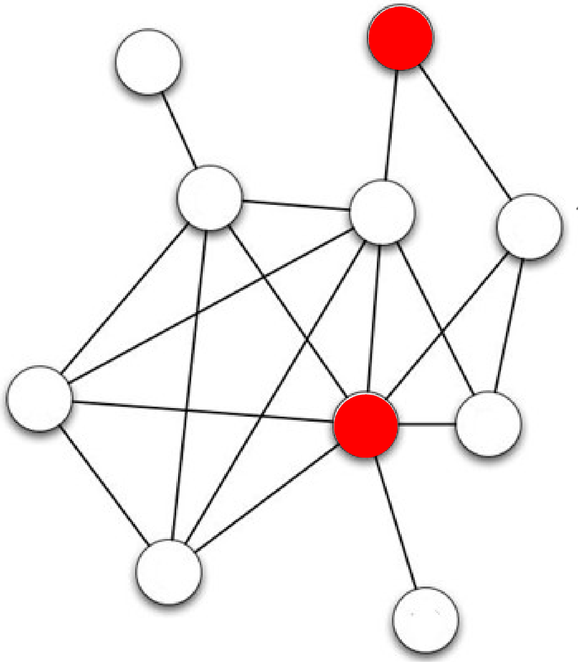
Complex Contagion

- Each node (e.g., person) is in one of two states, active or inactive

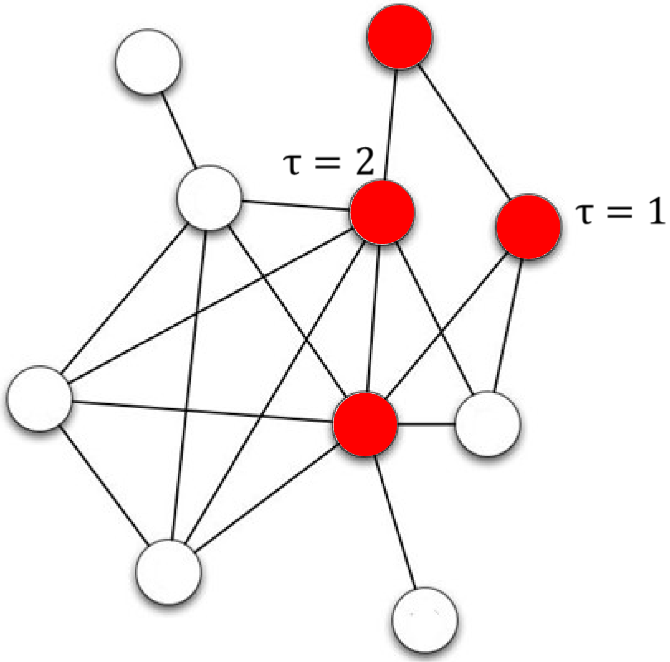
- Inactive nodes become infected when the number of active neighbors exceeds threshold
  - Sometimes the threshold is absolute # of neighbors (Granovetter, 1978)
  - Sometimes the threshold is a proportion of neighbors (Watts, 2002)

- Once infected, nodes are infected forever

Complex Contagion



Complex Contagion



Outline

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Where Next?

- Brainstorm some **research questions** of interest to you
  - Micro ideas about macro patterns?
  - Macro manifestations of micro theories?
- What sorts of **goals** do these questions suggest?
  - Heuristic?
  - Normative?
- How much detail **do you really need** to address your questions?
  - Easier to start simple (can always complicate later)

Where Next?

- Figure out how to implement your ideas
- What is your level of comfort with programming?
- NetLogo is a safe choice
  - Widely adopted
  - Lots of resources (e.g., examples and documentation)
- Python/R/Matlab will always provide maximum flexibility
  - Libraries mentioned earlier will help

Where Next?

- Find examples in your environment of choice (e.g., CoMSES library)
- Find one that is most similar to your idea
- Play around with it to gain familiarity
- Dive into the code
- Modify the code
  - It will either break (try again)
  - Or its behavior will be altered (in the way you specified)
- Incrementally work your way to your model...
- ...**voilà**!

Merci Beaucoup!

- Materials available
  - github.com/cluhmann/ABM-workshop
- Questions?
  - Feel free to harass me here or contact me later
  - christian.luhmann@stonybrook.edu

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