Social Life *in Silico*:
Population Health from the Bottom Up

Michael W. Macy
Cornell University

National Institutes of Health
July 13, 2007

Preview

- Introduction to ABC Modeling
- Two examples:
  - Ethnic preferences and residential segregation
  - Six degrees of separation and the spread of social contagions

Social life is more like improvisational jazz than a symphony orchestra

– we compose our parts on the fly, but not just as we please

– how is this possible with millions of players?

Requires a new modeling approach

- An earlier generation: interactions among variables
- ABC modeling: interactions among agents
- A computational tool for exploring the dynamic implications of a set of assumptions
  - complexity of social systems need not be based on complex behavior
  - can we discover simple rules to explain some of the persistent puzzles of social life?

Improvisational life: flocks, swarms, herds, & schools

- Three simple rules (c.f. Craig Reynolds):

1. Move with your neighbors
2. Move toward your neighbors
3. Avoid collisions

Click here to watch the whales…

Between discourse and deduction

- Computational modeling
  - more tractable than mathematical modeling but less generalizable
  - more rigorous than natural language but less nuanced

Modeling is as easy as ABC

- Begin with a puzzling population pattern
  - Why does segregation persist?
  - How does cooperation evolve?
- Look for the simplest set of conditions needed to generate the pattern.
- Test robustness of arbitrary assumptions (“sensitivity analysis”).
- Manipulate key assumptions to identify causal mechanisms.

What is a “social agent”?

- Cognitive architecture
  - agents are heuristic
  - agents are adaptive
- Social architecture
  - agents are autonomous
  - agents are interdependent
  - agents are networked

heuristic adaptive autonomous interdependent networked

- “Human beings viewed as behaving systems, are quite simple” (Simon 1998)
- We follow rules
  - behavioral routines that provide standard solutions to recurrent problems
  - norms, conventions, rituals, routines, moral and social habits

heuristic **adaptive** autonomous interdependent networked

- Rules compete for propagation
  - individual learning: selection <u>within</u>
    - reinforcement
    - error-correction
    - Bayesian updating
    - back-propagation
  - population learning: selection <u>between</u>
    - reproduction
    - role modeling

heuristic adaptive **autonomous** interdependent networked

- Populations do not act, their members do.

"…collectivities must be treated as solely the resultants and modes of organization of the particular acts of individual persons, since these alone can be treated as agents in a course of subjectively understandable action."

-- Max Weber, The Theory of Social and Economic Organization, 1920

Autonomous, not “representative”

- Not a model of the population but a population of models, each with its own
  - inputs
  - outputs
  - input-output functions

heuristic adaptive autonomous **interdependent** networked

- Behavioral interdependence
  - agents influence neighbors in response to the local influence that they receive
  - persuasion, sanctioning, exchange, imitation
- Strategic interdependence
  - consequences of each agent’s decisions depend in part on the choices of others.
  - “Prisoner’s Dilemma,” “Chicken”

heuristic adaptive autonomous interdependent **networked**

- Interdependent, but not with everybody
- Population dynamics depend on network properties
  - clustering
  - hubs ("scale free networks")
  - bridge ties ("small worlds")
  - elective ties (dynamic networks)
    - homophily
    - assortative matching
    - movement

Prisoner's Dilemma

- A mathematical tool for modeling conflict and cooperation
- Payoffs depend on the strategies of other players
- Rational self-interest can lead players into a collectively inefficient Nash equilibrium
  - a configuration of strategies such that no player has an incentive to deviate unilaterally (Nash 1950).

Power of game theory

- Game theory generally assumes
  - a fully connected population
  - perfect rationality, complete information, and unlimited calculating ability
  - representative agents
- Can identify if there is a Nash equilibrium
  - flypaper (once there, we don’t leave)
  - not a black hole (doesn’t pull us in)

From static to dynamic equilibrium

- Nash equilibrium
  - no incentive to unilaterally change strategy
  - population is stable because no one moves
- Self-reinforcing equilibrium
  - the more agents who do X, the higher the probability that each agent will do X next time.
  - cascades, fads, herd behavior
- Self-correcting (homeostatic) equilibrium
  - balance between forces pulling in opposite directions
  - individuals constantly change but population mean remains stationary.

Beyond game theory

- ABC models also tell us
  - probability that this equilibrium will obtain
  - path into or out of the equilibrium
  - what happens when
    - equilibrium is perturbed
    - interaction is local (complex networks)
    - agents are heterogeneous
    - agents do not have perfect information, rationality
    - system is far from equilibrium

Limitations of ABC models

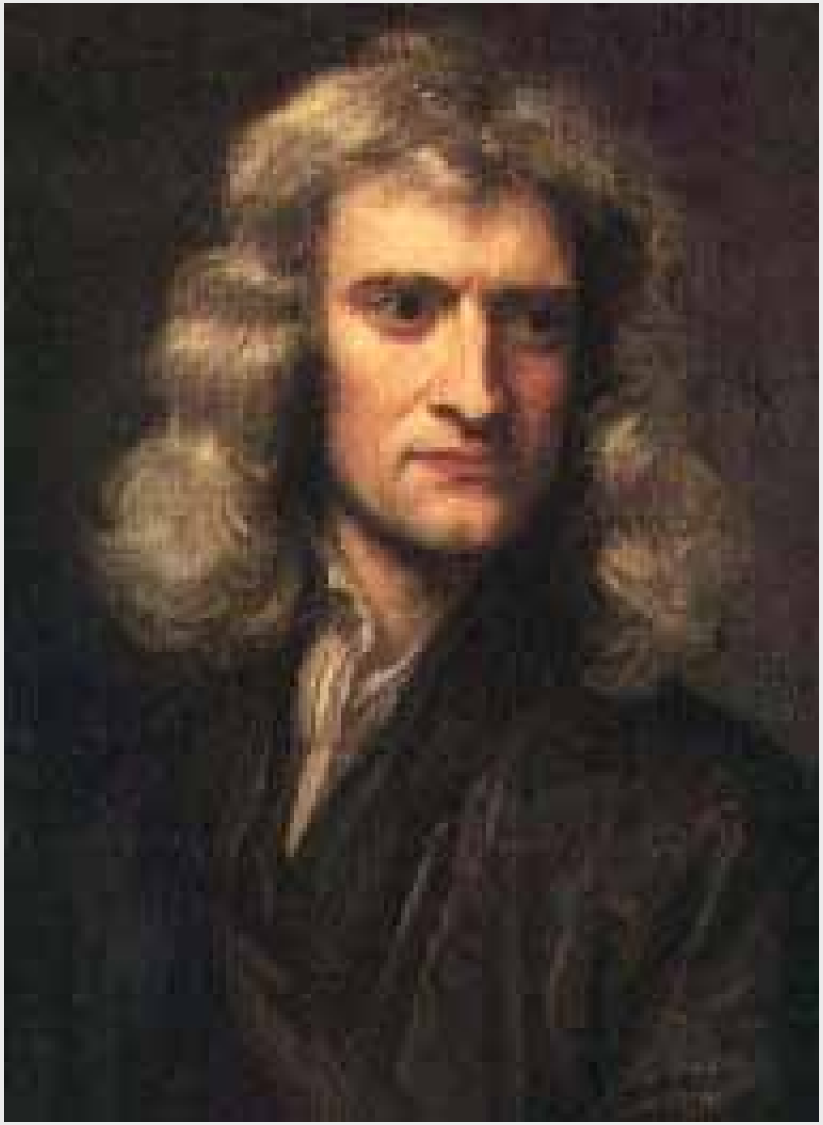
- Conclusions are less general than deductive proofs
  - results depend on numerical values
  - no way to test every possible number
- Causal processes are less transparent than in mathematical models
  - observe how results change with parameters
  - but why is this happening?

The lure of realism

- Analytical models may sometimes be too simple to explain the dynamics of a complex system
- ABC models can easily become too complex to explain the dynamics of a simple system.
  - correlation between inputs and outputs
  - but what is the explanatory mechanism?

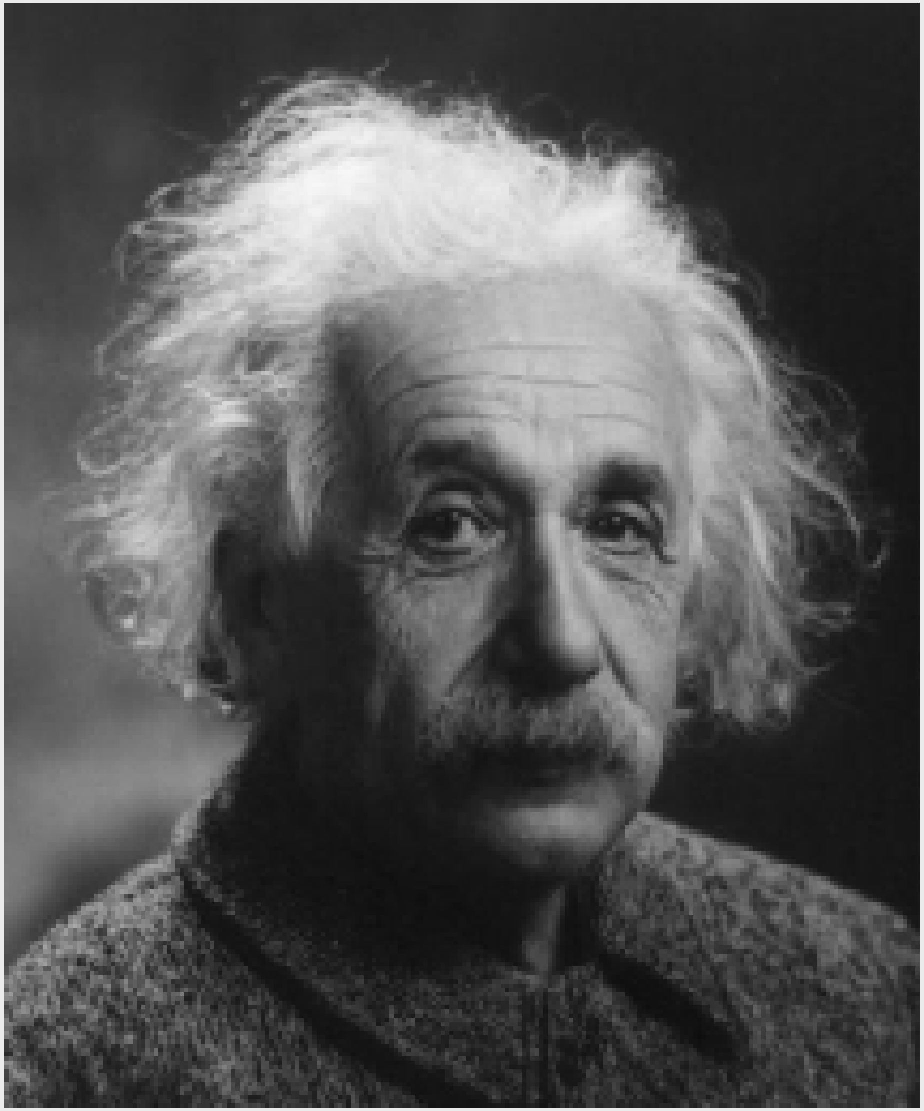
"All models are wrong but some models are useful."

-- George E.P. Box, statistician



"Truth is ever to be found in the simplicity, and not in the multiplicity and confusion of things."

-- Sir Isaac Newton



“Everything should be made as simple as possible, but not simpler.”

-- Albert Einstein

Don’t results depend on the assumptions?

- Yes (unless there’s a bug)
- Don’t trust your intuition!
  - “common sense” can be dangerous
  - implications of assumptions are not self-evident and are often surprising.
    - the whole is more than the sum of its parts.
    - population behavior need not reflect individual preferences or intentions.

I. The puzzle of segregation

(with Arnout van de Rijt & David Siegel)

Why has segregation persisted?

- Fair Housing Act (1964) outlawed housing discrimination based on race or ethnicity.
- Surveys show steady increase in racial and ethnic tolerance since 1964.
- Yet residential segregation persists.

Ethnic Preferences

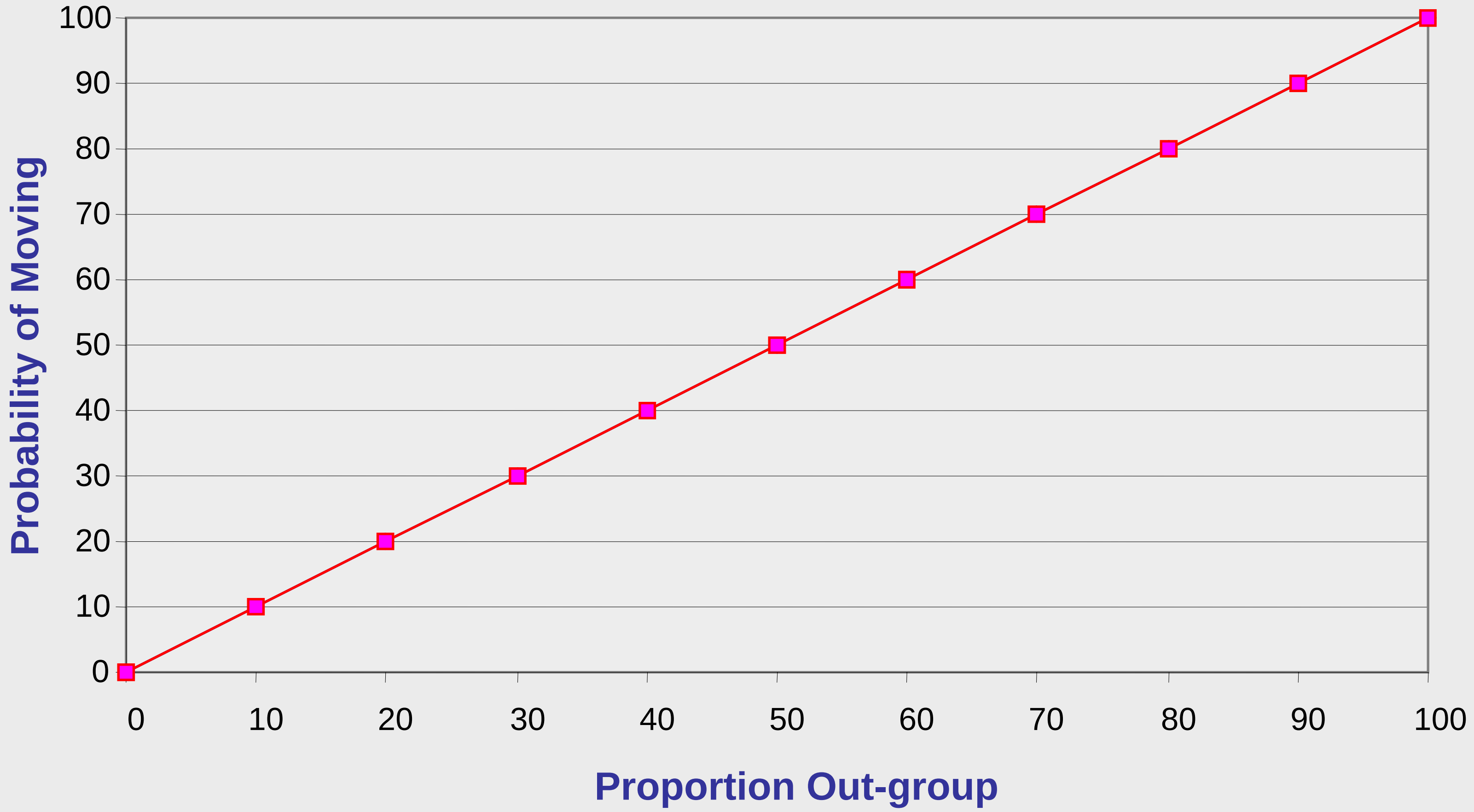
- Intolerance: the more out-group members who move in, the more dissatisfied (a monotonic preference function).

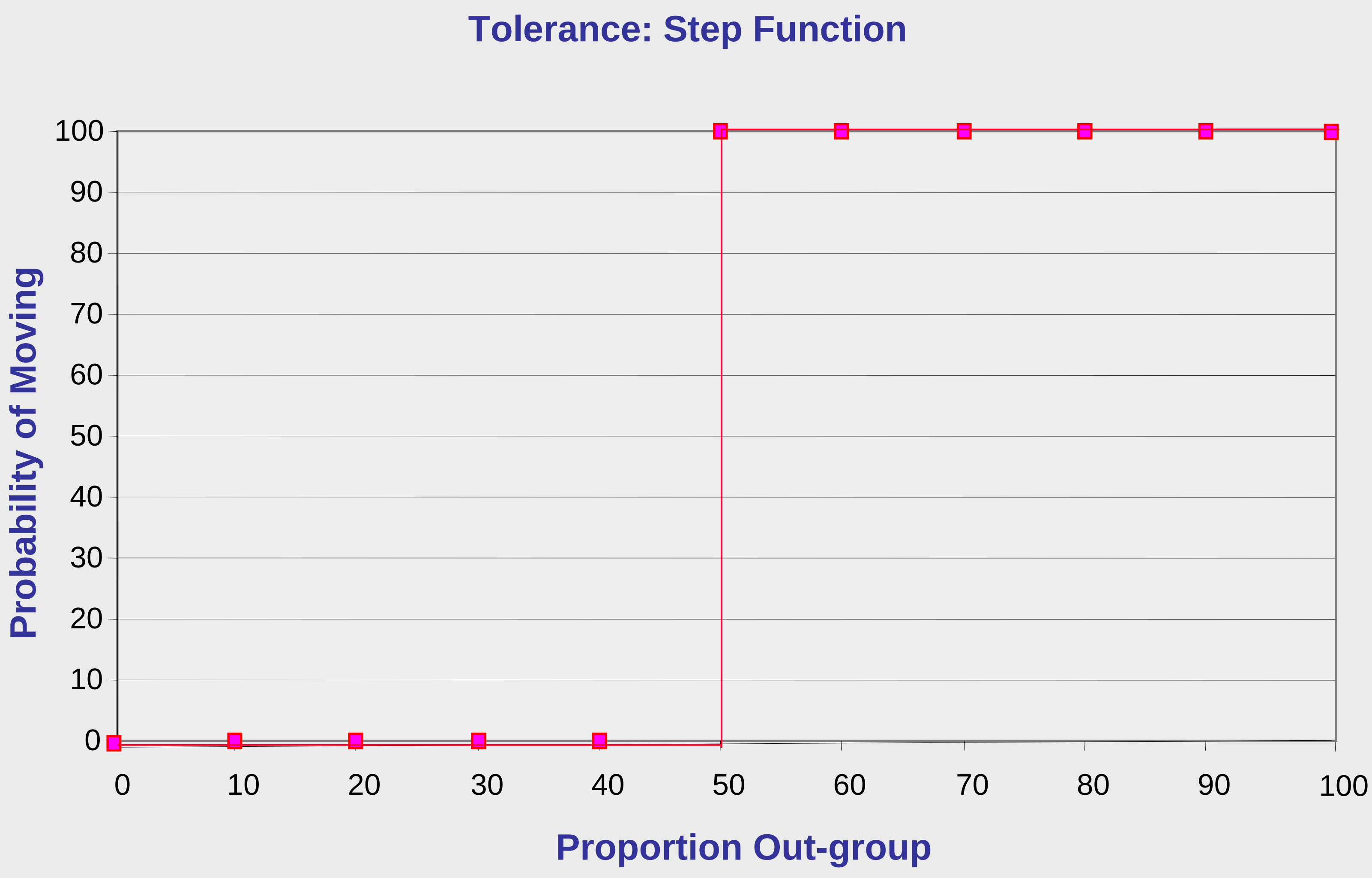
- Tolerance: No objection to out-group neighbors so long as they do not outnumber (a sigmoid or step function).

- Multi-culturalism: Preference for diversity compared to either in-group or out-group predominance (U-shape).

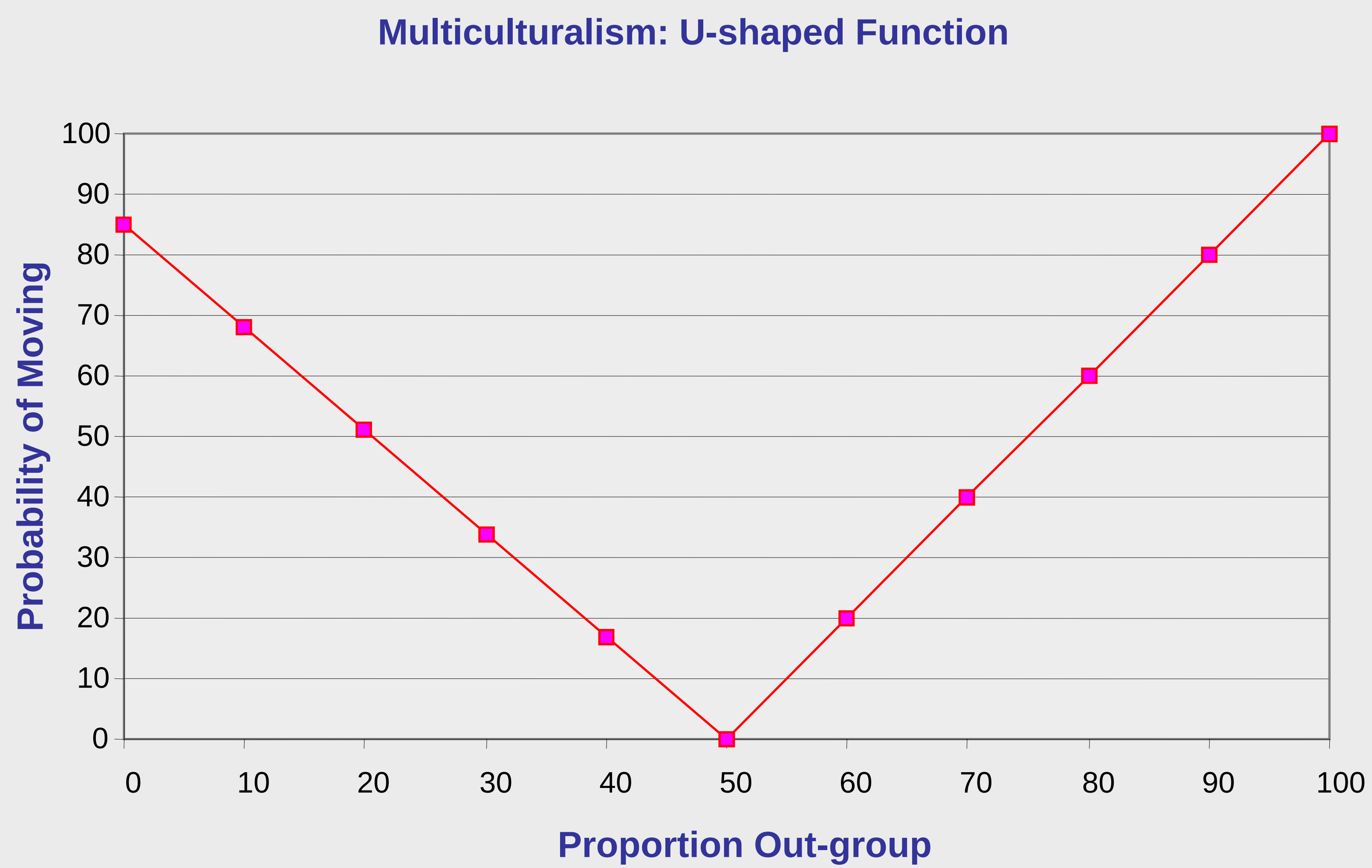
- Color-blindness: Ethnic composition has no effect on neighborhood satisfaction (flat line).

Intolerance: Monotonic Function

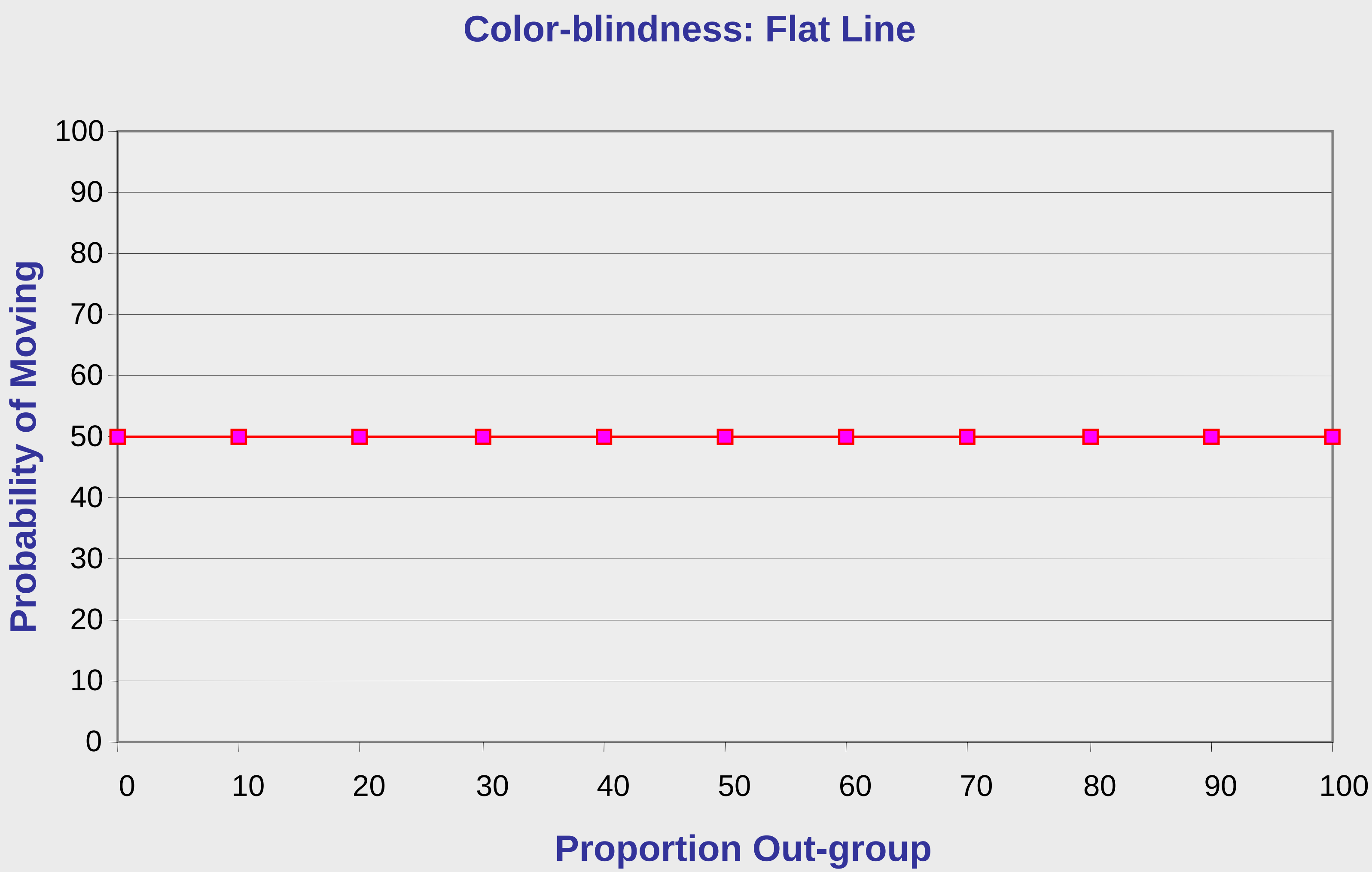




Tolerance: Step Function
100
90
80
70
60
50
40
30
20
10
0
Probability of Moving
0
10
20
30
40
50
60
70
80
90
100
Proportion Out-group



Multiculturalism: U-shaped Function
Probability of Moving
Proportion Out-group
0
10
20
30
40
50
60
70
80
90
100


Color-blindness: Flat Line
Probability of Moving
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Proportion Out-group

Predictions

- Intolerance promotes segregation.
- Tolerance, multi-culturalism, and color-blindness inhibit segregation.

Schelling model

- A regular lattice, N=[100-250K].
- Each agent has [4,8,24,48] contiguous neighbors.
- Two equal-sized ethnic groups, red & blue.
- If dissatisfied, agents pick the closest empty slot that is satisfactory.
- Random or segregated start.

From demonstration to experiment

- Begin with an intolerant population.
- Then introduce
  - tolerance of diversity
  - multicultural preference for diversity
  - color blindness
- Does segregation decrease?

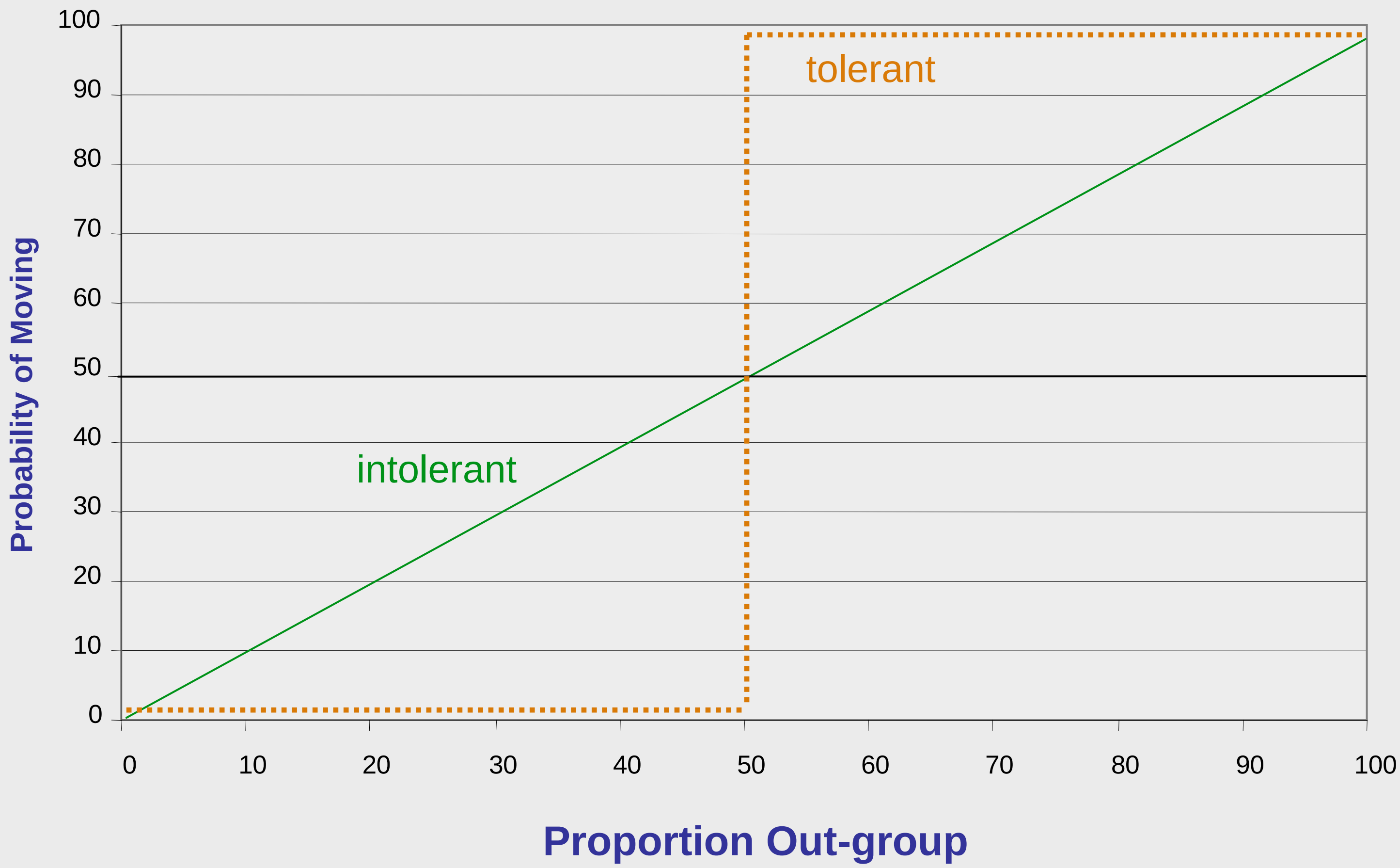
Click here to begin

From tolerance to multiculturalism

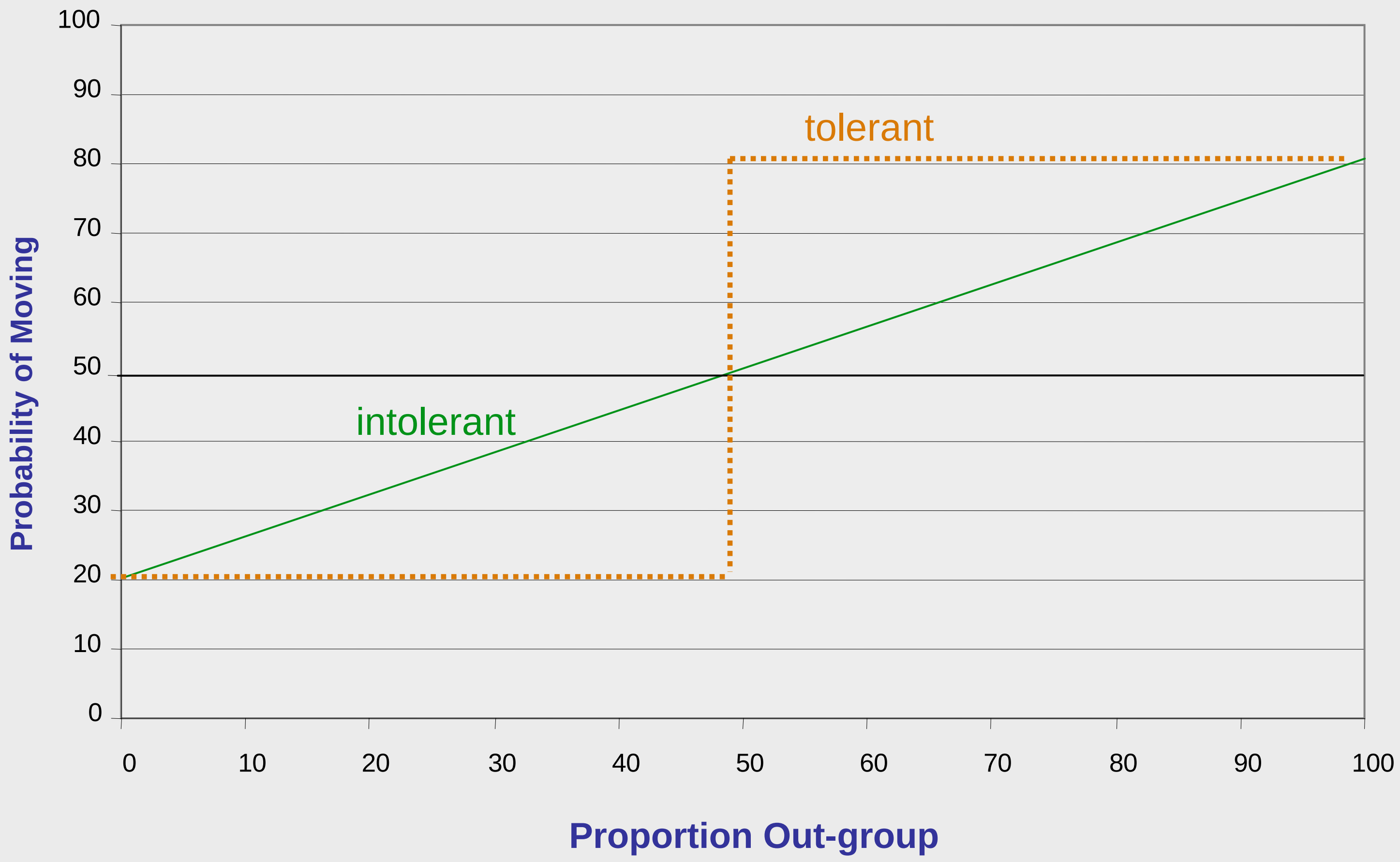
- Complete segregation is an equilibrium for agents who tolerate minority out-group neighbors.
- But suppose agents strictly prefer diversity?
- Segregation should now decrease…

Click here to begin

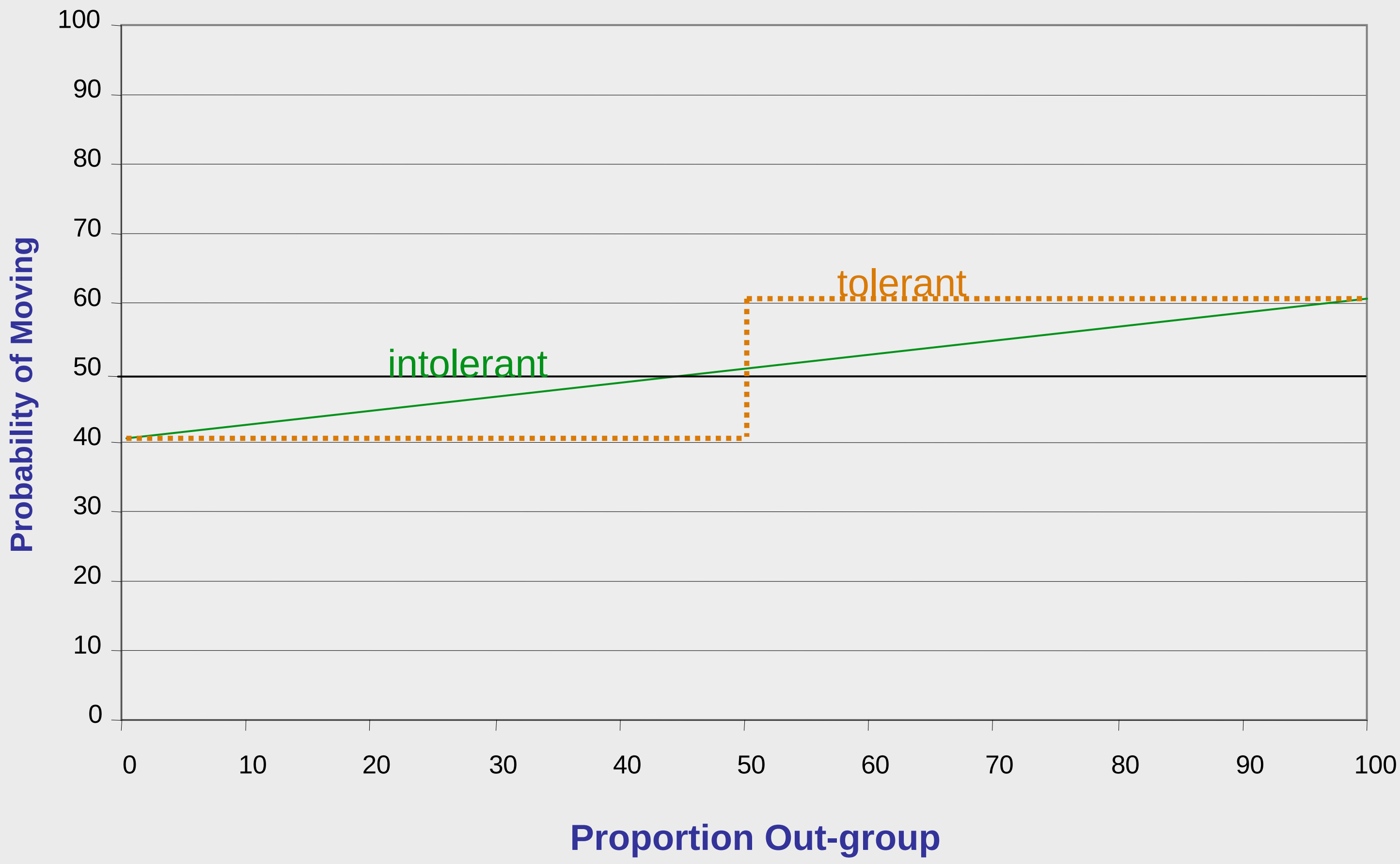
Strong ethic preference



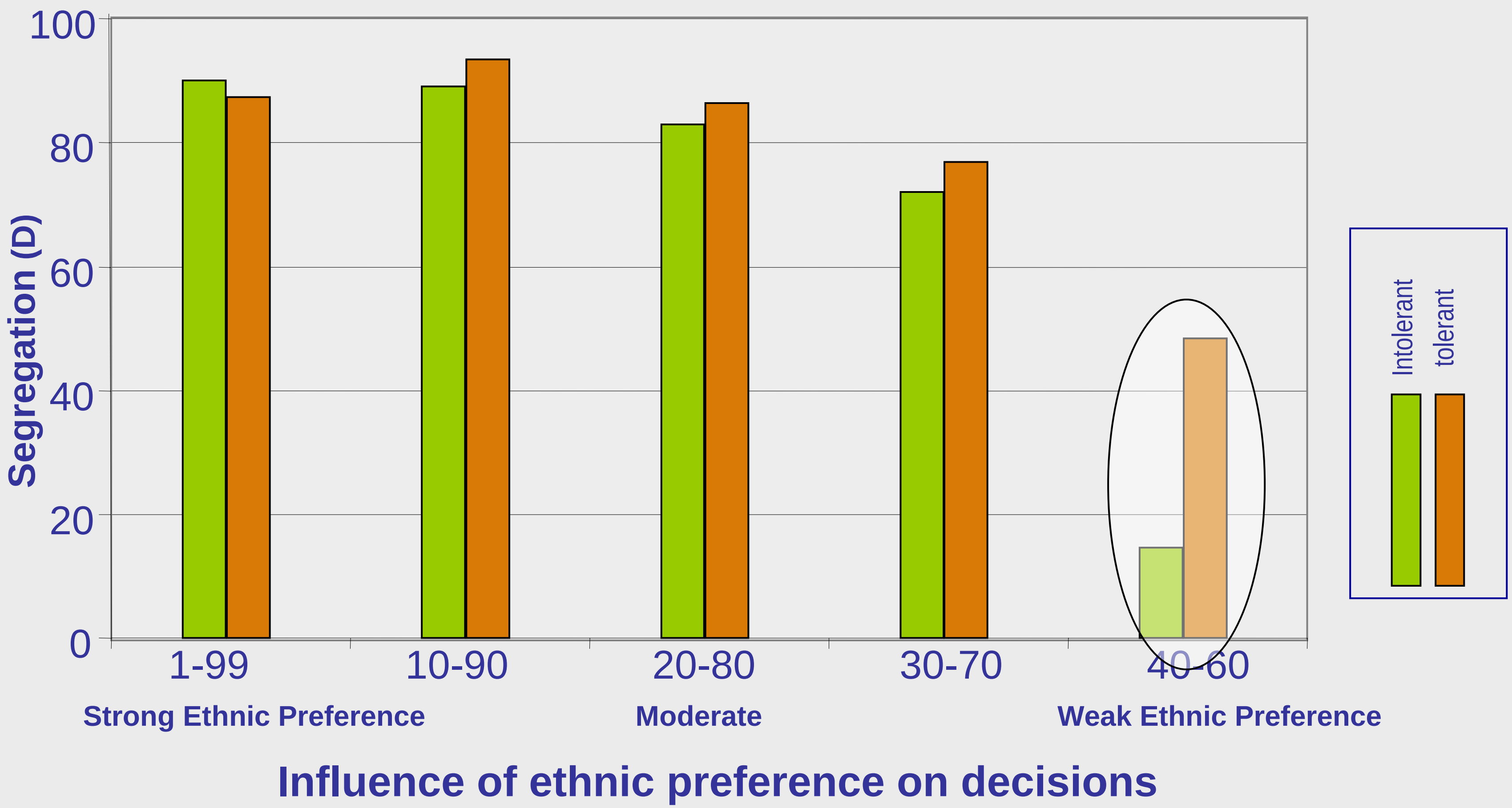
Moderate ethnic preference



Weak ethnic preference



Effect of tolerance and color-blindness



What did we learn?

- Schelling: segregation emerges despite tolerance of diversity.
- He <u>understated</u> the problem!
  - emerges even with a strict co-ethnic preference.
  - tolerance can lead to more segregation than intolerance.
- Key to integration
  - not multiculturalism (accentuates the salience of ethnicity).
  - but the opposite – color blindness.

But is the model realistic?

- Schelling’s neighborhood
  - a very small 10x10 checkerboard.
  - no housing prices, no crime, no train tracks, no lousy schools.
- Agent-based models are used for thought experiments
  - similar to game theory, only non-mathematical.
  - resist the temptation to make the models “realistic.”
    - requires numerous complications.
    - undermines the power to reveal micro-macro links.

II. Maybe it’s not such a small world after all?

(with Damon Centola, RWJ Fellow at Harvard)

The Spread of the Internet, 1993 – 2016

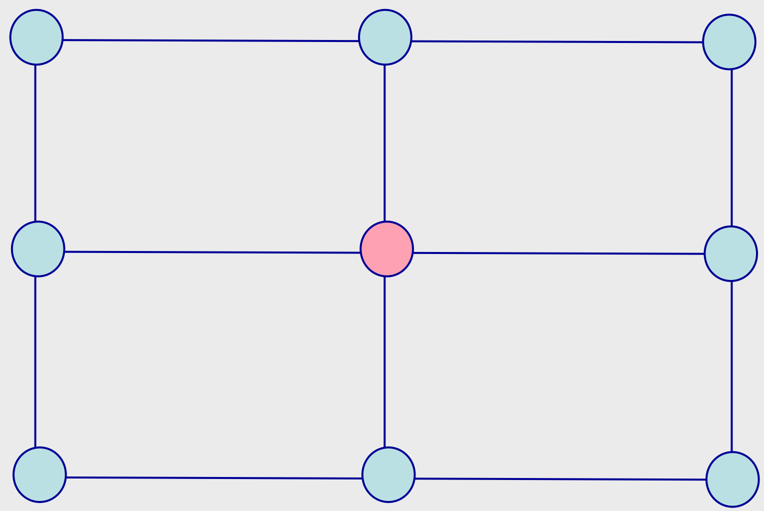
(click to view map)

Why contagions spread spatially?

- Standard explanation
  - disease, rumors require physical, respiratory, earshot contact
  - Social influence increases with physical proximity
- A new possibility: wide bridges


USGS

“Moore neighborhood” on a lattice



Each cell has 8 neighbors

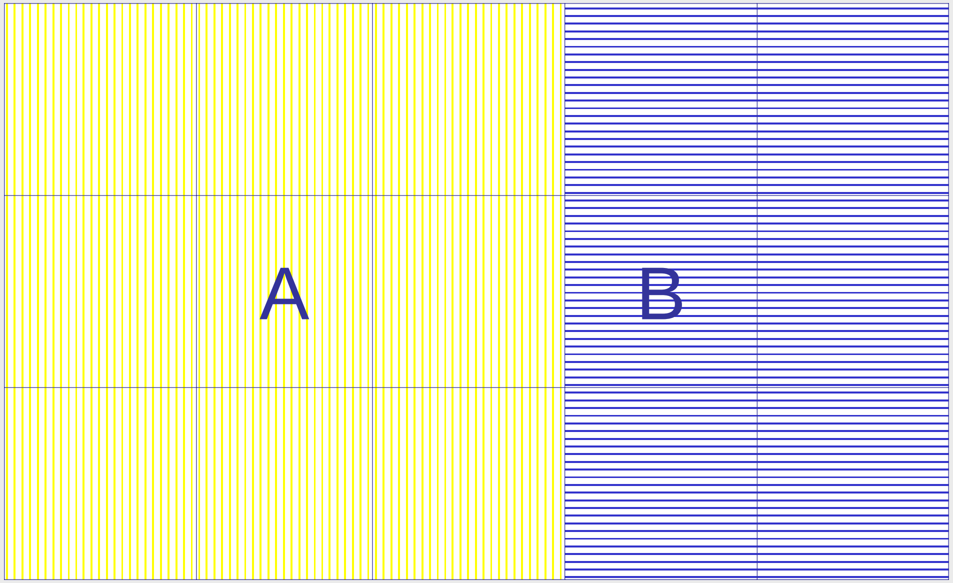
“Moore neighborhood” on a lattice

1	2	3
4		5
6	7	8

Each cell has 8 neighbors

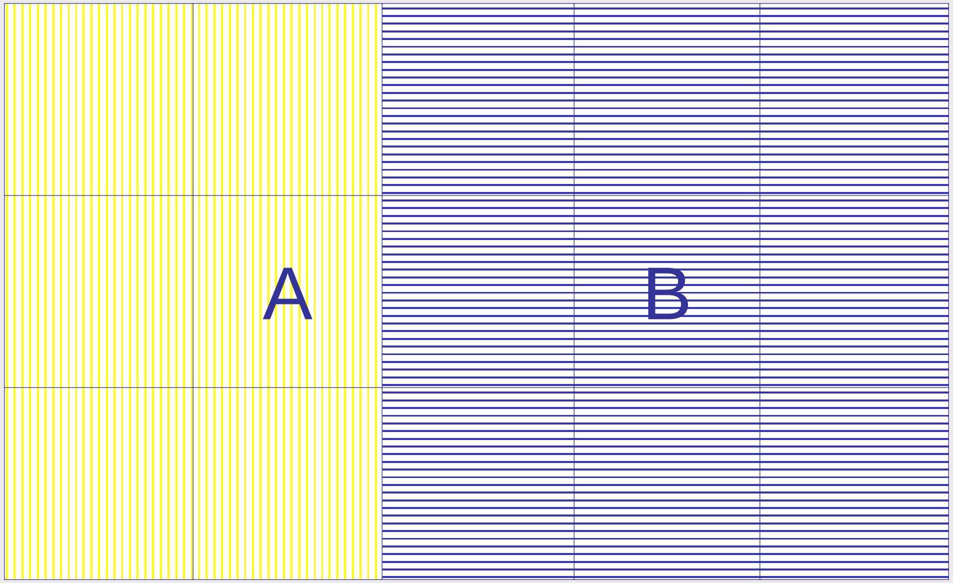
Spatial networks & wide bridges

A's neighborhood is in yellow



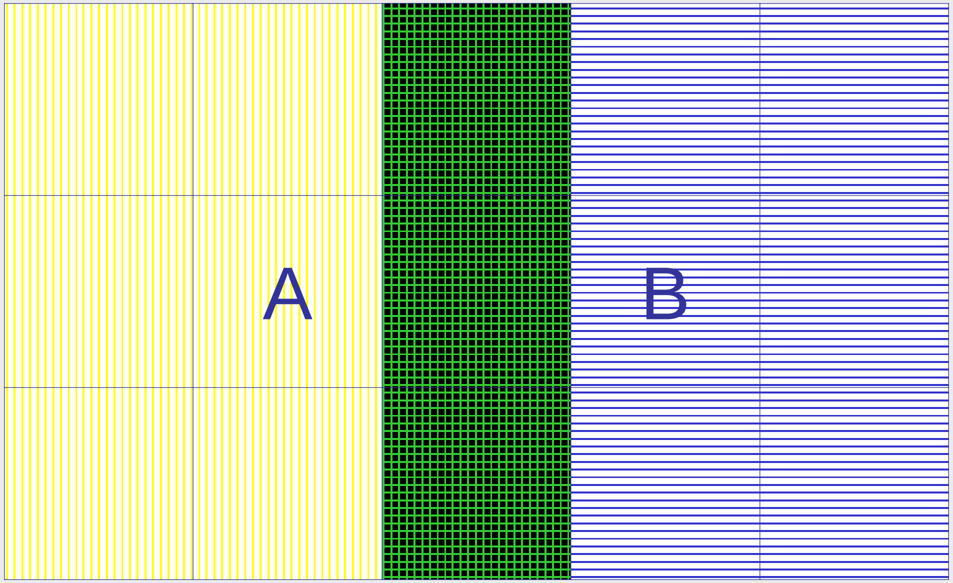
Spatial networks & wide bridges

B’s neighborhood is in blue



Spatial networks & wide bridges

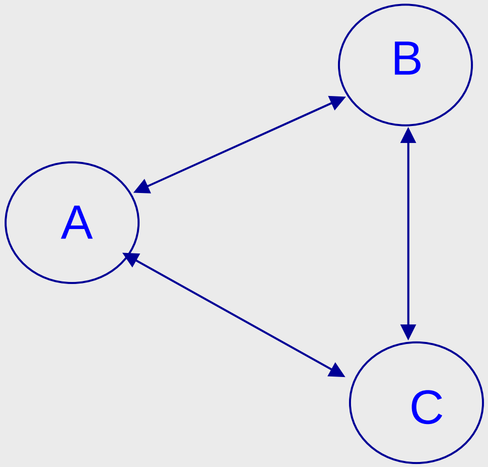
Overlap is in green: A and B have 3 common neighbors.



If A's neighborhood is activated, B will have 3 activated neighbors.

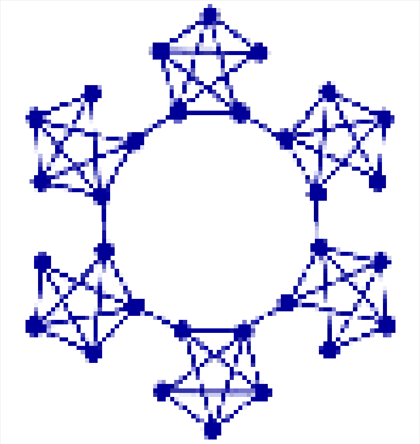
The puzzle of "six degrees"

- The path length between any two randomly chosen people on the planet (N=6.5 billion) is six friends
- Easy to explain if social ties were highly random
- But in fact social networks are highly clustered.
- How then is it possible that there are only "six degrees of separation?"



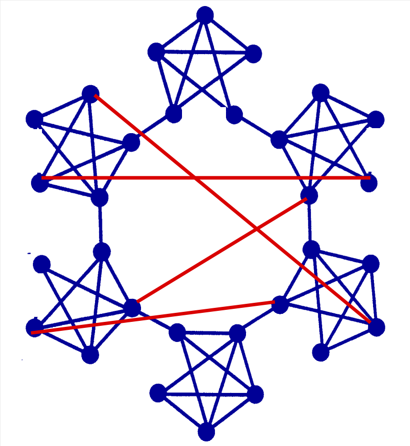
Answer: a few random ties

- A few random ties between otherwise distant nodes
  - Create “shortcuts” across the graph
  - While preserving the clustering of a “small world.”



Answer: a few random ties

- A few random ties between otherwise distant nodes
  - Create “shortcuts” across the graph
  - While preserving the clustering of a “small world.”



Small worlds

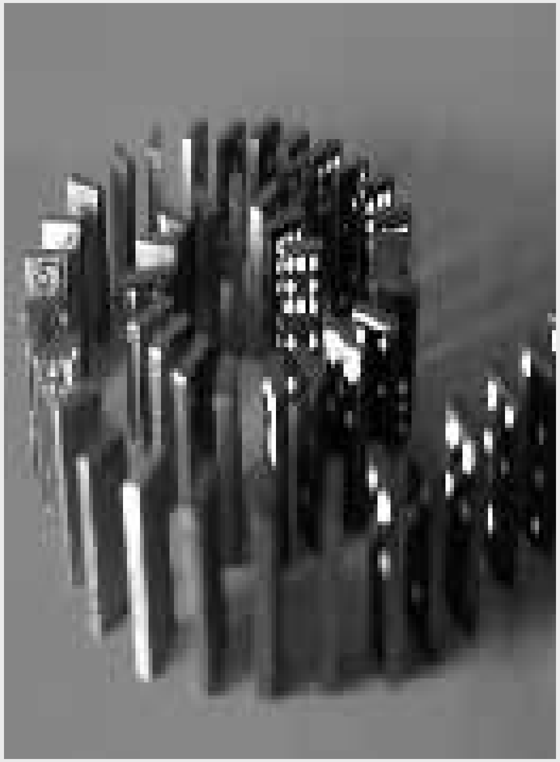
- Combine order with randomness
- Have local structure like a spatial network
- But a few random ties shrink average social distance
- Speeds up the spread of information and disease

Maybe it’s not such a small world after all?

- Disease and information spread spatially
  - But also “jump” across the map via bridge ties between clusters.
  - Those bridge ties are what make the world “small.”
- But is this also true for the spread of social contagions?

The domino effect

- A single activated node is sufficient to trigger activation of its neighbors.
- Contact with a single source is sufficient to spread disease or information.
- Social contagions can have higher activation thresholds.

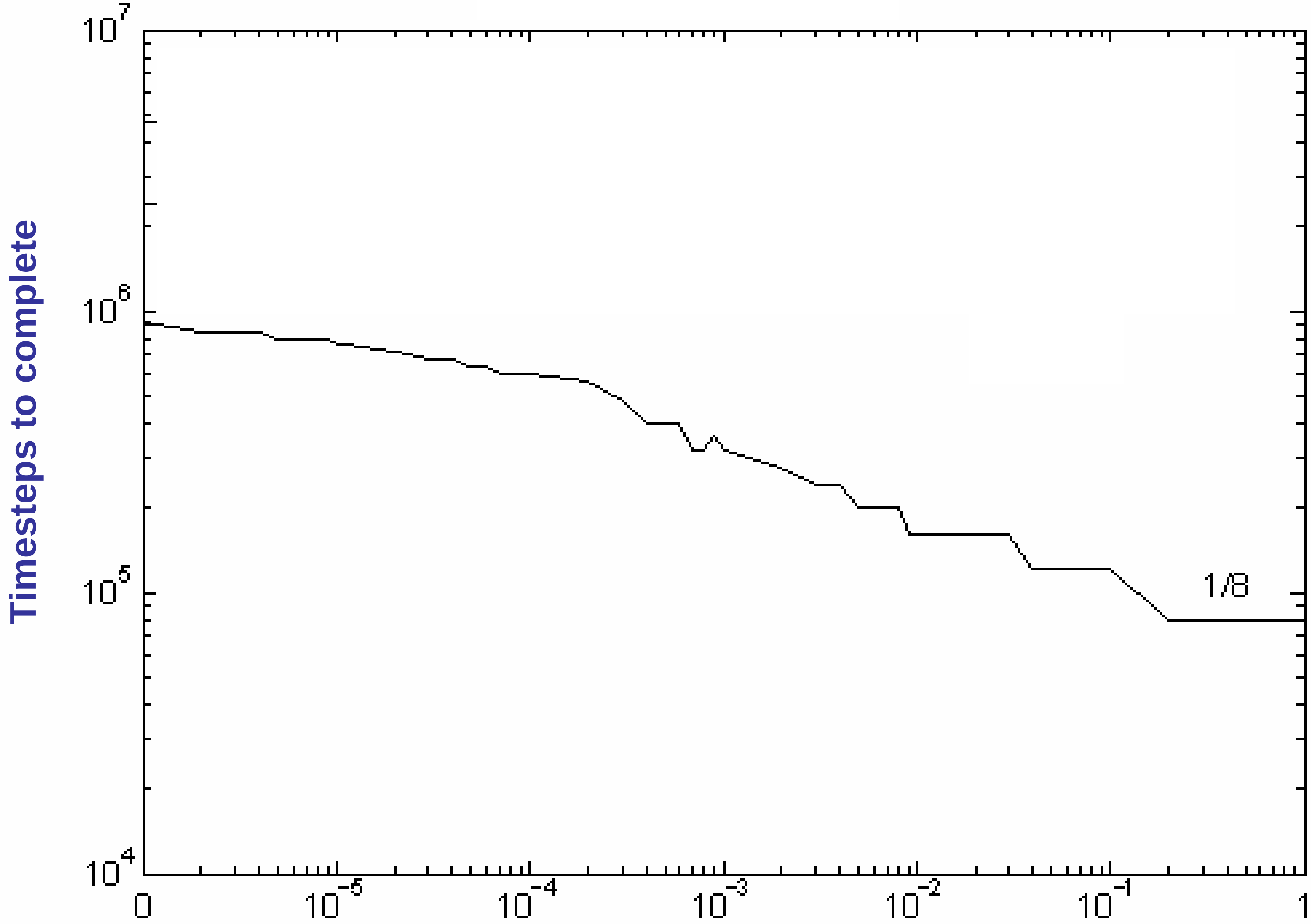


Not enough to simply <u>know</u> a fact

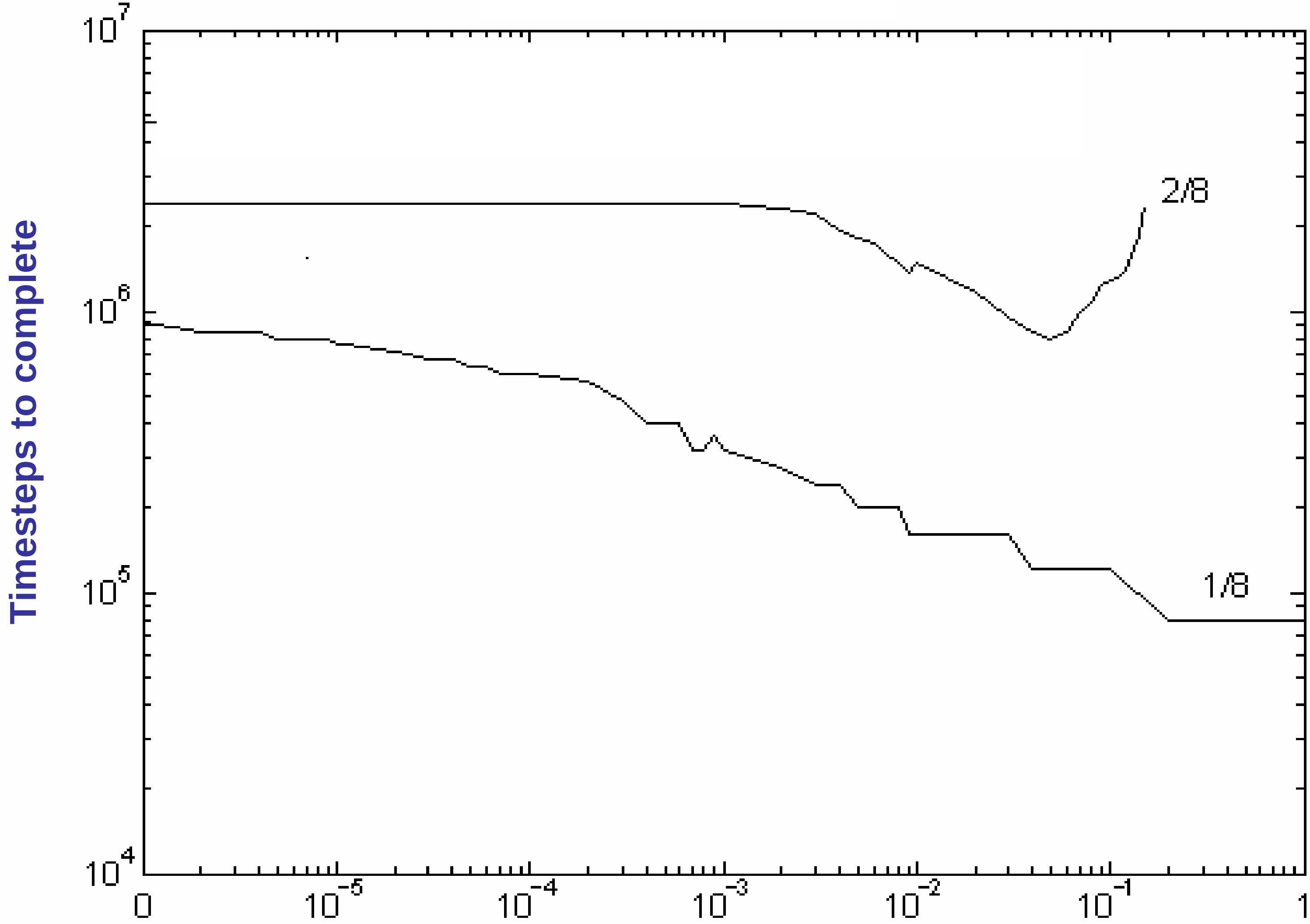
- Having information is not the same thing as <u>acting</u> on it.
  - is the information credible?
  - is the action socially acceptable?
  - is there a critical mass to make action worthwhile?
  - is it OK to tell others?
- Emotional contagions also require a critical mass.
- Does collective behavior spread the same way as information and disease?

Experimental design

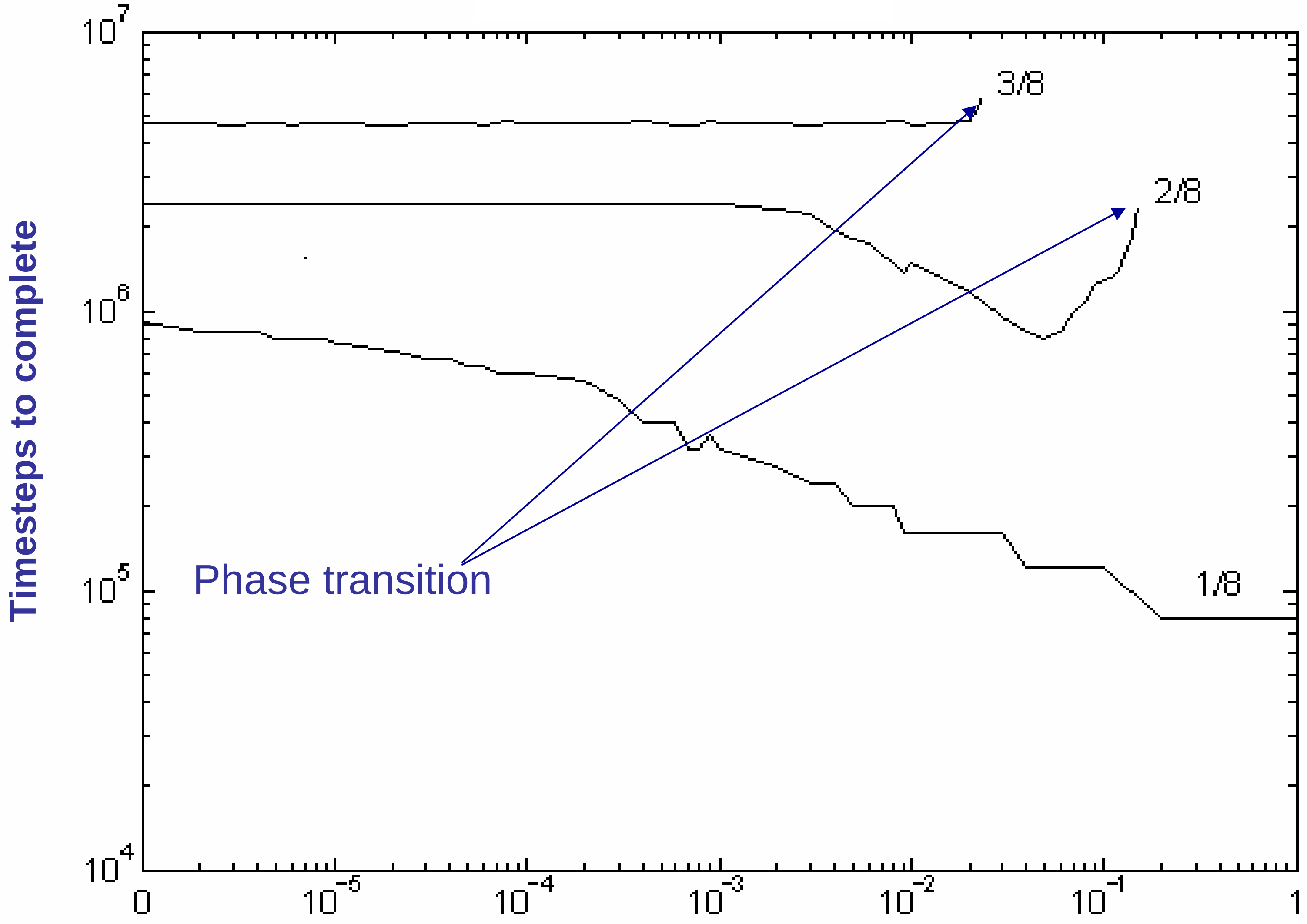
- Began with Watts and Strogatz’ small world experiment
  - agents on a regular lattice
  - infect a few “seed” nodes
  - see how long before all nodes are infected
  - repeat with a few randomized ties
  - see if the contagion spreads faster
- Replicated the experiment but with a contagion that requires confirmation from a second neighbor.



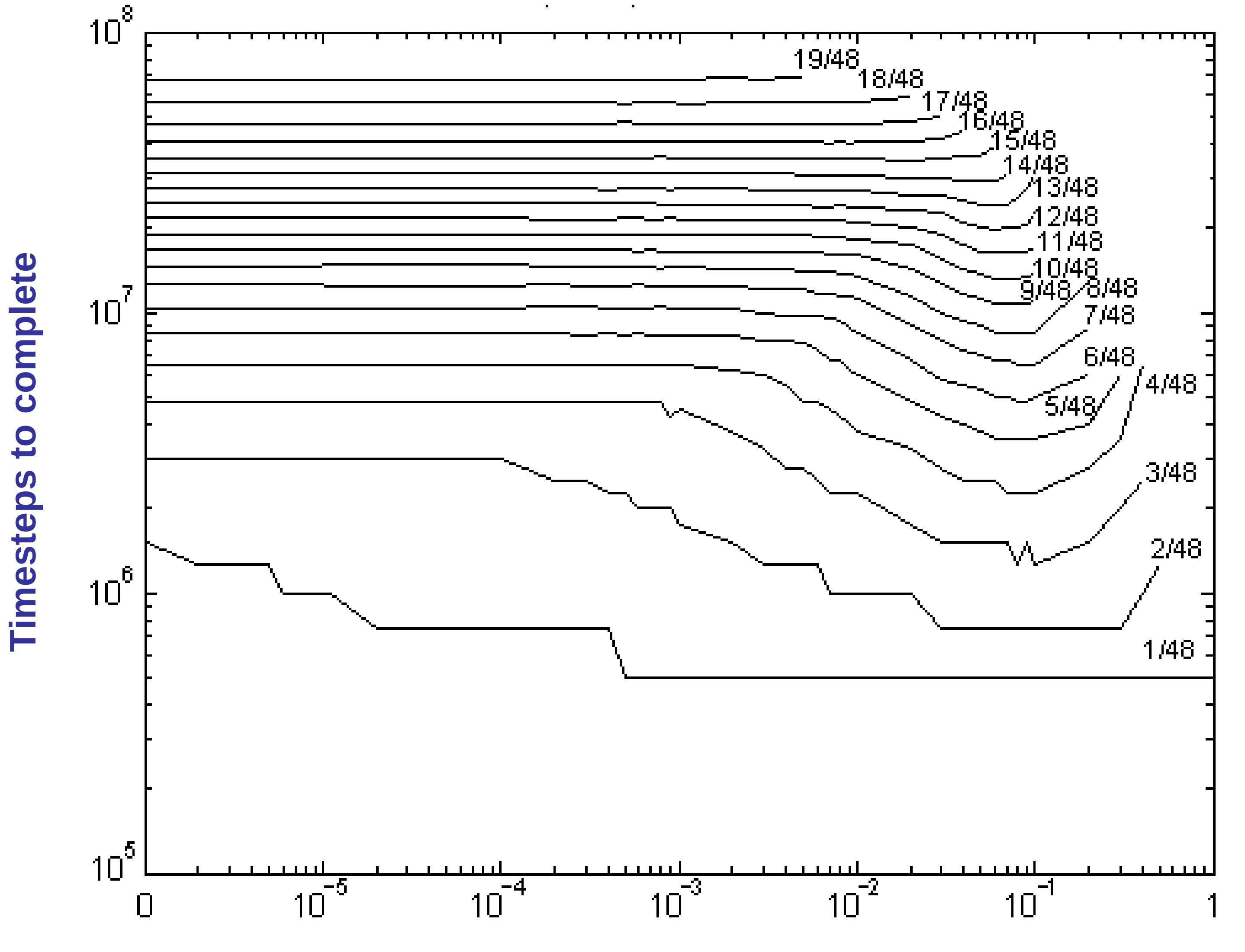
Random ties speed up the spread of disease or information



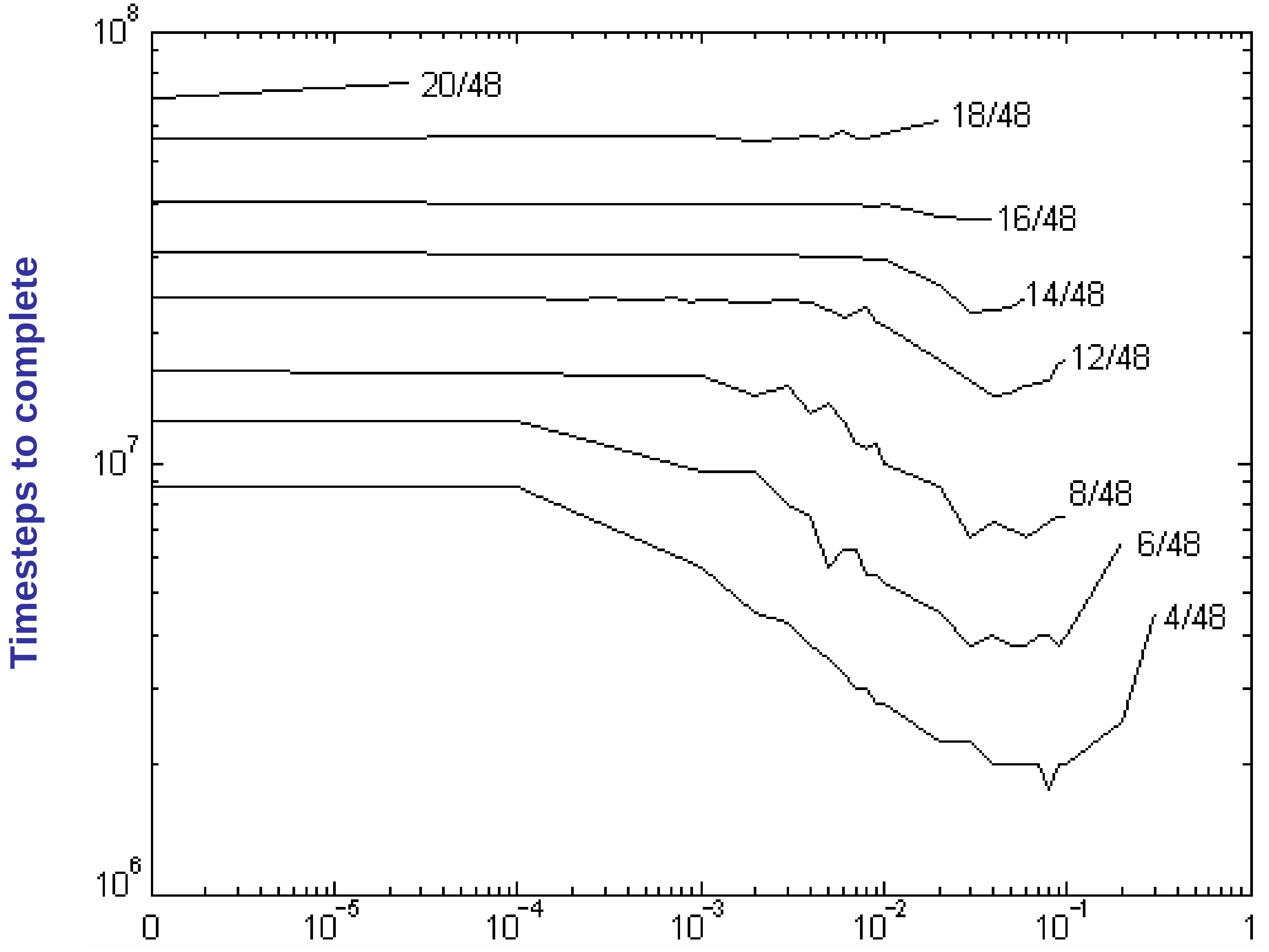
But not the spread of collective behavior



But not the spread of collective behavior



Higher degree, same story (N=240000, k=48)



Normal distribution, same story

So what did we learn?

- Changing behavior requires wider bridges than the spread of disease or information.
- Spatial networks tend to have wide bridges, small worlds do not.
- To spread information use the same network that spreads the disease.
- To change behavior, focus on residential neighborhoods or dormitories, not workplaces or airports.

END