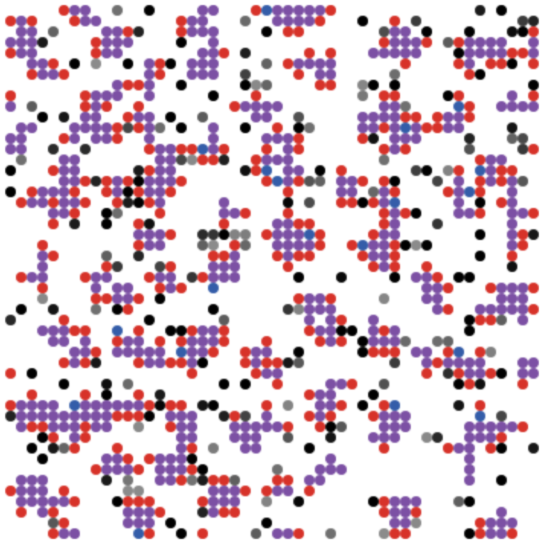


Agent Based Modeling

Dr. Milena Tsvetkova

MY560 Workshops in Advanced Quantitative Analysis

ST 2018

Overview

- (morning) What is agent based modeling?
  - Models in social science
  - Characteristics of ABMs
  - Prominent ABMs
    - Segregation
    - Cooperation
    - Contagion
  - Calibrating and validating models with data
    - Cooperation experiment -> model
    - Segregation model -> experiment
- (afternoon) NetLogo tutorial
  - Basic programing
  - Running experiments

Before we begin…

- Please download and install NetLogo

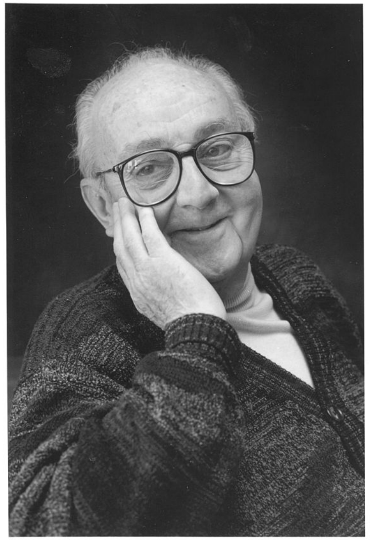
http://ccl.northwestern.edu/netlogo/

Modeling in social science

- In the social sciences, a model is a **mathematical abstraction or simplification** of a social process
- Modeling aims to **understand, quantify, or predict** the process
- Types
  - Statistical
  - Analytical
  - Agent based

All models are wrong but some are useful.

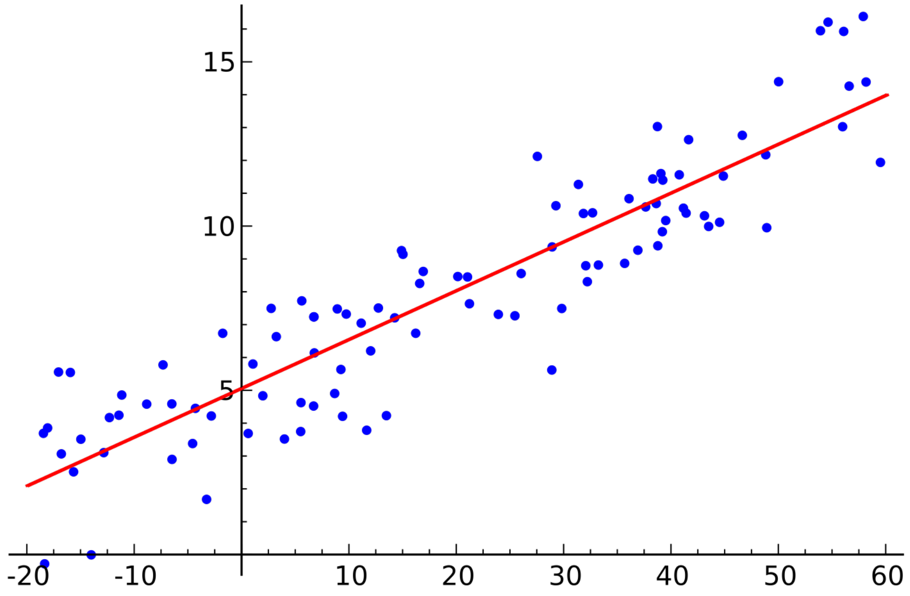
- George E. P. Box



Statistical models

- Based on empirical data
- Focus on mean values and average effects
- Estimate using statistical procedures
- May explain data but not necessarily process

$$\hat{Y} = \alpha + \beta X$$



Analytical models

- Based on theoretical assumptions
- Focus on solving for equilibrium
- Solve using mathematics
- May explain process but not necessarily data

Player 2

Player 1	Cooperate	Defect
Cooperate	5, 5	0, 8
Defect	8, 0	2, 2

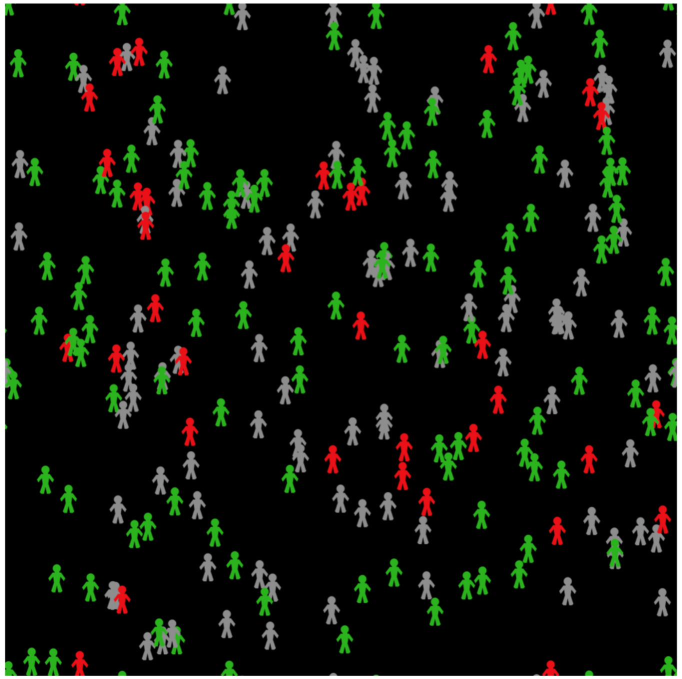
$x^* \in S$ is Nash equilibrium if

$$\forall i, x_i \in S_i\colon\ f_i(x_i^*, x_{-i}^*) \geq f_i(x_i, x_{-i}^*)$$

Agent based models

Use a computer program to create a number of “agents” with certain properties and rules of behavior and observe what happens as time passes

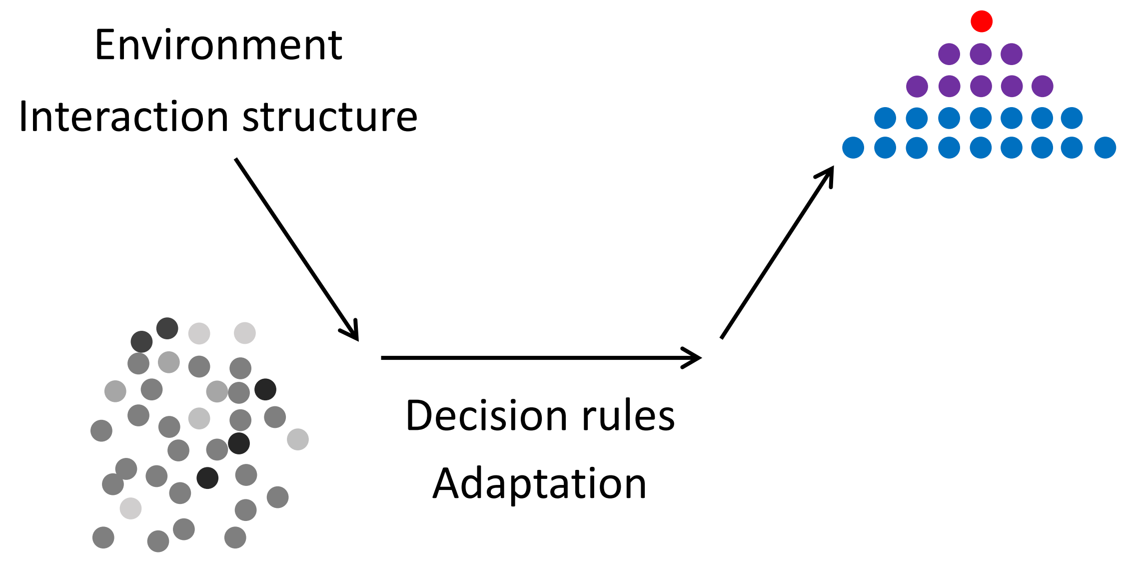
- Based on theoretical assumptions and/or empirical data
- Focus on simulating dynamics
- Simulate using computation



Elements of ABMs

- Numerous agents
- Decision rules
- Adaptive processes
  - E.g. learning, reproduction, movement
- Interaction structure
- Environment

Coleman's boat[1]



- Randomness
  - Monte Carlo methods (Repeat random sampling → Compute results → Aggregate)
  - Noise (errors)

1. Coleman, J.S. (1994). *Foundations of Social Theory*. Harvard University Press.

When are ABMs useful?

- To study complex adaptive systems
- To investigate how micro-level behavior leads to macro-level outcomes
    - Model cannot be solved analytically (**complexity**)
    - Macro outcome cannot be explained with the simple aggregation of micro behavior (**emergence, self-organization**)
    - Similar micro behavior can produce wildly diverging macro outcomes (**chaos**)
    - There is no equilibrium (**oscillation**)

Applications of ABMs

- Theory development
  - What are the macro outcomes from a set of empirically grounded behavioral assumptions?[1]
  - What micro assumptions and mechanisms can generate an observed social phenomenon?
    - **Sufficient but not necessary explanations**

By Oscar Ruiz

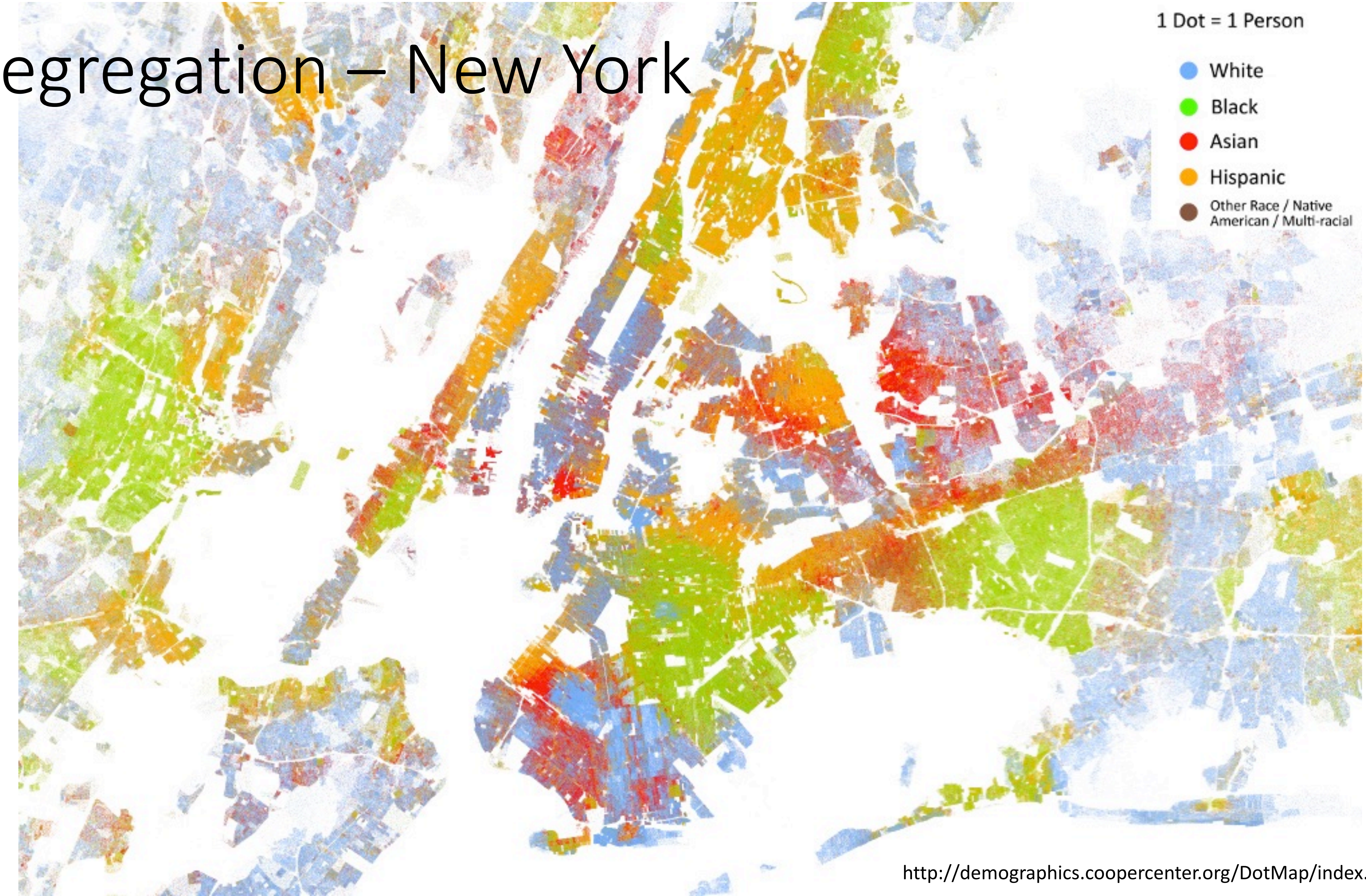
- Empirical predictions
  - Spread of epidemics
  - Evacuation of large venues
  - Traffic congestion in case of road closures

1. Shaw, A. K., Tsvetkova, M., & Daneshvar, R. (2011). The effect of gossip on social networks. *Complexity*, 16(4), 39–47.

Examples of ABMs

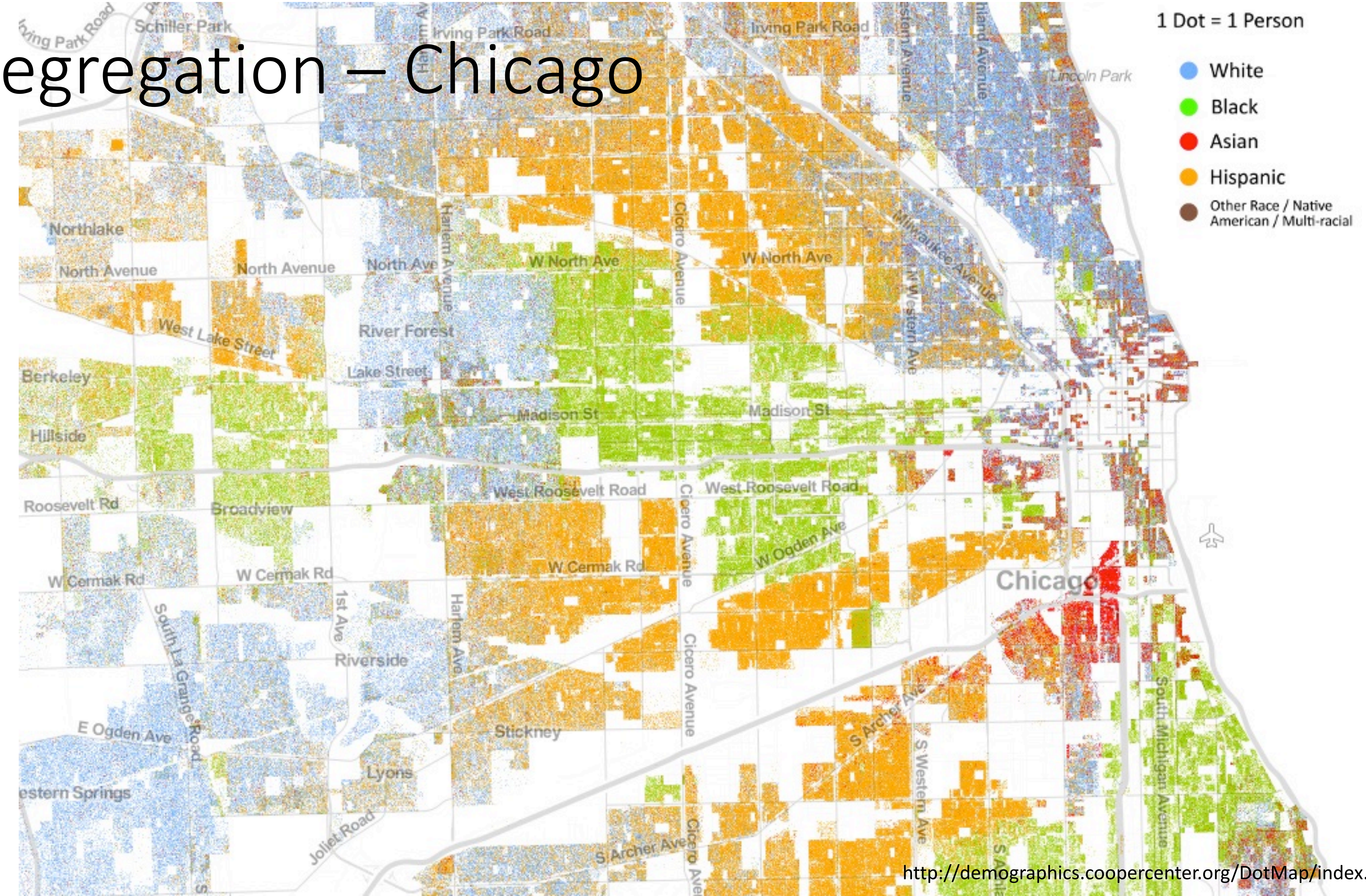
1. Segregation
2. Cooperation
3. Contagion

Segregation – New York



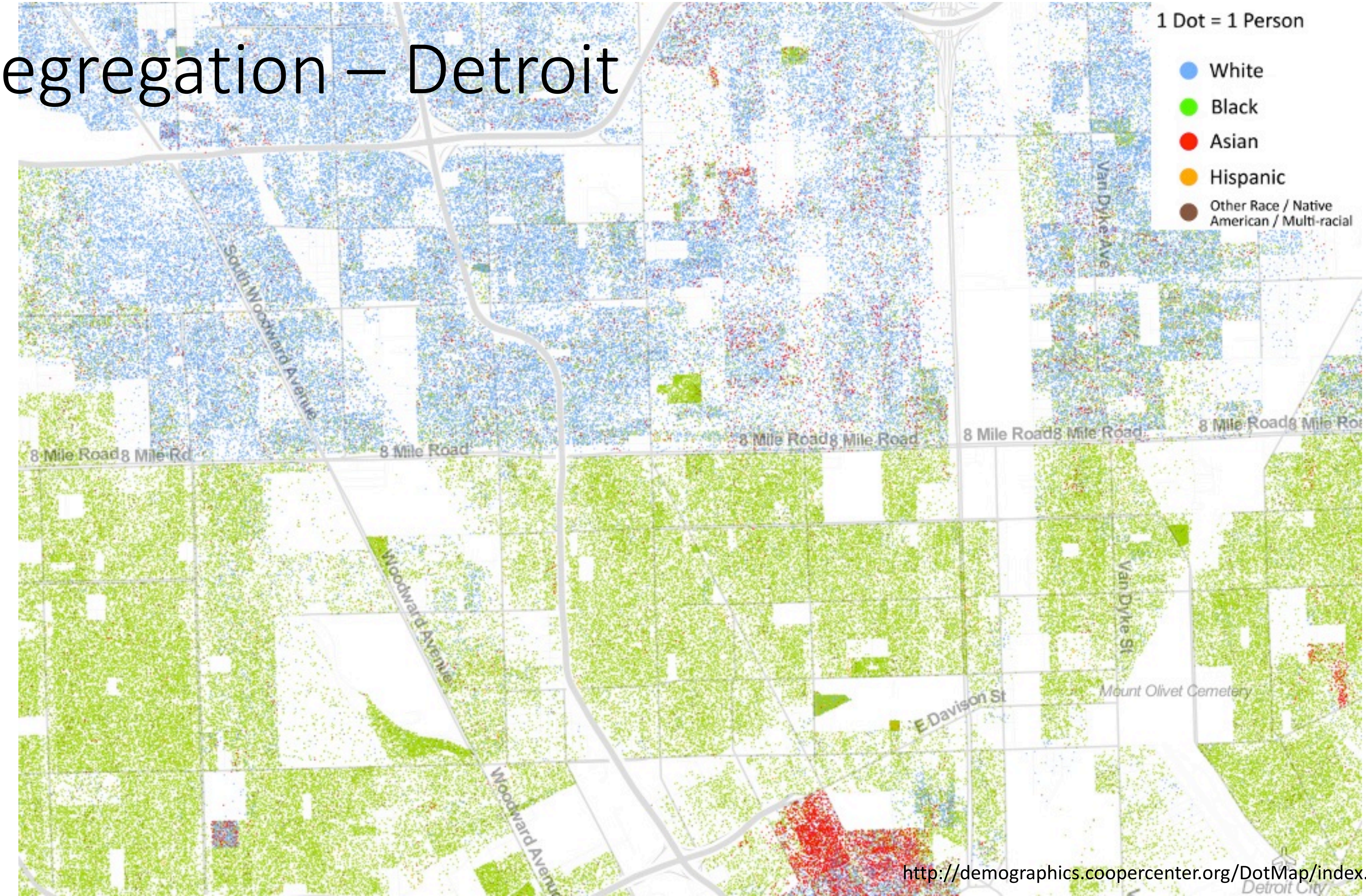
http://demographics.coopercenter.org/DotMap/index.html

Segregation – Chicago



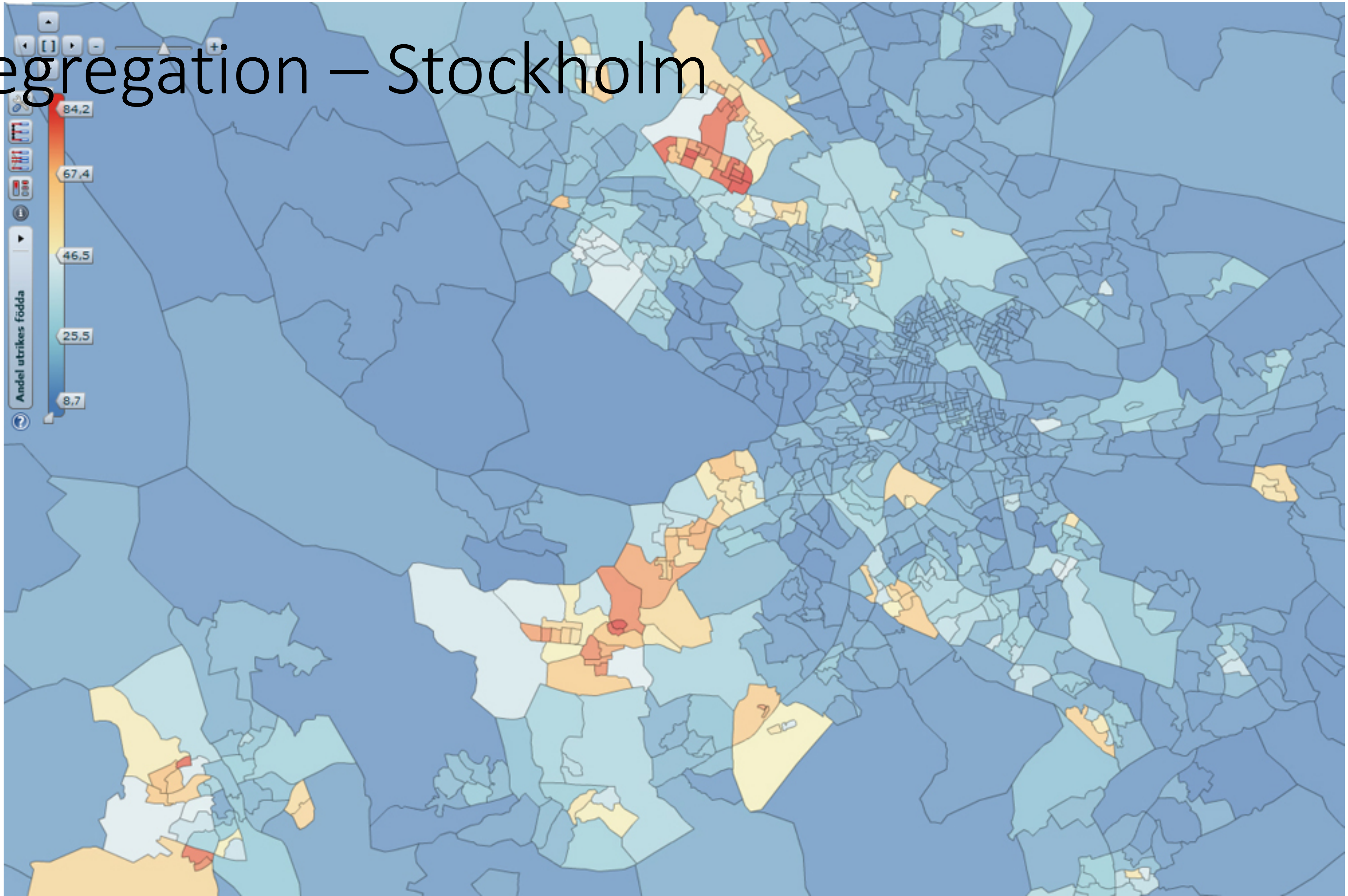
http://demographics.coopercenter.org/DotMap/index.html

Segregation – Detroit

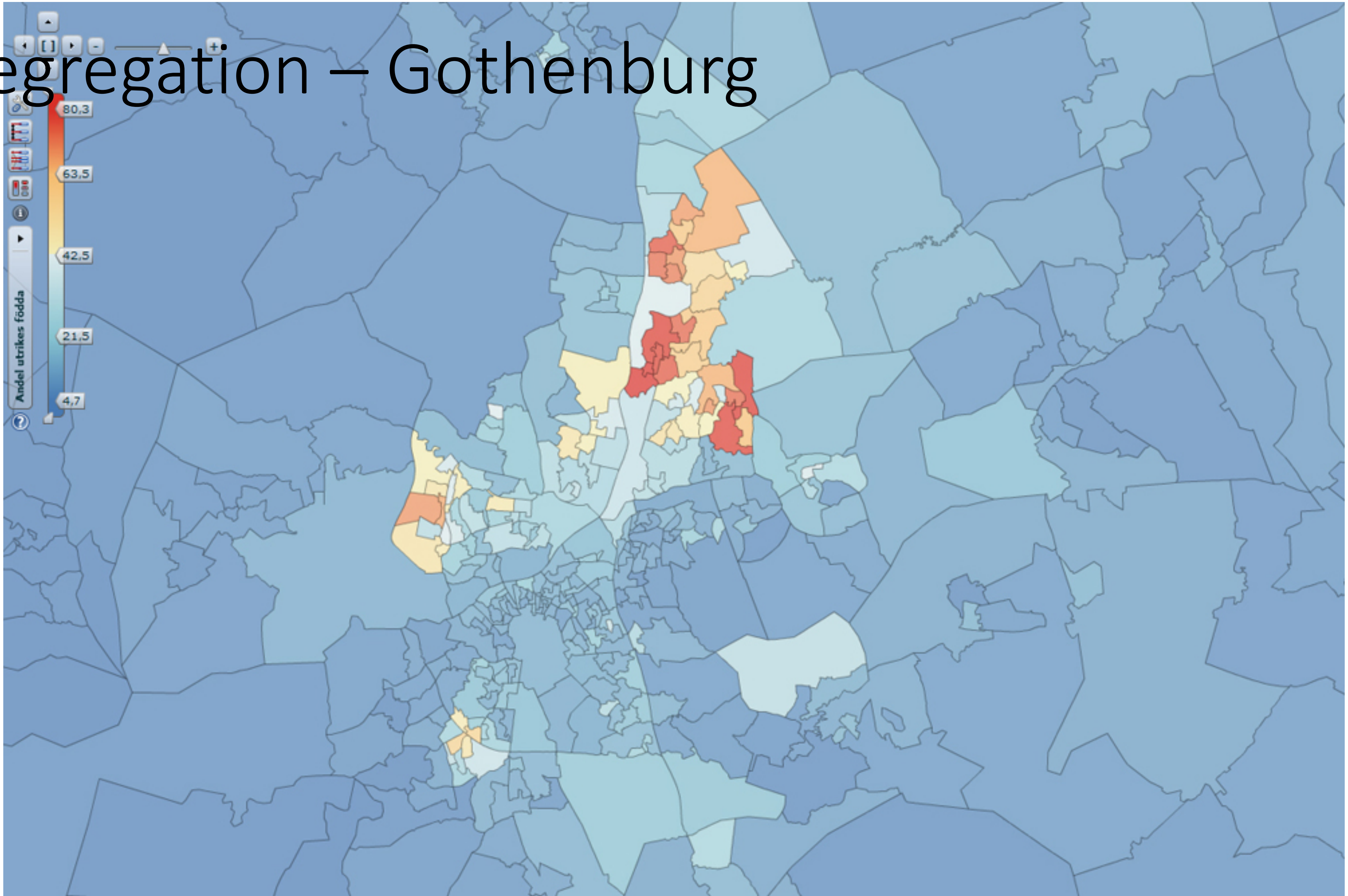


http://demographics.coopercenter.org/DotMap/index.html

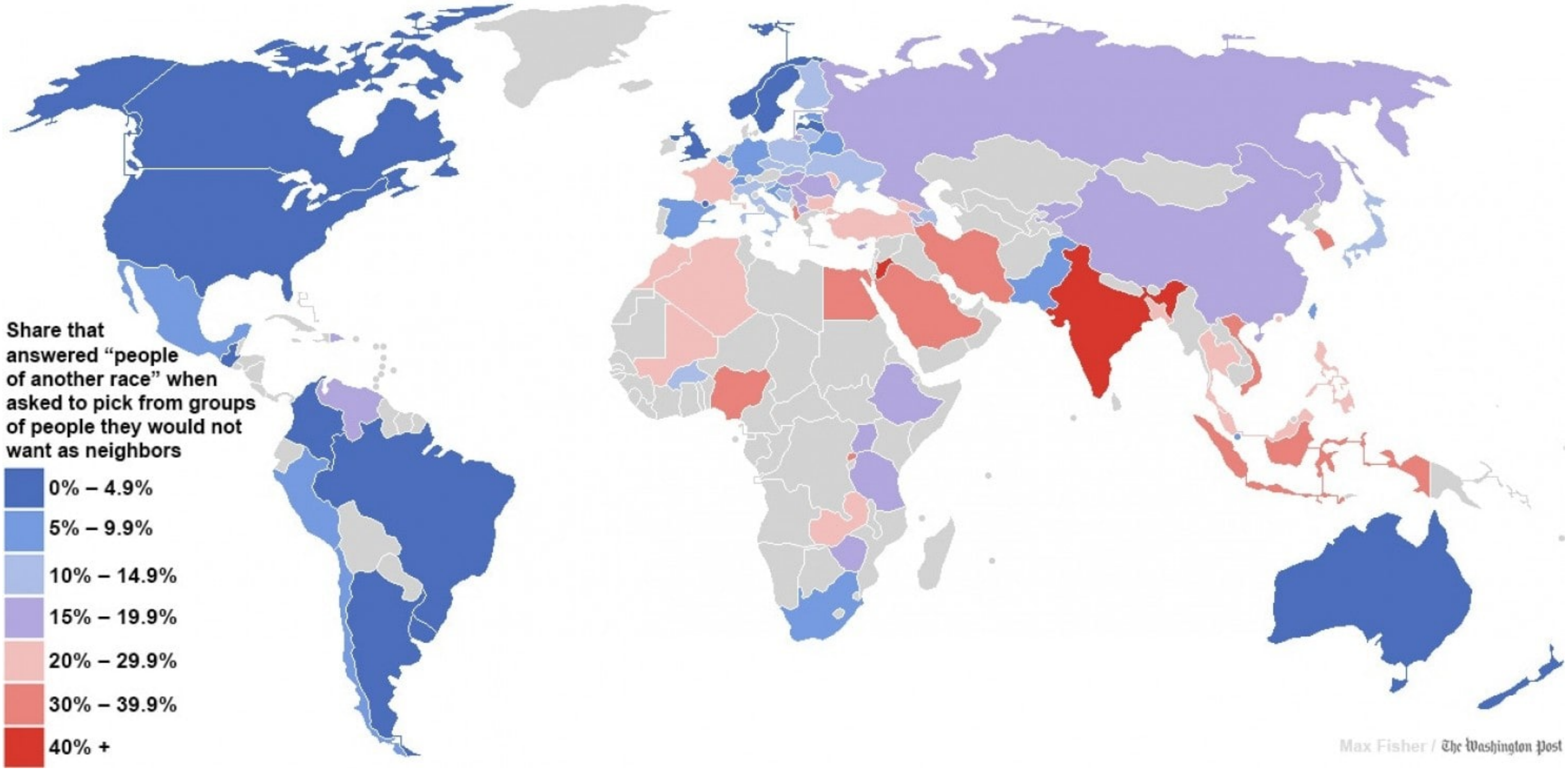
Segregation – Stockholm



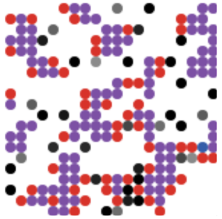
Segregation – Gothenburg



Segregation ≉ tolerance

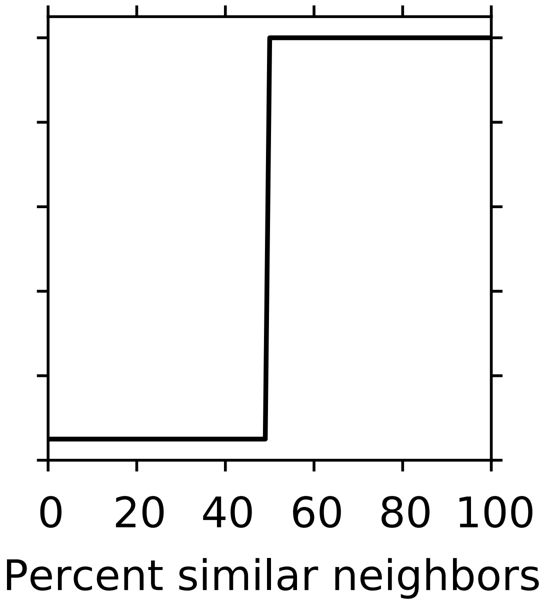


Fisher, M. (2013). A fascinating map of the world's most and least racially tolerant countries. *Washington Post*, 15.



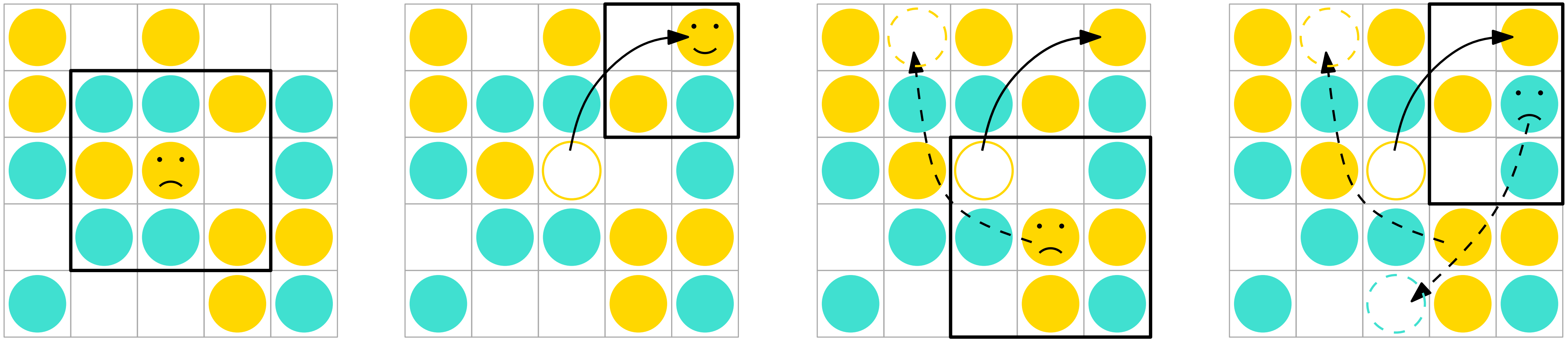
Schelling's model of segregation

- Agents prefer similar neighbors, but are not intolerant
- If unsatisfied, they move to another location that makes them happy



Schelling, T. C. (1971). Dynamic models of segregation. *Journal of Mathematical Sociology*, 1(2), 143-186.

Schelling's model of segregation



- Cascades lead to more segregated outcome than agents prefer
- Example of **unintended consequences** – the population pattern does not describe individual behavior

Schelling, T. C. (1971). Dynamic models of segregation. *Journal of Mathematical Sociology*, 1(2), 143–186.

Cooperation

Prisoner's Dilemma Game

		Player 2	
		Cooperate	Defect
Player 1	Cooperate	5, 5	0, 8
	Defect	8, 0	2, 2

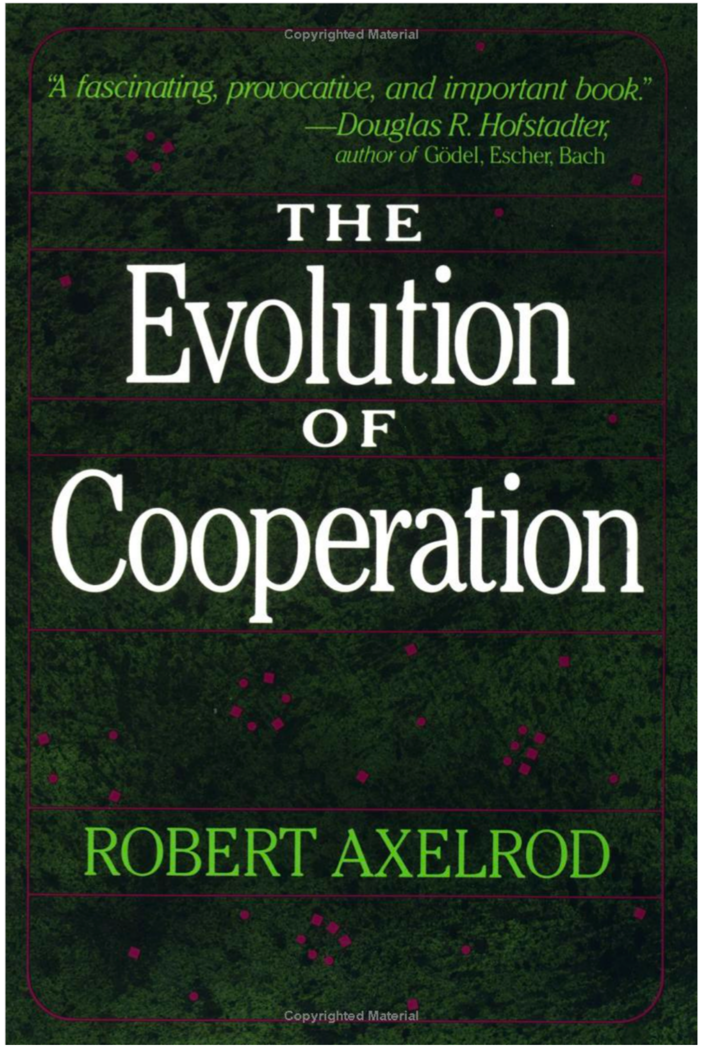
Evolutionary game theory

- Behavior shaped by trial-and-error adaptation through natural selection or individual learning
- Agents are not rational but follow habits/instincts
- Key idea: Strategies can mutate, successful strategies replicate

Axelrod’s model of cooperation

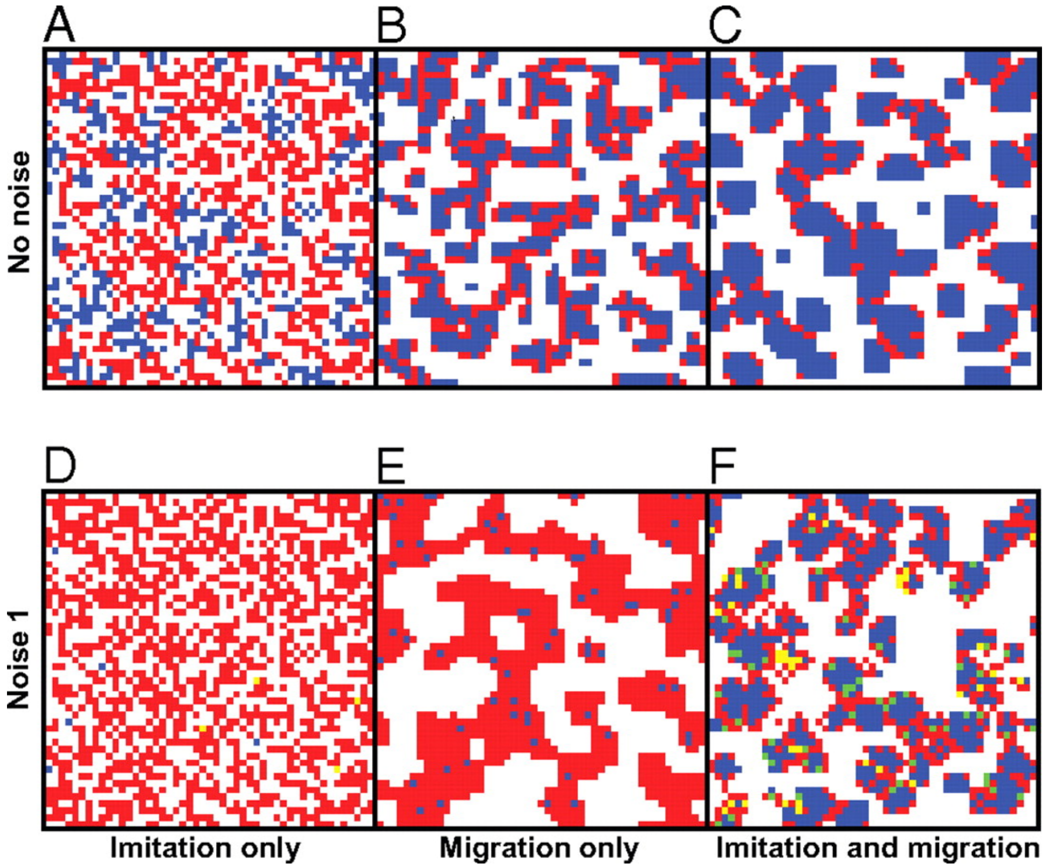
- Start with a population of different strategies
- Complete all-play-all tournament, where players play the PD game repeatedly with each other
- Total payoff determines the winner
- Winner is TIT FOR TAT
  - Cooperate on first move
  - Then do what opponent did in previous round
- Strategy is successful because it is nice, punishing, forgiving, and consistent



Axelrod, R. (1984). *The Evolution of Cooperation*. New York: Basic Books.

Models of the evolution of cooperation

- However, TIT FOR TAT fails under **noise**[1]
- So, let strategies/behavior evolve as result of mutation
- For example, ABM with imitation and success-driven migration[2]



1. Kollock P. (1993). "An eye for an eye leaves everyone blind': Cooperation and accounting systems. American Sociological Review, 58(6), 768–786.

2. Helbing, D., & Yu, W. (2009). The outbreak of cooperation among success-driven individuals under noisy conditions. *Proceedings of the National Academy of Sciences*, 106(10), 3680–3685.

Contagion

- Contagious disease
- Innovations
- Information
- Fake news
- Collective action
- Health-related behavior
- Prosocial behavior
- …




Models of contagion

- SI model: Susceptible → Infectious
  - Patient zero at time $t = 0$
  - After period Δt, infected node gets removed
  - During Δt, infected node can infect healthy neighbors with probability p
- SIS model: Susceptible ↔ Infectious
- SIR model: Susceptible → Infectious → Recovered
- SEIR model: Susceptible → Exposed → Infectious → Recovered

Watt’s model of network contagion

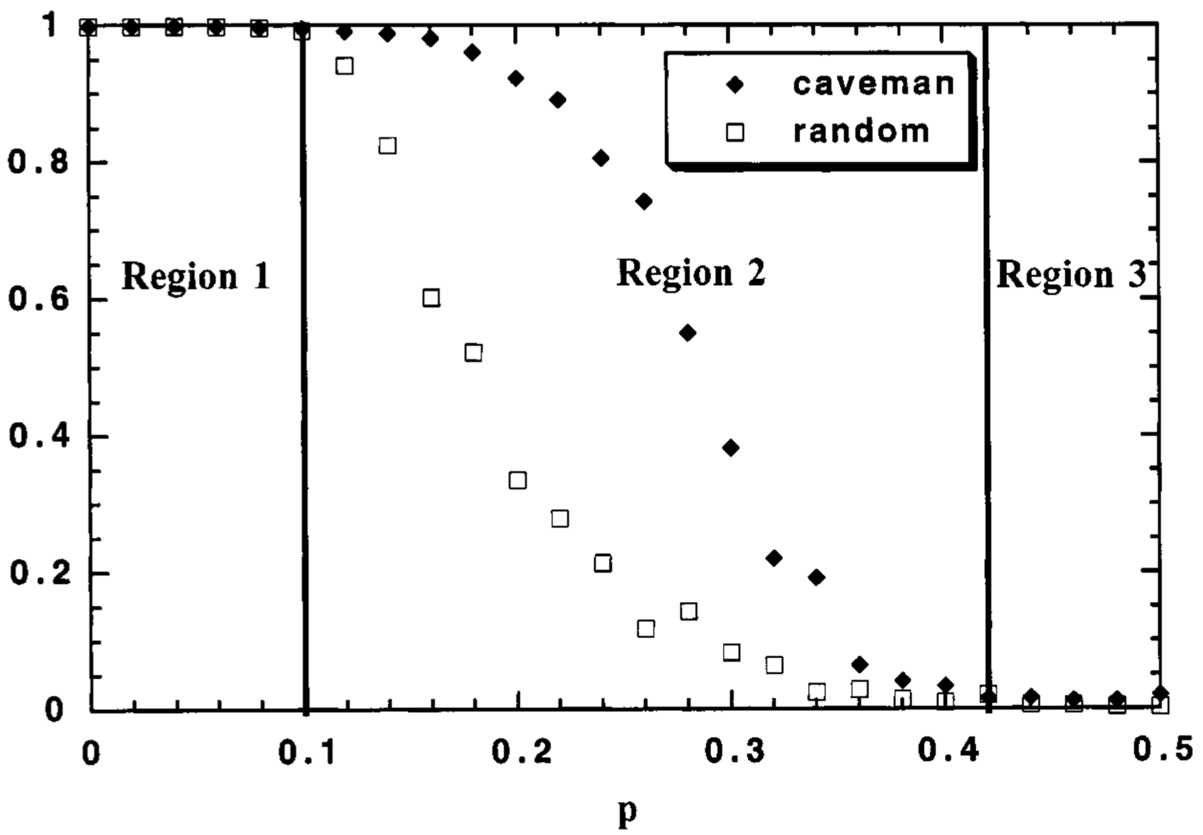
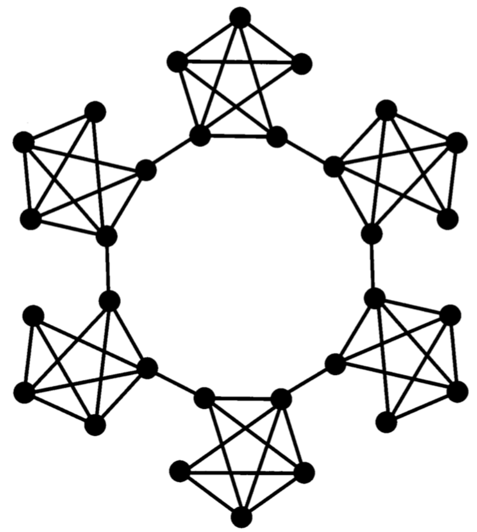


FIG. 11.—Fraction of uninfected survivors (F_s) versus infectiousness (p) for disease spreading dynamics on a network generated by the α-model at clustered and random extremes.



Watts, D. J. (1999). Networks, dynamics, and the small-world phenomenon. *American Journal of Sociology*, 105(2), 493-527.

Building ABMs

The K.I.S.S. principle

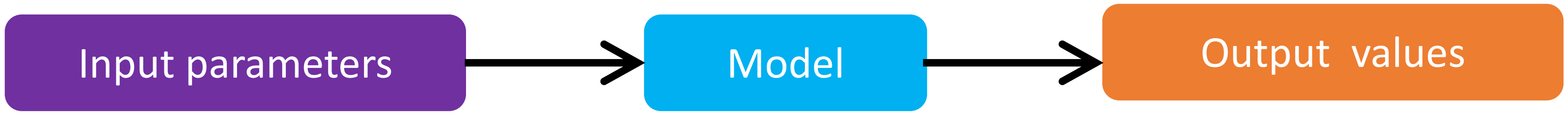
- "Keep it simple, stupid"
- Start small and only add additional assumptions if necessary
- The goal is to find the minimal set of assumptions and parameters sufficient to generate the phenomenon

1. Define behavior
   - Probabilistic behavior
   - Deterministic behavior with noise/errors
2. Define interaction structure
   - Geographic space (grid)
   - Network
   - Random interaction

Building ABMs

3. Understand dynamics and select what/when to record
    - Steady state – How many periods to reach?
    - Growth – Limited, linear, or exponential?
    - Oscillation/chaos – Rate?
4. Repeat 1-3 until system behavior is plausible
5. Systematically vary parameters and record results
6. Test robustness to noise
    - Macy, M., & Tsvetkova, M. (2015). The signal importance of noise. *Sociological Methods & Research*, 44(2), 306-328.
7. Test robustness to basic assumptions
    - Synchronous vs. asynchronous updating
    - Interaction structure
    - Etc.

Calibrating and validating ABMs with data



- **Verification**: Does the model do what it is supposed to do?
- **Calibration**: Are the model assumptions and parameters based on observable reality?
- **Validation**: Are the model predictions consistent with empirical data?

Calibration: Cooperation communities

- Why are mutual-help communities far more common online than in traditional online settings?
- Possible explanation
  - Generosity can be contagious[1]
  - Receiving and observing contributions have different spread effects (online experiment)[2]
  - Non-rival contributions spread more easily (agent-based model)[3]

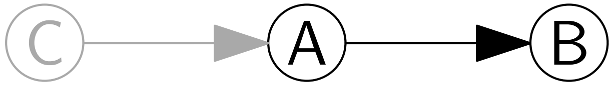
1. Fowler, J. H., & Christakis, N. A. (2010). Cooperative behavior cascades in human social networks. *Proceedings of the National Academy of Sciences*, 107(12), 5334–5338.

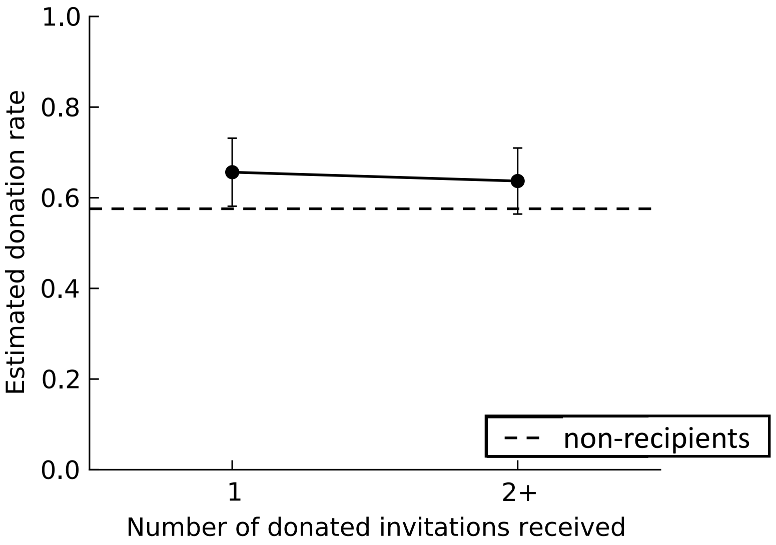
2. Tsvetkova, M., & Macy, M. W. (2014). The social contagion of generosity. *PLOS ONE*, 9(2), e87275.

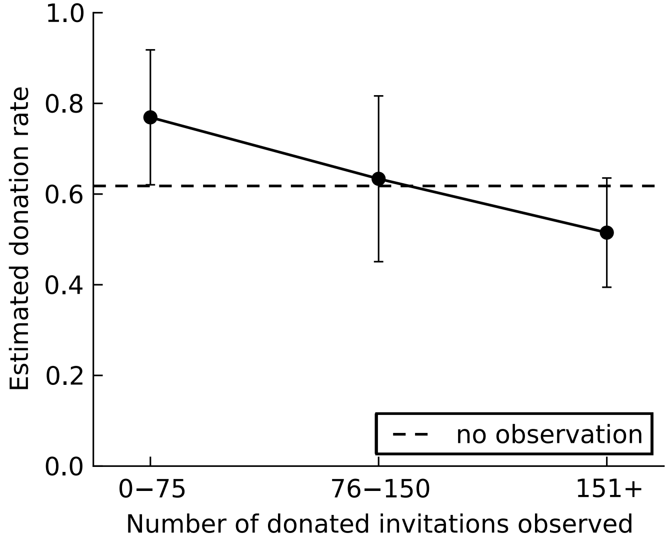
3. Tsvetkova, M., & Macy, M. (2015). The contagion of prosocial behavior and the emergence of voluntary-contribution communities. In *Social Phenomena* (pp. 117-134). Springer, Cham.

Empirical data: Mechanisms for the contagion of generosity

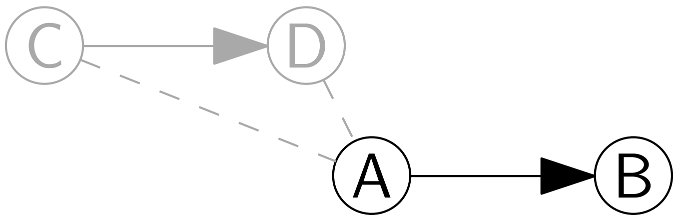
Generalized reciprocity

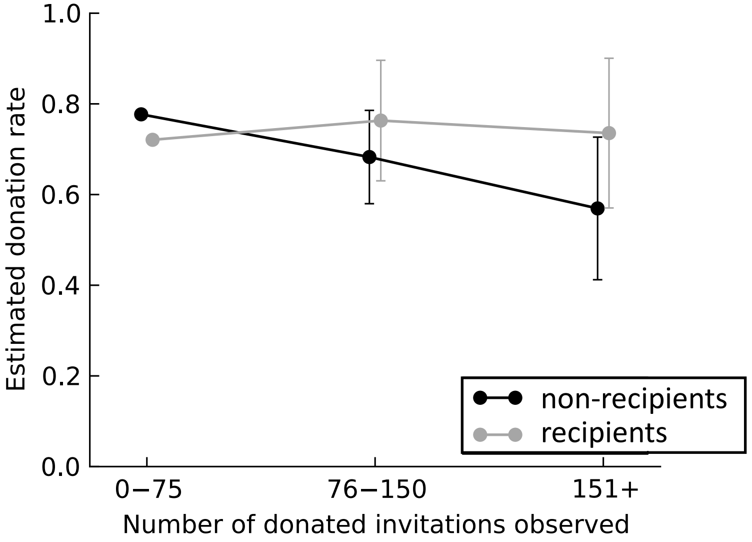




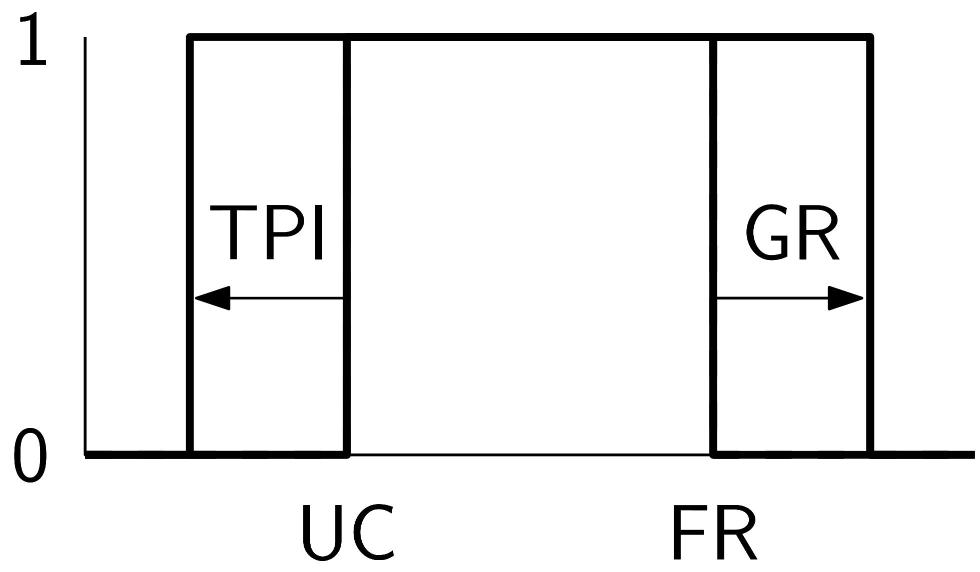


Third-party influence



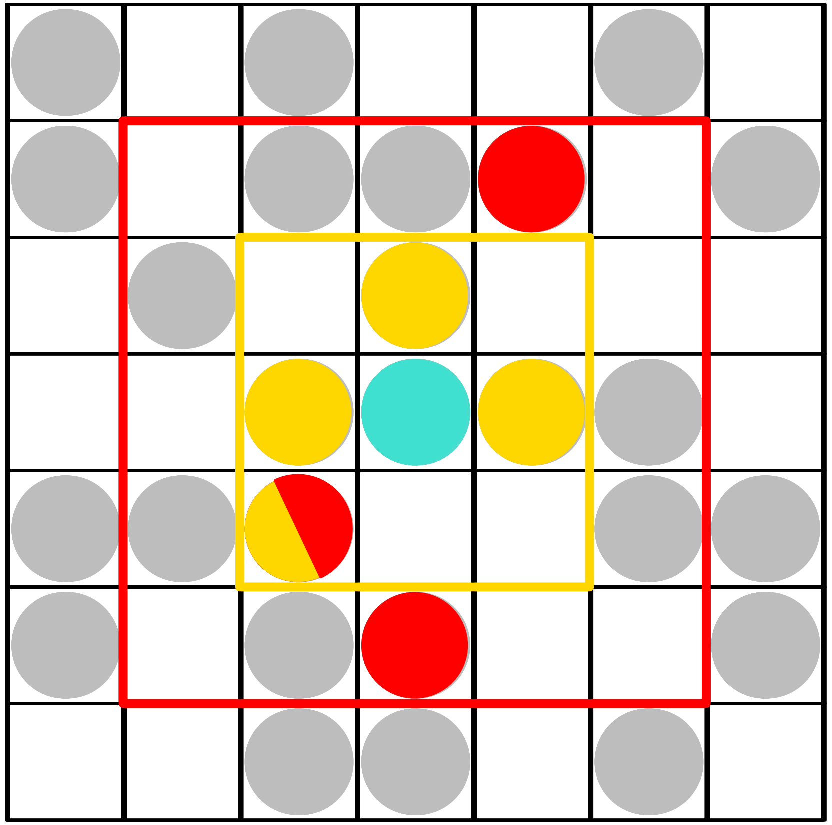


ABM: Adaptive contribution threshold



Granovetter, M. (1978). Threshold models of collective behavior. *American Journal of Sociology*, 83(6), 1420-1443.

ABM: Spatial interactions



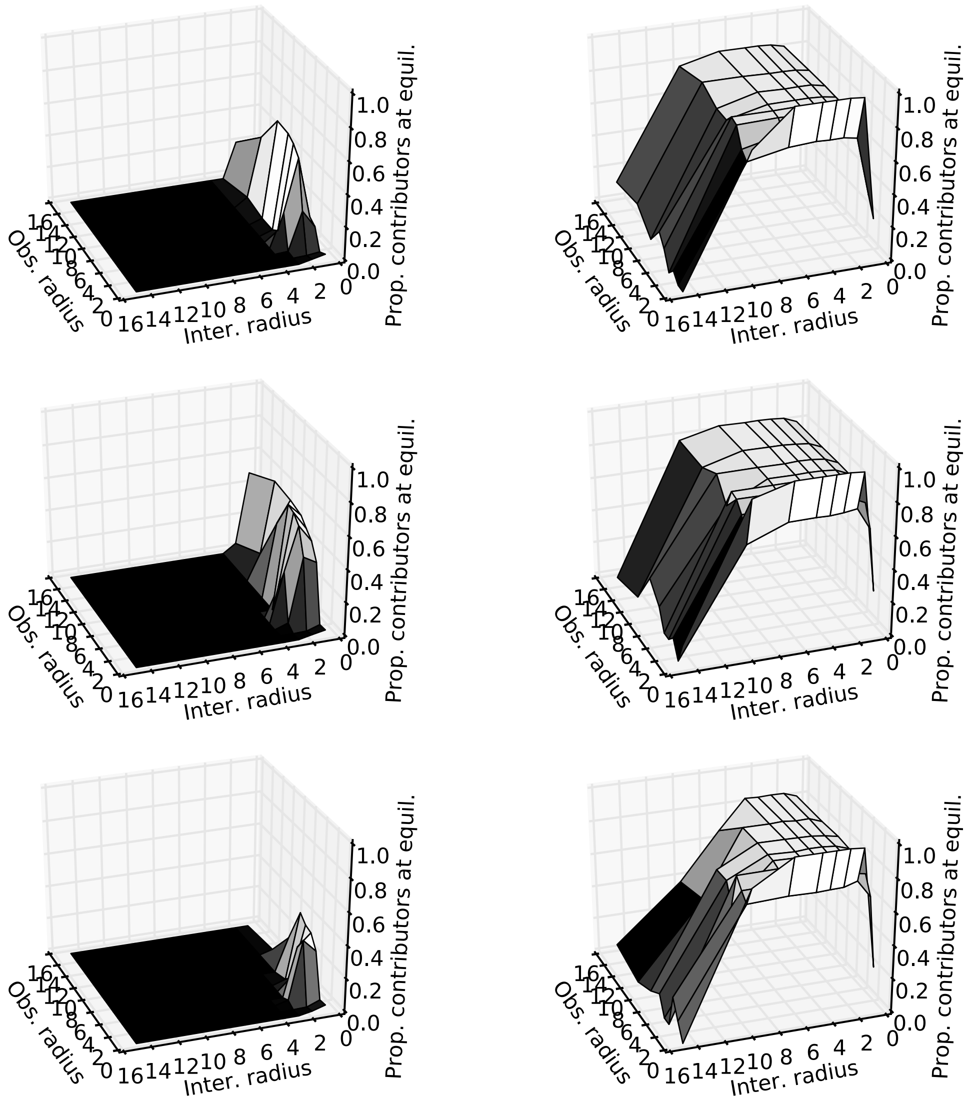
Simulation data: Conditions for emergence

Rival | Non-rival

No mobility

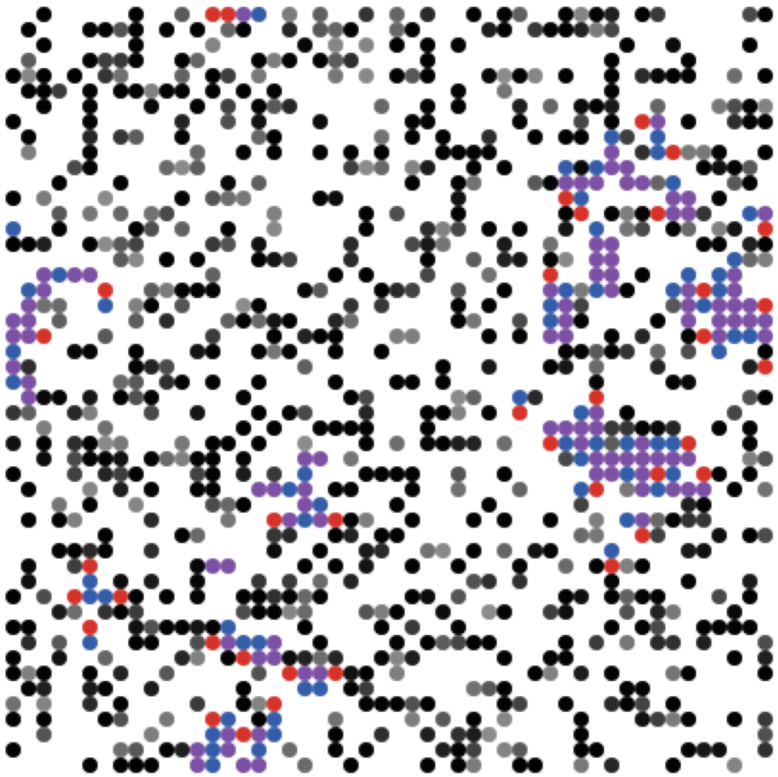
Low mobility

High mobility

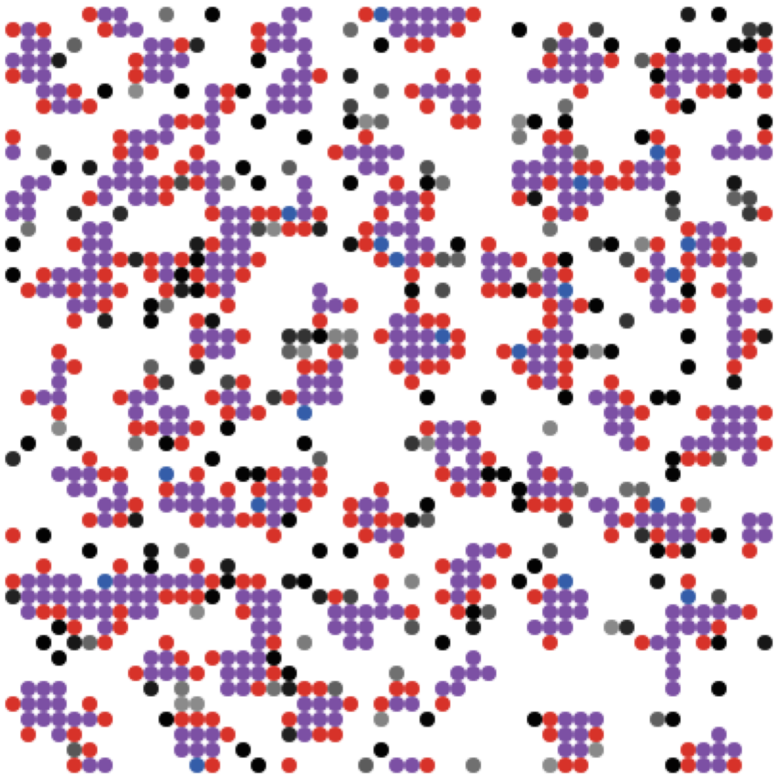


Simulation data: Two pathways for emergence

Rival

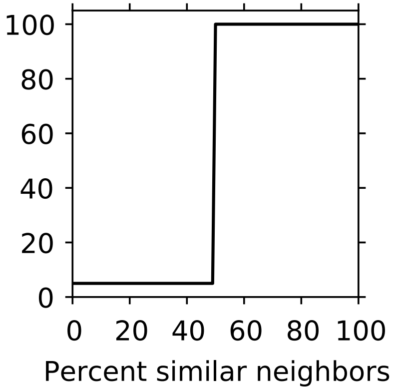


Non-rival

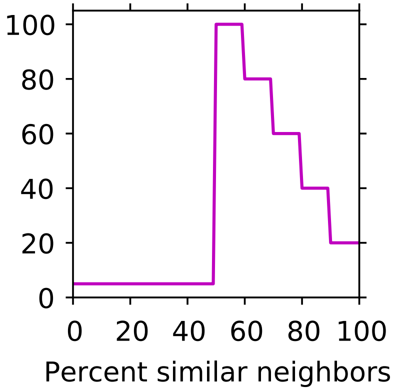


Agents in blue contribute but do not benefit, agents in red benefit but do not contribute, and agents in purple both contribute and benefit.

Validation: Diversity and segregation



- Even if people are tolerant, they will end up in a segregated world[1]



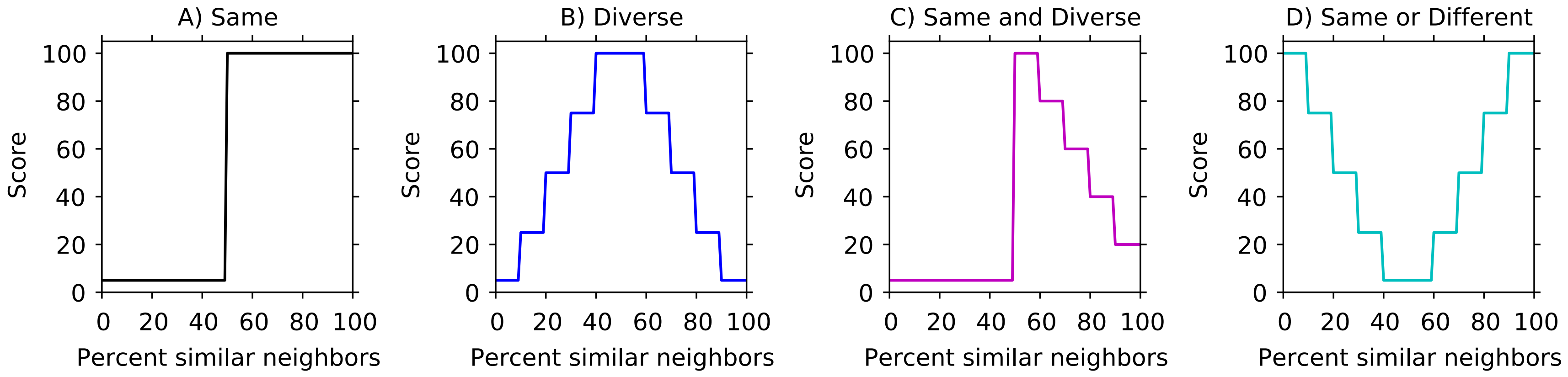
- Segregation may obtain even when people actively seek diversity. "Hence, public policies that promote tolerance are futile"[2]

1. Schelling, T. C. (1971). Dynamic models of segregation. *Journal of Mathematical Sociology*, 1(2), 143–186.

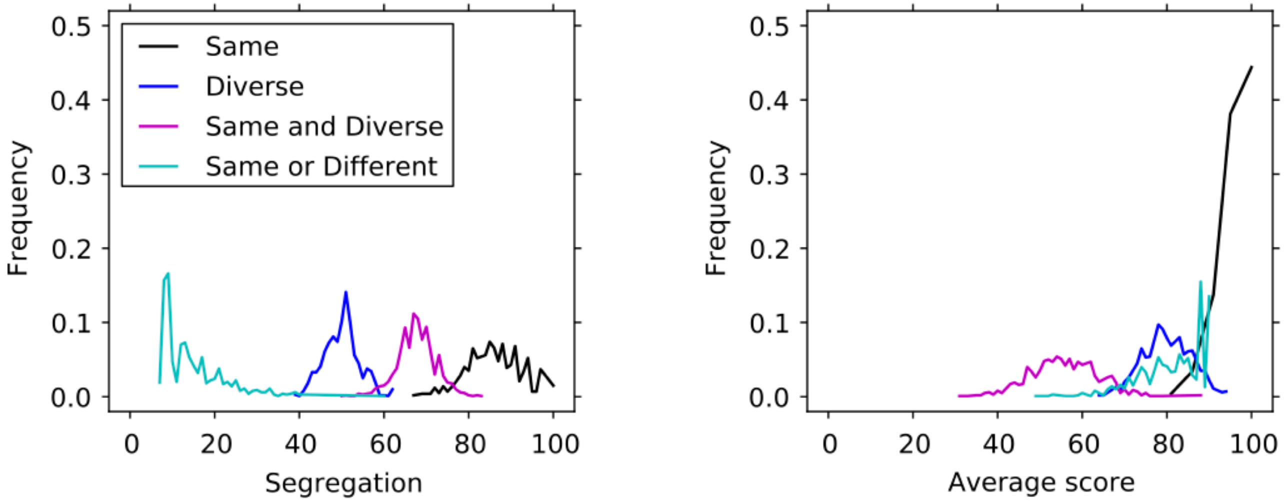
2. Pancs, R., & Vriend, N. J. (2007). Schelling's spatial proximity model of segregation revisited. *Journal of Public Economics*, 91(1-2), 1–24.

Empirical data: Experiment to test ABM predictions

- Four games

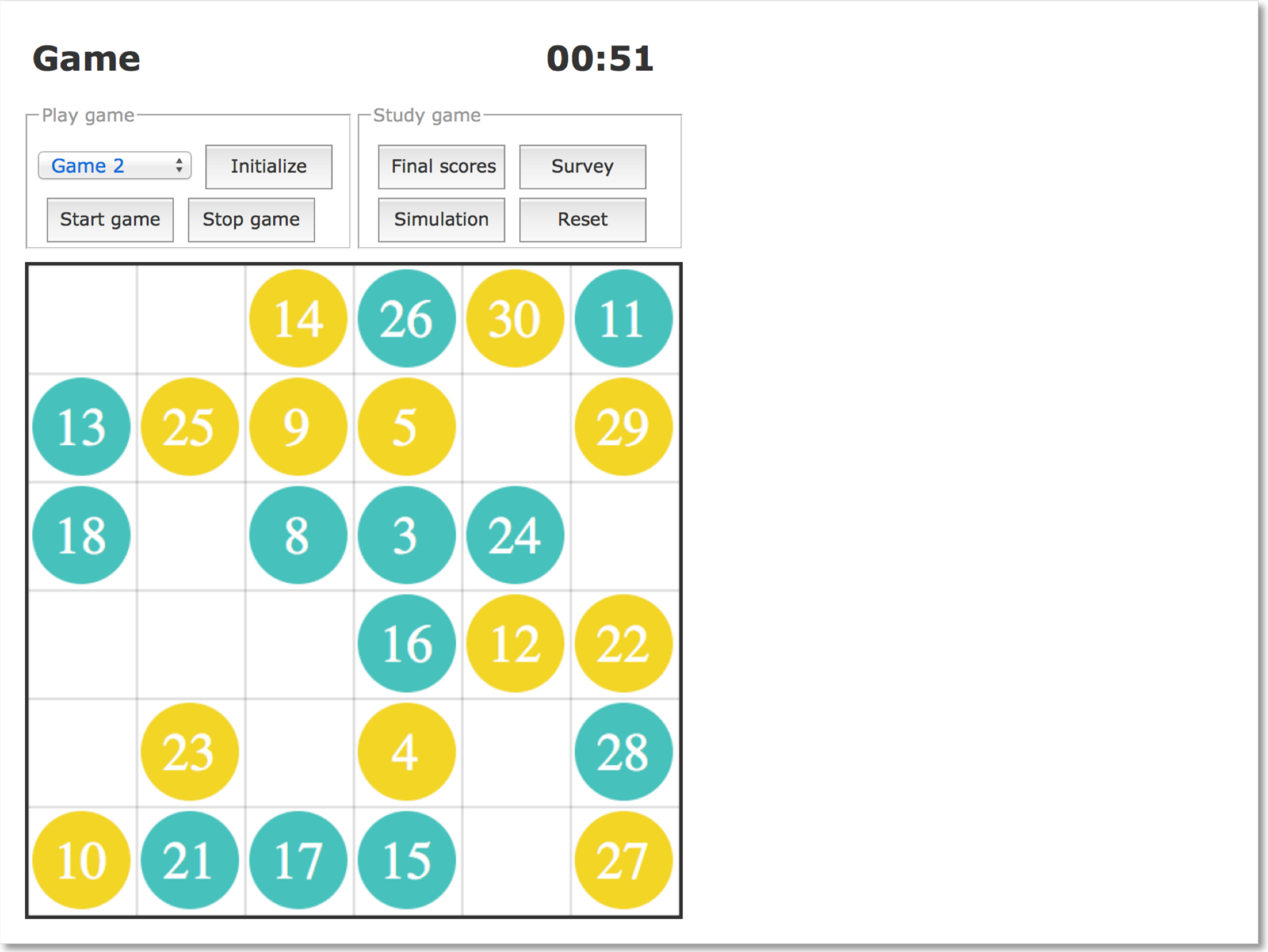


- Model predictions



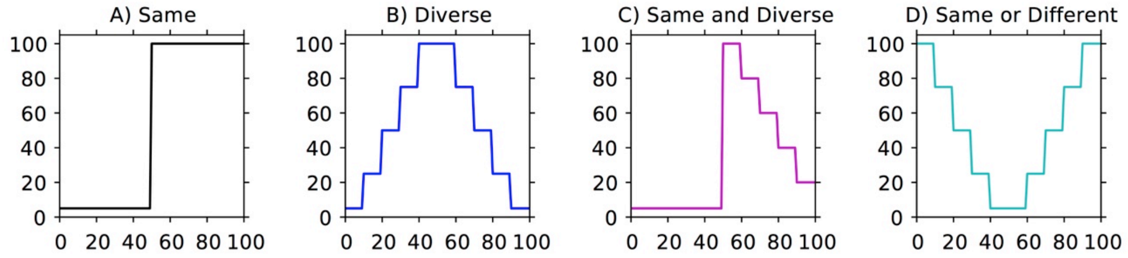
Tsvetkova, M., Nilsson, O., Öhman, C., Sumpter, L., & Sumpter, D. (2016). An experimental study of segregation mechanisms. *EPJ Data Science*, 5(1), 4.

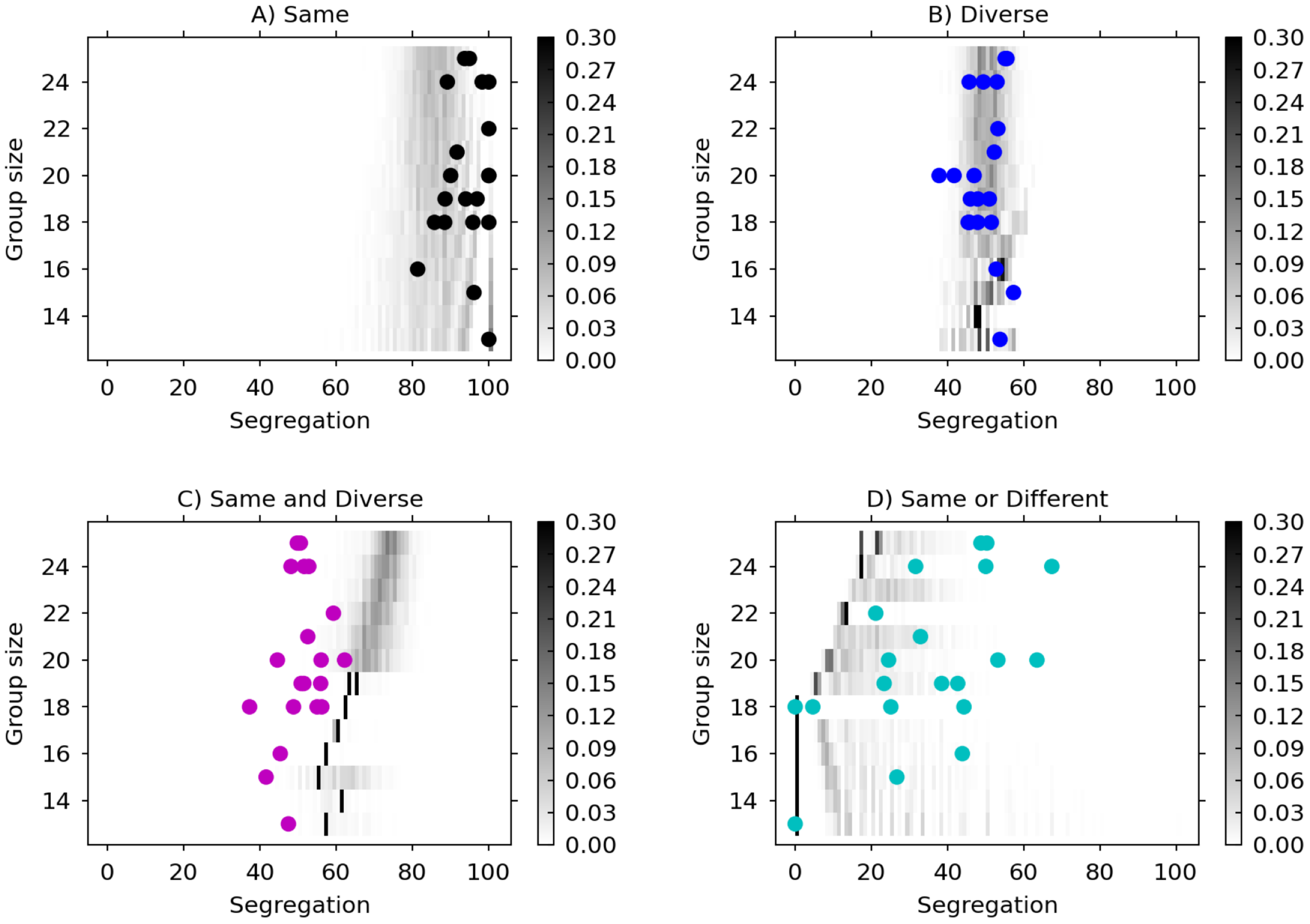
Empirical data: Experiment



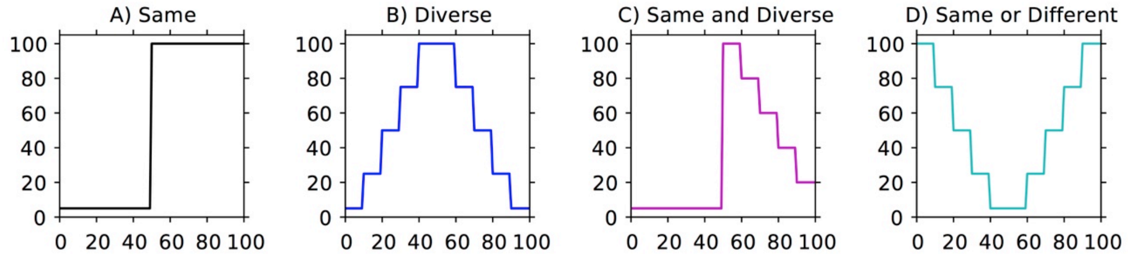

Game
02:00
Play game
Game 1
Initialize
Start game
Stop game
Study game
Final scores
Survey
Simulation
Reset
17 4 24 9 10
23 16 18 29 15 28
30 3 14
27 12 8 22
11 21 5 26
25

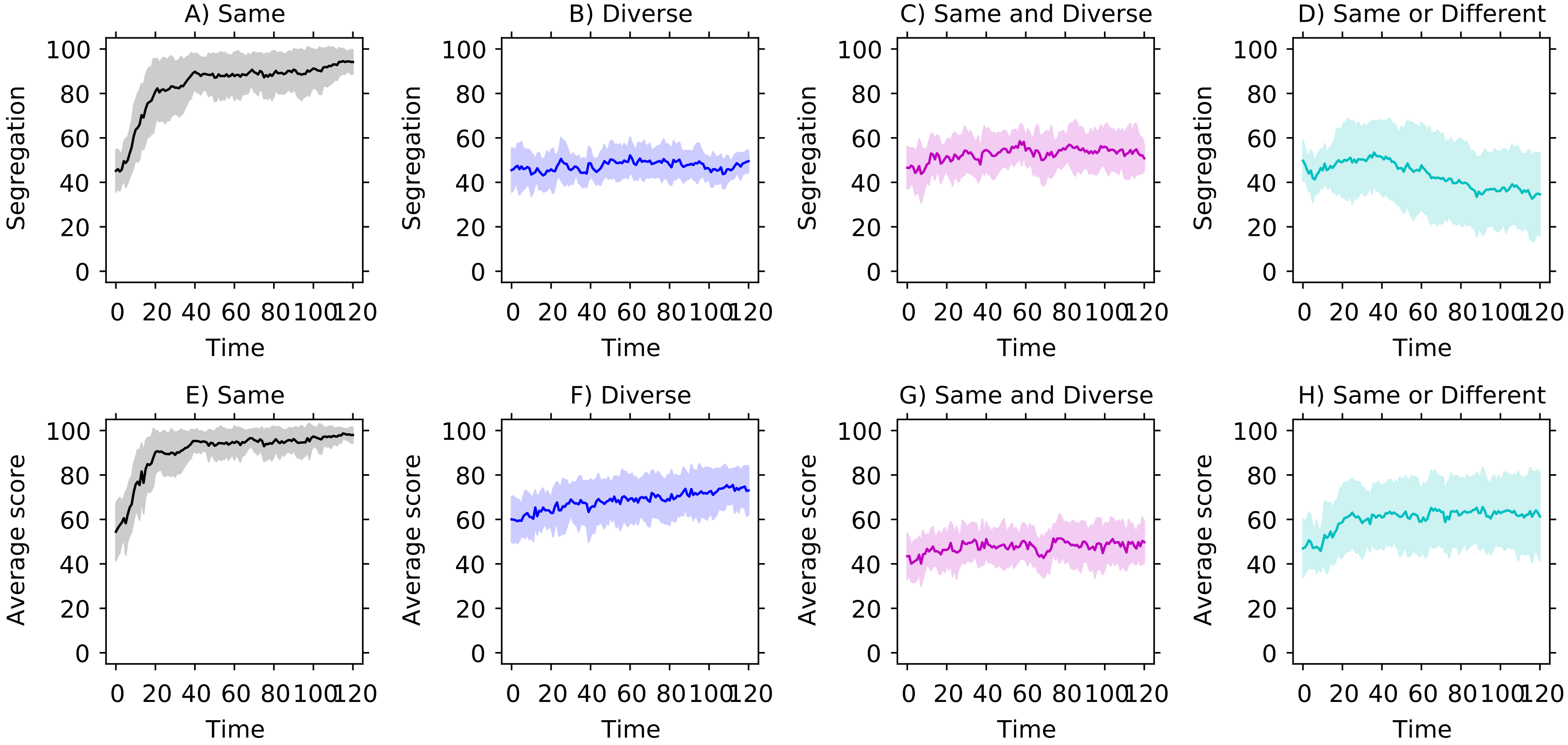
ABM: Validation



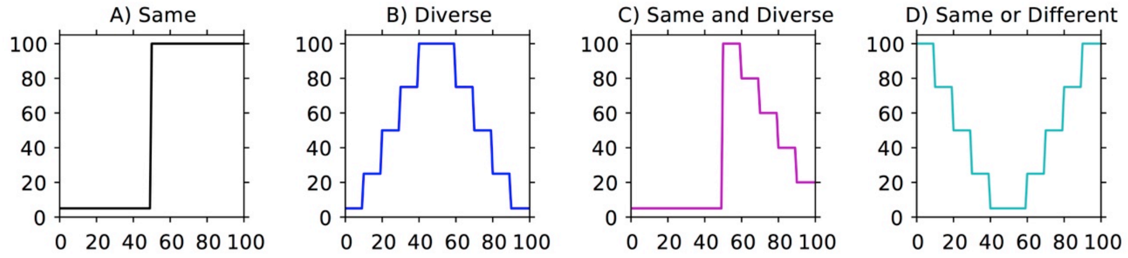


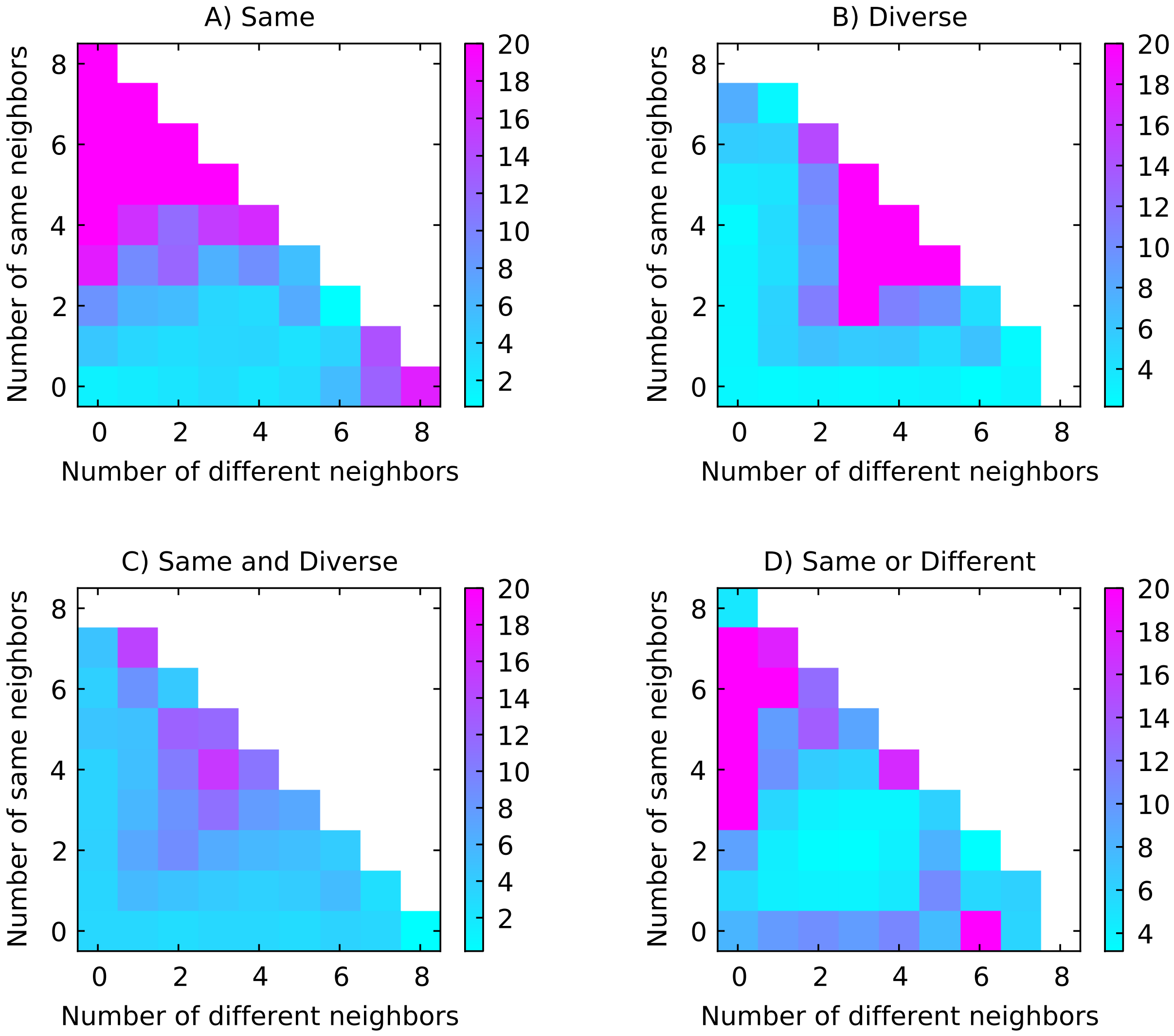
Experiment: Validity



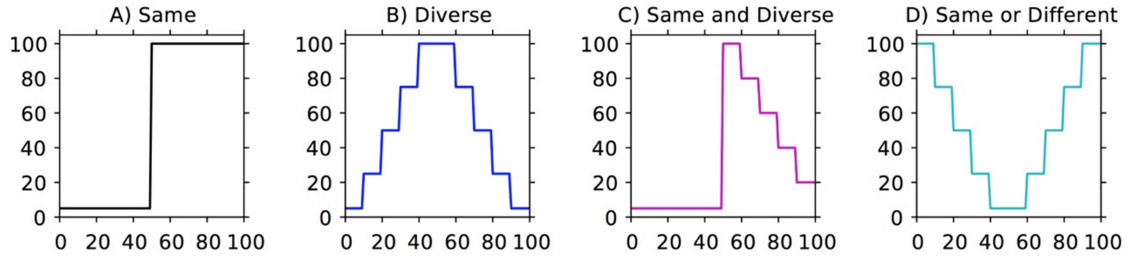


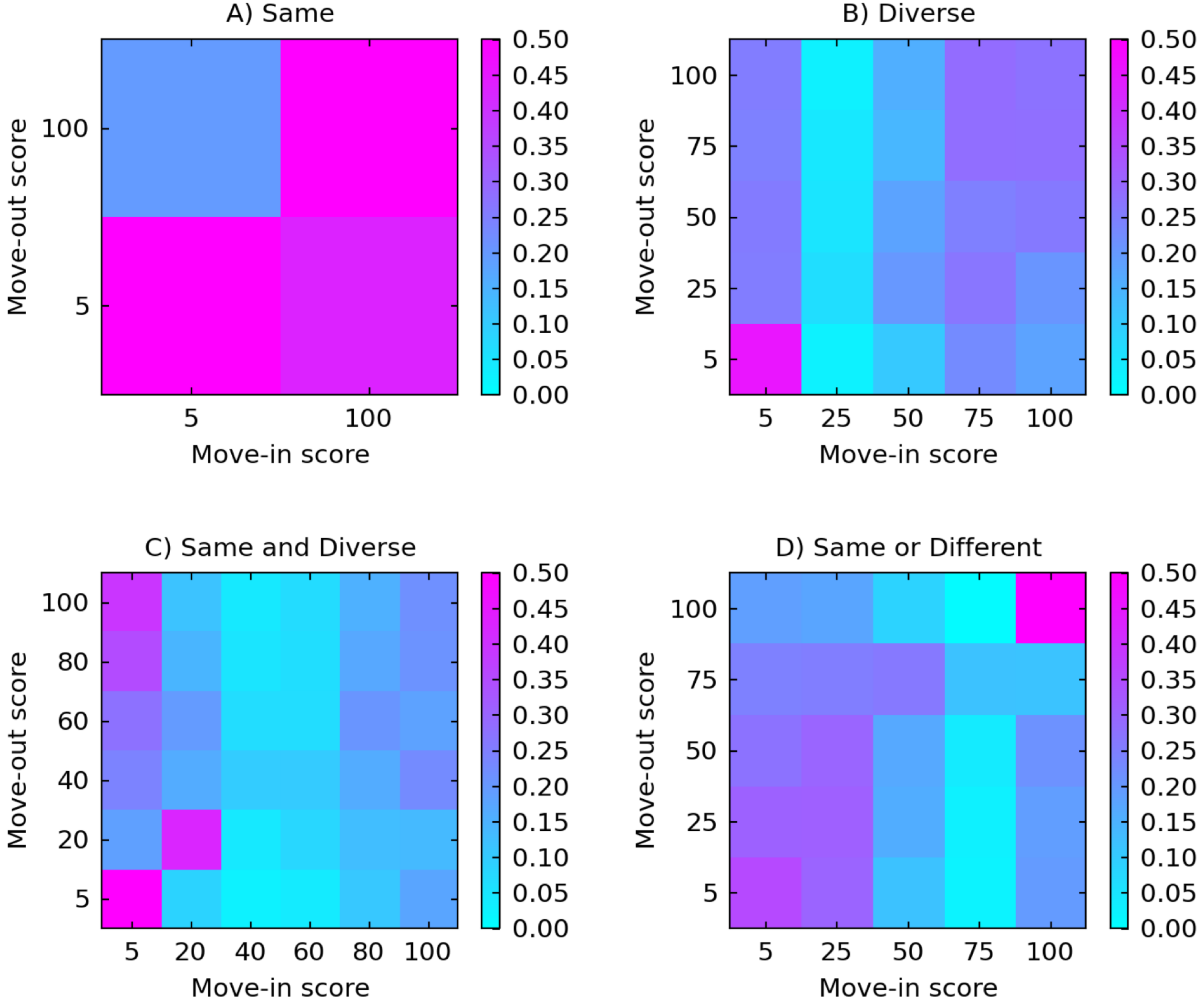
Experiment: Validity



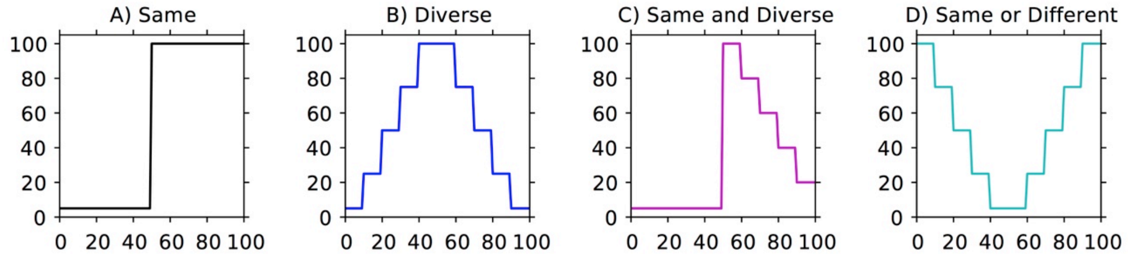


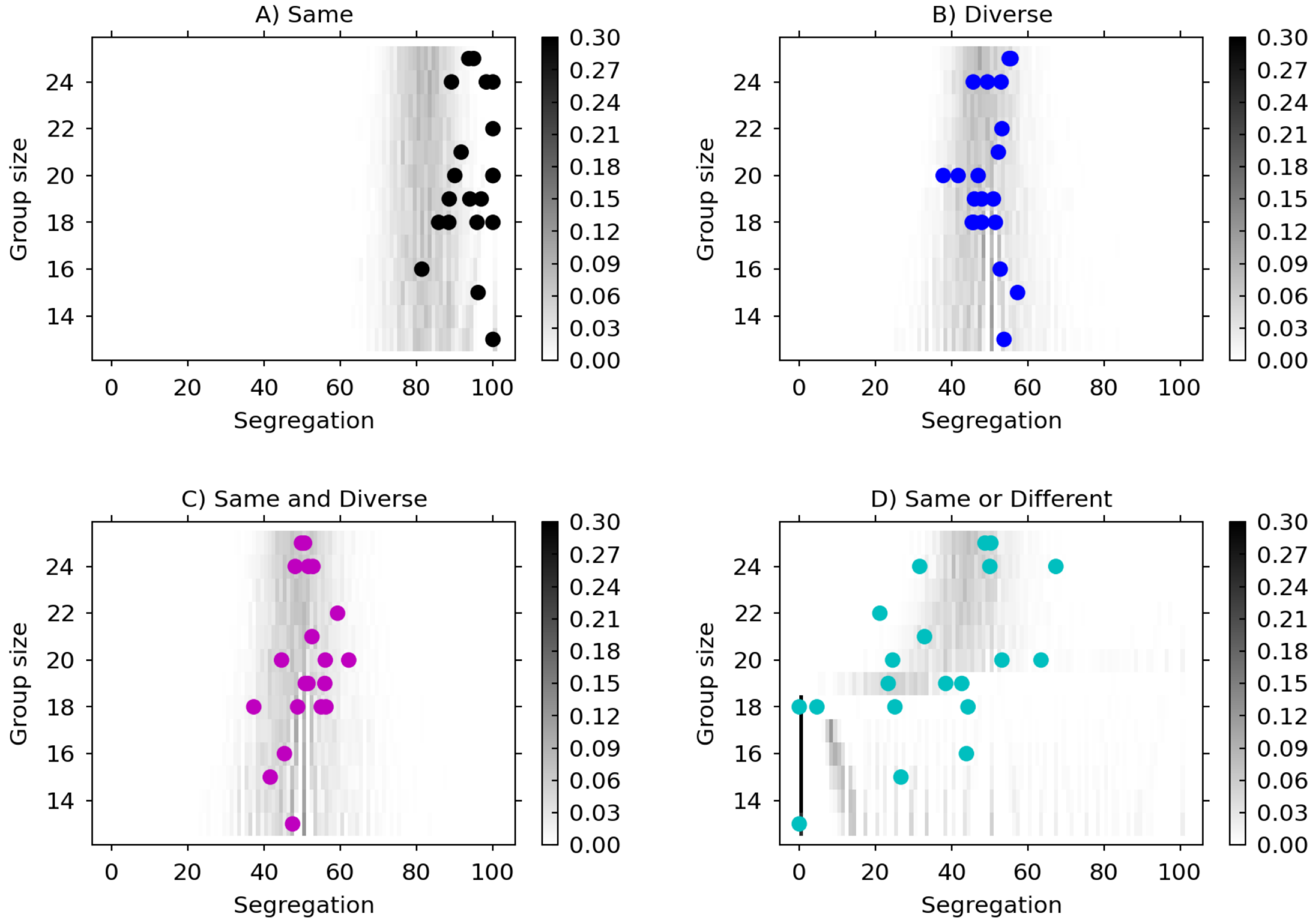
Experiment: Validity





ABM: Modification





NetLogo

- Designed by Uri Wilensky at Northwestern University
- “Low threshold and no ceiling”
- Free and open source

Interface panel

Panel selection

Right-click to edit or create new

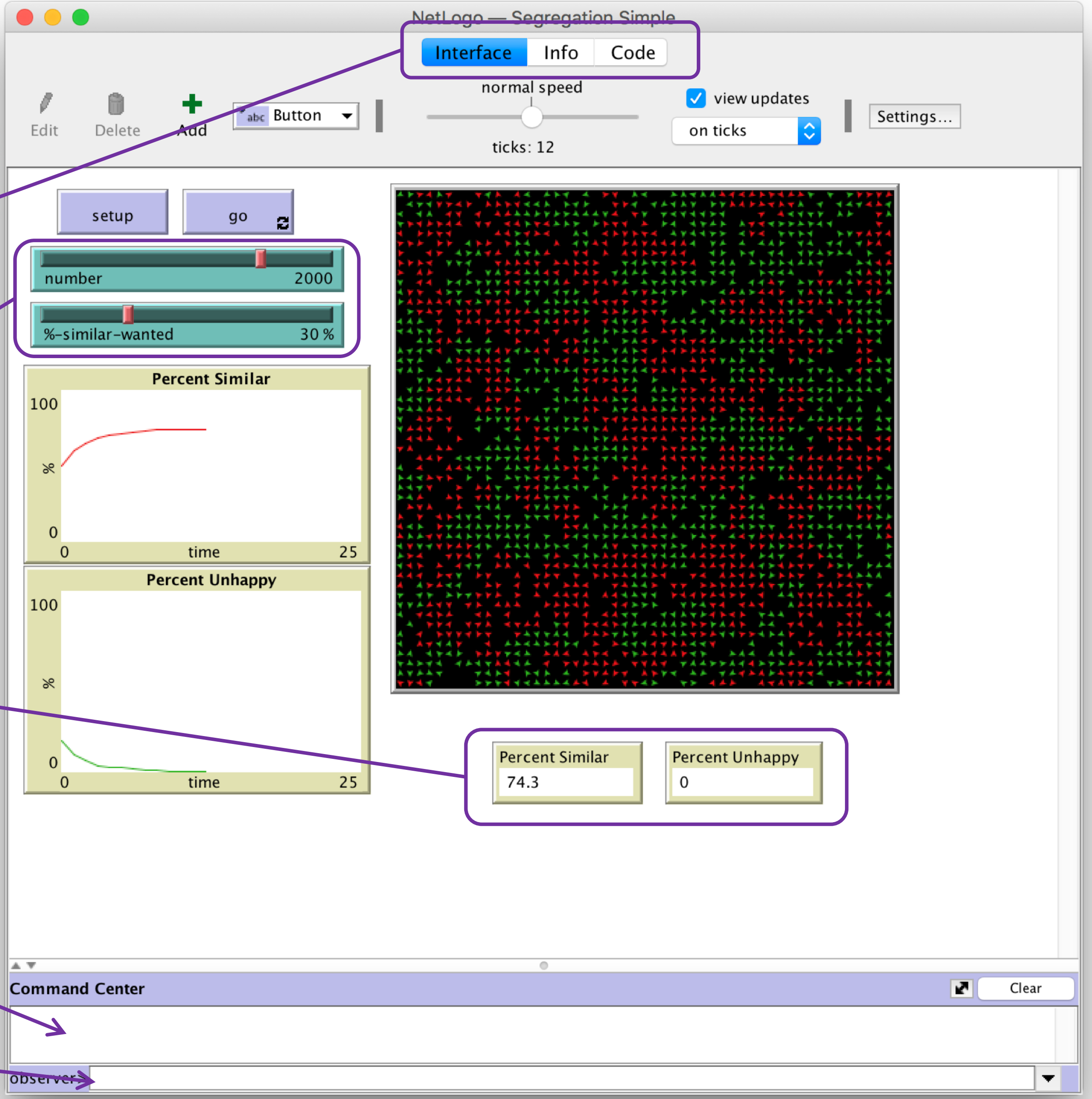
Parameter controls

Output viewers
(plots and monitors)

Use `print` or `show`

Text output

Typed direct commands

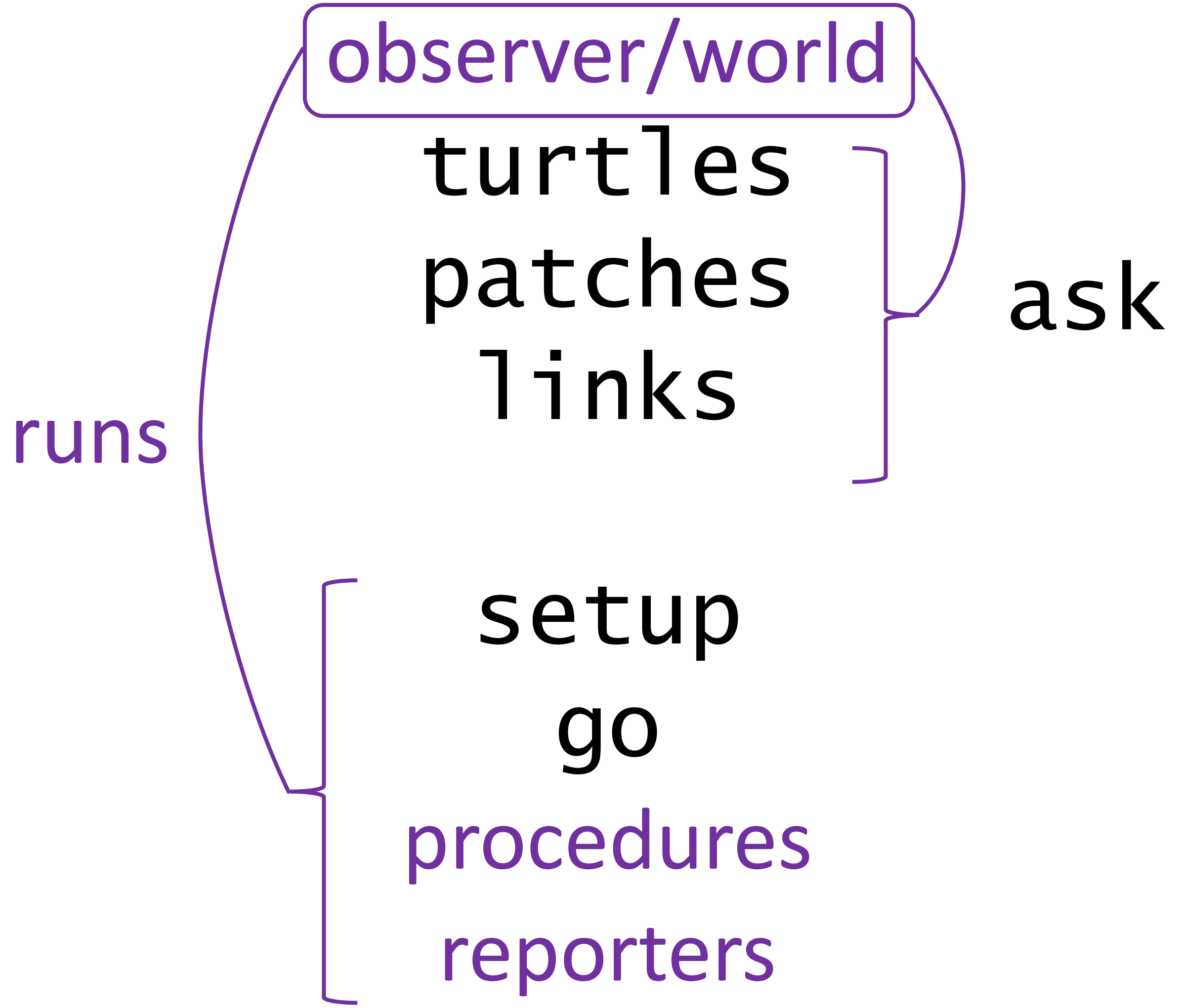


Primitives

Agents

- Have properties
- Can be given commands
- Can interact with the rest

Procedures



Program structure

```
globals []
turtles-own []
patches-own[]
links-own[]
```

Agent properties

```
to setup
  ;; code
end

to go
 ;; code
end

to custom-procedure
  ;; code
end

to-report custom-reporter
  ;; code
end
```

Procedures

Control flow commands

let *var-name value*

set *var-name new-value*

if *test* [*commands when true*]

ifelse *test*

  [*commands when true*]

  [*commands when false*]

while [*reporter*] [*commands*]

repeat *n* [*commands*]

and

or

not

report

How to program

1. Identify closely related program (see Models Library)
2. Change relevant code
3. Try it out
4. Find errors
5. Read the documentation or google the problem
6. Correct errors
7. Repeat 2–6

Running experiments and recording data

1. Tools -> BehaviorSpace -> New
    1. Name your experiment
    2. Define parameter space to explore
    3. Define number of repetitions for each configuration
    4. Define information to record
    5. Determine if need to record in each step
    6. Determine maximum number of steps
2. Run
    1. Save as “Table output”
3. Adjust speed, views, and plots to speed up simulation

Additional ABM resources

- (documentation) https://ccl.northwestern.edu/netlogo/docs/dictionary.html
- (article) Helbing, D. (2012). Agent-based modeling. In *Social Self-Organization* (pp. 25-70). Springer, Berlin, Heidelberg.
- (online course) Model Thinking on Coursera
- (journal) *The Journal of Artificial Societies and Social Simulation*
- (conference) ESSA Social Simulation Conference
- (summer school) Complex Systems Summer School and Graduate Workshop in Computational Social Science at the Santa Fe Institute
- (popular science book) Waldrop, M. M. (1993). *Complexity: The Emerging Science at the Edge of Order and Chaos*. Simon and Schuster.