What are agent-based models?

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Abstract

Developments in multi-agent based simulation have offered a new way of doing social science: by conducting virtual experiments on artificial societies.

I shall outline some types of social simulation, comment on the implications for research methodology, and provide a few examples of recent computational social science.

What is computational social science?

- Models
  - Programs as models
- Mechanisms
  - Realist accounts of the way the social world works
- Experiments
  - Experimenting on the model, as a second best to experimenting on the social world

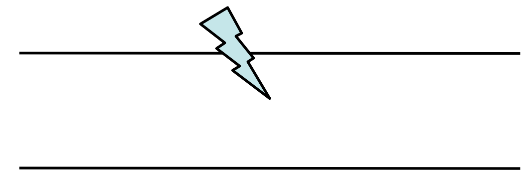
Models

- Mathematical models
  - Cobb-Douglas production function
  - $Y = AL^{\alpha}K^{\beta}$, Y = output, L = labour input, K = capital input
- Scale models
  - Reduced scale
  - Some features simplified
- Analogical models
  - Model is better understood than target
- Ideal-type models
  - Some features are exaggerated

Bill Phillips' MONIAC at the Reserve Bank museum, Wellington, New Zealand

Experiments

- Apply some treatment to an experimental group taken from the target and compare the effect with a control group



- Sometimes the target is too complicated, too inaccessible, or treatment is impossible for ethical reasons
  - Will a tower block fall down in high winds?
  - Who will gain and who will lose from a new tax?
- So experiment on the model
- If the model is a good one, it will react in the same way as the target would have done
- The experiment can be repeated many times if the effect varies randomly

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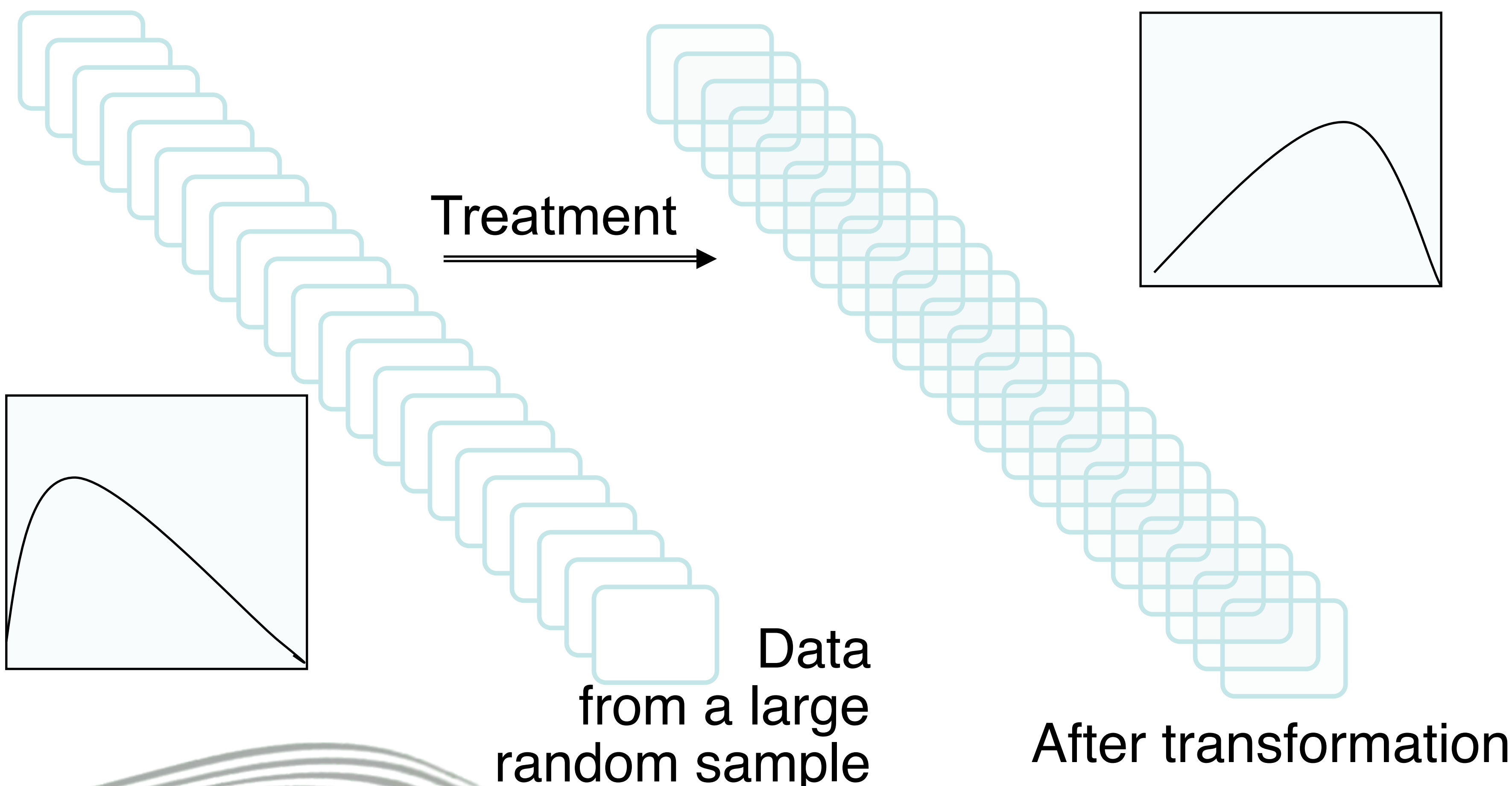
Types of simulation

- Microsimulation
- System dynamics
- Discrete event simulation
- Cellular automata
- Agent-based modelling

✦ but some simulation models use ideas and techniques from two or more of these types

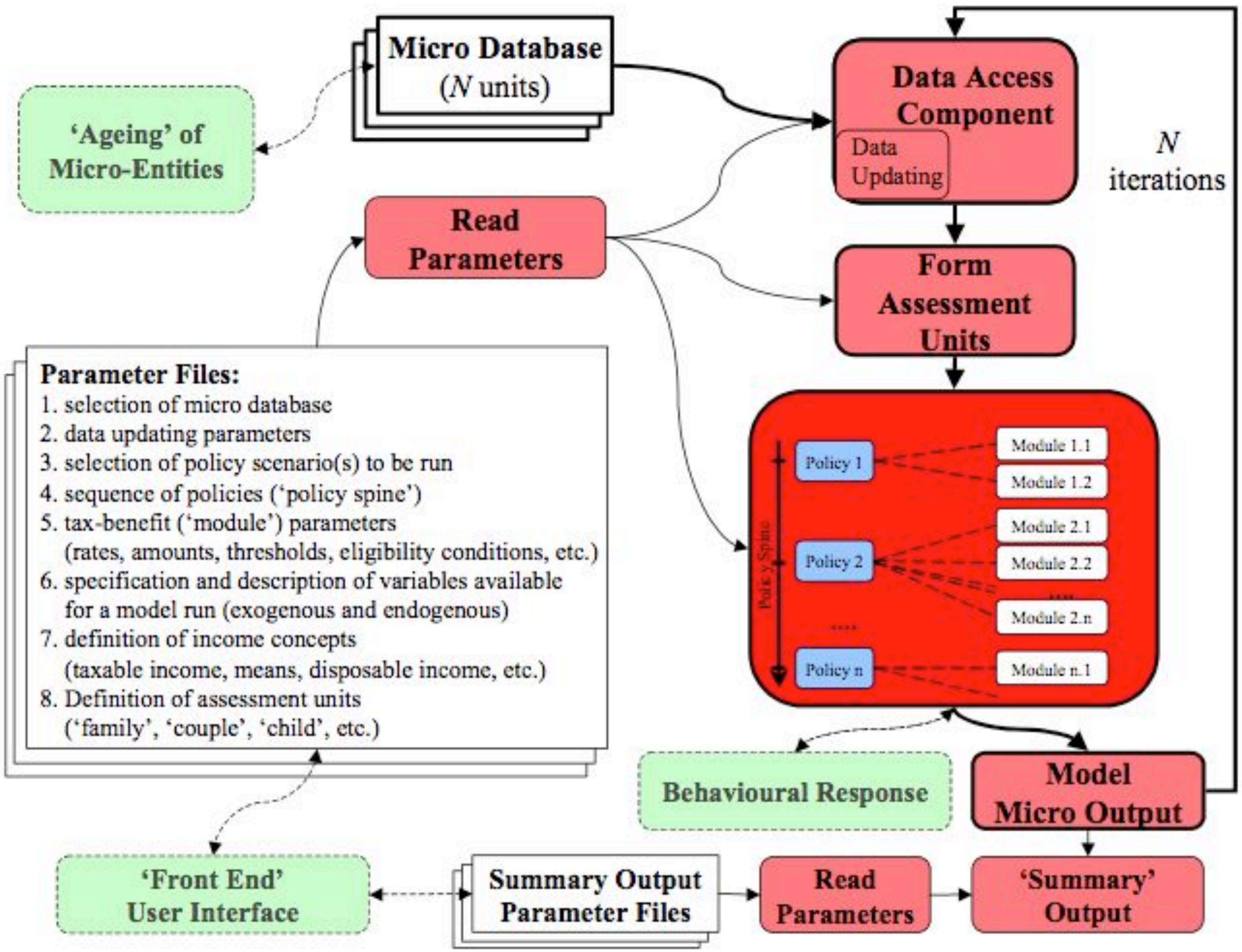
Microsimulation

- Start with a sample of individuals
  - Usually a national household survey
  - Could be a sample of firms or countries
- Apply some simulated treatment to all in the sample
- Measure the change in aggregate characteristics



Example

- Assessing the effects of tax and benefit changes



from http://www.iser.essex.ac.uk/msu/emod/workingpapers/em201_cov.pdf

System dynamics

- Start with a set of equations that express how some variable changes, depending on changes in other variables
- Use these equations to simulate how the dependent variables will change over time
- Feedback effects possible

$Pollution_{t+1} = Pollution_t + (PollutionGeneration_t - PollutionAbsorption_t) * \Delta t$

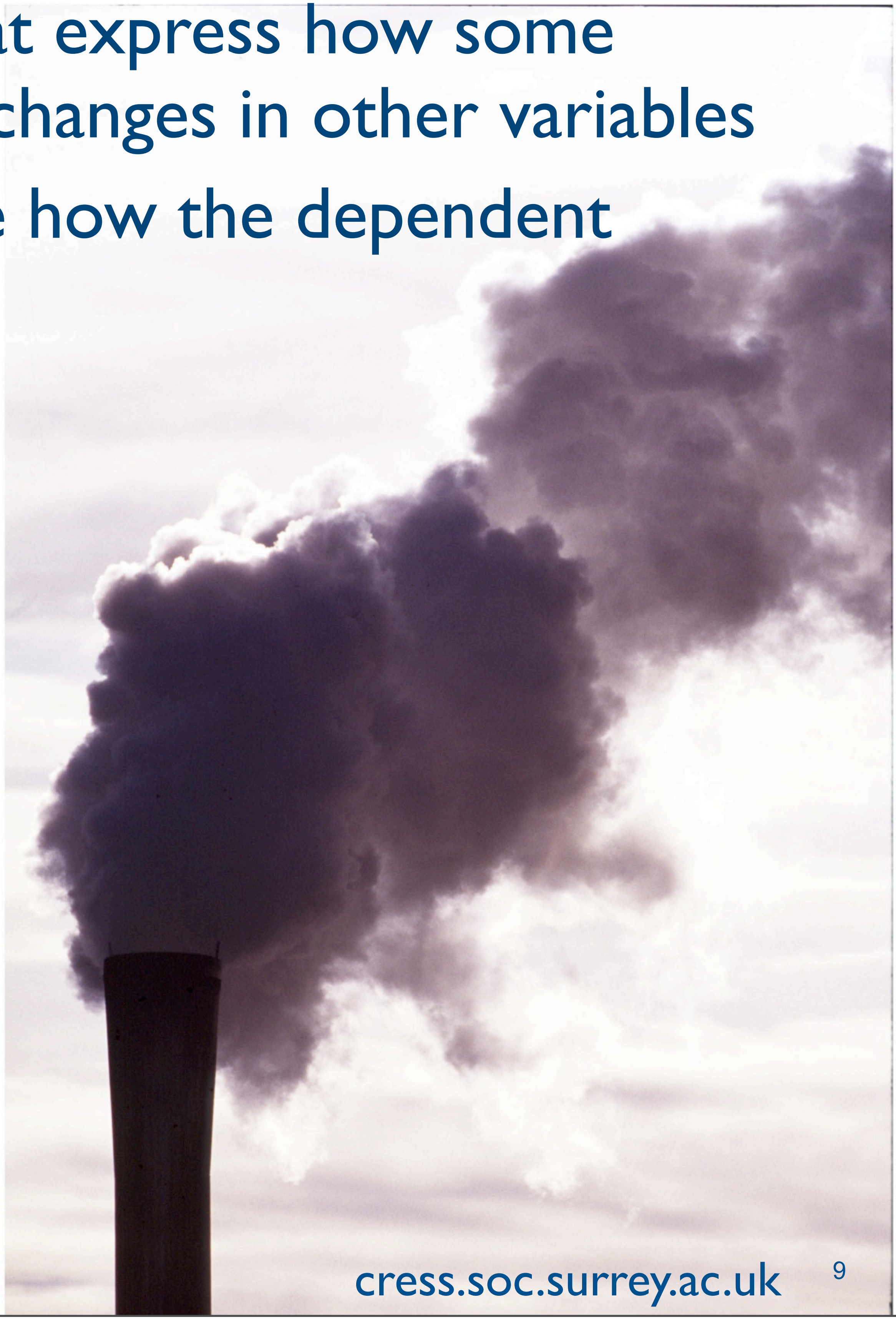
$PollutionGeneration_t = Population_t * PollutionNormal * PollutionFromCapitalMultiplier$

$PollutionAbsorbtion_t = Pollution_t / PollutionAbsorptionTime$

$PollutionAbsorptionTime_t = f(PollutionRatio_t)$

$PollutionRatio_t = Pollution_t / PollutionStandard$

$PollutionStandard = 3.6x10^9$



Example

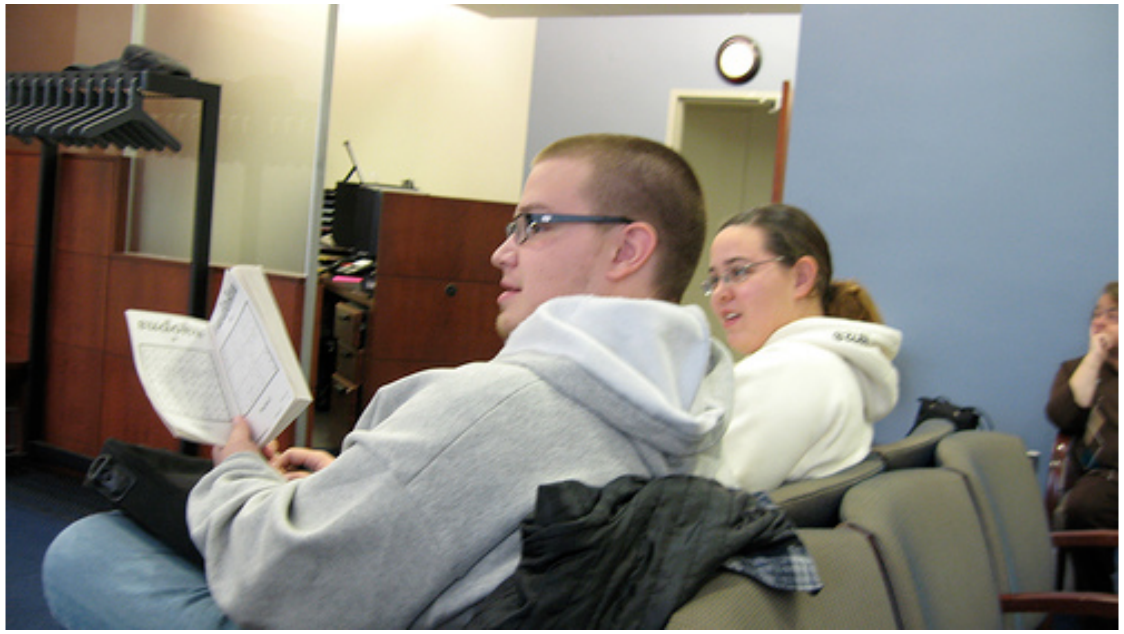
- Social and economic effects of climate change
  - Equations relating
    - change in agricultural yield to change in average temperature
    - change in gross national product to change in agricultural yield
    - (change in rate of climate change to change in GDP)
    - Etc.

Discrete event simulation

- A list of events are put on an agenda or queue
- Events are simulated one at a time, taking them from the front of the queue
- Some events may generate new events put on the back of the queue
- Event timing may be random

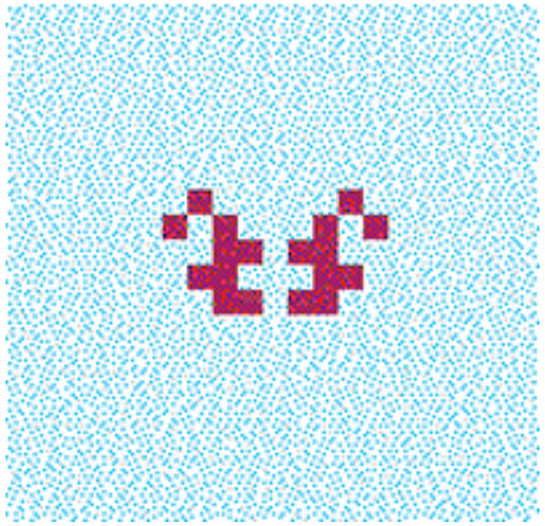
Example

- Hospital waiting lists
  - Events are
    - Patients arriving, seeking treatment
    - Doctors providing treatment
  - There may be many queues (waiting lists)
  - Time between events is random
  - Simulation shows how long the waiting lists will be
    - And perhaps what could be done to shorten them



Cellular automata

- Identical cells arranged in a square
- Each cell can be in one of two (or a few) different states
  - Think of them as changing colour when they change state
- Simulation advances through time steps
- The state of a cell at a time step is determined by its own previous state and the states of its immediate neighbours



Example: Market

- Many agents trading with each other
- Each trying to maximise its own welfare
- Neo-classical economics assumes that markets are at equilibrium, where the price is such that supply equals demand
- But with a cellular automata, we can model markets in which the price varies between localities according to local supply and demand

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Example: Sugarscape

- Agents located on a grid of cells
- Trade with local neighbours
- Two commodities: sugar and spice. All agents consume both these, but at different rates
- Each agent has its own welfare function, relating its relative preference for sugar or spice to the amount it has 'in stock' and the amount it needs
- Agents trade at a price negotiated between them when both would gain in welfare

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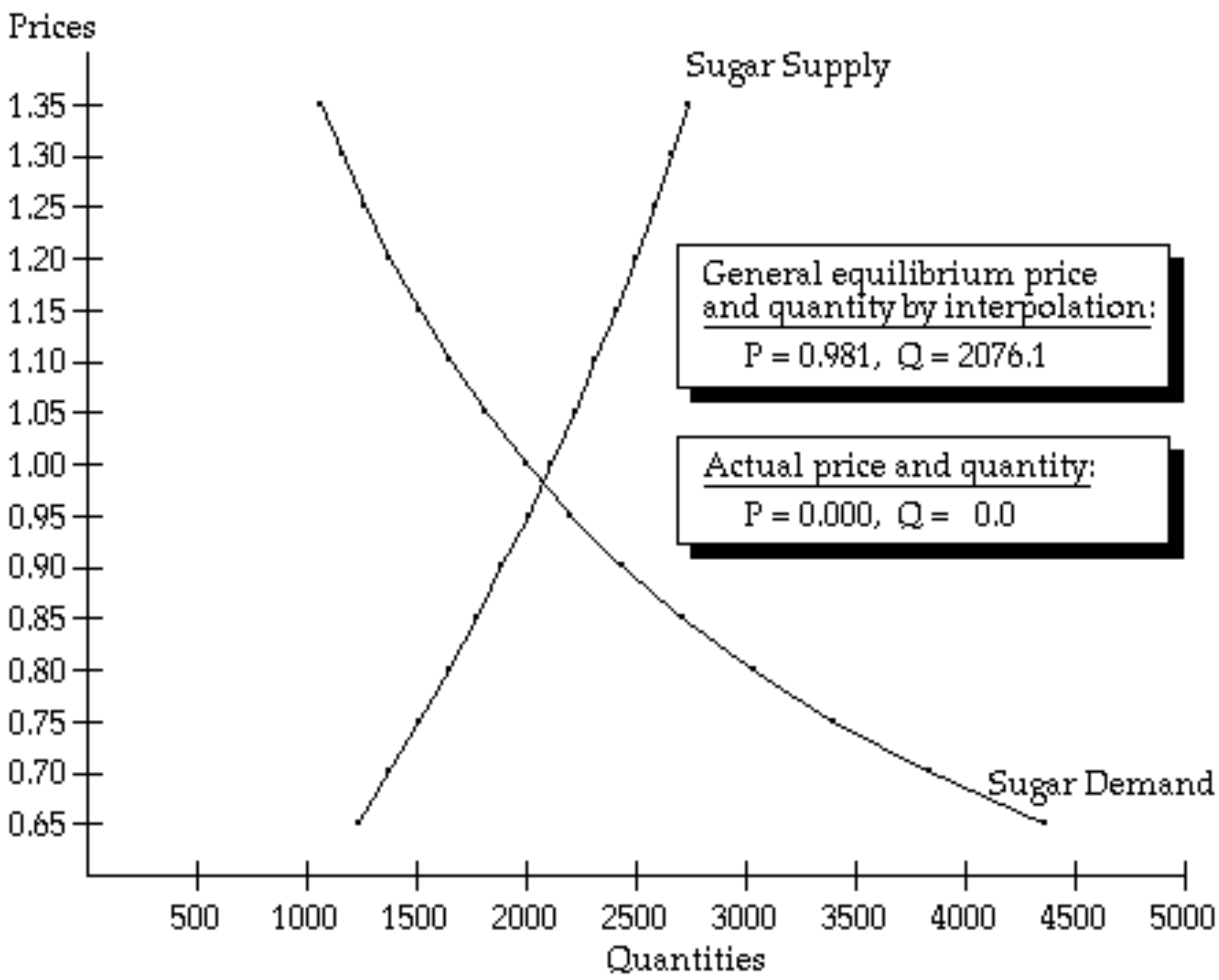
Example: Sugarscape

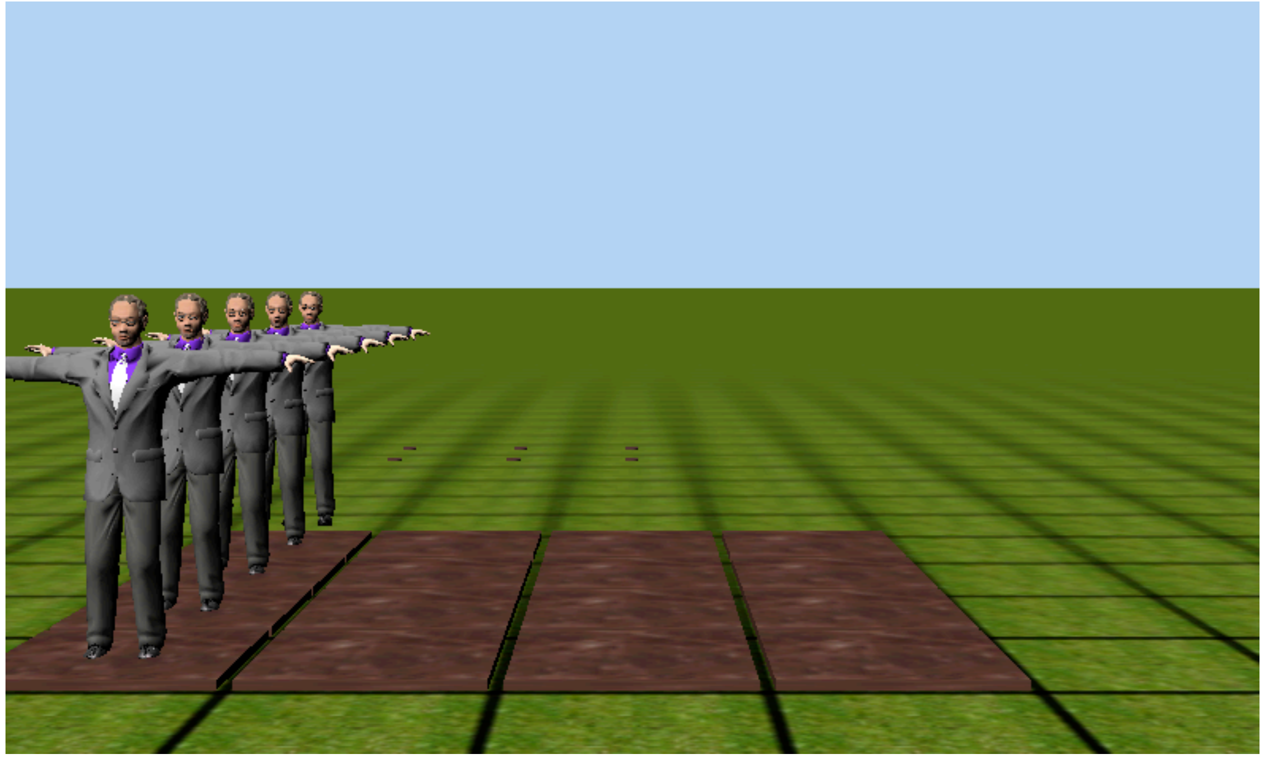


Results

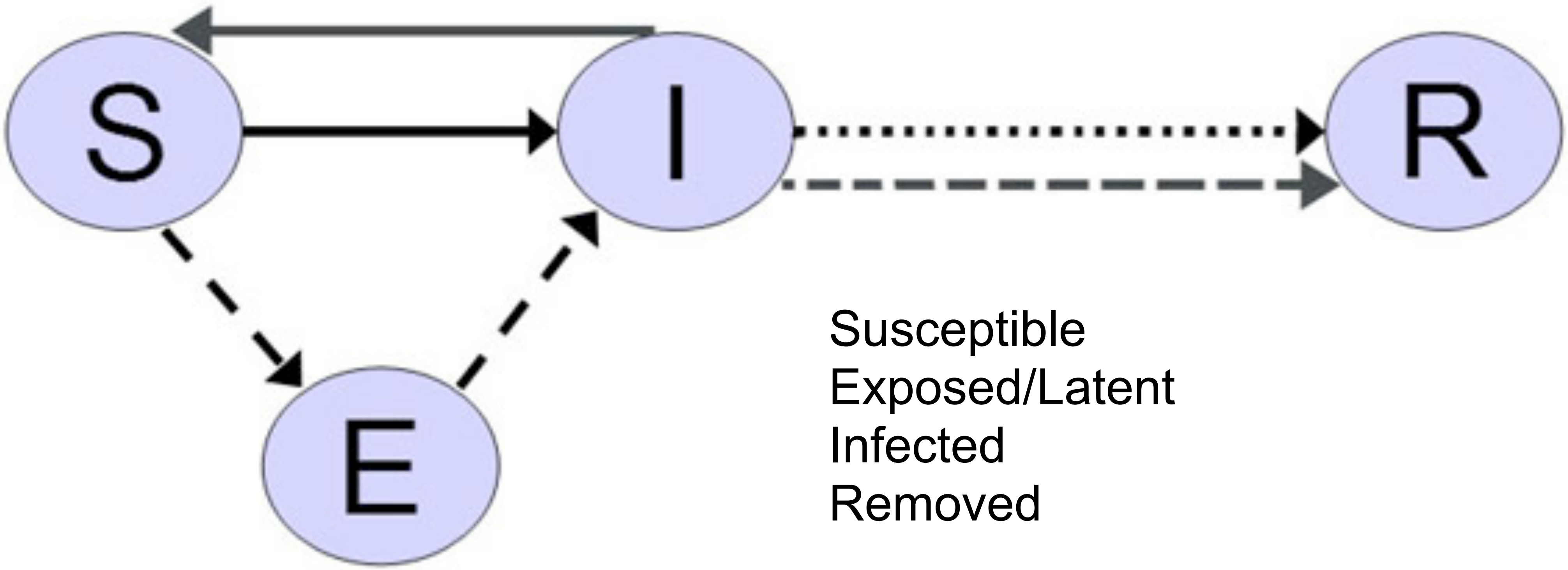
- The expected market clearing price emerges from the many bilateral trades (but with some remaining variations)
- The quantity of trade is less than that predicted by neoclassical theory
  - since agents are unable to trade with others than their neighbours
- And...
  - the effect of trade is to make the distribution of wealth (measured in sugar) more unequal

Agent-based models

- Agents are units that have behaviour
- They act within a (simulated) environment
- Agents can react to other agents, pursue goals, communicate with other agents, move around within the environment
- Macro-level features can emerge from the interaction of agents



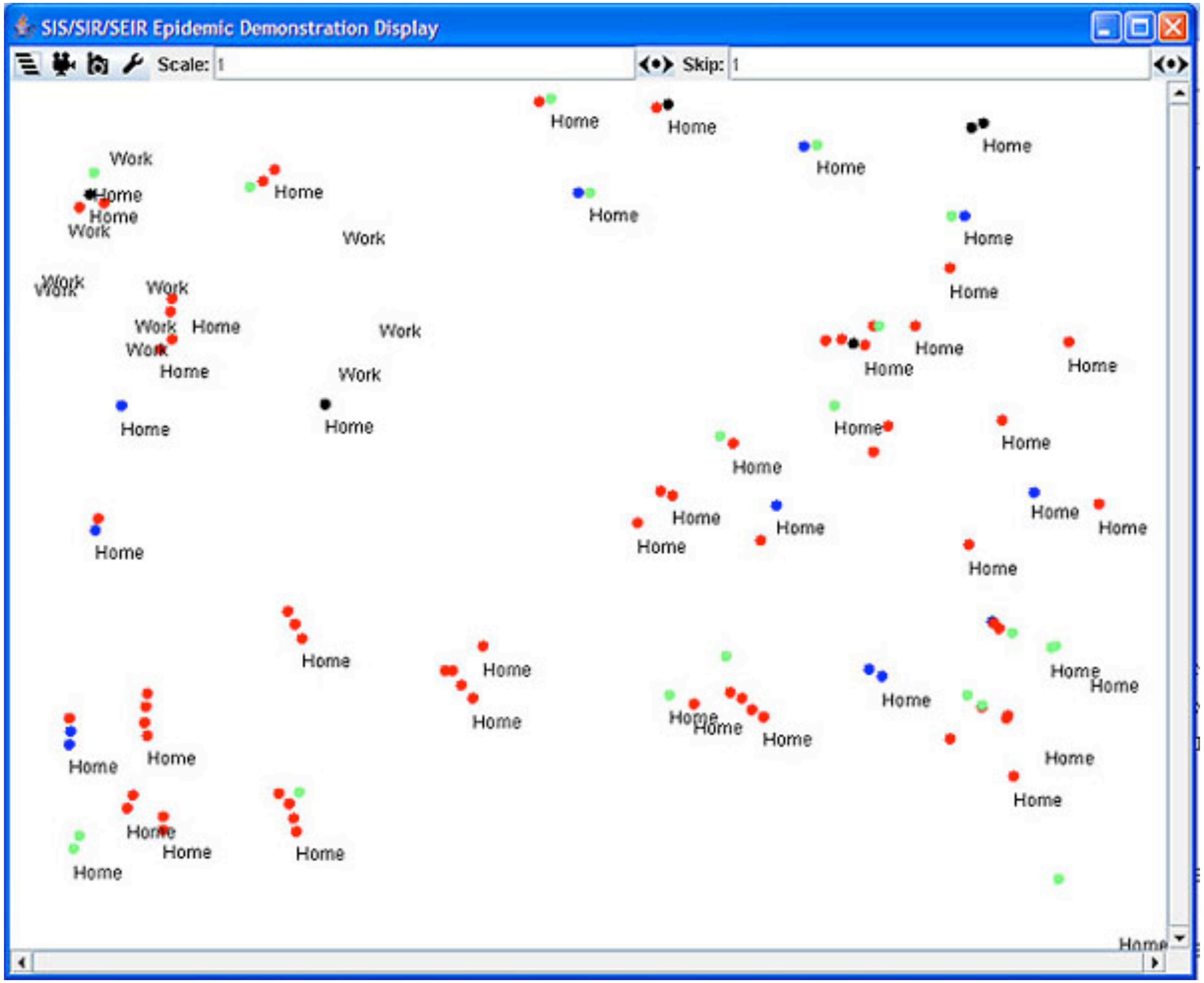
The spread of epidemics



Susceptible
Exposed/Latent
Infected
Removed

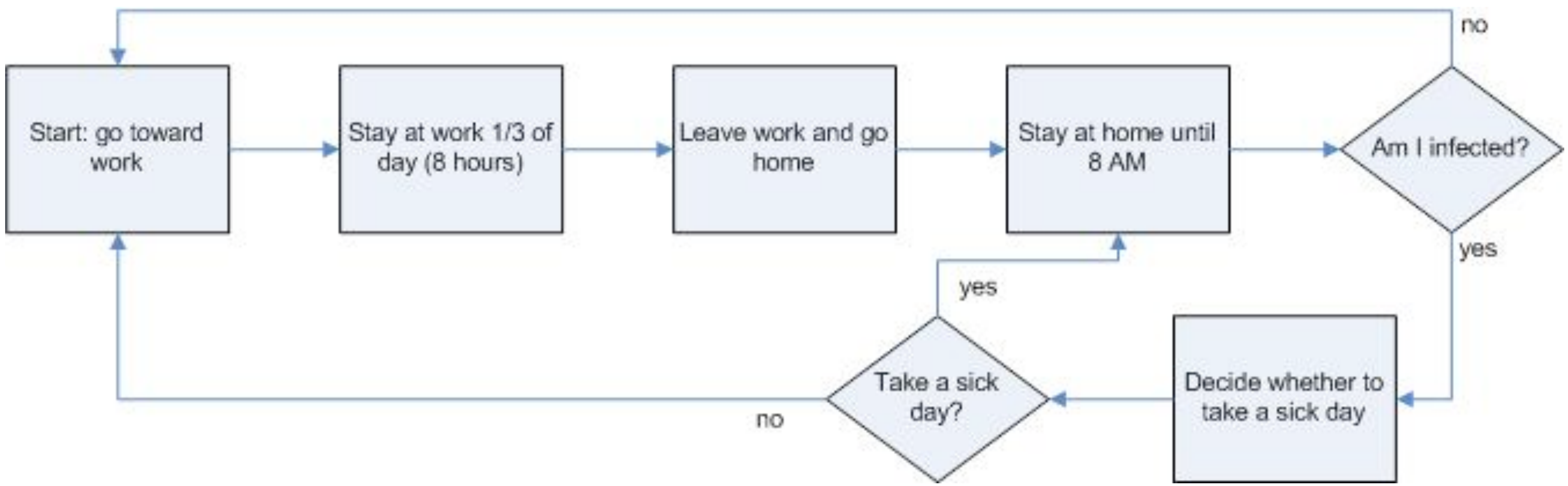
Dunham, Jill Bigley (2005). 'An Agent-Based Spatially Explicit Epidemiological Model in MASON'. *Journal of Artificial Societies and Social Simulation* 9(1) <http://jasss.soc.surrey.ac.uk/9/1/3.html>.

Map

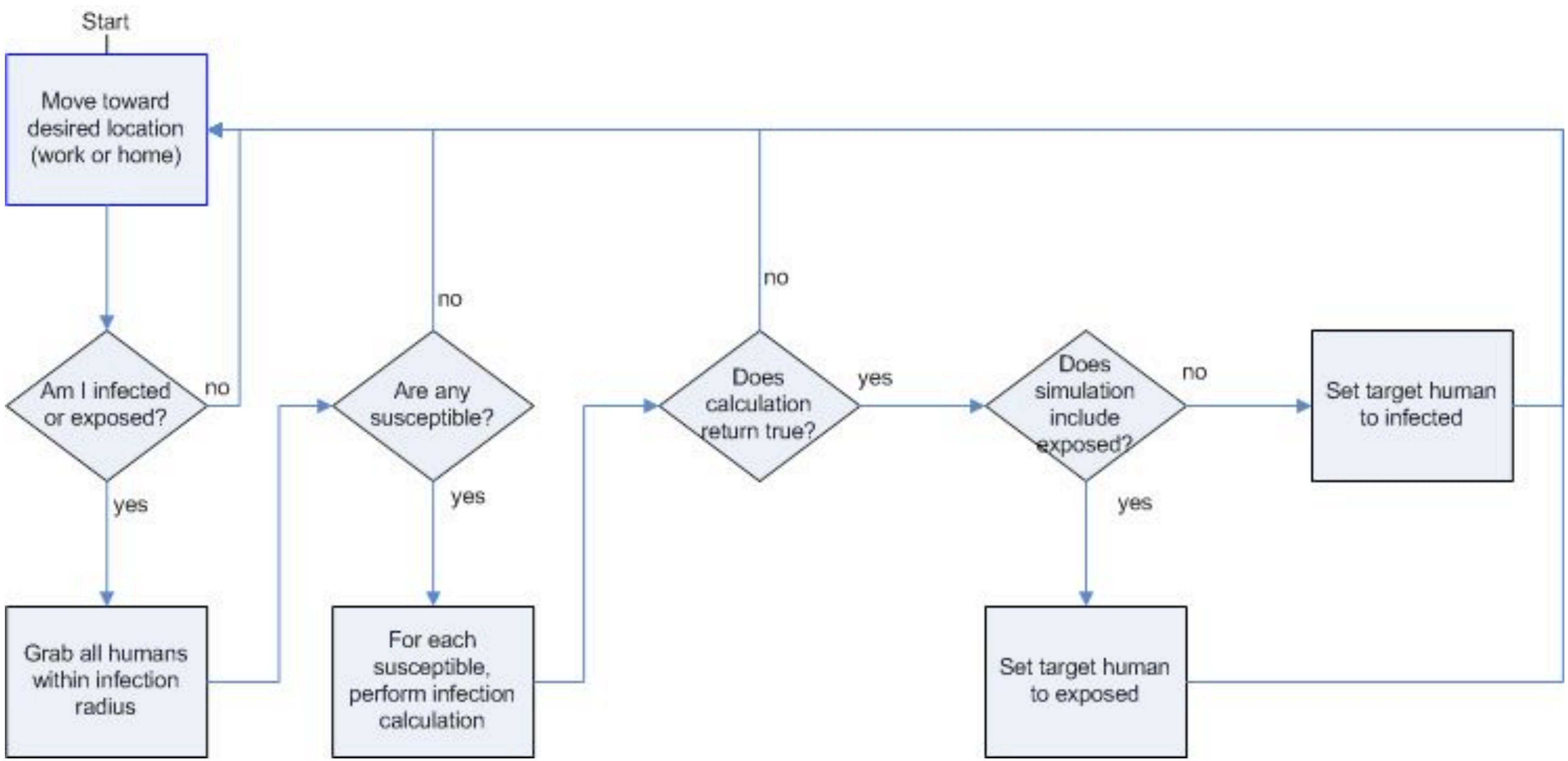


Susceptible agents are shown in green, Exposed in blue, Infected in red, and Removed in **black**

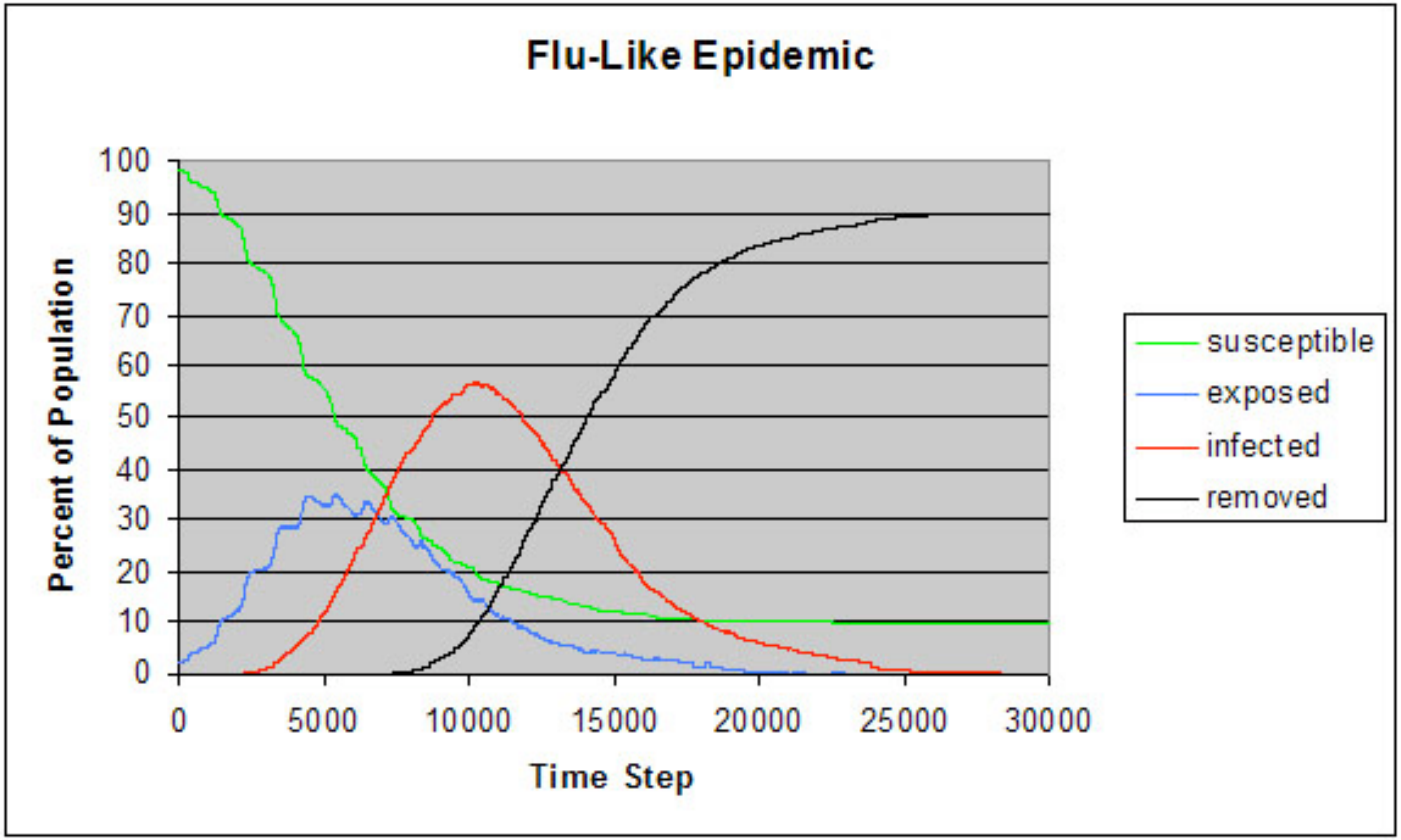
Agent rules: the working day



Agent rules: getting infected



A flu epidemic



Summary

- The model represents individuals in states of being susceptible or suffering from a disease
- The model is able to accommodate interactions leading to infections that vary according to the agent's involvement in different networks
  - (compare a microsimulation)
- The model can be used to study the effect of
  - Varying parameters (rate of infection etc.)
  - Varying distributions and numbers of initial infections
  - Different control strategies, such as vaccinations of all or part of the population

Research steps

i. Identify some macro regularities

= 'stylised facts'

ii. Specify the actors (agents)

iii. Propose some micro behaviours

iv. Build a model

v. Execute the model

vi. Verify the emergence of regularities

vii. Consider alternatives

= sensitivity analysis

viii. Compare with empirical data

= 'validation'

ix. Derive theoretical and policy implications

Strengths of ABM

- Experimentation
- Heterogeneity
- Emergence and Immergence
- Networks
- Change and learning

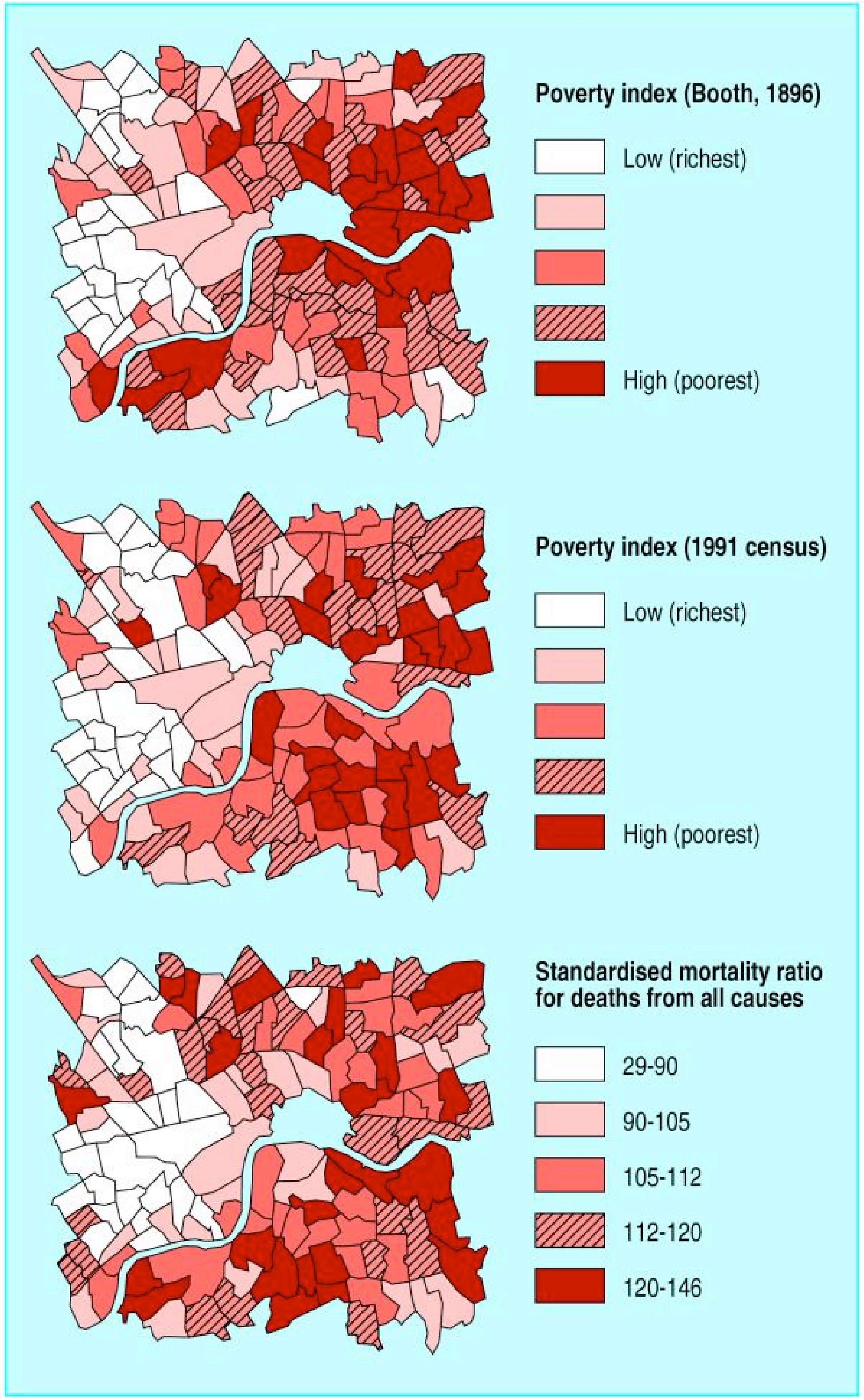
The persistence of spatial heterogeneity

Central London:

Poverty 1896
(deep red = poorest)

Poverty 1991
(deep red = poorest)

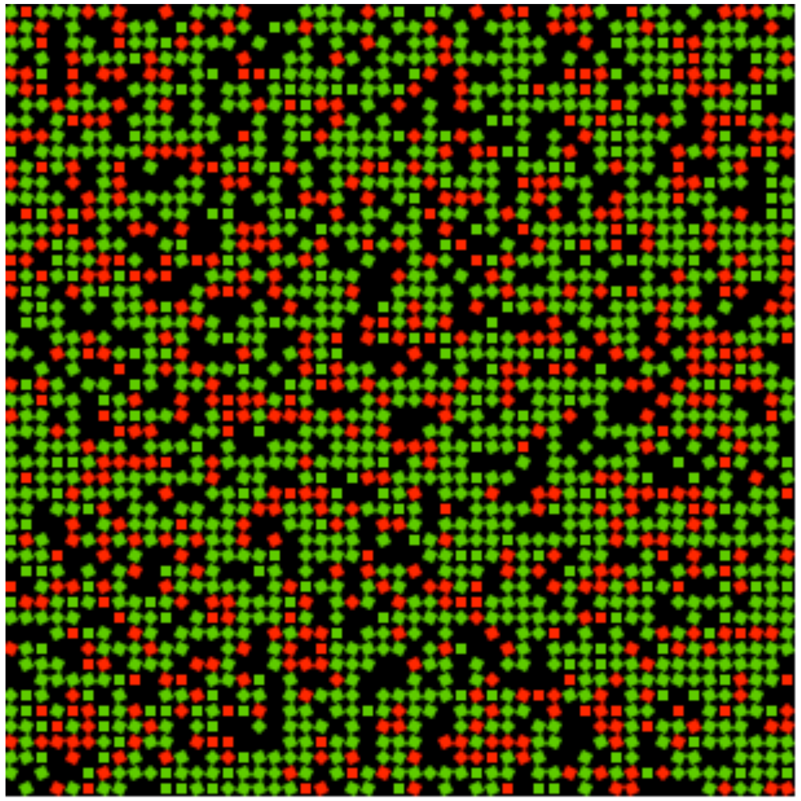
Standardised mortality ratio, 1991
(~ lifespan)



Danny Dorling, Richard Mitchell, Mary Shaw, Scott Orford, George Davey Smith (2000) The Ghost of Christmas Past: health effects of poverty in London in 1896 and 1991 *BMJ*. December 23; 321(7276): 1547–1551.

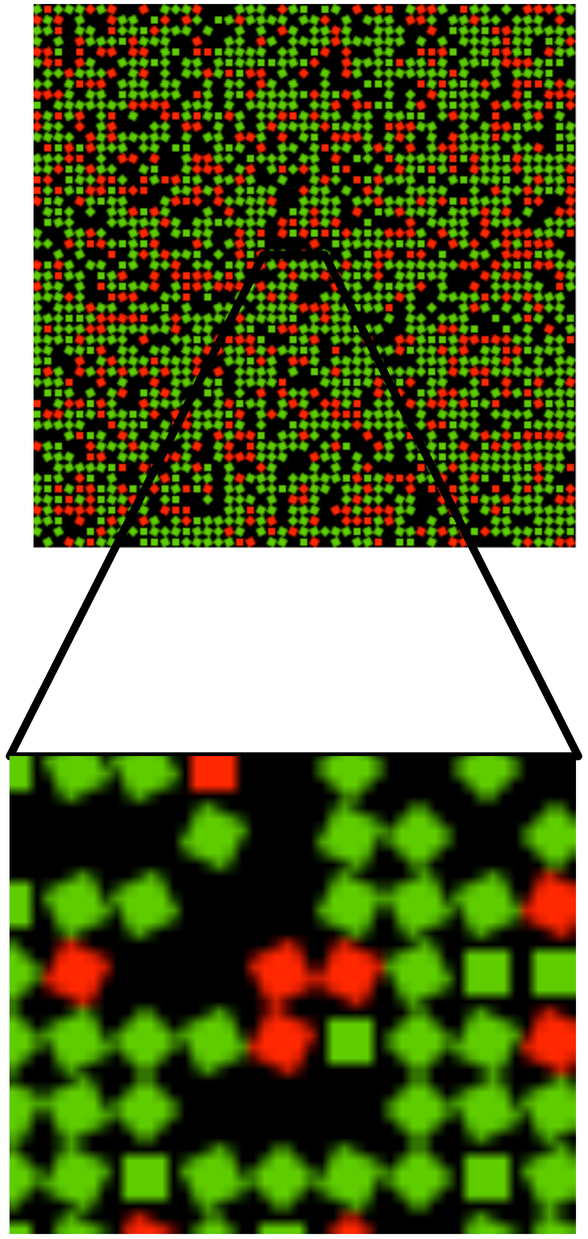
A segregation model

- Grid 50 by 50
- 1500 agents, 1050 green, 450 red
  - so: 1000 vacant patches
- Each agent has a tolerance
  - A green agent is 'happy' when the ratio of greens to reds in its Moore neighbourhood (i.e. in the 8 surrounding patches) is more than its tolerance
  - and vice versa for reds



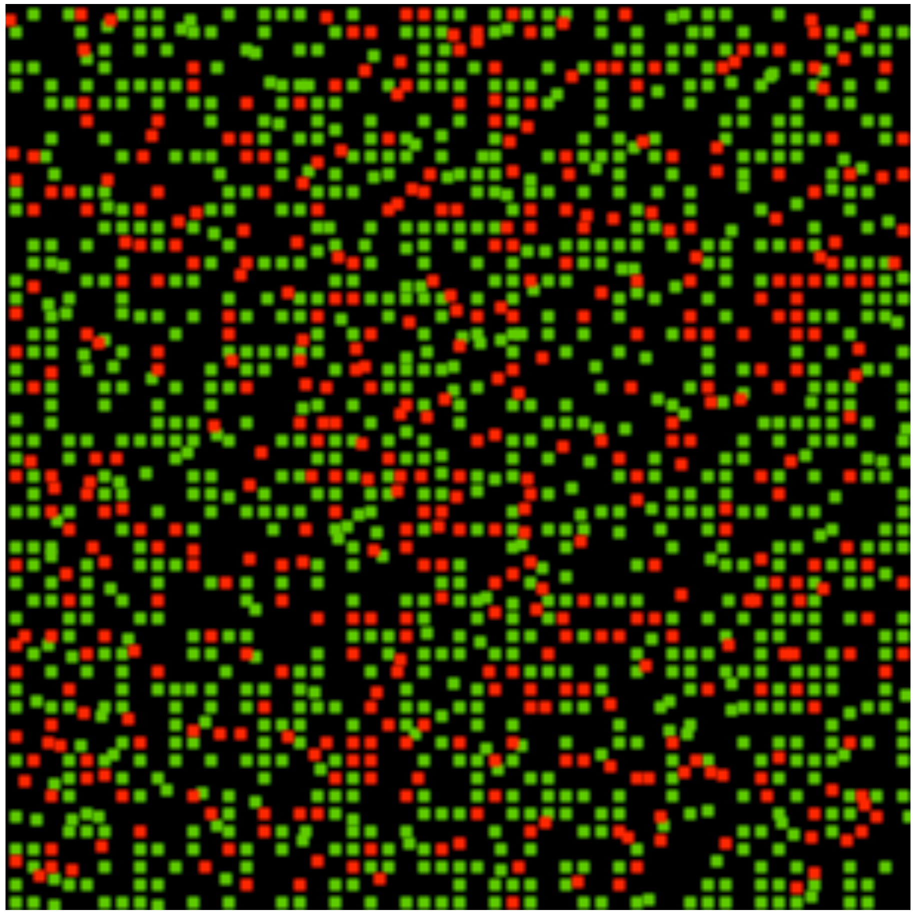
An initial random distribution

- With a tolerance of 40%, an agent is happy even when up to 60% of its neighbours (a slight majority) are the other colour
- Randomly allocate reds and greens to locations
- Then the average number of neighbours of the same colour is 58% (about 5)
- And about 18% of the agents are unhappy



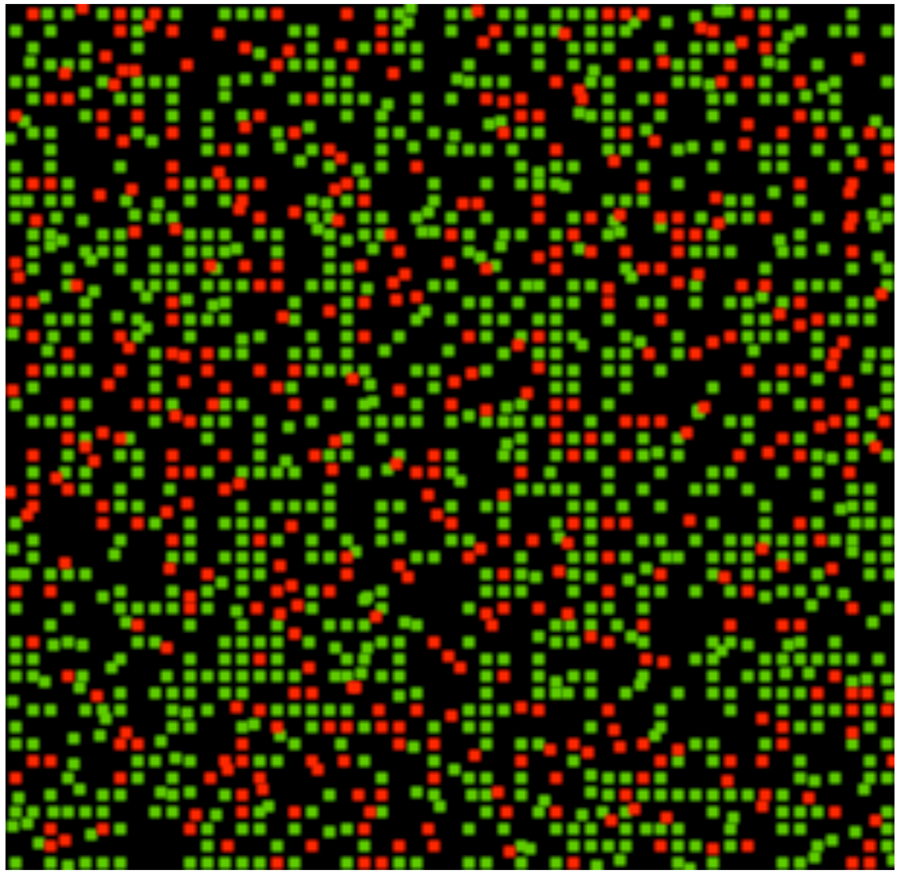
Emergence

- The Schelling model is used as a standard example of emergence
- Values of tolerance above 30% give clear display of clustering: 'ghettos'



Clusters remain even when agents come and go

5% of agents 'die' and are replaced with agents of random colour, red or green, every timestep



Emergence in time

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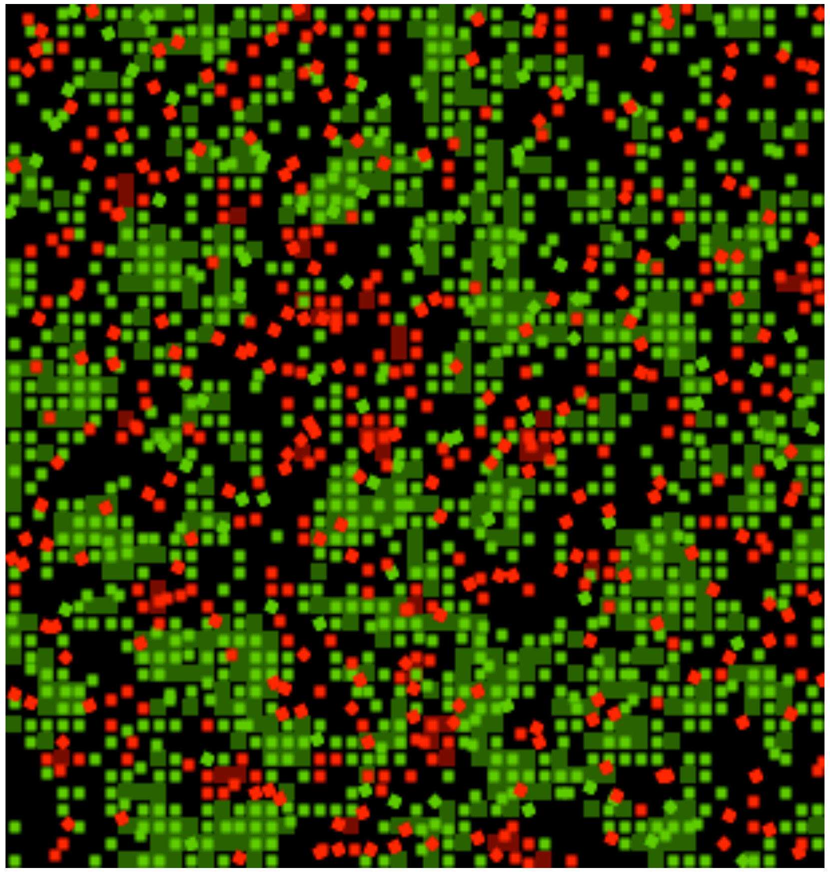
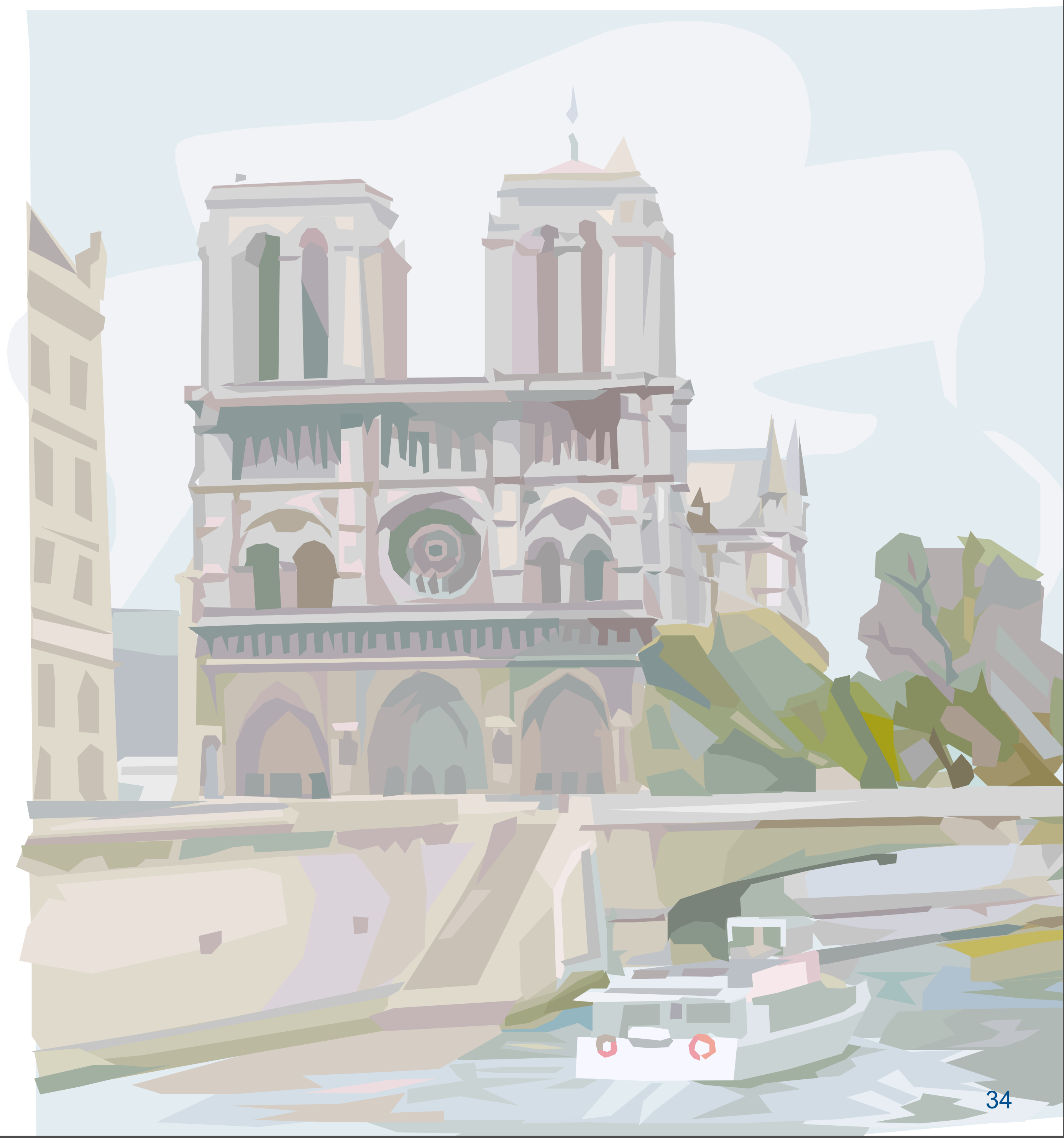
Second order emergence

- Interaction at the individual ('micro') level yields new patterns at the global ('macro') level
- These patterns remain even though the individuals come and go
- The patterns are recognised by people, who name them and respond to them
  - So the macro feeds back onto the micro: second-order emergence



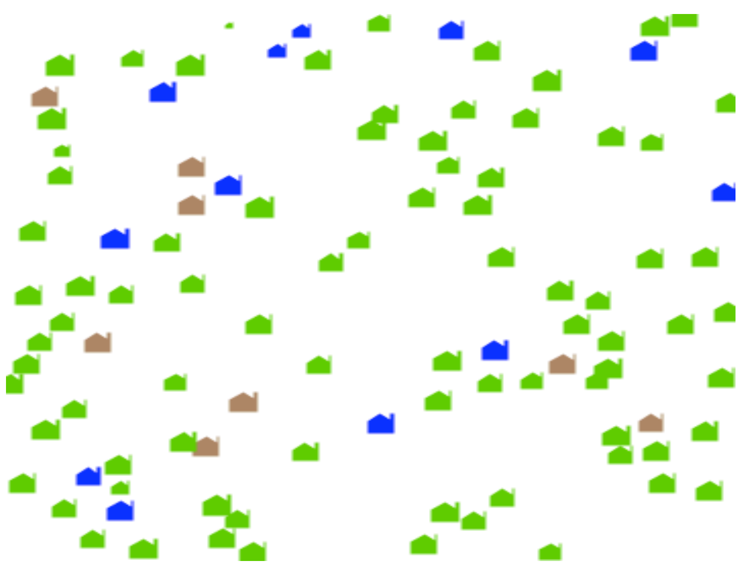
Second-order emergence

- Individual action leads to emergent social structures
  - Social structure = rules, norms and regularities
- These structures are the matrix in which action takes place
- This action maintains and changes the structures



Change and learning

- Hi-tech firms with generally short life span
- Simultaneously:
  - produce and consume in an economic market
  - generate and exchange knowledge
- Networks emerge from the activities of individual firms
- The firms innovate and the network learns



Simulating Knowledge Dynamics in Innovation Networks

Ahrweiler, P., Pyka, A., & Gilbert, N. (2004). Simulating knowledge dynamics in innovation networks (skin). In R. Leombruni & M. Richiardi (Eds.), *Industry and labor dynamics: The agent-based computational economics approach*. Singapore: World Scientific Press.

Data and modelling

89 Main Component, New Ties

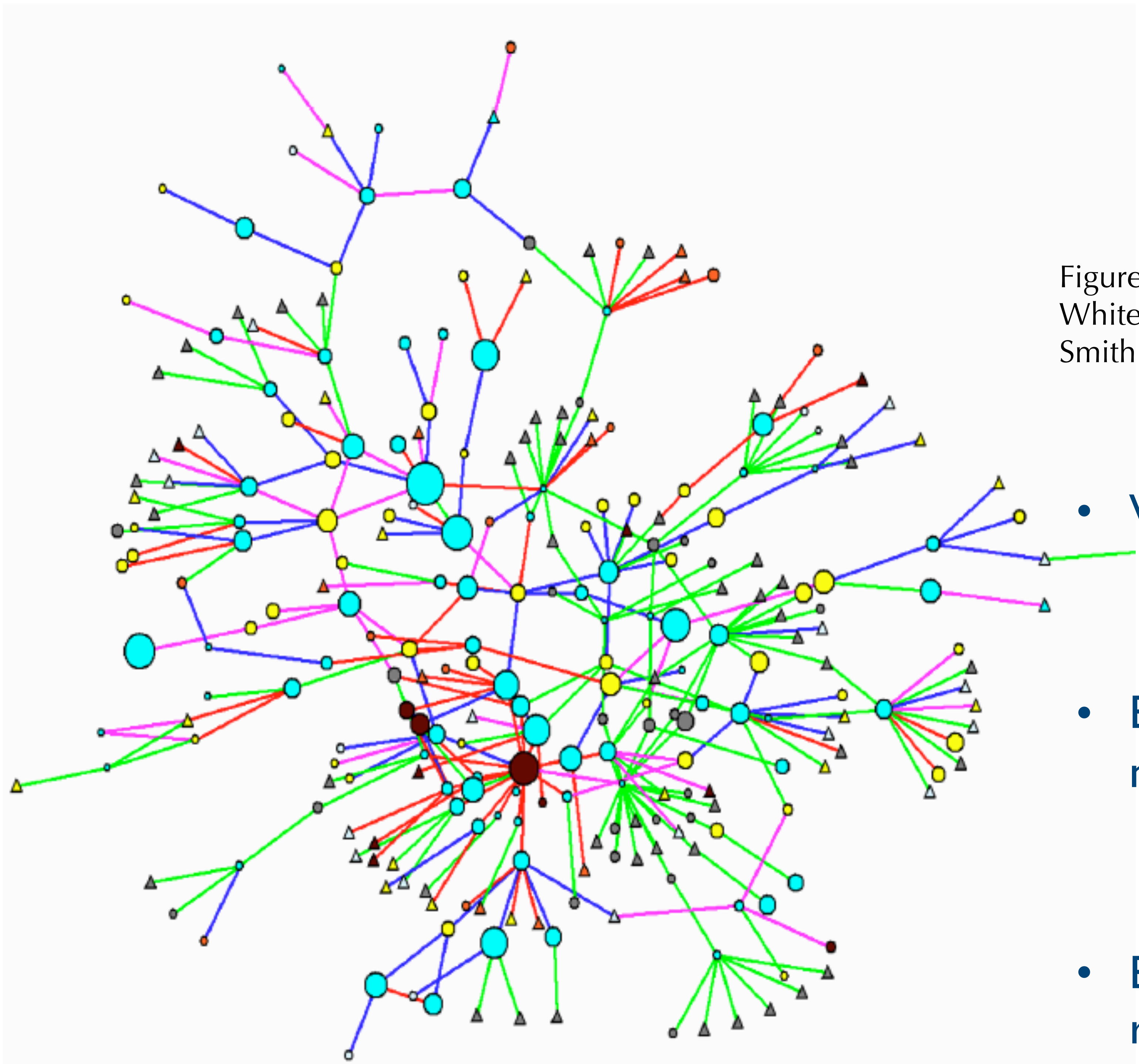


Figure 5 from W.W. Powell, Douglas R. White, Kenneth W. Koput & Jason Owen-Smith (2006) AJS

- We have the data
  - Powell et al
  - Biotech databases
- But we don't know *why* these networks are like that
  - Little theory
  - No mechanisms
- Experiments impossible in the real world

The SKIN model of innovation networks

- Knowledge level
  - Firm: Innovation
    - the agent's knowledge (represented as a *kene)* changes to represent innovation (new products)
  - Sector: Collaboration
    - collaboration is one way to achieve a change in the collaborating firms' knowledge, through exchange of parts of their kenes
- Market level
  - Firm: Costs and profits
    - firms buy the materials they need for manufacture from other firms, and sell their products to other firms.
  - Sector: Trade
    - firms adjust their products and their pricing to try to increase their trade

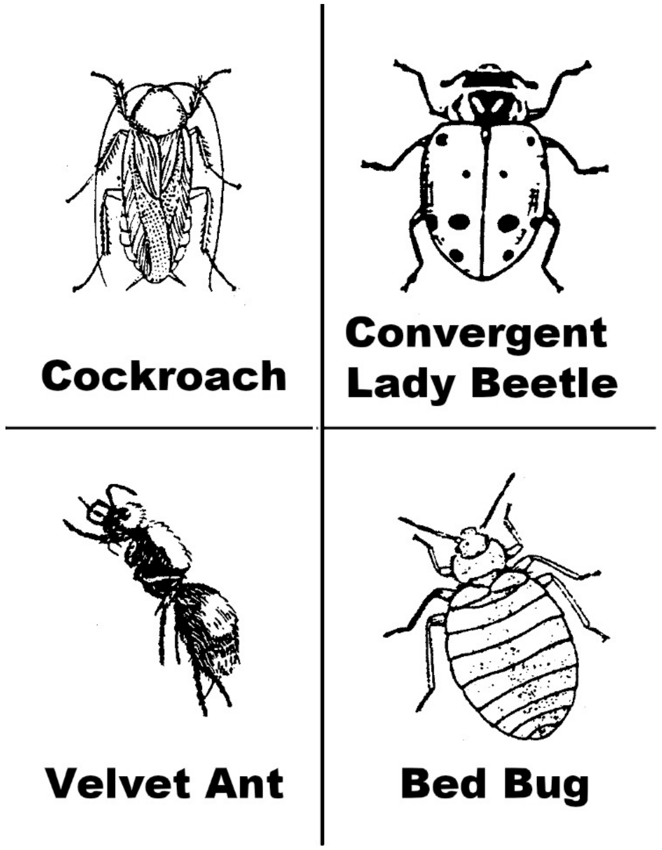
Tools

- NetLogo
  - http://ccl.northwestern.edu/netlogo/
  - free, runs on Windows, MacOS X, Linux, easy to learn, has lots of example models and a thriving user community
- RePAST
- MASON
  - for computer scientists, mainly
- MATLAB
- others


NetLogo — PwC Housing Market model_10_26 {/Users/scs1ng/Desktop/PwC}
Interface
Information
Procedures
Edit
Delete
Add
Button
normal speed
view updates
continuous
Settings...
PwC Housing Market model version 1.0
---Geography--
Density 70 %
InitialGeography
Clustered
InterestRate 7 %
CycleStrength 0.00
--- Owners--
Affordability 25 %
ExitRate 6 %
EntryRate 9 %
MeanIncome 25000 £
Shocked 10 %
MaxHomelessPeriod 5
0 means no limit
Buyer-search-length 10
---Realtors--
RealtorTerritory 10
Locality 3
RealtorMemory 5 periods
PriceDropRate 10 %
RealtorOptimism 3 %
ticks: 504
3D
---Houses--
HouseConstructionRate 0.45 %
HouseMeanLifetime 300
MortgageDuration 25
Setup
Go
Homes
Seeking a home
Empty houses
Houses
People
Population
10 x Moving up
10 x Moving down
House price distribution
All
For sale
Income distribution
Median house prices
For sale
Sold
Gini index
Incomes
Prices
Mortgage interest / income
Mean house price / mean income
Median time on market
Transactions
Number
time
Periods
Command Center
Clear
observer>

Verification and validation

- Verification
  - Getting rid of bugs
- Validation
  - Checking whether the model is a good model of something
  - ‘Good’ depends on one’s objectives

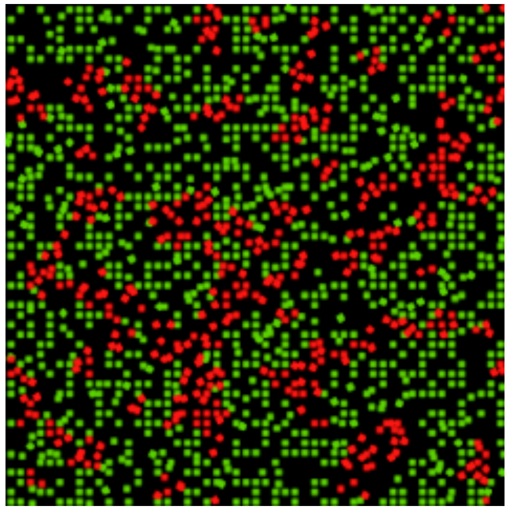


Validation

- Is the model a good model?
- Depends on the modeller's objectives
  - Formalising a theory
    - Usually an abstract model
  - Developing middle range theory
    - Model of a class of phenomena
  - Modelling a specific situation
    - Facsimile models

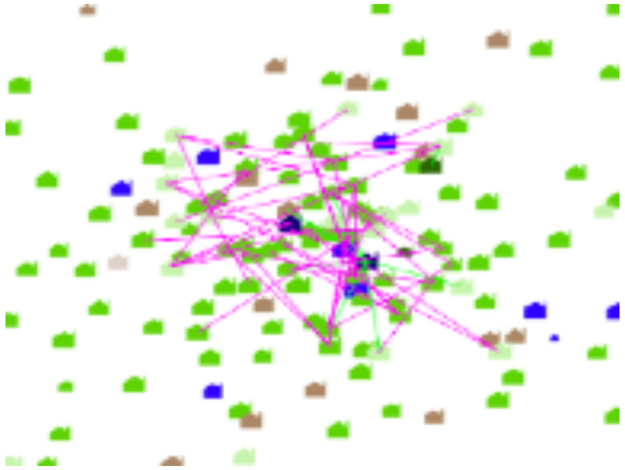
Abstract models

- Aim: demonstrate some (probably emergent) social process or mechanism
- No corresponding specific empirical case
- Example:
  - Schelling's segregation model
- Validation criterion:
  - Same as a sociological theory
  - Does it generate more specific ('middle range') theories that can be tested empirically?



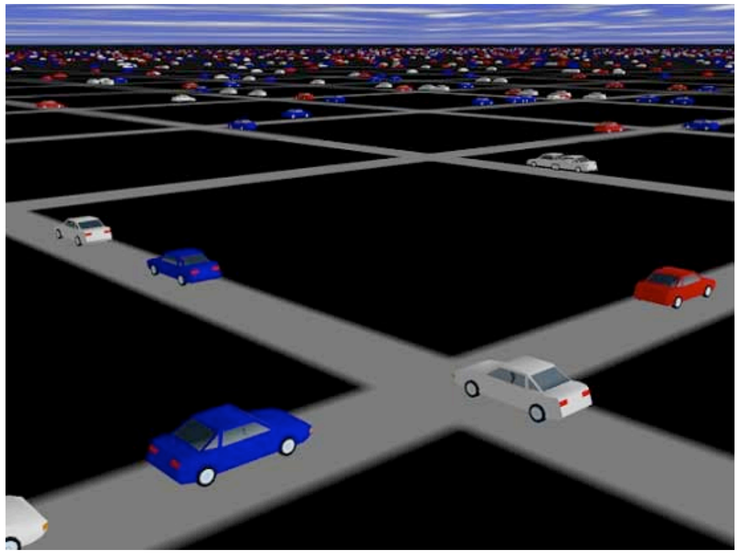
Middle range models

- Aim: describe the general characteristics of a particular social phenomenon
- Should be applicable to many specific cases
- Example:
  - models of innovation networks, industrial districts
- Validation criterion:
  - Qualitative resemblance
  - Similar dynamics
  - 'History friendly' models



Facsimile models

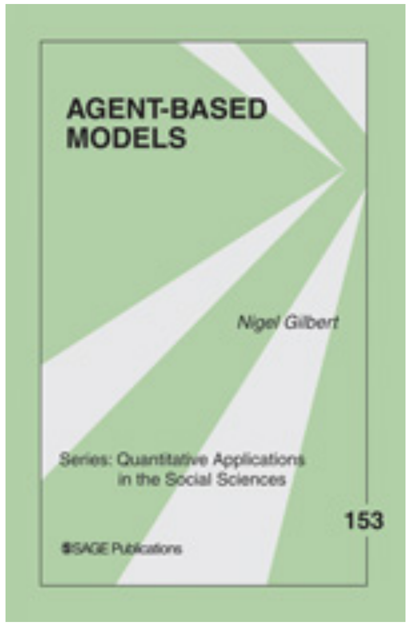
- Aim: provide an exact reproduction of some target phenomenon
- Often intended to provide predictions
- Example:
  - a model of the traffic in a city, used to predict locations of potential jams
- Validation criterion
  - Does it lead to accurate predictions?
- Problem:
  - behaviour of model may be heavily influenced by random events (simulated using a random number generator)



Humans and agents, all in the same system

- Some agents can be people
- Other agents in the same simulation can be computational
- This gives the humans a 'bottom up' view of what it is like to be an agent in the simulation
  - Compare with a flight simulator
- This can be useful for
  - Training
  - Participative modelling
    - Users/stakeholders are involved in the design and implementation
  - Data collection ('knowledge elicitation')

Advertisements!

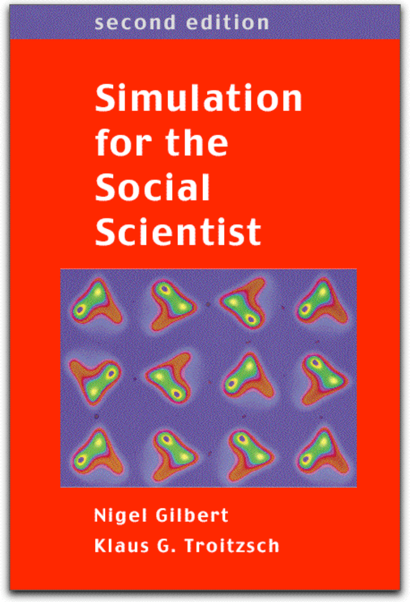


European Social Simulation Association
http://www.essa.eu.org

http://www.soc.surrey.ac.uk/JASSS/

JASSS

Journal of Artificial Societies and Social Simulation



the end