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
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

Data from a large random sample
After transformation
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

\[
\text{Pollution}_{t+1} = \text{Pollution}_t + (\text{PollutionGeneration}_t - \text{PollutionAbsorption}_t) \times \Delta t
\]

\[
\text{PollutionGeneration}_t = \text{Population}_t \times \text{PollutionNormal} \times \text{PollutionFromCapitalMultiplier}
\]

\[
\text{PollutionAbsorption}_t = \frac{\text{Pollution}_t}{\text{PollutionAbsorptionTime}_t}
\]

\[
\text{PollutionAbsorptionTime}_t = f(\text{PollutionRatio}_t)
\]

\[
\text{PollutionRatio}_t = \frac{\text{Pollution}_t}{\text{PollutionStandard}}
\]

\[
\text{PollutionStandard} = 3.6 \times 10^9
\]
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
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
Example: Sugarscape

General equilibrium price and quantity by interpolation:
\[ P = 0.981, \ Q = 2076.1 \]

Actual price and quantity:
\[ P = 0.000, \ Q = 0.0 \]
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
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

1. Move toward desired location (work or home)
2. Am I infected or exposed?
   - No
     - Are any susceptible?
       - No
         - Does calculation return true?
           - No
             - Set target human to infected
           - Yes
             - Does simulation include exposed?
               - No
                 - Set target human to exposed
               - Yes
                 - For each susceptible, perform infection calculation
                 - Grab all humans within infection radius
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)

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
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

Data and modelling

89 Main Component, New Ties

- 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

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

cress.soc.surrey.ac.uk
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 kenesis

• **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
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’)
the end