1. Simulation

The anecdote about the economist looking for his lost car keys:

"An accurate answer to the wrong question"? (using closed-form methods)

or: simulation (numerical methods)

"Approximate answers to the right questions"

Helped by the developments in computer hardware and software such as NetLogo.

Meanwhile: Computer Science has borrowed simulation tools from the natural world:
1. artificial neural nets, 2. simulated annealing,
3. genetic algorithms/programming

Want: dynamics, out-of-equilibrium characterisations in our models.

Simulation Social Science, not Physical Science

At the aggregate level, similar.

But at the micro level, the agents in social science models are people, with self-conscious motivations and actions. And social interactions in networks.

Beware: Aggregate behaviour may be well described by differential equations, with little difference from models of inanimate agents at the micro level.

The Five Functions of Simulations:

(from Hartmann 1996)

1. **As a Technique — to investigate the detailed dynamics of a system.**
2. **As a Heuristic Tool — to develop hypotheses, models, and theories.**
3. **As "Experiments" — perform numerical experiments, Monte Carlo probabilistic sampling (see Marks 2014 later).**
4. **As a Tool for Experimentalists — to support experiments.**
5. **As a Pedagogic Tool — to gain understanding of a process.**

1. As a Technique

- **Solution of a set of equations describing a complex (e.g. bottom-up) interaction.**
- ***Discrete* (Cellular Automata): if the model behaviour ≠ empirical, it must be because of the transition rules.**
- ***Continuous*: not so clear-cut: background theory v. model assumptions**

  Q: does more realistic assumption → more accurate prediction?

"A simulation is no better than the assumptions built into it" — Herbert Simon (Nobel laureate 1978).

2. As a Heuristic Tool

Simulation is useful where the theory is not well developed, and the causal relationships are not well understood:

- **theory development = guessing suitable assumptions that may imitate the change process itself;**
- **but how to assess assumptions independently?**

Steve Durlauf: Is there an underlying *optimisation* by agents? (his "Complexity and Empirical Economics," *EJ*, 2005)

3. As a Substitute for Experiment

When actual experiments are perhaps:

- ***pragmatically*** **impossible: scale, time; or**
- ***theoretically*** **impossible: counterfactuals; or**
- ***ethically*** **impossible: e.g. taxation, no minimum wage;**
- ***financially*** **impossible: too expensive to undertake.**

or **to complement lab experiments**
(See the link to Monte Carlo Probablistic Sampling.)

4. As a Tool for Experimentalists

- **to inspire experiments**
- **to preselect possible systems & set-ups**
- **to analyse experiments
(statistical adjustment of data)**

5. For Learning

A pedagogic device through play ...

See Mitchell Resnick. *Turtles, termites, and traffic jams: Explorations in massively parallel microworlds*. MIT Press, 1994.

Play with NetLogo models, and experience emergence: Life is famous, and others too.

See the Models Library that comes with the NetLogo download. e.g. Thomas Schelling's Segregation model (Nobel laureate 2005) in the NetLogo Models Library/Sample Models/Social Science

Summary

A simulation imitates one process by another process

With Social Sciences: few good descriptions of static aspects, and even fewer of dynamic aspects

(Remember the economists' focus on: existence, uniqueness, stability) — but what about out-of-equilibrium adjustments?

Robust Predictions from Simple Theory

(from Latané, 1996)

Four conceptions of simulation as a tool for doing social science:

1. **As a scientific tool: theory + simulation + experimentation**
2. **As a language for expressing theory:**
   - **natural language,**
   - **mathematical equations (i.e., closed form), and**
   - **computer programs, such as C++, Java, etc.**
3. **As an "easy" alternative to thinking: robust coding**
4. **As a machine for discovering consequences of theory: if this, then that. (i.e. sufficiency).**

A Third Way of Doing Science DIS

(from Axelrod & Tesfatsion 2006)

Deduction + Induction + Simulation.

- **Deduction: deriving theorems from assumptions**
- **Induction: finding patters in empirical data**
- **Simulation: assumptions → data for inductive analysis**

S differs from D & I in its implementation & goals.

S permits increased understanding of systems through controlled computer experiments

Emergence of self-organisation (Miller & Page, 2007, Ch. 4)

Examples: ice, magnetism, money, markets, civil society, prices, segregation.

Defn: emergent properties are properties of a system that exist at a higher level of aggregation than the original description of the system.
Not from superposition, but from interaction at the micro level.

Adam Smith's Invisible Hand → prices

Schelling's residential tipping (segregation) model:
People move because of a weak preference for a neighbourhood that has at least 33% of those adjoining the same (colour, race, whatever) → segregation.

Need models with more than one level to explore emergent phenomena.

Families of Simulation Models

1. **System Dynamics SD**
   (from differential equations)
2. **Cellular Automata CA**
   (from von Neumann & Ulam, related to Game Theory)
3. **Agent-Based Models ABM, or Multi-Agent Models MAM, or Agent-Based Computational Economics ACE, or Multi-Agent Systems MAS**
   (from Artificial Intelligence)
4. **Learning Models LM**
   (from Simulated Evolution and from Psychology)

Comparison of Simulation Techniques

Gilbert & Troitzsch compare these (and others):

Technique	Number of Levels	Communication between agents	Complexity of agents	Number of agents
SD	1	No	Low	1
CA	2+	Maybe	Low	Many
ABM	2+	Yes	High	Few
LM	2+	Maybe	High	Many

Number of Levels: “2+” means the technique can model more than a single level (the individual, or the society) and the interaction between levels.

This is necessary for investigating emergent phenomena.

So “agent-based models” excludes simple Systems Dynamics (SD) models, but can include the others.

Simulation: The Big Questions

from: www.csse.monash.edu.au/~korb/subjects/cse467/questions.html

- **What is a simulation?**
- **What is a model?**
- **What is a theory?**
- **How do we test the validity of any of the above?**
- **When do we trust them, what sort of understanding do they afford us?**
- **What is an experiment? What does it mean to experiment with a simulation?**
- **What is the role of the computer in simulation?**
- **How does general systems dynamics influence simulations?**
- **How do we handle sensitivity to initial conditions?**
- **How precisely can a simulation approximate real life / a model?**
- **How do we decide whether to use a theory / model / simulation / lab experiment / intuition for a given problem?**
- **Does a simulation have to tell us something?**
- **How complex is too complex, how simple is too simple?**
- **How much information do we need to (a) build and (b) test a simulation?**
- **How/when can the transition from a quantitative to a qualitative claim be made?**

Verification + Validation ≡ Assurance

Verification (or internal validity): is the simulation working as you want it to:

— is it "doing the thing right?"

Validation: is the model used in the simulation correct?

— is it "doing the right thing?"

To Verify: use a suite of tests, and run them every time you change the simulation code — to verify the changes have not introduced extra bugs.

Perhaps code using a different platform, or dock.

Validation

Ideally: compare the simulation output with the real world.

But:

1. ***stochastic*** **∴ complete accord is unlikely, and the distribution of differences is usually unknown**
2. ***path-dependence*****: output is sensitive to initial conditions/parameters**
3. **test for "retrodiction": reversing time in the simulation; or: test from a past date to the present: calibrate with history**
4. **what if the model is correct, but the input data are bad?**

Use Sensitivity Analysis, to ask:

- **robustness of the model to assumptions made**
- **which are the crucial initial conditions/parameters?**

use: randomised Monte Carlo, with many runs.

Judd's ideas (2006)

"Far better an approximate answer to the right question … than an exact answer to the wrong question."

— John Tukey, 1962.

That is, economists face a tradeoff between:

the numerical errors of computational work
and
the specification errors of analytically tractable models.

Two Kinds of ABM

We can think of two kinds of ABM:

1. ***demonstrative* ABM models ("exploratory")**

   These models demonstrate principles, rather than tracking historical phenomena. A demonstrative ABM is an existence proof.
   Examples: Schelling's Segregation Game, my Boys and Girls NetLogo model, my Emergence of Risk Neutrality, and others

2. ***descriptive* ABM models. ("phenomena-based")**

   These models attempt to derive sufficient conditions to match historical phenomena, as reflected in historical data. This requires validation (model choice).
   Examples: Midgley et al. modelling brand rivalry, alife models, etc