Agent-Based Modeling: Challenges for Computer Science

Peter McBurney
Department of Computer Science
University of Liverpool
Liverpool L69 3BX

www.csc.liv.ac.uk/~peter

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Outline

- Some working definitions (CAS, ABM, MAS)
- Objectives of modeling
- Challenges for Computer Science

Complex Adaptive Systems

- Complex Adaptive Systems (CAS)
  - Systems of interacting entities
  - Where the entities have (some degrees of) intelligence and autonomy, and
  - Where their states and relationships are dynamic.

- An example:
  - Malaria domain
    - Entities: parasites, hosts (mosquitoes), humans
  - Parasites and hosts evolve in response to interventions
    - eg, resistance to new drugs
  - Humans adapt in response to interventions
    - eg, use (or non-use) of precautions, treatments and drugs
    - Human activity may be mediated by beliefs and social constructs, and people may be aware of and respond to policy interventions.

Agent-Based Modeling

- Models of complex adaptive systems, in which
  - Domain entities are modeled as distinct software entities (agents)
  - Relationships between domain entities are modeled explicitly.

- These models are multi-agent systems (MAS)
  - Systems of intelligent, autonomous software entities

- ABM models are distinct from
  - Rational Expectations models in Economics
    - Economic actors assumed to have their own models of the values of economic variables
    - RE Models usually assume all actors have the same model
    - RE Models usually assume all actors know the model they are in
  - Conjoint models in Marketing
    - Consumers assigned to segments
    - Segments distinct, but consumers within segments the same.

Objectives of Modeling (1)

- To understand some CAS
  - In detail (quantitatively)
  - Qualitatively (the relationships between variables of interest)
  - To sharpen our intuitions (Ariel Rubinstein, 1998)

- To forecast or backcast some CAS
  - The behaviours of participants in the system
  - System states (micro, meso or macro-level)

- To support intervention in some CAS
  - To advise participants on their strategies
  - To advise system-owners (eg, policy-makers) on management of the system.

Objectives of Modeling (2)

- To **create** some reality
  - Models as *performative utterances*
  - eg: Black-Scholes options-pricing theory (1970s)
  - eg: Game theory for nuclear weapons doctrines (1950s)
  - eg: Iterated Prisoners' Dilemma games for nuclear strategy (1980s)
  - eg (?): UK national registers of animal movements (2000s)

- To enable co-ordination between stakeholders
  - Models as co-ordination artefacts
  - eg, Forecasting models in hedge funds
  - eg, Corporate strategy modeling
  - eg, Large-scale public policy modeling (national macro-economic models, IPCC models of climate change, communicable disease models).

Iain Hardie & Donald MacKenzie [2007]:

"Assembling an economic actor: the *agencement* of a hedge fund."

Sociological Review, 55 (1): 57-80.

Public policy ABMs as co-ordination artefacts

In public policy domains a model may act as *a co-ordination artefact*, enabling:

- Relevant stakeholders to be identified
- Stakeholders to learn about each other
- Stakeholders to become aware of and communicate their knowledge, preferences and goals
- Exploration of trade-offs between competing preferences and goals in policy-making

and

- Progress towards reconciliation or resolution of preferences and goals in policy-making.

In other words, a model can act as a stimulus and a locus for communication between stakeholders,

- ie, as a medium for stakeholder deliberation and potential agreement.

Towards theories of simulation

We still lack a generic, formal theory of simulation

- Such a theory would provide advice on (eg):
  - How many simulations should we do?
  - How should parameter values be chosen?
  - How should we reason across multiple simulations?
  - How should we select representative cases/scenarios?
  - How should the outputs of simulation be judged?

- Some economists talk about a *class-of-models* approach
  - A generic template model to study key variables
  - Abstracting away from specific instances and circumstances.
  - Economists also often use *stylized facts* – abstractions of real data.

John Sutton [2000]: *Marshall's Tendencies: What Can Economists Know?* (MIT Press, London UK)

Challenges for Computer Science (1)

1. Inter-disciplinary challenges
   - Language and terminology
   - Differing prior expectations (feasibility, speed, methods, novelty, publications)

2. Use of Agent-Oriented Software Engineering (AOSE) methods
   - Specification, design, implementation, validation
   - AOSE still immature

3. Upscaling
   - Migration of ABMs to parallel architectures not usually straightforward
   - Need to consider distributed architectures (eg, tuple space models)

4. Standards for ABM model specification, design and implementation
   - To support re-use and interfacing of ABMs.

Challenges for Computer Science (2)

5. Model calibration & assessment

- *Calibration*: Matching of input parameters to empirical data or stylized facts.
- *Verification*: Does the code implement the model design?
- *Validation*: Is the model a good representation of the intended reality?
- Robert Marks & David Midgley have called for Norms for Verification and Validation for research using ABMs.

DF Midgley, RE Marks & D Kunchamwar [2007]: The building and assurance of agent-based models: an example and challenge to the field. *Journal of Business Research*, **60**(8): 884-893.

Challenges for Computer Science (3)

6. Negotiating trade-offs in model development

- Subject-matter experts usually have unrealistic expectations
  - eg, model size, levels of granularity, treatment of time, goodness-of-fit, range of applications, speed of development.
- Software engineers need to manage dialogs over these issues and forge a consensus about trade-offs
  - Quality v. speed v. cost: Pick 2!
- The need for these skills is widely recognized in commercial SE practice
  - But SE theory has devoted little attention to them.
  - Even in practice, these skills are not as common as they should be.

Challenges for Computer Science (4)

7. Understanding the model-in-deployment

- ABM developers need detailed use-cases for the models-in-deployment before design and implementation
  - Called *Thick Studies* in sociology of science
- Will need to draw on public policy, simulation modeling, software engineering, and detailed domain knowledge
- Need for user-friendly pre-model and post-model infrastructure
  - eg, parameter initialization front-ends, automated statistical analysis back-ends, automated sensitivity analysis systems, automated linked front- and back-ends
- How to incorporate folksonomies, crowd-sourcing and social networks into public policy models
  - eg, Prediction Markets for influenza epidemics.

Thankyou!