

# Issues around verification, validation, calibration, and confirmation of agent-based models of complex spatial systems

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1 ABMs as representations of CSSs

2  $V^2C^2$

3 Validation in a complex world

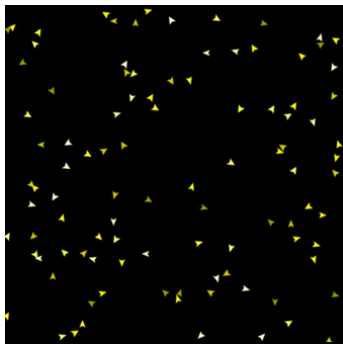
4 Frameworks

5 Types of model

6 Discussion points

# The nature of complex systems

- Medium–large numbers of interacting elements
  - Not trillions or more
  - Not just a few
- Interactions are generally localised but may scale up in ‘unexpected’ ways
- Interactions vary widely in nature
- Elements range from simple-reactive to complex-intelligent



# Complex systems are *irreducible*

- No compact model of a complex system is possible!
- A complex system is its own model
- “A complex system cannot be reduced to a simple one [...] if it wasn't simple to start off with” (page 9)

Cilliers (1998) *Complexity and Postmodernism: Understanding Complex Systems*, Routledge, London.

## Specific to complex *spatial* systems

- A complex system that is spatially embedded (*all* CSs?)
  - Multiple interacting complex systems
  - Hierarchical—or not
- Interested in the spatial location of outcomes
  - Patterns
  - Processes
  - Relationships between them
- However, with the preceding general remarks in mind, while outcomes may be predictable within limits (attractors) in general . . .
- . . . local prediction is impossible

# Validation $\neq$ verification

- Verification of any model of an open system is impossible and validation is not the same thing
  - *On verification*: “Model results are always underdetermined by the available data.” (page 642) *equifinality*
  - *On validation*: “. . . a model that does not contain known [. . .] flaws, and is internally consistent can be said to be valid.” (page 642)

Oreskes, Shrader-Frechette, Belitz (1994) Verification, Validation, and Calibration of Numerical Models in the Earth Sciences *Science* **263** 641-6.

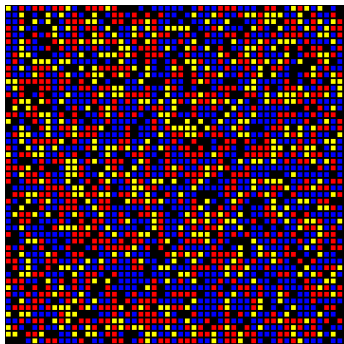
# Calibration and confirmation

- Calibration and confirmation are also not the same thing (as verification, or as one another)
  - *On calibration*: “. . . if a model result is consistent with [. . .] observational data, there is no guarantee the model will [. . .] predict the future.” (page 643)
  - *On confirmation*: “If a model fails to reproduce observed data, then we know [it] is faulty in some way, but the reverse is never the case.” (page 643)

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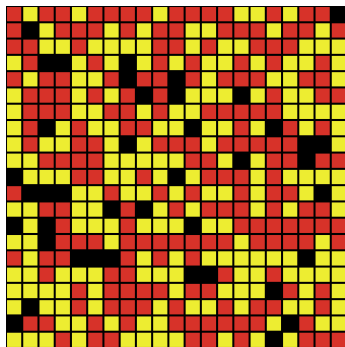
# Difficulties analysing ABM-CSS

- Many interacting agents
  - Keeping track of individuals is a challenge
  - Aggregate measures may hide the spatial variation we are interested in
- Spatial variation
  - Localised differences may be key drivers of change (e.g., tipping points)
- Interactions between spatial patterns and processes



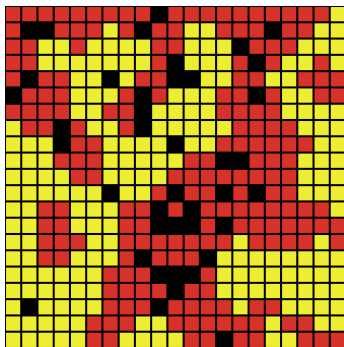
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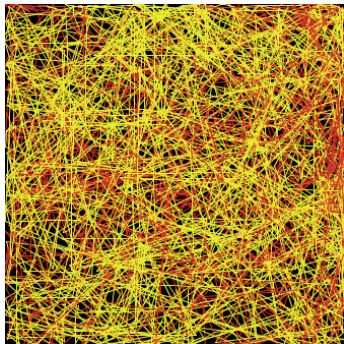
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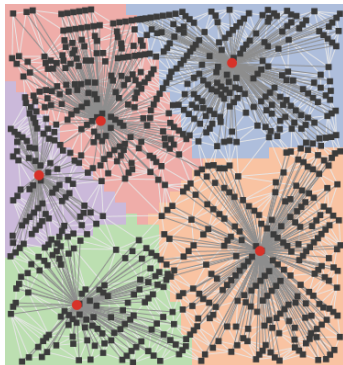
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# Self-fulfilling prophecy

- The end-product, with its very many individuals interacting to produce complex aggregate outcomes, in spatially complex settings, may result in
  - Ideas about the behaviours we expect or hope for, leading to ...
  - ... expectations about how such behaviour would be expressed, leading to ...
  - ... exploration of model behaviour only via a limited number of aggregate state variables
- Current tools don't support more open-ended exploration well ...
  - ... or if they do, they don't capture it

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# Alternative approaches

- Keith Beven has a proposal for a “coherent philosophy for modelling the environment”
  - Recognise equifinality
  - A mapping from ‘landscape space’ to ‘model space’  
( $n_L \Leftrightarrow n_M$ )
  - Build many models (using MC methods) and choose among them using GLUE (generalized likelihood uncertainty estimation)

Beven (2002) Towards a coherent philosophy for modelling the environment *Proceedings of the Royal Society of London A* **458** 2465-84.

Beven (1993) Prophecy, reality and uncertainty in distributed hydrological modelling *Advances in Water Resources* **16** 41-51.

# Alternative approaches

- Steve Banks advocates working with model *ensembles*
  - Again, recognise that *many* models may be reasonable representations
  - The ensemble of models should be maximally varied
  - Model selection is a social (and iterative) process

Banks (2002) Tools and techniques for developing policies for complex and uncertain systems  
*Proceedings of the National Academy of Sciences of the USA* **99** (Supp 3) 7263-6.

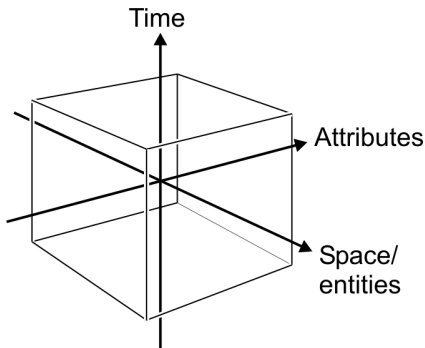
Banks (1993) Exploratory modeling for policy analysis *Operations Research* **41** 435-49.

# How to proceed mindful of these problems?

- Both Beven's and Bankes's approaches address these aspects:
  - Recognise that technical procedures for 'validation' are not the answer
  - Realise that more potential variation in model outcomes lies in the model structure than in the choice of parameters given a particular structure
- But (perhaps) don't do so well on these issues:
  - Neither is well adapted for agent models, where interpretation of the meaning of the model is a key (desirable) feature
  - Develop ways to explore variations in model structure (agent behaviour) more thoroughly *at an early stage*, preferably during model development

# Outline framework for thinking about appropriate tools

- The traditional GIS/quantitative geography S-T-A cube of Berry
- Model space consists of (very) many such cubes
- Space itself is also a dimension of this space

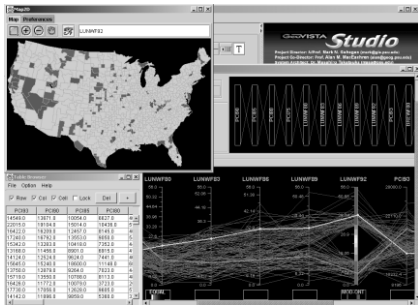






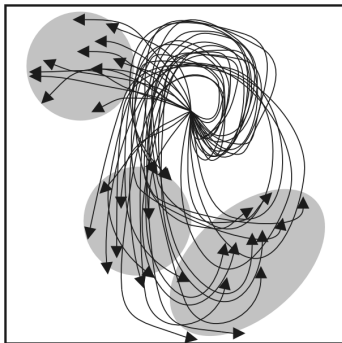
# Outline framework for thinking about appropriate tools

- Tracking progress in this complex space:
  - Projection pursuit in scientific visualisation is a similar problem
  - Use multivariate visualisations to make individual cubes and sets of cubes comprehensible
  - Automatically track where we've been



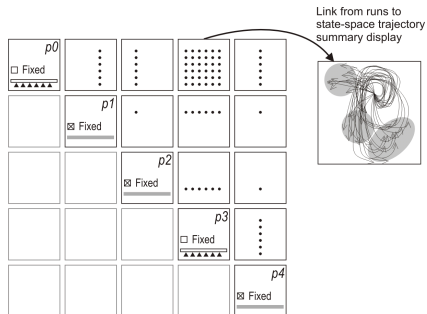
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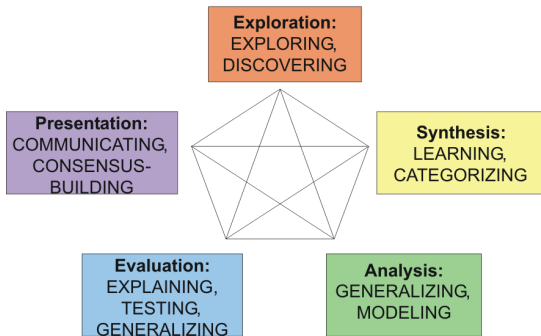


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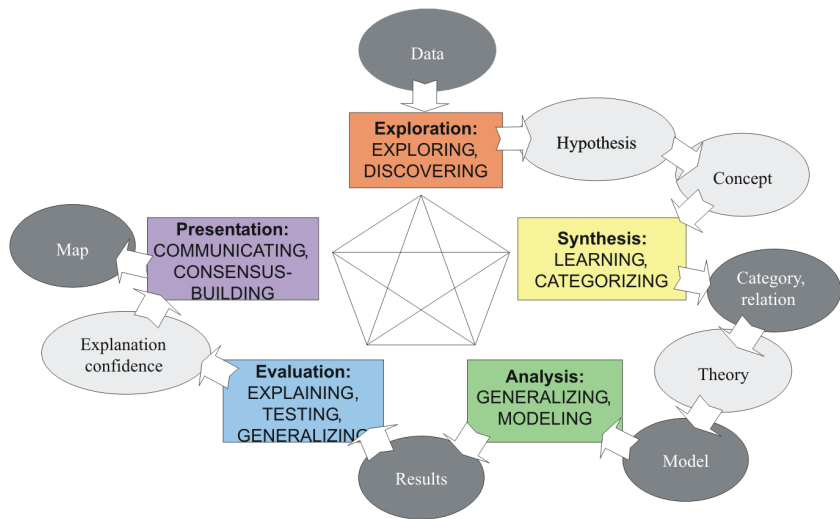
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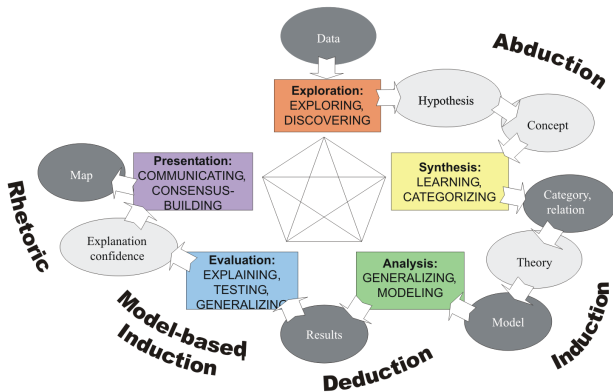
# Where ABMs sit in science



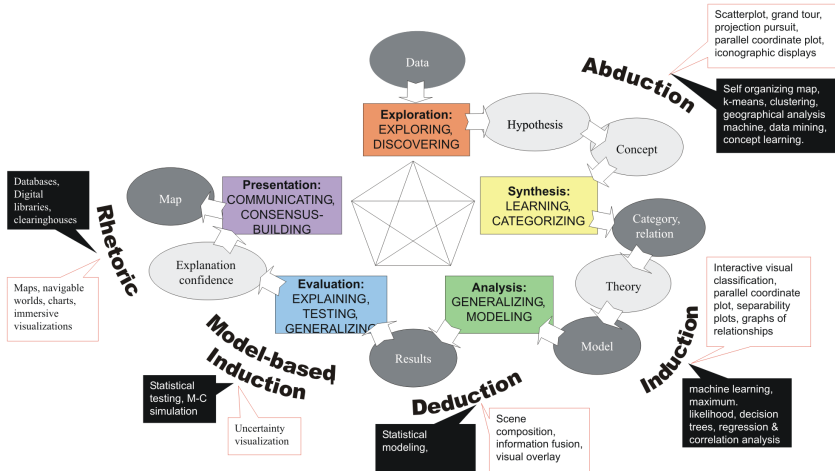
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Activity	Visualization	Computation	Representation		Reasoning
			Object	Collection	
Exploration	PCP, Scatterplot, iconographic displays	SOM, k-means, clustering methods, GAM	Attribute	Description	<i>Abductive</i>
			Description	Dataset	
Synthesis	Interactive visual classification, PCP	machine learning, max. likelihood, decision tree	Concept	Taxonomy	<i>Inductive</i>
Analysis	Scene composition, visual overlay	Statistical analysis	Rule	Theory	<i>Deductive</i>
			Occurrence	Model	
Explanation	Uncertainty visualization	Statistical testing, M-C simulation	Inference	Explanation	<i>Model-based</i>
Presentation	Maps, charts, reports, etc.	Web mapping, digital libraries, collaboratories	Narrative	Story	<i>Rhetorical</i>
			Symbol	Map	

# Abstract models



Dan Brown et al. Project SLUCE: Spatial Land Use Change and Ecological Effects at the Rural-Urban Interface: Agent-Based Modeling and Evaluation of Alternative Policies and Interventions.

- Aims to represent some theoretical framework or system
- ‘Seeing what happens’ is important: emphasis is on exploration, hypothesis generation:
  - A “tool to think with”
- Not clear what role (if any) *post hoc* ‘validation’ *per se* has here





# Issues for further discussion

- What type of science is ABM-ing?
- Are others more optimistic about the prospects for (technical *post hoc*)  $V^2C^2$  than I am?
- Are tools making the problem worse?
- Can they be part of a solution?
- How much difference does it make that we are interested here in spatial models?
- Does it make it harder, or just different?
- Does GIS have a role to play? (Or are generalisable S-T data models too hard?)
- ... others?