Descriptive and structural complexity

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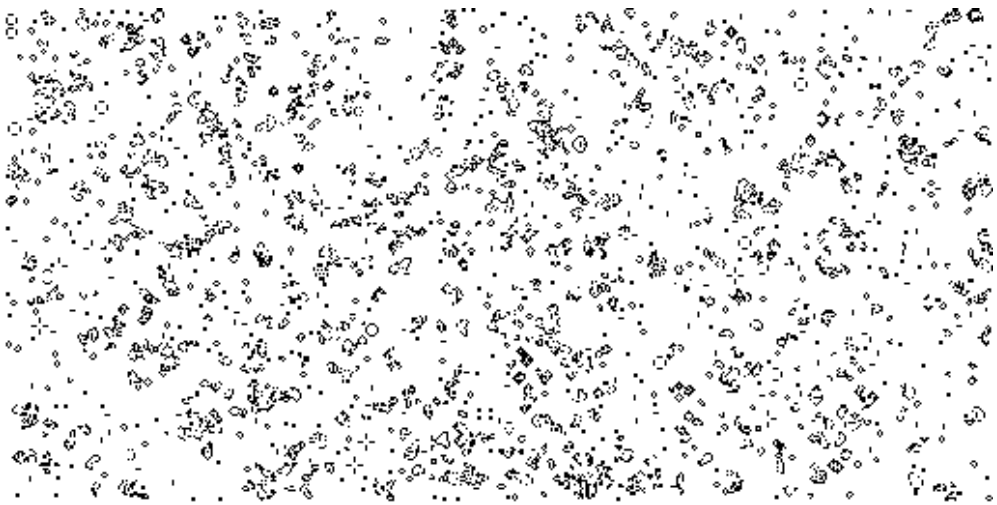


Prospectus

- Introduce two key concepts:
  - Vertical and horizontal modelling.
  - Epistemic and ontological emergence.
- Explore and compare two notions of complexity existing in the relevant literature:
  - Descriptive complexity.
  - Structural complexity.
- Argue that these two notions are associated with different kinds of emergence and different modes of modeling.

Horizontal and vertical modeling

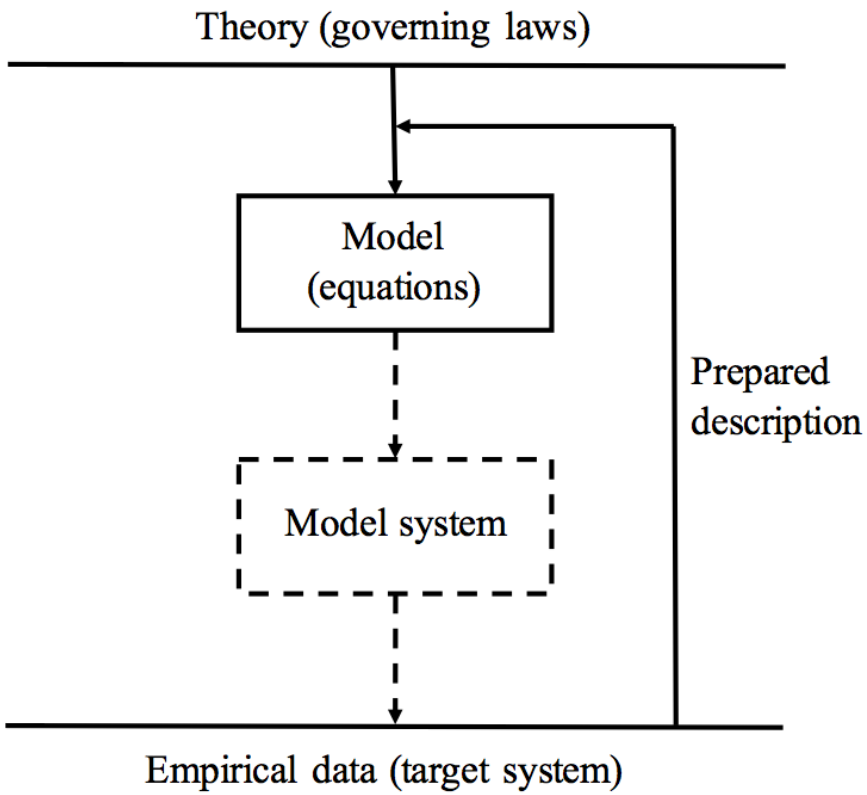
"[However,] I shall use 'theoretical modelling' in a broader sense, to include any case in which scientists deliberately simplify or idealize a system in order to explain or predict its behaviour ..."
(Toon, 2012)

Construction of vertical models:

- Constructed from empirical knowledge about a target system and the governing theory.
- Process can be described as compiling a "prepared description" (Cartwright, 1983).
- The prepared description can involve idealizations, simplifications, discretization ...
- Top-down or bottom-up construction.

Horizontal and vertical modeling

Construction of vertical models:



Horizontal and vertical modeling

Construction of horizontal models:

- Introduced by Bokulich (2003) as a second class of models besides vertically constructed ones.
- Not constructed from governing theory and empirical data but as variations of existing models.
- Horizontal models therefore have no preset target systems.
- I maintain that a different kind of horizontal modeling is associated with either notion of complexity.

Emergence

"A theory [which] describes properties or behavior which are novel and robust relative to what is described by some other theory with which it is appropriate to compare - often a theory of the system's component parts."
(Butterfield, 2011)

- The concept of emergence dominates the scientific and philosophical discourse on complexity.
- It is itself contested and various definitions of emergence exist:
  - **Epistemological emergence**: emergence on the level of theories, i.e. a behavior/property that warrants a novel and irreducible description.
  - **Ontological emergence**: emergence on the level of dynamics, i.e. a behavior/property that is caused by a novel and irreducible mechanism.

Preliminary complexity definition

"A complex system is a many-component system with directed interactions for which locally distinct patterns can be recognized in at least one representation of its behavior." (Zuchowski, 2012)

- Developed to distinguish complexity from chaos and randomness.
- Distinction between phenomenology and dynamics.
- 'Phenomenological sieve' left intentionally vague.
- **Now:** Develop into two definitions for descriptive and structural complexity, respectively.

Gliders in the Game of Life

Conway's Game of Life

- Life is a two-state, two-dimensional Cellular Automaton (CA).
- Its rules are roughly modeled on population dynamics. However, no clearly defined target system exists.
- The two states of being 'live' and 'dead' translate into black and white cells on the CA grid.
- Each cell has eight 'neighbours' which can influence its development.
- Updating of the cells' states occurs in discrete time steps and simultaneously for all cells.

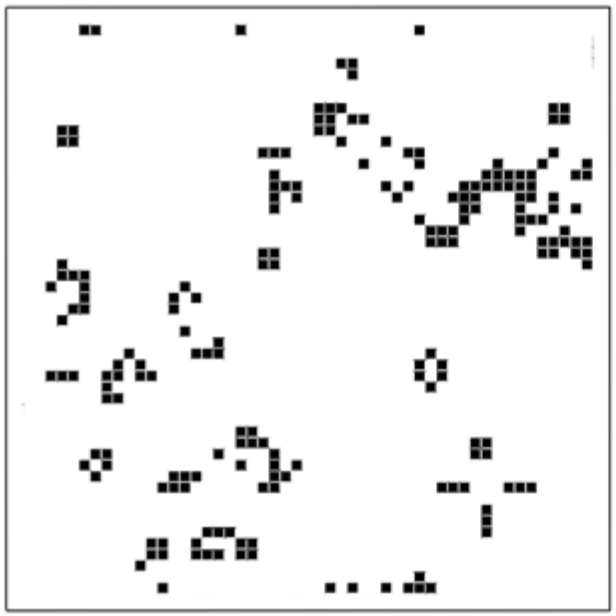
Gliders in the Game of Life

Life rule set

- A live cell with one or fewer live neighbors dies.
- A live cell with two or three live neighbors survives.
- A dead cell with three live neighbors comes alive.
- A live cell with four or more live neighbors dies.

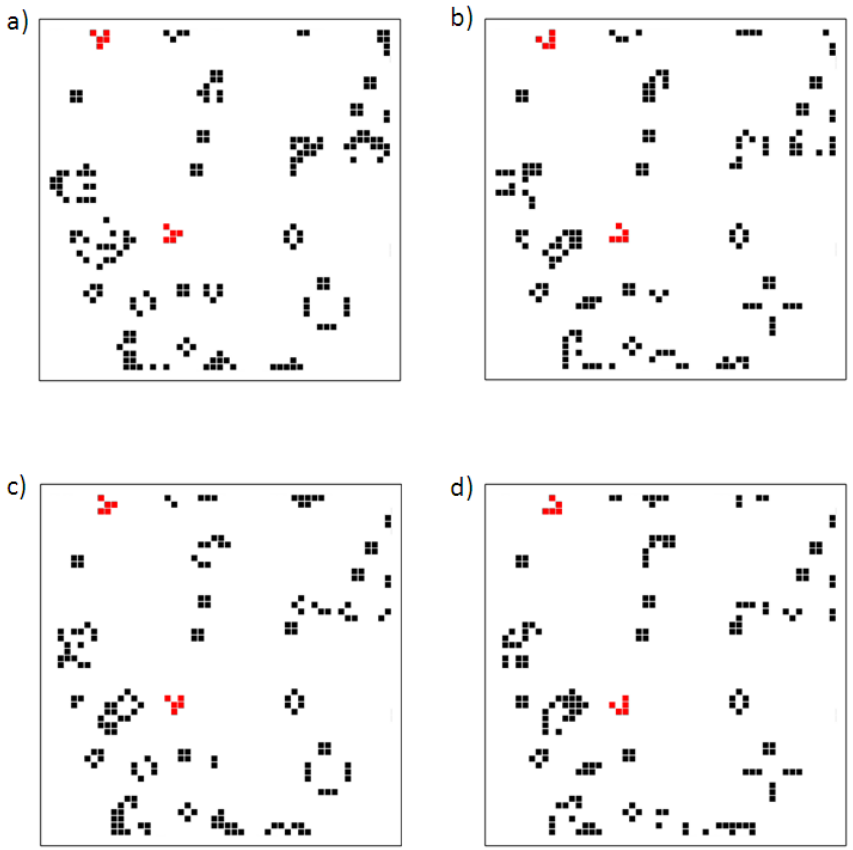
Gliders in the Game of Life

a)



b)

Gliders in the Game of Life



DC Example: Order from chaos

Holland (1998)

- **Catalogue of systems:** Game of Life; other CAs; simple game playing machines (checkers).
- **Terminology:** Microlaws, macrolaws.
- **Emergence:** (Macro)-Patterns from component behaviour.
- **Modeling:** Horizontal modeling.

DC Example: Order from chaos

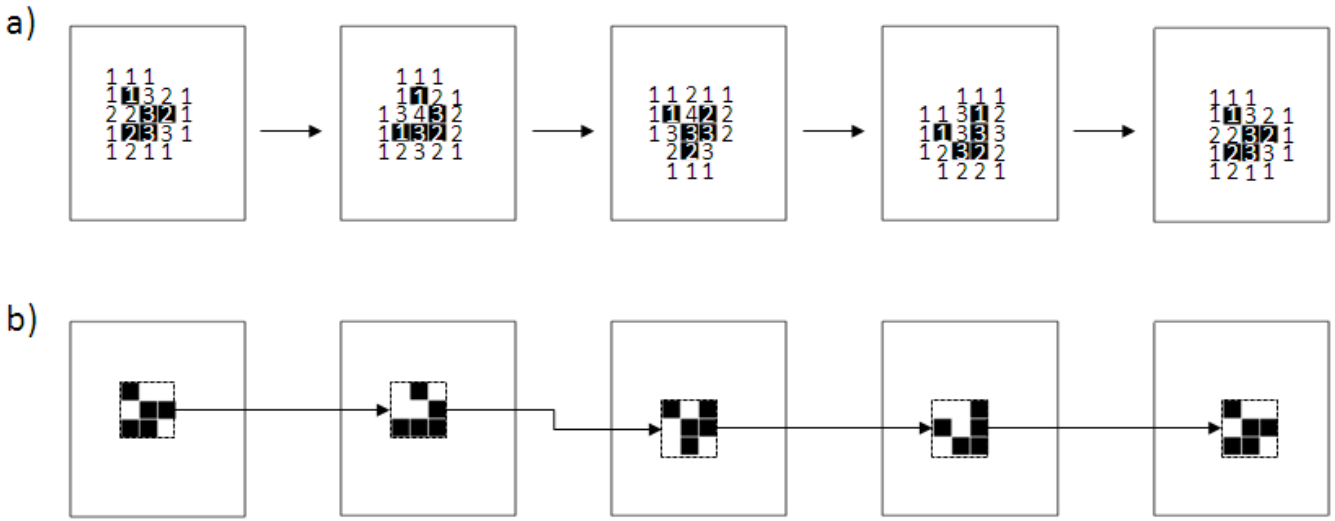
Holland (1998)

"Persistent patterns often satisfy macrolaws. When a macrolaw can be formulated, the behaviour of the whole pattern can be described without recourse to the microlaws. Macrolaws are typically simple relative to the behavioural details of the component elements."

Complexity notion: Multi-component systems with simple microlaws and phenomenologies with persistent patterns, which can be described by macrolaws.

DC Example: Order from chaos

Micro- and macrolaws in the Game of Life



Further DC examples

- **Wolfram (2002)**: Emergence of (ordered) patterns in CAs.
- **Bak (1997); Strevens (2003)**: Self-organization; Emergence of patterns describable by power-laws.
- **Crutchfield (1997); Shalizi (2001)**: Efficient predictability; Emergence of macrolaws.
- **Bedau (2008)**: Weak emergence; emergence of macrolaws, which increase causal powers of the complex system.
- **Cohen & Steward (1994; 1997)**: Simplexity (single set of complex rules leading to simple patterns).

Descriptive complexity

A **descriptively complex system** is a many-component system with directed interactions governed by a fixed rule-set for which epistemological emergent patterns can be recognized in at least one representation of its development.

- The definition is very similar to my original definition.
- The addition of a fixed rule-set condition serves to demarcate descriptively complex and structurally complex systems.
- Descriptive complexity uses epistemological emergence as a means to 'sieve out' systems with interesting phenomenologies.
- Descriptively complex models usually have no clearly defined target systems; they are often constructed by rule space parsing.

Descriptive complexity

	Descriptive Complexity
Phenomenology	Patterns
Dynamics	Fixed Many components
Emergence	Epistemological
Reductionism	Yes
Modelling	Horizontal RS Parsing
Examples	CAs Networks

SC Example: Everything emerges

Morowitz (2002)

- **Catalogue of systems:** Twenty-eight emergences in the history of the universe and mankind.
- **Terminology:** Pruning rules.
- **Emergence:** Higher-level dynamical entity selected by pruning rule. (Note that the emergent event is the selection, not the process.)
- **Modelling**: Vertical?

SC Example: Everything emerges

Morowitz (2002)

"The beginning state is one of great simplicity. Yet lurking within it must be all the forthcoming complexities [...]. The bottom line is that the emerging planet is complex both structurally and kinetically. Within this complexity lies the possibility of far more development of structures and processes and emergence of new features."

Complexity notion: A system with different interacting dynamical subsystems and with multiple possibilities for the development of these dynamics.

SC Example: Everything emerges

Gliders?

- It is difficult to make sense of pruning rules in the context of deterministic systems like Life.
- Fromm (2004) on Gliders:
  "A temporary increase in complexity" but not a fully emergent phenomenon.
- BUT: Morowitz (2002) endorses Holland (1998) as a "ground-breaking book on emergence".

Further SC examples

- **Kauffmann (2000; 2008)**: Self-construction by autonomous agents; expansion into the adjacent possible.
- **Cohen & Steward (1994; 1997)**: Complicity (several sets of rules converging to produce simple patterns).
- **Langton (1990)**: Genetic algorithms; transition to 'the edge of chaos'.
- Learning systems?

Structural complexity

A **structurally complex system** is a system with several components governed by a variable rule-set which changes in response to either patterns in its phenomenology or a meta rule-set.

- The definition covers those examples prevalent in the complexity literature but poorly served by my original definition.
- The variable rule-set condition serves to demarcate descriptively complex and structurally complex systems.
- Structural complexity is associated with ontological emergence since it entails an alteration of the underlying mechanisms.
- Structurally complex models appear to be usually envisioned as vertical models.

Structural complexity

	Descriptive Complexity	**Structural Complexity**
Phenomenology	Patterns	*Patterns*
Dynamics	Fixed Many components	Changing Several components
Emergence	Epistemological	Ontological
Reductionism	Yes	*No*
Modelling	Horizontal -RS Parsing	Horizontal -Genetic Parsing Vertical
Examples	CAs Networks	Genetic algorithms Learning systems Composite models

Conclusion

- There are two co-existing notions of complexity:
  - Descriptive complexity.
  - Structural complexity.
- A main difference between the two notions is the existence of fixed and variable dynamics, respectively.
- The two notions are poorly distinguished in the literature but are associated with different notions of emergence and different modes of modeling.
- Open questions:
  - Are structurally complex models always associated with descriptive complexity at some stage in their development?
  - What are the advantages and limitations of the predominantly horizontal construction of descriptively complex models?