Introduction to Cellular Automata (CAs)

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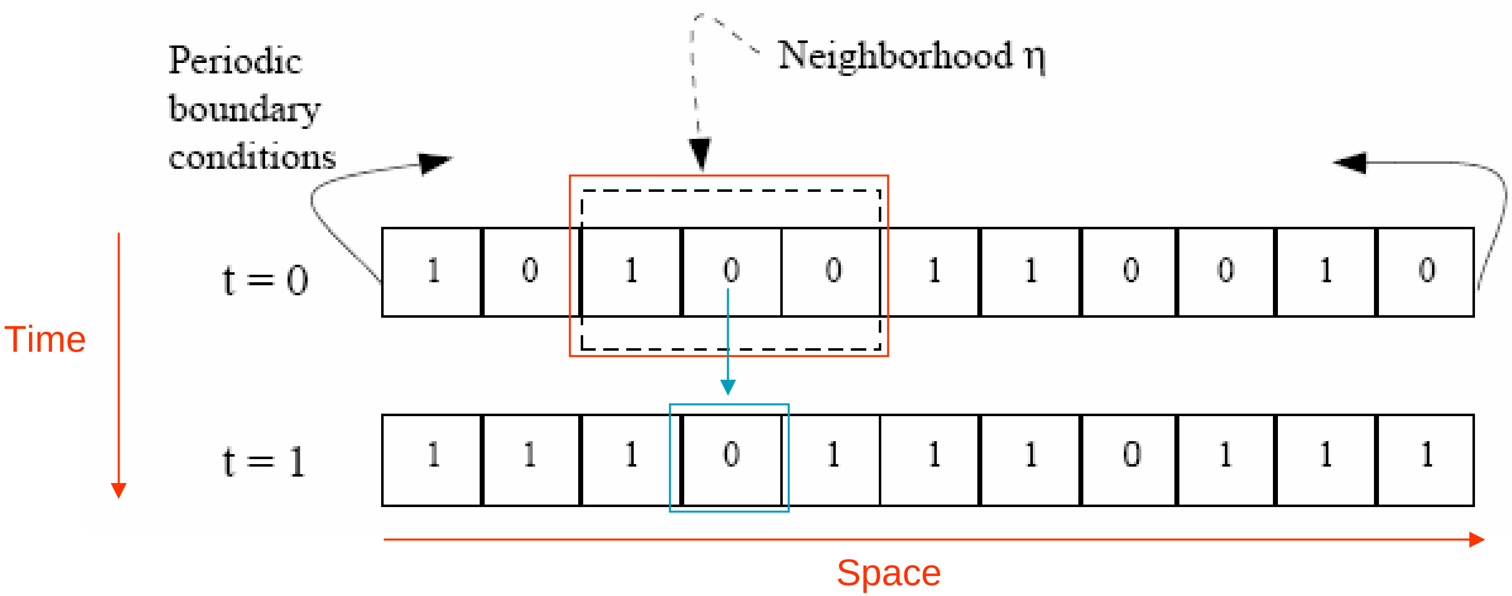
Cellular Automata – micro-level rules

Rule table ϕ:

neighborhood:	000	001	010	011	100	101	110	111
output bit:	0	1	1	1	0	1	1	0

= Rule 0x6e = Rule 110

Lattice:



- From “Computation in Cellular Automata: A selected review”, Mitchell, 1998

CA tools

- NetLogo
  - Models Library / Sample Models / Computer Science / Cellular Automata
- Mirek’s Cellebration
  - Mirek’s Java Cellebration
- Wuensche’s DDLab
- Or just google it …

Why are we interested in CAs?

- Highly flexible modelling tools used to model many real systems:
  - Bushfires
  - Biological pattern formation
  - Fluid flow
  - Galaxy formation
  - Earthquakes
- Exhibit typical behaviour of complex systems.
- Great test-bed for complex system analysis.
- Interesting as dynamical systems in their own right: difficult to effectively predict behaviour for some rules ...

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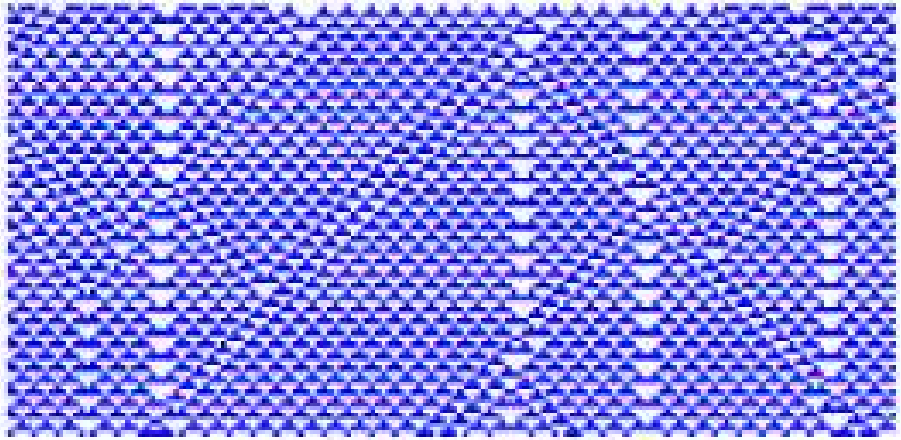
Interesting CAs

- ECA (1D, binary states, r=1) rule 110
- Conway's Game of Life (2D, binary states, r=1):
  - Cell off & 3 living neighbours -> alive.
  - Cell on requires 2 or 3 living neighbours to survive.
- Wolfram's four classes of asymptotic behaviour:
  - Class I: Homogeneous state
  - Class II: Simple stable or periodic (rule 90)
  - Class III: Chaotic aperiodic behaviour (rule 30, 18)
  - Class IV: Complex, localised structures, some propagating (rule 110)
    - Conjectured to be capable of Turing universal computation
  - Much criticism, but interesting analogies and focus on emergent structure

Cellular Automata – emergent structure

- “Classifying Cellular Automata Automatically …”, Wuensche, 1999



cells by value

- Emergent structure:
  - Domain: set of background configurations
  - Particles: dynamic elements of coherent spatiotemporal structure
    - Gliders, Blinkers, Domain walls
  - Collisions

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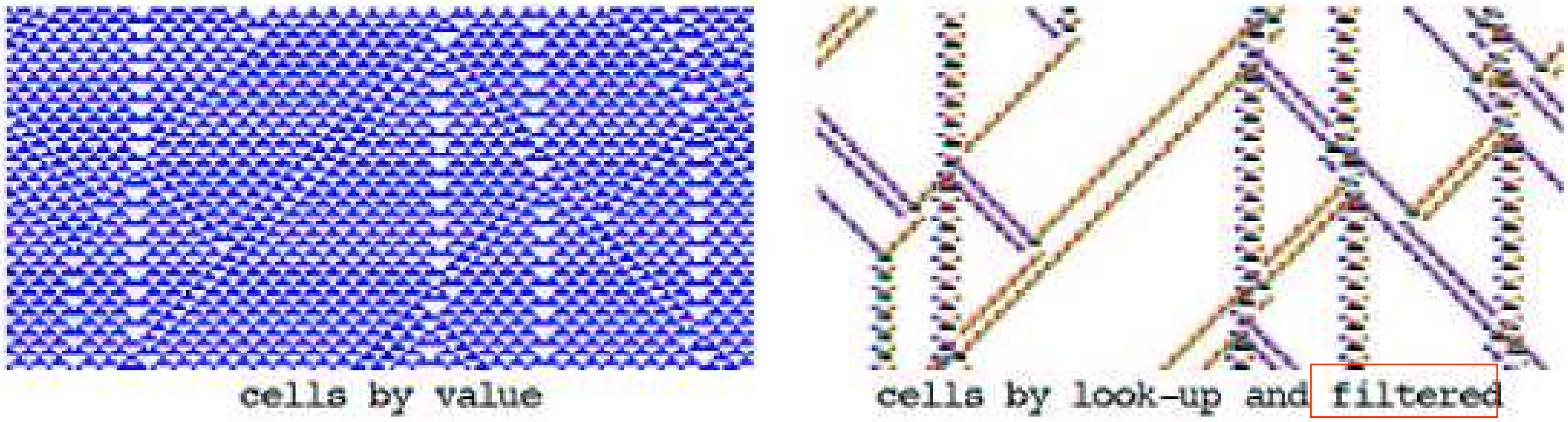
Cellular Automata – filtering for structure

- "Classifying Cellular Automata Automatically …", Wuensche, 1999



- Existing filtering methods to highlight emergent structure:
  - Computational dynamics (finite state transducers) (Crutchfield and Hanson)
  - Frequency of rule execution (Wuesnche)
  - Local statistical complexity and sensitivity (Shalizi et al)
  - Local information (really local spatial entropy rate) (Helvik et al)

Cellular Automata – computation

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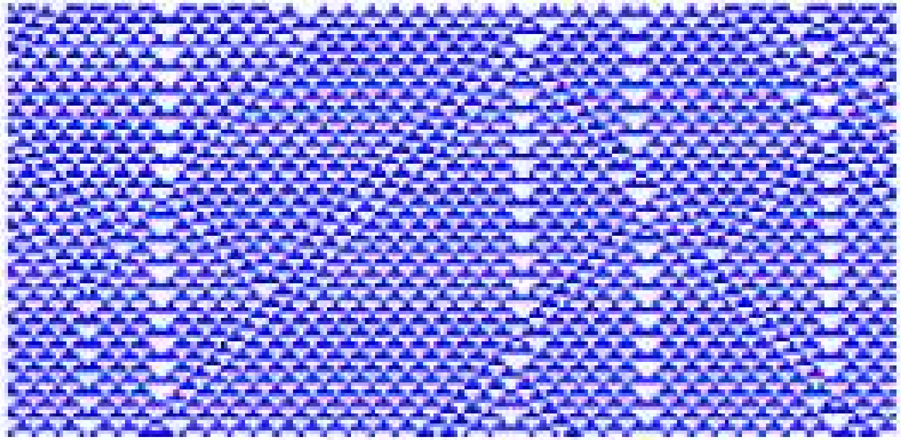
- "Classifying Cellular Automata Automatically …", Wuensche, 1999



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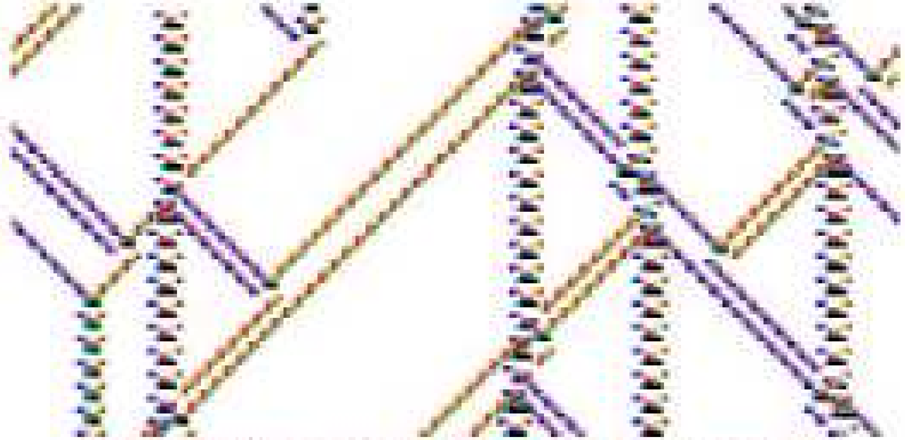

cells by look-up and filtered

- Emergent structure:
  - Domain
  - Particles
    - Gliders, Domain wa
  - Collisions

- Conjectured to represent:
  - nformation transfer
    - "
  - Information modification

No quantified evidence (yet)!!

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References

- Wolfram: "A new kind of science", 1986, 2002.
- Mitchell: "Computation in CAs: A review", 1998.
- Wuensche: "Classifying cellular automata automatically …", 1999.
- Lizier et. al.: "Detecting non-trivial computation in complex dynamics", 2007.