Patterns in Nature 7
Cellular Automata

Stephan Matthiesen

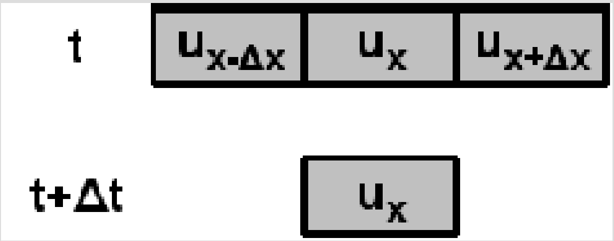
Self-organization Definition

Self-organization is a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level components of the system. Moreover, the rules specifying interactions among the system's components are executed using only local information, without reference to the global pattern.

(Camazine et al 2001, p. 8)

(1-dimensional) Cellular automata

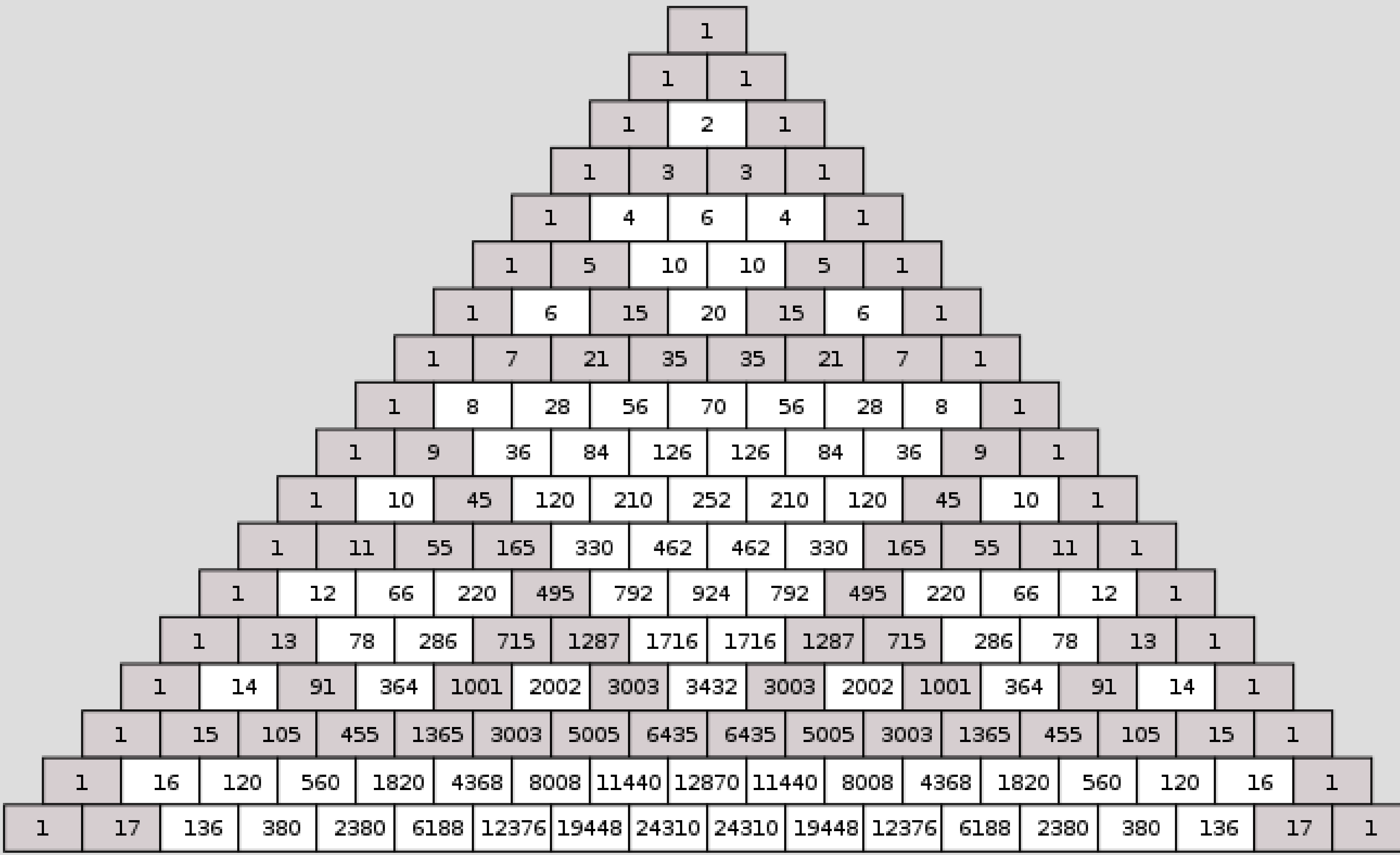
- Computer model
- The model is “discrete”:
  - Array (line) of cells
  - Each cell can have a finite number of different states (“alive” or “dead”)
- State of a cell changes each timestep depending on the state of its neighbours



Example of 1-d CA: Pascal's triangle

- A cell becomes alive if there is exactly 1 neighbouring cell alive in the previous timestep
- This is a **totalistic** rule (i.e. only the sum of values for all neighbours counts)

Pascal's triangle (modulo 2)



Cellular automata programme

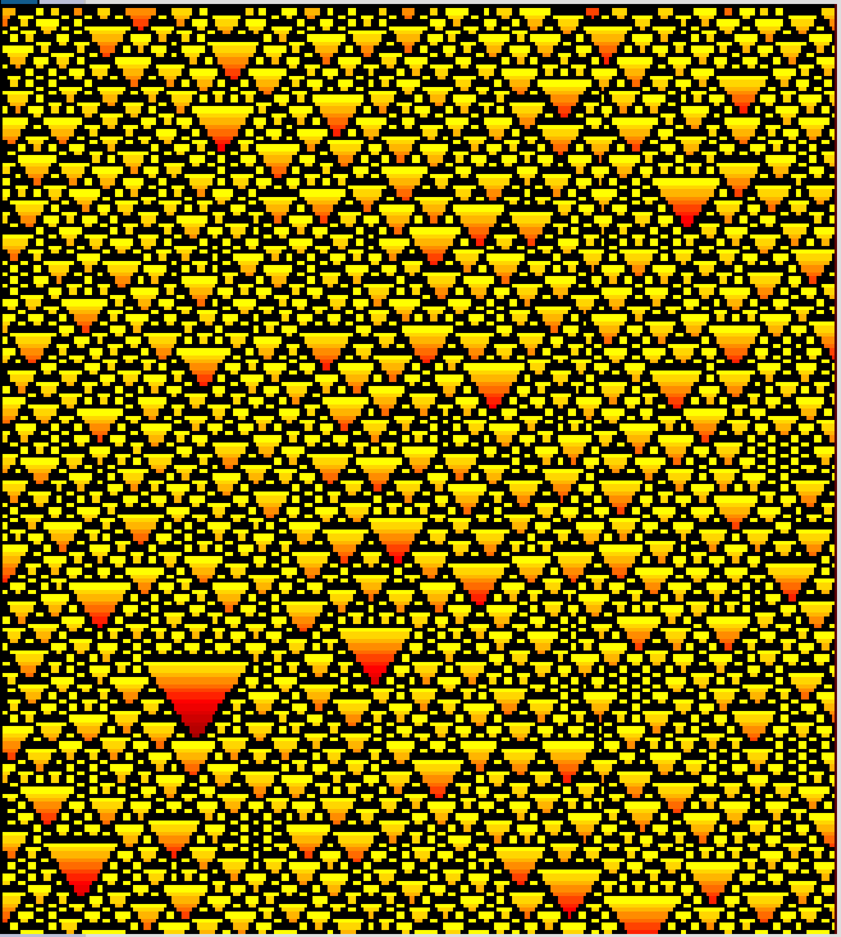
Cellular automata programme:

Mirek's Cellebration
1D and 2D Cellular Automata explorer
by Mirek Wojtowicz

Mcell (download) or MJCell (online Java)
http://www.mirekw.com/ca/index.html

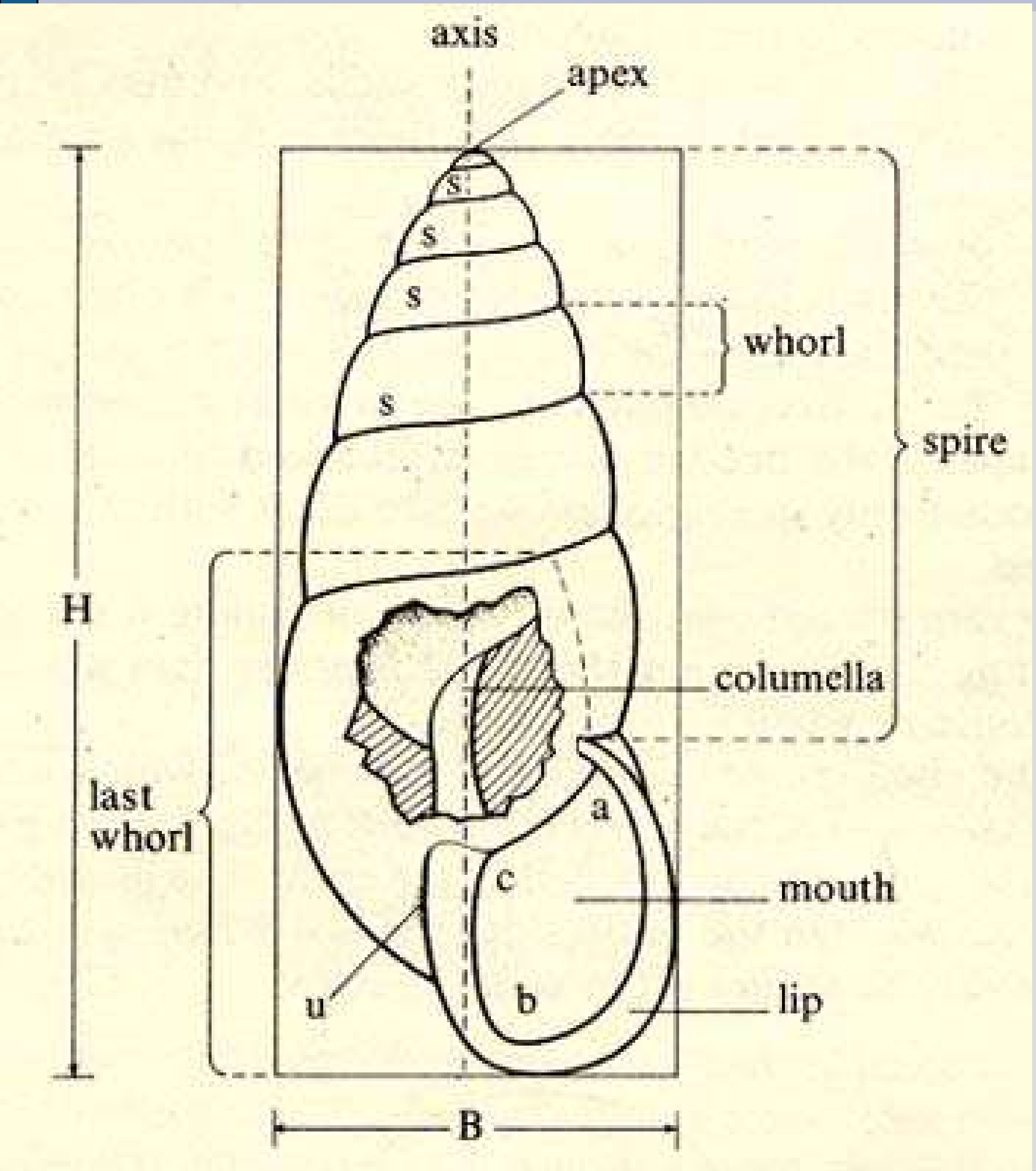
Some more 1-d automata

- “Porridge” (R1,C0,M1,S0,S3,B0,B2)



Conus textile

Shell patterns

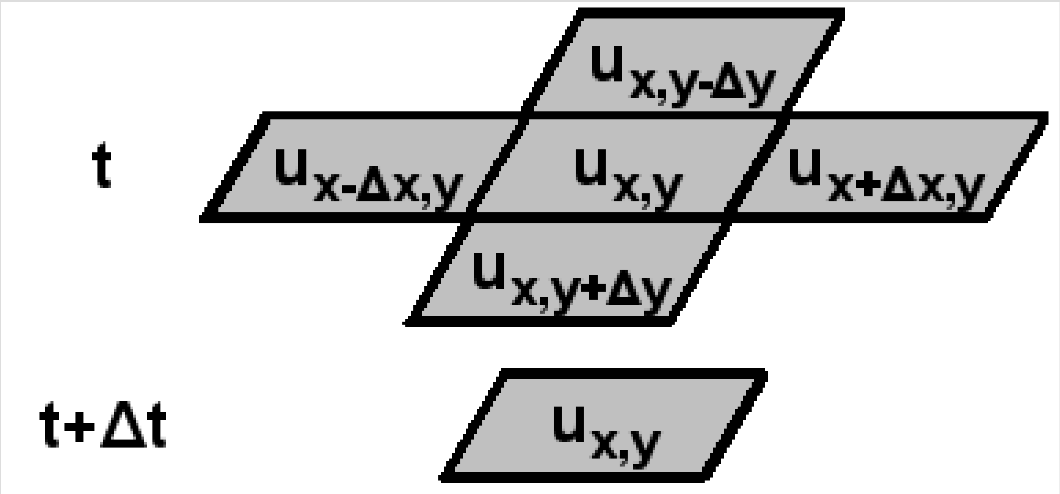


Some 1-d CAs to try out

- Totalistic rules:
  - Date palms (Range 5, Count 0, Middle Cell 1, Survive 0, S7, S8, S9, S10, S11, Born 0)
  - Forest (R10, C0, M0, S1, S2, S6, S7, S9, S12, S14, S17, B1, B7, B10, B11, B13, B15, B16, B17, B19)
  - Walls (R2,C15,M1,S2,S3,B1,B3)
- Binary rules
  - Filiform gliders (R2, W1C2A4798)
  - Scaffolding (R2, W6EEAED14)

2-dimensional CAs

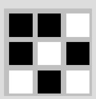
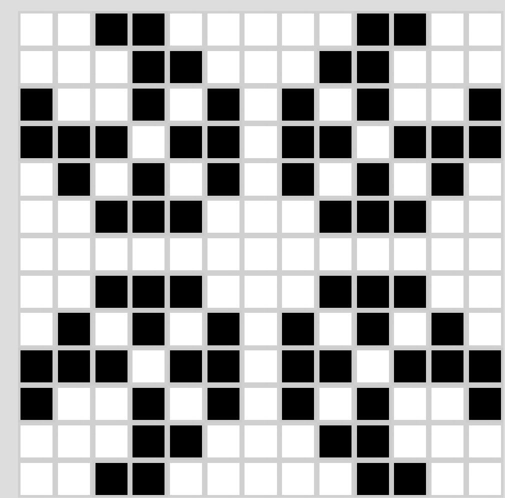
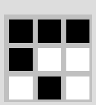
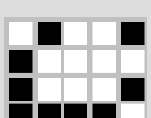
- Instead of a row of cells, use an array
- Neighbourhoods:
  - von Neumann: 4 cells
  - Moore: 8 cells (i.e. also diagonals)



Conway's “Game of Life”

- 2-dimensional array
- John Horton Conway (1970)
- Outer totalistic (i.e. middle cell doesn't count)
- Rule S23/B3
  - Survive if they have 2 or 3 neighbours
  - Are born if they have 3 neighbours
- Complex behaviour
  - Still: “Blocks”, “boats”
  - Stationary 2-phase oscillators: “blinkers”, “toads”
  - 3-phase oscillator “pulsar”
  - Moving: “gliders”, “lightweight spaceship”

Conway's “Game of Life”

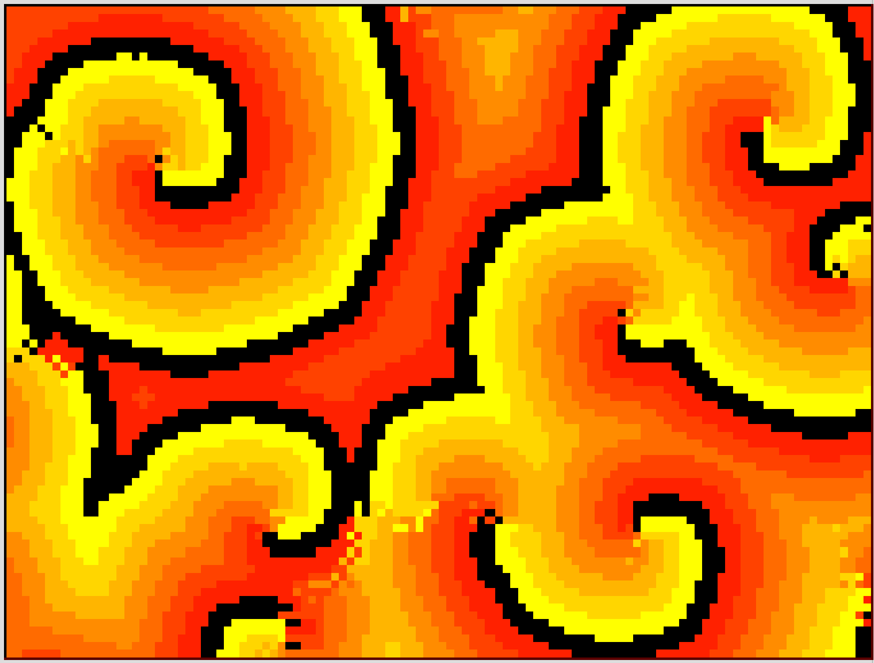
- Still:
  
  - “Blocks”
  
  - “boats”
- Stationary 2-phase oscillators:
  
  - “blinkers”
  
  - “toads”
- 3-phase oscillator:
  
  - “pulsar”
- Moving:
  
  - “gliders”
  
  - “lightweight spaceship”

Cyclic CAs

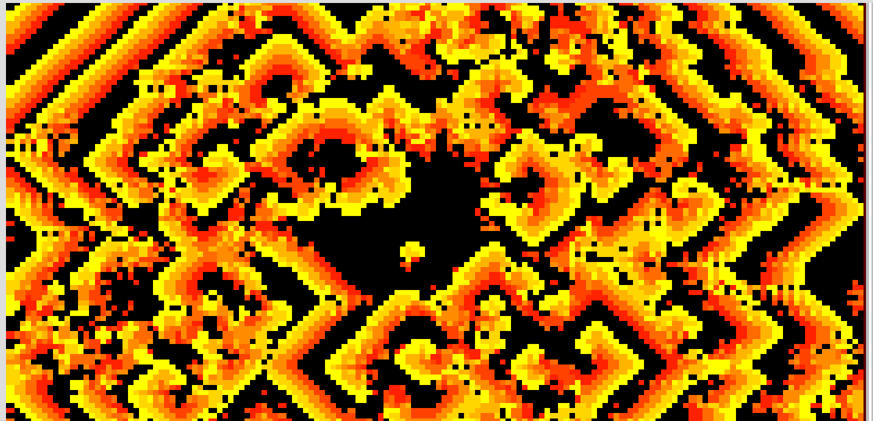
- Cells can only cycle through a sequence of states:
  e.g. 0-1-2-3-...-n-0-1-2-3-...-n-0-...
- Advance to next state if enough neighbouring cells are already in that state
- Special case: Greenberg-Hastings model:
  - 0-1 when enough neighbours are in state 1
  - from state 1, advance through states 1-..-n-0 automatically

Belousov-Zhabotinski

GH (cyclic Range3 / Threshold5 /Count8 / N.Moore / GH)



BelZhab (Gen 23/23/8)



Other interesting ones

- Amoeba (cyclic Range 3, Threshold 10, Count 2, N. v. Neumann) – try with 50% random seeds
- Brian's brain (generations) – a cell fires if exactly two of its neighbours fire

Applications

- Cellular automata are sufficiently simple to allow detailed mathematical analysis, yet sufficient complex to exhibit a wide variety of complicated phenomena.
(Stephen Wolfram, 1983)

... not many models based on cellular automata really grew over the phenomenon hype to a useful tool.
(anonymous Wikipedia author, 2005)

Patterns in Nature
Outline


1. Introduction
2. Waves and oscillations
3. Regularity and chaos
4. Animal cooperation
5. Spatial patterns
6. Aggregation and growth processes
7. Cellular automata
8. Fractals
9. Miscellaneous topics
10. Concluding session