Emergence in Artificial Life

Sebastian Marius Kirsch
skirsch@moebius.inka.de

Artificial Life

- ‘not life as it is, but life as it could be’
- very recent field of science
- first a-life conference in Los Alamos 1987
- traditional biology is limited to the study of carbon-based life on planet earth
- a-life generates a laboratory for the study of the general principles of life
- usually experiments conducted with the help of computers
- complex structures emerge from extremely simple rules
- local interaction plays a crucial role
- the whole is larger than the sum of its parts

Emergence

emer·gence

1. the act or an instance of emerging

emerge

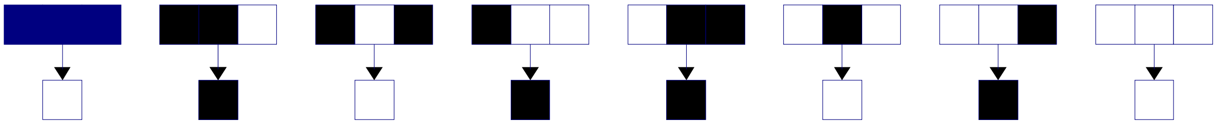
1. to become manifest
2. to rise from or as if from an enveloping fluid: come out into view
3. to rise from an obscure or inferior position or condition
4. to come into being through evolution

Emergence is used to describe features that are not obvious from the description of the system, but only emerge after simulating it.

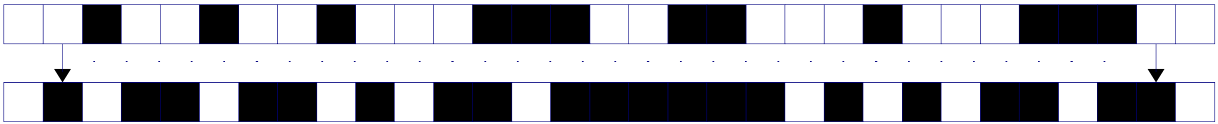
Back
Close

Cellular Automata

- grid of ‘cells’
- state is determined by the state of the neighbourhood cells
- time discrete and space discrete model of strictly local interaction
- parameters: dimension, number of states, neighbourhood
- simplest kind: a string of cells, each with one of two states, looking only at its immediate neighbours
- ruleset



- sample update step



Back
Close

CA: Four Classes of Behaviour

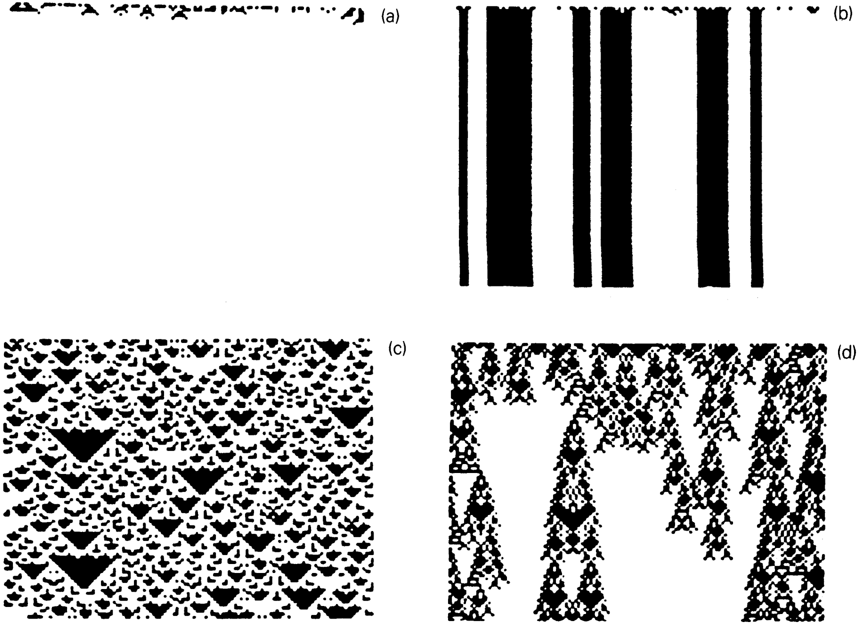
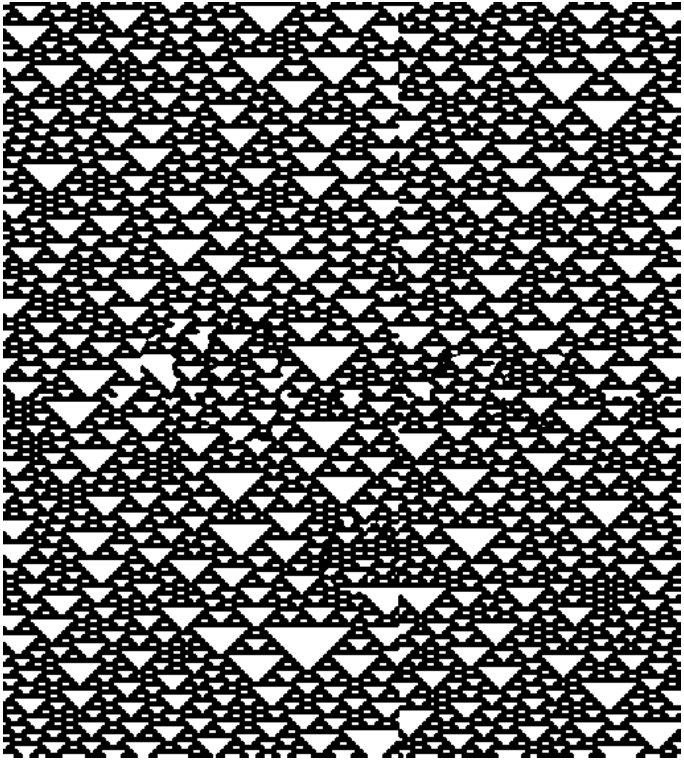


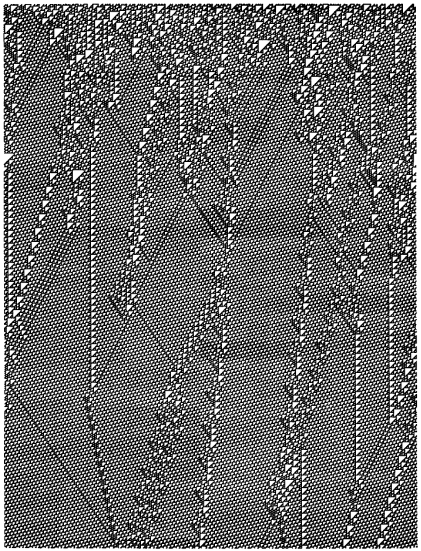
Figure 3. Four classes of behaviour found in evolution of one-dimensional cellular automata from disordered initial states. [5]

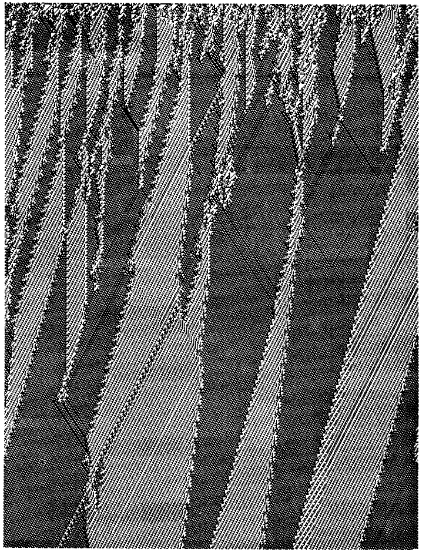
CAs and sea shells



CA: Rule 110

- rule 110 is turing complete (proof by simulation of a cyclic tag system) [6, p. 678]
- examples of localized structures





Langton’s loop

- self-reproducing cellular automaton
- inspired by von Neumann’s self-reproducing automaton
- reminiscent of a coral
- 8 states, 207 rules; smaller loops have been found
- extremely fragile, not a model for natural self-reproduction

Back
Close

Lindenmayer systems

- developed as a tool in biology
- substitution system, originally implemented using 'turtle graphics'
- vocabulary:

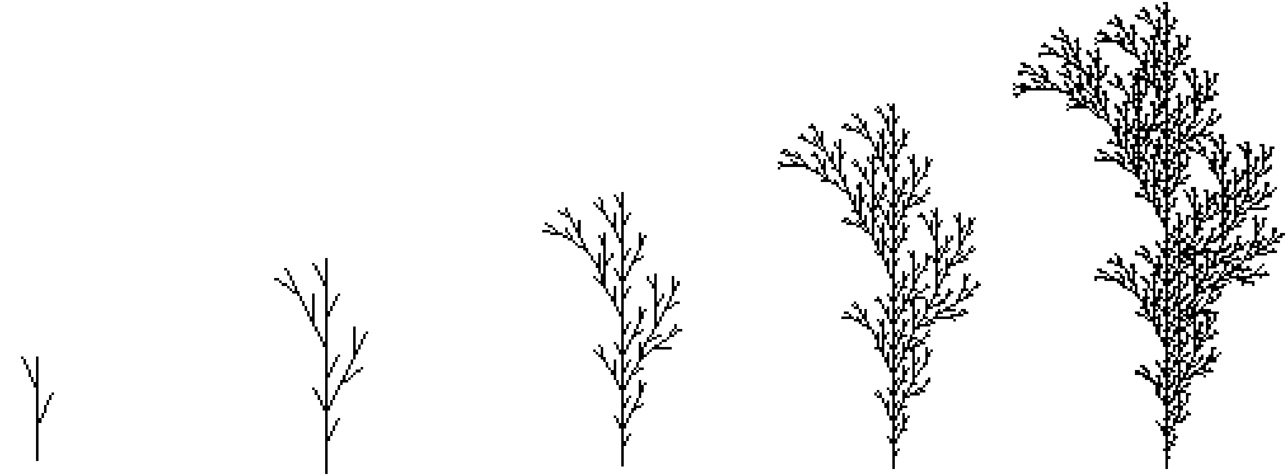
F	draw line
+	rotate left
−	rotate right
[	push current position on stack
]	pop current position from stack

- simple rules generate complex shapes (Chaitin-Kolmogoroff complexity)
- 'fractal geometry of nature' (Mandelbrot)
- certain fractals (Koch curve, Koch islands, Peano curves) can also be expressed using this formalism

Development of an L-System

$\rightarrow$ F

F $\rightarrow$ F[$-$F]F[$+$F][F]



F[-F]F[+F][F]

F[-F]F[+F][F][-F
[-F]F[+F][F]]F[-
F]F[+F][F][+F[-
F]F[+F][F]][F[-F
]F[+F][F]]

F[-F]F[+F][F][-F
[-F]F[+F][F]]F[-
F]F[+F][F][+F[-
F]F[+F][F]][F[-F
]F[+F][F]][-F[-F
]F[+F][F][-F[-F]
F[+F][F]]F[-F]F[
+F][F][+F[-F]F[
+F][F]][F[-F]...

F[-F]F[+F][F][-F
[-F]F[+F][F]]F[-
F]F[+F][F][+F[-
F]F[+F][F]][F[-F
]F[+F][F]][-F[-F
]F[+F][F][-F[-F]
F[+F][F]]F[-F]F[
+F][F][+F[-F]F[
+F][F]][F[-F]...

Back
Close

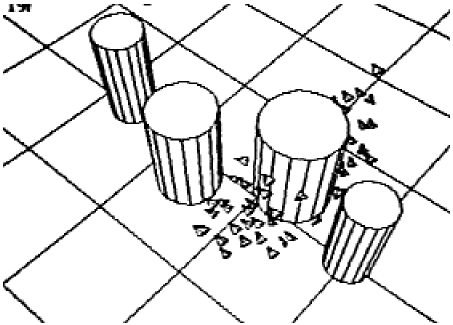
Lindenmayer systems: examples

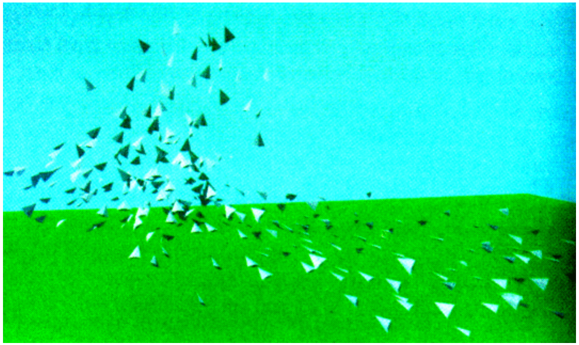
angle 22.5°
$\longrightarrow F$
$F \longrightarrow FF - [-F + F + F] + [+F - F - F]$

angle 22.5°
$\longrightarrow X$
$X \longrightarrow F - [[X] + X] + F[+FX] - X$
$F \longrightarrow FF$

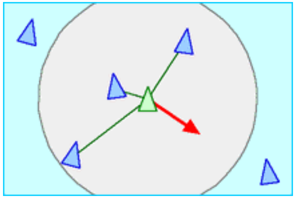
Flocking

- Craig Reynolds: *Flocks, Herds, and Schools: A Distributed Behavioral Model*, 1987
- 'boids'
- emergent behavious from simple, local rules (again)
- 'boids flock, but that's not what they think they are doing'
- other applications: schools of fish, swarms of insects, stampedes

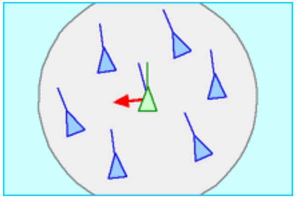




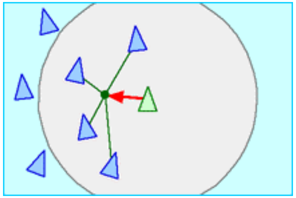
Flocking: Local rules



Separation: steer to avoid crowding local flockmates



Alignment: steer towards the average heading of local flockmates



Cohesion: steer to move toward the average position of local flockmates

Fractals?

- a strong indication that the geometry of nature is indeed fractal
- so artificial life must also be fractal
- what is a fractal?
- 'A fractal is by definition a set for which the Hausdorff Besicovitch dimension strictly exceeds the topological dimension.'[2, p. 15]
- Hausdorff dimension is difficult to determine from first principles
- other indications: scale invariance, yardstick length ($L(\epsilon)$)
- some cellular automata exhibit those characteristics
- L-Systems are similar in construction to certain fractals (have also been called 'graphtals')

Chaos?

- chaos theory
- theory of nonlinear dynamic systems
- usually expressed in terms of partial differential equations
- can be approximated using cellular automata
- eg. thermodynamics, formation of galaxies
- activator-inhibitor models

References

[1] Steven Levy: *Artificial Life.* New York: Vintage Books, 1993.

[2] Benoit B. Mandelbrot: *The Fractal Geometry of Nature.* New York: W. H. Freeman and Company, 1977.

[3] Prszemislav Prusinkiewicz, Aristid Lindenmayer: *The Algorithmic Beauty of Plants.* New York: Springer, 1990.

[4] Hugh Stix: *The Shell.* New York: Harry N. Abrams, 1978.

[5] Stephen Wolfram: *Cellular Automata and Complexity.* Reading: Addison-Wesley, 1994.

[6] Stephen Wolfram: *A New Kind of Science.* Champaign: Wolfram Media, 2002.

The slides for this talk are available online at `http://sites.inka.de/moebius/origami/dessau2003.pdf`