rule 110

{ Alife Mutants Hackingsession on Systems and Organisms, Bielefeld 2004 }

{ Cellular Automata in Biology }

One-dimensional CA, rule 110
Lambda Parameter
Two-dimensional and mobile CA
Natural CA-like Phenomena
Alife Mutants

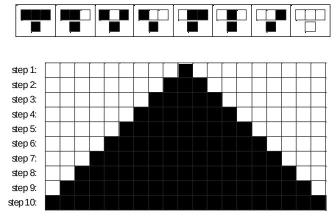
rule 110

{ *1D Cellular Automata* }

- Cellular Automata (CA) – a type of computing machine
- The formalism for CA was invented by Jon von Neumann in the 1940

- Linear grid extends to the left and right. The grid consists of the cells that may be in only one of a finite number of states. At each time step, the next state of a cell is computed as a function of its neighbors local in space

- A graphical representation of the rule 254 for one-dimensional CA
- Evolution a cellular automaton (10 steps)



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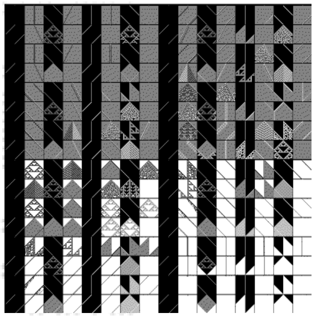
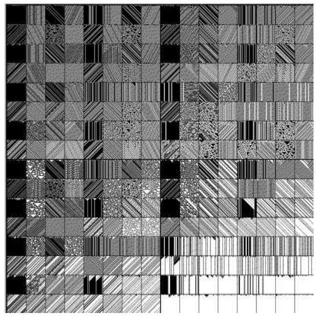
{ *The World of 256 Simple Programs* }



Each array was started with a single "on" cell in the middle



The top line in each block is a random initial array of 1's (white) and 0's (black)

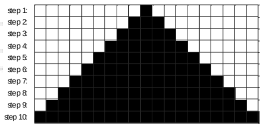
rule 110

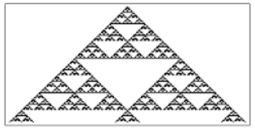
{ *Wolfram's CA Classification (1980)* }

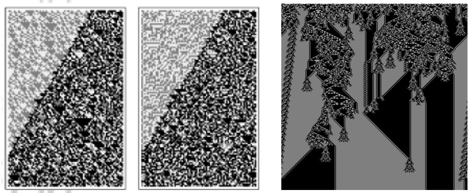
The behavior of all CA falls into one of only four classes:

I. Evolution leads to a homogeneous state
II. Evolution leads to a set of separated simple stable or periodic structures
III. Evolution leads to a chaotic pattern
IV. Evolution leads to complex localized structures, sometimes long-lived (i.e. gliders)

{ I-IV Wolfram's Classes }







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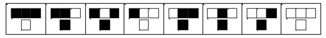
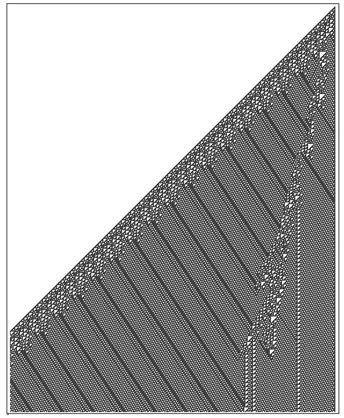
{ rule 110 }



- The number 110 refers to the enumeration scheme introduced by Stephen Wolfram in 1983. Its rule outcomes are encoded in the binary representation $110=01101110_2$
- Rule 110 was investigated by Matthew Cook (1999). Amazingly, the rule 110 cellular automaton is universal
- Rule 110 if applied to a sufficiently large graph, begins to generate complex irregular structures that do not appear to be predictable from the input row – the top row of the graph



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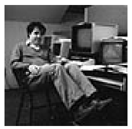
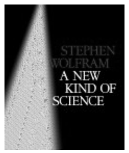
{ New Kind of Science }

- Rule 110 has recently gained attention as a result of a book written by Stephen Wolfram, known as the author of the software program *Mathematica*. The book, called a *New Kind of Science*, suggests that both space and time can be modeled by cellular automata such that a relatively simple set of rules governing the content of a cell might lead to the actual complexity that we experience in the physical world. A cell in this case would be a discrete unit of space, itself spread into discrete units along a time axis, with rules governing its transition from one state to another based on the properties of neighboring cells





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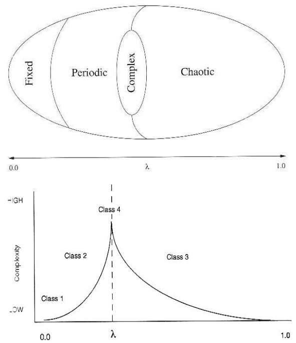
{ Langton's Lambda Parameter }

- Like Wolfram, Langton ran thousands of CA simulations and cataloged the rules that yielded the types of dynamics

$\lambda=(N-n_q)N$, where

- N – total number of entries in the rule table
- n_q – number of rules that map to the quiescent state
- λ – fraction of all the rules that map to a non-quiescent state

$\lambda=[0, 0.8]$; {0.228, 0.439, 0.816, 0,502} are average values of λ for different classes I-IV



λ=0,502 – only here can information be stable enough to support a message and loose enough to transmit messages. Life lives there!

{ 2D Cellular Automata }

John Conway's *Game of Life*. In 1960, Conway was motivated to extend von Neumann's work

- If a live cell has less than two neighbors, then it dies (loneliness)
- If a live cell has more than three neighbors, then it dies (overcrowding)
- If an empty cell has three live neighbors, then it comes to life (reproduction)
- Otherwise (exactly two live neighbors), a cell stays as is (stasis)

Chris Langton's *Self-Reproducing Loop* (1979)

{ Mobile Cellular Automata }

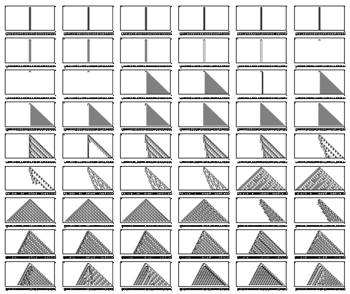
Vants – virtual ants (Langton) – the simplest and most persuasive examples of emergence of high-level structures from low-level dynamics

- Vants live on a 2D Euclidean lattice and come in two flavors, *red* and *blue*
- Each vant can move in any of four directions. Each lattice site is either empty or contains one of two types of food, *green* or *yellow*
- How a vant moves through the lattice depends on its color…

Agent based *StarLogo* programming – decentralization, parallel execution

{ Natural CA-like Phenomena }

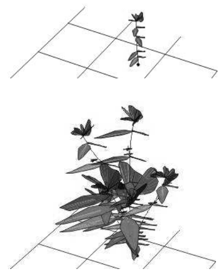
- Evolution of CA obtained by successive random mutations



- *L-systems* (Lindenmeyer , 1987)
- *Biomorphs* (Richard Dawkins)
- Biological Pigmentation Patterns
- The Algorithmic Beauty of
  - Plants
  - Seaweeds, Sponges and Corals
  - Sea Shells

{ Principia Evolvica }

- Genetic algorithms (GA) are computational models of adaptation based on natural selection (John Holland, 1960)
- Genetic operations: *reproduction*, *crossover*, *mutation*
- CA + GA = evolution
- Christian Jacob – Principia Evolvica, 1997



{ Artificial Worlds }

Artificial Life (AL) is an attempt to understand life as a larger context

- Tom Ray – *Tierra* http://www.talkorigins.org/faqs/tierra.html
- Larry Yaeger – *PolyWorld* http://homepage.mac.com/larryy/larryy/PolyWorld.html
- Karl Sims – *3D Creatures* http://www.genarts.com/karl/evolved-virtual-creatures.html
- Carlo Comis – *DarwinBots* http://digilander.libero.it/darwinbots
- Jeffrey Ventrella – *Gene Pool* http://www.ventrella.com/GenePool/gene_pool.html

{ CA Rule Extraction }

Konrad Zuse's (1967) idea that the simple rules generate both the common structures and the complexity

Ed Fredkin's point of view that a mouse, for example, is "a big, complicated informational process“

- Genomes sequencing and investigation of patterns of gene activity – NCBI http://www.ncbi.nlm.nih.gov
- Richards, Meyer, Packard (1989) have suggested a way to extract 2D CA rules directly from experimental data
  - They idea is to use a genetic algorithm to search through a space of a certain class of cellular automata rules for a local rule that best reproduces the observed behavior of the data
  - It was applied to pattern of dendrites formed by NH_4Br

{ rule 110, AMHSO, 06-13 march 2004, Bielefeld (Germany) }

- Annual meeting to discover the rules that govern life, the universe and everything by computer simulation
- Cellular automaton that is able to perform universal computation
- Mutants of all species, recombine!

{ Key Topics }

- artificial societies
- evolution and development
- growth and form
- dynamic systems
- networks and small worlds
- origins of life
- swarm intelligence
- selfassembly
- selforganisation and selfreplication

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{ Alife Mutants }