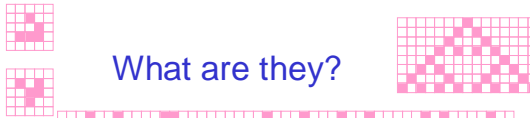


Cellular Automata

The game of life or a new kind of science?

Richard Ladner

1

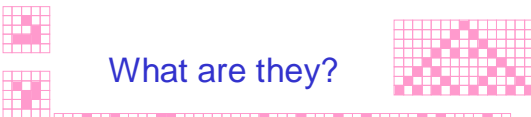


What are they?

“Cellular automata have been invented many times under different names... In pure mathematics they can be recognized as a branch of topological dynamics, in electrical engineering they are sometimes called iterative arrays, and high school kids may know them as a sort of home-computer game. They have been used and abused by interdisciplinary scientists as well as interdisciplinary bumbler.”

*Toffoli and Margous
Cellular Automata Machines
1987*

2

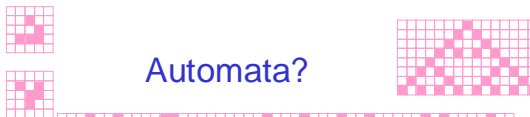


What are they?

“When I made my first discoveries about cellular automata in the early 1980s I suspected that I had seen the beginning of something important. But I had no idea just how important it would all ultimately turn out to be. And indeed over the past twenty years I have made more discoveries than I ever thought possible. And a new kind of science that I have spent so much effort building has seemed an ever more central and critical direction for future intellectual development.”

*Stephen Wolfram
A New Kind of Science
2002*


3



Automata?

- Automata is the plural of automaton
- Simple computing device
- Properties
 - Finite set of states
 - Transitions from state to state
 - Sense the environment.
 - Possibly change the environment.
 - Go to a new state,

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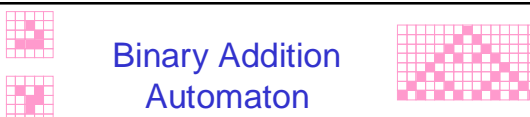


Binary Addition

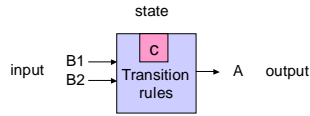
$$\begin{array}{r}
 1111\ 10 \\
 10111 \\
 \underline{11011} \\
 110\ 010
 \end{array}$$

← carry = state
← inputs
← output

5



Binary Addition Automaton



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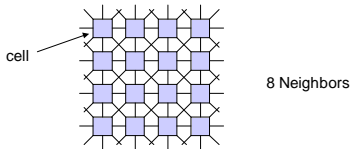
Binary Addition Transition Rules

Current state	Input	Next state	Output
0	0 0	→ 0	0
0	0 1	→ 0	1
0	1 0	→ 0	1
0	1 1	→ 1	0
1	0 0	→ 0	1
1	0 1	→ 1	0
1	1 0	→ 1	0
1	1 1	→ 1	1

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Cellular Automata


- Automata are arranged geometrically
- All automata are identical



- Neighborhoods established

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Communication



- Inputs are states of neighbors and self
- Output is the state (indicated by color)

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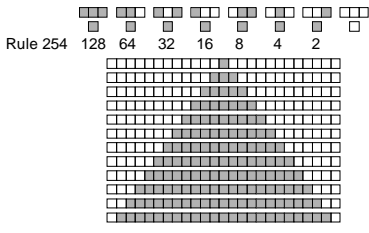
One-Dimensional



- Each cell has a left and right neighbor
- All cells identical
- Cell can be initialized to different states

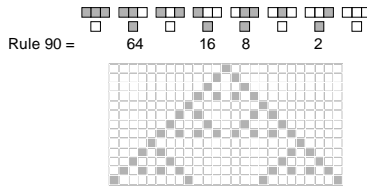
10

Two State Example



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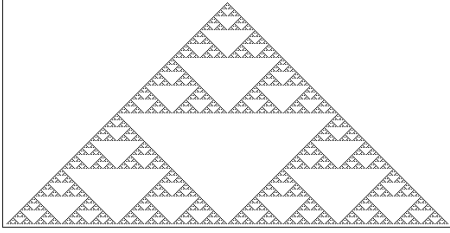
Rule 90



12

Rule 90

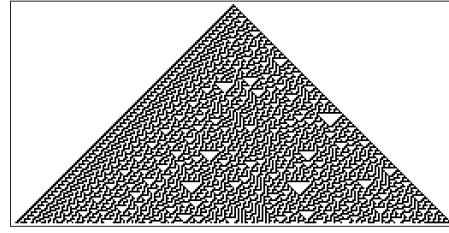
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Rule 30

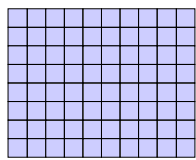
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Two-Dimensional

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- Each cell has 4 or 8 neighbors





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Game of Life

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- Each cell is "live" or "dead"
- Transition rules
 - $N =$ number of live neighbors among the 8
 - $N \leq 1 \rightarrow$ death (loneliness)
 - $N = 2 \rightarrow$ no change
 - $N = 3 \rightarrow$ birth
 - $N \geq 4 \rightarrow$ death (overcrowding)

examples

			
□	■	■	□

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Game of Life

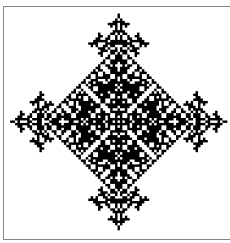
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- The Glider
- The Glider gun and eater
- Alternative life games

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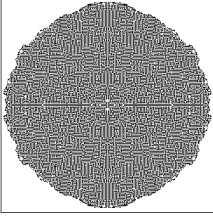
Code 494

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Code 746



Created by A NEW KIND OF SCIENCE ENGINEERING - 1992/01/15/1992

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History

- John von Neuman (1950s)
 - Self reproducing Machines
- John Conway (1970)
 - The game of life
 - Popularized by Martin Gardner in *Scientific American* magazine
- Stephen Wolfram (2002)
 - “A New Kind of Science”

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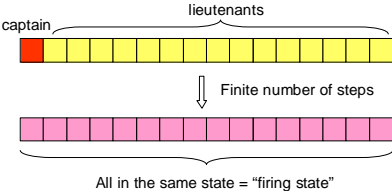
Applications

- Biological systems
- Iterative arrays – parallel computer hardware
- Artificial societies
- Art and design
- Computer graphics
- Image processing
- Games

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Firing Squad Problem

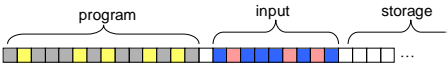
- One-dimensional cellular automaton
- Synchronous behavior possible



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Universality

- There is a one-dimensional cellular automaton that is a general purpose computer.



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Self-Reproducing Cellular Automaton

- Two-dimensional with 4 neighbors
- Initial configuration is exactly duplicated

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Image Processing Example

- Gray scale to black and white

The diagram shows a 2x2 grid of gray squares at the top. An arrow points down to four 2x2 grids below it. The first is all white, the second has the top-right square black, the third has the top-right and bottom-left squares black, and the fourth is all black.

Pick the 2x2 black and white block that Best approximates the input block

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Follow the Scent Game

- Food is the highest number
- Numbers smaller farther from the food

The diagram shows a 3x3 grid with an 'x' in the center. An arrow labeled 'x is largest' points to a 3x3 grid with a red square in the center.

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“A New Kind of Science”

- Wolfram's thesis
 - Complex behaviors are often the result of simple computational rules.
 - The proof: simple cellular automata and their variants produce such complex behavior.
- Corollary
 - Traditional mathematical approaches (continuous mathematics) to modeling complex behavior is not enough.

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Resources

- Books -
 - Martin Gardner - *Wheels, Life, and Other Mathematical Amusements*
 - Toffoli and Margolus - *Cellular Automata Machines*
 - Stephen Wolfram - *A New Kind of Science*
- Web Pages
 - <http://nojava.cafaq.com/index.shtml>
 - <http://psoup.math.wisc.edu/>

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Acknowledgements

- Jim Fix - developed the software
- Sam Coskey - developed some of the applications
- Many other students who helped over the years.

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