Computational Intelligence

Unit # 14

Artificial life

- In the context of Computer Science,
  - Artificial life is the study of artificial systems that exhibit behavior/characteristic of natural living systems.
- It is an interdisciplinary study of life and life-like processes

Cellular Automata

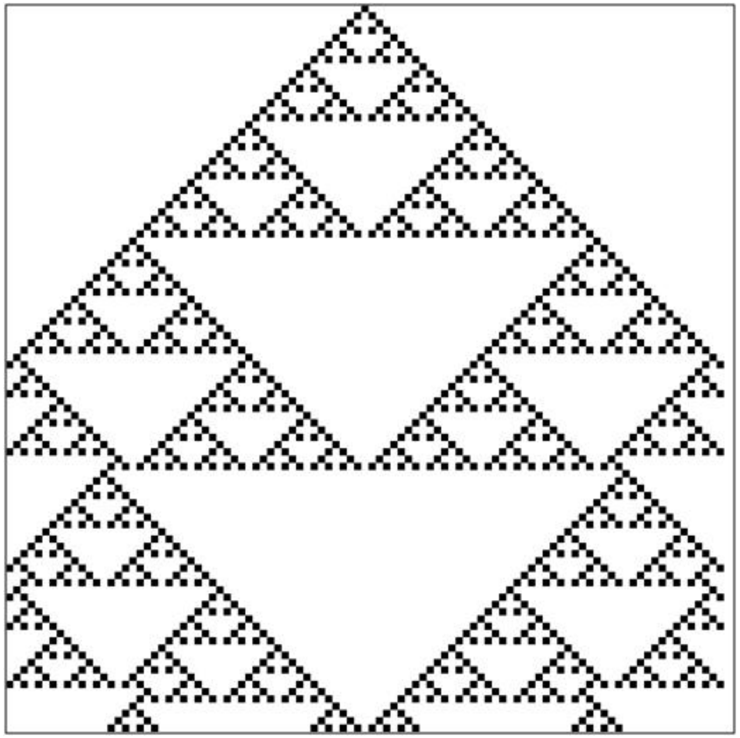
Hat Rule

- *A* student will wear the hat in the following class if one or the other—but not both—of the two classmates sitting immediately on her left and on her right has the hat in the current class (if nobody wears a hat, a hat is out of fashion; but if both neighbors wear it, a hat is now too popular to be trendy).

https://plato.stanford.edu/entries/cellular-automata/#Intr

- *Initial class*: during the first class in the morning, only one student in the middle shows up with a hat.

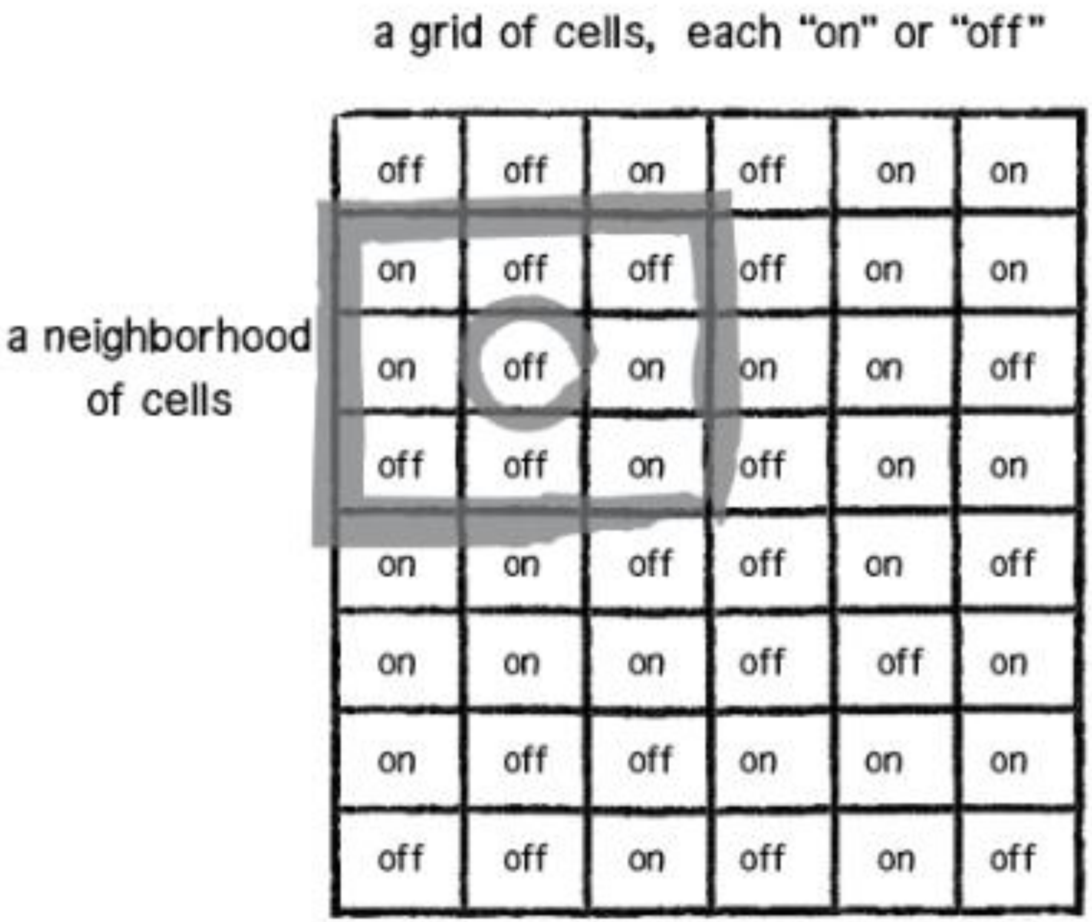
- Consecutive rows represent the evolution in time through subsequent classes.



Cellular Automata

- A cellular automaton is a model of a system of "cell" objects with the following characteristics:
  – The cells live on a ***grid.***
  – Each cell has a ***state***. The number of state possibilities is typically finite. The simplest example has the two possibilities of 1 and 0 (otherwise referred to as "on" and "off" or "alive" and "dead").
  – Each cell has a ***neighborhood***. This can be defined in any number of ways, but it is typically a list of adjacent cells.

https://natureofcode.com/book/chapter-7-cellular-automata/

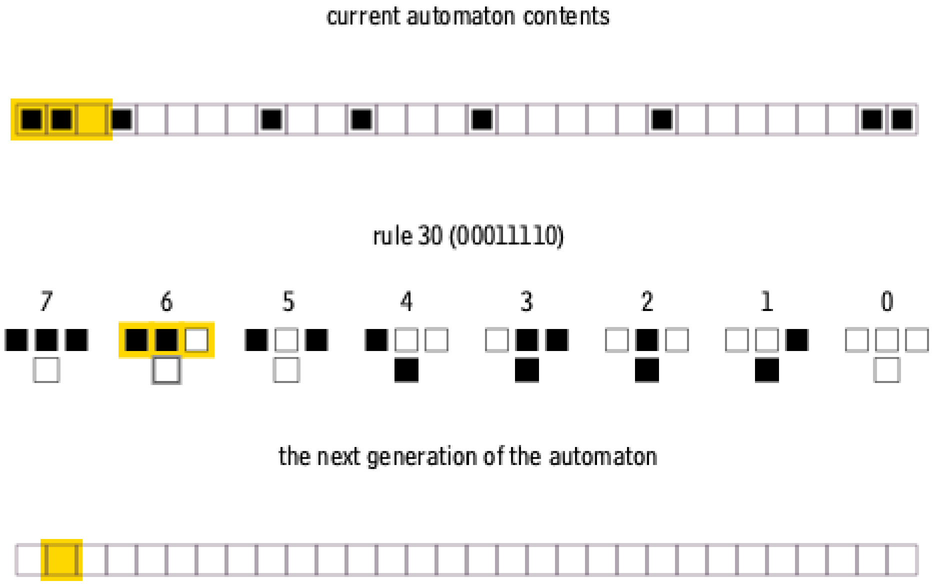


a grid of cells, each "on" or "off"
a neighborhood of cells
off off on off on on
on off off off on on
on off on on on off
off off on off on on
on on off off on off
on on on off off on
on off off on on on
off off on off on off

1	0	1	0	1	1	1	0	0	1

0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
↓	↓	↓	↓	↓	↓	↓	↓
0	1	0	1	1	0	1	0

Cellular Automata



Rule 90

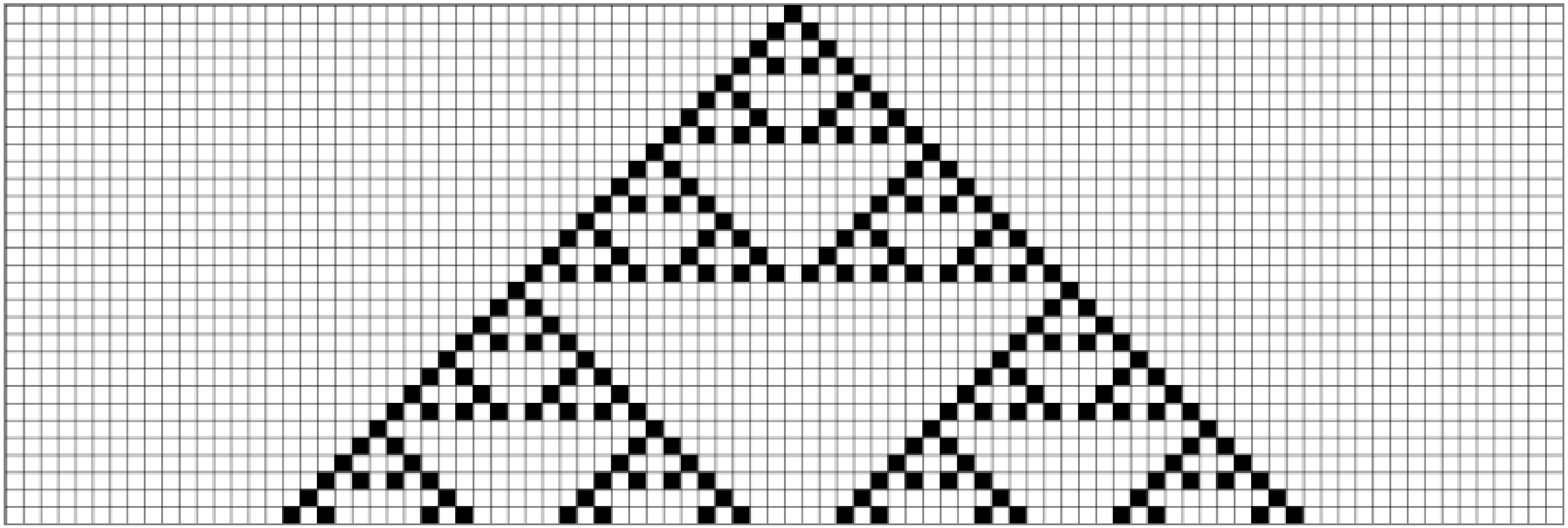


Figure 7.12: Rule 90

Rule 256

- https://plato.stanford.edu/entries/cellular-automata/supplement.html

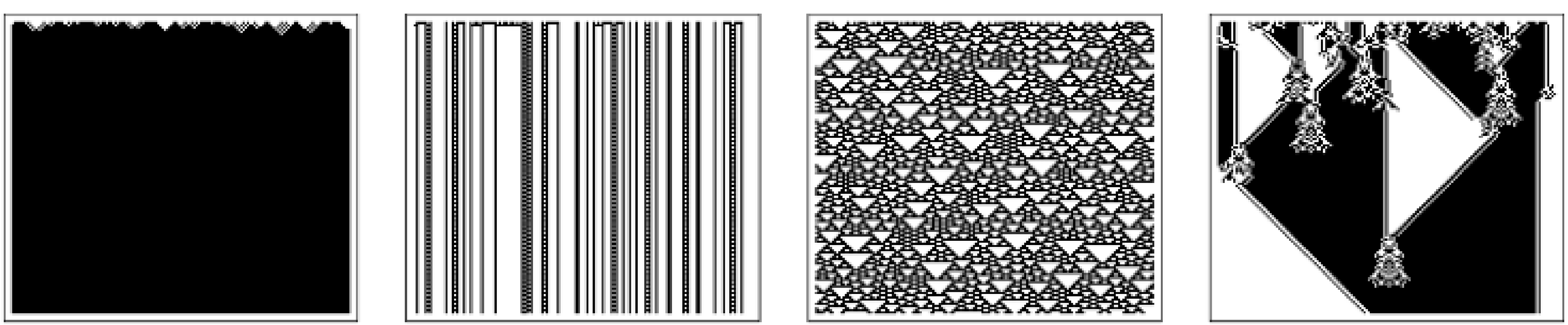
Wolfram Classification

- The vast majority of elementary CA rulesets produce uninspiring results, while some result in wondrously complex patterns like those found in nature. Wolfram has divided up the range of outcomes into four classes:

Classes

- Wolfram defined four classes into which cellular automata can be divided depending on their behavior.
- **Class 1 (Uniformity)**: Nearly all initial patterns evolve quickly into a stable, homogeneous state. Any randomness in the initial pattern disappears.
- **Class 2 (Stability/Oscillation)**: Nearly all initial patterns evolve quickly into stable or oscillating structures. Some of the randomness in the initial pattern may filter out, but some remains. Local changes to the initial pattern tend to remain local
- **Class 3(Chaotic/Random)**: Nearly all initial patterns evolve in a pseudo-random or chaotic manner. Any stable structures that appear are quickly destroyed by the surrounding noise. Local changes to the initial pattern tend to spread indefinitely.
- **Class 4 (Complexity)**: Nearly all initial patterns evolve into structures that interact in complex and interesting ways, with the formation of local structures that are able to survive for long periods of time.

Demo: https://natureofcode.com/book/chapter-7-cellular-automata/

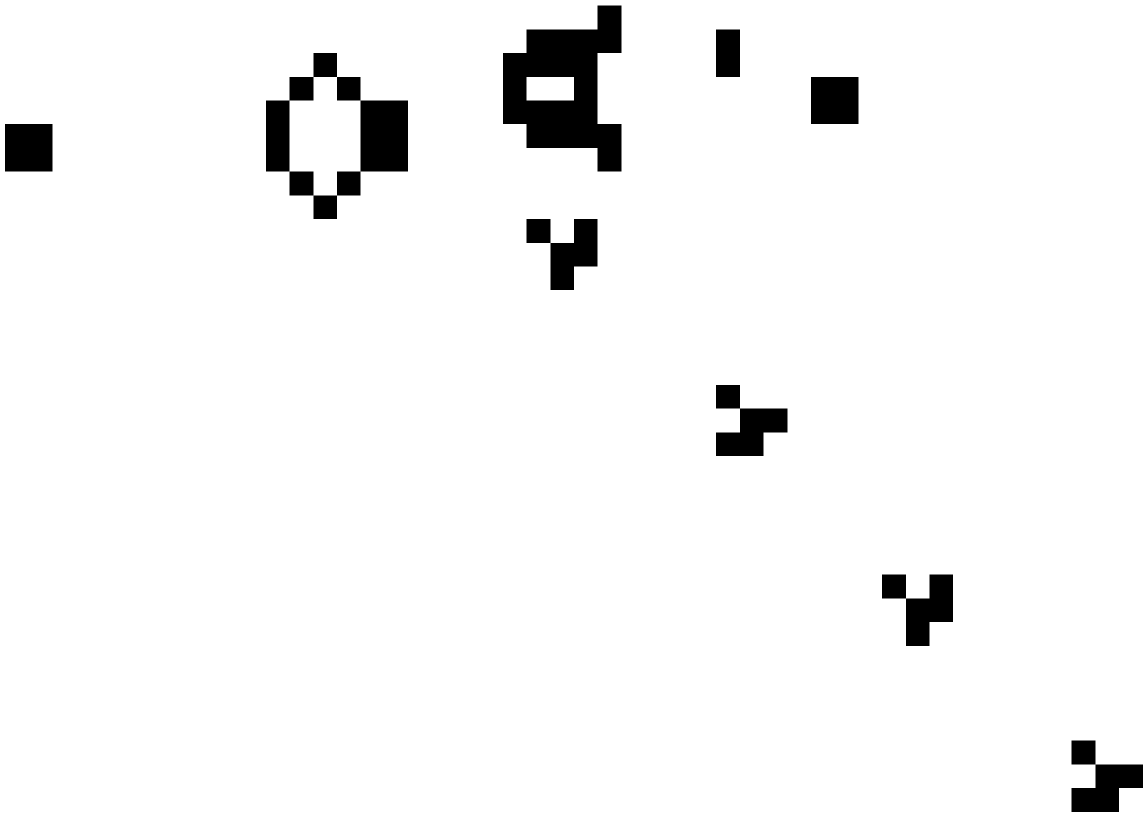


class 1 class 2 class 3 class 4

Game of Life

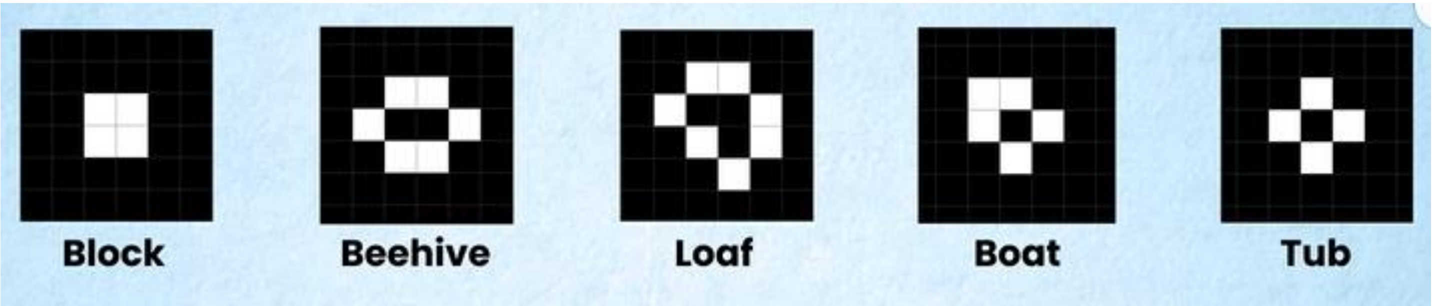
- In the 1970s a two-state, two-dimensional cellular automaton named Game of Life became widely known, particularly among the early computing community. Invented by John Conway and popularized by Martin Gardner in a *Scientific American* article, its rules are as follows:
  - **Birth** - Any dead cell with exactly three live neighbours becomes a live cell, as if by reproduction.
  - **Death**
    - Any live cell with fewer than two live neighbours dies, as if caused by lonliness.
    - Any live cell with more than three live neighbours dies, as if by overpopulation.
  - **Survive** - Any live cell with two or three live neighbours lives on to the next generation.

Game of Life

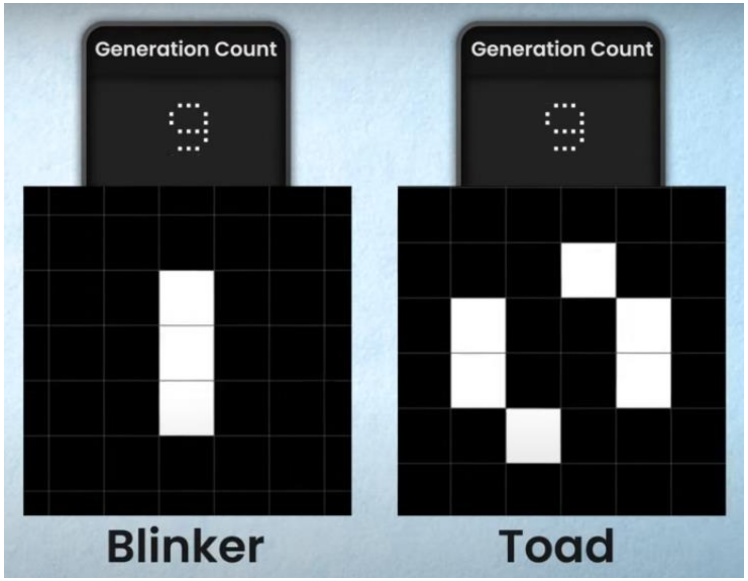


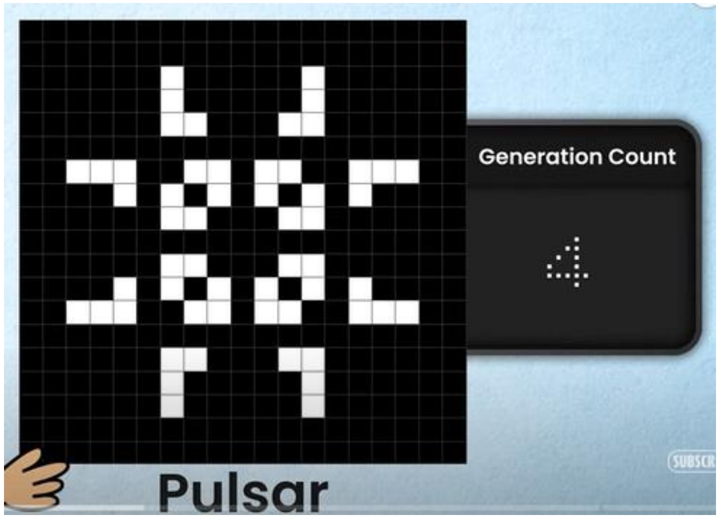
[Play John Conway's Game of Life (playgameoflife.com)](playgameoflife.com)

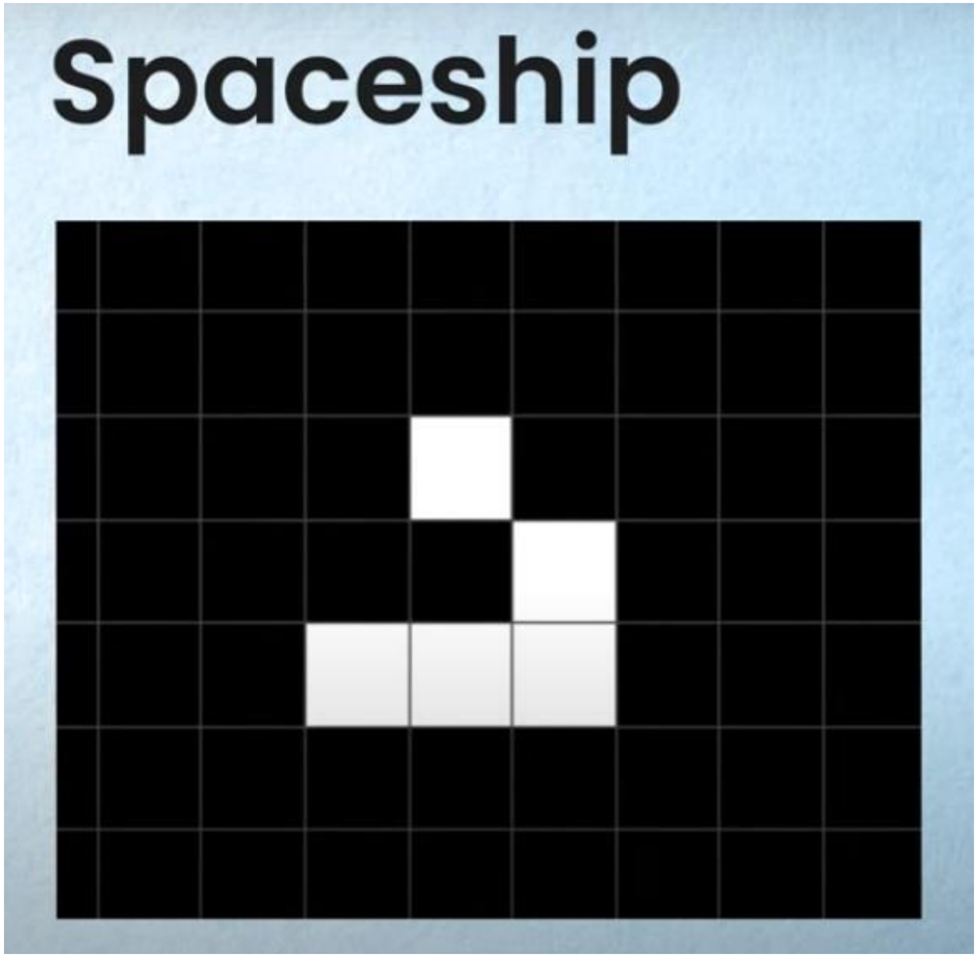
Still Life

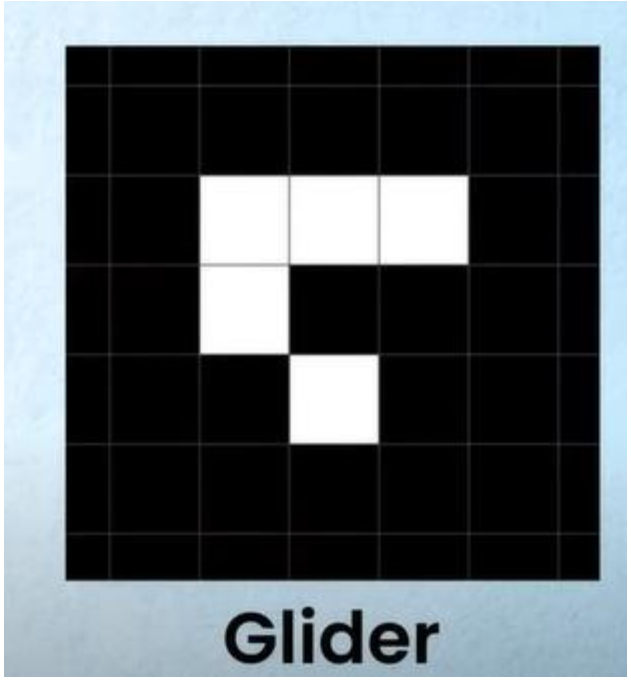


Oscillators



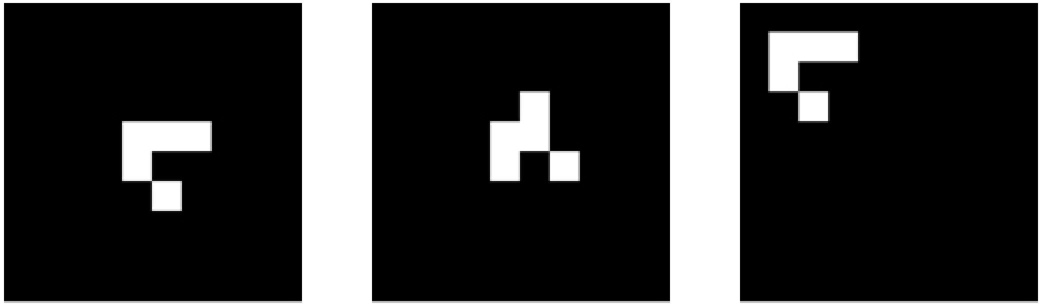



Spaceship


Glider

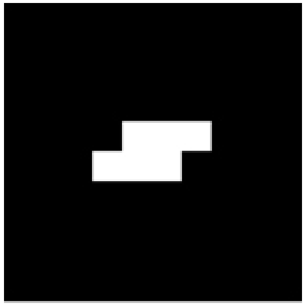
Gliders

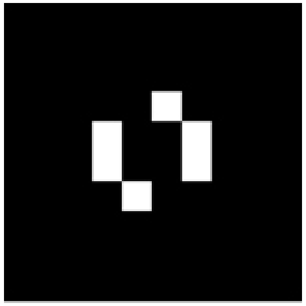
- *Gliders* are the most popular among the basic *Life* inhabitants: a simple 5-bit structure, a glider can travel the *Life* grid in a 4-time step cycle:

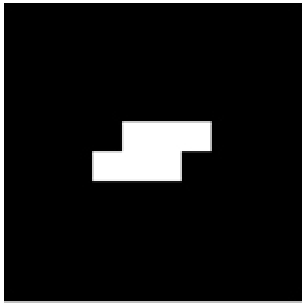


Toads

- *Toads* are period 2 blinking configurations: together with *Blinkers* and *Beacons* they are the simplest oscillators of the universe.

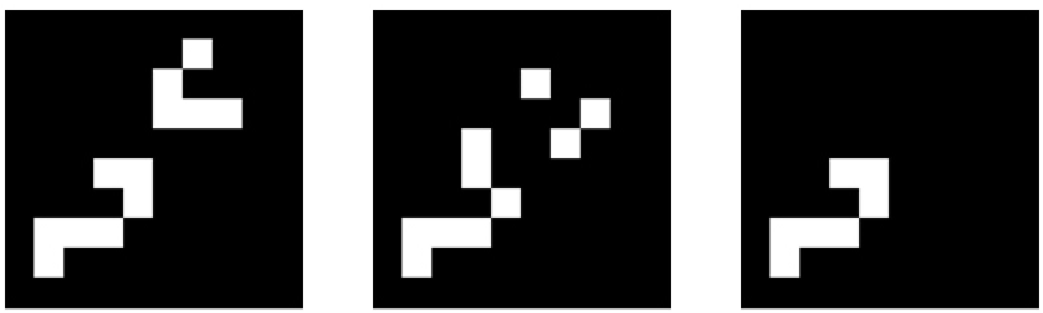

t_0


t_1


t_3

Eaters

- *Eaters* have the feature of devouring other configurations, e.g., gliders, maintaining intact their own form (because of this, they play an important role for *Life*'s computational abilities).



t_0 t_2 t_4

Videos

- The Incredible Story of The Game of Life (youtube.com)
- Stephen Hawkings The Meaning of Life (John Conway's Game of Life segment) (youtube.com)

Play Game of Life

[Play John Conway's Game of Life (playgameoflife.com)]

Some interesting characters

- https://en.wikipedia.org/wiki/Conway%27s_Game_of_Life

3D Cellular Automata

- https://www.youtube.com/watch?v=_W-n510Pca0

Butterfly Effect

The metaphor goes:

“Does the flap of a butterfly’s wings in Brazil set off a tornado in Texas?”

It isn’t meant to imply that this could happen, just that a small event, like this, at the right time and place could, in theory, trigger a set of events that will ultimately culminate in the formation of a hurricane on the other side of the world.

“The Butterfly Effect” metaphor is simply meant to demonstrate that little insignificant event can lead to significant results over time.

https://simplicable.com/new/chaos-theory

Applications

- Despite their simplicity, they are capable to solve many intractable scientific problems.
- They are used in:
  - **Physical systems**: One of their applications is **description of recrystallization** in certain types of metals an alloys.
  - **Cracks propagation** within materials.
  - **Laser behavior** is modeled.
  - **Avalanches**. Think about Per Bak sand pile models.
  - **Traffic flow** on highways and within cities.
  - Description of **Flood propagation** within the country.
  - **Epidemiology -** Cellular automata are used to study the evolution of disease epidemics through computer modeling.
  - **Anthropology - i**n anthropology, CA with fundamental space-time representations are used to model the formation of civil societies.
  - **Sociology -** CAs are used to study the causes and effects of civil violence.
  - **Music** - Various musical composition techniques use the Game of Life, especially in MIDI sequencing.A variety of programs exist for creating sound from patterns generated in the Game of Life.

https://www.quora.com/What-are-some-real-world-applications-of-cellular-automata

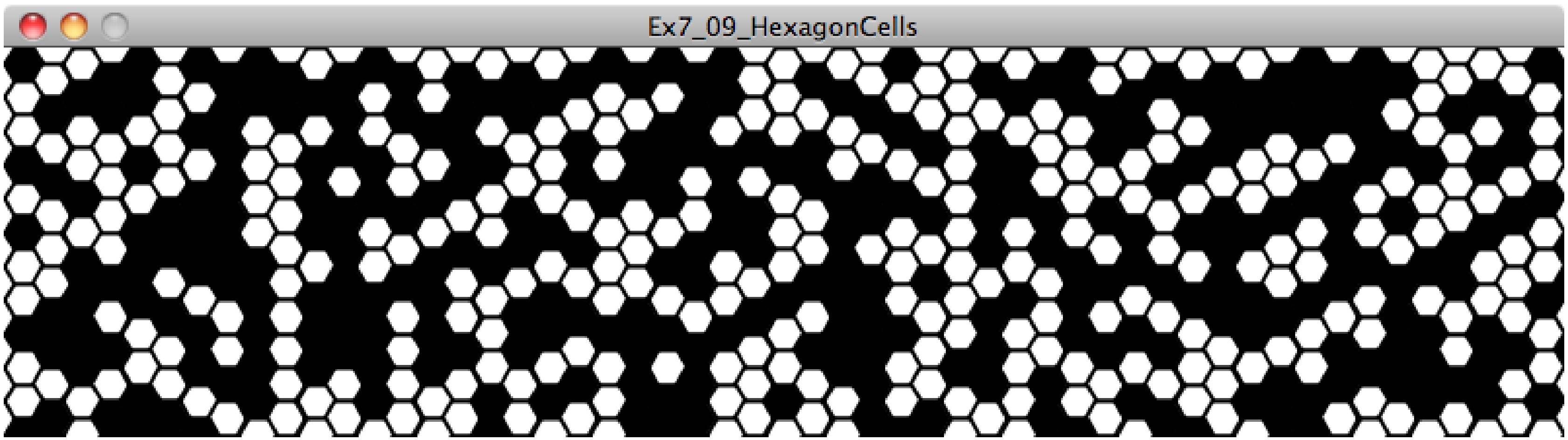
Applications

- **Biology** to model ecosystems
- **Chemistry**: chemical and biochemical reactions.
- **Medicine**, cellular automata model spread of diseases.
- **Coding messages** by cellular automata, which produce very strong codes.
- **Picture compression** gives very good results.

- **They enables theoretical studies of self-organization and emergence.** They are extremely well suited for theoretical studies of complex systems *per se.*
- Cellular automata are also used in visual effects to create various patterns and growth animations

Variations of Traditional CA

- Non-rectangular grids



Variations of Traditional CA

- ***Probabilistic***. The rules of a CA don't necessarily have to define an exact outcome.
  - Overpopulation: If the cell has four or more alive neighbors, it has a 80% chance of dying
  - Loneliness: If the cell has one or fewer alive neighbors, it has a 60% chance of dying.
    Etc.
- ***Continuous***. We've looked at examples where the cell's state can only be a 1 or a 0. But what if the cell's state was a floating point number between 0 and 1?

Variations of Traditional CA

- ***Image Processing***. Many image-processing algorithms operate on CA-like rules. Blurring an image is creating a new pixel out of the average of a neighborhood of pixels.
  - Simulations of ink dispersing on paper or water rippling over an image can be achieved with CA rules
- ***Nesting***. Another feature of complex systems is that they can be nested. Our world tends to work this way:
  - a city is a complex system of people, a person is a complex system of organs, an organ is a complex system of cells, and so on and so forth.
  - Design a CA in which each cell itself is a smaller CA

References

- Cellular automata
  - Algorithmic Beauty: An Introduction to Cellular Automata | by Evan Kozliner | Towards Data Science
- Simulations
  - https://www.youtube.com/watch?v=dQJ5aEsP6Fs
  - https://www.youtube.com/watch?v=_W-n510Pca0
  - https://www.youtube.com/watch?v=C2vgICfQawE