

# Artificial life

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### Definition

**Artificial life** as a science discipline

- studies artificial systems mimicking some features of living systems and their processes.
- Simulations are the main tool of research.
- Types of ALife:
  - Soft alife: simulations by means of software
  - Hard alife: simulations by means of hardware (robotics)
  - Wet alife: "in vitro simulations" (biochemistry)
- In a narrower sense, "alife" usually refers to the soft alife.
- **Emergence**<sup>a</sup>: simple behavior of individuals → complex behavior of the whole system

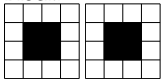
<sup>a</sup>Not emergency.

### Conway's Game of Life

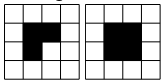
- Cells in a rectangular grid (infinite, with zero boundary conditions, or toroidal).
- Each cell is either living or dead.
- The state of the cell depends on its previous state and on the states of the surrounding cells.
- The state of all cells changes synchronously (all at once).
- All cells are controlled by the same rules:
  1. A living cell with less than 2 living neighbours dies (insufficient inhabitation).
  2. A living cell with more than 3 living neighbors dies (starvation).
  3. A living cell with 2 or 3 neighbors survives.
  4. A dead cell with exactly 3 neighbors revives.
- The rules can be simplified: a cell is alive in the next generation if
  1. it has 3 living neighbors, or
  2. it is alive and has 2 living neighbors.
- The behavior of the whole system depends on the initial pattern only!

## Game of Life: example configurations

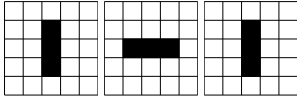
Block:



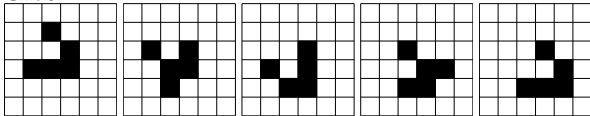
L-shape:



Blinker:



Glider:

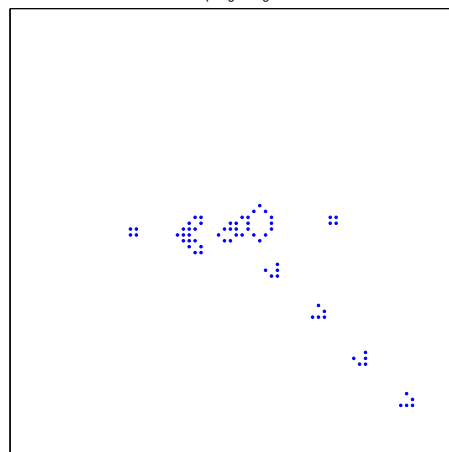


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## Game of Life: Demo

Gosper glider gun



t=123, pop= 68

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## Game of Life: Only a toy?

- Conway formulated a hypothesis that in GoL one cannot create a configuration which will grow infinitely.
  - It was refuted very soon (Glider Gun, ...)
- It turned out that it is possible to create blocks which work as logic functions AND, OR, NOT, ...
- GoL has the power of universal Turing machine!  
<http://www.igblan.free-online.co.uk/igblan/ca/>
- GoL can generate
  - prime numbers,  
[http://pentadecathlon.com/lifeNews/2010/02/prime\\_numbers.html](http://pentadecathlon.com/lifeNews/2010/02/prime_numbers.html),  
<http://www.youtube.com/watch?v=68nEX5CEmZE>
  - Ludolfine number  $\pi$  and golden section  $\phi$   
[http://pentadecathlon.com/lifeNews/2011/01/phi\\_and\\_pi\\_calculators.html](http://pentadecathlon.com/lifeNews/2011/01/phi_and_pi_calculators.html)
  - ...

## Examples of other alife systems

- Cellular automata (1D and 2D version)
- Evolutionary algorithms
- Ant colonies
- Swarms optimization
- Multiagent systems
- Neural networks
- ...

Examples of the behavior of the above mentioned system can be found e.g. in

- MASON, or  
<http://cs.gmu.edu/~eclab/projects/mason/>
- NetLogo  
<http://ccl.northwestern.edu/netlogo/models/index.cgi>

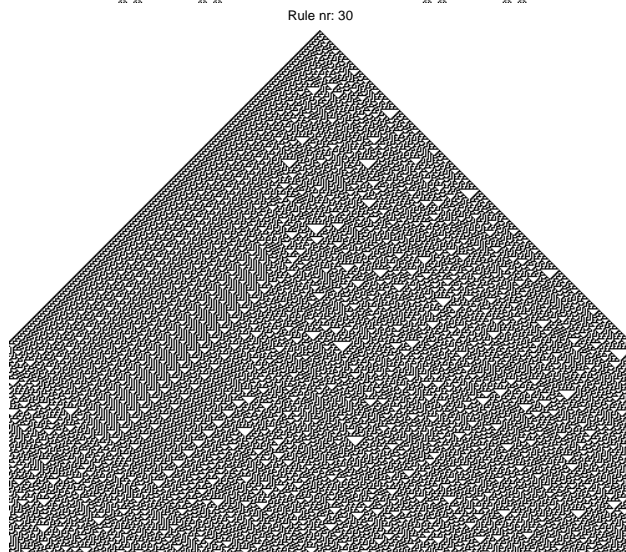
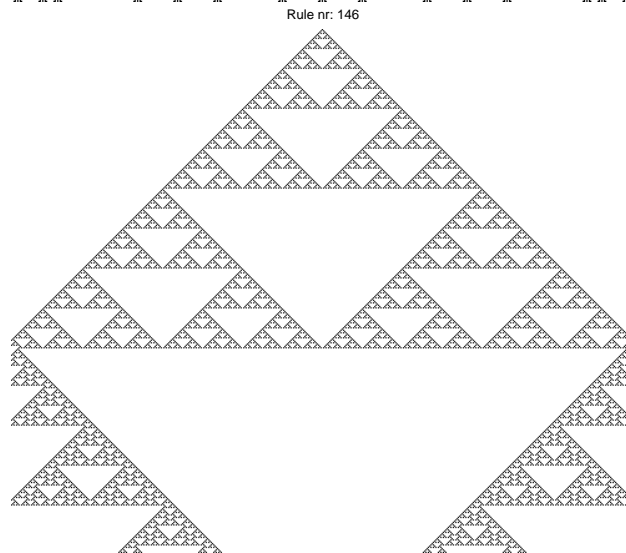
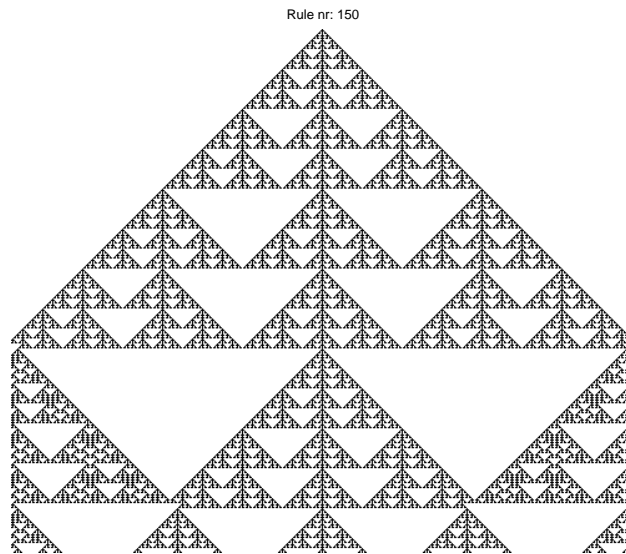
**1D celular automata**

- The cells form a string (infinite, with zero boundary conditions, or cyclic)
- $s_i(t)$ : the state of  $i$ th cell in time  $t$ .
- A **rule** describes the future state of cell based on its current state and the state of the neighboring cells.
- A rule has the form  $\{s_{i-1}(t), s_i(t), s_{i+1}(t)\} \rightarrow s_i(t+1)$
- How many rules can be created for such a 1D CA?

		State of the neighborhood							
111	110	101	100	011	010	001	000	Rule number	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	1	1	
0	0	0	1	1	1	1	0	30	
0	0	1	0	1	1	0	1	45	
0	1	0	1	1	0	1	0	90	
1	0	0	1	0	1	1	0	150	
1	1	0	0	1	0	0	0	200	
1	1	1	1	1	1	1	0	254	
1	1	1	1	1	1	1	1	255	

## Real-world application of CA

Pseudo-random number generator: bit stream generated by the cellular automaton



## 2D cellular automaton

- Example: Conway's Game of Life
- How many rules can be constructed for GoL-type 2D CA?
  - Number of different configurations of the neighborhood:  $2^9$
  - Number of possible rules:  $2^{2^9} \approx 1.34 \cdot 10^{154}$

## Ant colonies

### Ant colonies: principle

Typical application: search for the shortest path in graph

- Ants usually do not communicate directly, they use a *pheromone*:
  - They lay pheromone to places they walked through.
  - Artificial ants can lay and detect more than 1 type of pheromone.
  - Artificial ants can deploy a varying amount of pheromone according to the length of the path they found.
  - Pheromone evaporates.
- Ants can be attracted or distracted by the pheromone.
- The decision where to go next is stochastic, but is influenced by the amount of pheromone.

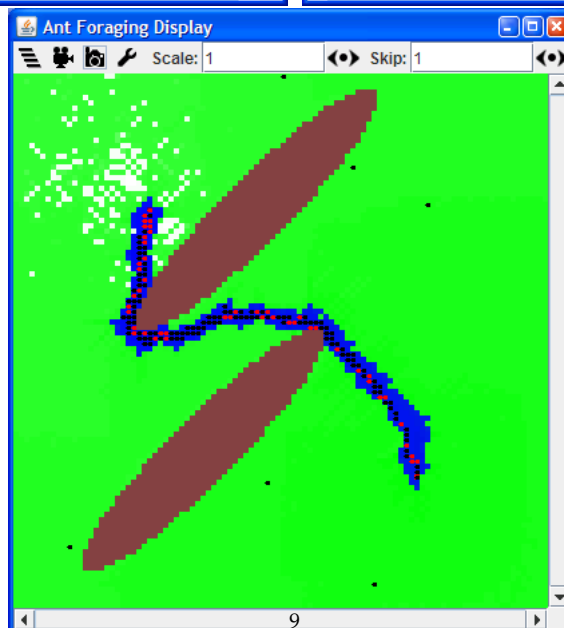
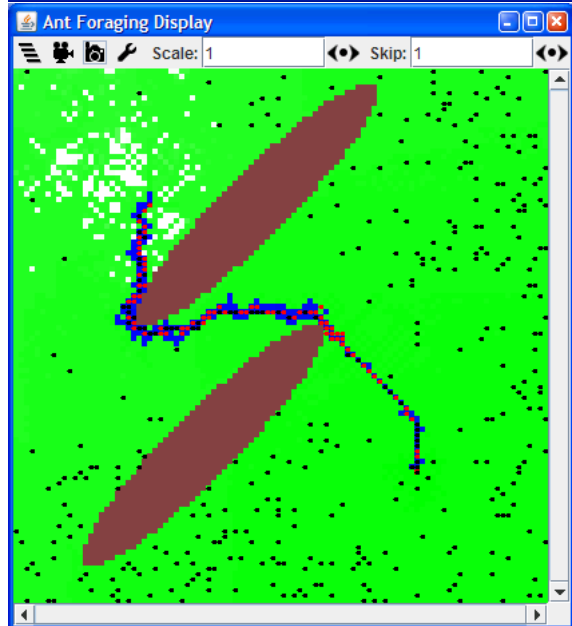
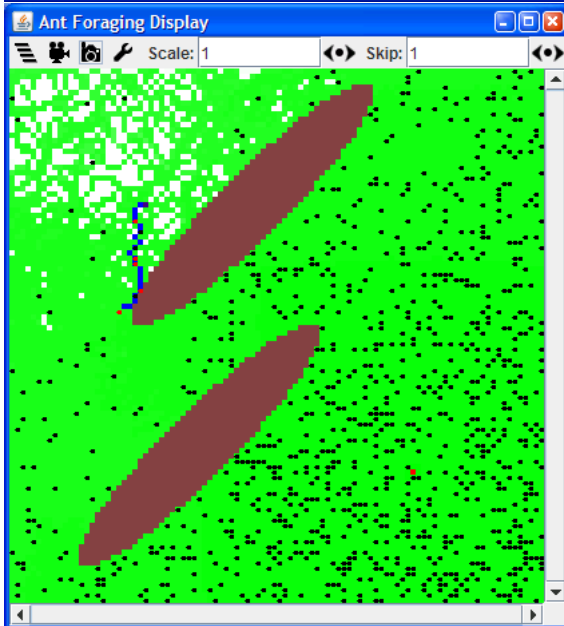
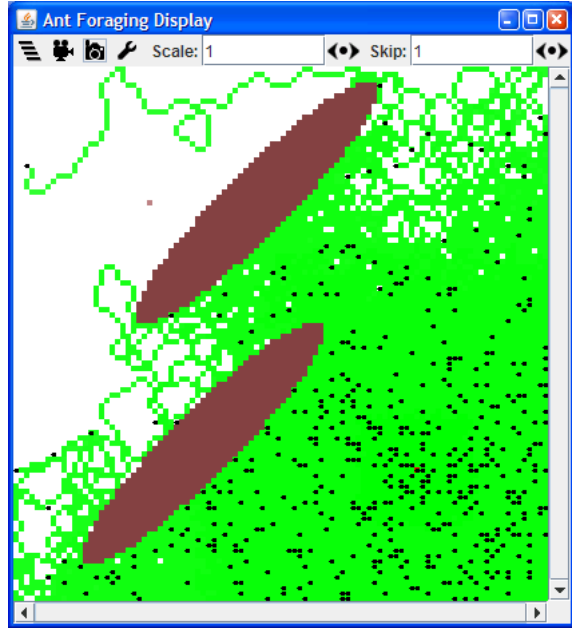
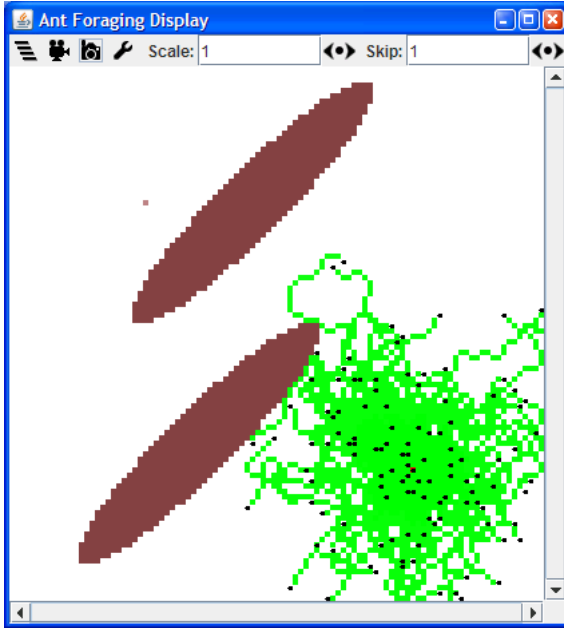
Example on the following slides:

- Source: MASON <http://cs.gmu.edu/~eclab/projects/mason/>
- Two types of pheromone:
  - Green: deployed when searching for food; the closer to the nest, the higher the intensity
  - Blue: deployed when bringing food back to the nest; the closer to the food source, the higher the intensity
- Ants have 2 modes:
  - Black: searches for food, follows blue pheromone, deploys green pheromone
  - Red: brings food to the nest, follows green pheromone, deploys blue pheromone





# Ant colonies: Example



## Particle Swarm

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### Particle swarm: Motivation and principle

Inspiration:

- bird flocks and fish schools

The particle position update rule usually contains several parts:

- continue in your current direction,
- prevent collisions with obstacles and other particles,
- modify your direction according to your neighbors, and
- add a stochastic component.

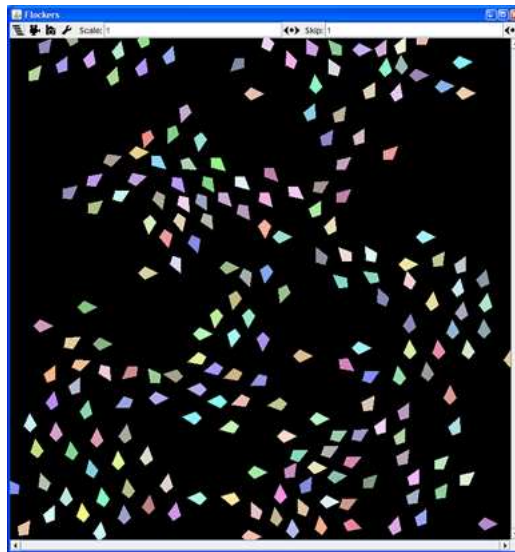
Applications:

- Simulations of the flock moves.
- With a bit different rules, simulations of human crowds behavior, e.g. in case of rush hours, emergencies, catastrophes, ...
- Optimization (Particle Swarm Optimization)

## Particle swarm: Demo

Zdroj: MASON

<http://cs.gmu.edu/~eclab/projects/mason/>



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## Particle swarm optimization (PSO)

The task is to find the optimum of an objective function; this function says how good a candidate solution represented by a particle is.

Update rule for the position of the  $i$ th particle:

$$v_i(t+1) = w \cdot v_i(t) + r_1 \cdot \phi_p(p_i - x_i(t)) + r_2 \cdot \phi_g(g - x_i(t)),$$
$$x_i(t+1) = x_i(t) + v_i(t+1),$$

where

- $x_i(t)$  is the position of the  $i$ th particle in time  $t$ ,
- $v_i(t)$  is the speed of the  $i$ th particle in time  $t$ ,
- $p_i$  is the best position visited by the  $i$ th particle (personal best),
- $g$  is the best position visited by any member of the swarm (global best),
- $w$ ,  $\phi_p$  and  $\phi_g$  are the momentum, attraction factor to the personal best, and to the global best position,
- $r_1$  and  $r_2$  are random vectors uniformly distributed between 0 and 1.

Demo:

<http://www.stud.fit.vutbr.cz/~xgraliz00/pso/applet.html>

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**EA: Motivation and principle**

The task is to find the optimum of an objective function; this function says how good a candidate solution represented by an individual in a population is.

Evolutionary optimization algorithms model the principles of

- Mendel's theory of genetics and
- Darwin's theory of natural selection.
- They work with a *population* of candidate solutions.

Principle: 4 basic operations executed iteratively:

- **Selection:** selection of parents which are allowed to mate; high-quality individuals are allowed to produce more offsprings.
- **Crossover:** offsprings are created such that the parents exchange some of their parts.
- **Mutation:** some parts of offsprings are changed randomly.
- **Replacement:** offsprings and parents compete for their place in population; higher-quality individuals have higher chance to survive.

Demo: Marek Obitko

<http://obitko.com/tutorials/genetic-algorithms/>

**Conclusions****Summary**

- Artificial life studies the laws and phenomena taking place in real living systems.
- The basic research tool is simulation.
- Goals:
  - Understand the effects of simple rules in complex systems.
  - Take advantage of these (maybe modified) principles to solve practical tasks.

Do you want to learn more?

- A4M33BIA: Biologically inspired algorithms <http://www.feld.cvut.cz/education/bk/predmety/12/58/p12584904.html>
  - Intro to neural networks and evolutionary algorithms.
  - Focus on breadth (what can be achieved using these algorithms), rather than depth (how exactly it is done).
- A0M33EOA: Evolutionary optimization algorithms <http://www.feld.cvut.cz/education/bk/predmety/12/58/p12589004.html>
  - More specialized, focus on depth.
- A4M33MAS: Multi-agent systems <http://www.feld.cvut.cz/education/bk/predmety/12/58/p12585904.html>
  - Agent technologies in depth.