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**[a]: simple behavior of individuals $\rightarrow$ complex behavior of the whole system

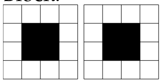
[a] Not emergency.

Conway's Game of Life

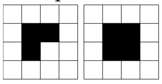
- Cells in a rectangular grid (infinite, with zero boundary conditions, or torroidal).
- Each cell is either living or dead.
- The state of the cell depends on its previous state and on the states of the surrounding cells.
- The state of all cells changes synchronously (all at once).
- All cells are 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

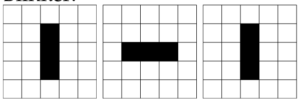
Block:



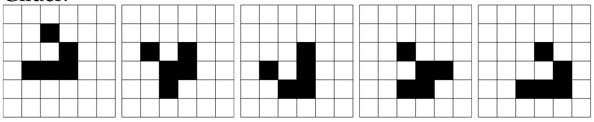
L-shape:



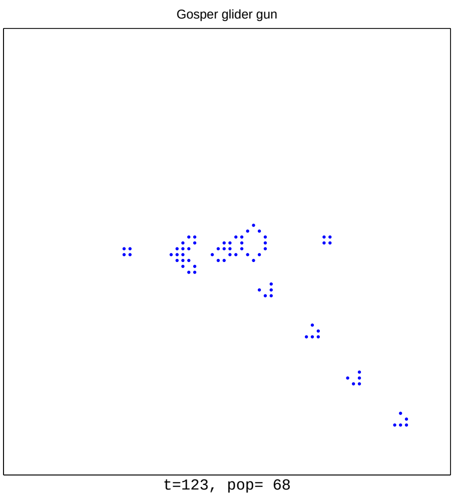
Blinker:



Glider:



Game of Life: Demo



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://www.youtube.com/watch?v=68nEX5CEmZE`
  - Ludolfine number π and golden section ϕ
    `http://pentadecathlon.com/lifeNews/2011/01/phi_and_pi_calculators.html`
  - ...

Examples of other alife systems

- Celular automata (1D and 2D version)
- Evolutionary algorithms
- Ant colonies
- Swarm 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

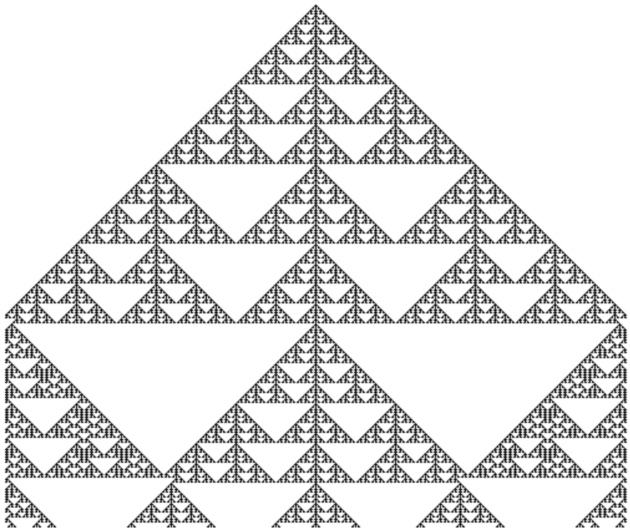
- The cells form a string (infinite, with zero boundary conditions, or cyclic)
- $s_i(t)$: the state of ith cell in time t.
- A **rule** describes the future state of cell based on its current state and the state of the neighboring cells.
- A rule has the form $\{s_{i-1}(t), s_i(t), s_{i+1}(t)\} \rightarrow s_i(t+1)$
- 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

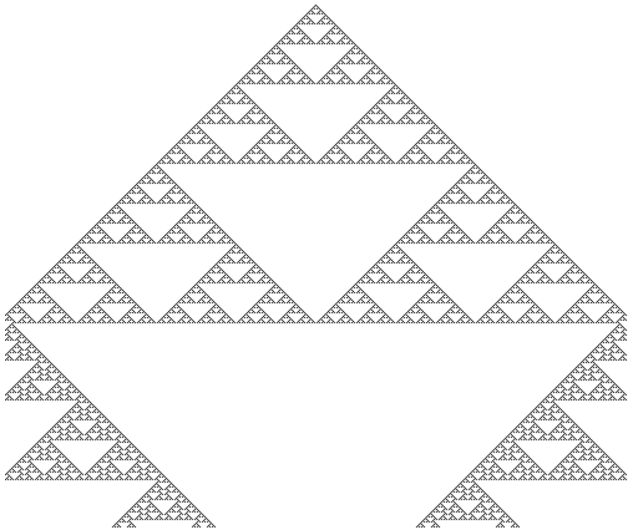
Real-world application of CA

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

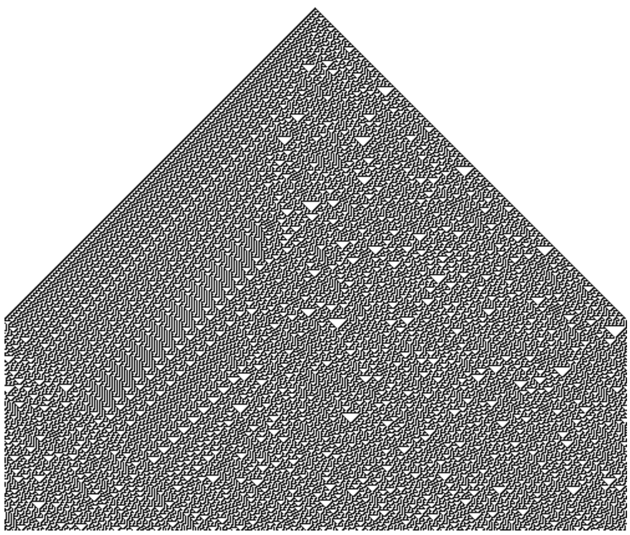
Rule nr: 150



Rule nr: 146



Rule nr: 30



2D cellular automaton

- Example: Convay'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

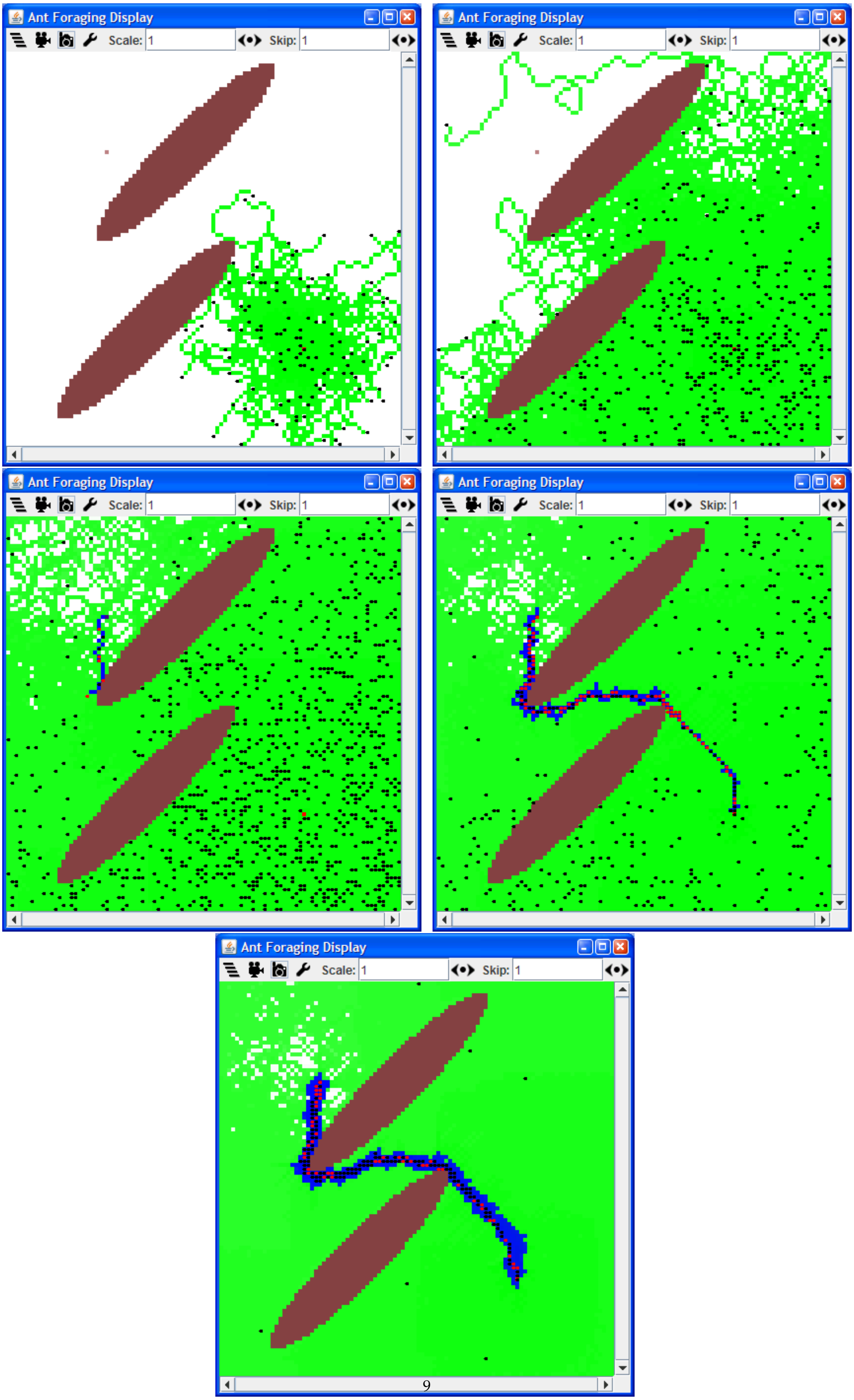
Typical application: search for the shortest path in a graph

- 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

Particle swarm: Motivation and principle

Inspiration:

- bird flocks and fish schools

The particle position update rule usually contains several parts:

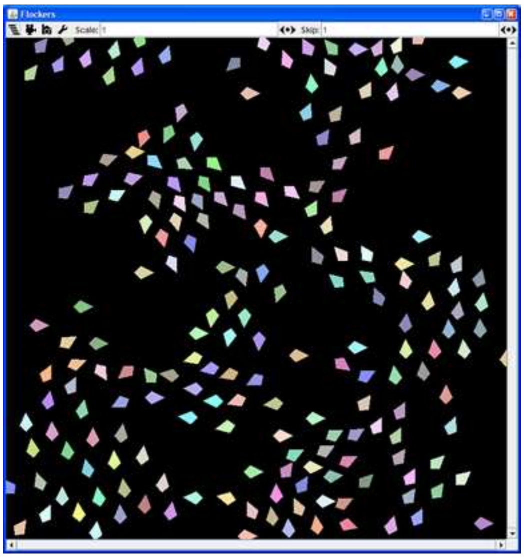
- continue in your current direction,
- prevent collisions with obstacles and other particles,
- modify your direction according to your neighbors, and
- add a stochastic component.

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/



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 ith 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 ith particle in time t,
- $v_i(t)$ is the speed of the ith particle in time t,
- p_i is the best position visited by the ith particle (personal best),
- g is the best position visited by any member of the swarm (global best),
- w, ϕ_p and ϕ_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 $\mathbf{0}$ and $\mathbf{1}$.

Demo: http://www.stud.fit.vutbr.cz/~xgraiz00/pso/applet.html

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/`

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 then 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.