Cellular Automata

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CA - what is it?

CAs are computer models suitable to describe spatially-explicitly, discrete phenomena.

They consist in a grid of cells (any dimension possible).

The development of the state of each cell at time step t+1 usually depends on the states of the neighbouring cells in the previous time step t.

History

- 1950-60:
  Stanislaw Ulam and John von Neumann search for
  a self-reproducing automaton
  (self-reproducing patterns – causal networks instructing themselves - "esoteric" math)

- 1960s:
  John Conways (mathematician)
  radical simplification : "Game of Life" as a kind of intellectual exercise

History

- Scepticism against CAs:
  „too simple for worthwhile use"

- 1970s:
  increasing success by „serious“ physical applications:
  - diffusion of gases and liquids,
  - magnetic phenomena,
  - better and faster results than classical models
    (differential equations)

History

- 1980s:
  the “artificial life“ group booms. Numerous applications in various diciplines including physiology and ecology. Further development of the theoretical framework leads to new modelling approaches.

- 1990s: main approach in ecology for spatially explicit, dynamic models, the so called „grid-based“ models.

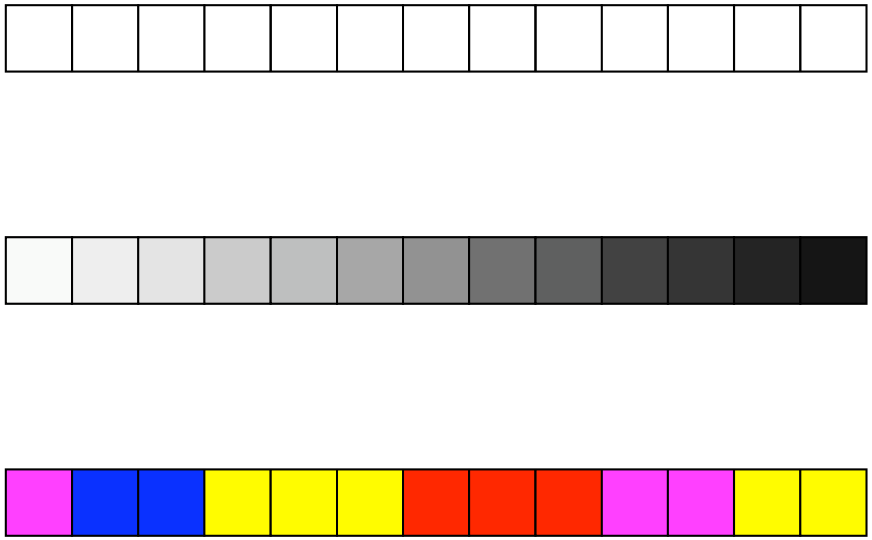
Technical details

The topology of the grid – everything is possible:

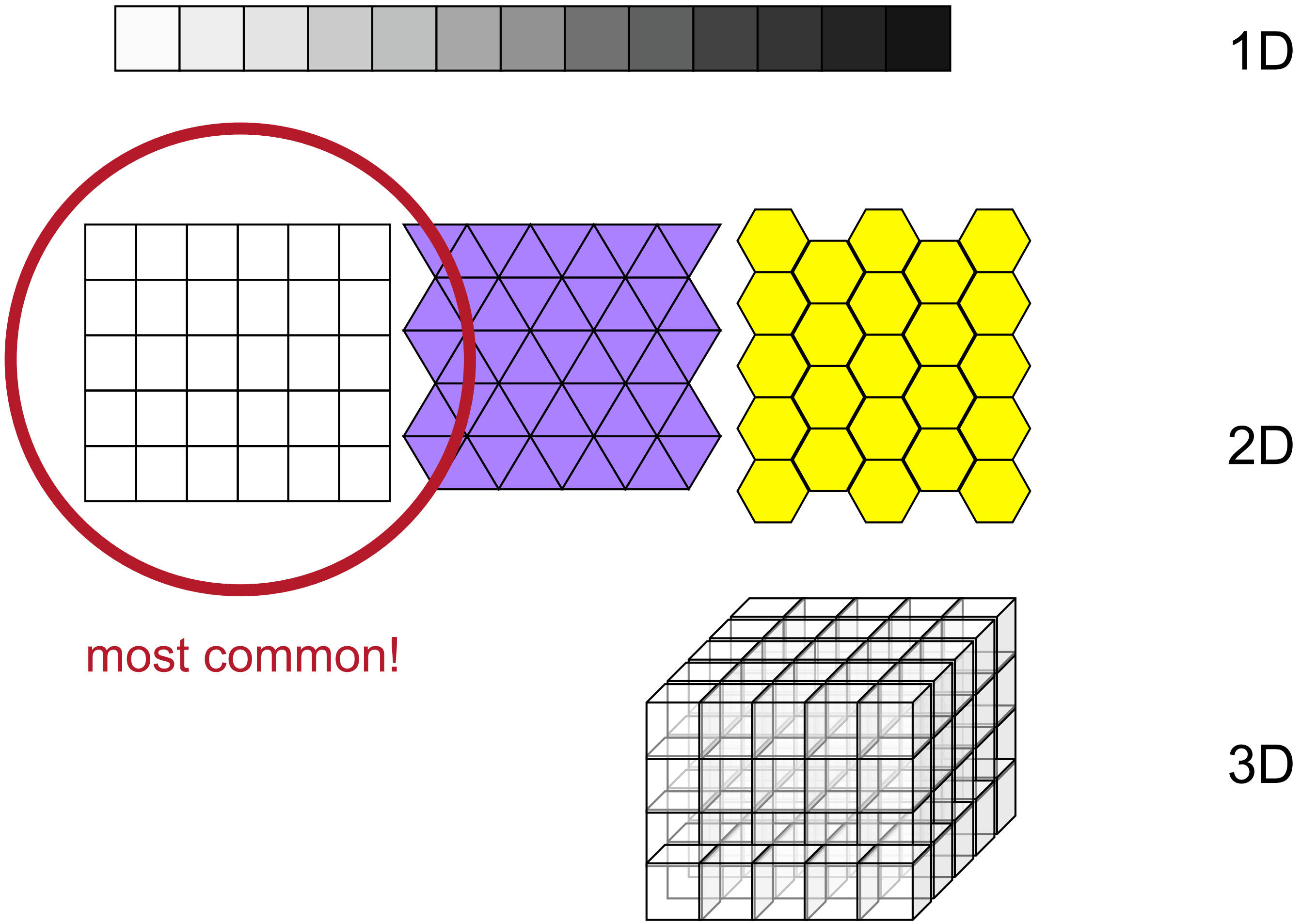
- regular, irregular (the latter is complicated)
- 1, 2, 3, n-dimensional,
- hexagonal,
- triangular,
- the 2D topography, rectangular grid is the most common

Grid - topologies

1D grid



Grid - topologies



Technical details

For each cell, a set of possible states will be defined.

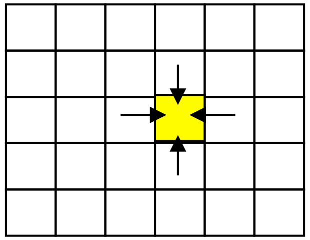
- either
  discrete states (e.g. „alive“, „dead“) or continuous (variable) states
- a combination of states is possible in order to define the exact situation of a cell
  (e.g. biomass & age)

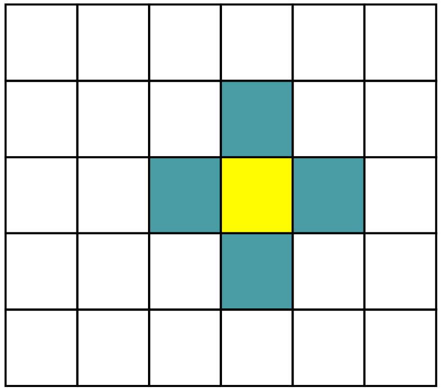
Technical details

For each cell, the „neighborhood“ must be defined.

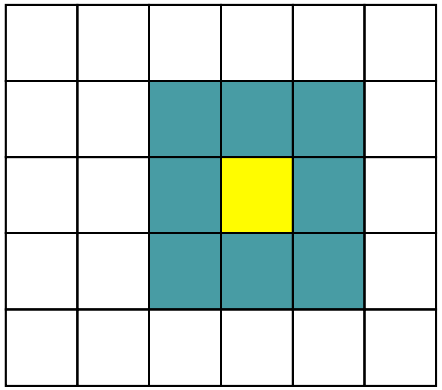
- each cell has neighboring cells (usually the adjacent cells)
- the neighborhood can be regular or irregular, rectangular, circular ..
- the states of the neighbor cells influence the state of focal cell

neighborhood

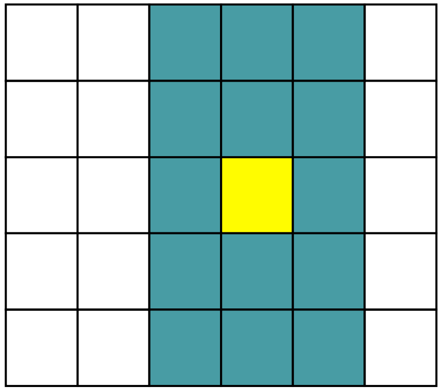




von Neumann



Moore



... others

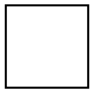
Technical details

Rules define how the state of each cell changes during each simulation step.

- both the state of the focal cell and the states of the neighbor cells will be considered.
- the rules define what happens to the system in each possible situation.

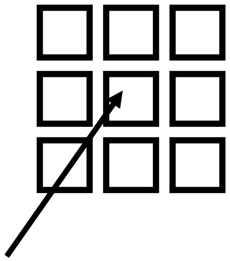
Examples of rules and states

states



„dead"

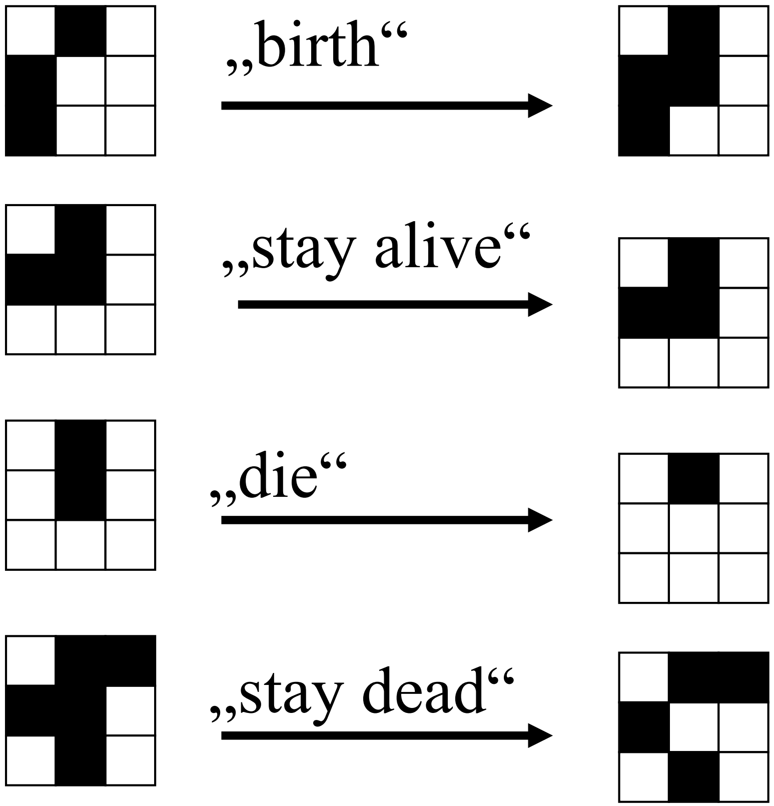
„alive"



Focal cell in the middle. All other cells are neighbors (Moore-neighborhood).

Rules

use 8-cell (Moore-) neighborhood surround focal cell



A dead cell becomes alive if three neighbors are alive.

A living cell stays alive if 2 or 3 neighbors are alive.

A cell dies or stays dead if less than 2 cells live (loneliness) or more than 3 cells live (overcrowding).

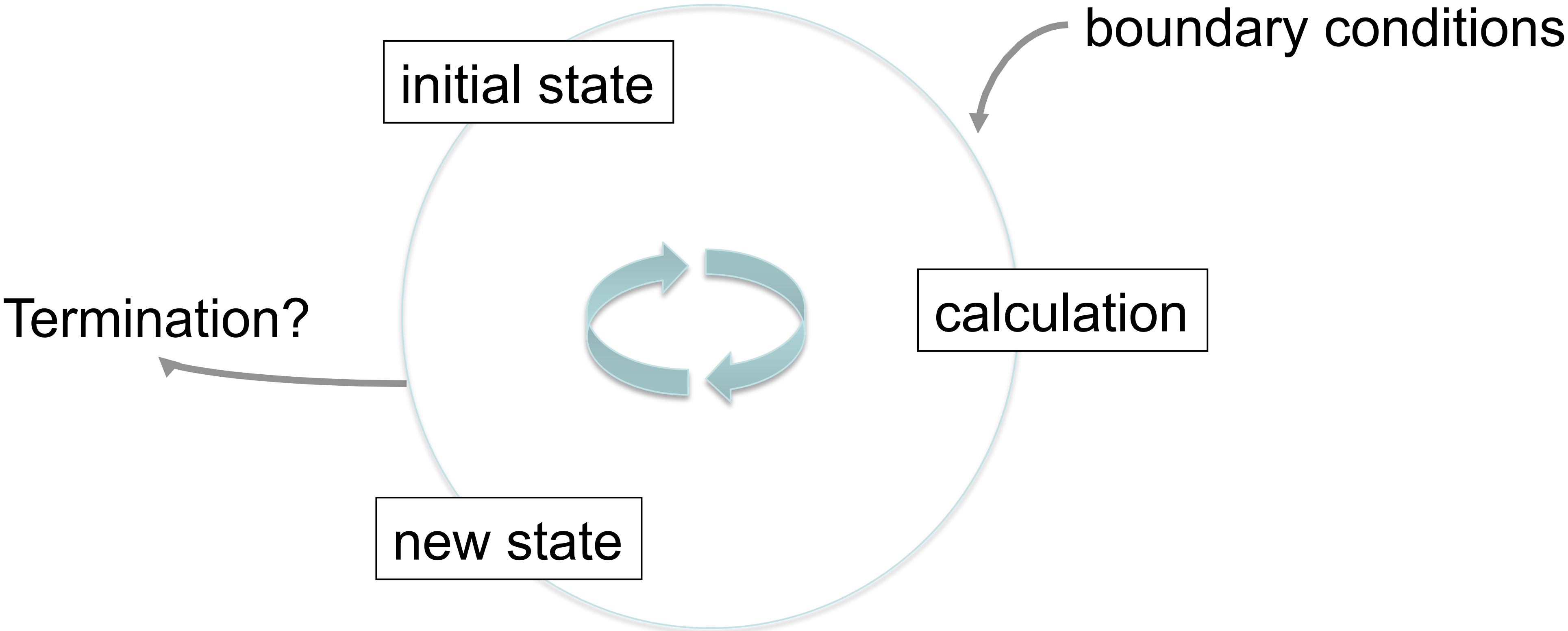
How do we calculate the states and update the CA?

The whole grid - cell by cell - will be calculated.

The calculation will be repeated according to the rules until the conditions of termination are fulfilled.

Does it have a familiar ring?

Algorithmus: Iteration



The definition of the Initial state is important.

Example showing the principle of an iteration.

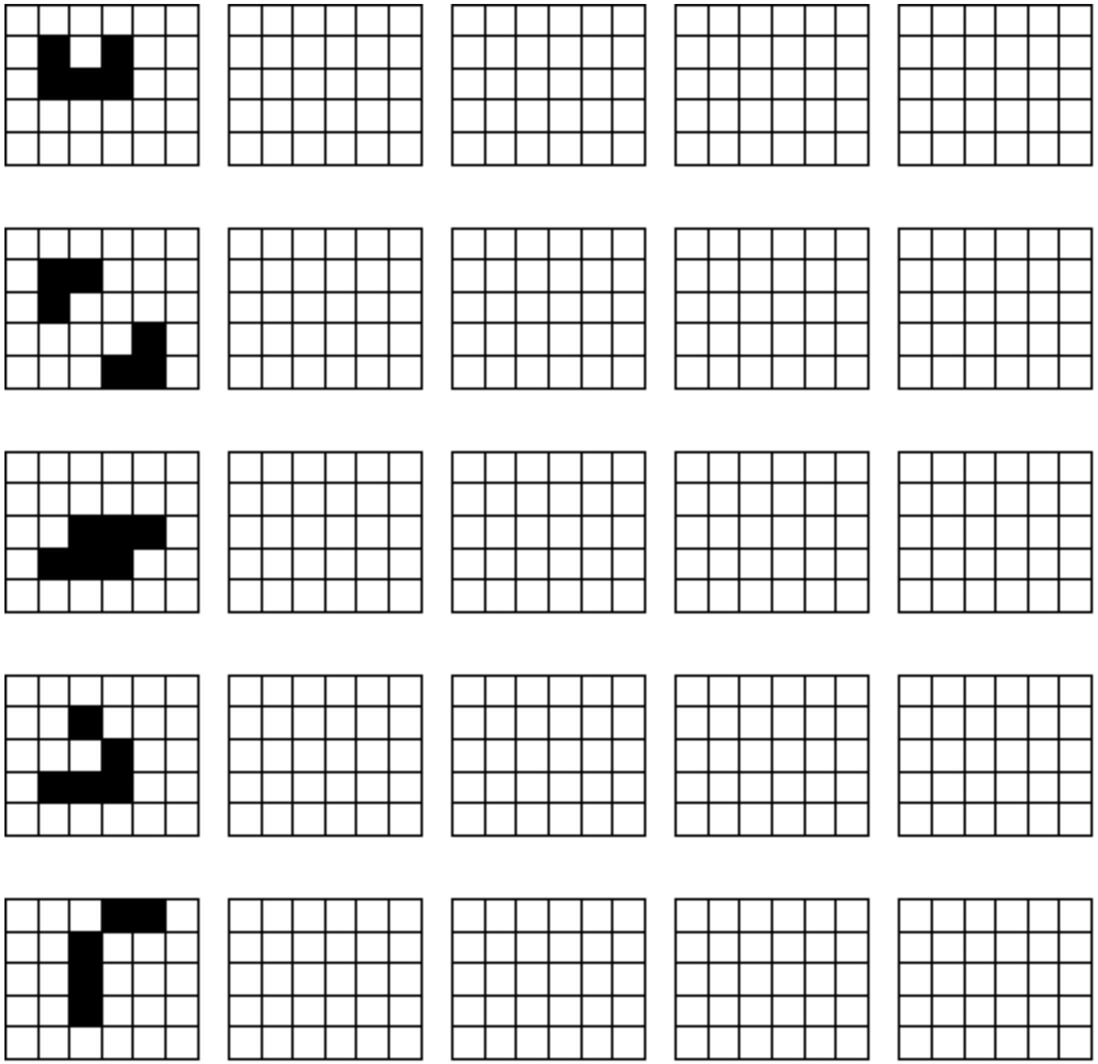
$N_{n+1} = N_n + \mathit{2.0}$ rule

$N_0 = 0$ initial state

Iteration

0	0.0
1	2.0
2	4.0
3	6.0
4	8.0
5	10.0

The Game of Life by John Conway



Each cell can have 2 states – *alive* or *dead*

neighborhood:

8 cells (Moore)

***Stay dead*:**

dead cell has 0, 1, 2 or >3 living neighbors

***birth*:**

dead cell has exactly 3 living neighbors

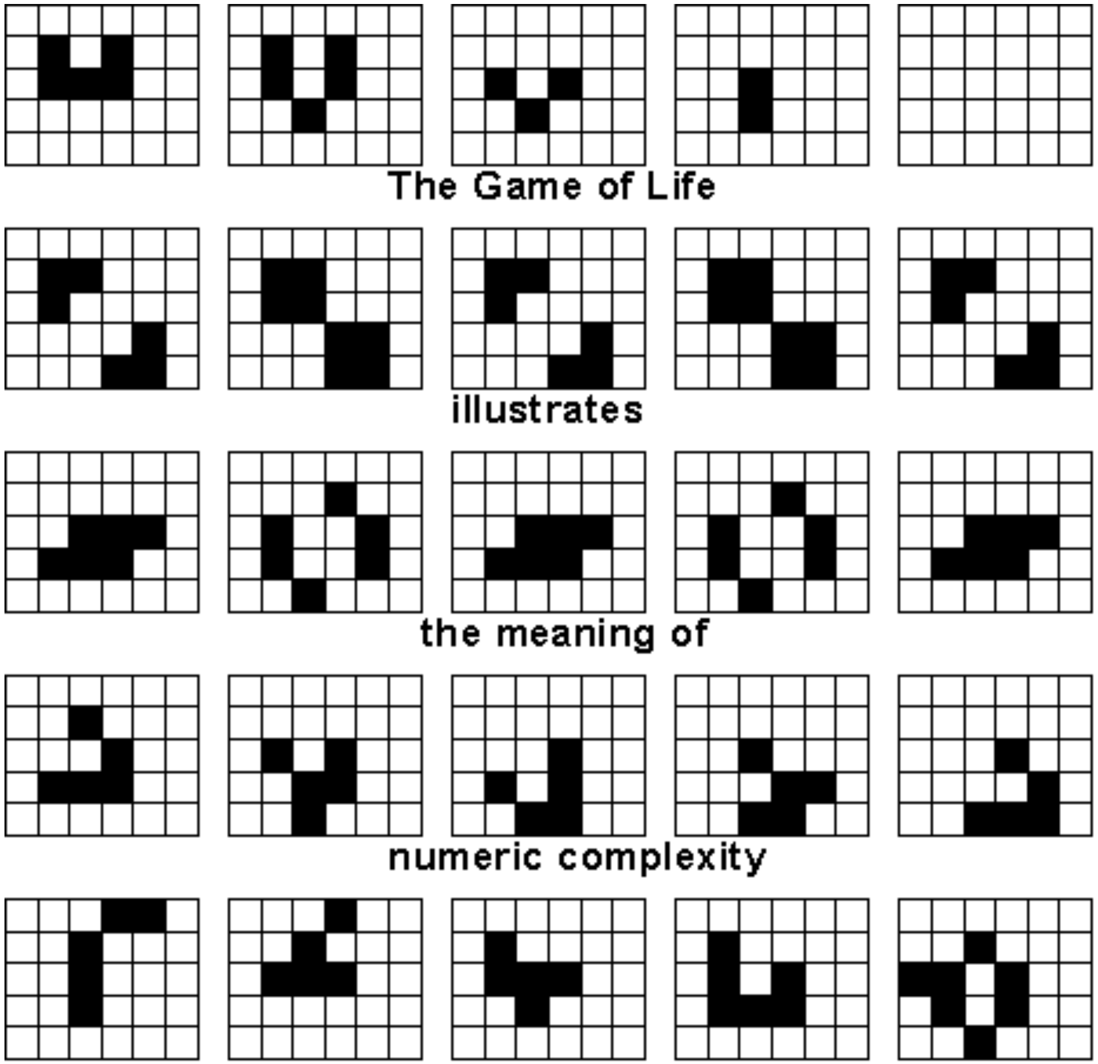
***Stay alive*:**

living cell has 2 or3 living neighbors

***die*:**

living cell has 0, 1 or >3 living neighbors

The Game of Life by John Conway



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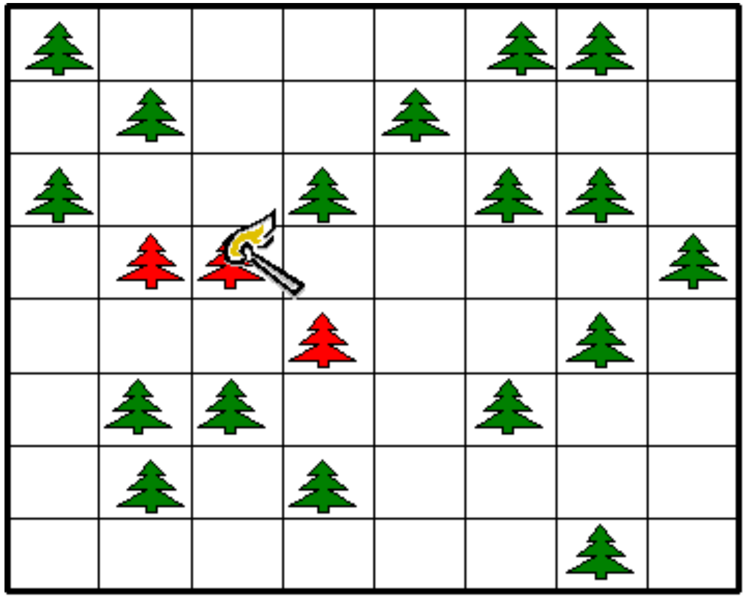
Ecological Applications

A cellular automaton for simulating the spread of fire (see NetLogo exercise).



www.nazteam.com

rechtes Bild: Jason Gorman

Ecological Applications

A cellular automaton for simulating self-organized vegetation patterns in semi-arid landscapes.

A Model Simulating the Genesis of Banded Vegetation Patterns in Niger

J. M. Thiery; J.-M. D'Herbes; C. Valentin

The Journal of Ecology, Vol. 83, No. 3. (Jun., 1995), pp. 497-507.

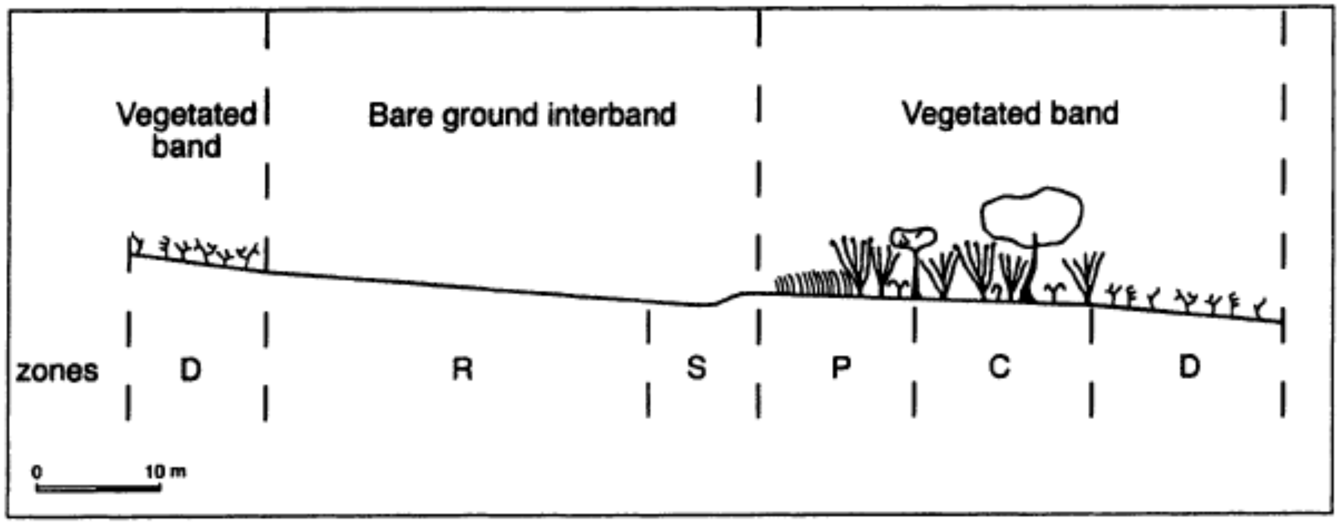
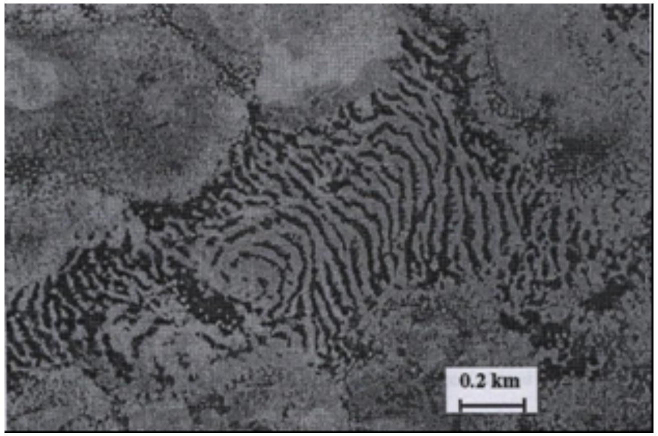
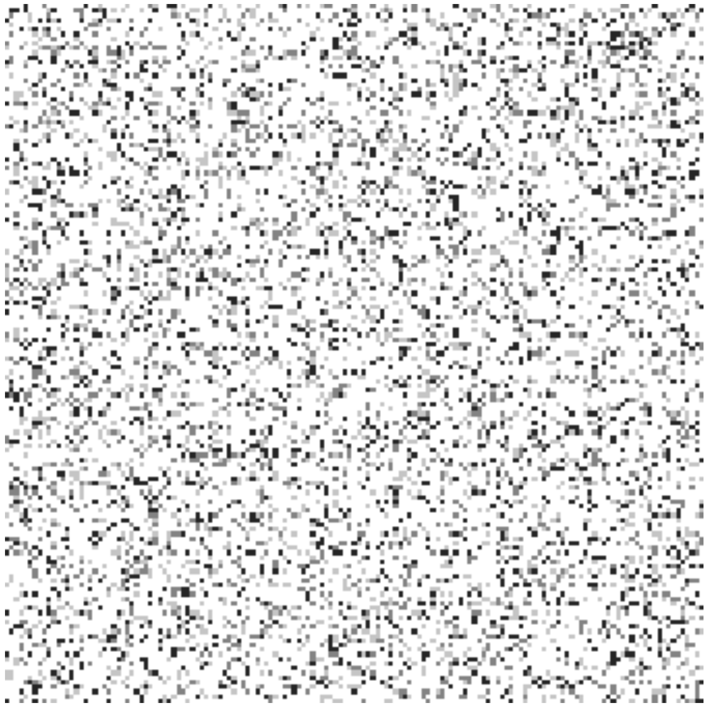


Fig. 2 Schematic cross-section of a '*brousse tigrée*' showing the different zones: D (Degraded), R (Run-off), S (Sedimentation), P (Pioneer front), C (Central, or Close bush). The transect described in the article starts with the up-slope D-zone and finishes with the C-zone.



Satellitenbild: C. Valentin, J. M. d'Herbes, and J. Poesen, Catena 37, 1 ©1999.



Model (NetLogo)

neighborhood

0	–a	0
0	–a	0
0	–a	0
0	–a	0
0	–a	0
0	–a	0
b	*	b
0	3	0
0	1	0

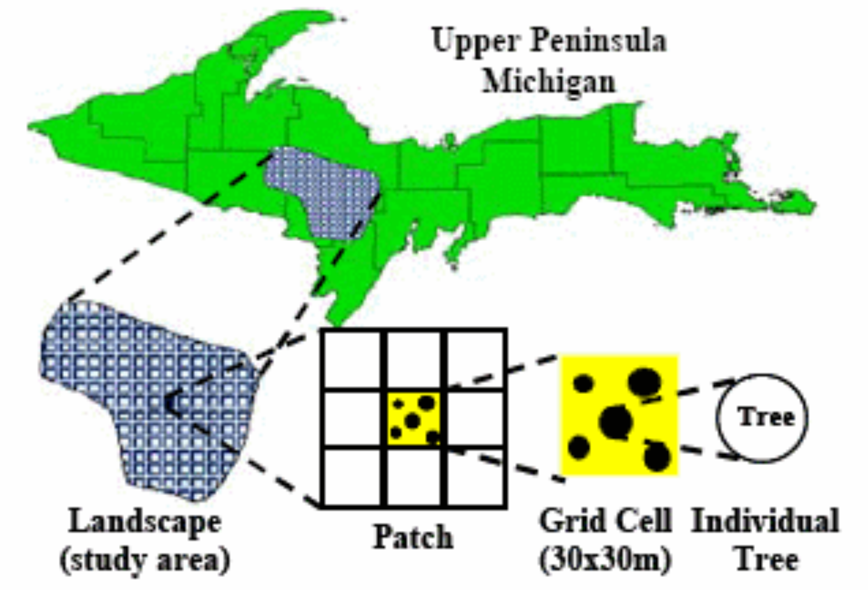
iteration rule

$$S_{i,j,k+1} = S_{i,j,k} + Max(B, Min(H, c\sum_{m,n} C_{m,n} S_{i+m,j+n,k}))$$

mit B = -1, H = 1, c = 1

Ecological Applications

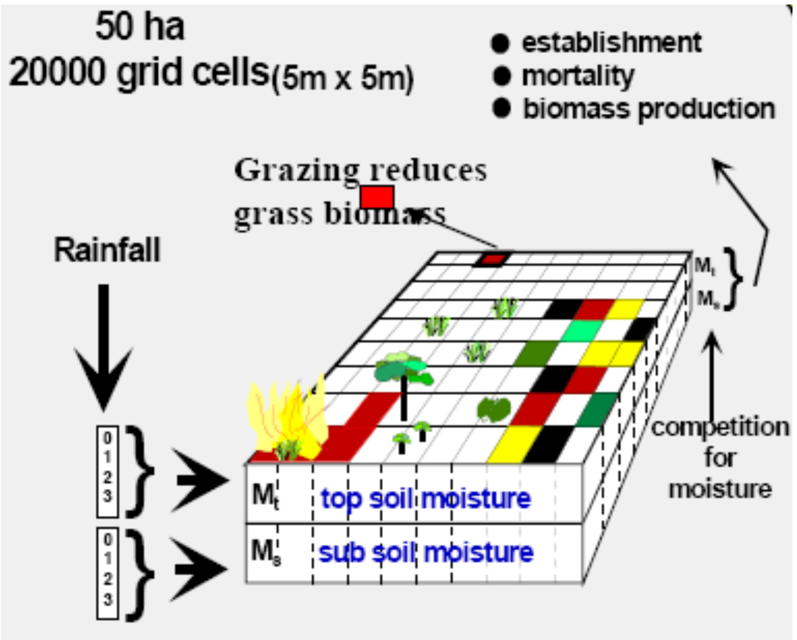
Grid-based for simulating the forest dynamics embedded in a GIS.



http://www.csis.msu.edu/UPStudyArea.gif

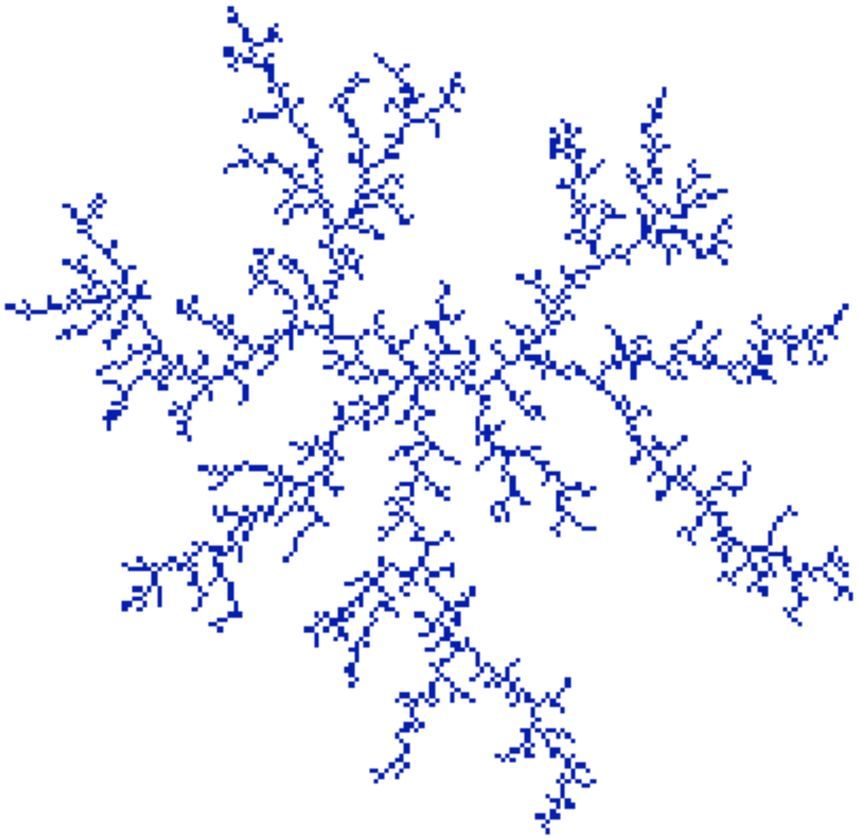
Further applications:

Savannah models Florian Jeltsch (1996, 97, 98, 99, 2000, ..)



- Trees (*Acacia erioloba*)
- Perenial grass and herbs (e.g., *Stipagrostis obtusa*)
- Shrubs (e.g., *Rhigozum trichotomum*)
- Annual grass and herbs (e.g., *Schmidtia kaahariensis*)
- mixed
- unoccupied

Application: diffusions-limited growth



River catchments

Geographical topographies
(hills and valleys)

branch- and root systems of plants

Growth of Mycorhizza

Growth of bacterial colonies

Other characteristic applications in ecology:

- Self-organized patterns
  - skin
  - Shell shapes of mussels
- Organismic interactions
  - Plant competition
  - “home range” models
  - “patch occupancy”
- Landscape processes
  - Fire ecology
  - Spread of deseases (e.g. rabies)
  - Species invasions