Natural Computing

LMU Munich
summer term 2025

Thomas Gabor

Who strongly prefers German?

Who strongly prefers English?

Preface

- lecture
- exercises
- exam

current schedule and all further information
to be found on moodle
https://moodle.lmu.de/course/view.php?id=38504

Material

- what happens in this room
- slides
- video recordings (as much as possible)
- the definition sheet
- exercise sheets (with solutions)
- literature

Slides

- found on moodle
- versions: preview — raw — scribbled

Video Recordings

- we try to capture as much as possible
- not everything is guaranteed to be found online

Video Recordings

We need some help with that!!

The Definition Sheet

Natural Computing
Definition Sheet

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summer term 2022

Notation. $\wp(X)$ denotes the power set of X. $+\!\!+$ denotes vector or sequence concatenation, i.e., given two vectors $\mathbf{x} = \langle x_1, ..., x_{|\mathbf{x}|}\rangle$ and $\mathbf{y} = \langle y_1, ..., y_{|\mathbf{y}|}\rangle$, $\mathbf{x} +\!\!+ \mathbf{y} = \langle x_1, ..., x_{|\mathbf{x}|}, y_1, ..., y_{|\mathbf{y}|}\rangle$. A vector $\langle x_0, ..., x_{n-1}\rangle$ with length $n \in \mathbb{N}$ can also be written as $\langle x_i\rangle_{0\leq i\leq n-1}$ for a new iteration variable i. $\_$ denotes unspecified function arguments ($f(\_) = 0$ is the constant function that always returns zero, e.g.). We commonly write set operators ($\in, \subseteq, \wp$ etc.) for multisets where they can be used trivially.

Definition 1 (Conway's game of life)**.** Let $G = (V, E)$ be a graph with vertices V and (undirected) edges $E \subseteq V \times V$. We define $\mathit{neighborhood} : V \to \wp(V)$ via $\mathit{neighborhood}(v) = \{w \mid (v, w) \in E\}$ as a topology for G. A state $x \in \mathcal{X}$ is a mapping of vertices to the labels $\{\mathit{dead}, \mathit{alive}\}$, i.e., the state space $\mathcal{X}$ is given via $\mathcal{X} = (V \to \{\mathit{dead}, \mathit{alive}\})$. Let x_t be a state that exists at time step $t \in \mathbb{N}$. We define $|v|_{x_t} = |\{w \mid w \in \mathit{neighborhood}(v) \wedge x_t(w) = \mathit{alive}\}|$. In the game of life, the evolution of a state x_t to its subsequent state x_{t+1} is given deterministically via

$$x_{t+1}(v) = \begin{cases} \mathit{dead} & \text{if } |v|_{x_t} \leq 1, \\ x_t(v) & \text{if } |v|_{x_t} = 2, \\ \mathit{alive} & \text{if } |v|_{x_t} = 3, \\ \mathit{dead} & \text{if } 4 \leq |v|_{x_t}, \end{cases}$$

for all $v \in V$. A tuple (G, x_S) is called an instance of the game of life for initial state $x_S \in \mathcal{X}$.

Exercise Sheets

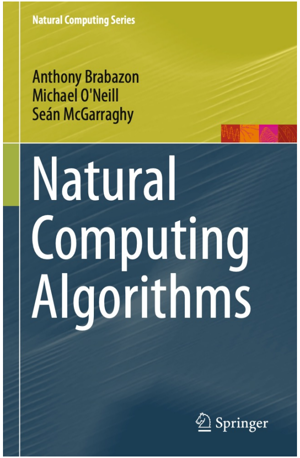
- published online, solutions discussed in this room, then solution suggestion published online
- include programming exercises

Look forward to...

Max
Zorn

Literature

Brabazon, O'Neill, McGarraghy.
Natural Computing Algorithms.
Springer, 2015.
link-springer-com.emedien.ub.uni-muenchen.de/book/10.1007/978-3-662-43631-8



…more later!

Questions?

Who is doing a Master's degree?

Who took Computational Intelligence?

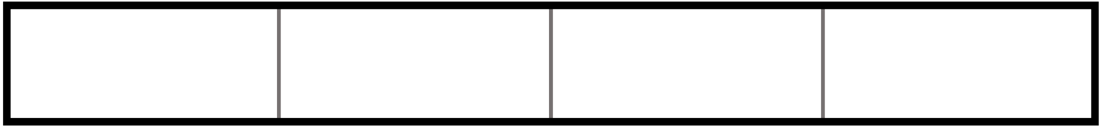
Who has experience in any natural science?

Who can program a deep neural network?

Who can program a quantum computer?

Who has mastered at least one programming language?

Who is fluent in Python?

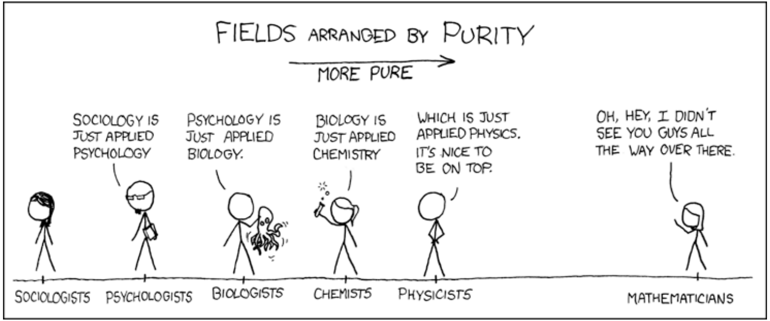


Introduction

Natural Computing
is
algorithms
found in or inspired by
nature.

A different perspective on computer science

Does computer science belong among the sciences?

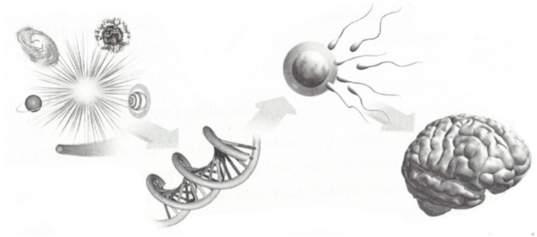
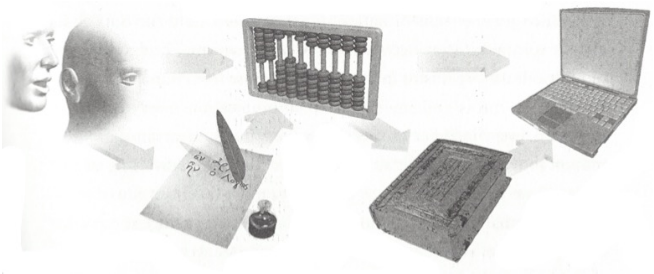


xkcd.com/435/

“Computer science is no more about computers than astronomy is about telescopes, biology is about microscopes or chemistry is about beakers and test tubes.”

Michael R. Fellows and Ian Parberry (1993)

en.wikiquote.org/wiki/Computer_science#Disputed
archive.cra.org/CRN/issues/9301.pdf

“The history of the universe can be thought of as a sequence of information processing revolutions, each of which builds on the technology of the previous ones.”

Seth Lloyd. Programming the Universe. Vintage Books, 2006.

Why nature?

Physics

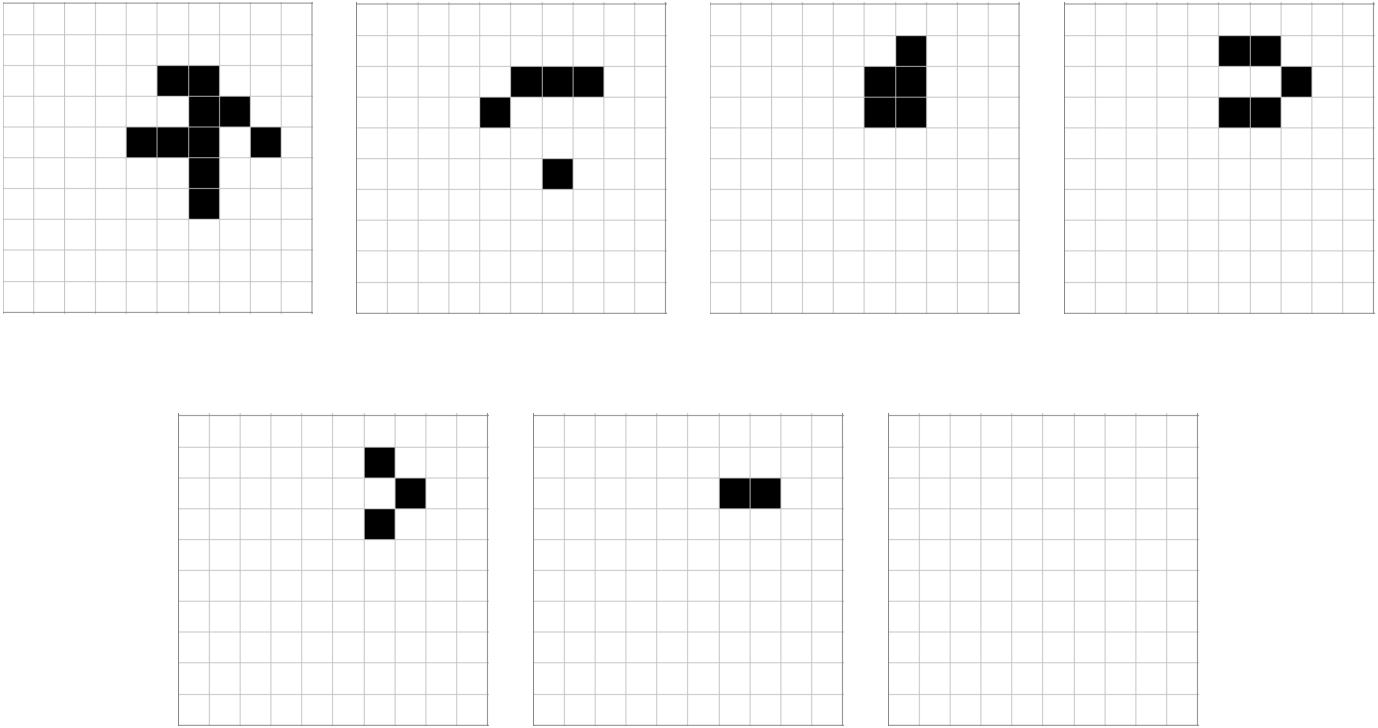
Chemistry

Biology

quantum computing
simulated annealing
particle swarms
artificial chemistry systems
cellular automata
game of life
evolutionary algorithms
neural networks
social computing

The Game of Life

Who knows Conway's Game of Life?



Definition 3 (Conway's game of life (standard)). Let $G = (V, E)$ be a graph with vertices V and (undirected) edges $E \subseteq V \times V$ with a fixed degree of 8 for all nodes. We define $\mathit{surroundings} : V \to \wp(V)$ via

$$\mathit{surroundings}(v) = \{w \mid (v, w) \in E\}$$

so that $|\mathit{surroundings}(v)| = 8$ and $v \notin \mathit{surroundings}(v)$ for all $v \in V$. A state $x \in \mathcal{X}$ is a mapping of vertices to the labels $\{\mathit{dead}, \mathit{alive}\}$, i.e., the state space $\mathcal{X}$ is given via $\mathcal{X} = (V \to \{\mathit{dead}, \mathit{alive}\})$. Let x_t be a state that exists at time step $t \in \mathbb{N}$. We define

$$|v|_{x_t} = |\{w \mid w \in \mathit{surroundings}(v) \wedge x_t(w) = \mathit{alive}\}|.$$

In the game of life, the evolution of a state x_t to its subsequent state x_{t+1} is given deterministically via

$$x_{t+1}(v) = \begin{cases} \mathit{dead} & \text{if } |v|_{x_t} \leq 1, \\ x_t(v) & \text{if } |v|_{x_t} = 2, \\ \mathit{alive} & \text{if } |v|_{x_t} = 3, \\ \mathit{dead} & \text{if } |v|_{x_t} \geq 4, \end{cases}$$

for all $v \in V$. A tuple (G, x_0) is called an instance of the game of life for initial state $x_0 \in \mathcal{X}$.

Let’s try

conwaylife.com

Still Lifes

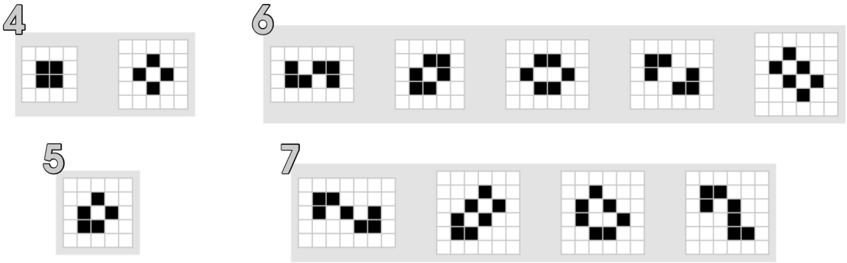
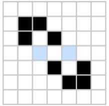


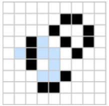
Figure 2.1: All still lifes with 7 or fewer live cells, arranged by their cell count. From left to right: (4 cells) block, tub, (5 cells) boat, (6 cells), snake, ship, beehive, aircraft carrier, barge, (7 cells) long snake, long boat, loaf, and eater 1 (which is sometimes called **fishhook**).

source: conwaylife.com/book/

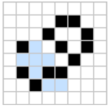
Oscillators



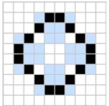
(a) bipole (p2).



(b) jam (p3).



(c) mold (p4).



(d) octagon 2 (p5).

Figure 3.1: Some more small naturally occurring (but rare) oscillators that can be found via computer-assisted soup searches. These oscillators were found by (a) early Lifenthusiasts at M.I.T. in 1970, (b,c) Achim Flammenkamp in 1988,[2] and (d) Sol Goodman and Arthur Taber in 1971.

source: conwaylife.com/book/

Space Ships

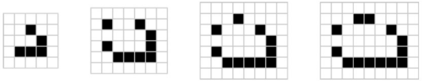
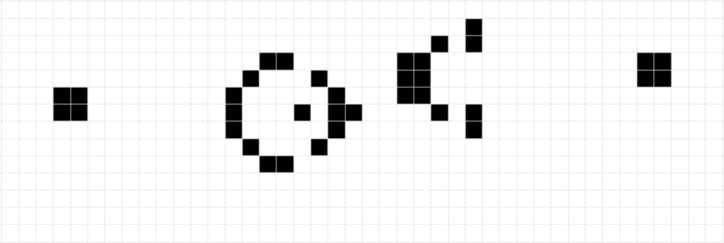


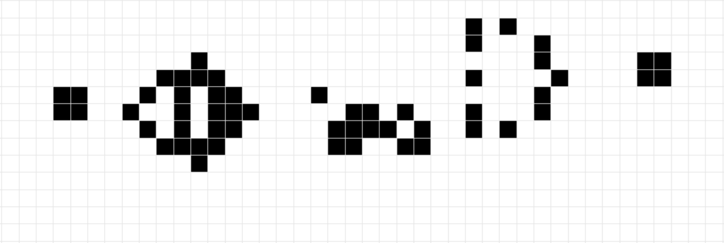
Figure 4.1: The four basic spaceships in Conway's Game of Life. From left to right, these are the glider (which moves diagonally at a speed of $c/4$) and the light/middle/heavyweight spaceships (which each move orthogonally[1] at a speed of $c/2$).

source: conwaylife.com/book/

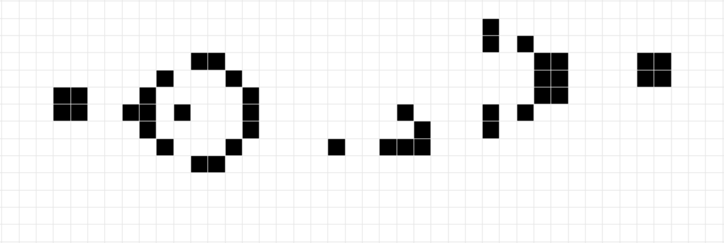
Guns



t = 1



t = 14



t = 15

[try online]

source: conwaylife.com

Space Ship Maneuvering

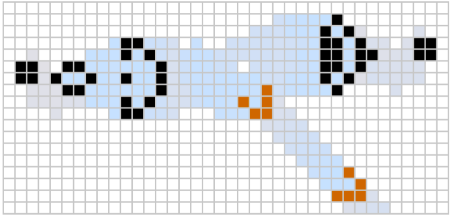


Figure 6.2: A Gosper glider gun producing gliders at a spacing of 30 generations.

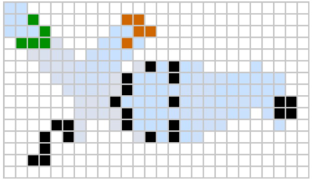


Figure 6.3: A buckaroo can reflect a glider by 90 degrees, from the position marked in green to the one in orange 30 generations later.

source: conwaylife.com/book/

More Space Ship Maneuvering

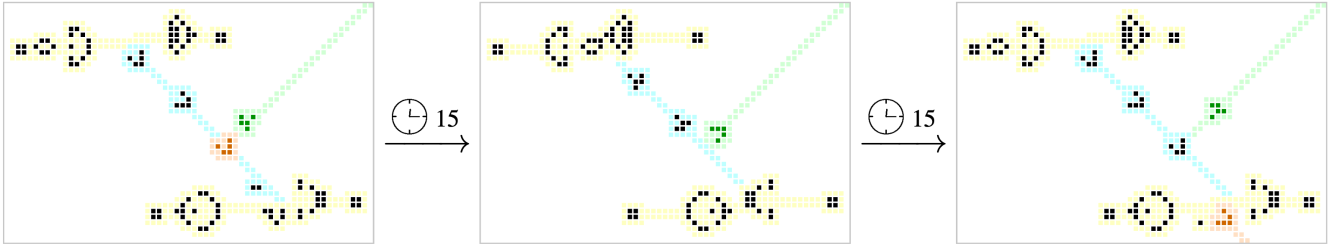


Figure 6.7: Two Gosper glider guns can be placed near each other so as to create a finite stream of gliders (highlighted here in aqua) between them. Here, we bounce a single glider (in green) off of one of those gliders (in orange) so that it is destroyed and thus released by the inline inverter to the southeast.

source: conwaylife.com/book/ conwaylife.com/book/periodic_circuitry