Artificial Life
Summer 2025

Summary and
Questions & Answers

Master Computer Science [MA-INF 4201]
Mon 14:15 – 15:45, HSZ, HS-2

Dr. Nils Goerke, Autonomous Intelligent Systems,
Department of Computer Science, University of Bonn

Topics of the 2025 Artificial Life Lecture

1. Natural Life – Artificial Life, Langton's Ant
2. Cellular Automata (1dim)
3. Cellular Automata 2D, Conway's Game of Life
4. Self Replication, Langton's Loop, Lindenmeyer Systems
5. Pattern Formation in Biological Systems
6. Evolutionary Algorithms, part 1
7. Evolutionary Algorithms, part 2
8. Evolutionary Algorithms, part 3
9. Self Organizing Criticality (SOC), Ant Algorithms
10. Complex Behavior, Braitenberg Vehicles
11. Swarm Behavior, Boids, Particle Swarm Optimization (PSO)
12. Subsumption Architecure
13. Summary, Questions & Answers

Natural Life – Artificial Life

- Definitions of Life or Living
- Sets of common criteria
- What is Artificial Life?
- Weak Artificial Life – Strong Artificial Life

Langton's Ant

- CA like agent, on a 2-dim rectangular grid
- 2-dimensional Turing Machine
- Computational universality
- Micro behavior: scan – turn – flip – move
- 3 phases of macroscopic behavior: “symmetry”, “chaos”, “highways”

Cellular Automata (1dim)

- CA: discrete model of information processing (space, time, value)
- Ingredients: lattice, neighborhood, alphabet, rule, initial state
- Boundary of the grid / lattice
- No of rules, incl. formula
- Properties: symmetric, silent state, legal , peripheral, totalistic
- Rule table
- Wolfram number
- 4 Classes of behavior: homogeneous, periodic, chaotic, patterns

Cellular Automata 2-dim

- Grid in higher dimensions 2-dim ,3-dim, ...
- Neighborhood in 2 dim:
- Neighborhood for a 2 dim rectangular grid: von Neuman, Moore
- Probabilistic extensions to CAs
- Example: majority voting CA,
- Example: forest fire CA
- Example: Conway's Game of Life

Conway's Game of Life

- Game of Life, Conway's Game of Life
- 23/3 rule, survival, birth, death, loneliness, overcrowding
- 4 classes of behavior and special prototypic patterns
- Special Game of Life Patterns:
  - block
  - blinker
  - glider
  - glidergun
  - r-pentomino
- Computational universality

Self Replication, Langton's Loop

- Self replication as a fundamental principle for living
- Von Neumanns universal constructor
- Von Neumanns self replicating constructor
- Self replicating loops
- Chris Langton's self replicating loop
- CA, d=2, r=1, k=8, with 219 interesting entries
- Initial pattern (loop) with 86 cells replicates in 151 steps
- Loop, arm, channel, sheath, message string, signals

Lindenmeyer Systems, L-Systems

- Idea, purpose, model plant growth
- D0L-Systems
- Definition: symbols, constants, axiom, rules, (depth)
- Example: {C,A} , C, $C \rightarrow A$, $A \rightarrow CA$
- Visualization in 2 dim or 3 dim
- Applications of L-Systems

Pattern Formation in Biological Systems

- Iterated functions
- Linear and exponential growth
- Fibonacci sequence
- Logistic growth
- Predator-prey system
- Lotka-Volterra equations
- Activator-inhibitor equations
- Reaction-diffusion systems
- Plant morphogenesis, phylotaxis
- Golden section, Golden angle
- Self similarity

Evolutionary Algorithms

- Evolutionary Computation,Historic Remarks
- Different Approaches
- Optimization, some basics
- Idea of Evolutionary Algorithms (EA)
- EA Steps
  - Individual, Genome, Fitness, Population
  - Parent selection
  - Inheritance
  - Mutation
  - Fitness evaluation
  - External selection
  - Finish
  - Initialization

Evolutionary Algorithms

- Strategy: (μ + λ), (μ , λ)
- Performance Graph
- Genome structure
- Examples: Fkt.Maximum, Sorting, 42, TSP,
- Example: 8 queens
- Super-individuals
- External-selection and parent-selection combined
- Probabilistic parent-selection
  - Wheel of fortune
  - Softmax selection
  - Tournament selection
- Genetic programming
- Co-evolution

Self Organizing Criticality, SOC

- What is Self Organized Criticality?
- Motivation
- Power law, Scaling law
- Examples of SOC systems
  - Sandpile model
  - Land slides
  - Forest fire model
  - Size distribution of cities
  - Gutenberg-Richter law, Earthquakes
  - Zipf's law
  - Lotka’s law
  - Auerbach’s detection

Ant Algorithms

- Ant Algorithms are a family of method for discrete optimization.
- Essential ingredients of an Ant System (AS) are:
  - Multiple cooperating agents,
  - which are simple structured;
  - they have a sensory system,
  - a method to deposit pheromones (stigmergy),
  - and a simple mechanism to decide where to go.
  - The pheromones evaporate after a while.
- Ant System (AS),
  Ant Colony System (ACS),
  Ant Colony Optimization (ACO),
  Ant Net

Roots of Complex Behavior, Braitenberg Vehicles

- Ideas from biology and from engineering
- Control architectures, reactive control, proactive control
- SMPA architecture
- some systems theory
- Braitenberg vehicles
  - Type 1
  - Type 2
  - Type 3
  - Type 3b based obstacle avoidance
  - Type 4
  - Type 5 - 14

Swarms, Swarming, Swarm behavior

- Cooperating Robots
- The Didabot Experiment, Swiss-Robots
  Clustering, building heaps
- Swarm Behavior
- Swarms
- C.Reynolds: Boids

Boids

- Craig Reynolds' Boids are a simple model to build swarm like behavior.
- 3 rules of individual behavior
  - Separation:
    steer to avoid crowding local flockmates
  - Alignment:
    steer towards the average heading of local flockmates
  - Cohesion:
    steer to move toward the average position of local flockmates
- Applications of Boids

Particle Swarm Optimization, PSO

Particle Swarm Optimization is an Artificial Life inspired, multi hypothesis, meta heuristic method for optimization.

The PSO consists of:

- a population of P particles
- a search space ***S***, with positions **X** in ***S***
- an objective function f(**X**)
- a memory for global best: $\mathbf{X}_{gb}$, f($\mathbf{X}_{gb}$)
- (several sub-groups of particles)

Each particle i has:

- a position $\mathbf{X}_i$ in search space **S**
- a velocity $\mathbf{V}_i$, (change in position)
- a memory to store the best result for the individual so far personal best: $\mathbf{X}_{i,pb}$, f($\mathbf{X}_{i,pb}$)
- (group of particles it belongs to, group best $\mathbf{X}_{i,grb}$, f($\mathbf{X}_{i,grb}$))

Subsumption Architecture

The subsumption architecture is:

- A hierarchical control architecture
- Organized in layers of competence
- Each layer is working autonomously (unless)
- Controlled by higher layers
- Inhibition and suppression control lower layers
- The layers consist of simple structured modules
- Rather robust against damage or module failure
- Implementation can be very complex

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Exam Information

Master Computer Science [MA-INF 4201]
Mon 14:15 – 15:45, HSZ, HS-2

Dr. Nils Goerke, Autonomous Intelligent Systems,
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Examination:

After the end of the lecture period (18.7.25) there will be an examination for the module Artificial Life.

To be admitted for the exam , you will need

- to register
- a minimum of **50%** of the possible reachable points
- a minimum **two presentations** of your solutions in the exercises.

Exam date: Tuesday **22 July 2025, 12:00**, Lecture Hall 1+2, HSZ

The examination will be a written exam,
operated in presence, Lecture Hall 1+2, HSZ
exam duration is 100 minutes
up to 100 points are reachable (approx. 1 minute per point)
2 large tasks, worth 10 points
16 small tasks, worth 5 points.

Some details for the exam

Exam:
Tuesday 22.7.25 12:00 - 15:00
Lecture Hall 1 and Lecture Hall 2

Date for resit exam:
Monday 8.9.25 9:00 - 12:00
Lecture Hall 1

Some important details for the exam

Tuesday 22nd July 2025, Lecture Hall 1+2, 12:00 – 14:00

For the exam:

- Please take your students id card (Studentenausweis) with you.
- Documents with a photo, to check your an identity with you (identity card, or passport, or drivers license, …).
- Bring a pen, ball pen, felt-tip pen with you.
- You will not need a calculator for the exam.
- Paper will be provided.

Some important details for the exam

Thursday 22nd July 2025, Lecture Hall 1+2, 12:00 – 14:00

- Exam time is 100 minutes
- up to 100 points are reachable (approx. 1 minute per point)
- only pen, ball pen, felt-tip pen are allowed, NO pencil.
- only blue or black, NO red or green colors.
- NO correction fluid, No white out (Tipp-Ex).
- all answers need an explanation.
- please indicate clearly what you consider to be the solution.
- when you use formulas, all variables must be explained explicitly.
- short sentences and keywords are preferable to long text passages.
- no extra tools or utilities or electronic devices are allowed.

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Q & A

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**All the best for you,
and good luck for the exams**

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