Artificial Life
Summer 2025

Agenda for Monday 7.4.25

- Welcome Message
- A: Some Organizational Issues
- B: Introduction, Natural Life - Artificial Life
- C: Langton's Ant

Master Computer Science [MA-INF 4201]

Mon 14 c.t. – 15:45, HSZ, HS-2

Dr. Nils Goerke, Autonomous Intelligent Systems,

Department of Computer Science, University of Bonn

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Artificial Life
Summer 2025

A: Some Organizational Issues

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Modalities MA-INF 4201, Artificial Life SS25

The module **Artificial Life** in summer 25 teaching period will be operated in presence in HS-2, HSZ

I will be available by 14:00, HS-2
I will start with the slides at 14:15.

The **slides** will be provided before the lecture on eCampus.

The **assignments** will be handed out after the lecture and will have to be handed in one week later, **before 14:00**.

The **exercises** will be operated in presence.

Assignments:

There will be 13 mandatory weekly assignment sheets with paper and pencil and programming assignments.

Work on the assignments in 3 or 4 person working groups. We believe, that practicing to explain the assignments during the exercises is helpful to comprehend the content.

They are operated in a Monday -- Monday cycle:
distributed on eCampus after the lecture
to be handed in by uploading a pdf file in eCampus
before 14:00 o'clock, Mondays.

The first assignment sheet is published today (7.4.25)
it is due in one week, on Mon 14.4.25 **before 14:00**.

Assignments:

- weekly assignments (13 in total, 11 that yield points),
- paper & pencil assignments (11*15=165)
- programming assignments (total of 50 points)
- thus a total of: 11*15 + 50 = 165 + 50 = 215

- work in 3- or 4-person groups
  members have to be in the same exercise group

- hand in the solutions via eCampus page,
  before 14:00, the start of the lecture.
- the eCampus system will establish a strict deadline

To be admitted to the exam you need:

- >50% => **108 points minimum** in the assignments
- two presentations of your solutions in the exercises

Exercise Groups:

The exercises are designed to help you to comprehend the content of the Artificial Life lecture.

The tutors will give you feedback for your assignments, and will answer questions regarded to the lecture.

The exercise groups will be operated in presence Room 0.011.

We have arranged 6 time-slots and the room for this.

Please prepare for the exercises;
use the opportunity to ask questions;
prepare to get a fruitful discussion.

Exercise Groups:

At the moment we have organized 6 exercise groups,

A:	Wed	14 – 16
B:	Thu	12 – 14
C:	Thu	14 – 16
D:	Fri	8:30 – 10
E:	Fri	10 – 12
F:	Fri	12 – 14

The distribution to the respective groups is done via the tutorial assignment system TVS, until: Fri 11.4.25, 23:00.

https://puma.cs.uni-bonn.de

Password: C

Exercise Groups distribution:

After the TVS has assigned you to one of the 6 groups please register on the eCampus page of the lecture
only in that very group you have been assigned to.
It will be possible from Saturday 12.4.25.

Hand in your solution
only in that very group you have been assigned to.

For those who are late, or have not been assigned to a group, there will be an extra slot where to hand in your solutions until we have cured the problem.

Examination:

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

To be admitted for the exam , you will need
- a minimum of 108 points (**50%** of the possible reachable points) from the assignments,
- a minimum of **two presentations** of your solutions in the exercises.

The examination will be in presence
probably end of July.

The resit exam will be probably beginning of September.

Artificial Life
Summer 2025

B:
Introduction
Natural Life - Artificial Life

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

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Overview:

- What is: Artificial Life ?
- What is: Natural Life ?
- At the border of natural Life
- Systems of Artificial Life
- Initiating a discussion

Overview:

- **What is: Artificial Life ?**
- What is: Natural Life ?
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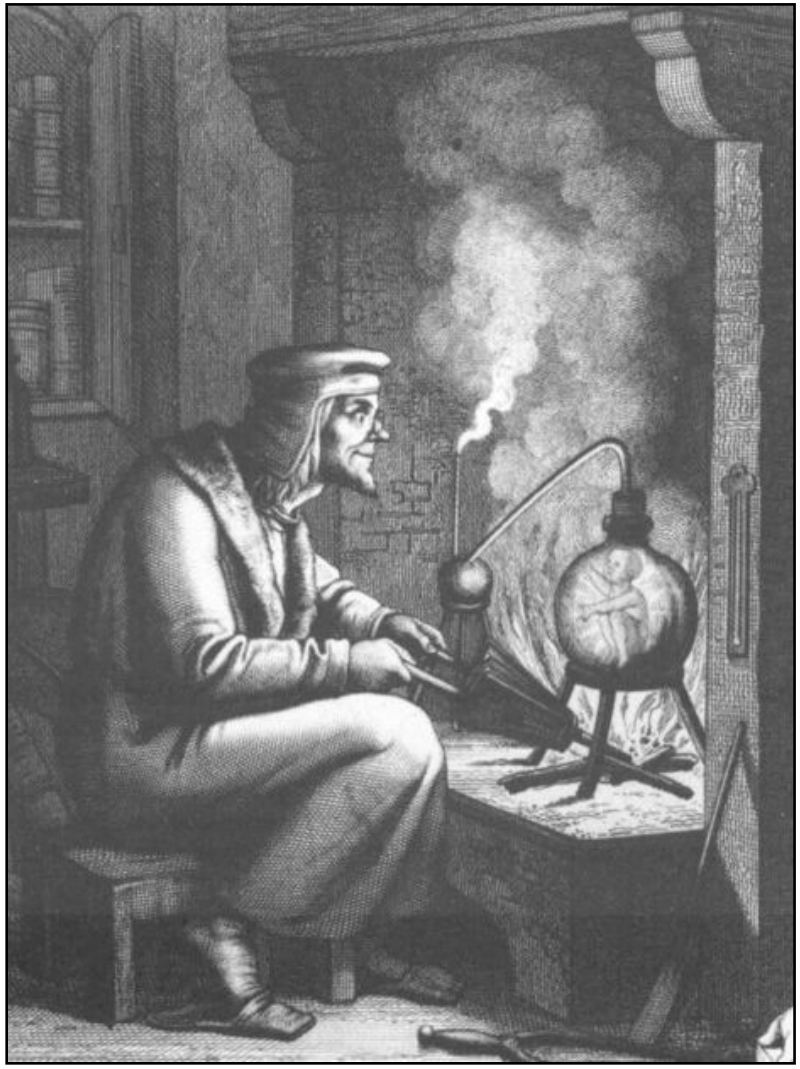
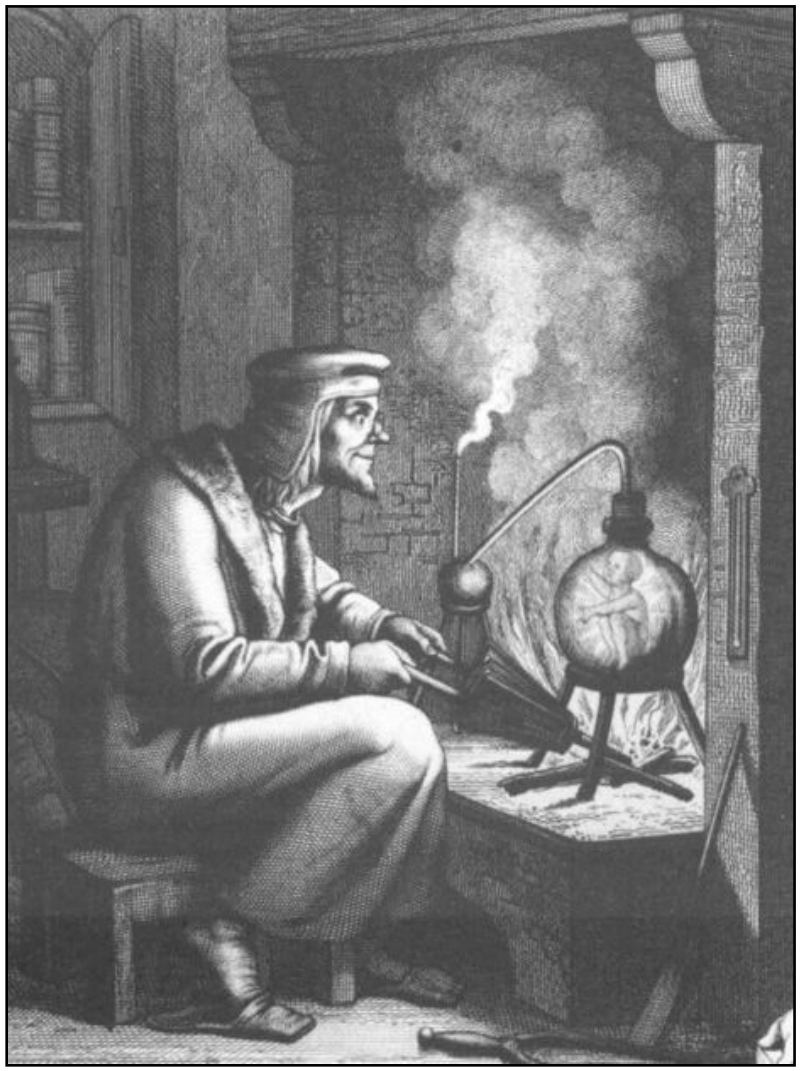
What is: Artificial Life ?

What is: Artificial Life ?



What is: Artificial Life ?



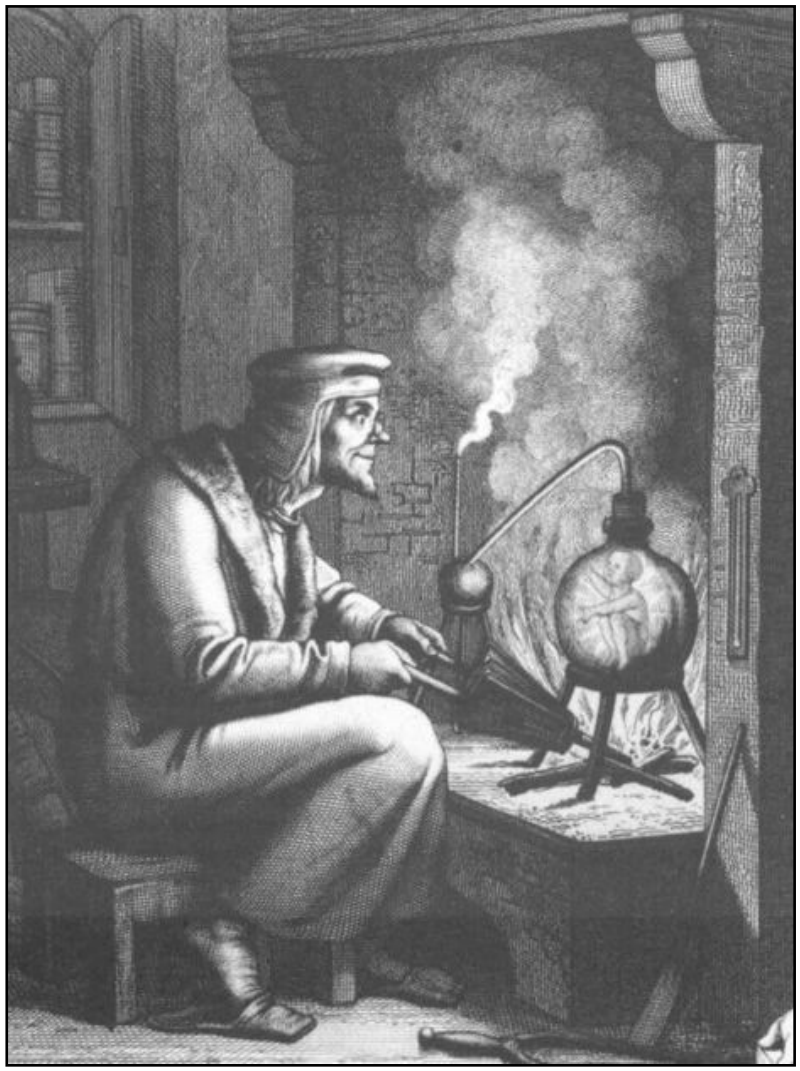
„“

Johann Wolfgang von Goethe, 1832,
Faust II, zweiter Akt Laboratorium

Nach Paracelsus' Anleitung
De generatione rerum naturalium
(Über die Erzeugung der natürlichen Dinge).

Following Paracelsus' recipe
De generatione rerum naturalium
(On the generation of natural things).

What is: Artificial Life ?



„Es leuchtet! seht! - Nun läßt sich wirklich hoffen,
Daß, wenn wir aus viel hundert Stoffen
Durch Mischung - denn auf Mischung kommt es an -
Den Menschenstoff gemächlich komponieren,
In einen Kolben verlutieren
Und ihn gehörig kohobieren,
So ist das Werk im stillen abgetan.
Es wird! die Masse regt sich klarer!
Die überzeugung wahrer, wahrer:
Was man an der Natur Geheimnisvolles pries,
Das wagen wir verständig zu probieren,
Und was sie sonst organisieren ließ,
Das lassen wir kristallisieren.“

Johann Wolfgang von Goethe, 1832,
Faust II, zweiter Akt Laboratorium

Nach Paracelsus' Anleitung
De generatione rerum naturalium
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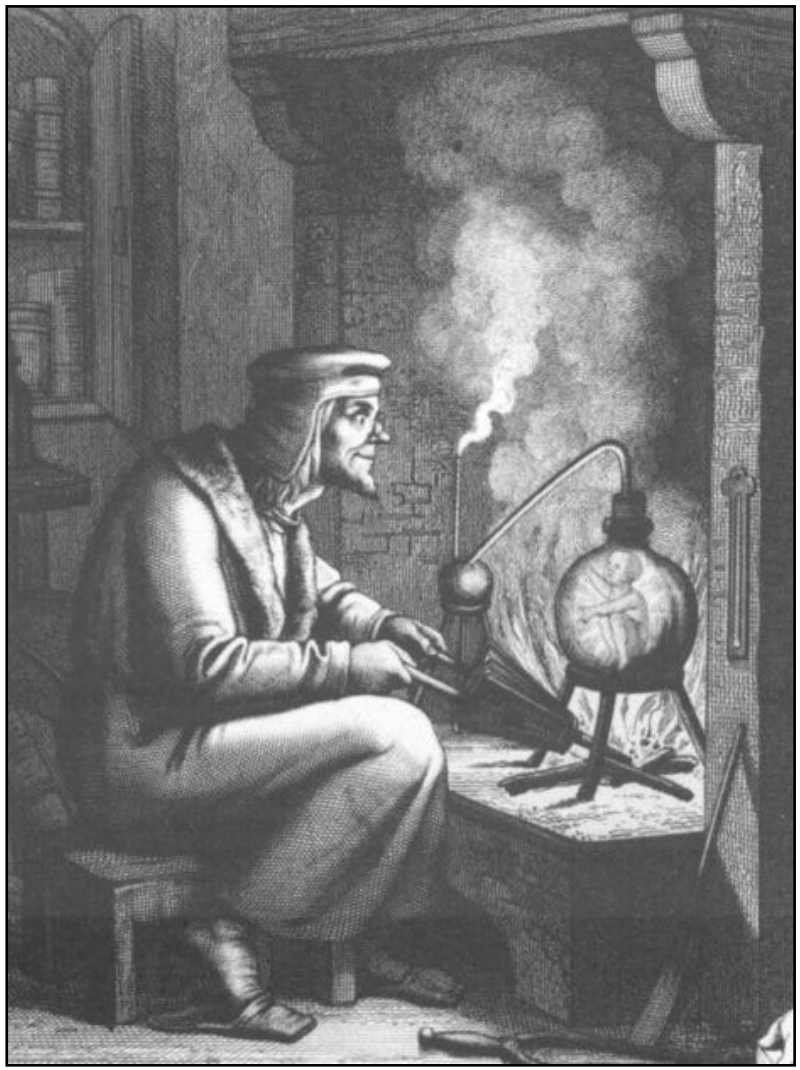
What is: Artificial Life ?



„It flashes, see! Now truly we may hold
That if from substances a hundredfold,
Through mixture - for on mixture all depends-
Man's substance gently be consolidated,
In an alembic sealed and segregated,
And properly be cohobated,
In quiet and success the labour ends.
'Twill be! The mass is working clearer,
Conviction gathers, truer, nearer.
What men as Nature's mysteries would hold,
All that to test by reason we make bold,
And what she once was wont to organize,
That we bid now to crystallize.“

Johann Wolfgang von Goethe, 1832,
Faust II, zweiter Akt Laboratorium
Translation George Madison Priest
http://www.levity.com/alchemy/faust29.html

Following Paracelsus' recipe
De generatione rerum naturalium
(On the generation of natural things).

What is: Artificial Life ?

Golem:

What is: Artificial Life ?

Golem:
In Jewish folklore, a golem is an animated anthropomorphic being
created entirely from inanimate matter.

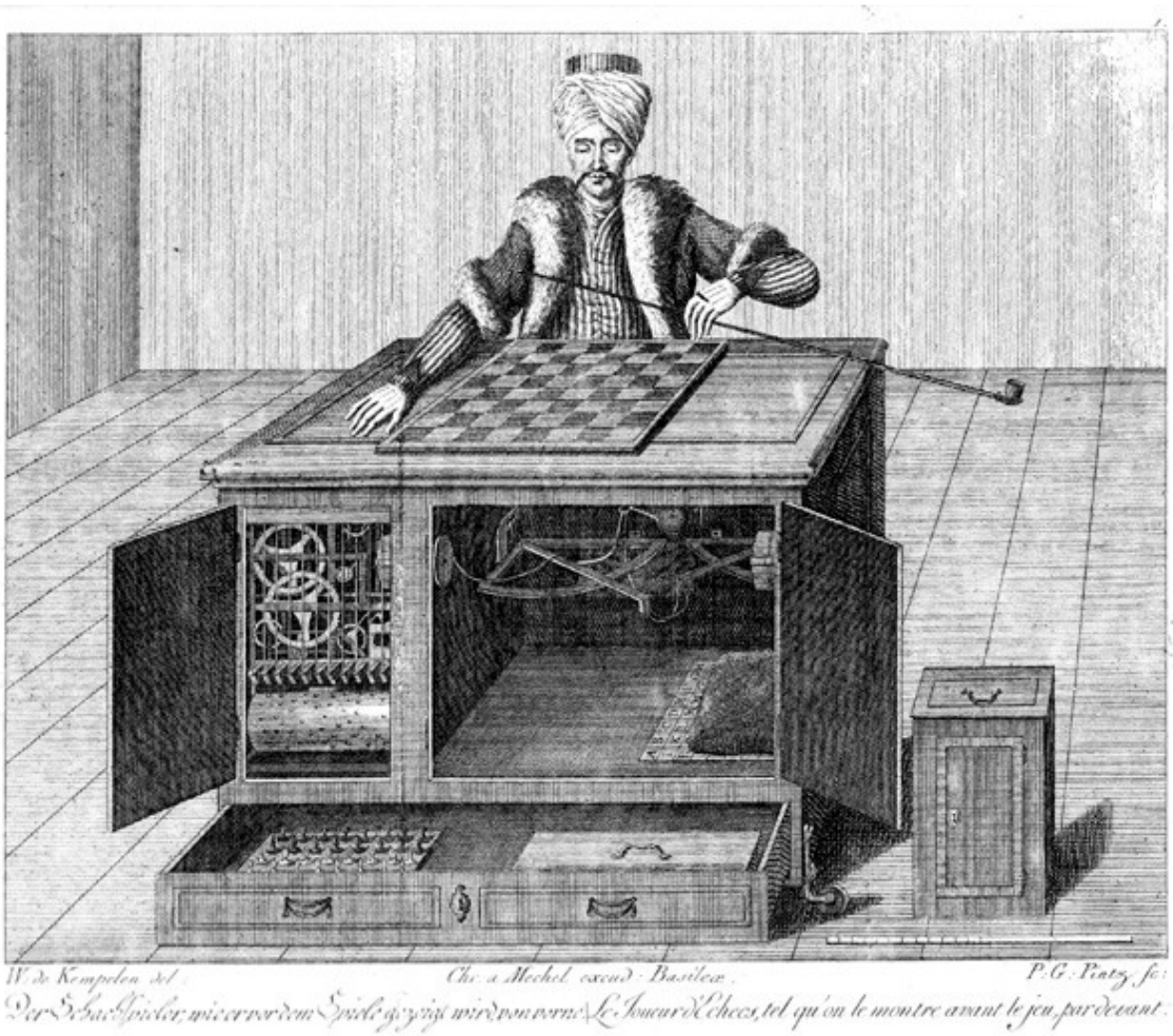
Depending on the version of the legend the rabbi of Prague constructed the Golem out of clay from the banks of the Vltava river, and brought it to life through rituals and Hebrew incantations.

The existence of a golem is sometimes a mixed blessing. Golems are not intelligent: If commanded to perform a task, they will take the instructions perfectly literally.

From: *http://en.wikipedia.org/wiki/Golem*

What is: Artificial Life ?

What is: Artificial Life ?



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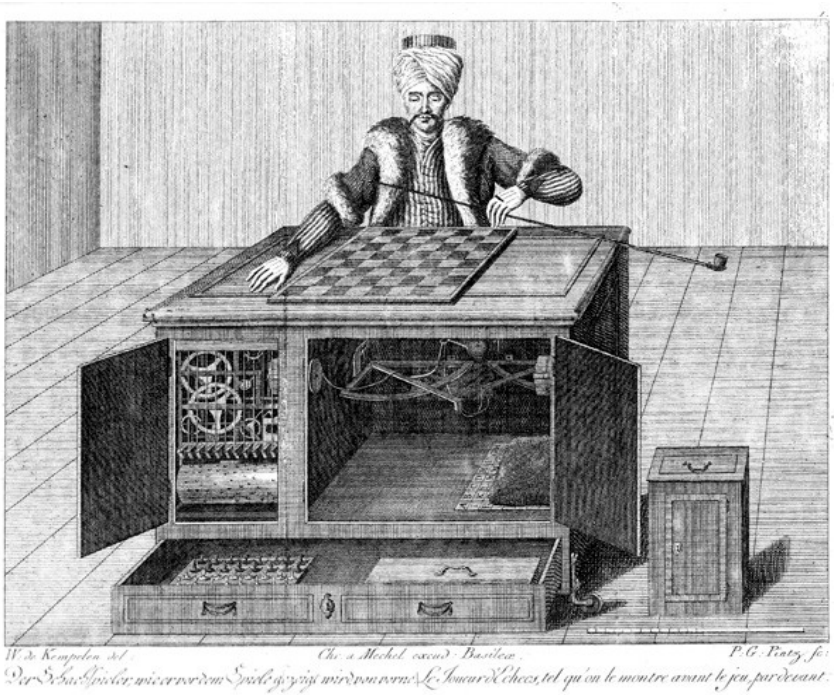

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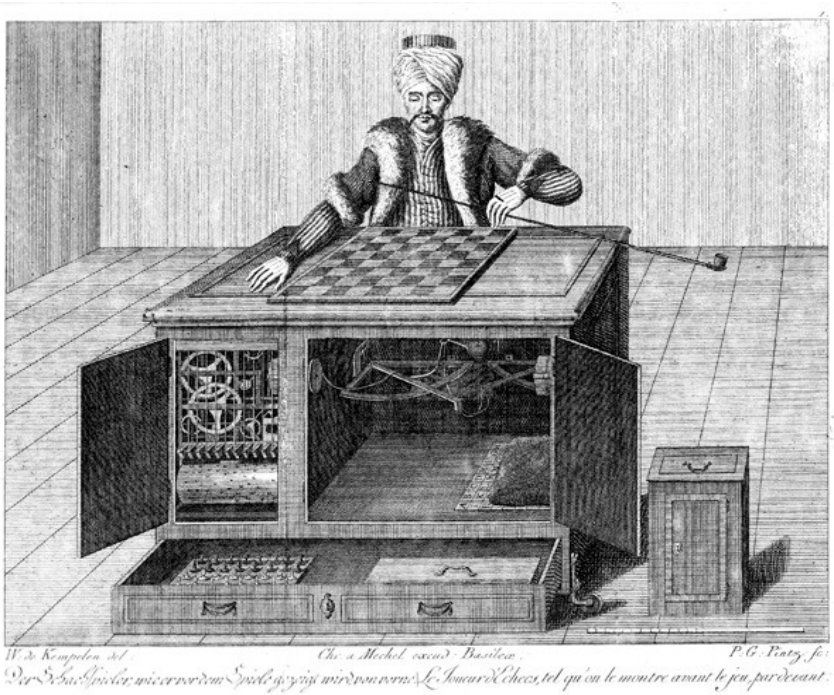
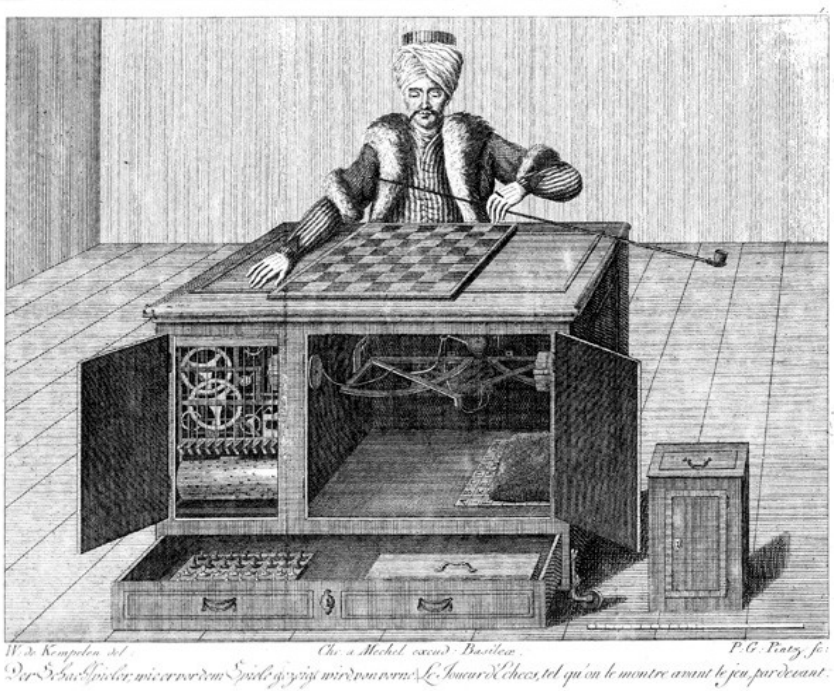
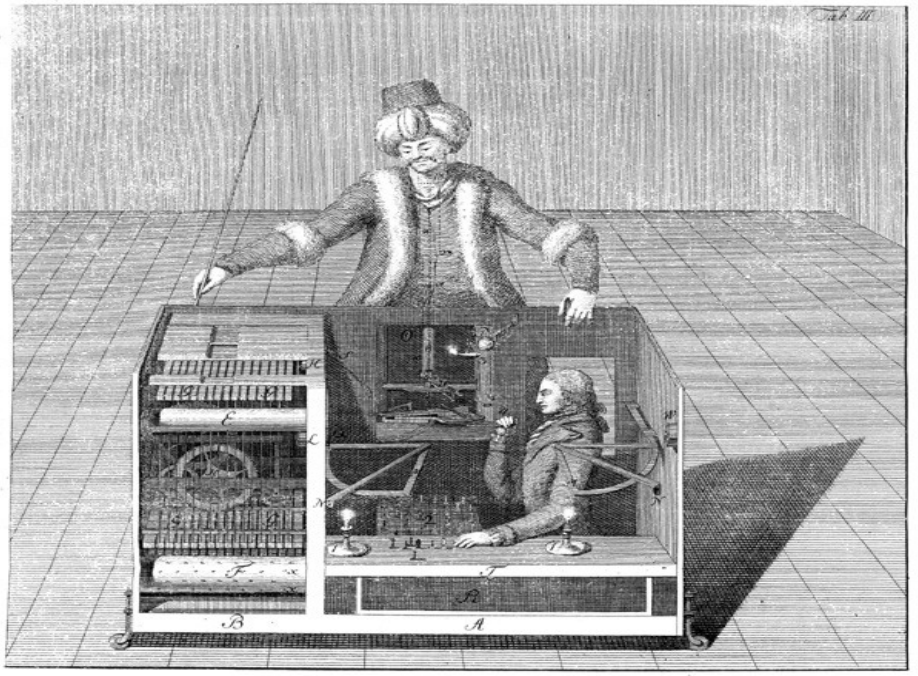


The Turk: a chess playing automaton was a famous (1769) chess playing machinery, build in 1769 by the Austrian-Hungarian constructor Wolfgang von Kempelen.

What is: Artificial Life ?

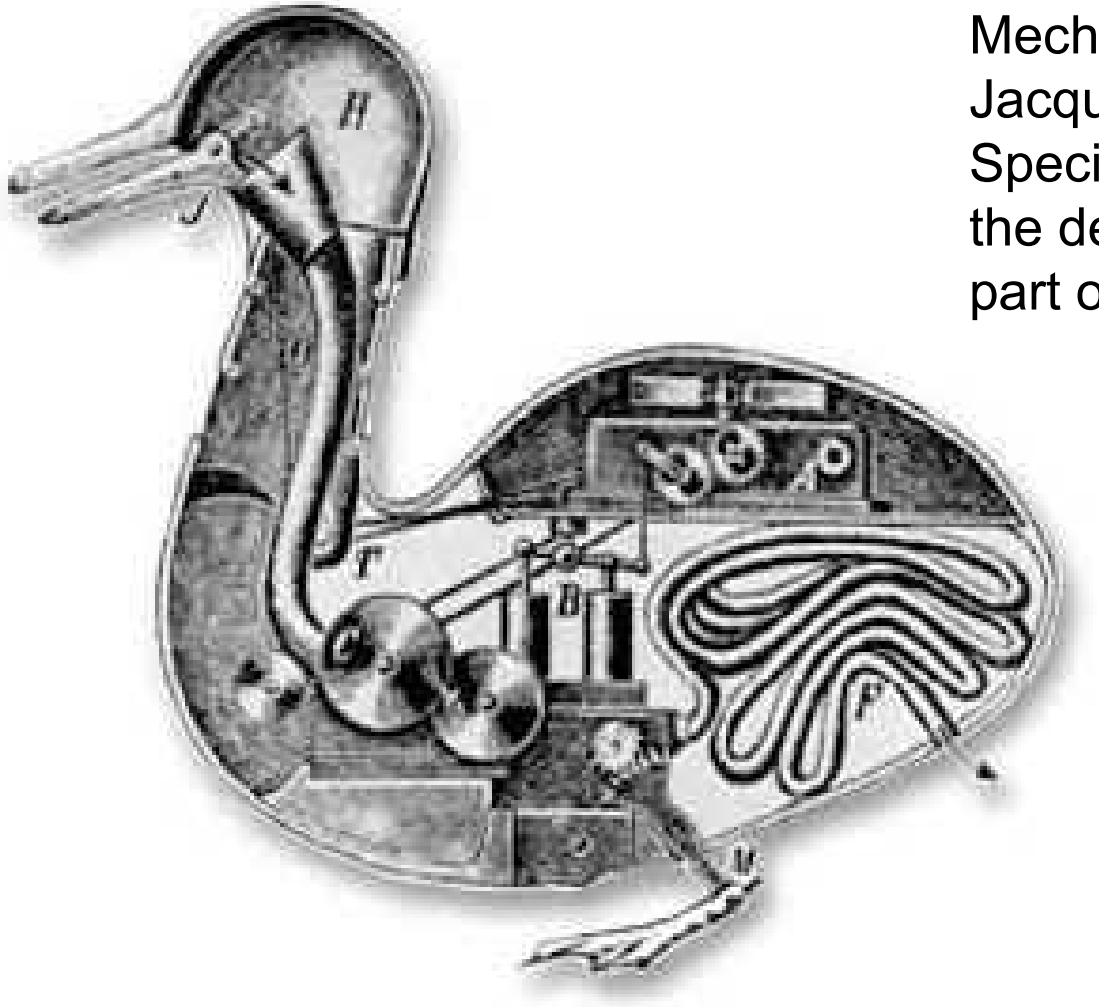




The Turk: a chess playing automaton was a famous (1769) chess playing machinery, build in 1769 by the Austrian-Hungarian constructor Wolfgang von Kempelen. Later on it has been revealed to be a hoax; a human was sitting in the lower part of the machinery controlling the Turks movements.

From:http://de.wikipedia.org/wiki/Wolfgang_von_Kempelen

What is: Artificial Life ?



Mechanical Duck (1735) by Jacques de Vaucanson. Special focus was layed on the design of the digestive part of the duck.

From: http://en.wikipedia.org/wiki/Digesting_Duck

What is: Artificial Life ?

The Writer:
Automaton of Jaquet-Droz
1738

What is: Artificial Life ?

What is: Artificial Life ?

What is: Artificial Life ?

What is: Natural Life ?

What is: Artificial Life ?

What is: Natural Life ?

What is: Life ?

Overview:

- What is: Artificial Life ?
- **What is: Natural Life ?**
- At the border of natural Life
- Systems of Artificial Life
- Starting a discussion

Definitions of Life or Living :

At the moment no commonly accepted definition what **life** or **living** is, can be found in literature.

But you can find a variety of attempts to define **life.**

Most definitions try to define **live** or **living** based on sets of criteria that have to be fulfilled.
The individual sets are different with respect to size, quality and kind.
Some are missing relevant aspects, some are contradictory to each other.

Definitions of Life or Living :

On the other hand, it is noticeable that most people will respond without any hesitation to the question

Is a specific item XXXX living or not ?

There seems to be a wide consensus among most people in this very question, although a concise definition reveals to be still difficult.

Definitions of Life or Living :

The Freedictionary

The property or quality that distinguishes living organisms from dead organisms and inanimate matter, manifested in functions such as
- metabolism,
- growth,
- reproduction, and
- response to stimuli or
- adaptation to the environment originating from within the organism.

From: http://www.thefreedictionary.com/life

Definitions of Life or Living :

The molecular biologist **Daniel E. Koshland Jr.** was asked to write a special essay (**Science, March 22, 2002**) where he would set out to define life. In this article, he suggested that something could be considered "alive" if it meets the following 7 conditions.

1) … a program to make copies of themselves ...
2) Life adapts and evolves … through mutation and selection
3) … complex, highly organized, have compartmentalized structures
4) … ability to take energy from their environment ...
5) … regeneration systems that replace parts of themselves ...
6) … respond to environmental stimuli through feedback ...
7) … numerous metabolic reactions ..separated from each other

From: http://www.physicalgeography.net/fundamentals/9a.html

Definitions of Life or Living :

To qualify as a living thing, an organism must in one way or another meet each of those criteria.

MOTION -- does it seem to move under its own power? Does it move with some discernible purpose? (Toward food, away from heat, etc)

REPRODUCTION -- does it have some way of making more of itself, either through sexual reproduction or by budding or fissioning in some way?

CONSUMPTION -- does it eat or drink? Does it take in nutrients in one way or another in order to survive, grow, and eventually multiply?

GROWTH -- does the organism develop over time, increase in complexity, until it reaches a mature stage?

STIMULUS RESPONSE -- does the organism respond to external stimuli, i.e. has a nervous system of some sort to detect external conditions?

From: http://www.newton.dep.anl.gov/askasci/bio99/bio99171.htm

Definitions of Life or Living :

Cybernetic formulation of the definition of life

Korzeniewski B. , *J Theor Biol. 2001 Apr 7;209(3):275-86.*

A definition of life (a living individual) in cybernetic terms is proposed. In this formulation, life (a living individual) is defined as a network of inferior negative feedbacks (regulatory mechanisms) subordinated to (being at service of) a superior positive feedback (potential of expansion). It is suggested that this definition is the minimal definition, necessary and sufficient, for life to be distinguished from inanimate phenomena and, as such, it describes the essence of life. Subsequently, a quantitative expression for the amount of the biologically relevant ("purposeful") information (as opposed to the amount of information in the thermodynamic sense) is proposed. This is followed by the application of the formulated approach to different phenomena of a dubious status existing presently on the Earth as well as to the process of origination of life on our planet.

Definitions of Life or Living :

Random House Webster's Dictionary

There, the following definitions for life are found. Life is

- the general condition that distinguishes organism from inorganic objects and dead organisms, being manifested by growth through metabolism, a means of reproduction, and internal regulation in response to the environment.
- the animate existence or period of animate existence of an individual.
- a corresponding state, existence, or principle of existence conceived of as belonging to the soul.
- the general or universal condition of human existence.
- any specified period of animate existence.
- the period of existence, activity, or effectiveness of something inanimate, as a machine, lease, or play.
- animation; liveliness; spirit: (example: The party was full of life).
- the force that makes or keeps something alive; the vivifying or quickening principle.

Adopted from Prof. Dr. R. Pfeifer, Dale Thomas, Lecture Artificial Life, Summer 2001
http://www.ifi.uzh.ch/groups/ailab/teaching/AL01.html

Definitions of Life or Living :

The German DTV Atlas zur Biologie says:

Biology is the science of the living creatures, and of their biological properties, like shape, morhogenesis, structure ,...

(further on it says:)

Creatures consist of cells.
The minimal creature is a monad, protozoon (Einzeller).
Cells are build out of carbon based organic material.

Definitions of Life or Living :

Among others, here is one set of common criteria

- Existence in space and time
- Reproduction
- Metabolism
- Phylogenetic development
- Ontogenetic development
- Growth
- Movement out of itself
- Reaction as a consequence to the environment
- Decay, death
- Storage of information about oneself

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Natural Life: animals

Bumble-bee

From: *http://commons.wikimedia.org/wiki/File:Bumblebee_2007-04-19.jpg*

From: *http://de.wikipedia.org/wiki/Hummeln*

Natural Life: animals

Panthera Tigris

From: *http://de.wikipedia.org/wiki/Tiger*

Natural Life: plants

From: http://de.wikipedia.org/wiki/Seerose

From: http://de.wikipedia.org/w/index.php?title=Datei:Michaelseiche_bei_Albertshausen,_3.jpg&filetimestamp=20070609201042

Natural Life: plants

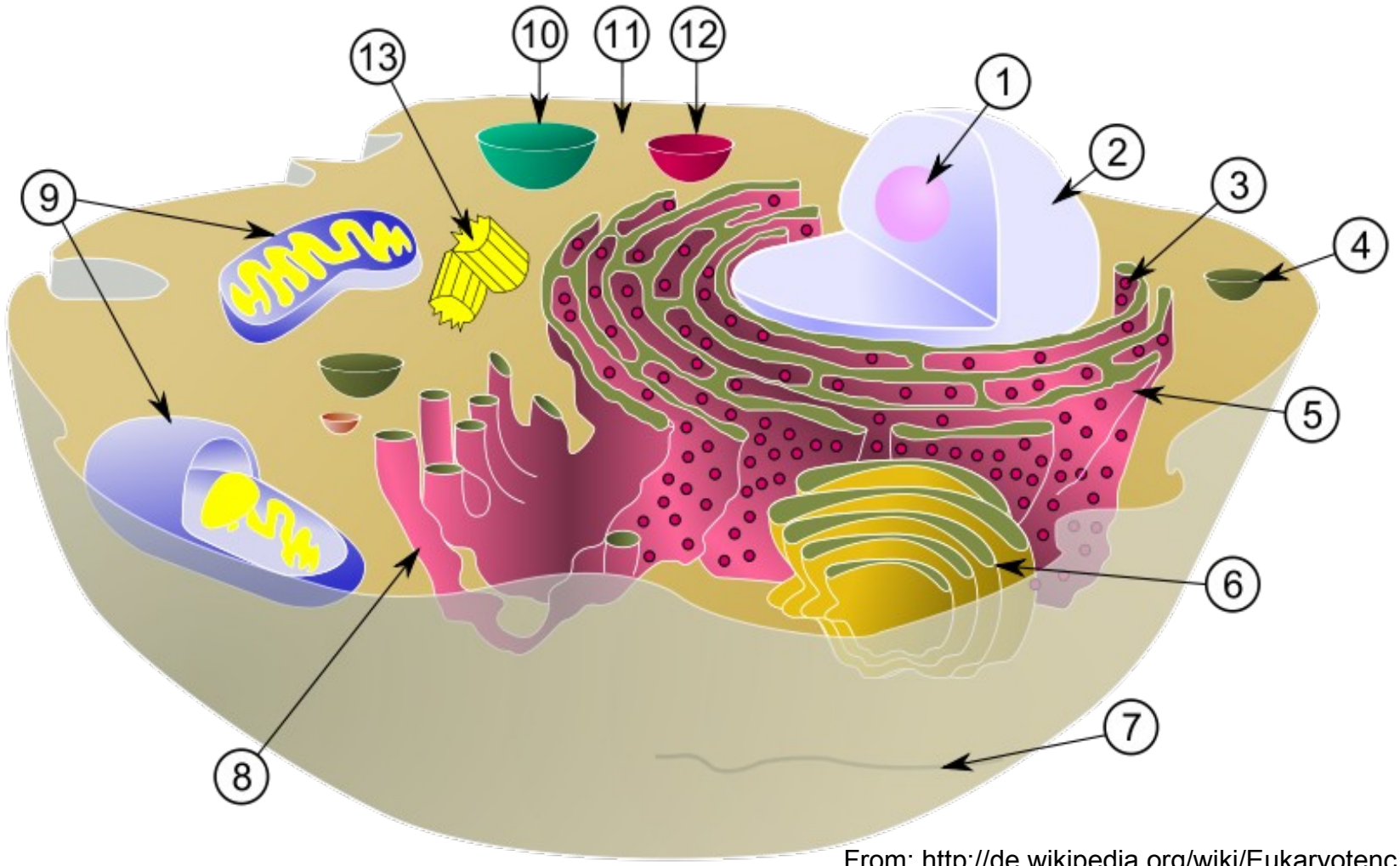
Natural Life: plants

Brassica oleracea (Romanescu) © Biopix.dk: N Sloth

Natural Life: plants

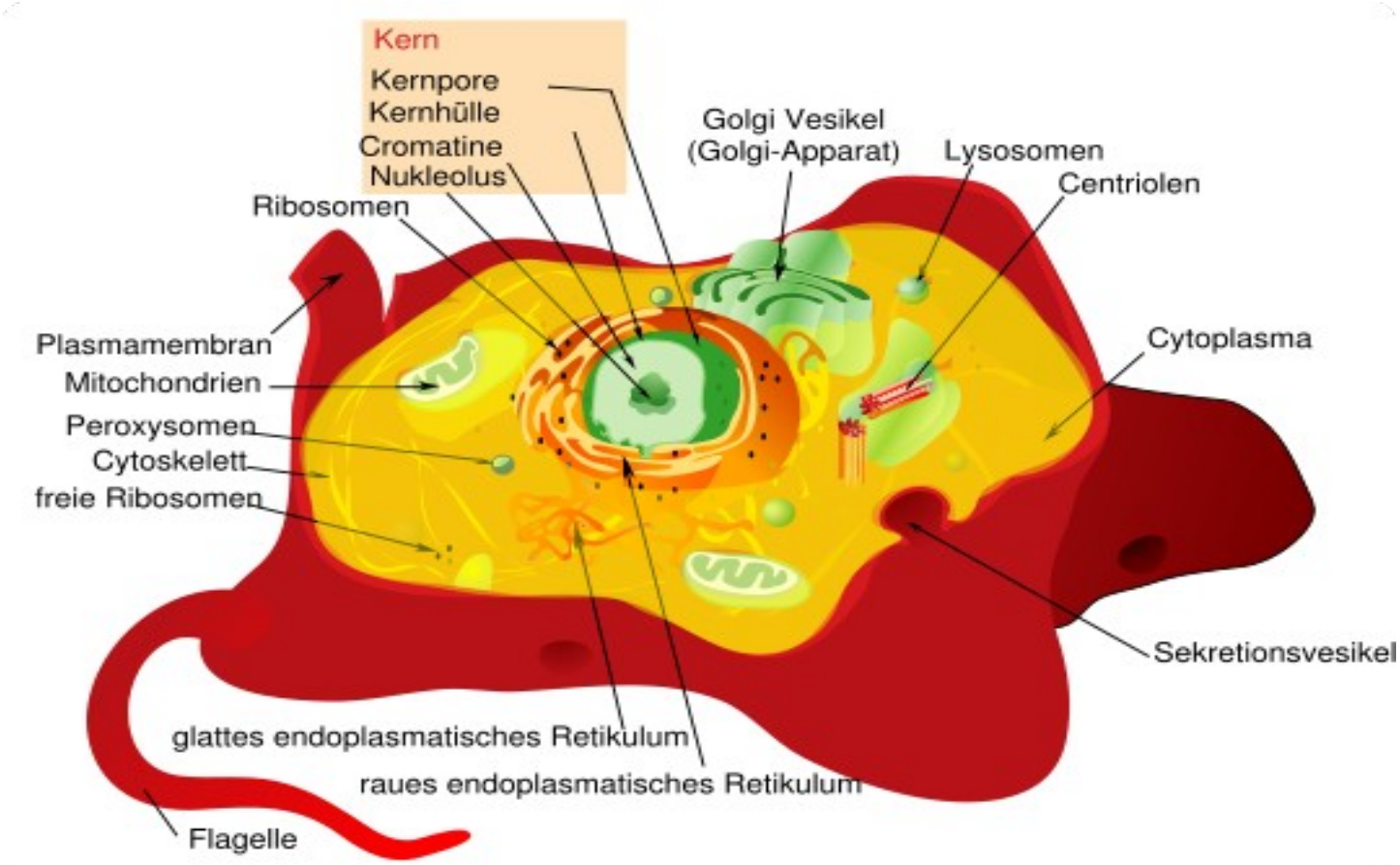
Brassica oleracea (Romanescu) © Biopix.dk: N Sloth

Natural Life: animal (eucariyotic cell)



From: http://de.wikipedia.org/wiki/Eukaryotenc

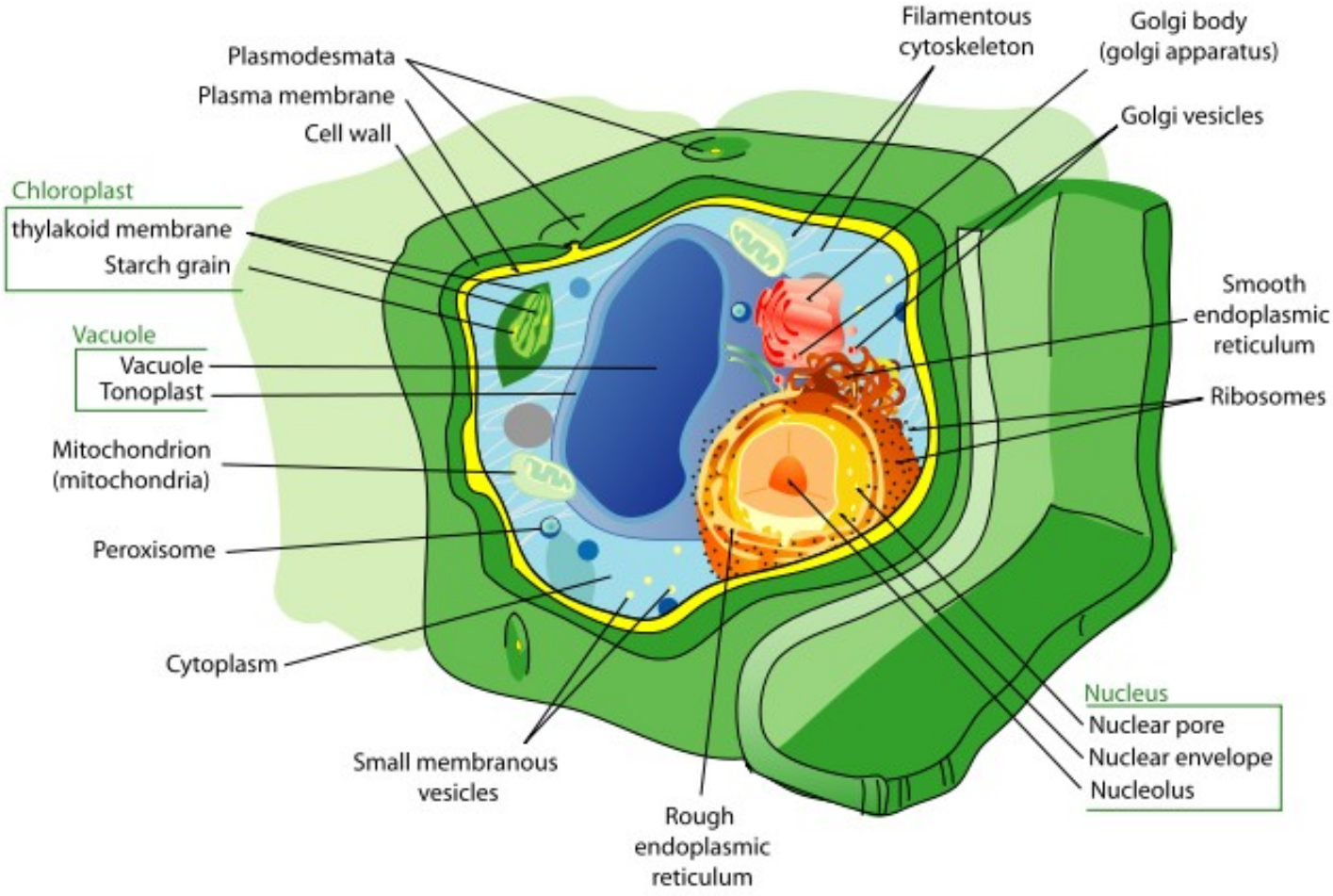
Natural Life: animal (eucariyotic cell)



Einzeller: Prokaryoten, Eurakyoten, Bazillen

From: *http://de.wikipedia.org/wiki/Eukaryoten*

Natural Life: plant cell



From: *http://de.wikipedia.org/wiki/Eukaryoten*

Natural Life: monad, protozoa

Sonnentierchen,
heliozoan
acathocystis turfacea

From: http://de.wikipedia.org/wiki/Eukaryoten

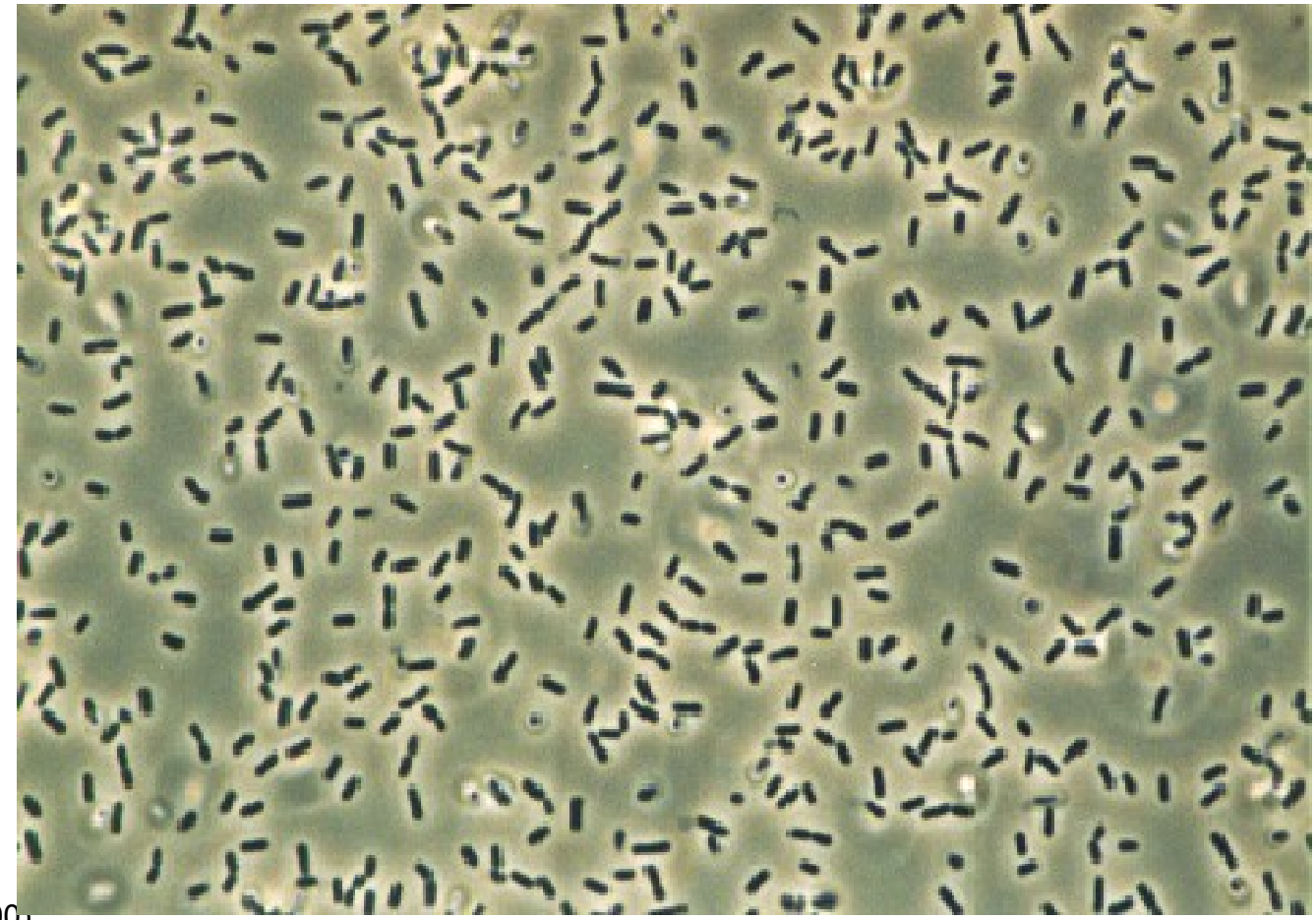
Natural Life: monad, protozoa

Pantoffeltierchen,
paramecium,
paramecium aurelia

From: *http://de.wikipedia.org/wiki/Pflanzenzelle*

Natural Life: bacterium, bacillus, germ

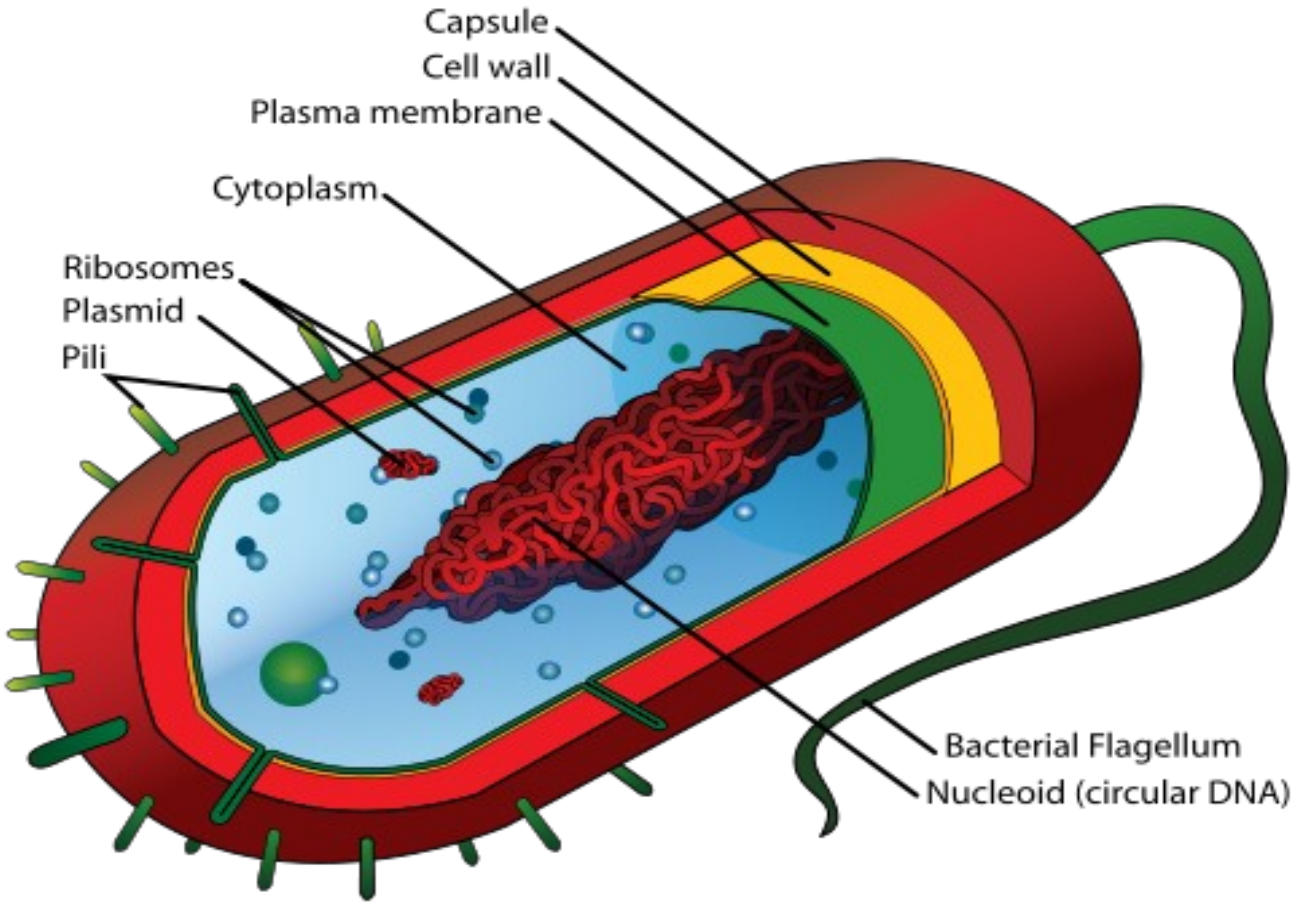
Bacterium: The bacteria are a large group of unicellular, prokaryote, microorganisms.



Microscope picture,
Bacillus subtilis (x1000)

From: *http://de.wikipedia.org/wiki/Pflanzenzelle*

Natural Life: bacterium



Structure and contents of a typical Gram positive bacterial cell

From: *http://en.wikipedia.org/wiki/Bacterium*

Overview:

- What is: Artificial Life ?
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- **At the border of natural Life**
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At the border of natural life:

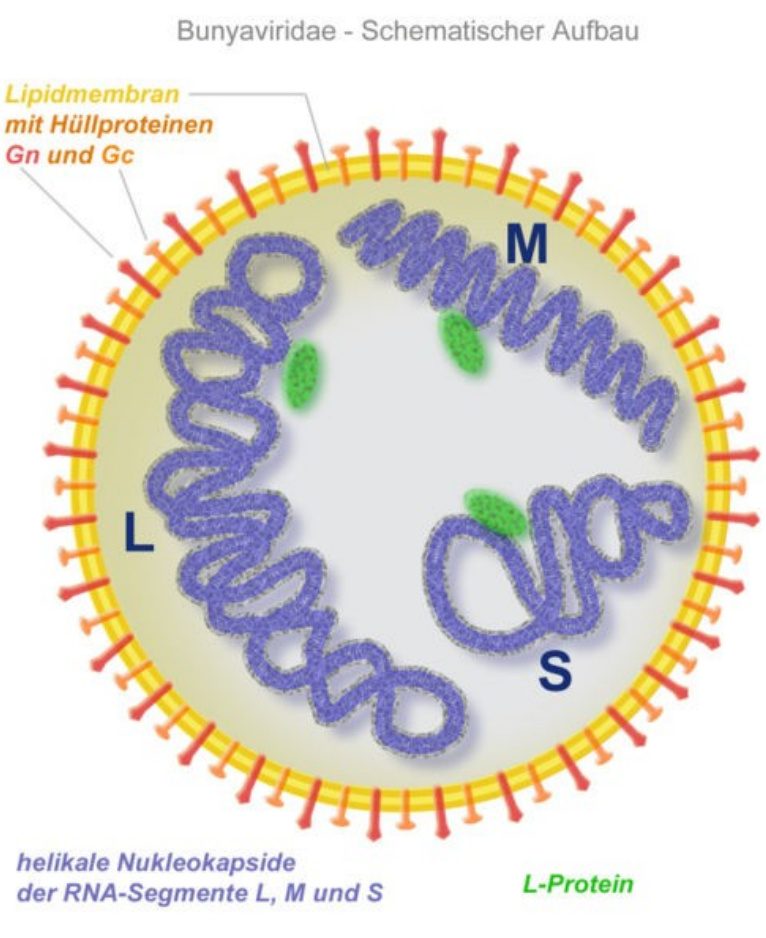
At the border of natural life:

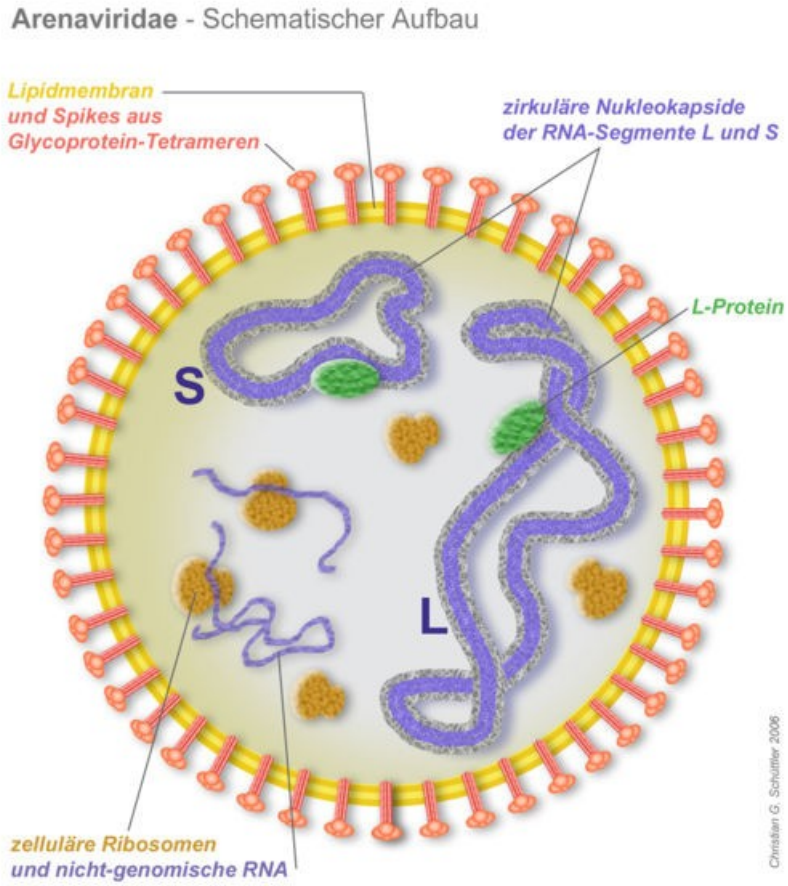
- animals
- plants
- procaryotes
- bacteria

- virus
  ???
- crystals
- artificial structures
- Artificial Life Systems

At the border of natural life:

Virus: A virus is a small infectious agent that can replicate only inside the living cells of other organisms.





From: *http://de.wikipedia.org/wiki/Viren*

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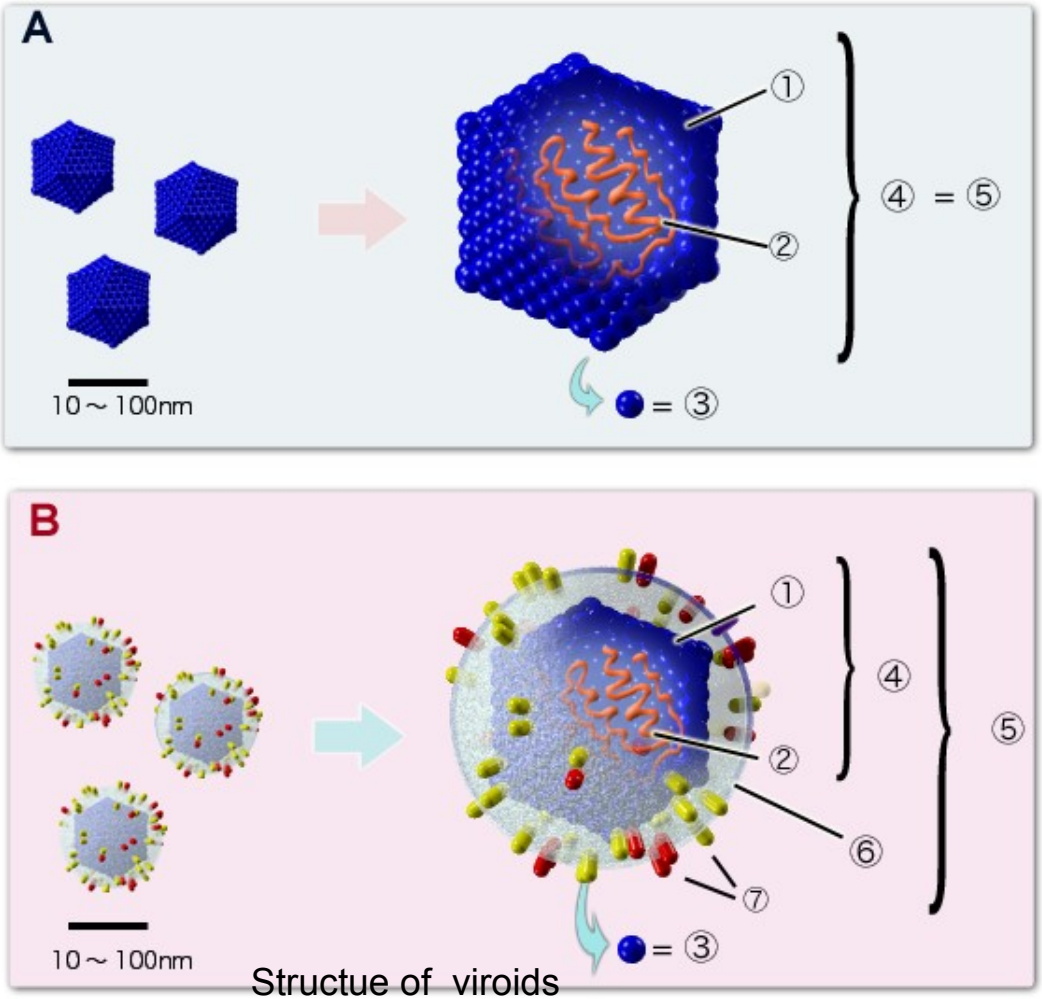
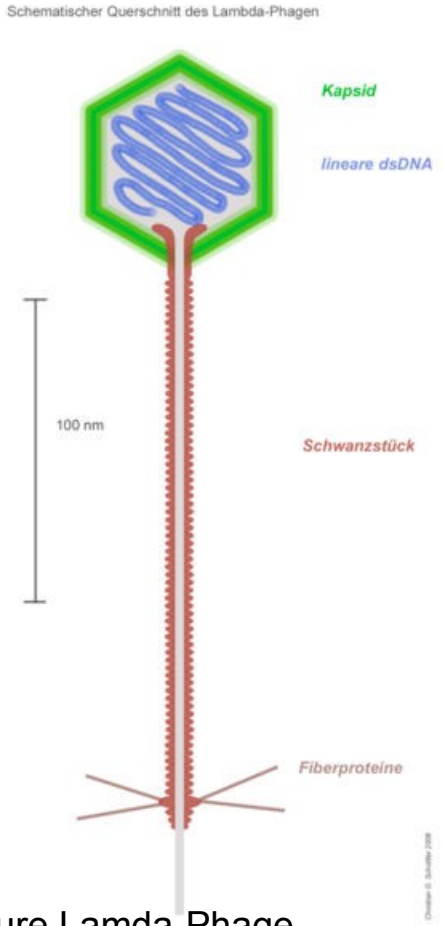
Virus: A virus is a small infectious agent that can replicate only inside the living cells of other organisms.



Structue of viroids



Structure Lamda-Phage
From: *http://de.wikipedia.org/wiki/Viren*

At the border of natural life:

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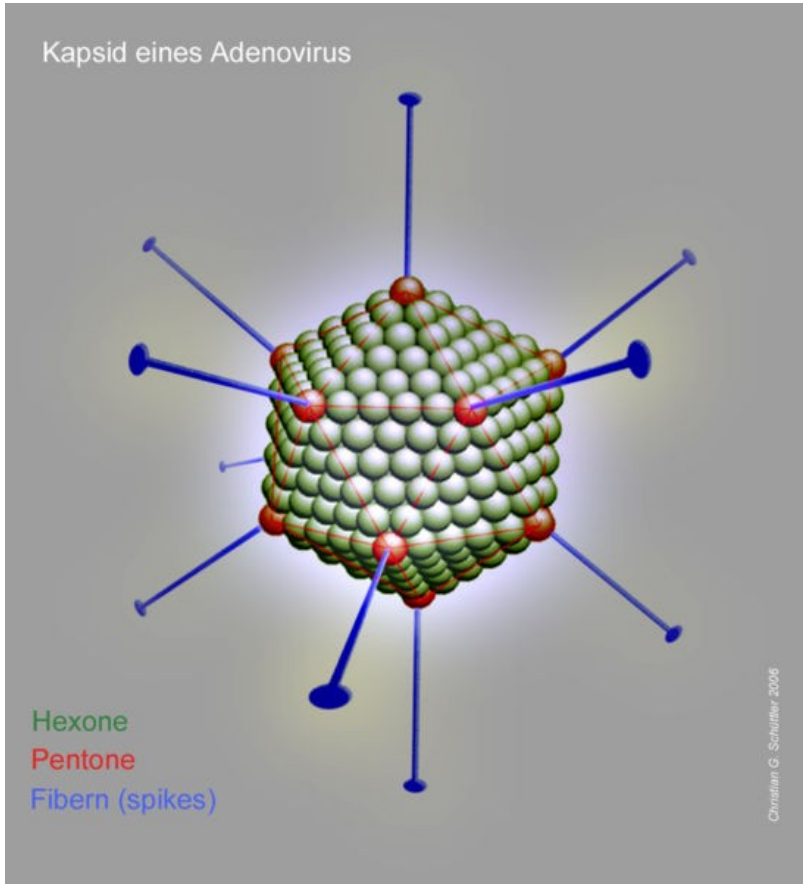
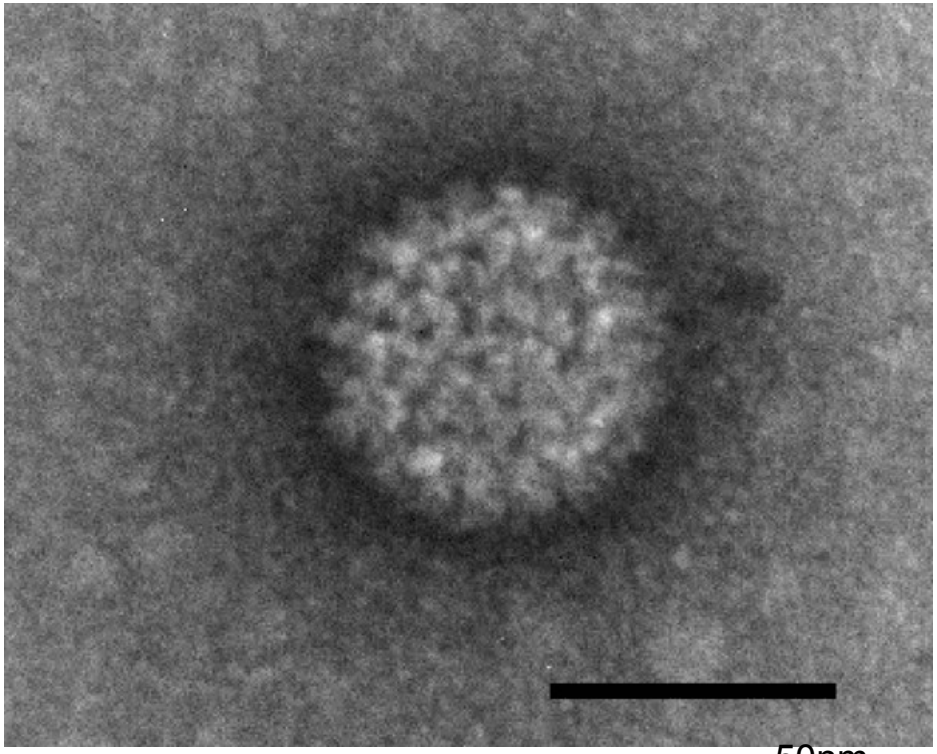


Adenovirus, modelled



Bluetongue virus microscope picture

From: *http://de.wikipedia.org/wiki/Viren*

At the border of natural life:

Crystals show a variety of well organised structures.

Nadeliger Habitus beim Krokoit

Lockenförmiges Aggregat beim Chalkanthit

At the border of natural life:

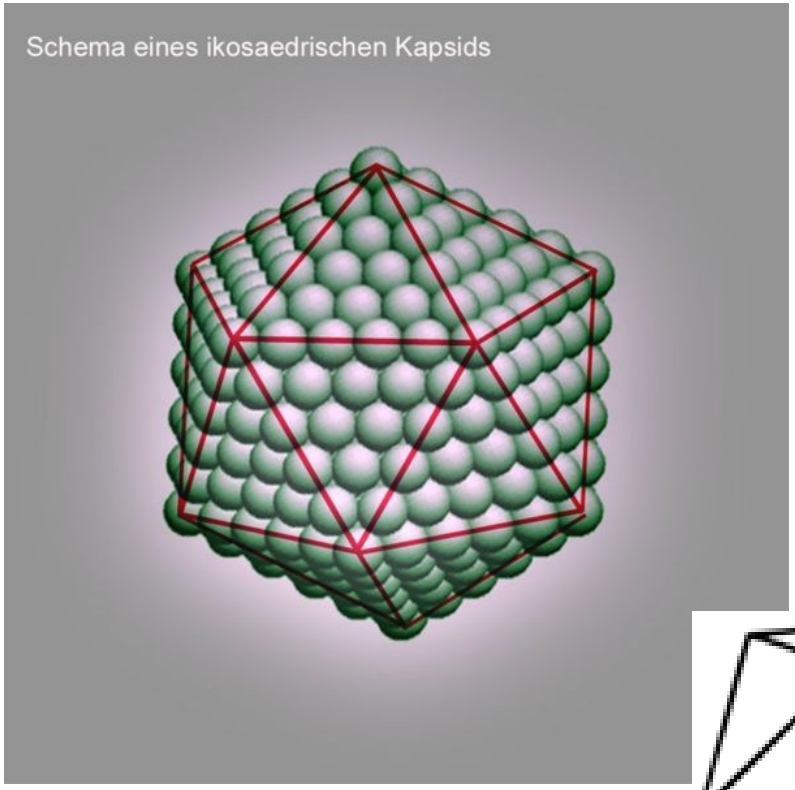
Crystals show a variety of well organised structures.

Drahtförmiges Aggregat in silver

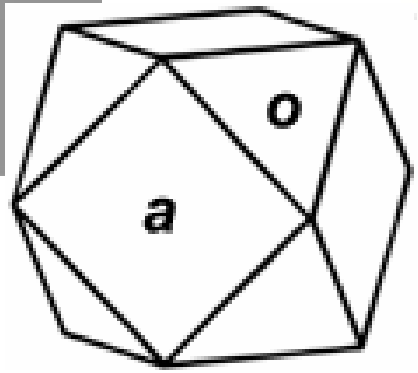
Tafeliger Habitus beim Baryt

At the border of natural life:

Crystals show a variety of well organised structures.



Model of virus structure



pyrite crystal

From: *http://de.wikipedia.org/wiki/Pyrit*

Life at the border:

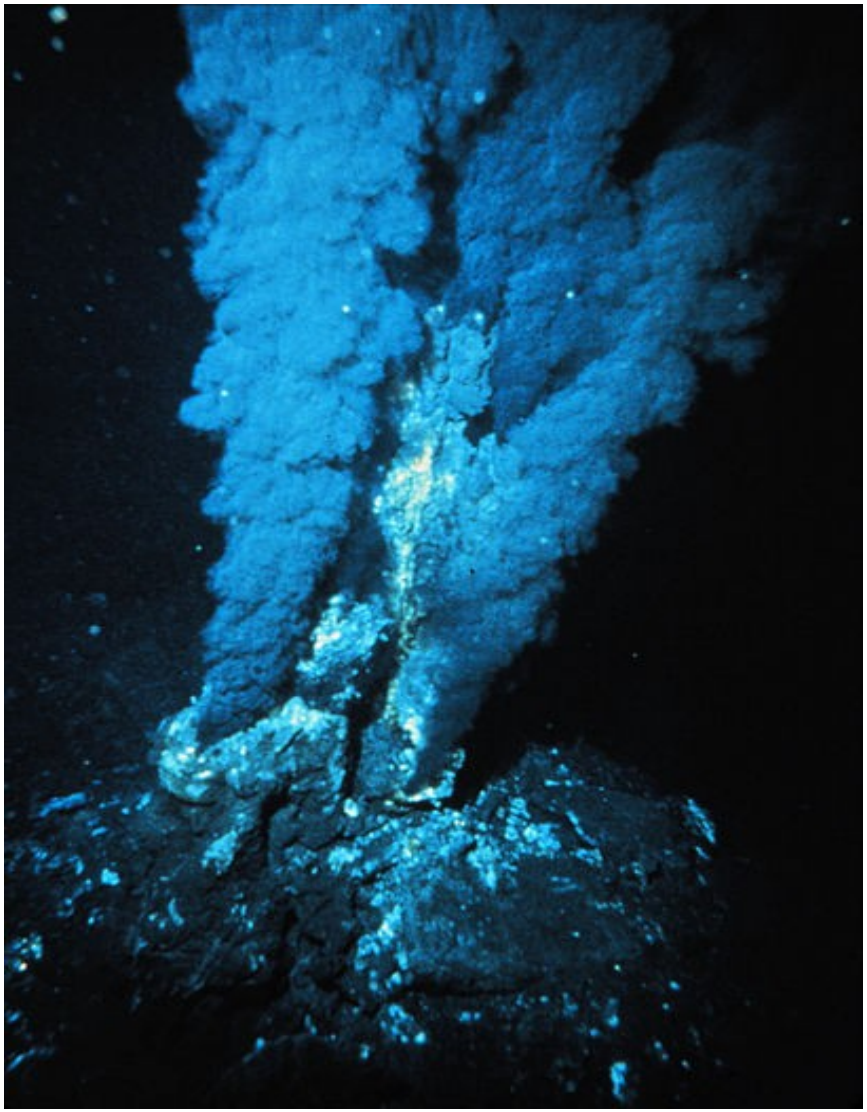
Geysir Strokkur in Island

From: *http://en.wikipedia.org/wiki/Strokkur*

Life at the border:

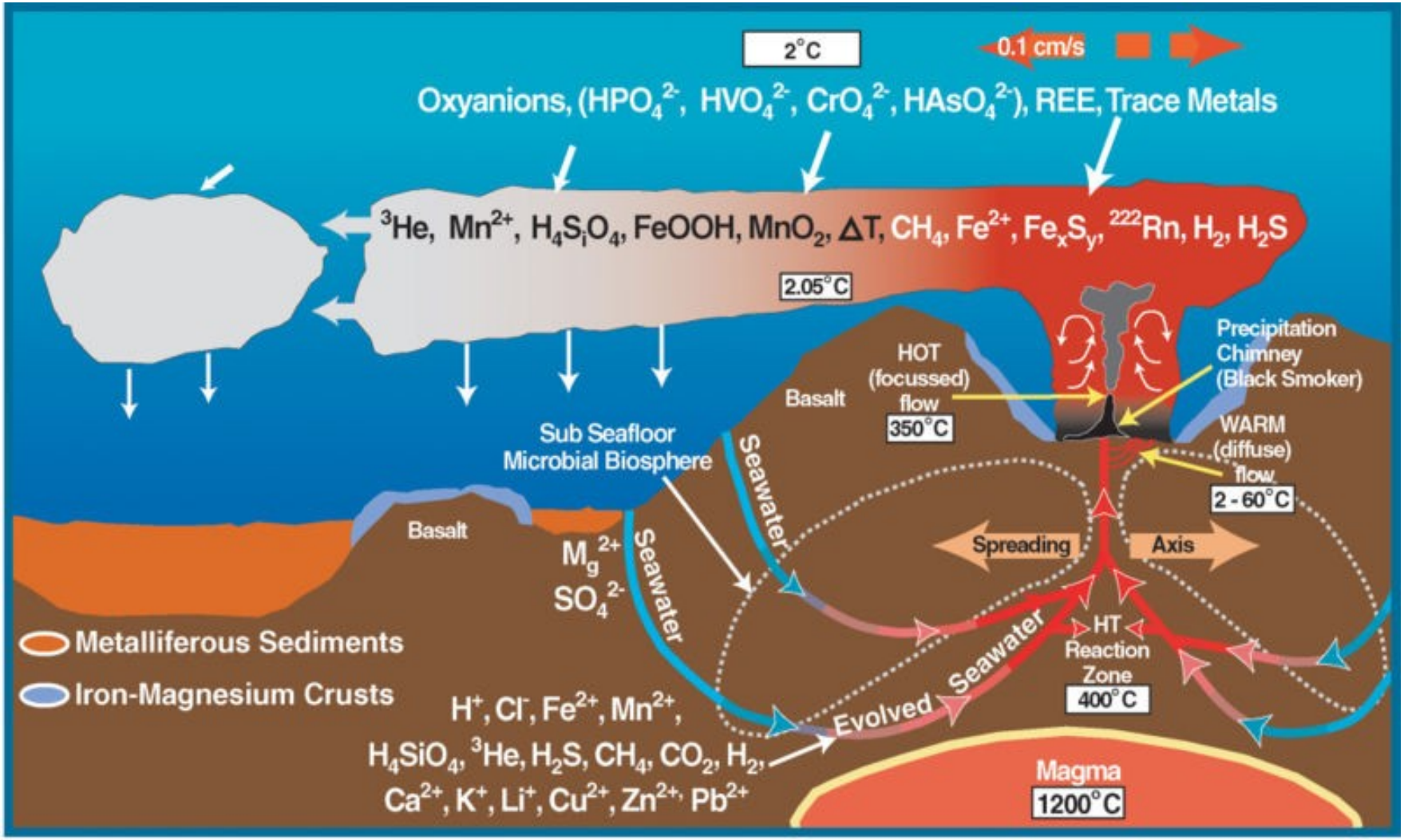
A **black smoker** or sea vent is a type of hydrothermal vent or underwater hot spring found on the ocean floor.

Although life is very sparse at these depths, black smokers are the center of entire ecosystems. A species of photo-trophic bacterium has been found living near a black smoker off the coast of Mexico at a depth of 2,500 m (8,200 ft).



From: *http://en.wikipedia.org/wiki/Black_smoker*

Life at the border:



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Overview:

- What is: Artificial Life ?
- What is: Natural Life ?
- At the border of natural Life
- **Systems of Artificial Life**
- Starting a discussion

Systems of Artificial Life

- Cellular Automata
- Conway`s Game of Life
- Langton`s Self-Replicating Loop
- Lindenmayer Systems
- Foundations of building structures, nonlinear dynamics
- Population dynamics
- Evolutionary Methods & Genetic Algorithms
- Self Organizing Criticality
- Braitenberg Vehicles
- Swarm behavior and swarm Intelligence
- Autonomous Robots

What is Artificial Life ?

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- Artificial-Intelligence,
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The scientific subject Artificial Life became popular during the last two decades. The foundations of Artificial Life research are originating from the 50ies of the last century.
The idea of (artificially) creating life is a lot older.

What is Artificial Life ?

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The goal of Artificial Life research has nicely been phrased as:

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Life made by man rather than by Nature

[C. Langton, 1989]

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Life made by man rather than by Nature

Artificial Life is trying to perform the step

from: ***Life as we know it***

to: ***Life as it could be***

[C. Langton, 1989]

Strong Artificial Life & Weak Artificial Life

Today, we distinguish between two variants of Artificial Life:

Strong Artificial Life:

Weak Artificial Life:

Strong Artificial Life & Weak Artificial Life

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Strong Artificial Life:
The goal of strong AL is to really create artificial lifeforms;
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Strong AL is mainly operating on a molecular basis.

Weak Artificial Life:

Strong Artificial Life & Weak Artificial Life

Today, we distinguish between two variants of Artificial Life:

Strong Artificial Life:
The goal of strong AL is to really create artificial lifeforms; to create life out of non living materials.
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Weak Artificial Life:
The goal of weak AL is to identify properties, principles and circumstances for life. Rather than creating a living entity, weak AL simulates the conditions and the behavior of life.
Most weak AL researchers are working with simulations.

Overview:

- What is: Artificial Life ?
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Which one of the following systems is alive?

pin worm
table
yeast
influenza virus
dried pea
latin
bacterium
lettuce
rock
ant
TV screen
car
protozoa
drop of grease
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not-living **living**

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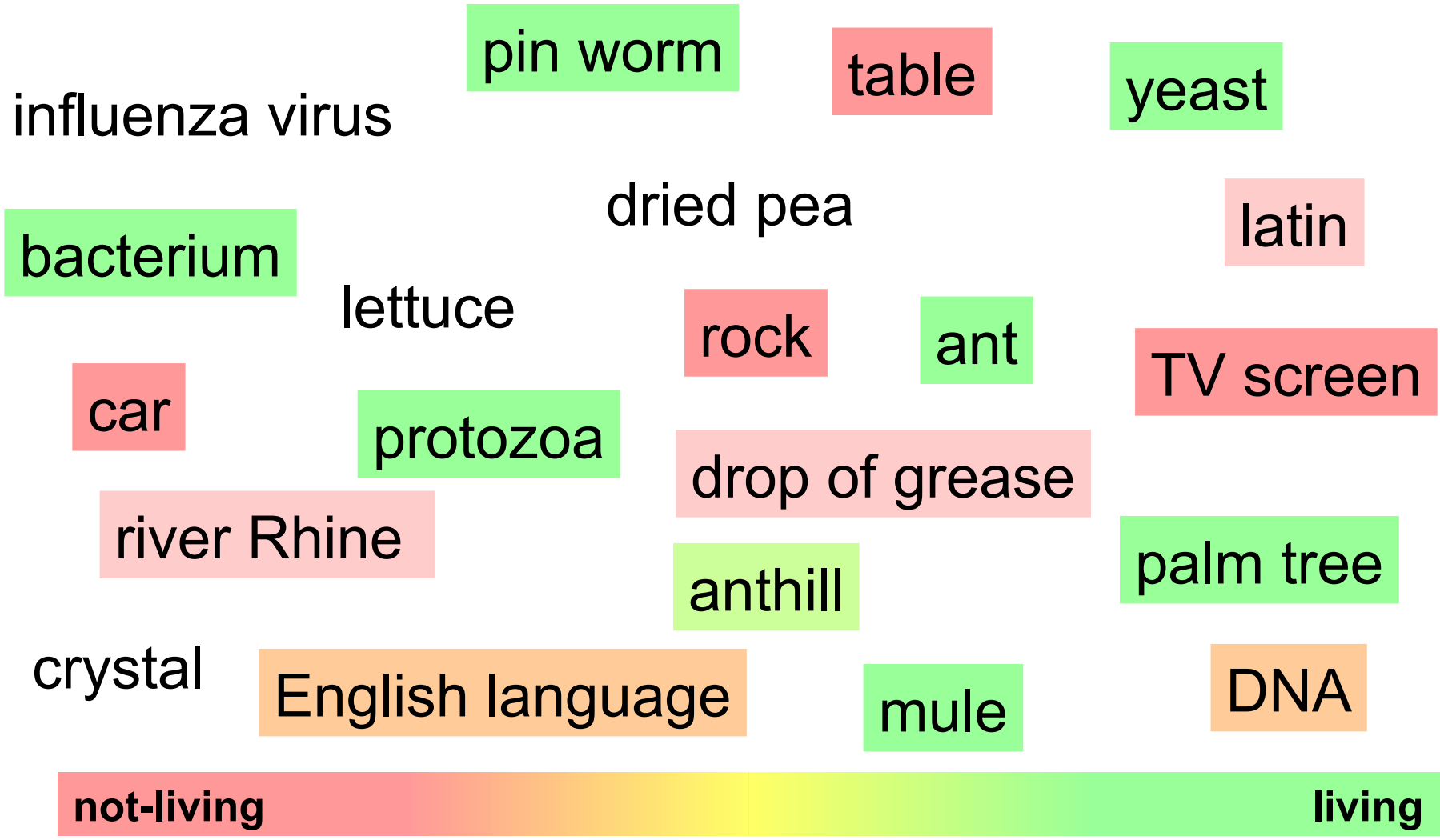

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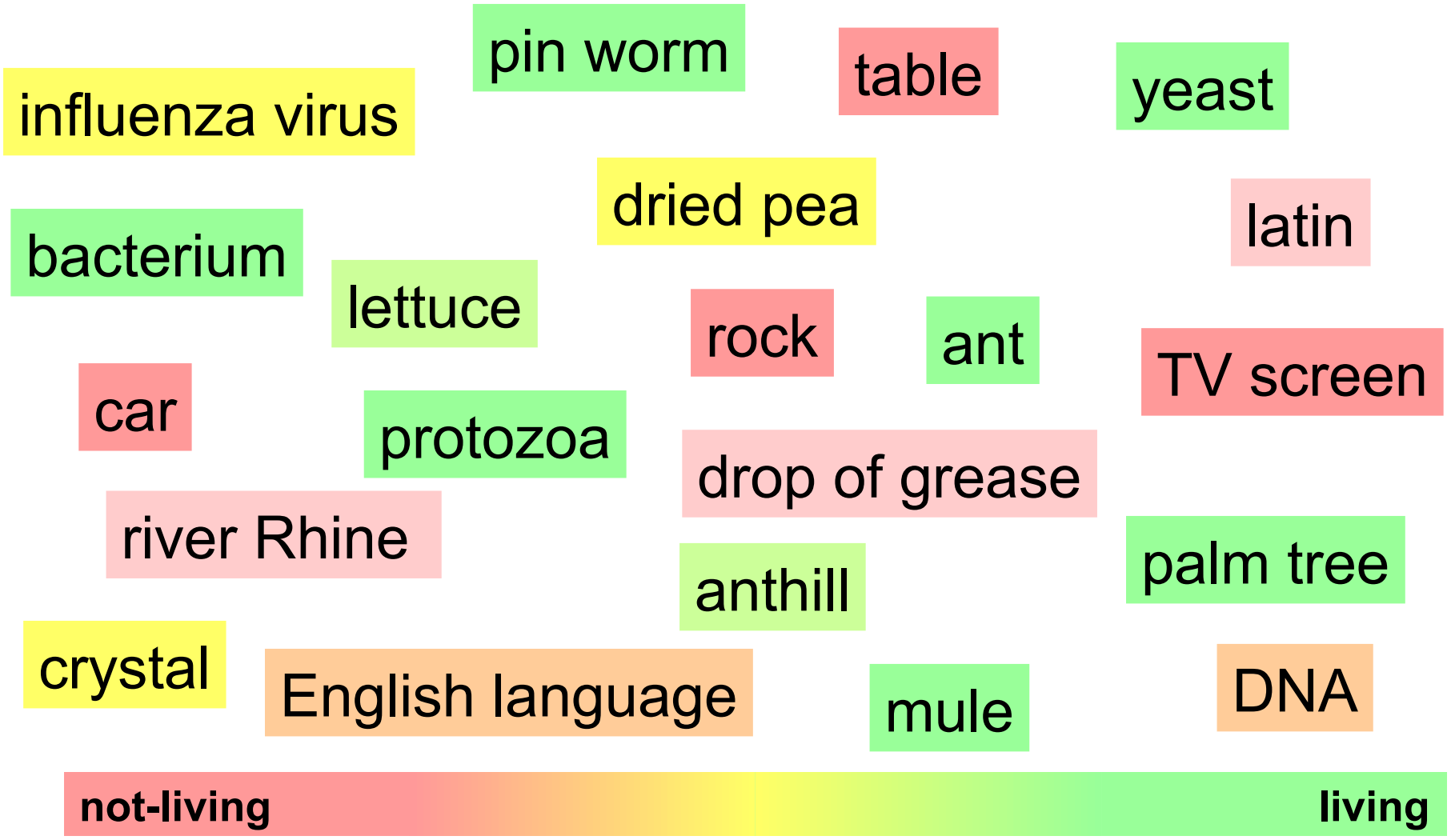

Rethink the definition of *alive* ?

Do we really need a strong definition of alive?

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Do we really have to classify everything into one of these two binary categories?

…. or might it be possible to have a somehow softer transition between **living** and **not-living** ?

At least, it should be allowed to think about.

Artificial Life
Summer 2025

C: Langton's Ant

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

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

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Langton's Ant:

Each cell of the 2-dimensional, rectangular grid has a binary state {O, I} or {black,white}.
The ant has a spatial position (x,y) and a heading (NESW), the ant can move one cell (heading), can turn (+90° / -90°), and can change the state of the cell it is on (flip cell).

At a white cell,

turn 90° right, flip the cell, move forward one step.

At a black cell,

turn 90° left, flip the cell, move forward one step.

Micro behavior: scan – turn – flip – move

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Langton's Ant micro behavior:

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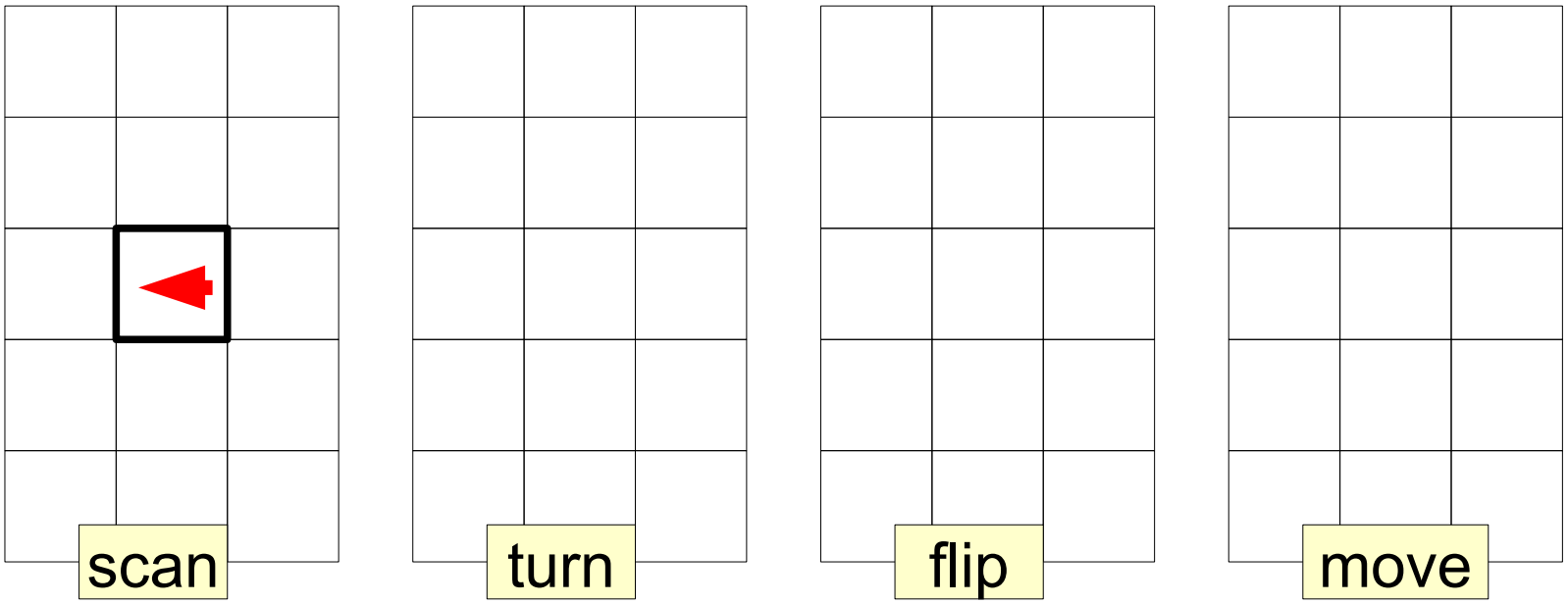

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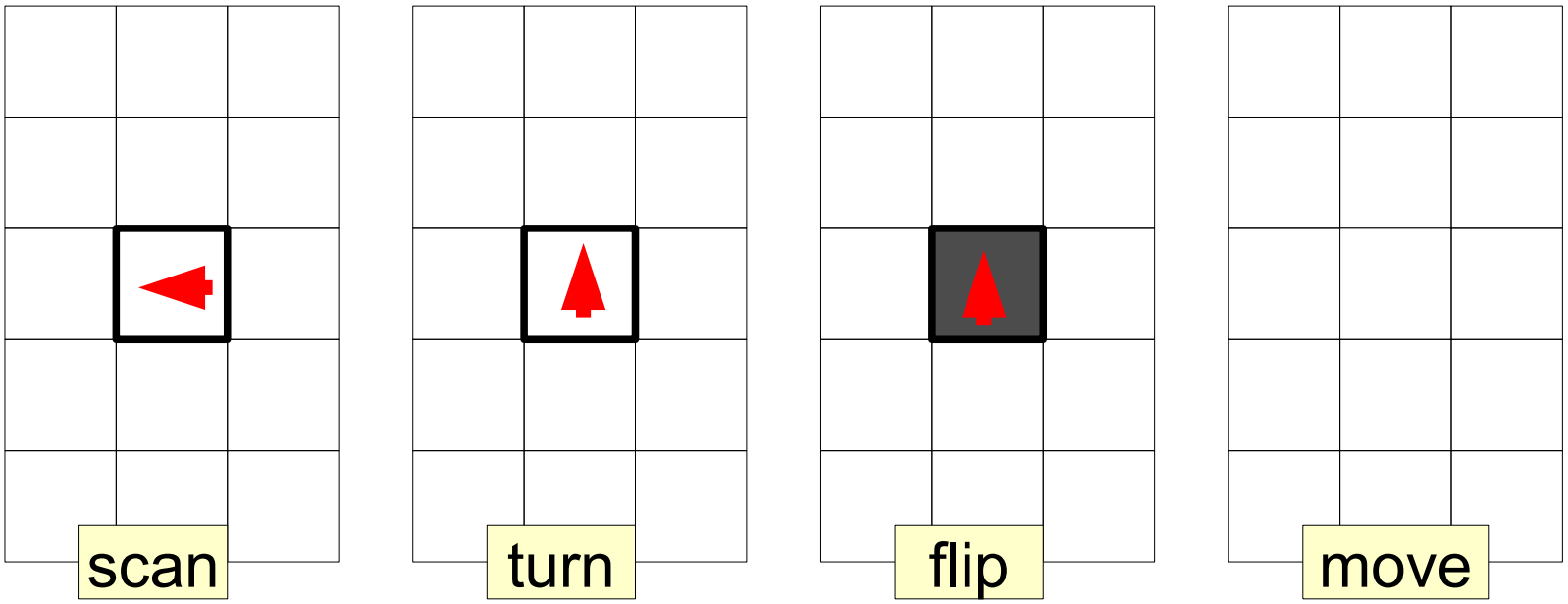

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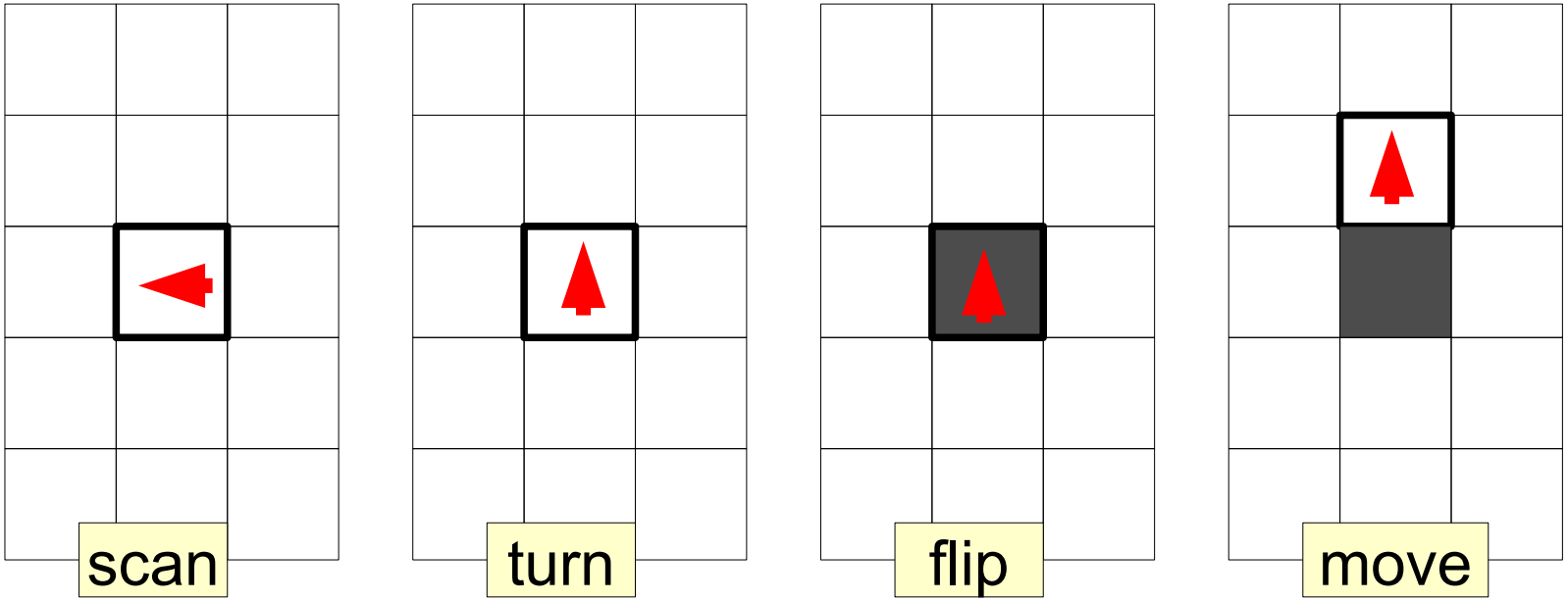

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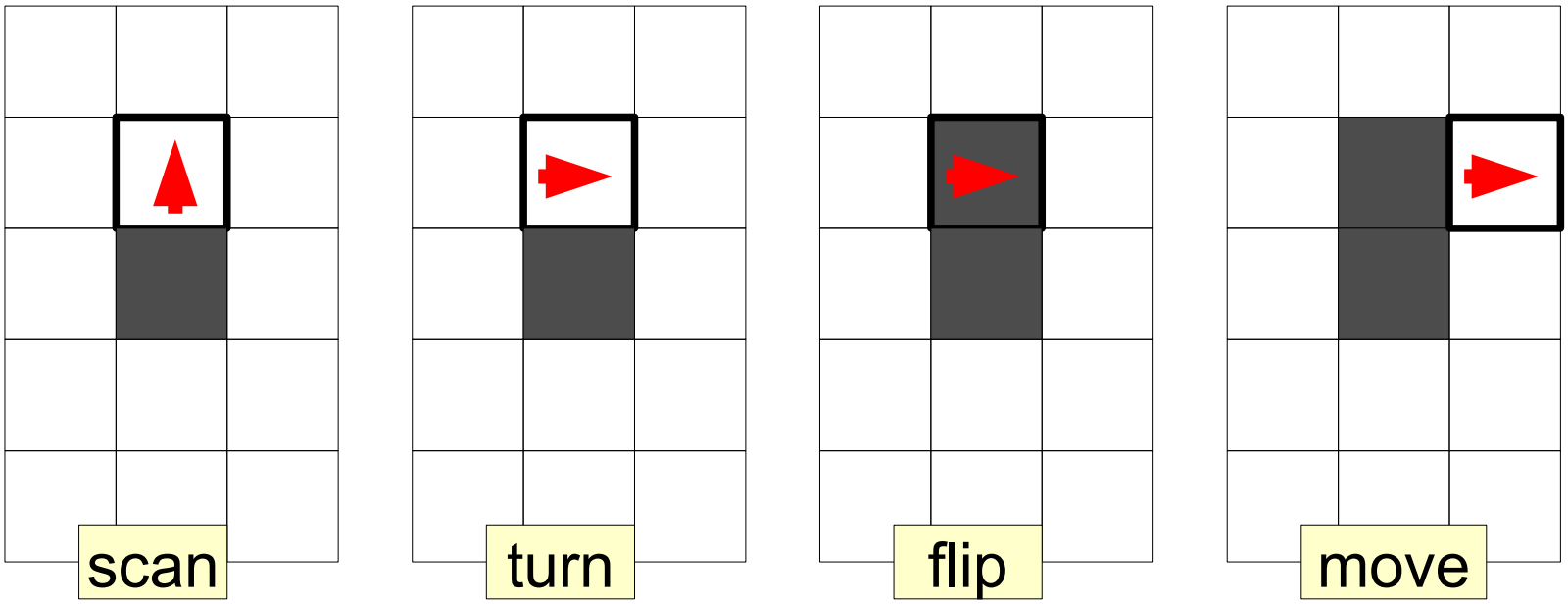

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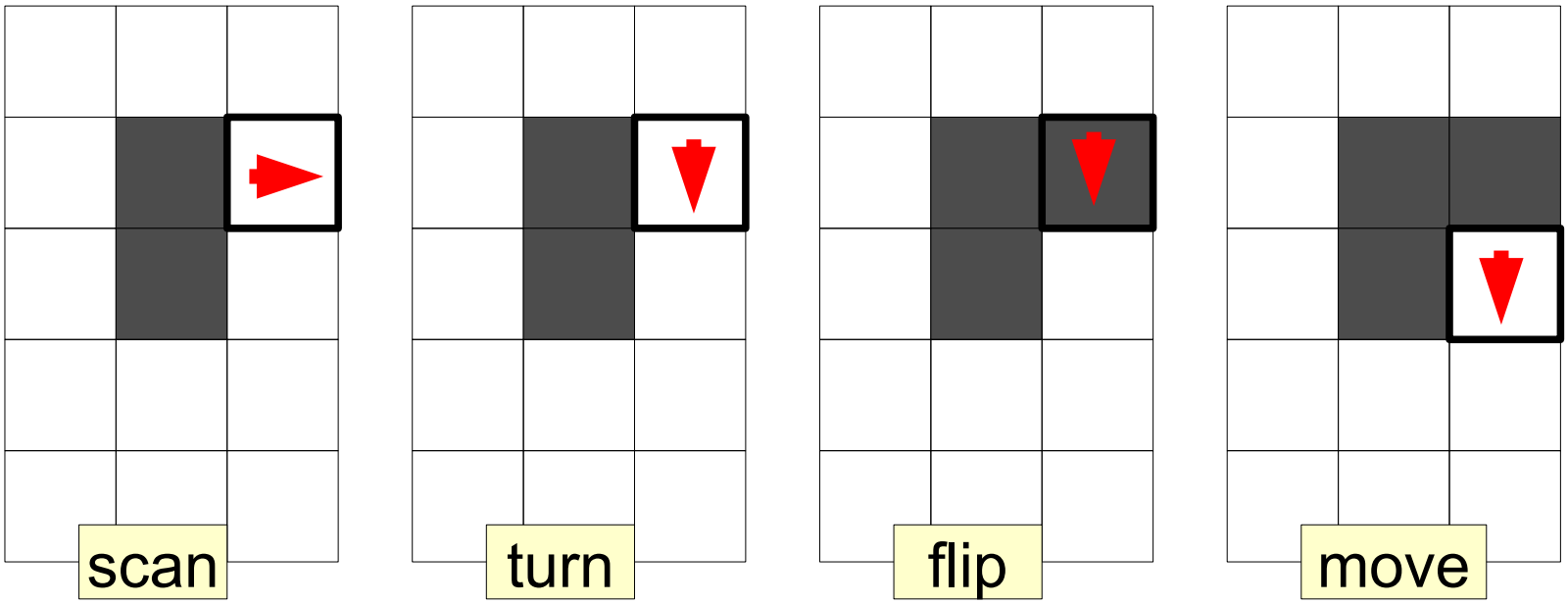

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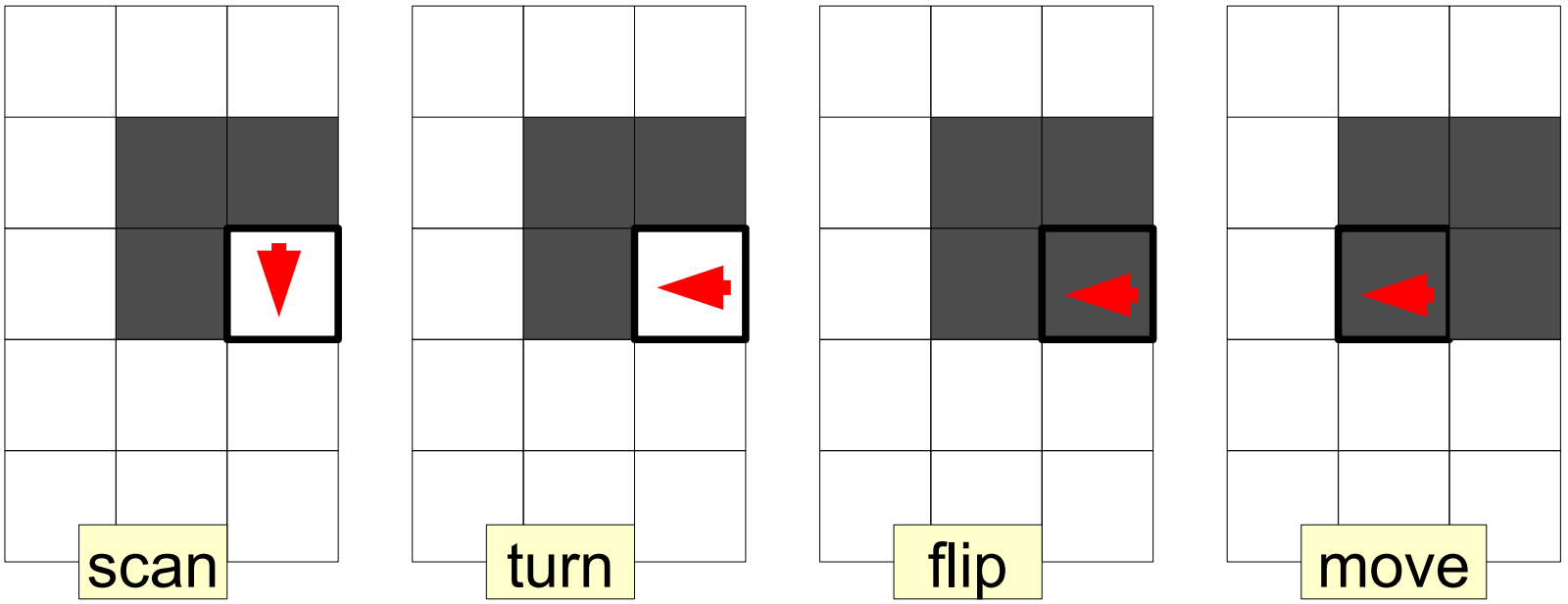

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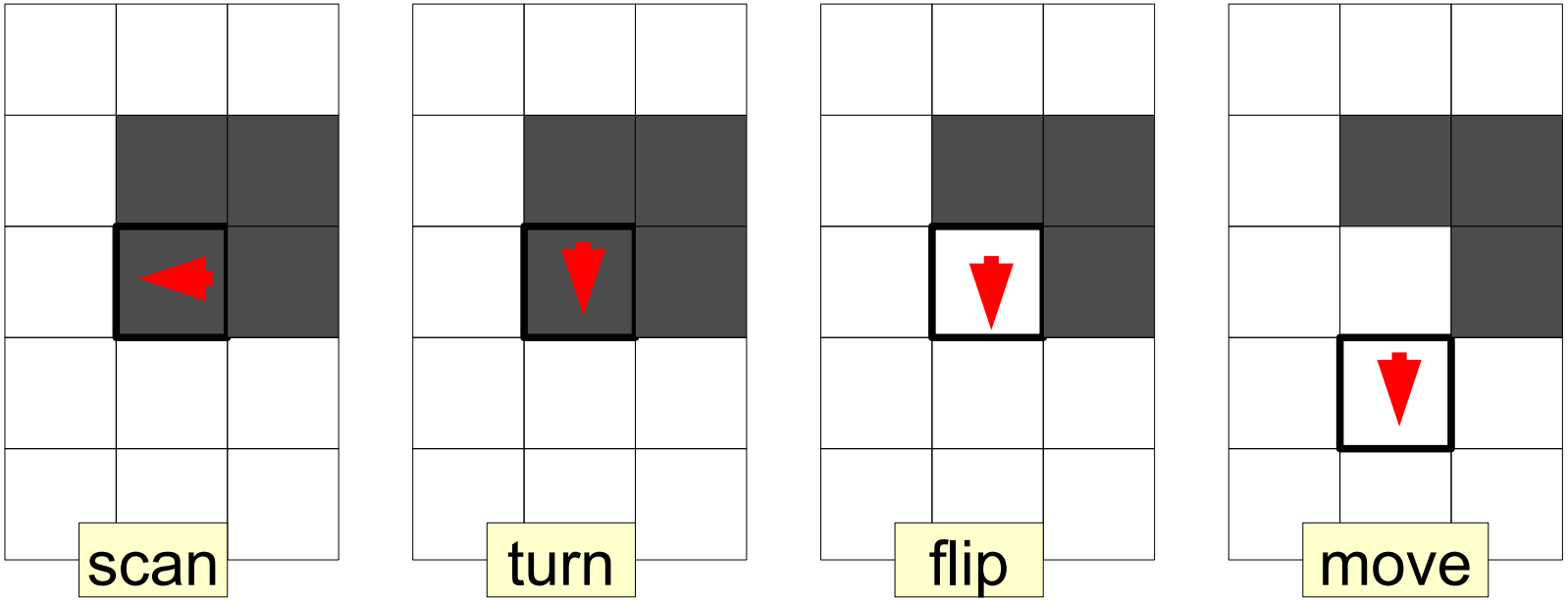

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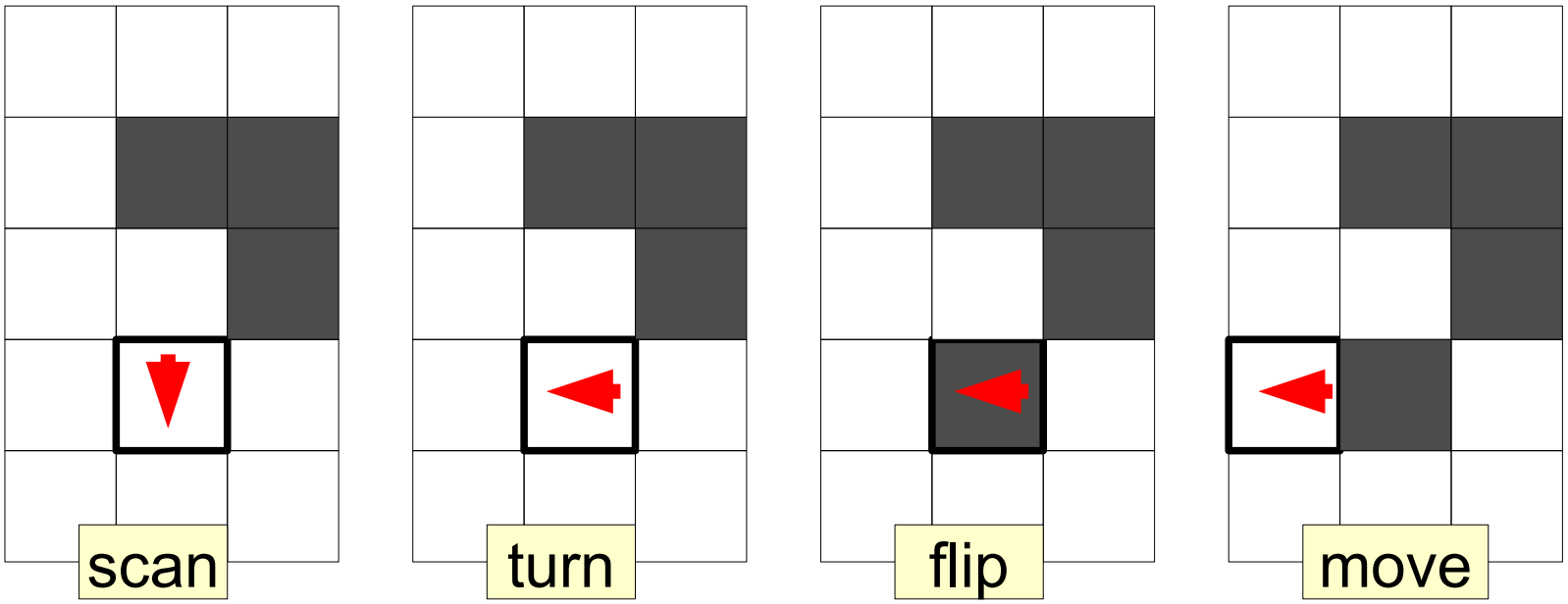

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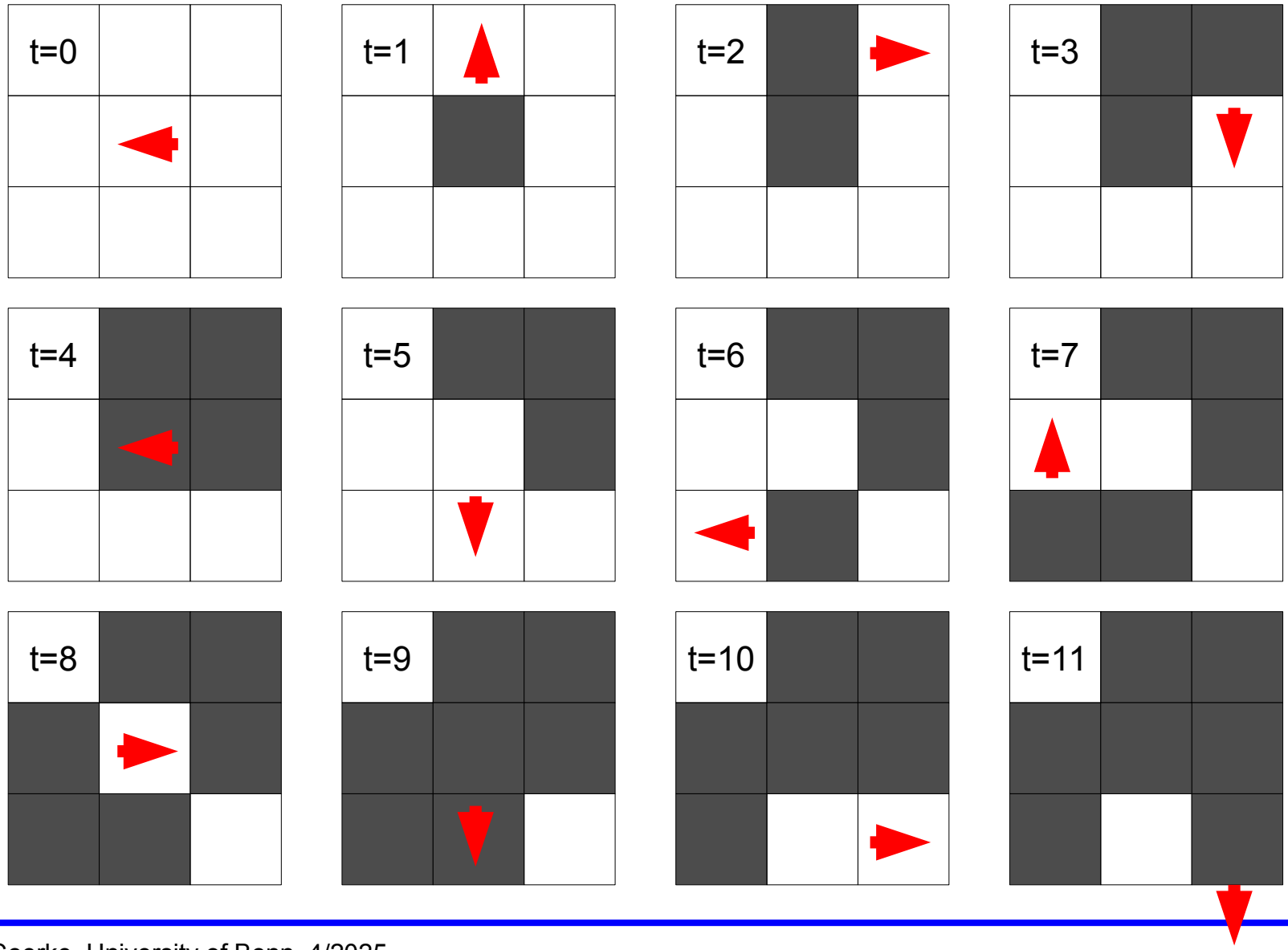

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Langton's Ant:

Although, the rule for Langton's Ant is simple,
and the micro behavior is comprehensible in every step,
the short term behavior is between hard and impossible to predict.

The mid term behavior resists any attempt of prediction and is often described as chaotic (although not random at all).

The only way to determine the state of the grid, and the ant after a given time t, is to run the simulation and monitor the changes.

The long term behavior of Langton's Ant is sometimes leading to a surprising different kind of behavior.

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Langton's Ant:

The macroscopic behavior that can be observed when Langton's Ant is started on a uniform white grid undergoes three 3 phases:

Phase 1: **Symmetric growth**

Phase 2: **Chaotic growth**

Phase 3: **Highway**

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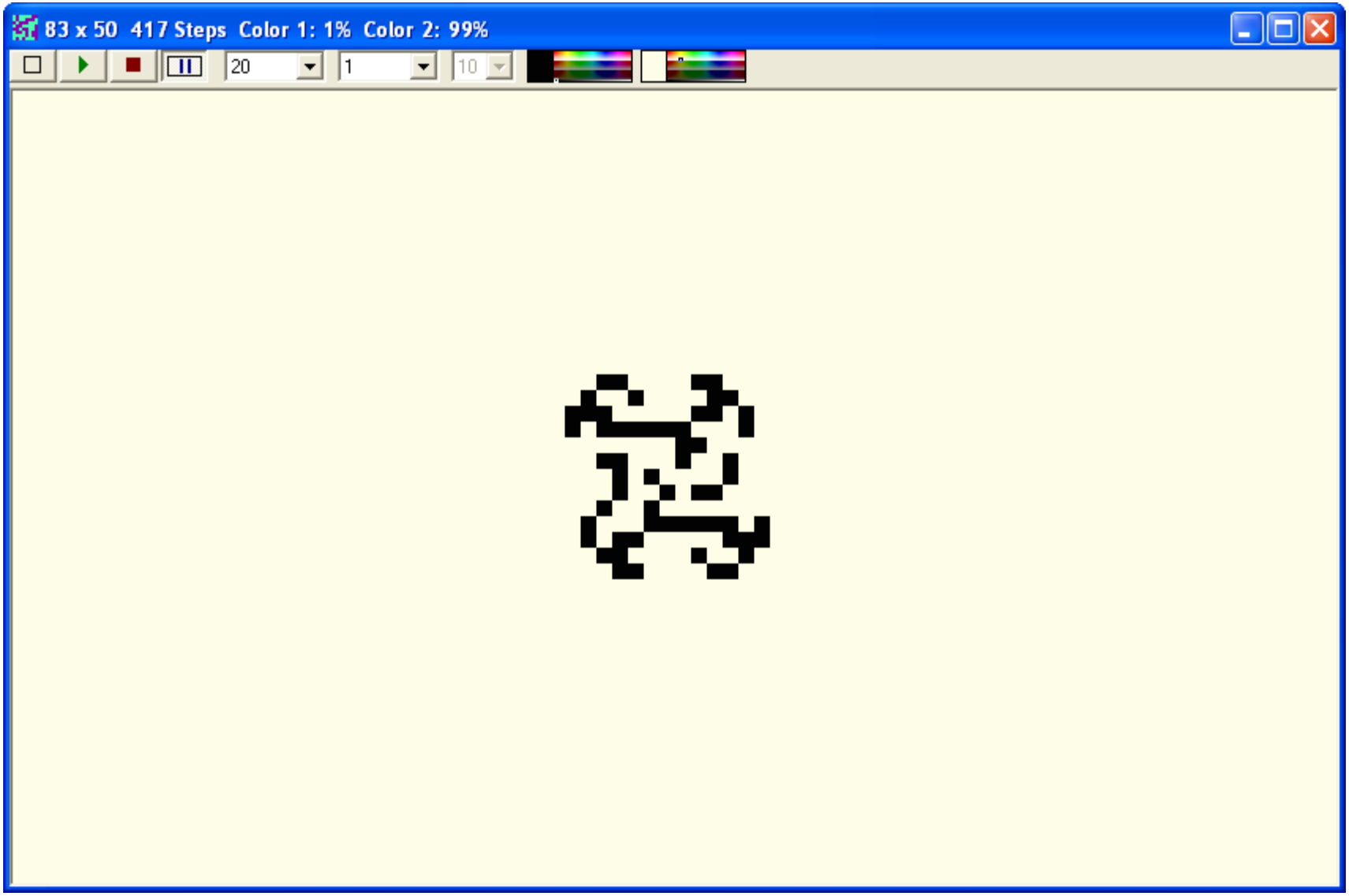
Phase 1: **Symmetric growth**



From *http://www.markuswelz.de/freeware/langton_ant.zip*

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The macroscopic behavior that can be observed when Langton's Ant is started on a uniform white grid undergoes three 3 phases:

Phase 1: Symmetric growth

growth, almost symmetric pattern
up to step 420 (approx)

Phase 2: **Chaotic growth**

Phase 3: **Highway**

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Phase 2: **Chaotic growth**

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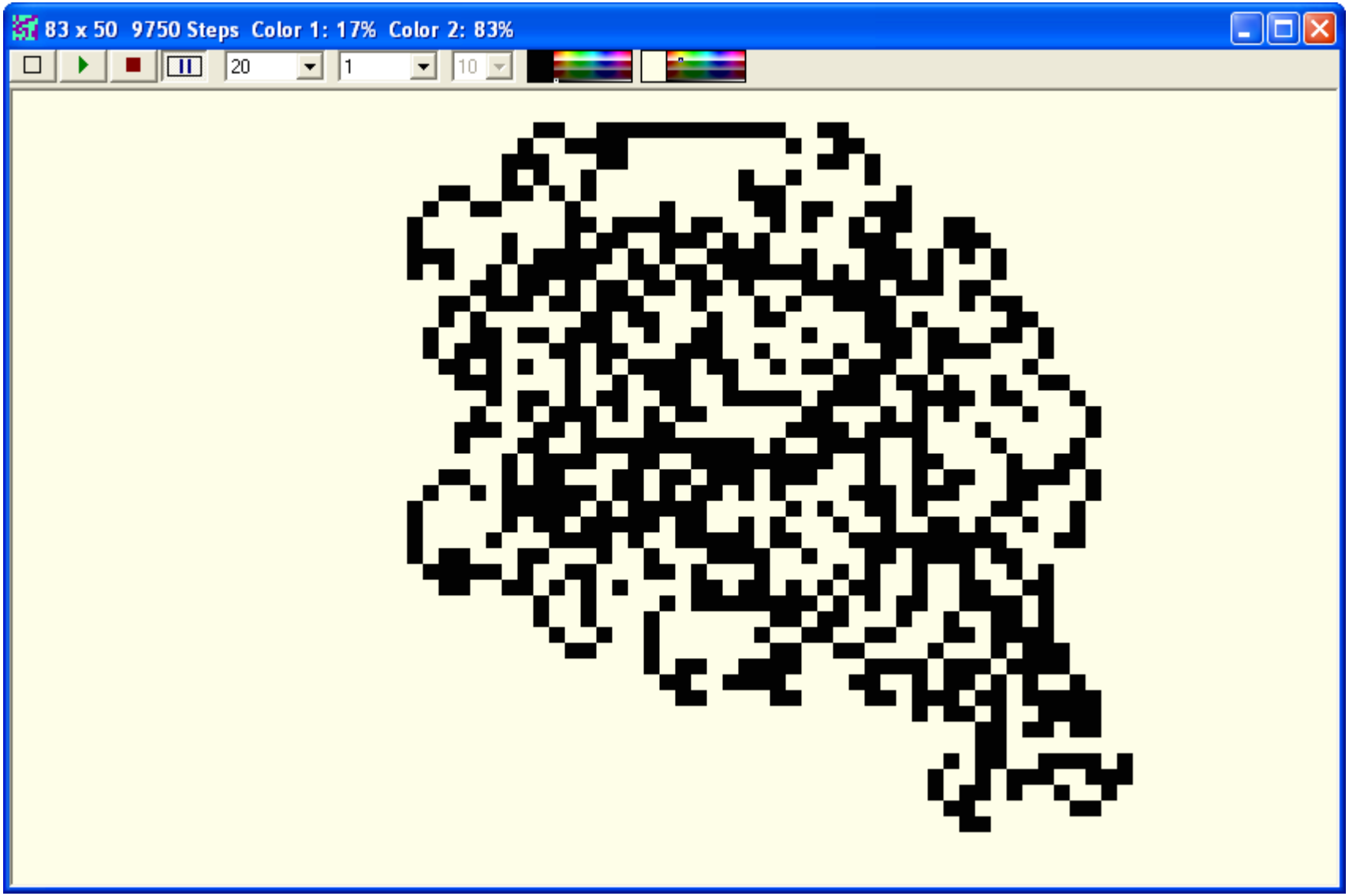
Phase 2: **Chaotic growth**



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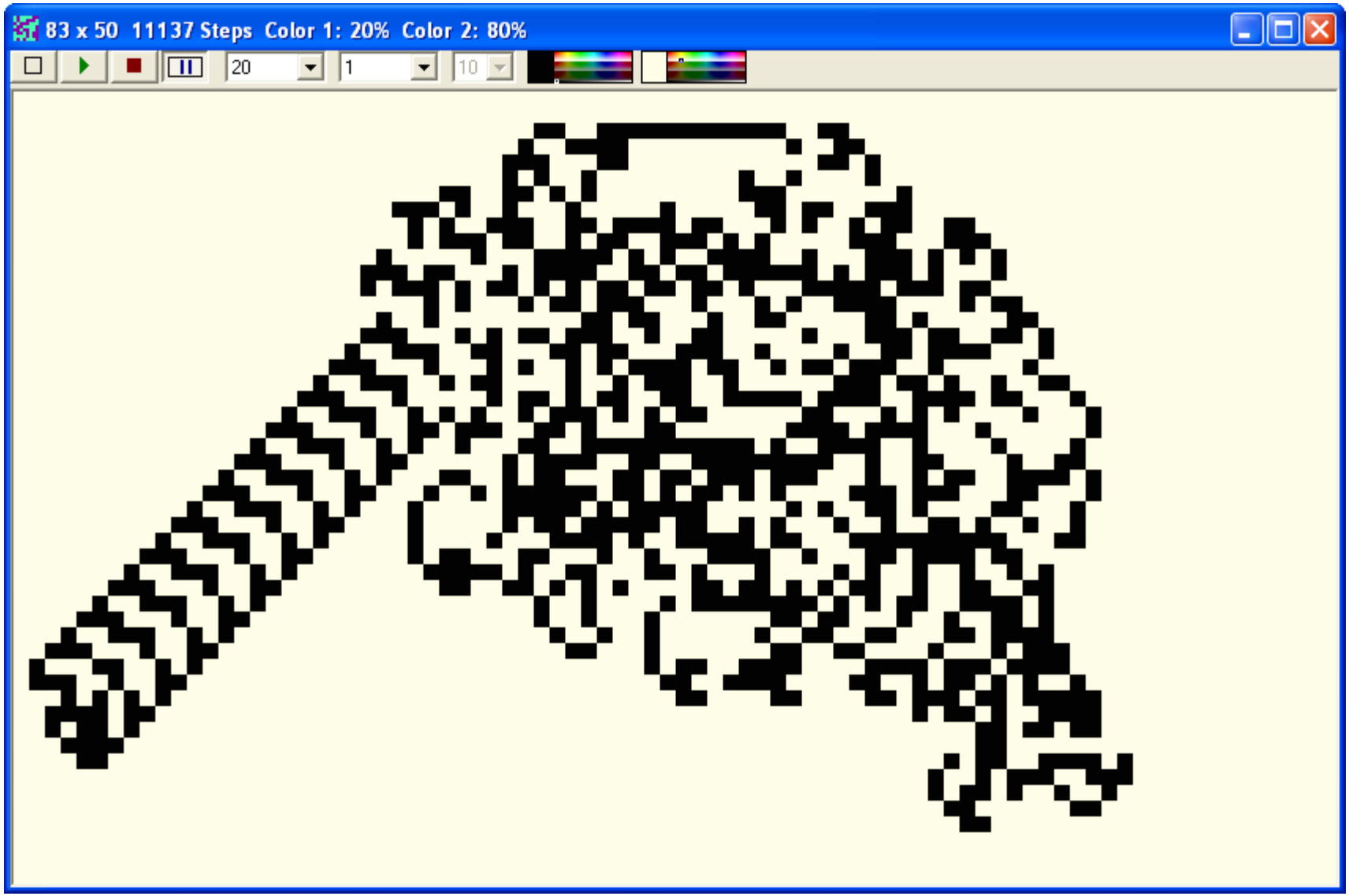

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Phase 2: Chaotic growth

further growth, but no structure distinguishable,
deterministic chaos from step 400 – 10000 (approx)

Phase 3: Highway

suddenly a highly structured, repetitive pattern is build by the Ant (Highway), the structure is persistent from step 10000 (approx), cycle time 104 steps.

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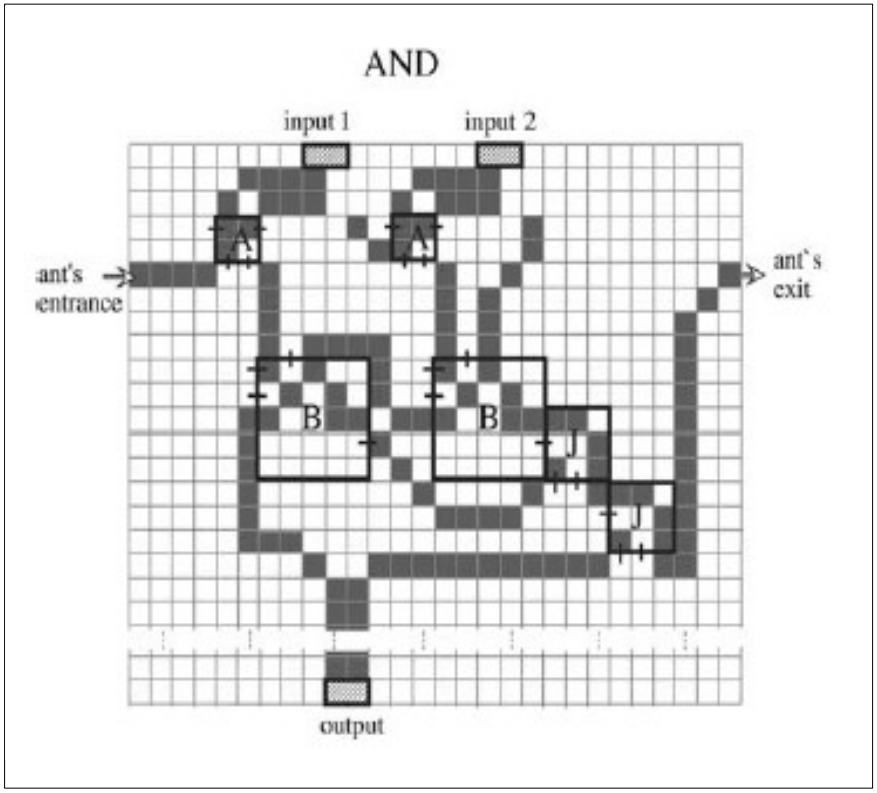
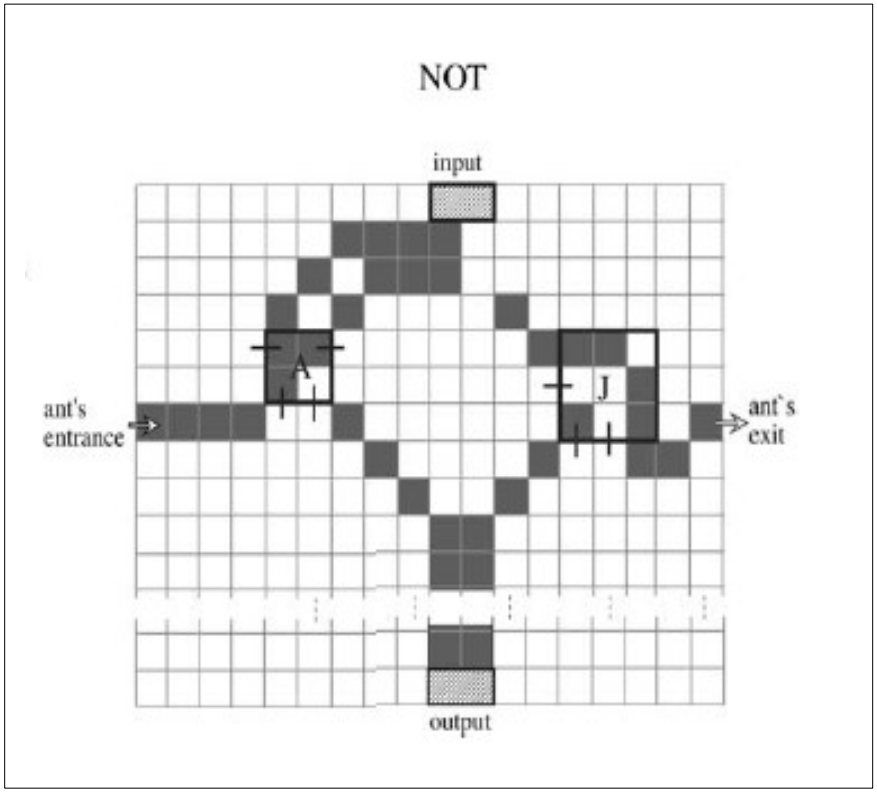
Langton's Ant extras:

It has been shown (*Gajardo, A.; A. Moreira, E. Goles, 2000)* that the movement of one single of Langton's Ants can implement any Boolean function.





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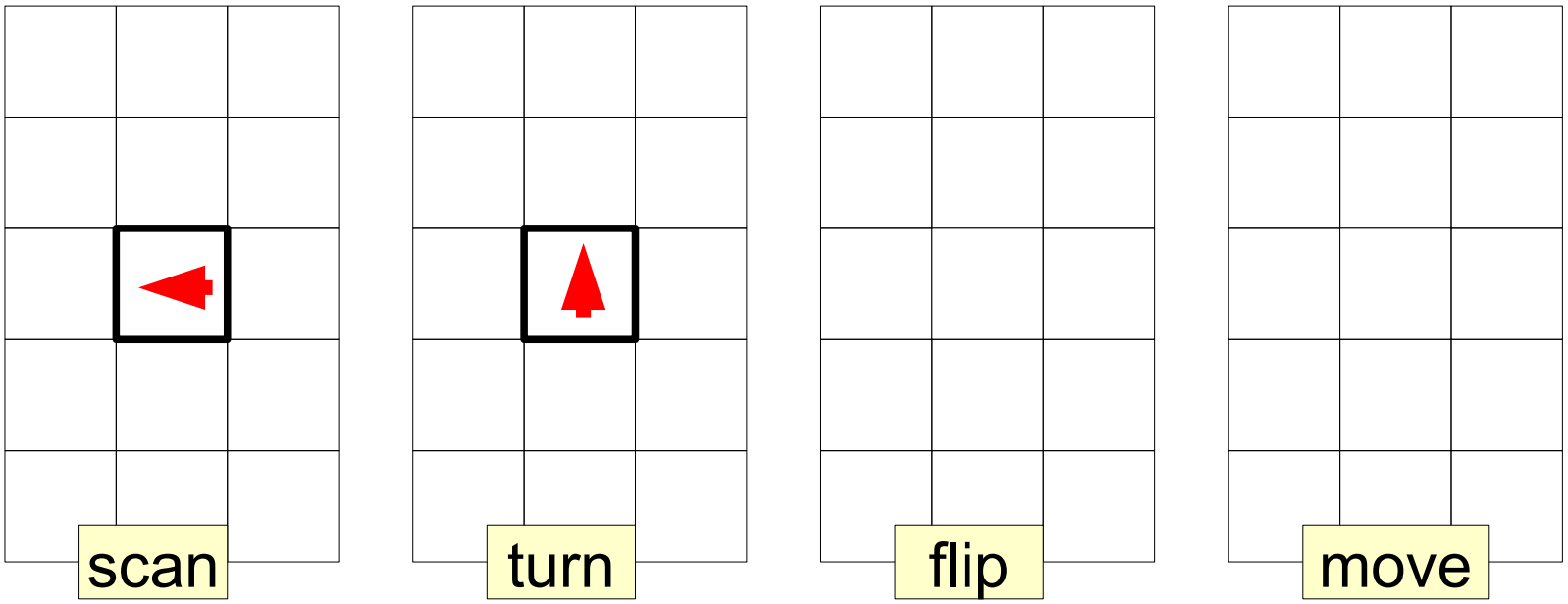

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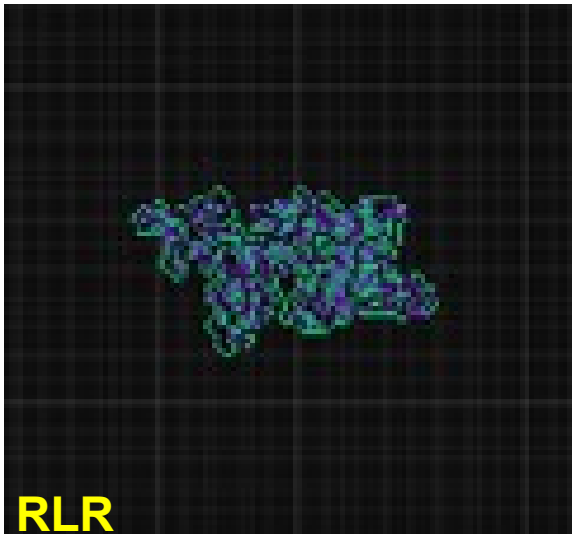
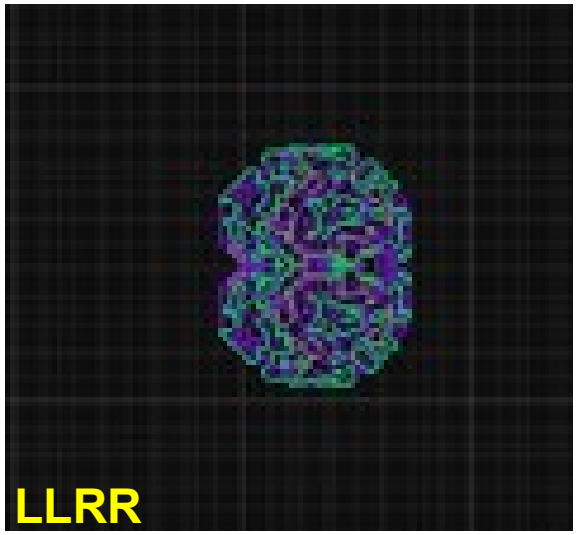
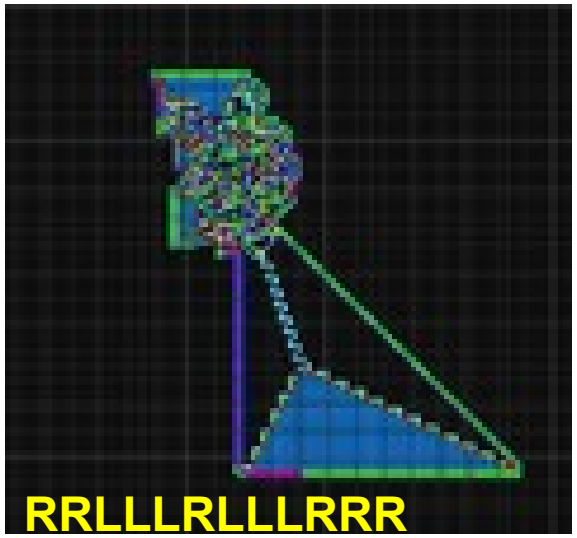
Langton's Ant extras:

A simple extension to Langton's Ant is using more than two states for the cells e.g. k=3, {0,1,2}.
In every move, the state is increased by one (cyclic).
The rules can now be easily denominated by the direction the Ant is turning to, with respect to the very state:
Langton's original Ant would then be **RL.**







From: http://en.wikipedia.org/wiki/Langton's_ant

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Artificial Life
Summer 2025

Agenda for Monday 7.4.25

- A: Some Organizational Issues
- B: Introduction, Natural Life - Artificial Life
- C: Langton's Ant

Thank you for your attention

and please stay healthy and peaceful

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