

Artificial Life Summer 2015

Introduction Natural Life - Artificial Life Langton's Ant

Master Computer Science [MA-INF 4201]
Mon 8:15 – 10:00, LBH, Lecture Hall III.03a

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

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Modalities MA-INF 4201, Artificial Life SS15

Lecture:

Mondays, 8:15 - 9:45, Lecture Hall III.03a, LBH
some slides will be on the respective exercises page.
They will not cover the complete lecture !!!

Assignments: on a **voluntary** basis
11 times weekly assignments, pencil & paper and programming,
work in 2 person groups, >50% points are favorable.

Exercise groups:

weekly, 2hrs, participation is **voluntary**

Exam: written examination, 100 minutes
probably between Mon 27.7.15 – Fri 31.7.2015

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Access to Slides & Exercise Sheets

The exercise sheets, and some of the slides from the lecture
will be available on the web page for the module:
www.ais.uni-bonn.de/SS15/4201_L_AL.html

There is a link to the **Exercises** page:
www.ais.uni-bonn.de/SS15/4201/4201_E_AL.html

Benutzername: **AL-SS15**
Passwort: *will be given in the lecture*

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Voluntary exercise groups:

The exercises will probably start on **Tuesday 21.4.2015**

The exercises will be in the LBH building,
Friedrich-Ebert-Allee 144
Room **E.23** (ground floor),
turn right after entering the building,
almost last door on left side.

The detailed times for the exercises will be negotiated
during the lecture on Mon 20.4.2015:

A: Tue 14-16 (almost confirmed)
B: Tue 16-18 (almost confirmed)
C: Fri 10-12 (tentative)

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Artificial Life [MA-INF 4201], Mon April 13, 2015

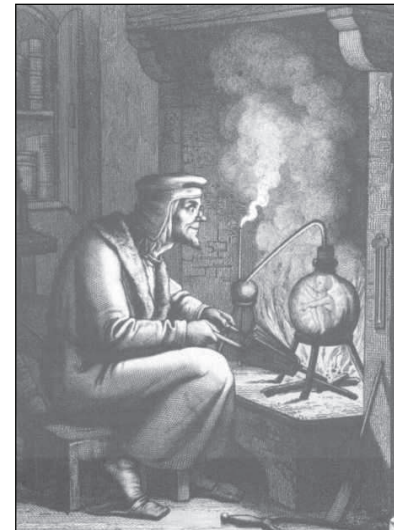
Overview:

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

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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.“*

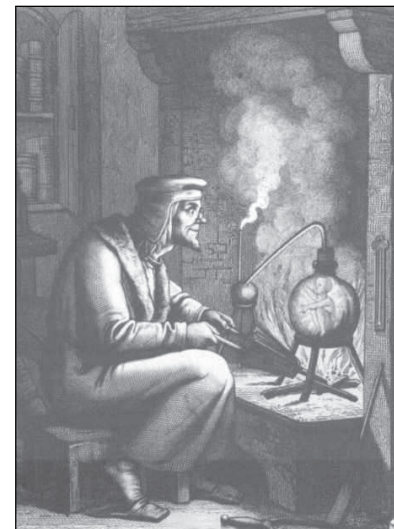
Johann Wolfgang von Goethe, 1832,
Faust II, zweiter Akt Laboratorium

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

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Artificial Life [MA-INF 4201], Mon April 13, 2015

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/faith29.html>

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

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What is: Artificial Life ?



Golem:

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

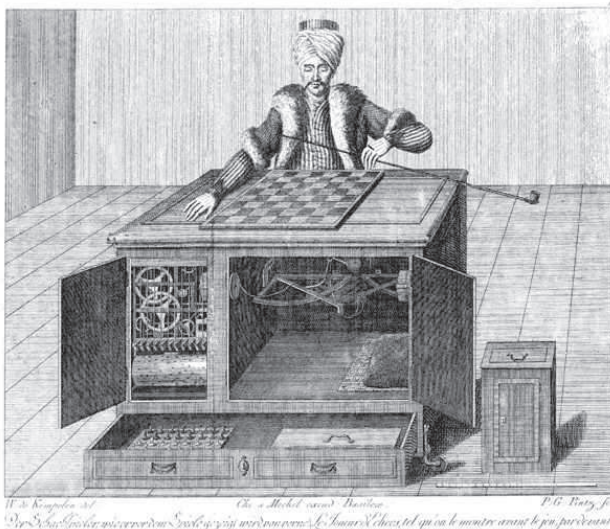
Depending on the version of the legend the rabbi of Prague constructed the Golem out of clay from the banks of the Vltava river, and brought it to life through rituals and Hebrew incantations.

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> 9

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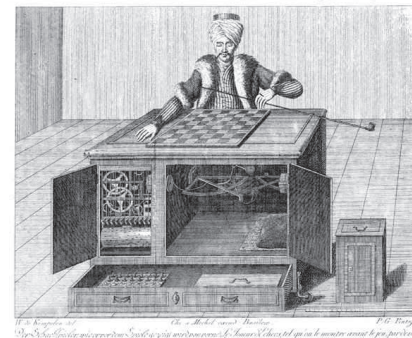
What is: Artificial Life ?



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What is: Artificial Life ?

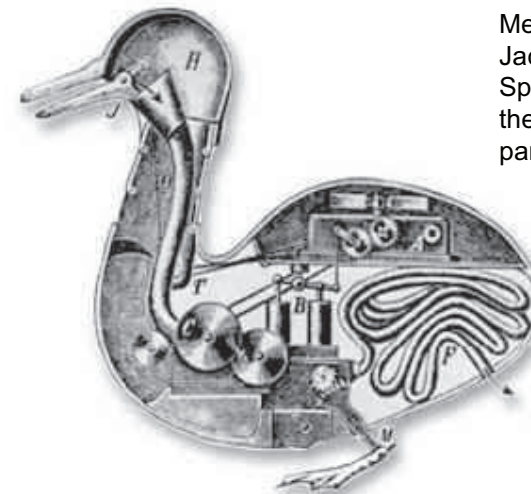


The Turk: a chess playing automaton was a famous (1769) chess playing machinery, build in 1769 by the Austrian-Hungarian constructor Wolfgang von Kempelen. Later on it has been revealed to be a hoax; a human was sitting in the lower part of the machinery controlling the Turks movements.

From: http://de.wikipedia.org/wiki/Wolfgang_von_Kempelen 11

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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 12

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What is: Artificial Life ?



The Writer:
Automaton of
Jaquet-Droz
1738

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What is: Artificial Life ?

What is: Natural Life ?

What is: Life ?

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Overview:

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

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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.

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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.

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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>

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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>

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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>

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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.

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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>

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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, morphogenesis, 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.

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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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- Starting a discussion

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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>

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Natural Life: animals



Panthera Tigris

From: <http://de.wikipedia.org/wiki/Tiger> 27

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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 28

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Natural Life: plants



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Natural Life: plants



Brassica oleracea (Romanesco) © Biopix.dk: N Sloth 30

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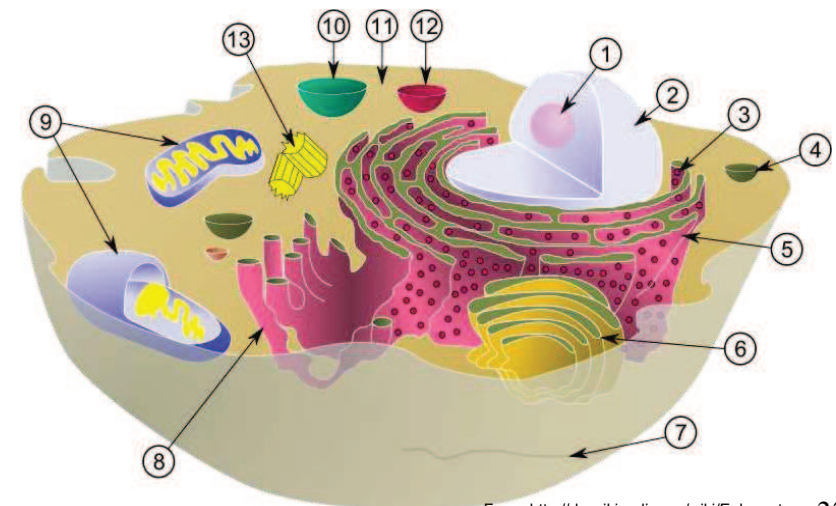
Natural Life: plants



Brassica oleracea (Romanesco) © Biopix.dk: N Sloth 31

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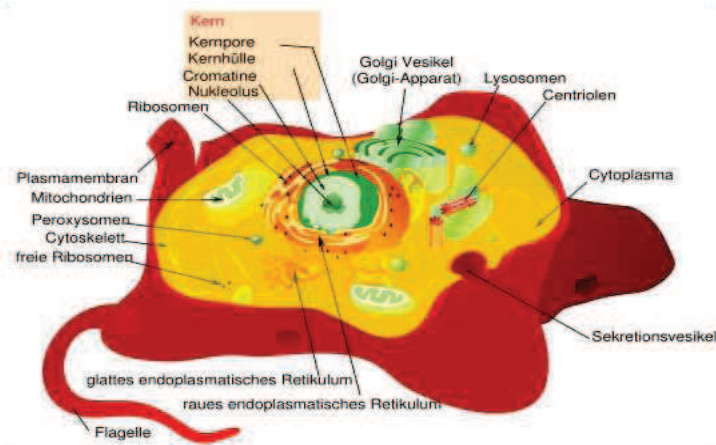
Natural Life: animal (eucariyotic cell)



From: <http://de.wikipedia.org/wiki/Eukaryotenc> 32

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Natural Life: animal (eucariyotic cell)



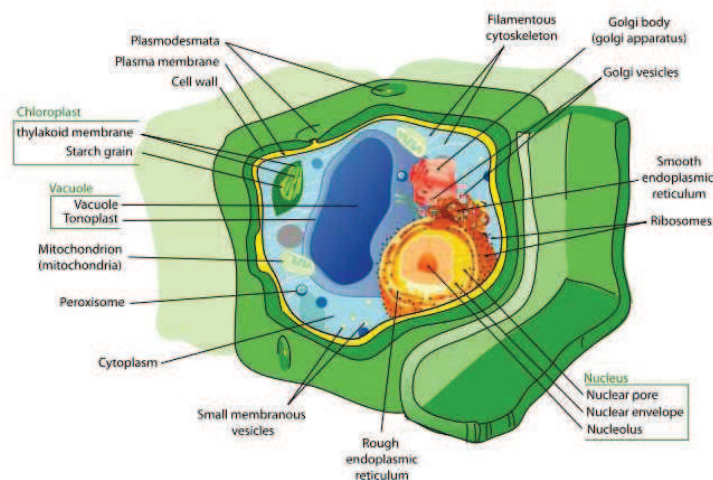
Einzeiler: Prokaryoten, Eukaryoten, Bazillen

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

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Natural Life: plant cell



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

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Natural Life: monad, protozoa



Sonnentierchen,
heliozoan
acathocystis turfacea

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

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Natural Life: monad, protozoa



Pantoffeltierchen,
paramecium,
paramecium aurelia

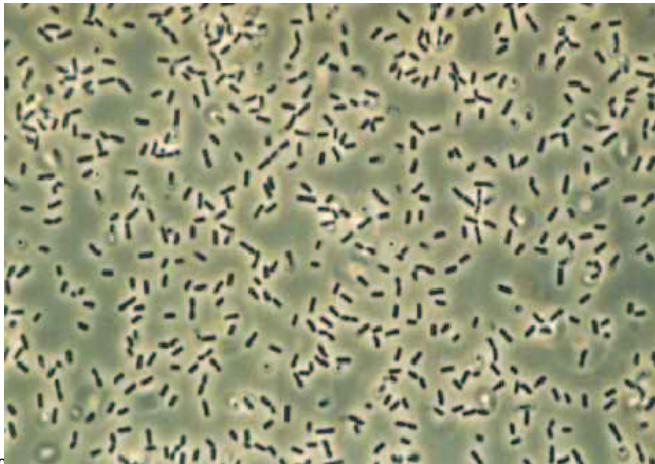
From: <http://de.wikipedia.org/wiki/Pflanzenzelle>

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Natural Life: bacterium, bacillus, germ

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

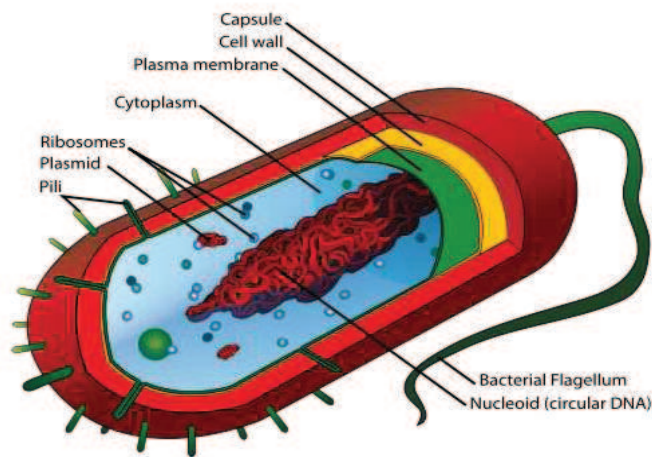


Microscope picture,
Bacillus subtilis (x1000)

From: <http://de.wikipedia.org/wiki/Pflanzenzelle> 37

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Natural Life: bacterium



Structure and contents of a typical Gram positive bacterial cell

From: <http://en.wikipedia.org/wiki/Bacterium> 38

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At the border of natural life:

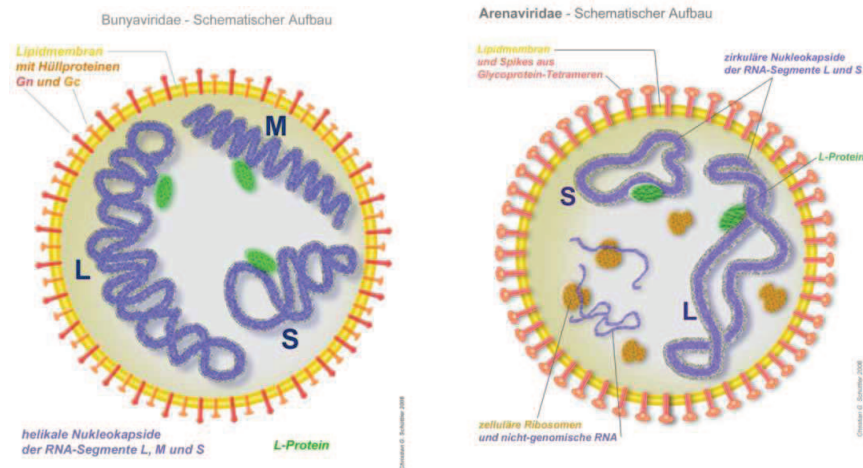
- animals
- plants
- procaryotes
- bacteria
- virus
- ???
- crystals
- artificial structures
- Artificial Life Systems

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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.



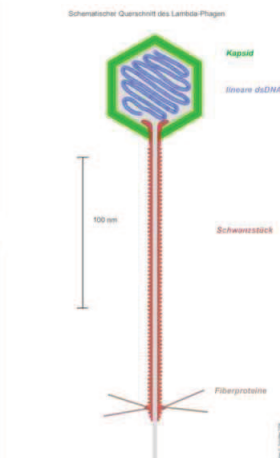
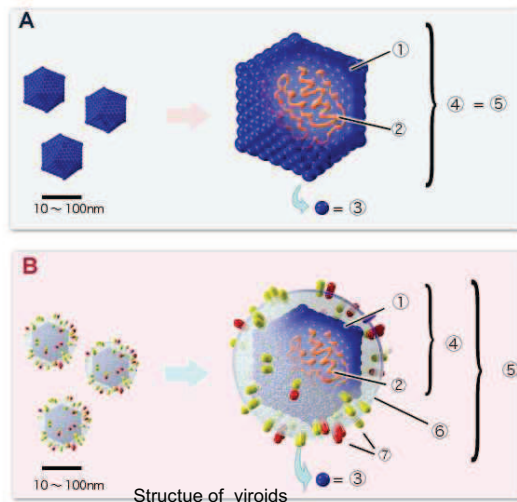
From: <http://de.wikipedia.org/wiki/Viren>

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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.



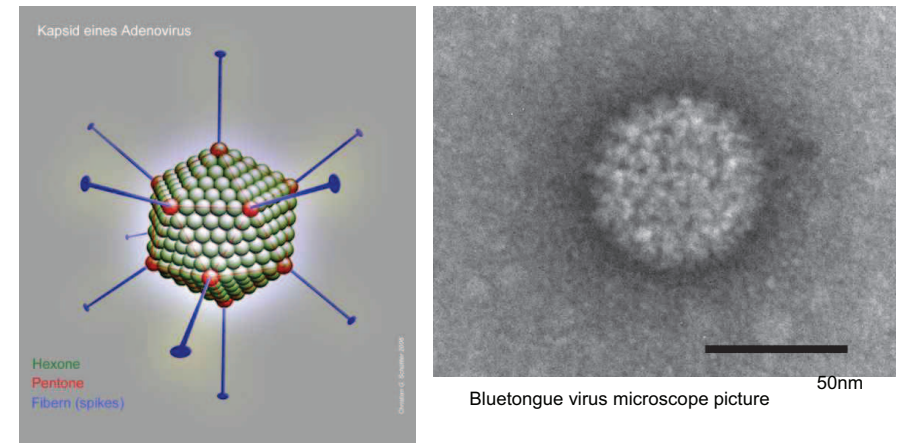
Structure Lambda-Phage
From: <http://de.wikipedia.org/wiki/Viren>

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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.



Adenovirus, modelled

From: <http://de.wikipedia.org/wiki/Viren>

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At the border of natural life:

Crystals show a variety of well organised structures.



Nadeliger Habitus beim Krokot

Lockenförmiges Aggregat beim Chalkanthit

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At the border of natural life:

Crystals show a variety of well organised structures.



Drahtförmiges Aggregat in silver



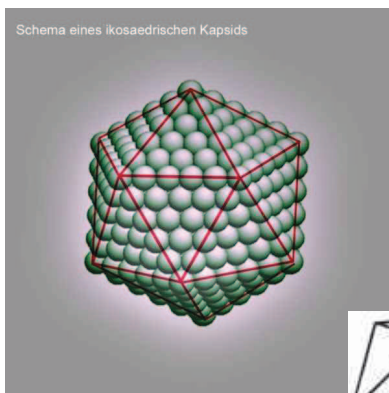
Tafeliger Habitus beim Baryt

45

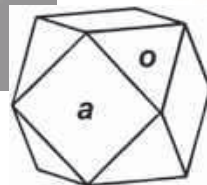
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At the border of natural life:

Crystals show a variety of well organised structures.



Model of virus structure



From: <http://de.wikipedia.org/wiki/Pyrit>

pyrite crystal

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Life at the border: hostile environment



Geysir Strokkur in Island

From: <http://en.wikipedia.org/wiki/Strokkur>

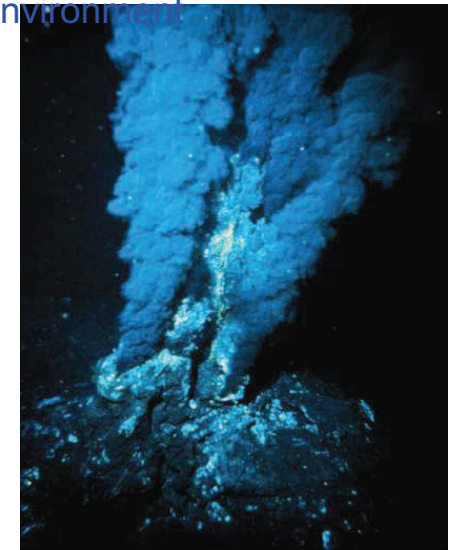
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Life at the border: hostile environment

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).

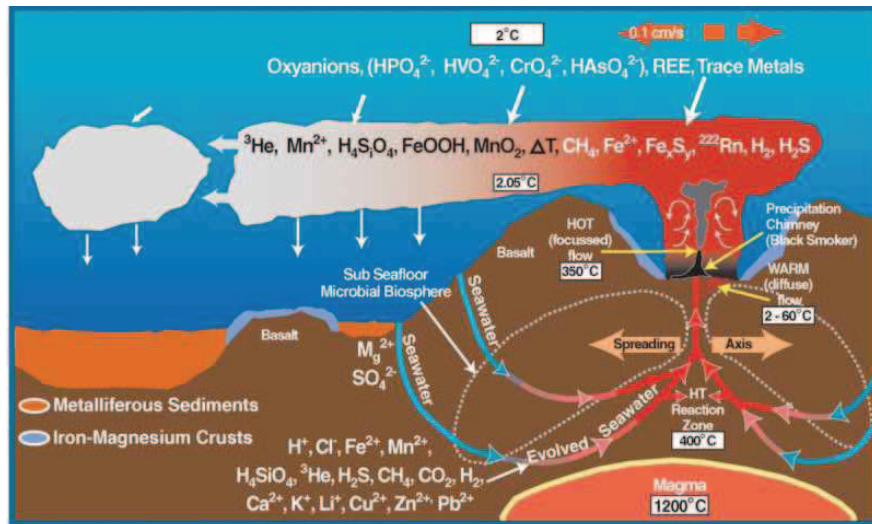


From: http://en.wikipedia.org/wiki/Black_smoker

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Life at the border: hostile environment



From: http://en.wikipedia.org/wiki/Black_smoker 49

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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 ?

Artificial Life is a rather exotic sub-topic in Computer Science with numerous relations to:

- Artificial-Intelligence,
- Computational-Intelligence,
- Bionics,
- Systems-Biology,
- Molecular-Biology,
- Philosophy.

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 ?

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

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]

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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.

Strong AL is mainly operating on a molecular basis.

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.

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Which one of the following systems is alive?

influenza virus pin worm table yeast

bacterium dried pea latin

lettuce rock ant TV screen

car protozoa drop of grease

river Rhine anthill palm tree

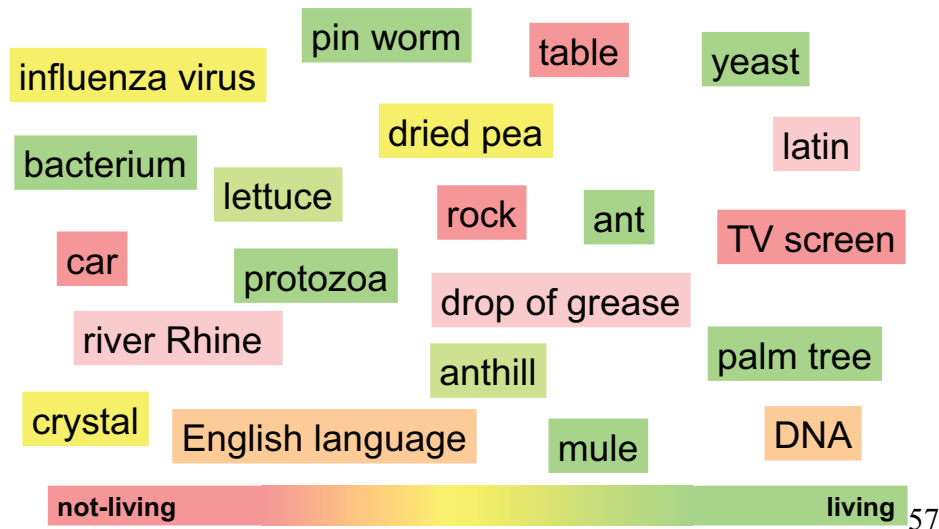
crystal English language mule DNA

not-living living

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Which one of the following systems is alive?



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Rethink the definition of *alive* ?

Do we really need a strong definition of alive?

Do we need a strict **YES NO** categorization?

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.

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

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Langton's Ant

In 1986 Christopher Langton has proposed the „**Ant**“, mostly called „**Langton's Ant**“, which is a very simple system that shows an tremendous potential to generate complicated behavior.

In 2000 it was even proven, that Langton's Ant is **universal** with respect to computation (**Turing equivalent**).

Langton's Ant is often denoted to be a **2-dimensional Turing Machine** with an easy to understand rule.

Langton's Ant is an **agent** working on a 2 dimensional rectangular grid of cells, with binary content {0,1}, {□,■}

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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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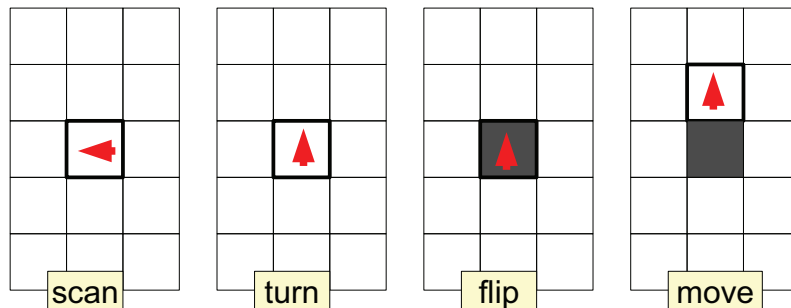
Langton's Ant micro behavior:

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.



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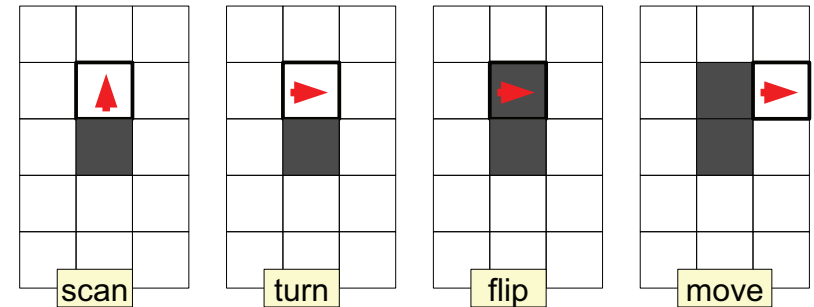
Langton's Ant micro behavior:

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.



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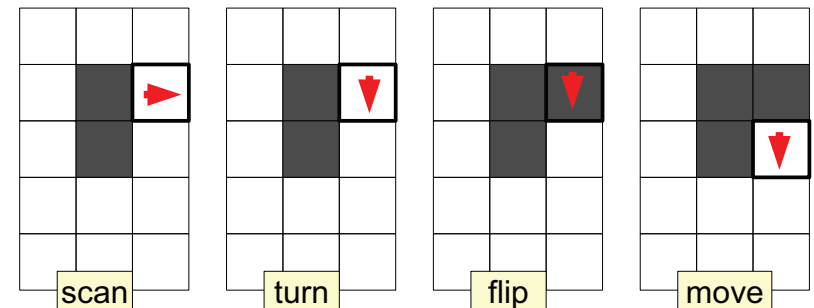
Langton's Ant micro behavior:

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.



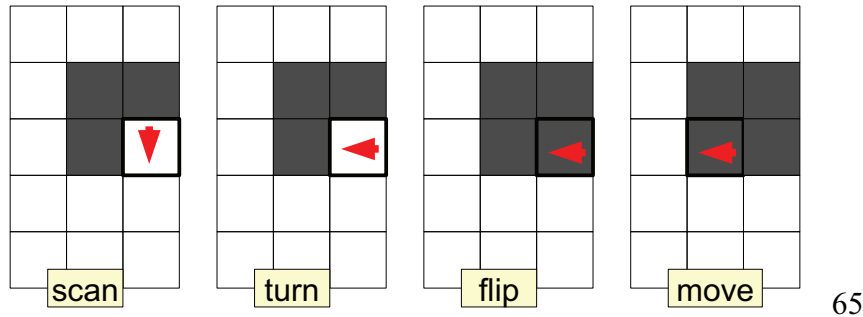
64

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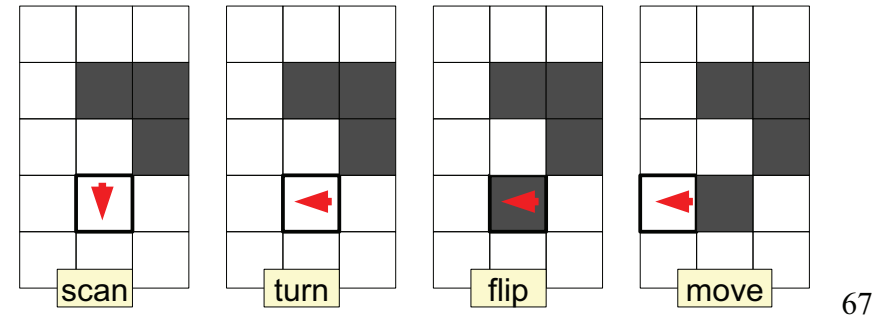
65

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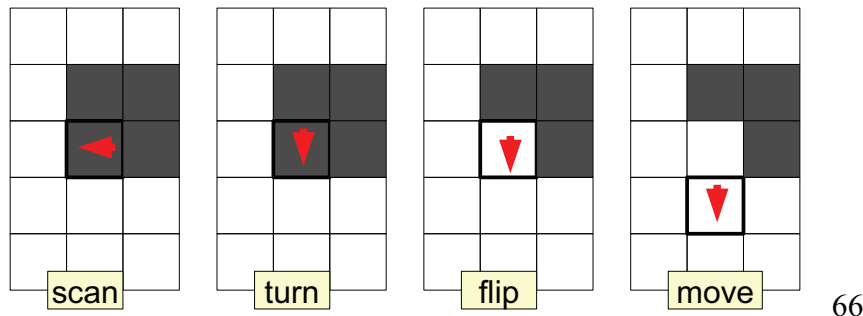
67

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Langton's Ant micro behavior:

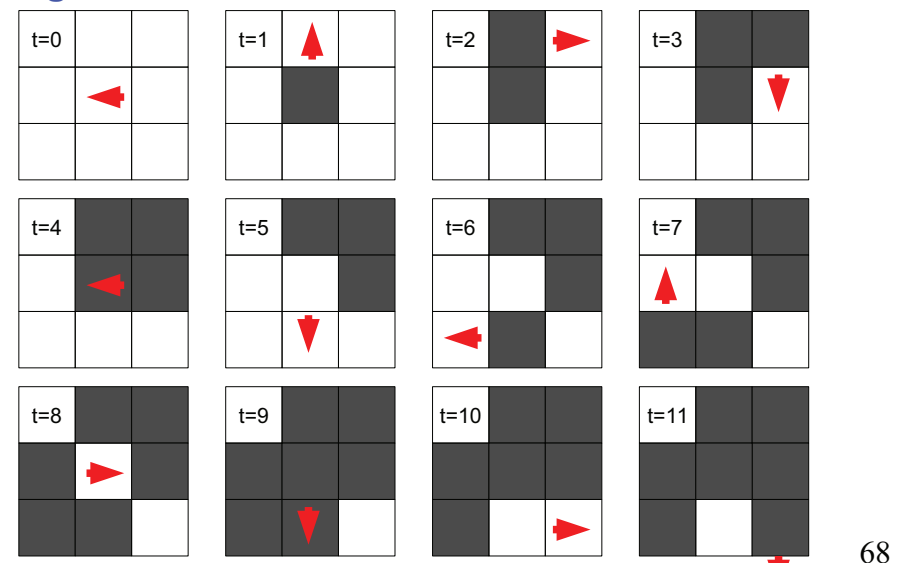
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Langton's Ant:

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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

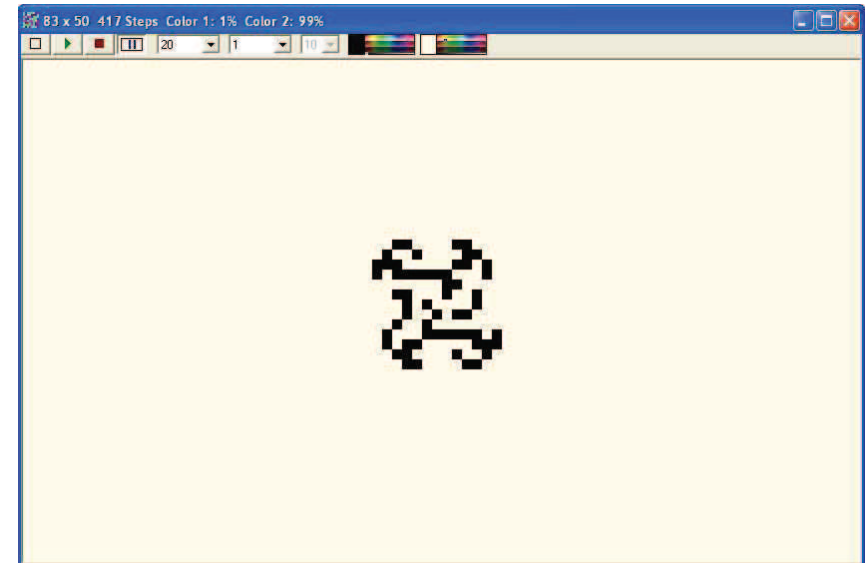
growth, almost symmetric pattern
up to step 420 (approx)

Phase 2: Chaotic growth

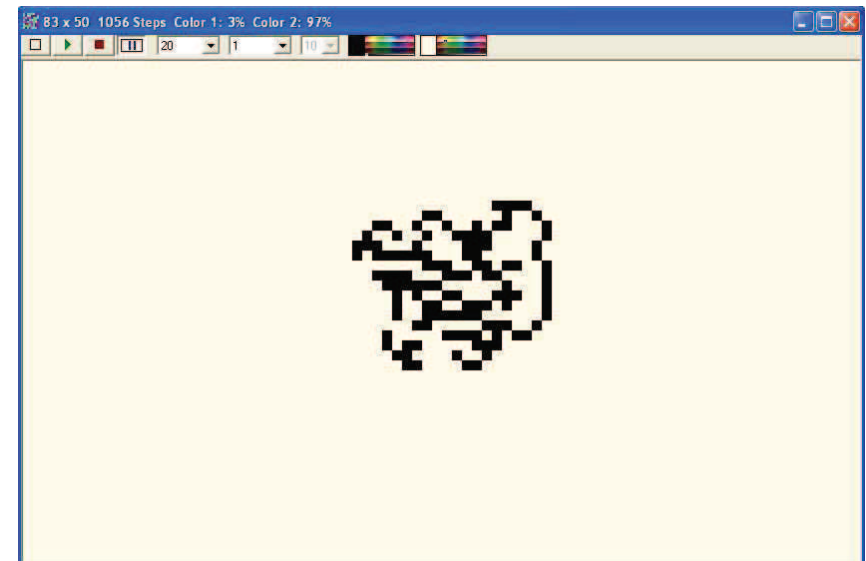
Phase 3: Highway

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From http://www.markuswelz.de/freeware/langton_ant.zip 71

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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**

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

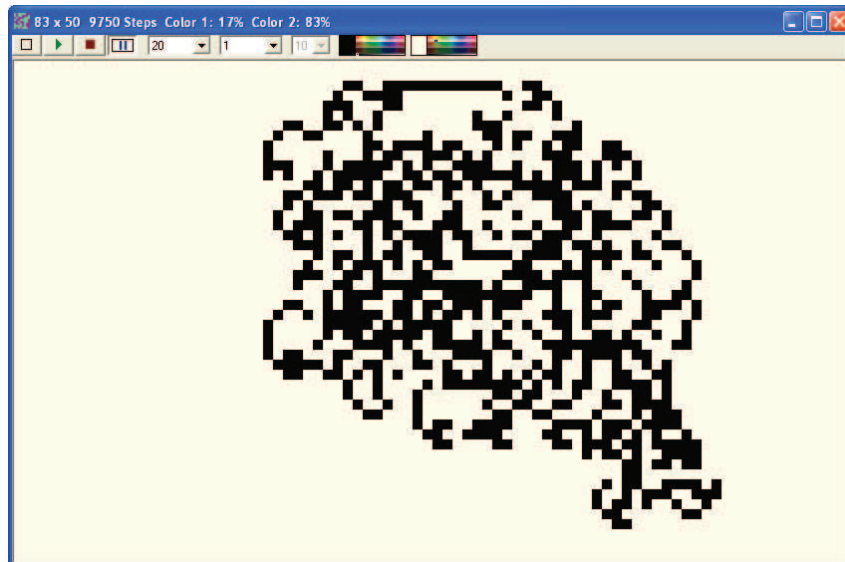
Phase 2: **Chaotic growth**

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

Phase 3: **Highway**

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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**

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

Phase 2: **Chaotic growth**

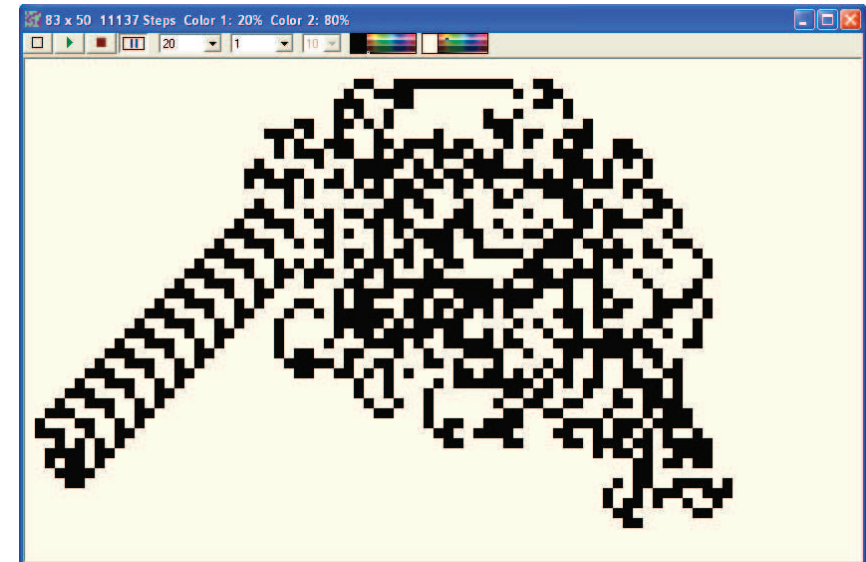
further growth, but no structure distinguishable, chaos
from step 400 – 10000 (approx)

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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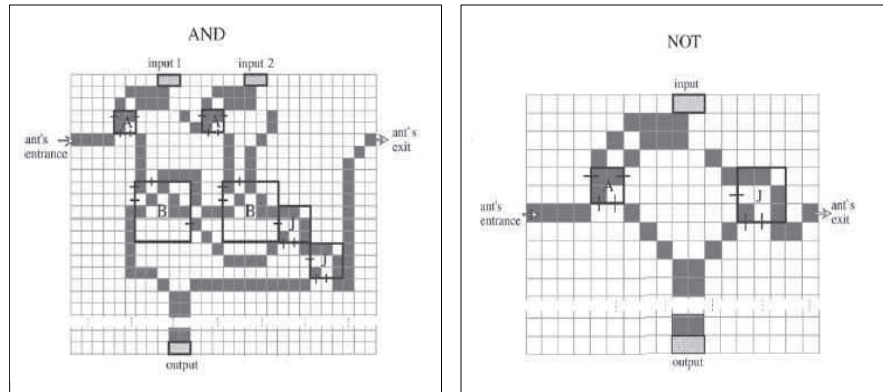


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Langton's Ant extras:

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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Artificial Life Summer 2015

Introduction
Natural Life - Artificial Life
Langton's Ant

Thank you for your attention

Master Computer Science [MA-INF 4201]
Mon 8:15 – 10:00, LBH, Lecture Hall III.03a

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

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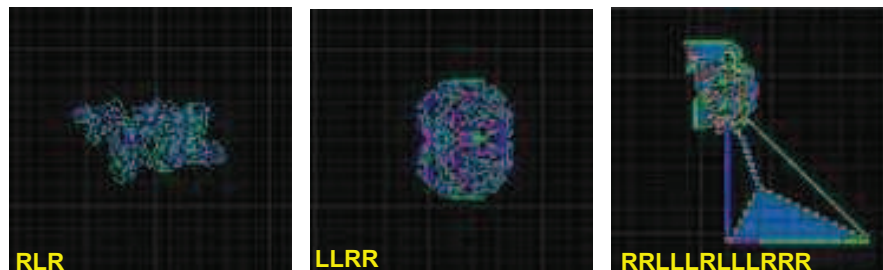
Langton's Ant extras:

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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