Artificial Life & Complex Systems

Lecture 1

Intro and History

May 25, 2007

Max Lungarella

Important Information

- Dates:
  - May 25,26; June 1,2; June 8,9 [12:30-18:30]
- Location:
  - BIN 2.A.01 (probably, here)
- Registration / Cancellation deadline:
  - Today!
- Hands-on project due for:
  - July 12, 2007, 23:59 CET# (email is fine!)
- Written exam:
  - June 29, 2007, 14:00-15:00
- Points (AP):
  - 2 + 2 + 2 scheme (attendance + project + written exam)
- Office hours:
  - Tuesday, Wednesday, Thursday, around 16:00-18:00 (better send an email – or try your luck!)
- Web:
  - http://www.ifi.unizh.ch/ailab/teaching/AL07/

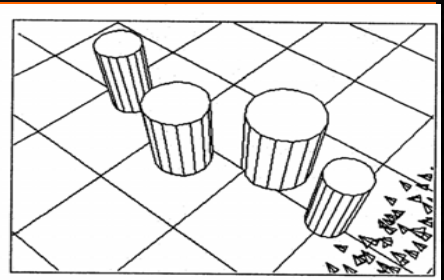
Lecturer – Introduction

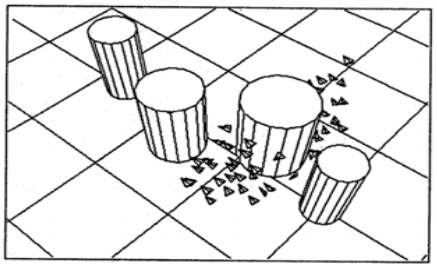
Beam me up, Scotty! No intelligent life down here!

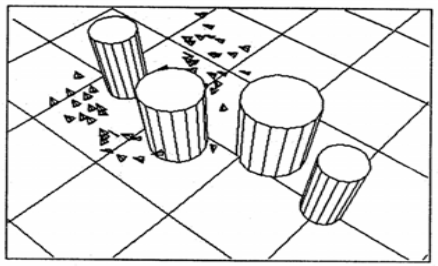
Course Organization – Three Main Objectives

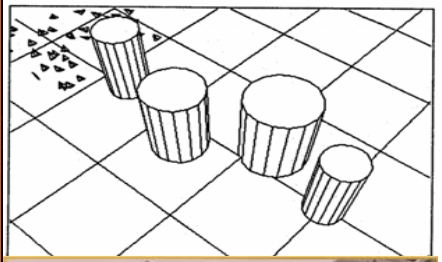
1) Examine prominent case studies and models of **natural and artificial life** and complex system science across a variety of topics: *Animal patterns, sea shells, insect societies, artificial societies, group behavior, excitable media, gene and cell differentiation, computational ecologies, evolution, cities, economy, Internet, digital art, …*
2) Understand the key concepts that unify these phenomena: *Emergence, self-organization, pattern formation, morphogenesis, nonlinear dynamics, order, chaos, complexity, feedback, phase transitions, adaptation, edge of chaos, criticality, …*
3) Introduce some of the theoretical and computational fields of artificial life research and their important potential for applications: *Cellular automata, swarm intelligence, complex networks, complex systems science …*

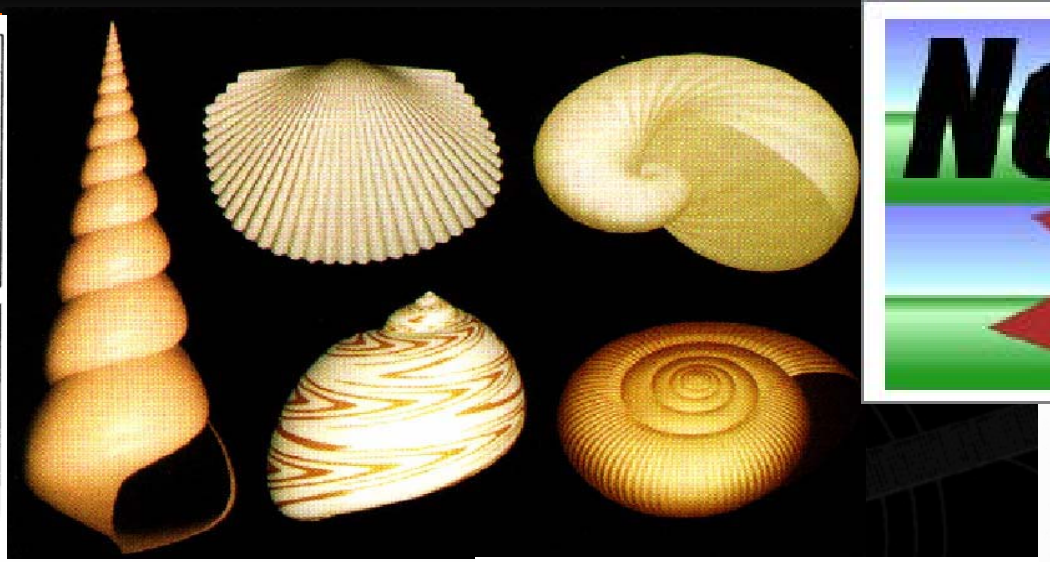
Disclaimer: Artificial Life → VAST discipline!! *It is not the intention of this course to be exhaustive or systematic. The course will offer an exploration of artificial life (and complex systems) through selected "sampling" of the literature and demos in class*









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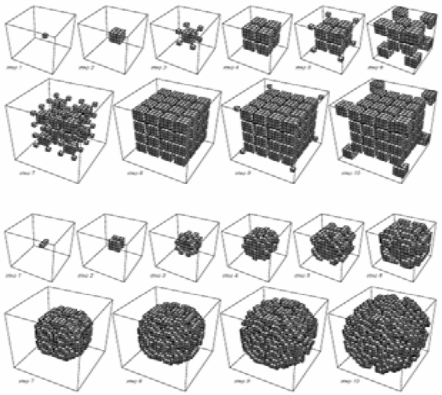

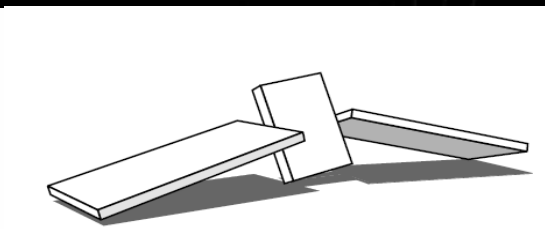

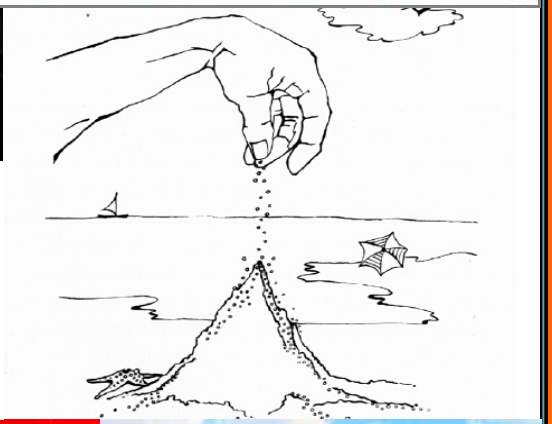

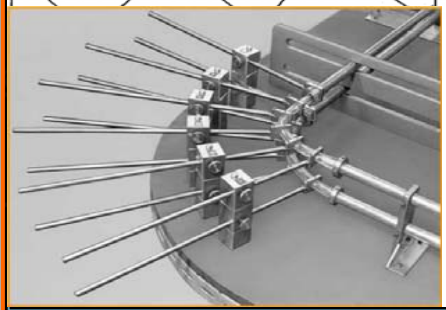

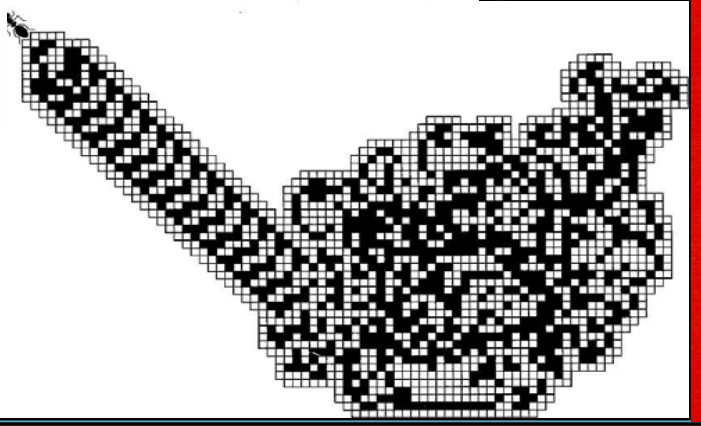

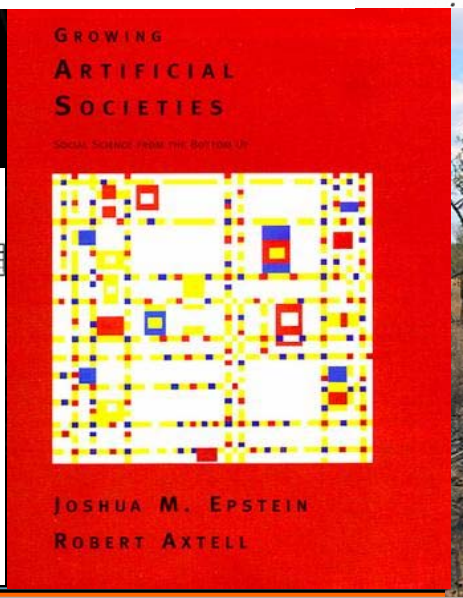
GROWING
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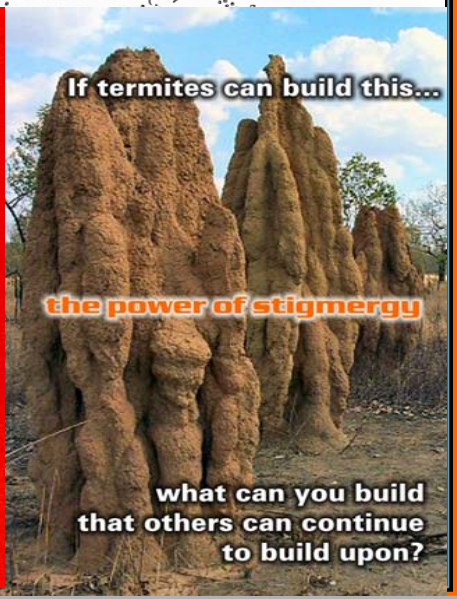
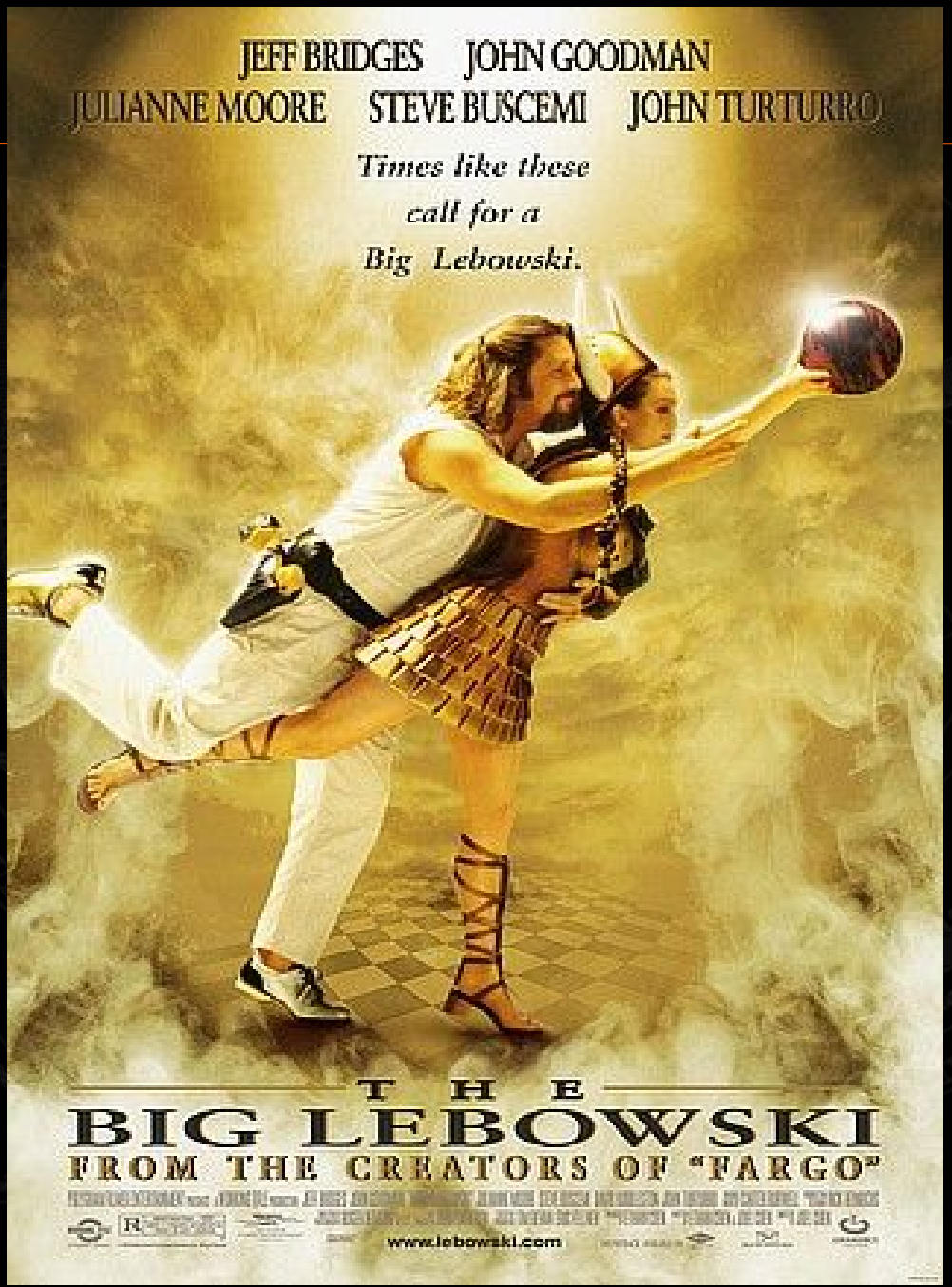
SOCIETIES
JOSHUA M. EPSTEIN
ROBERT AXTELL


If termites can build this...
the power of stigmergy
what can you build
that others can continue
to build upon?

Course Organization – Key Points

- **Exploration of (simple and complex) "life-like" systems by modeling and simulation**
- Notion of complex system: system composed of a large number of elements interacting locally (with each other and/or environment). Complex systems pervade nature and human structures, yet "complexity" is only a recent scientific topic
- Notions of emergence and self-organization: simple microscopic behavior can lead to complex (emergent) behavior which is difficult to predict or explain analytically
- Advancement in information technology allow us to see new patterns and convince ourselves that decentralized order is possible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Contents

- What is Life?
- Life-as-we-know-it
- Life-as-it-could-be
- Complex Adaptive Systems
- Artificial Life
- Very Brief History of Alife
- Modern Alife

Bedau, M.A. (2003) “Artificial life: organization, adaptation and complexity from the bottom up”, *Trends in Cognitive Sciences* 7(11):505-512

Bedau, M.A. et al (2000) “Open problems in artificial life” *Artificial Life* 6:363-376

What is Life?

What is Life?

Topic is highly controversial

But given that the class is on “artificial” life it makes sense to have a rough idea of the topics involved in the study of natural life

What is Life?

Indeed … in the words of Steven Harnad:

"What is it to be 'really alive'? I'm certainly not going to be able to answer this question here, but I can suggest one thing that's not: It's not a matter of satisfying a definition, at least not at this time, for such a definition would have to preceded by a true theory of life, which we do not have."

What is Life?

Some quick answers:

- Hydro-carbon chains
- Something that squishes when you step on it
- Watery, membrane-bounded encapsulation of space-time
- Information islands
- Far-from-equilibrium phenomenon
- Bacteria

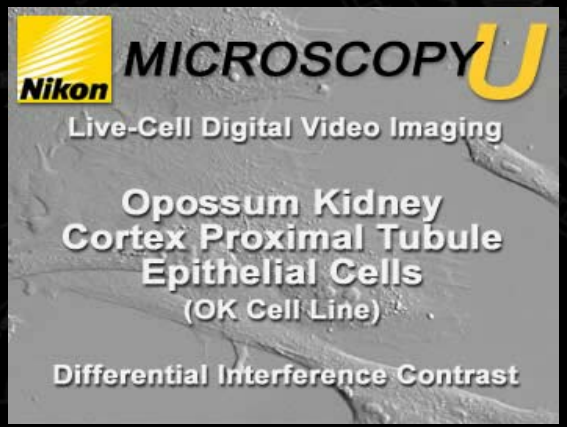
Main Features of Life

- Dynamic, self-organized, autonomous
- Unicellular and multicellular organization
- Made of H2O, C, H, O, N, S, P, organic molecules
- Reproduction (sexual and asexual), growth, and development
- Can extract and recycle matter and energy
- Metabolism
- Adaptable and subject to evolution by natural selection
- Self-maintaining, self-repairing, self-reproducing
- Organized at multiple scales
- Complex
- Interact with and respond to stimuli
- Choice, decision making
- May exhibit conscious thought, language, etc.

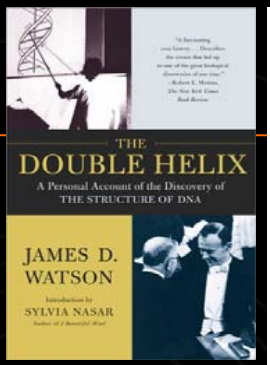
Note: List is not exhaustive!

Life-as-we-know-it

Only cells, organisms made of cells, and biospheres made of organisms can metabolize and are autopoetic (self-creating or self-producing)

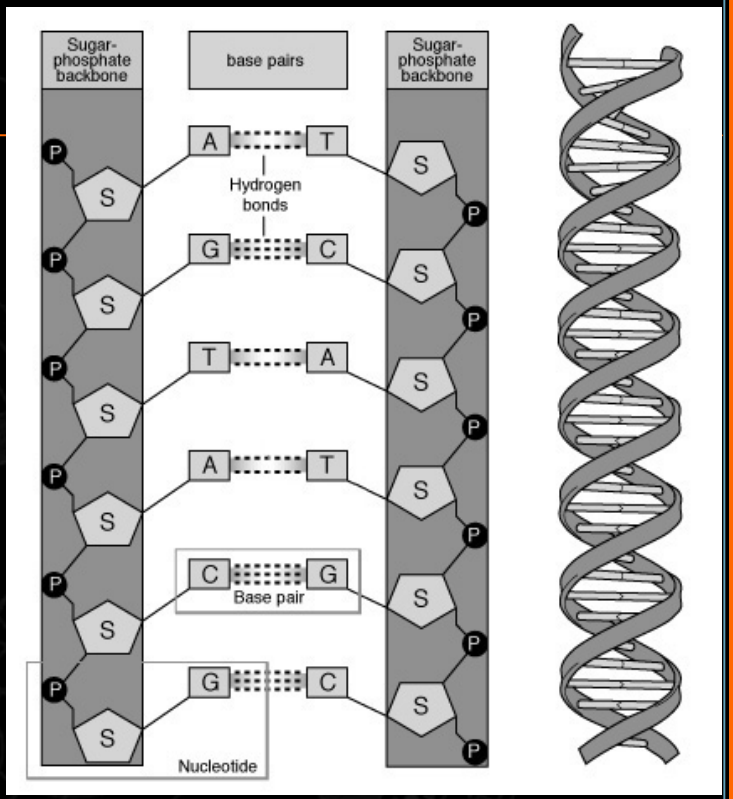


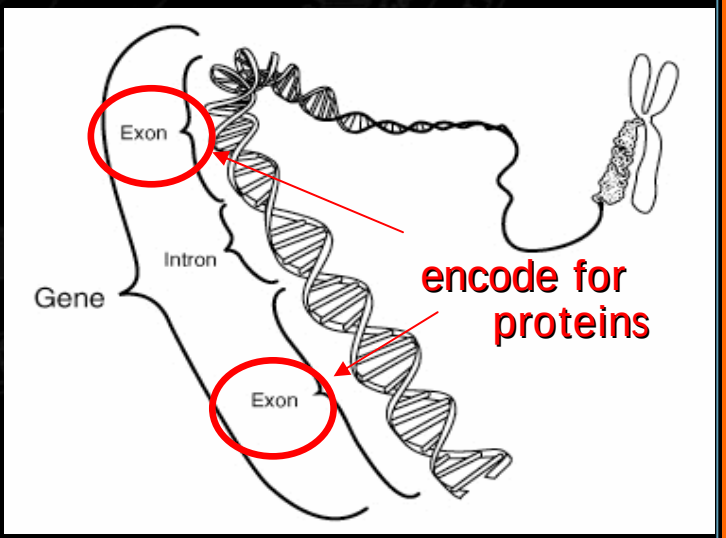
Molecule of Life



DNA (Deoxyribonucleic Acid)

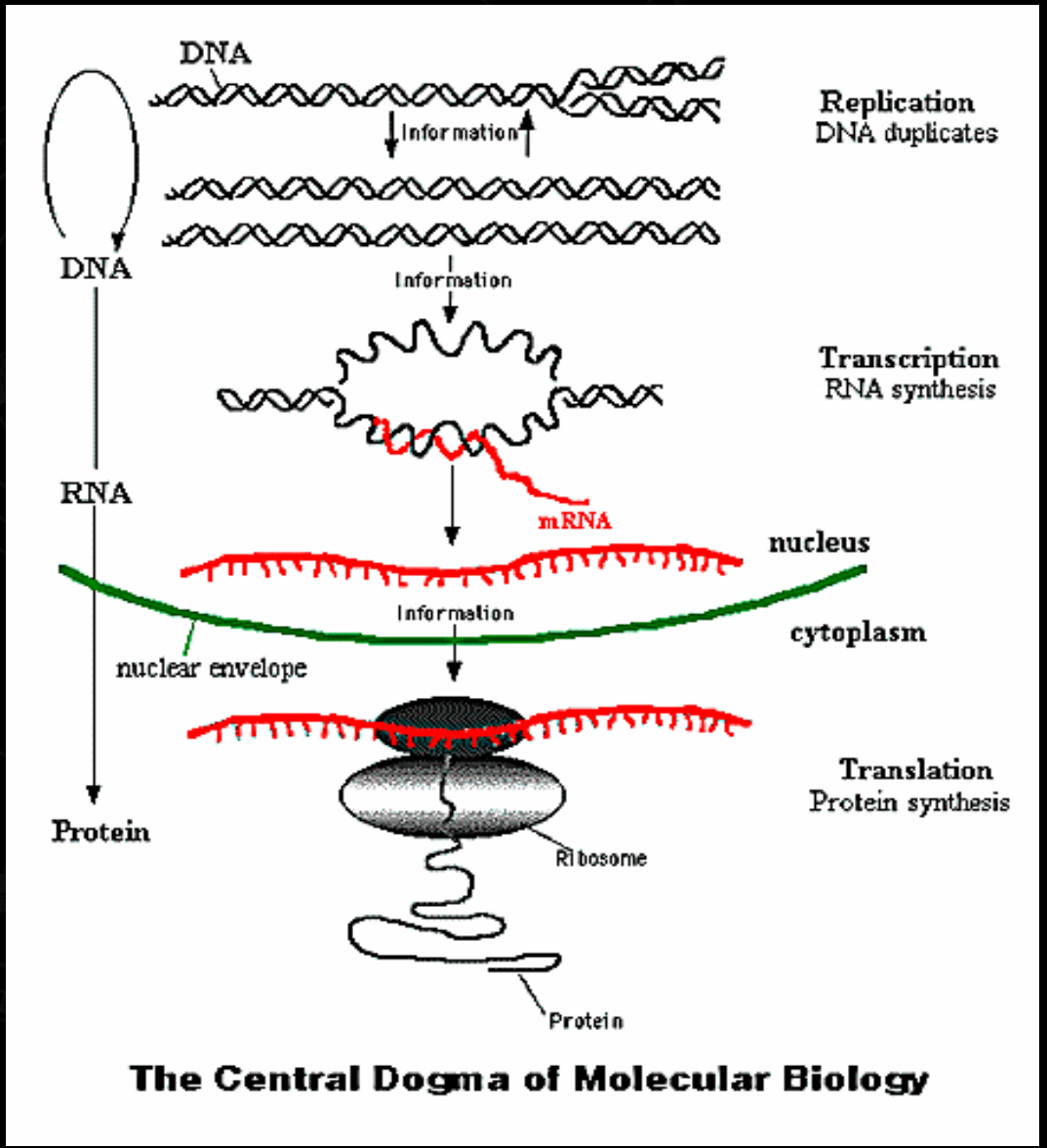
- Molecule encoding "recipe" for a living organism (blueprint of life)
- Double helix with a sequence of base pairs A-T and C-G (where A=adenine, T=thymine, G=guanine, and C=cytosine)
- A,C,G,T are called nucleotides
- Base pair triplets (codons) encode for amino acids and genes which are then expressed to form proteins that underlie cellular structure and function
- Human genome is estimated to be about 3*10^12 base pairs long (20'000-25'000 genes)





Central Dogma: 4 Major Stages

1. **Replication:** DNA replicates its information in a process that involves many enzymes
2. **Transcription:** DNA codes for production of messenger RNA (mRNA)
3. **Processing:** In eukaryotic cells mRNA is processed and migrates from nucleus to cytoplasm
4. **Translation:** mRNA carries coded information to ribosomes which "read" the information and use it for protein synthesis



The Central Dogma of Molecular Biology

Fundamental Aspects of Life-Like Systems

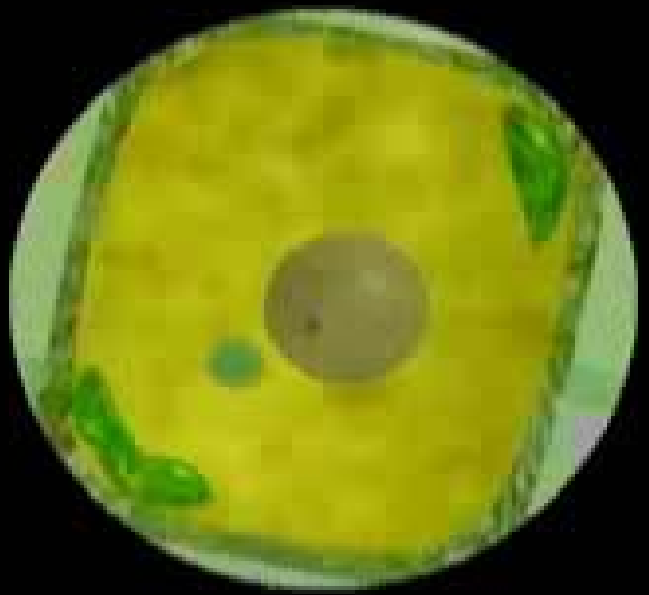
Development: The process by which a system transforms itself as it matures. This includes processes such as metamorphosis (e.g., in insects), cell growth, cell differentiation, morphogenesis, etc.

Cell growth: Cell reproduction (parent cell reproduces to form two daughter cells)

Cell differentiation: The transformation of a generic stem cell into a particular type of cell (e.g., skin, blood, bone, brain, etc.) by the expression of specific genes

Morphogenesis: The emergence of form through growth, e.g., the way various organs take shape

Cell Division in Eukaryotic Cells (Mitosis)



But then ... what about?

Mule? — cannot self-reproduce; cannot evolve

Virus? — cannot self-reproduce; does not have a metabolism

- Tobacco mosaic virus can be decomposed into its proteins, the proteins separated and stored separately, but when combined they will self-organize into the fully functional, "living" virus

Prion? — like a virus; no self-representation but itself (phenotype == genotype)

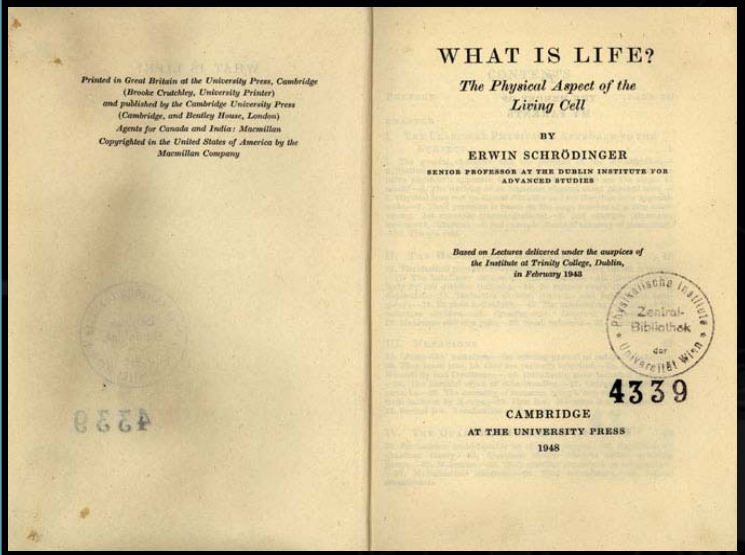
- Blurs the distinction between living and non-living
- Reveals the mechanistic nature of life
  - no nucleic acids, just an oddly shaped protein
  - corrupts production of a normal protein to reproduce

Levels of Organization for Bio-Systems

Life is organized at many different levels and scales

- Molecules (DNA, RNA, proteins, amino acids, messengers, etc.)
- Subcellular structures (membranes, channels, organelles, etc.)
- Cells (neurons, blood cells, skin cells, bone cells, etc.)
- Cell Assemblies (pancreatic islets, central pattern generatrs, etc.)
- Sub-organs and Sub-systems (cortex, spinal cord, arteries, etc.)
- Organs (skin, brain, heart, stomach, liver, etc.)
- Systems (nervous system, digestive system, immune system, etc.)
- Organisms (plants, animals)
- Populations
- Ecosystems
- Biosphere

Smart Things Said By Smart People



Printed in Great Britain at the University Press, Cambridge
(Brooke Crutchley, University Printer)
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WHAT IS LIFE?

The Physical Aspect of the Living Cell

BY

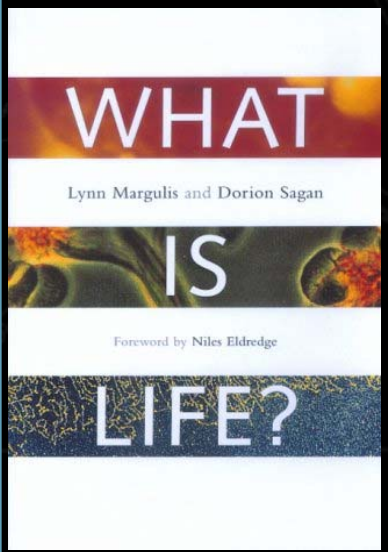
ERWIN SCHRÖDINGER

SENIOR PROFESSOR AT THE DUBLIN INSTITUTE FOR ADVANCED STUDIES

Based on Lectures delivered under the auspices of the Institute at Trinity College, Dublin, in February 1943

CAMBRIDGE
AT THE UNIVERSITY PRESS
1948

"What is the characteristic feature of life? When is a piece of matter said to be alive? When it goes on 'doing something', moving, exchanging material with its environment, and so forth, and that for a much longer period than we would expect of an inanimate piece of matter to 'keep going' under similar circumstances." *(Schrodinger, 1944)*



"Life is the representation, the presencing of past chemistries, a past environment of the early Earth that, because of life, remains the modern Earth. [...] Life is bacterial and those organisms that are not bacteria have evolved from organisms that were." *(Margulis and Sagan, 1995)*

Smart Things Said By Smart People

- "The existence of life must be considered as an elementary fact that can not be explained, but must be taken as a starting point in biology." *(Niels Bohr, 1933)*
- "In connection with the origin of life, I should like to say that it is sometimes easier to study a subject than to define it." *(Linus Pauling, 1938)*
- "Living organisms are CITROENS – Complex Information-Transforming Reproducing Objects that Evolve through Natural Selection." *(Leslie Orgel, 1973)*
- "Life is a dynamic state of matter organized by information." *(Manfred Eigen, 1992)*
- "Life is something edible, lovable, or lethal." *(James Lovelock)*

Smart Things Said By Smart People

"What was life? No one knew. It was undoubtedly aware of itself, so soon as it was life; but it did not know what it was ... it was not matter and it was not spirit, but something between the two, a phenomenon conveyed by matter, like the rainbow on the waterfall, and like the flame." *(Thomas Mann, The Magic Mountain*)

Life – A Dictionary Definition

"The condition that distinguishes animals and plants from inorganic objects and dead organisms, being manifested by growth through metabolism, reproduction, and the power of adaptation to environment through changes originating internally."
(1984 Random House College Dictionary)

How Many Kinds of Life are There?

- “Intelligent” human life
- Animal life
- Plant life
- Fungal life
- Multicellular life
- Unicellular life
- Complex and simple viruses
- Molecular life (replicating, autocatalitic)

What is Life? Characterizations

Life is a pattern in space-time, rather than a material object. For example, most of our cells are replaced many times during our lifetime. It is the pattern and set of relationships that are important, rather than the atoms themselves.

Reproduction, if not in the organism itself, at least in some related organism.

(After Farmer and Belin)

What is Life? Characterizations

Recombining instruction sets. For example, biological organisms store a description of themselves in DNA molecules, which is interpreted and executed in the context of the protein/RNA machinery.

Metabolism which converts matter and energy from the environment into the pattern and activities of the organism.

(After Farmer and Belin)

What is Life? Characterizations

Interaction with the environment. A living organism can respond to or anticipate changes in its environment. Organisms create and control their own local (internal) environments.

Interdependence of parts. The components of living systems depend on one another to preserve the identity of the organism. Thus, we are not one but many acting as one.

(After Farmer and Belin)

What is Life? Characterizations

Stability under perturbations and insensitivity to small changes, allowing the organism to preserve its form and continue to function in a noisy environment, or after being subjected to minor damage.

Ability to evolve. This is not a property of an individual organism, but rather of its lineage. Indeed, the possession of a lineage is an important feature of living systems.

(After Farmer and Belin)

Two Important Concepts

Homeostasis

= “self-regulation”

The property of an open system, especially living organisms, to regulate its internal environment to maintain a stable, constant condition, by means of multiple dynamic equilibrium adjustments, controlled by interrelated regulation mechanisms.

Walter Cannon, Ross Ashby, Grey Walter, …

Two Important Concepts

Autopoiesis

= “self-production”

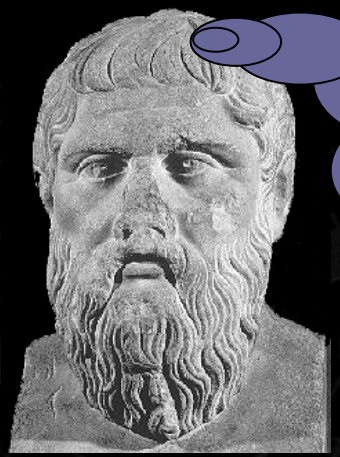
Term originally conceived as an attempt to characterize the nature of living systems. Canonical example of autopoietic system: biological cell. The eukaryotic cell, for example, is made of various biochemical components (e.g. nucleic acids and proteins), and is organized into bounded structures (e.g. cell nucleus, organelles, cell membrane and cytoskeleton). These structures, based on an external flow of molecules and energy, *produce* the components which, in turn, continue to maintain the organized bounded structure that gives rise to these components.

Note: An autopoietic system is to be contrasted with an allopoietic system, such as a car factory, which uses raw materials (components) to generate a car (an organized structure) which is something *other* than itself (a factory).

Humberto Maturana, Francisco Varela, …

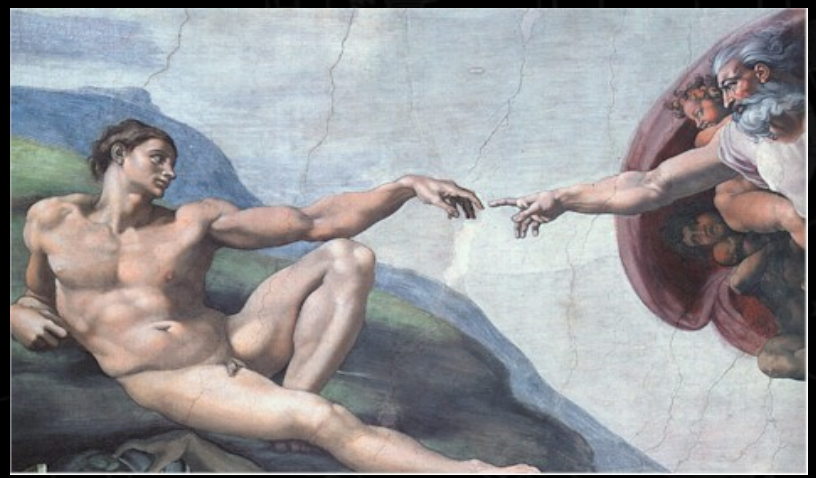
Origins of Life – Where Did It Come From?

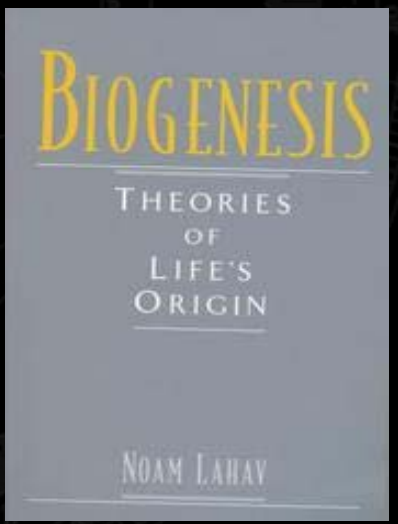
Idealism – Greek philosphers



Life is endowed with a mysterious and divine life-force

Creationism





Cosmica panspermia: "intelligent ETs may have seeded Earth with a start-up kit for life." *(F. Crick)*

Chemical evolution (C. Darwin)

Spontaneous generation (S. Kaufmann)

Approaches to the Origins of Life

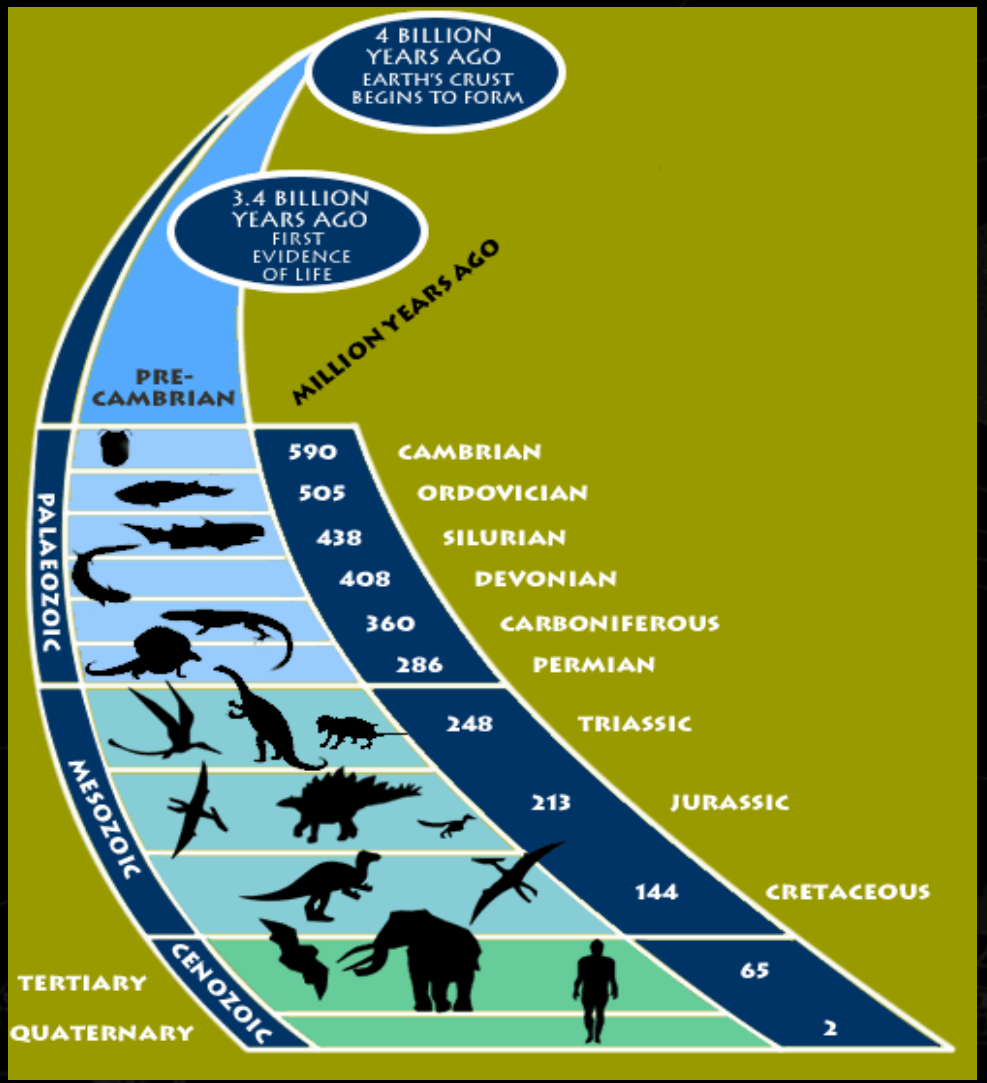
Top-down approach (mostly analysis)

- Looking for clues about early life, e.g. study fossils
- Study primitive/ancient life, e.g. bacteria and other prokaryotic organisms
- Look out for extra-terristrial life

Bottom-up approach (mostly synthesis)

- Create a (artificial) living system
- Study transition from “nonlife” to life

Clues about Early Life



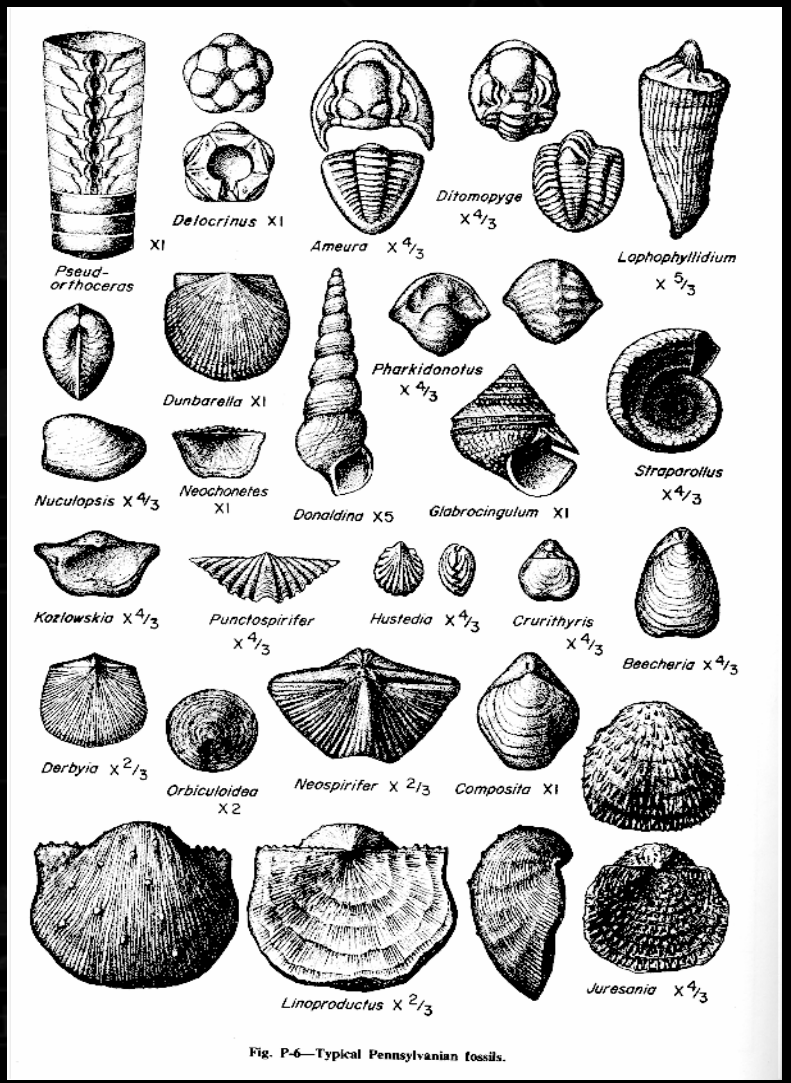
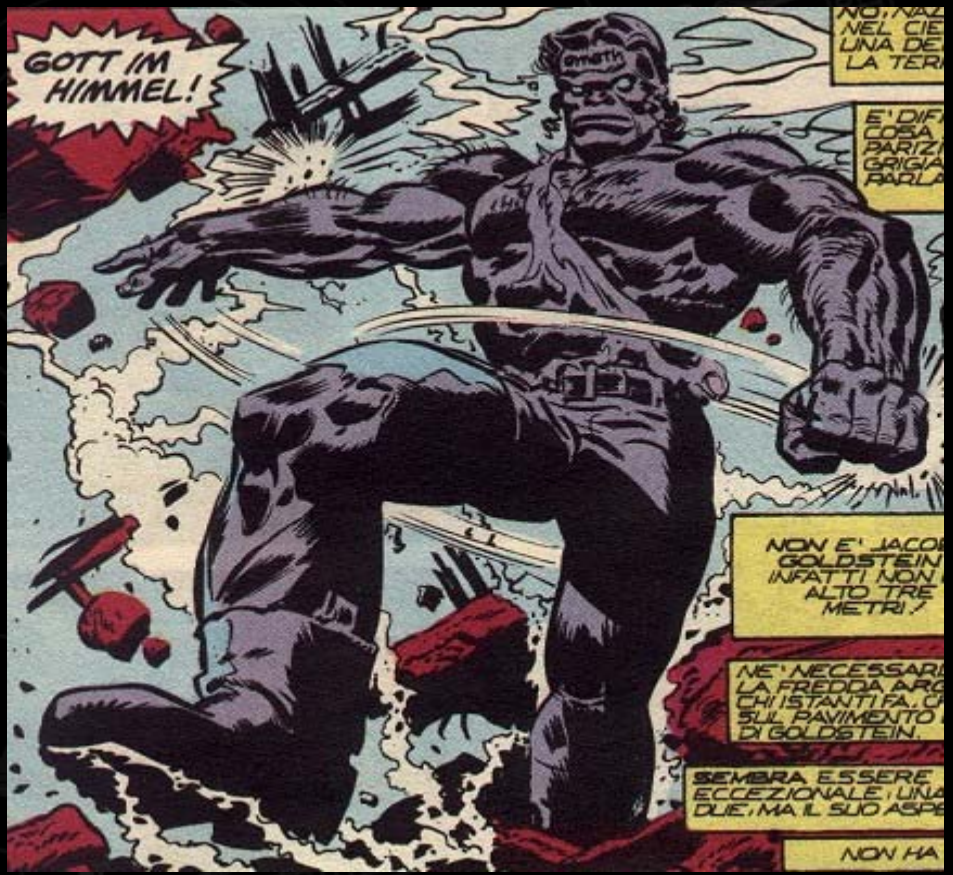


Fig. P-6—Typical Pennsylvanian fossils.

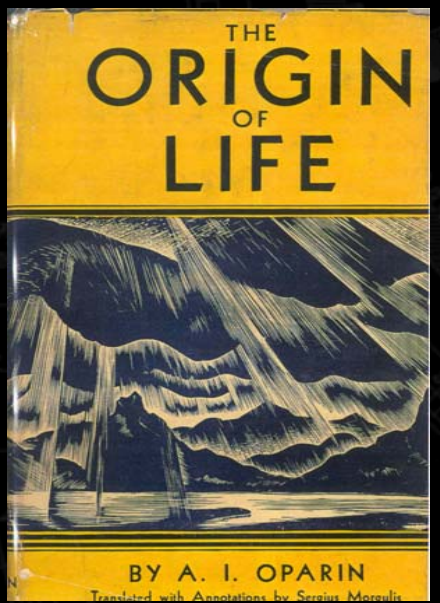
Creating Life – Bottom-Up Approach



Prebiotic Synthesis

Prebiotic chemistry is concerned with molecules that are important for the origin of life and could have been formed on the primitive Earth

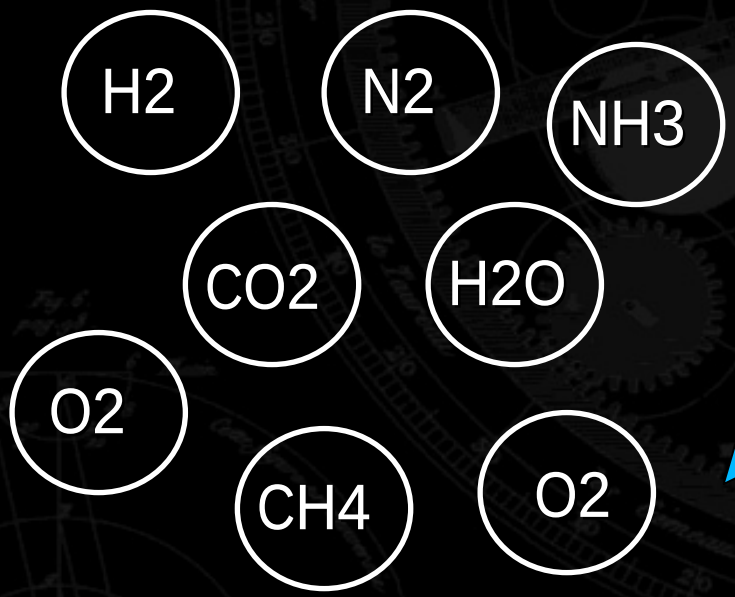
What kind of chemical environment is needed to allow life to begin?



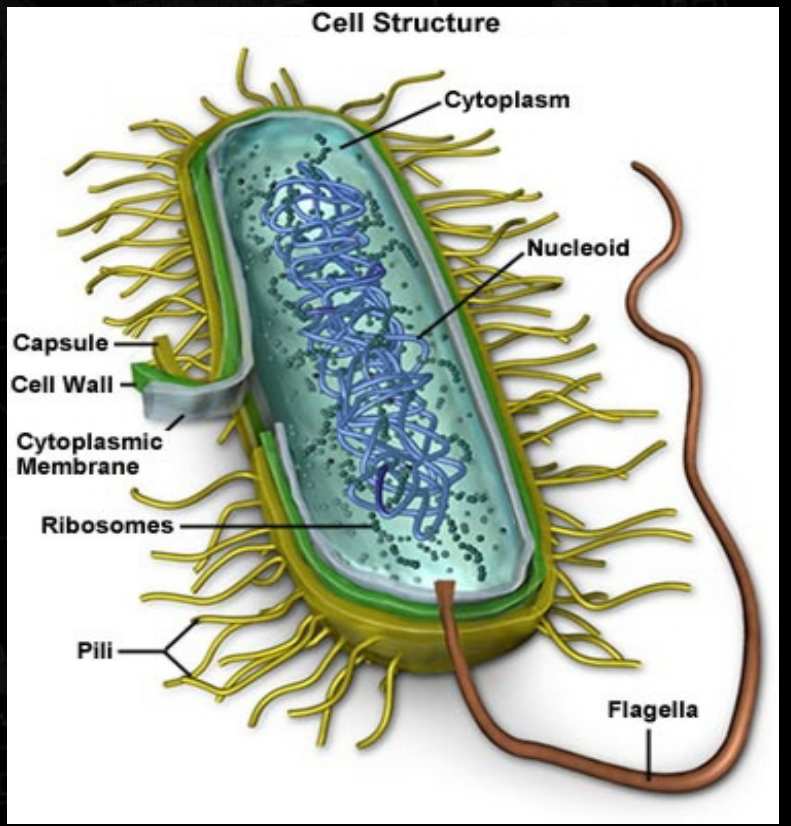
Oparin-Haldane model (“prebiotic soup”)

Creating Life – Bottom-Up Approach

Is it possible to create life in a test tube from simple chemical building blocks ?



MOJO



Creating Life – Miller-Urey (1953)

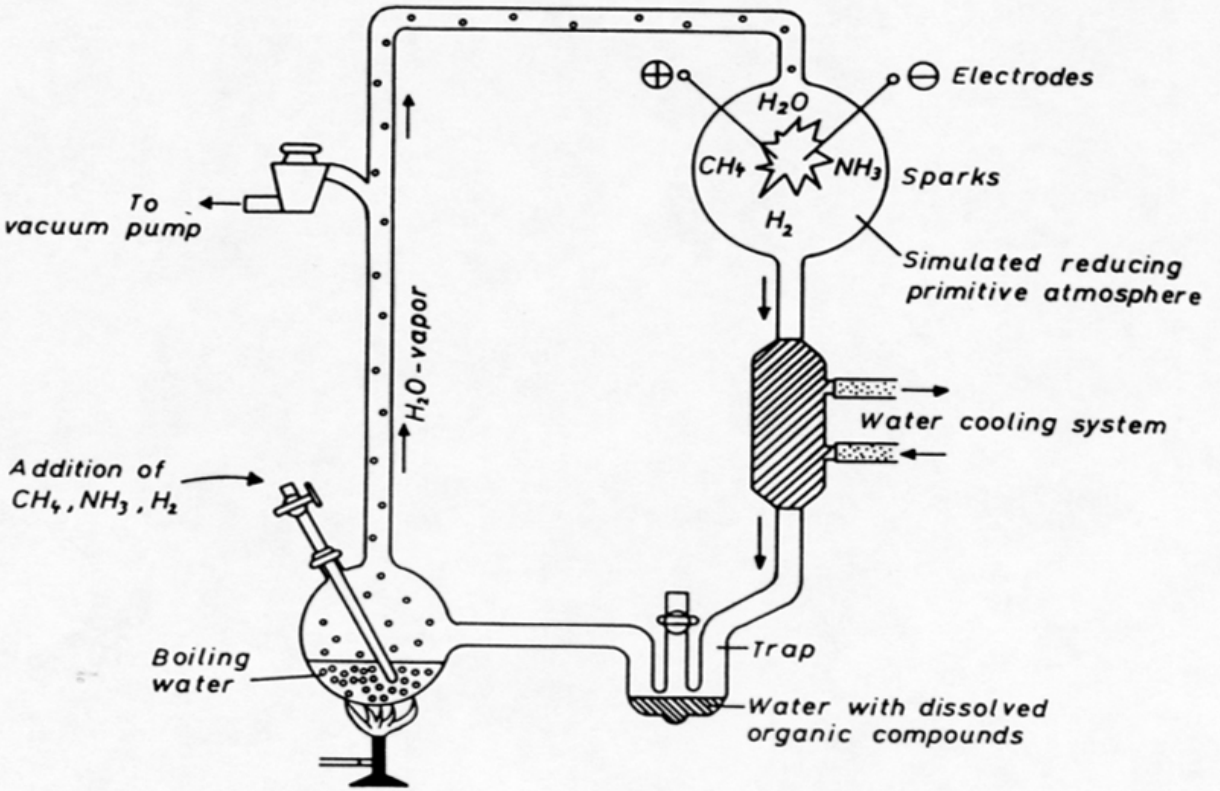


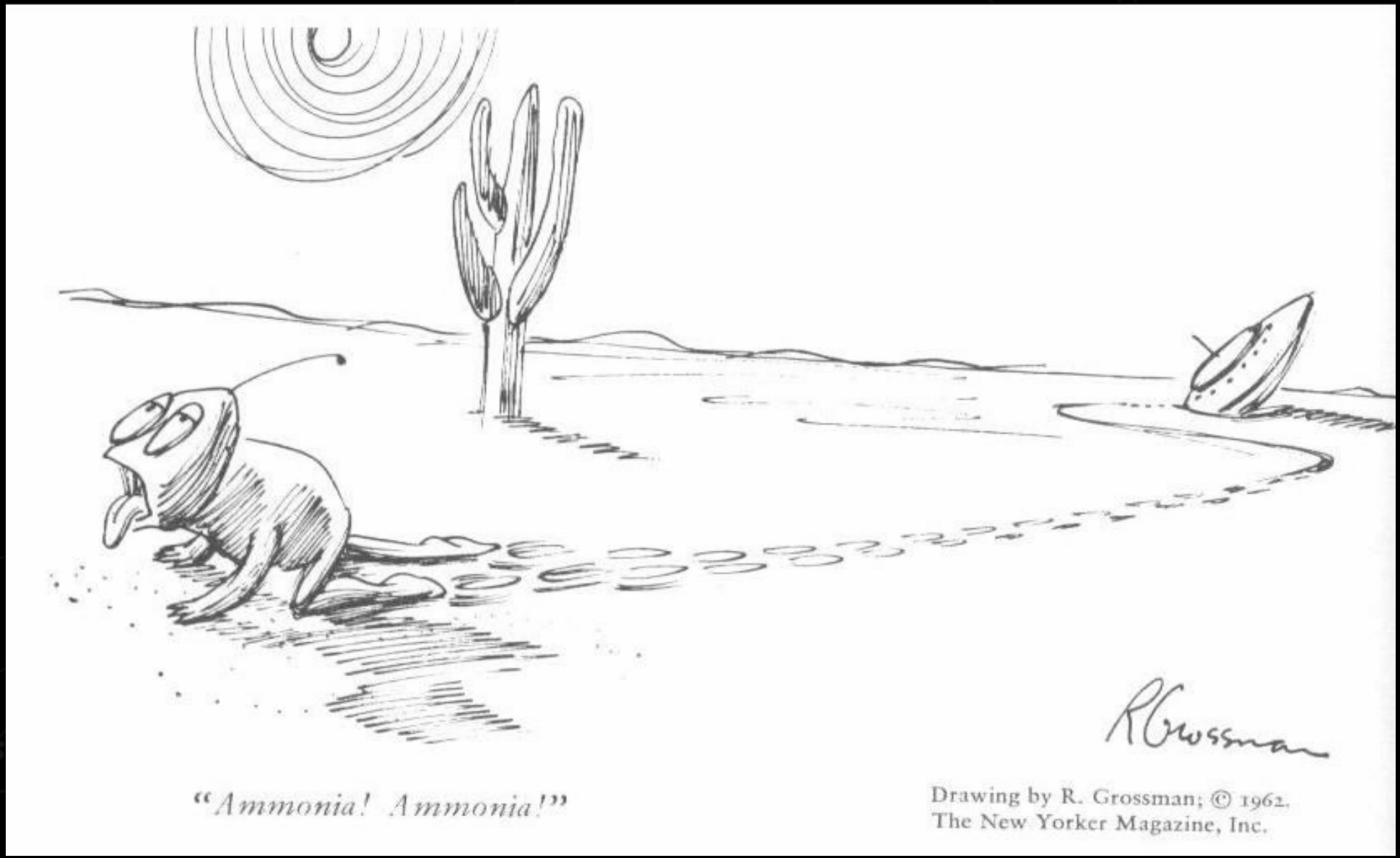
FIGURE 9.13 The Miller experiment conducted at the University of Chicago in 1953 to study the formation of organic compounds under simulated primitive-atmosphere conditions. Miller placed water in the flask and an atmosphere of H_2 (10 cm pressure), CH_4 (20 cm pressure), and NH_3 (20 cm pressure) above it. The electrical discharge simulated lightning. After one week of operation, the water in the flask and the trap had turned orange–red. Chemical analysis revealed the presence of at least four amino acids in such concentrations that Miller suggested using his method for the industrial production of amino acids. Subsequent, similar experiments have succeeded in producing all 20 protein-forming amino acids. (Schwemmler W. 1984, *Reconstruction of Cell Evolution—a Periodic System*, p. 20, Fig. 1, with permission of CRC Press, Boca Raton, Florida.)

"A production of amino acids under possible primitive earth conditions"
(Science, 1953)

Creating Life – Juan Oro (1961)

- Found that amino acids can be made from hydrogen cyanide (HCN) and ammonia (NH_3) in an aqueous solution (as Miller and Urey)
- In addition: **Adenine** (one of the four bases and a component of ATP) can also be produced in a large amount + other three bases can also be obtained through simulated prebiotic chemistry with a reducing atmosphere

The Origin of Life

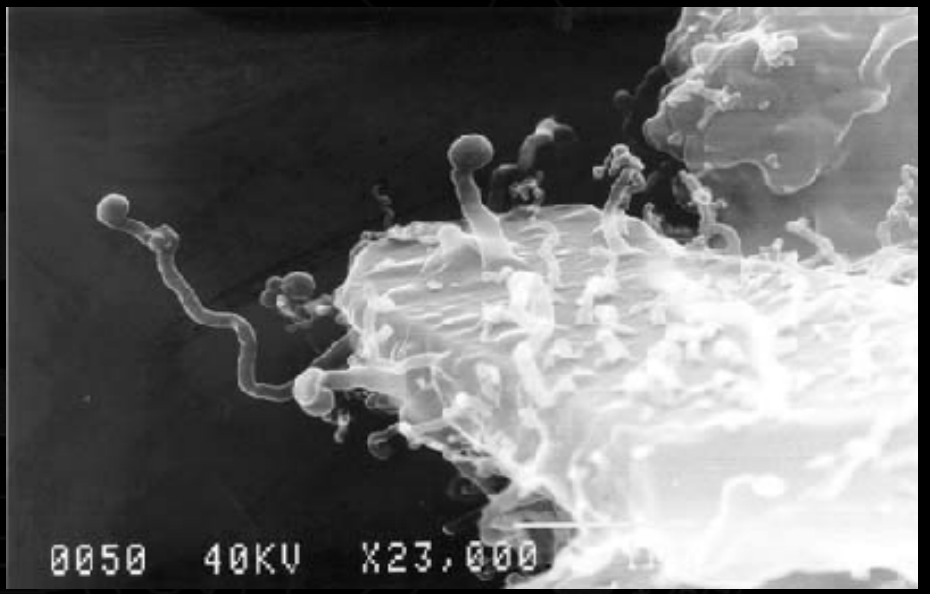


"Ammonia! Ammonia!"

Drawing by R. Grossman; © 1962.
The New Yorker Magazine, Inc.

What about Starting with “Minimal Life” ?

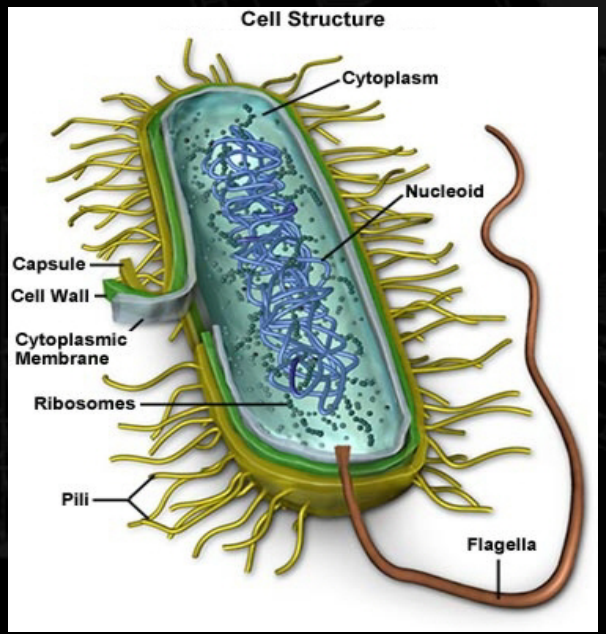
- Nanobes are thought by some to be the smallest known organism, about ten times smaller than the smallest known bacteria (the smallest are 20 nm long)
- First described in 1996 by P. Uwins. Some researchers believe them to be merely crystal growths, but a purported find of DNA in nanobe samples may prove otherwise
- Similar to the life-like structures found in ALH84001, the famous Mars meteorite from the Antarctic

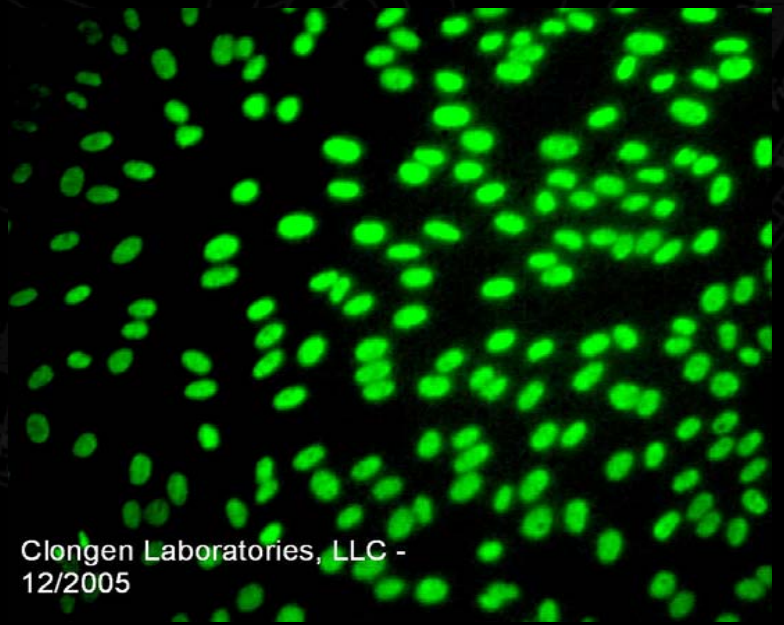


“Minimal Life” ?

Minimal free-living autopoietic entity (as of today):

- Tiny, spherical, oxygen-shunning bacterium which requires energy and food to keep going its 500 genes and proteins
- Or maybe *mycoplasm genitalium* (bacterium <1 micrometer in diameter lacking a cell wall)?





Minimal Genome Project

Study headed by Craig Venter that attempted to find the smallest working set of genes necessary for an organism to live and reproduce successfully. The chosen organism for study was the bacterium *Mycoplasma genitalium*, an obligate intracellular parasite, because of its naturally small genome. The experiment consisted of random gene knockouts, with each knockout mutant being tested for signs of life.

Study suggested that only 265-330 of the genes of the bacterium are essential for growth (under the conditions examined), thus providing an estimate of the minimal genome require for life.

From Origins of Life to Life on Earth

Given a “minimally alive” unit (call it the ‘seed’), what happens/happened?

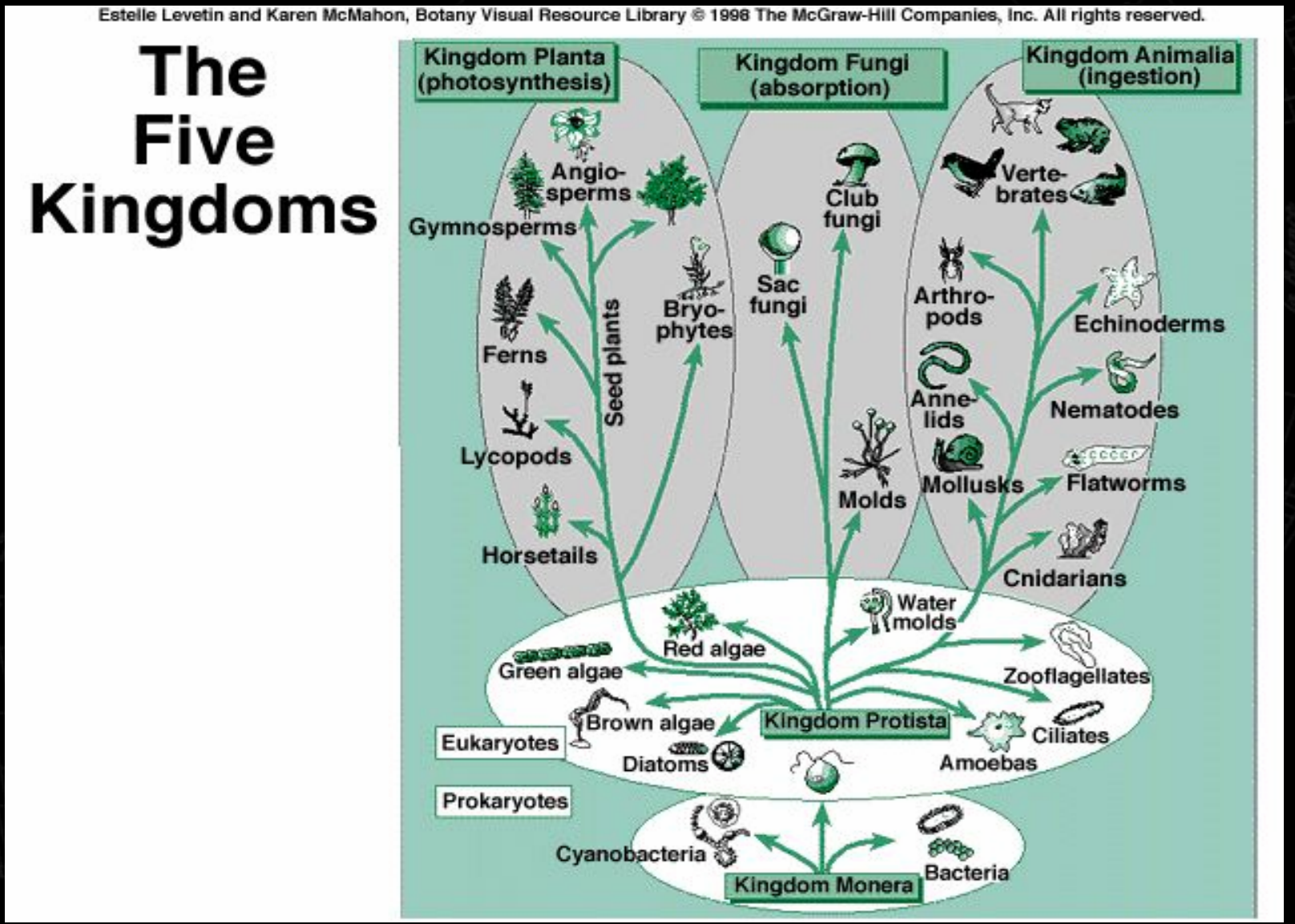
Tree of Life

$4*10^9$ yrs. ago:
evolution of bacterial cell (prokaryote)

$2*10^9$ yrs. ago:
evolution of nucleated cell (eukoryote)

http://tolweb.org/tree/

Classification: 5 Kingdoms of Life

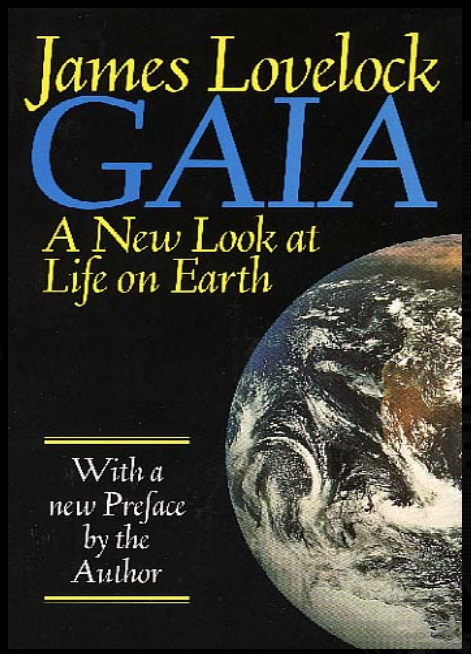


From Life on Earth …

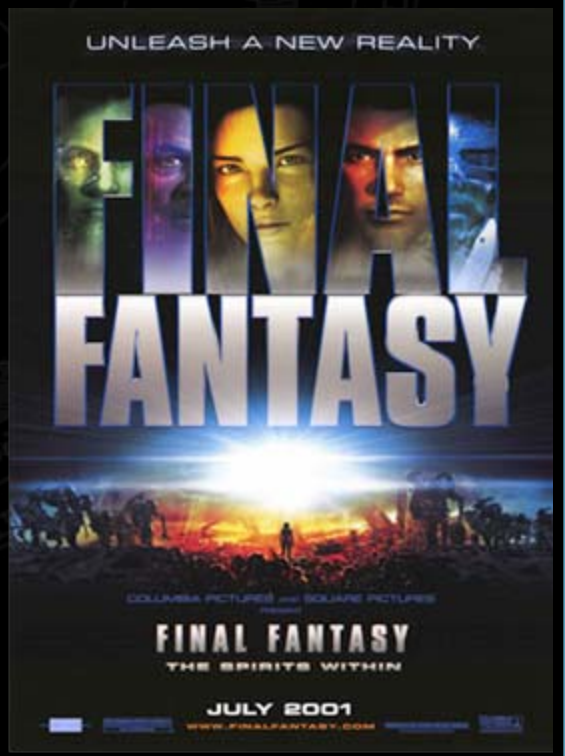
"The Biosphere is the place on earth's surface where life dwells" *(Eduard Suess, 1875)*

"Living matter as a whole […] is a unique system, which accumulates chemical free energy in the biosphere by the transformation of solar radiation." *(Vernadsky, 1922)*

To Earth as Life …



"Gaia is a complex entity involving the Earth's biosphere, atmosphere, oceans, and soil; the totality constituting a feedback or cybernetic system which seeks an optimal physical and chemical environment for life on this planet." *(James Lovelock)*

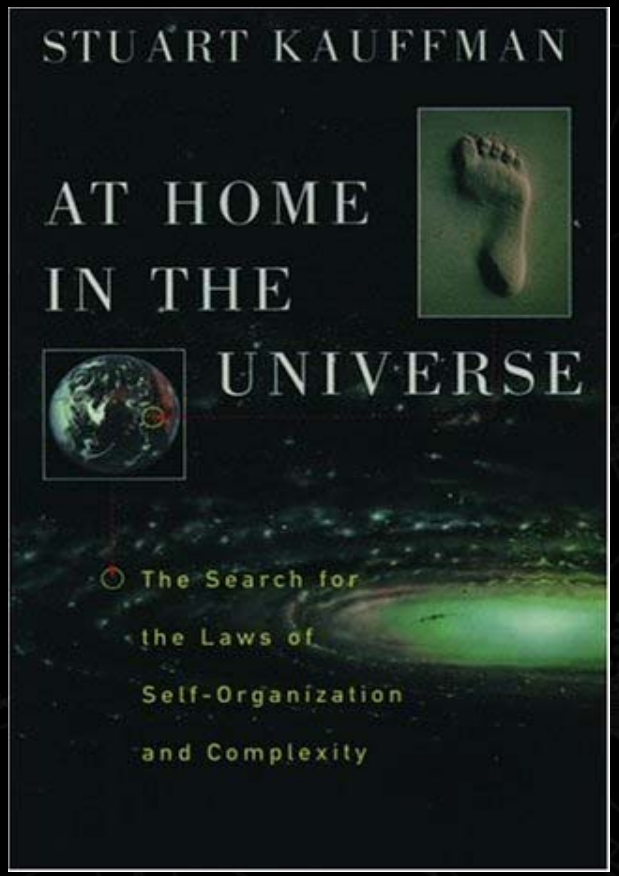


"Through their experiences on Earth, each spirit matures and grows. When the physical body dies, the mature spirit, enriched by its life on Earth, returns to Gaia, bringing with it the experiences, enabling Gaia to live and grow" *(quote from the movie)*

Onto Life on Mars ...

- Under the scanning electron microscope structures were revealed that may be the remains—in the form of fossils—of bacteria-like lifeforms (nanobes!).
- The structures found on ALH 84001 (mars meteorite) are 20-100 nanometres in diameter, similar in size to the theoretical nanobacteria, but smaller than any known cellular life at the time of their discovery.
- http://www2.jpl.nasa.gov/snc/alh.html

To “Intelligent” Life in the Universe …



The **Drake equation**:

N = N* fp ne fl fi fc fL

N = represents the number of stars in the Milky Way Galaxy

fp = fraction of stars that have planets around them

ne = number of planets per star that are capable of sustaining life

fl = fraction of planets in **ne** where life evolves

fi = fraction of **fl** where intelligent life evolves

Fc = fraction of **fi** that communicate

fL = fraction of the planet's life during which the communicating civilizations live

http://www.activemind.com/Mysterious/Topics/SETI/drake_equation.html

To “Intelligent” Life in the Universe …

- We need an answer, if our biological sciences are going to help us understand alien or artificial life
- Conversely, an opportunity to study and understand artificial life will help us answer this question and broaden and generalize our biological sciences.
- “If we ever make contact with life from other planets, will our science of biology help us understand it?” *(Farmer and Belin)*

Life-as-we-know-it as a Special Case of "Life"

Biology is the study of carbon-based life forms and the entities governing their actions

- DNA
- RNA
- Proteins
- Chemicals/metabolites

However, in theory, nothing says that life cannot have another chemistry or governing factors

Also, we can be reductionists and study components and aspects of life, but what about the **interaction** of its component parts and rules governing its evolution?

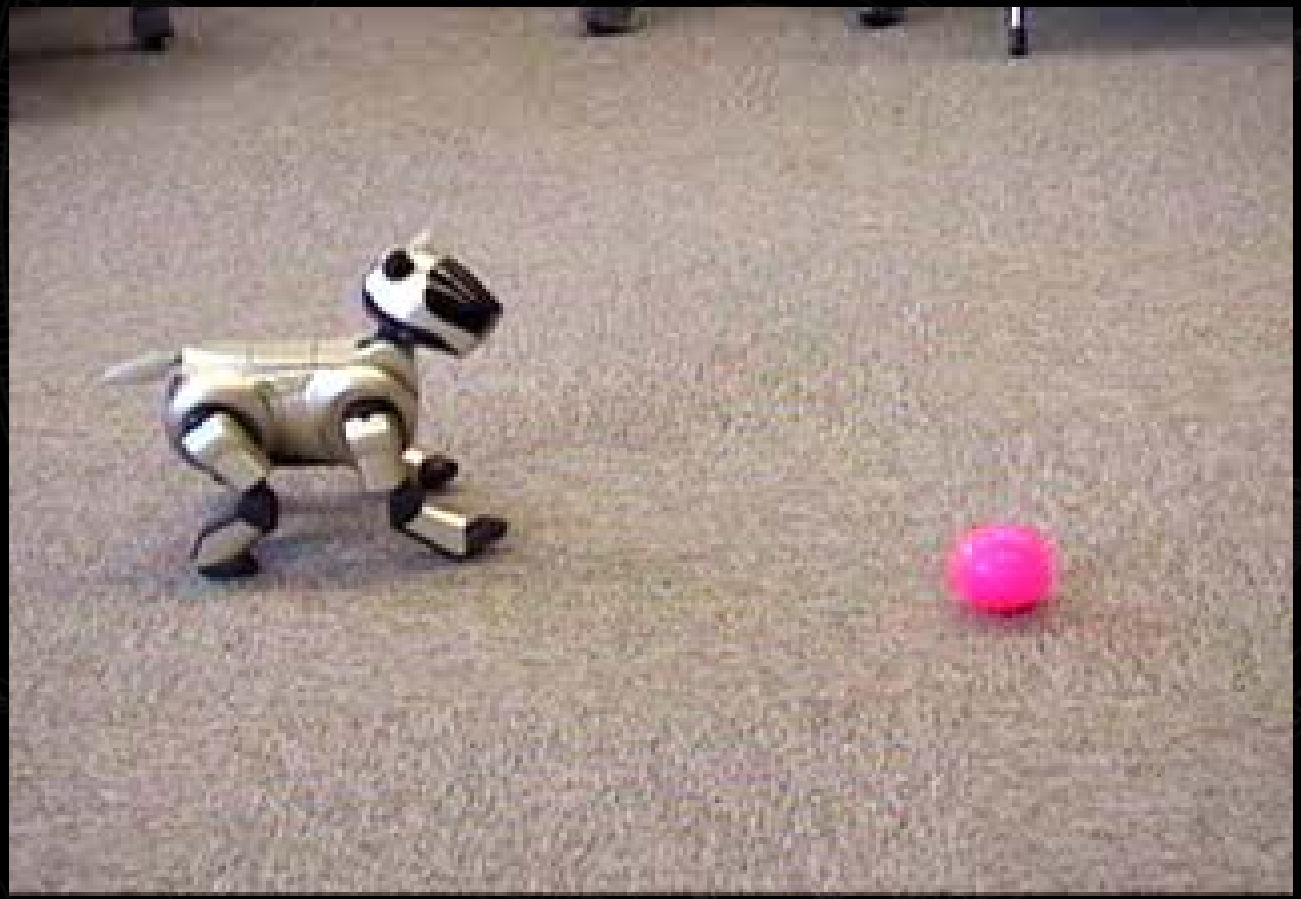
Life-as-it-could-be

"The *big* claim is that a properly organized set of artificial primitives carrying out the same functional roles as the bio-molecules in natural living systems will support a process that will be 'alive' in the same way that natural organisms are alive. Artificial Life will therefore be *genuine* life — it will simply be made of different stuff than the life that has evolved here on Earth." *(Chris Langton, 1988)*

Life-as-it-could-be – Example

http://www.frams.alife.pl/

Life-as-it-could-be – Example



http://www.sonydigital-link.com/aibo/

Life-as-it-could-be – Example

http://cswww.essex.ac.uk/staff/owen/machine/cronos.html

Life-as-it-could-be – Example

http://www.ai.mit.edu/projects/sociable/videos.html

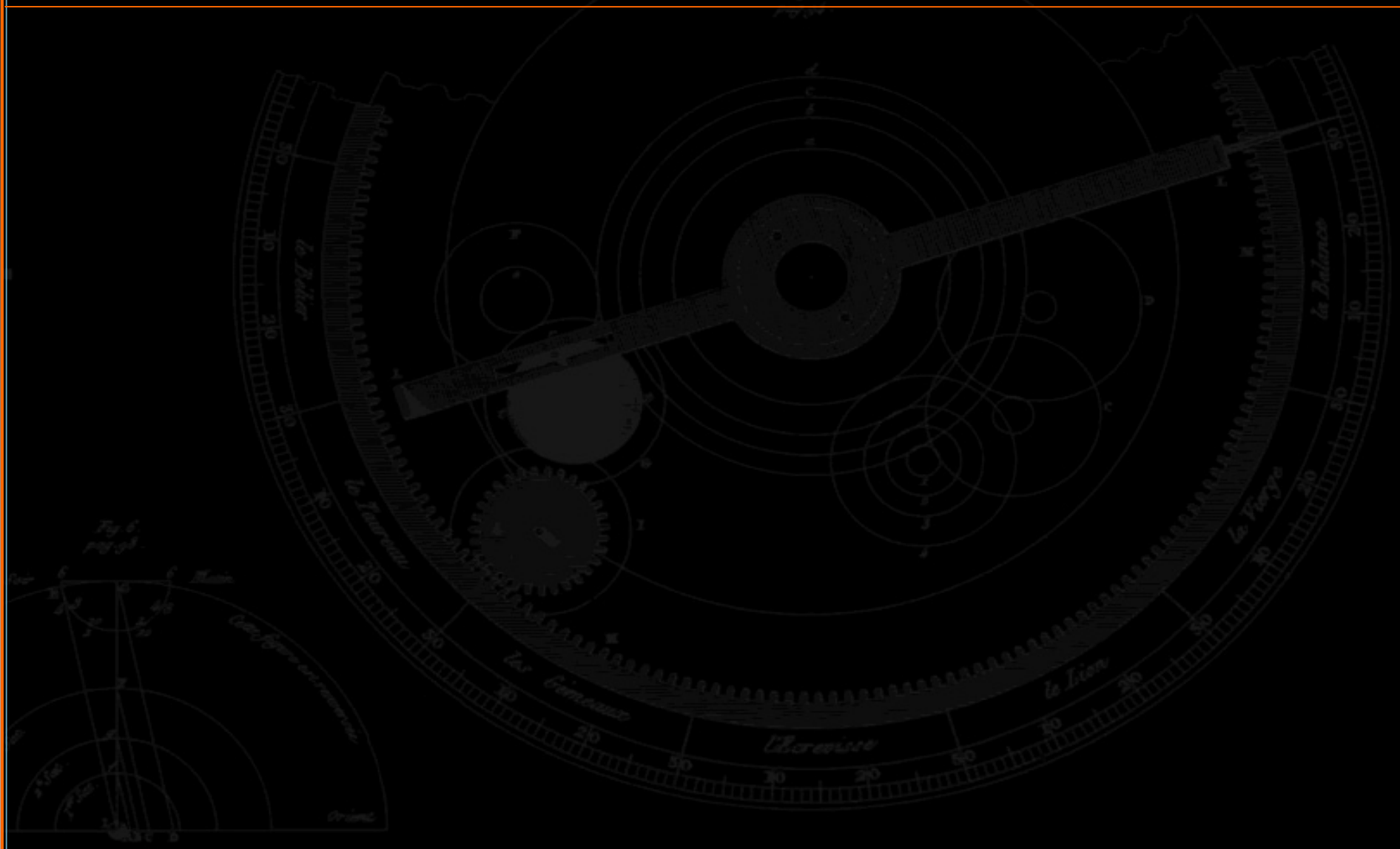
Life-as-it-could-be – Example

Geminoid is a remote-controlled doppelganger droid designed by and modeled after Hiroshi Ishiguro.

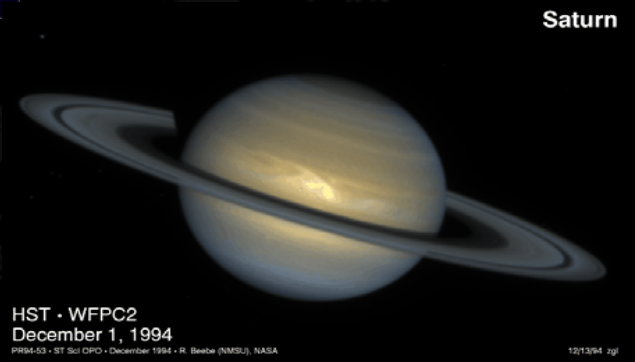
Life-as-it-could-be – Example

Chinese Sexy Singing Robot …

What Makes “Objects” Alive?



Aren't All These Systems "Alive"?



Why are these?

more like this

than like this

????

Potential Answers ...

- Multiple scales of organization
- Lots of similar elements/agents at each scale
- No one has the big picture
- No one is in total control
- There is no grand plan
- Every agent acts autonomously and locally
- Specific interactions are mostly local or agent-agent
- Global organization emerges without explicit design

Complex Adaptive Systems

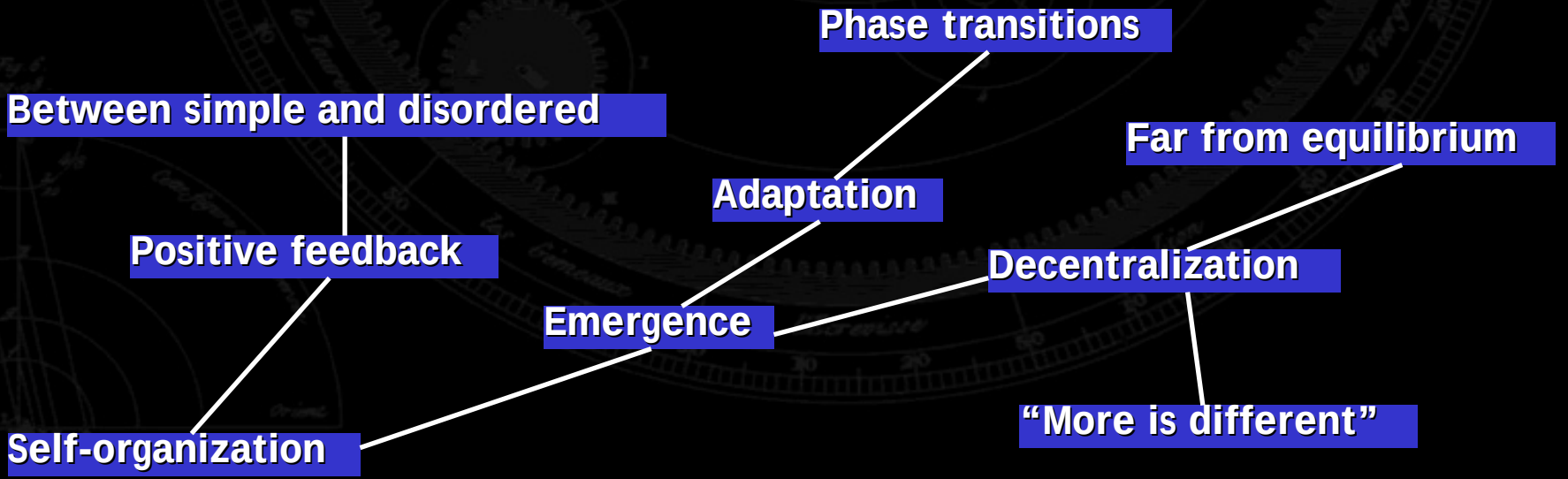
Life as a Complex Adaptive System

- Living organisms
- Nervous systems (brains)
- Immune systems
- Ecosystems
- Insect colonies
- Human societies
- Cities
- Economies
- Markets
- The world-wide web

Life as a Complex Adaptive System

Key concepts ("buzzwords") expressing different facets of CAS:

- Some have different definitions across disciplines, i.e. no global agreement
- Terms overlapping but not equivalent; yet, often grouped or interchanged



Artificial Life – Definition

"Artificial Life is the study of man-made systems that exhibit behaviors characteristic of natural living system. It complements the traditional biological sciences concerned with the analysis of living organisms by attempting to synthesize life-like behavior within computers and other artificial media. By extending the empirical foundation upon which biology is based beyond the carbon-chain life that has evolved on Earth, Artificial Life can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could-be." *(Langton, 1989)*

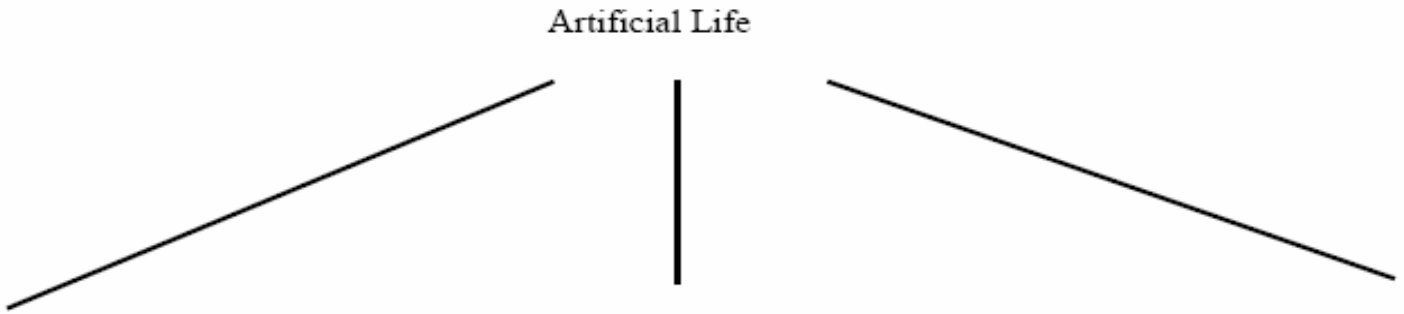
Natural and Artificial Life

"Natural organisms are, as a rule, much more complicated and subtle, and therefore much less well understood in detail, than are artificial automata. Nevertheless, some regularities which we observe in the organization of the former may be quite instructive in our thinking and planning of the latter." *(von Neumann, 1948)*

Artificial Life – In Other Words …

Artificial Life is about the synthetic study of complex adaptive (life-like) systems (natural and artificial ones). The goal is not only to provide biological models but also to investigate general principles of life.

Goals of Artificial Life



Biological issues
- evolution
- pattern formation
- origins of life
- synthesis of RNA/DNA

Principles of intelligent behavior
- emergence and self-organization
- distributed systems
- group behavior
- autonomous robots

Practical applications
- computer-animation
- computer games
- optimization problems
- design

Three Additional Pros ...

1) "The act of construction is instructive about the nature of function." It is a fundamental educational tenet that construction of a thing is one of the best ways to learn about it. (Seymour Papert)
2) Playing with artificial systems provides a "broader palette", making it possible to "separate the universal from the parochial aspects of life."
3) Constructed life forms, particularly those in the computer, are much easier to dissect and study.

Some Methodological Issues

Traditional biology (Science, in general) is analytic and top-down: starts from the top (e.g. organism level) and seeks for explanations in terms of lower level entities

Artificial life is synthetic and bottom up: starts at the bottom (e.g. molecular level) and works its way by synthesizing complex systems from many simple interacting entities.

Some Methodological Issues

- Robots and computer simulation are employed ‘cognitive’ tools
- Using the analytic approach we always end up with a description
- Using the synthetic approach we not only have the description but also a mechanism that underlies the observed behavior

Frame-of-Reference Problem (Key)

Perspective issue:

We have to distinguish between observer perspective and agent perspective. In particular, descriptions of behavior from the observer perspective must not be taken as the internal mechanism underlying the behavior of the agent.

Behavior-vs-mechanism issue:

The observed behavior of an agent is always the result of a system-environment interaction. It cannot be explained only on the basis of internal mechanisms.

Complexity issue:

Seemingly complex behavior does not necessarily require complex internal mechanisms. Seemingly simple behavior is not necessarily the result of simple internal mechanism.

What is Alife? Spec Sheet

Artificial life studies life-as-it-is and as-it-might-be

Artificial Life is:

- Artifactual (man-made), but *not* unreal
- Bottom-up, not top-down
- Synthetic, not analytical
  - Top-down analysis informs and tests Alife research. But bottom-up synthesis plays a larger role than in more traditional sciences (synthetic methodology)
- Leverages *emergence*

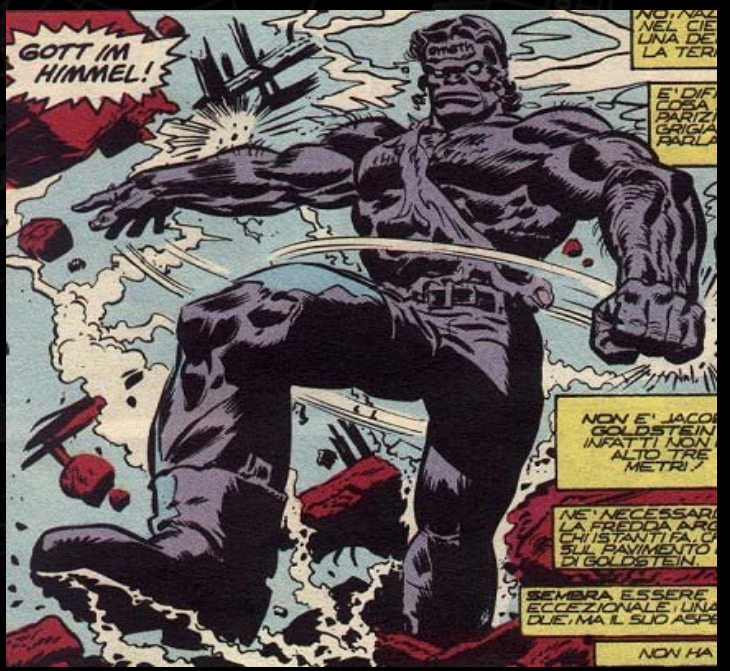
Goals:

1) **understand complex adaptive (living) systems** – e.g., brains, organisms, insect colonies, ecosystems, economies, etc.
2) **use principles derived from this study to design new, successful complex adaptive systems** – e.g., self-configuring robots, smart structures, swarms of unmanned vehicles, self-organized networks, etc.

Brief (and Biased) History of Artificial Life

1495: Leonardo da Vinci designed and possibly built the first humanoid robot in Western civilization

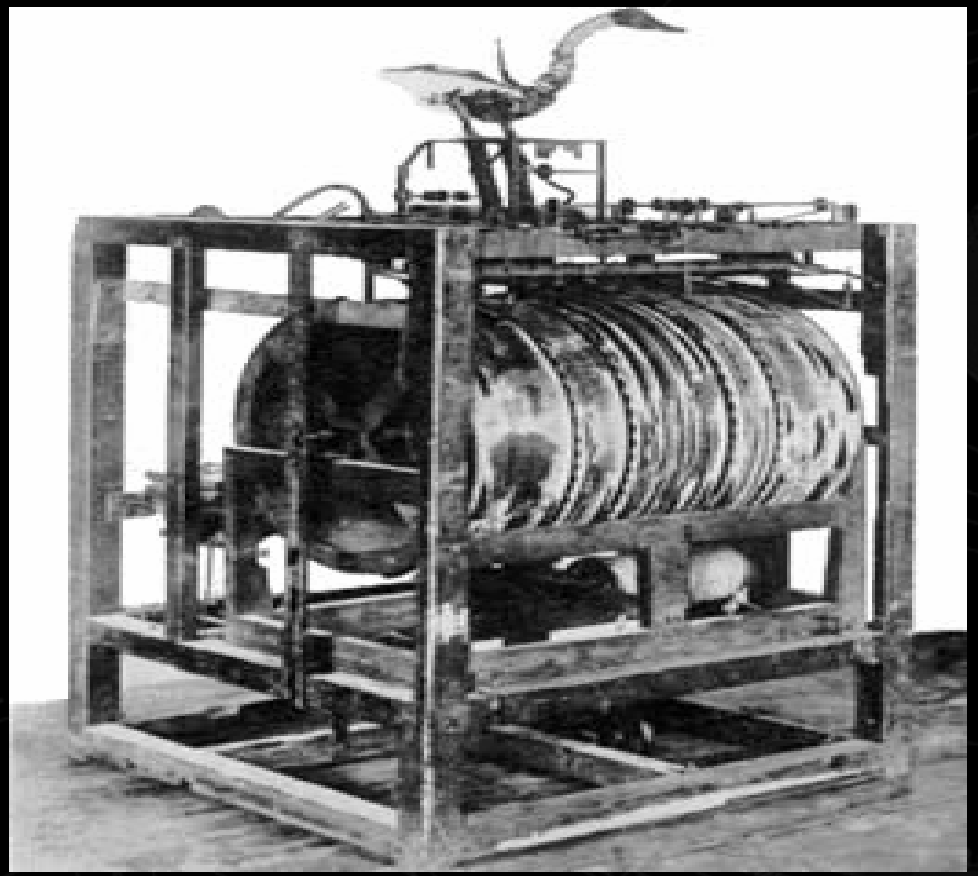
1580: Rabbi Loew of Prague is said to have invented the Golem, a clay man brought to life from the mud of the Moldau



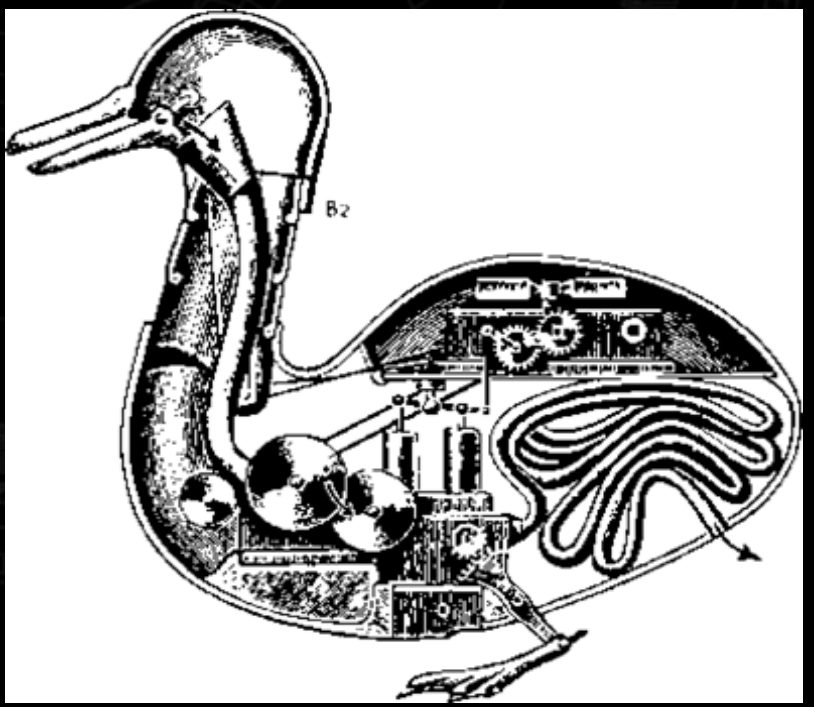
Brief (and Biased) History of Artificial Life

16th century: Karakuri-ningyo (Japanese automata)

Brief (and Biased) History of Artificial Life



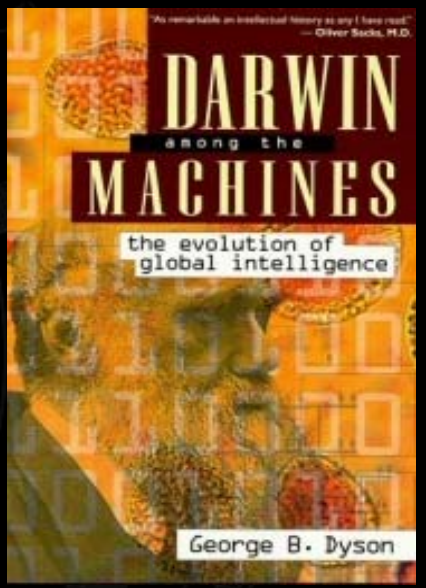
Vaucason's Duck (1739) could flap its wings (with over 400 moving parts in each wing), eat, and (ostensibly) digest and defecate



Brief (and Biased) History of Artificial Life

Samuel Butler (1863) "Darwin Among the Machines"

The first to suggest the possibility that machines could someday be considered "alive":



"I first asked myself whether life might not, after all, resolve itself into the complexity of arrangement of an inconceivably intricate mechanism. If, then, men were not really alive after all, but were only machines of so complicated a make that it was less trouble to us to cut the difficulty and say that that kind of mechanism was 'being alive,' why should not machines ultimately become as complicated as we are, or at any rate complicated enough to be called living, and to be indeed as living as it was in the nature of anything at all to be?"

Brief (and Biased) History of Artificial Life

Fritz Lang's movie "Metropolis" is released. Maria the female robot in the film is the first robot to be projected on the silver screen. The android is built in the form of its creator's wife. This robot is commonly known as the precursor to Star War's C-3PO.

Brief (and Biased) History of Artificial Life

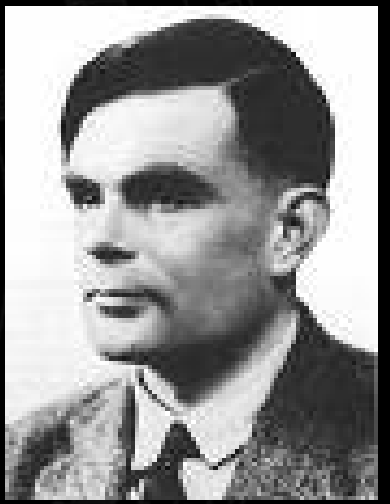
Alan Turing

"Intelligent machinery" (1948, 1969)

- "Machine with an element of randomness and an analogue of the pleasure principle"
- "genetic or evolutionary search"

"Computing machinery and intelligence" (1950)

- "We may hope that machines will eventually compete with men in all purely intellectual fields."
- Introduces the Turing Test" (imitation game)



John von Neumann

"Theory and Organisation of Complicated Automata" (1949)

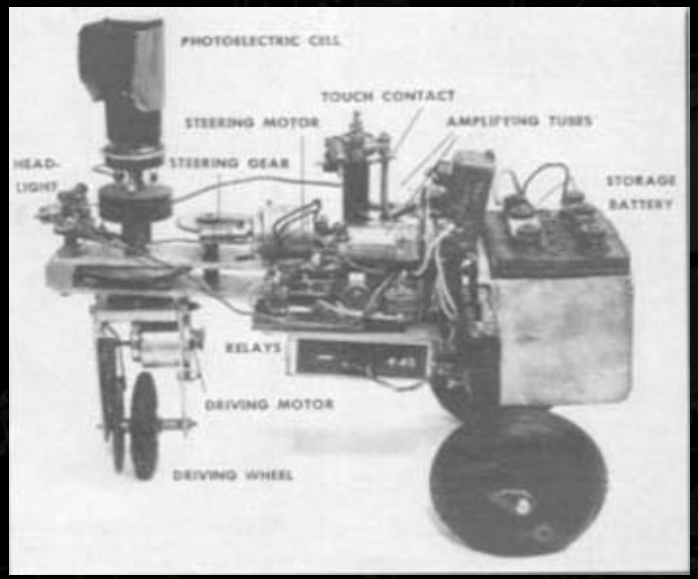
"The Computer and the Brain" (1958)

Brief (and Biased) History of Artificial Life

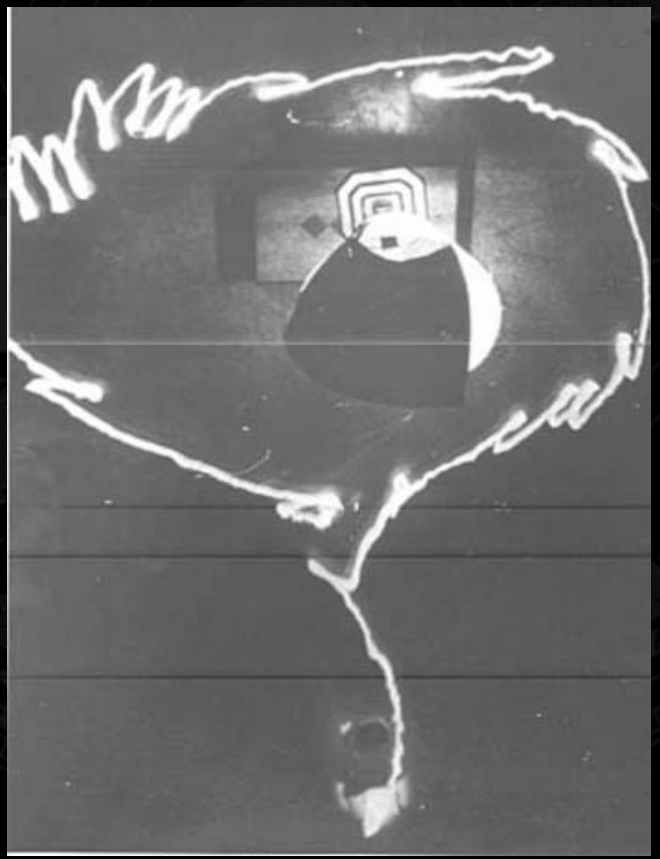
Grey Walter:

"An imitation of life" (1950)

"A machine that learns" (1951)

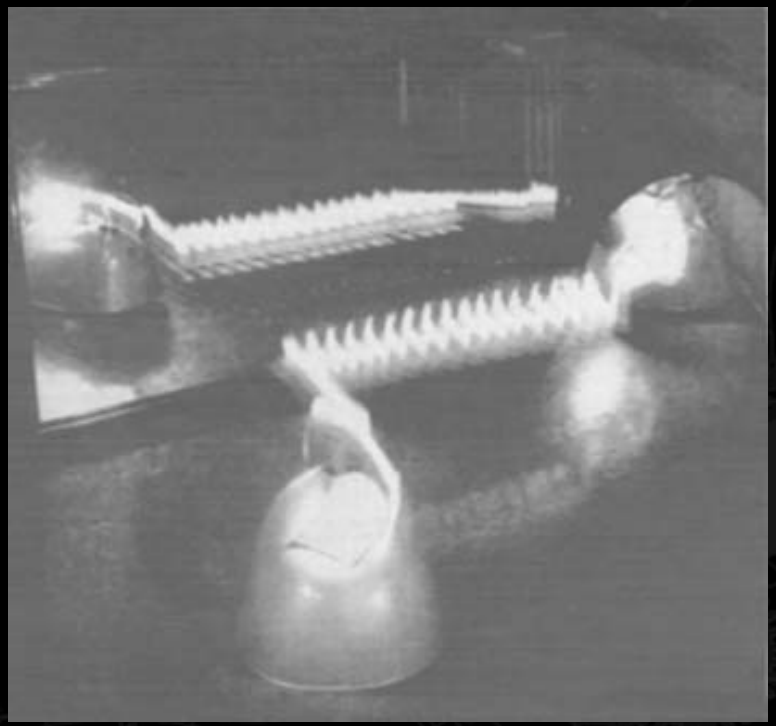


This annotated photograph from 1950 shows Elsie with her shell off and all the parts labeled.



Photograph is first of 9 taken at a single session in Grey Walter's house in 1950. Candles were fixed to the turtles' shells, and long exposures were used. The light streaks show the paths of the turtles. This photograph shows Elsie approaching a light, and then circling around it at a distance.

Brief (and Biased) History of Artificial Life



Elsie performs the famous mirror dance.

Elsie enters the hutch. Note the battery charger at the back of the hutch; Grey Walter fixed the charger terminals to contacts on the hutch floor, enabling the turtles to recharge automatically when they entered the hutch.

http://extremenxt.com/walter.htm

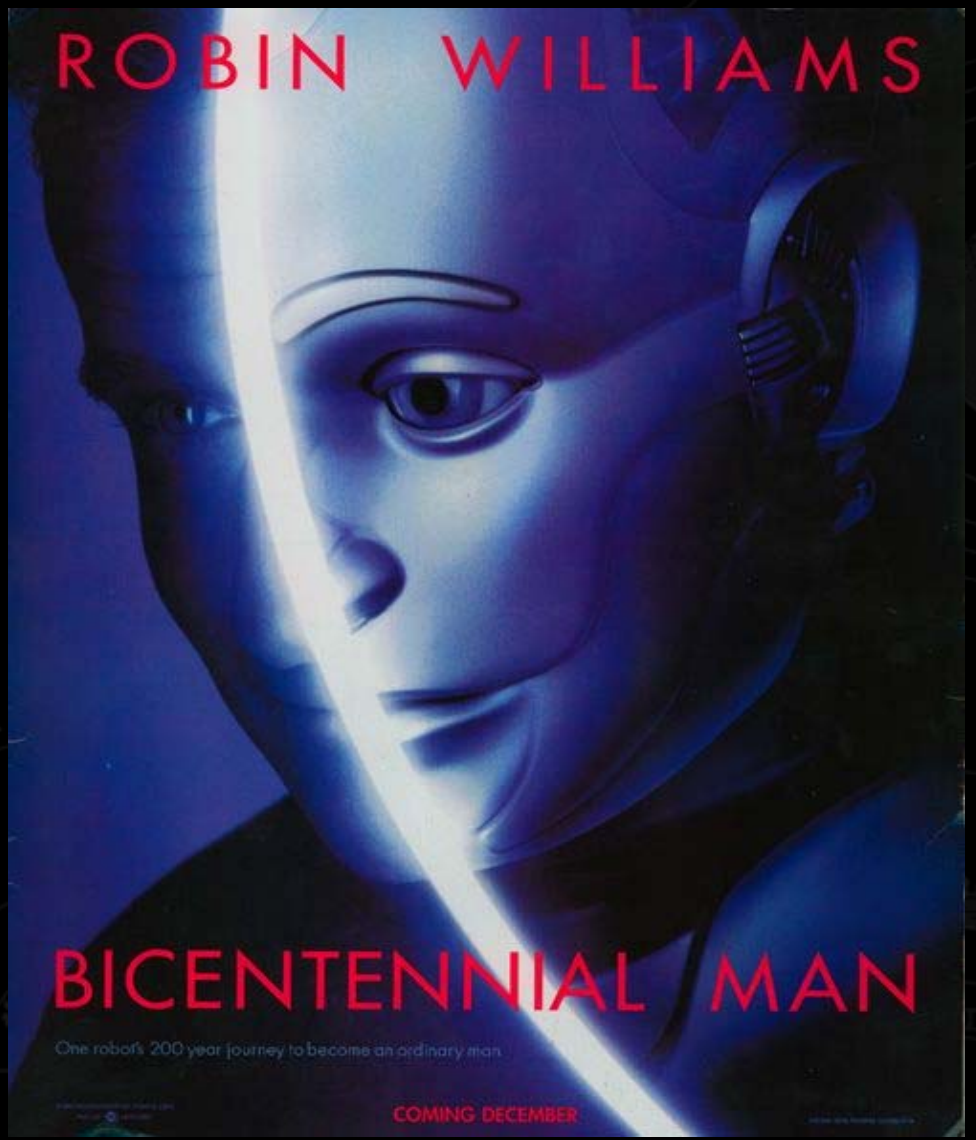
Intelligent Robots – Alife?

They may not be able to reproduce; may not have a complete self-representation; may not be able to evolve, yet …

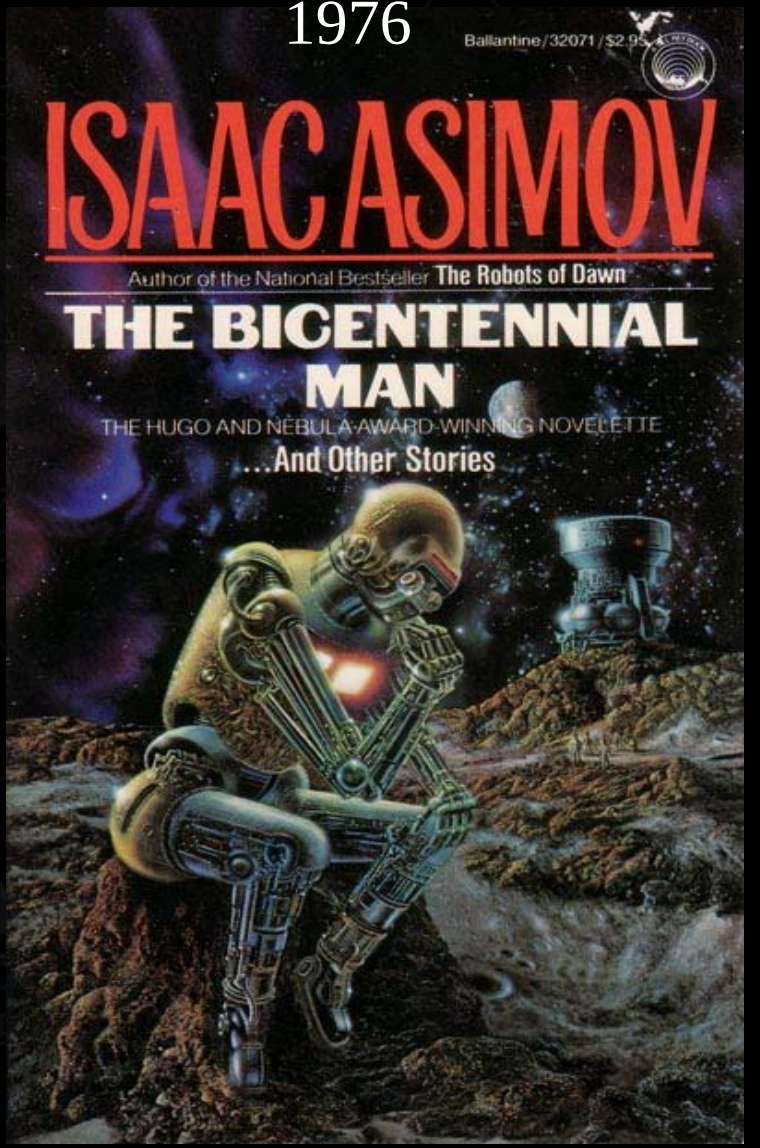
- Say a robot shared your tastes in science fiction, but preferred jazz to your musical preference for rock …
- Say a robot agreed with you that the first Matrix film was great, but definitely preferred the second one …
- Say a robot understood the concepts of *noblesse oblige*, of the *gentleman farmer*, of *belaboring the obvious* …

Would you consider it as anything but alive?

Intelligent Robots – Alife?



1976



Brief (and Biased) History of Artificial Life

Nils Barricelli

- 1953 “symbiogenesis” simulations on Von Neumann’s IAS computer (symbiogenesis = merging of two organisms to form a single new organism)
- "Symbiogenetic Evolution Processes Realized by Artificial Methods" Methodos (1957)

John Holland

- World’s first PhD in Computer Science
- Genetic Algorithms (1960s)
- *Adaptation in Natural and Artificial Systems* (1975)

Brief (and Biased) History of Artificial Life

John Conway – "Life" (1970)

- "Cells" that divide or die based upon a set of rules

Tom Ray – Tierra (early 90s)

- Digital organisms compete for CPU time & memory
- Evolution of ecosystems (computational ecologies)
- Modeling of punctuated equilibrium, host-parasite co-evolution and density-dependent natural selection

“Wet” Artificial Life

- Plant breeding, animal husbandry, and pet domestication have already created a plethora of artificial (man-made) organisms
- Genetic engineering is already used to create more radical variations on existing life forms, and is likely to be applied to humankind some day
- Urey & Miller, Miller & Orgel, and Fox “primordial soup” experiments have yielded amino acids and “protenoid” spheres
- “Test tube evolution” is used to amplify desired behaviors of enzymes, drugs, RNA (Gerald Joyce)
- Early ALife pioneers – Norm Packard, Steen Rasmussen, Mark Bedau – have formed ProtoLife organization, to re-evolve organic matter from inorganic matter (www.protolife.net)

Soft vs. Hard Artificial Life

The *strong alife* position states that "life is a process which can be abstracted away from any particular medium" (see J. von Neumann). Notably, Tom Ray declared that his program Tierra is not simulating life in a computer, but synthesizing it.

The *weak alife* position denies the possibility of generating a "living process" outside of a chemical solution. Its researchers try instead to mimic life-like processes to understand the underlying mechanics of phenomena.

Modern Artificial Life

- Cellular Automata and other stuff
- Pattern formation
- Self-organization
- Networks
- Self-replication
- Computational ecologies
- Adaptation …

see course program ☺

Modern Artificial Life (Applications)

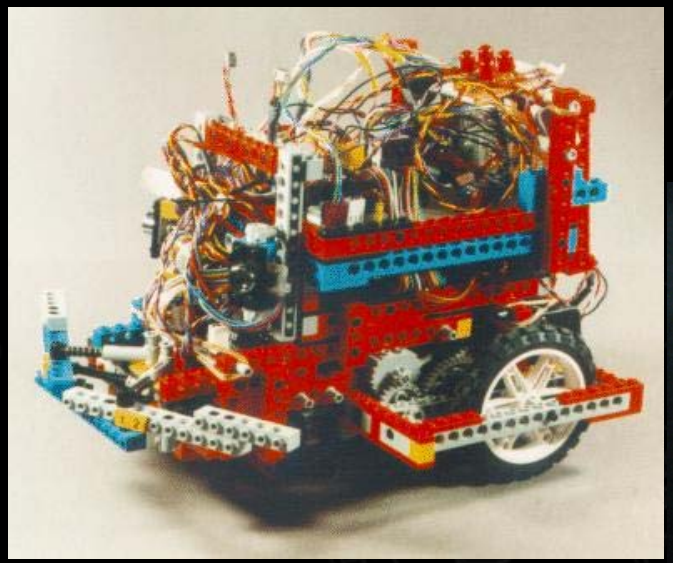
Agent-based modelling applied to:

- Economics
- Ecological resource management
- Infectious disease
- Societal structures and dynamics
- Consumer markets

...

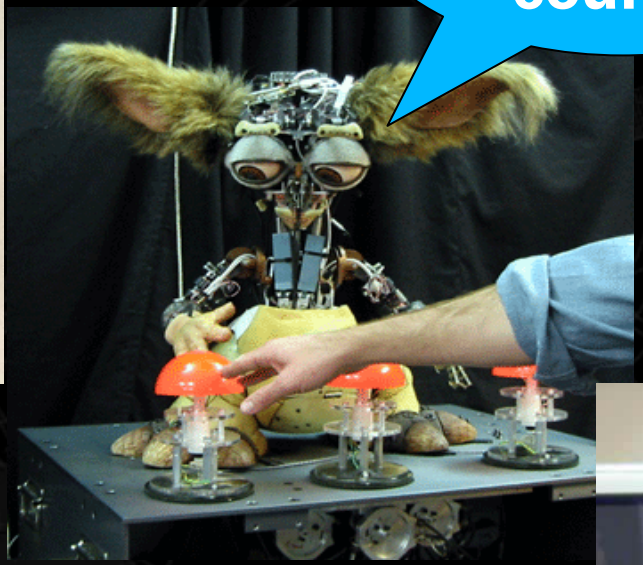
see course program ☺

Modern Artificial Life (Robots)



Robot cricket
(Webb)

Not part of this course!



Leonardo
(Breazeal et al.)

Geminoid *(Ishiguro et al.)*

Modern Artificial Life (Computer Games)

Creatures was one of the first commercial titles to code Alife organisms from the genetic level upwards using biochemistry and neural network brains.

The user “hatches” small furry creatures (Norns) into a world called Albia, and teaches them how to talk, feed themselves, and protect themselves against other creatures (Grendels).

Norns and their DNA develop and “evolve” in increasingly diverse ways, unpredicted by the makers.

Most interestingly, the Norns turned out to behave similarly to living creatures.

Creatures 1

Creatures 2

Modern Artificial Life (Virtual Worlds)

Second Life …

http://www.lindenlab.com/

http://www.getafirstlife.com

Points To Take Home

A) There are many ways of characterizing life

B) In this course, life is looked at through the lens of complex systems science and artificial life is "defined" as the synthetic study of complex adaptive (life-like) systems (natural and artificial ones).

C) Artificial life is based on ideas of emergence and self-organization in distributed system with many elements that interact with each by means of local rules.

D) Artificial life is driven by four major motivations:

- Firmer theoretical and multidisciplinary grounding of life sciences such as biology, economy, sociology, …
- Understand complex systems that shape human life and much of our immediate world such as evolution, learning processes, emergence, self-organization, …
- Make new analytical tools situated at the frontiers of computational, applied physical, and biological sciences
- Synthesis of life-like systems in forms that will be of great practical use in our industrial and engineering endeavours

Things To Think About

- What is the ontological status of artificially created living entities?
- What rights do they have?
- What is the nature of the relationship between ourselves as creators and our artifacts as living creations?
- How will Artificial Life impact society?
- How can we guarantee peaceful coexistence with autonomously evolving synthetic life forms sharing our environment?
- What is the future of life, natural and artificial?

Open Problems in Biology Addressable by Alife

The Molecular level:

- Origin of life (e.g., what were the 1st self-replicating molecules? How did RNA come about, or cell membranes?)

The Cellular level:

- Heterozygosity & homozygosity strategies
- Tendency towards co-heritable units (e.g. operons)
- Multi-cellular cooperation

The Organism level:

- Symbiosis
- The origin of sex
- Model organism's sensory and nervous system, its body, and its environment (e.g., mobile robots and ants)

The Population level:

- Emphasis on evolution & ecosystems
- Predatory-prey interactions