Overview of Lecture: This View of Life

Read: Text ch 25, plus 2 papers:

We’ll ponder “the meaning of life,”
wrestle with some challenging cases,
and come to grips with how little we know about
the origin of life.

Bullet Points:
• what is life?
• properties of living things; criteria for defining life
• life on Mars?
• the biosphere - Gaia
• are viruses alive?
• artificial life
• virtual life
• origins of life
• prebiotic soup
• the RNA world
• Space, the final frontier?
• “this view of life;” origin of life versus origin of species & biodiversity
Richard Dawkins, J. Craig Venter, Nobel laureates Sidney Altman and Leland Hartwell, Chris McKay, Paul Davies, Lawrence Krauss, and The Science Network’s Roger Bingham discuss the origins of life, the possibility of finding life elsewhere, and the latest development in synthetic biology.
1943: Physicist Erwin Schrödinger suggests an ‘aperiodic crystal’ directs maintenance of localized ‘negative entropy’ & invites other physicists into biology.

1953: Watson & Crick accept the invitation; figure out molecular structure of DNA, which suggests its function.

1955: Sagan & Margulis honor Schrödinger & try to foster a more holistic view of self-maintenance – Gaia Hyp: is ‘Mother Earth’ alive?

Shakespeare

What's this?
“The phenomenon we call life defies a simple one sentence definition.”

Note: the text appeals to the “I know it when I see it” gambit – “… almost any child perceives that a dog .. is alive but a rock is not.”

Science is about things we can measure objectively; “I know good art, good food or life when I see it” is not very scientific!

Recall - properties & processes associated w/ life:

a. order \{low entropy\},
   
d. regulation – homeostasis. \{maintaining low entropy\}
   
e. energy utilization, \{create & maintain low entropy\}

f. growth & development, \{decreasing entropy\}

c. sensitivity - responsiveness,

g. reproduction

Erwin Schrodinger proposed in 1943 that life is negative \{low\} entropy ~ order -later published these ideas as the book What Is Life?

What problems w/ this order-entropy definition?

What problems w/ sensitivity-reproduction definitions?

What problems w/ evolution definition?
In the mid-1960’s, Dr James Lovelock was approached by NASA, who asked him for help in **searching for life on Mars**. Lovelock proposed some physical tests … analyze the composition of the planet's atmosphere. If it held no life, the planet should have an atmosphere close to the chemical equilibrium state, as determined by chemistry and physics. (J.E. Lovelock, A physical basis for life detection experiments, *Nature* 207 (1965), pp. 568–570.)

If the planet held life, the metabolic activities of life-forms would result in an atmosphere far from the equilibrium state. *low entropy*

Lovelock examined the **Martian atmosphere**.

The scientists concluded that Mars was probably lifeless; almost a decade later the Viking 1 and 2 landings conformed their conclusion.
Lovelock began to think that such an unlikely combination of gases such as the Earth had, indicated a homeostatic ability of the Earth biosphere to maintain environmental conditions conducive for life.

The novelist William Golding, Lovelock’s neighbor, suggested he call the control system Gaia, after the ancient Greek Earth Goddess.

“Gaia, as a total planetary being, has properties that are not necessarily discernible by just knowing individual species or populations of organisms living together.”

James Lovelock - The Ages of Gaia

The Gaia Hypothesis is definitely holistic! … and rests on which criteria for life?

It would be comforting if Gaia regulated atmospheric CO₂ and other greenhouse gases, ex: by plants fixing more CO₂ into carbohydrate when CO₂ increases. Negative feedback regulation (like blood CO₂) – but …
If we take a reductionist approach to the hierarchy of life on earth, **where does life emerge (or disappear)?**

“The cell is life’s fundamental unit ... “ C&R p 5

“... viruses ... exist in a shady area between life-forms and chemicals.” C&R p 381

“In *The Selfish Gene* I constantly emphasized ... genes as the central units of natural selection. Anything that is self-replicating anywhere in the universe is fair game for natural selection.”

Richard Dawkins, in C,R,&M (5th ed) pg 412-413.

A virus is a genome enclosed in a protective coat. *(C&R ch 19)*

Hyp: **viruses** are obligate parasites of cells that originated as mobile (‘selfish’) bits of host cell nucleic acids, possibly plasmids or transposons (‘jumping genes’)

**Can non-living things evolve from living ancestors?**

An isolated virus is ... unable to replicate its genes or regenerate its own supply of ATP

Yet it has a genetic program written in the universal language of life.

Viruses are in the semantic fog between life and non-life.
The discovery of a giant virus that falls ill through infection by another virus is fuelling the debate about whether viruses are alive. “There’s no doubt this is a living organism,” says Jean-Michel Claverie, a virologist at the CNRS UPR laboratories in Marseilles ...
Giant viruses are ancient living organisms, study suggests

Are viruses — DNA wrapped in a protein coat — alive? The latest research says yes

Researchers have debated whether viruses, which have genes but no cellular structure, should be considered forms of life. A new study suggests they should, showing that giant viruses have some of the most ancient protein structures found in all organisms on the planet.

The researchers conducted a census of all the protein folds occurring in more than 1,000 organisms in the three traditional branches on the tree of life — bacteria, microbes known as archaea and eukaryotes. Giant viruses, which are considered "giant" based on the size of their genomes, also were included in the study because they are large and complex, with genomes rivaling some bacteria, University of Illinois researcher Gustavo Caetano-Anollés said in a statement.

For instance, the ocean's largest virus, a giant virus called CroV, has genes that let it repair its genome, make sugars and gain more control over the very machinery the virus hijacks in host cells to replicate itself. (Since viruses are essentially DNA wrapped in a protein coat, they need the goods of a host to replicate themselves.)
Search for a definition of life may be a never-ending quest
Production of synthetic virus raises new questions

THERE is no easy answer to the simplest question raised by today’s announcement that scientists have made a synthetic virus in a laboratory: what, exactly, is life?

Prof Eckard Wimmer, head of the team that built poliovirus from scratch, said:

Chemical synthesis of poliovirus cDNA: Generation of infectious virus in the absence of natural template.
SCIENCE 297: 1016-1018 AUG 9

See: Editorial: Meanings of ‘life.’
Nature 447, 1031-1032 (28 June 2007)
Scientists in the US have succeeded in developing the first living cell to be controlled entirely by synthetic DNA.

The advance, published in Science, has been hailed as a scientific landmark, ... the researchers hope eventually to design bacterial cells that will produce medicines and fuels and even absorb greenhouse gases.

The team was led by Dr Craig Venter of the J Craig Venter Institute ...

But critics say there are dangers posed by synthetic organisms.

[Venter] said: "In 2003, when we made the first synthetic virus, it underwent an extensive ethical review that went all the way to the White House."

"... the National Academy of Sciences, has done a comprehensive report on this new field."

We think these are important issues and we urge continued discussion ..."
The work by Gibson and colleagues in this issue of Science raises questions about the nature of life. The ensuing discussion has featured concerns about biosecurity and ethics …

Synthetic genomics and synthetic biology may necessitate a new model for addressing ethical and policy issues because of the complexity of the biological systems being mimicked …

Even addition of a single gene, e.g., encoding a well-characterized fungal toxin, to a [different] fungal host species led to unexpected virulence and host range in infected plants (22).
But many scientists take it seriously

“I have recently begun new research on the evolution of artificial life, in the form of self-replicating computer programs that mutate at random, compete for CPU time, and thereby adapt by natural selection to become faster and more efficient replicators.”

Discover, Feb 2005
If you want to find alien life-forms, you may only need to catch a plane to East Lansing, Michigan. The aliens of East Lansing are not made of carbon and water. They have no DNA. These are strings of commands - akin to computer viruses. Billions of them are quietly colonizing a cluster of 200 computers in the basement of the Plant & Soil Sciences building at Michigan State University.

GOLEM
A GIANT MADE OF MUD
BY MARK FODWAL

ARTIFICIAL LIFE
is an old idea,

often associated with … evil or no sense of humor.

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Puppet Master: ... neither modern science nor philosophy can explain what life is.

Puppet Master: I refer to myself as an intelligent life form because I am sentient and I am able to recognize my own existence, but in my present state I am still incomplete. I lack the most basic processes inherent in all living organisms: reproducing and dying.

Major Motoko Kusanagi: But you can copy yourself.

Puppet Master: A copy is just an identical image. There is the possibility that a single virus could destroy an entire set of systems and copies do not give rise to variety and originality.

Life perpetuates itself through diversity ...
How Did Life Begin?

What is your definition of life?

I think you can say that life is a system in which proteins and nucleic acids interact in ways that allow the structure to grow and reproduce. It's that growth and reproduction, the ability to make more of yourself, that's important. Now, you might argue that that's a local definition of life, that if we find life on Europa at some time in the future, it might have a different set of interacting chemicals.

People have tried to find more general, more universal definitions of life. They're speculative, because we don't know about any life other than ourselves. But one definition that I kind of like says life is a system that's capable of Darwinian evolution. What does it require to have a system that evolves in a Darwinian fashion? First, you have to be able to reproduce and make more of yourself, so that fits with our local definition. You also need a source of variation so that all of the new generation is not identical either to the previous generation or to all its brothers and sisters. And once you have that variation, then natural selection can actually select, by either differential birth or death, some of the variants that function best. That may turn out to be a fairly general definition of life wherever we might find it.
When the earth formed some 4.6 billion years ago {?}, it was a lifeless, inhospitable place. A billion years later it was teeming with organisms resembling blue-green algae. \(\text{not 'algae,' cyanobacteria}\)

How did they get there? **How, in short, did life begin?**

...**the theory of natural selection** suggested an answer.

The theory implied that

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**Darwin** ...posited in the final paragraph of The Origin of Species that "the Creator" originally breathed life "into a few forms or into one."

Then evolution took over: **From sosimple a beginning endless forms most beautiful and most wonderful have been, and are being evolved.**

In private correspondence ...he suggested life could have arisen through chemistry, "in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc. present."
For much of the 20th century, origin-of-life research aimed to flesh out Darwin's private hypothesis - to elucidate how, without supernatural intervention, spontaneous interaction of the relatively simple molecules dissolved in the lakes or oceans of the prebiotic world could have yielded life's last common ancestor.

One can safely infer that intricate features present in all modern varieties of life... all living things \{what definition?\} consist of similar organic (carbon-rich) compounds. ... the proteins ... are fashioned from one set of 20 standard amino acids. ... ... carry their genetic information in nucleic acids - RNA and DNA - and use essentially the same genetic code. \{C&R Fig 17.5\}

... relied on proteins to direct ... the reactions required for self-perpetuation.  \{in jargon, these are “shared derived traits”\}

Hence, the central problem of origin-of-life research can be refined to ask,

By what series of chemical reactions did this interdependent system of nucleic acids and proteins come into being?
Nowadays nucleic acids are synthesized only with the help of proteins, and proteins are synthesized only if their ... nucleotide sequence is present. In the late 1960s Carl R. Woese ... Francis Crick ... and I ... independently ... proposed that RNA might well have come first and established what is now called the RNA world - a world in which RNA catalyzed all the reactions necessary for a precursor of life's last common ancestor to survive and replicate.

It is now widely believed that four billion years ago life consisted of self-reproducing macromolecules, {note – not cells} but there is still debate about whether RNA was the first or the only macromolecule to participate in such activity, with both protein and DNA (or any combination) representing alternatives.
The "RNA World" hypothesis for the origin of life on Earth posits that the path to DNA-based organisms included a stage where RNA acted both as an information storage molecule, like DNA, and as an effector molecule, like protein, and was capable of replicating itself.

Lincoln and Joyce (p. 1229) generated an in vitro RNA-based self-replicating system lacking any protein component. Each ribozyme is present as two halves, which are cross-ligated. Sequence variation in the "halves" showed that recombination is rife in the system. Competition experiments allowed the most efficient replicator combinations to emerge through selection and become dominant.

Self-Sustained Replication of an RNA Enzyme

Tracey A. Lincoln and Gerald F. Joyce

A long-standing research goal has been to devise a nonbiological system that undergoes replication in a self-sustained manner, brought about by enzymatic machinery that is part of the system being replicated. One way to realize this goal, inspired by the notion of primitive RNA-based life, would be for an RNA enzyme to catalyze the replication of RNA molecules, including the RNA enzyme itself. This has now been achieved in a cross-catalytic system involving two RNA enzymes that catalyze each other's synthesis from a total of four component substrates.
... it seems prudent to consider other mechanisms for the accumulation of the constituents of proteins and nucleic acids in the prebiotic soup.

... some of the organic materials required for life ... may have arisen in deep-sea vents, the submarine fissures in the earth's crust through which intensely hot gases are cycled.

... the amino acids and nitrogen-containing bases needed for life on the earth might have been delivered by interstellar dust, meteorites and comets. …

NASA’s Astrobiology Program addresses three fundamental questions:

1. How does life begin and evolve?
2. Is there life beyond Earth ... how can we detect it?
3. What is the future of life on Earth and in the universe?

How and Where Did Life on Earth Arise?

Science, Vol 309, Issue 5731, 89, 1 July 2005
Carl Zimmer
“Ammonia (NH₃) was discovered in interstellar space in 1968. H₃C₂N, cyanoacetylene, was detected in 1970. Alcohol (CH₃CH₂OH) abounds in the constellation Orian. Other compounds found both in space and in living things include water, acetylene, formaldehyde, cyanide, methanol, and formic acid.”

1999 Kuiper Prize Lecture:
Cometary origin of the biosphere.
Delsemme AH Icarus 146: (2) 313-325 AUG 2000
Most of the biosphere was brought on the primitive Earth by an intense bombardment of comets. This included
the atmosphere,
{Not O₂ – from photosynthesis}
the seawater and
those volatile carbon compounds
needed for the emergence of life. …
New candidates for oldest fossils
Remains in 3.4-billion-year-old rocks hint at when cellular life arose, and how it powered itself.
Researchers have found what could be the oldest microbial fossils yet documented.
The traces, discovered in 3.4-billion-year-old Australian rocks, might help to resolve the question of when cellular life arose....
Martin Brasier and his collaborators found the cell-like fossils ... in Western Australia

... it is difficult to prove that fossils that resemble cells are truly signs of life. Such uncertainty has made the question of when life arose hugely controversial.

The fossils' sizes, shapes and carbon-containing cell walls are characteristic of bacterial colonies. The cell walls are of uniform thickness, unlike the highly variable carbonaceous layers found in inorganic traces ... The fossils are low in carbon-13 - the heavier form of carbon in the atmosphere. This is a sign of biological activity, because

Brasier ... says. "This goes some way to resolving the controversy ..."
Following origin(s) – descent with modification, from “LUCA”

**nature** news feature  
*Nature* 427, 674 - 676 (19 February 2004);  
**Origins of life:** Born in a watery commune.

If you go back far enough, humans, frogs, bacteria ...  
share a common ancestor:  
the Last Universal Common Ancestor - **LUCA**

The search for LUCA began with the study of **ribosomal RNA** ...  
{see C&R pg 102}

Because these sequences have changed so little over time,  
they are ideal for building family trees, or phylogenies,  
of evolutionary splits that occurred billions of years ago.

So far, efforts to reconstruct LUCA's genes have ended in frustration.  
... the patterns of ancestry vary depending on which gene you look at.  
This showed genes had hopped between lineages.

Carl Woese: “I picture genes and their products  
flowing through a sea of cells.“  
{recall: ~8% of ‘your genes’ are HERV:  
**Human Endogenous RetroVirus**}

Of course,  
**finding LUCA would not solve the puzzle of how life began.**
Will the traditional units of biology — the organism and the species — be swept away in the flood of new genomics data? ... Goldenfeld and Woese argue that, for microbes at least, it could happen. Free-living marine microbes, unlike their lab-grown 'clonal' cousins, are adept at acquiring useful characteristics from a shared pool of genetic material. It's beginning to look as if a genetic continuum, rather than a series of discrete species, is the natural condition in many instances.

The emerging picture of microbes as gene-swapping collectives demands a revision of such concepts as organism, species & evolution. ... the convergence of fresh theoretical ideas in evolution and the coming avalanche of genomic data will profoundly alter our understanding of the biosphere and is likely to lead to revision of concepts such as species, organism & evolution. ... microbes absorb and discard genes as needed, in response to their environment. Rather than discrete genomes, we see a continuum of genomic possibilities, which casts doubt on the validity of the concept of a 'species' when extended into the microbial realm. We foresee that in biology, new concepts will require a new language, grounded in mathematics ...
The Argument from Design:
…the eighteenth-century theologian William Paley:
Just as a watch is too complicated and too functional
to have sprung into existence by accident,
so too must all living things, with their far greater complexity,
be purposefully designed. **Natural selection is ‘The Blind Watchmaker’**

Francisco J. Ayala  http://www.counterbalance.net/evolution/revo-frame.html

… The functional design of organisms and their features
would therefore seem to argue for the existence of a designer.
It was **Darwin's greatest accomplishment to show that**
the directive organization of living beings can be explained
as the result of a natural process, natural selection, …

… **Darwin's** most significant intellectual contribution is that he
brought the origin and diversity of organisms into the realm of science.
The Copernican Revolution consisted in a commitment to the postulate that
the universe is governed by natural laws
that account for natural phenomena.
Darwin completed the Copernican Revolution
by extending that commitment to the living world.

Science is valued for **useful predictions**:  
**IF (do this) THEN (that happens), ELSE …**
**Based on understanding ‘laws acting around us’**
The Concluding Passage from
The Origin of Species
by Charles Darwin

It is interesting contemplate an entangled bank,
clothed with many plants of many kinds,
with birds singing on the bushes,
with various insects flitting about, and
with worms crawling through the damp earth,
and to reflect that
these elaborately constructed forms,
so different from each other, and
dependent on each other in so complex a manner,
have all been produced
by laws acting around us. …
There is grandeur in this view of life,
with its several powers, having been
originally breathed into a few forms or into one;
and that,
whilst this planet has gone cycling on
according to the fixed law of gravity,
from so simple a beginning
endless forms most beautiful and most wonderful
have been, and are being, evolved.

http://evolution.berkeley.edu/evosite/misconceps/IAorigintheory.shtml