Biological Evolution

Darwinian Evolution
and
Natural Selection

Major Concepts

1. Linnaean Classification
2. Fossils
3. Radioactive Dating
4. Fossil Record and Genetic Analysis
5. Theory of Evolution
   Random, Inheritable Variations
   Natural Selection

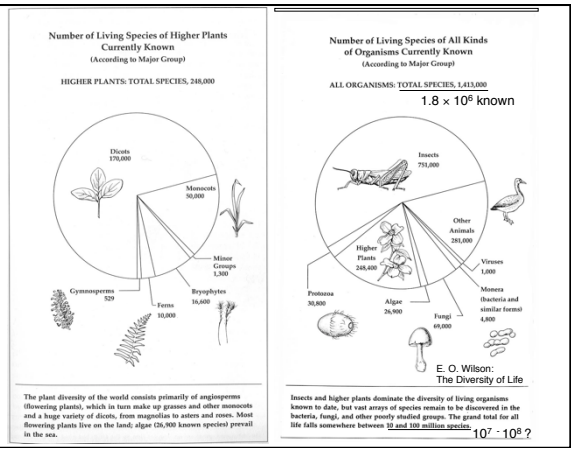
Major Concepts, cont.

6. Examples of Evolution
7. Gradualism and Punctuated Equilibrium
8. Mass Extinctions
9. Sex and Evolution
10. Timescales
11. Estimate of f_i (includes next lecture)

Diversity of Life

More than 1.8×10^6 species known
Mostly Insects!
More species on land than in sea (~10 times)
Bacteria & other prokaryotes? (hard to count)
Samples of DNA in nature: > 99% unidentified
Similarity at biochemical level (genetic code)
$\Rightarrow$ Common ancestor

Origin of Diversity?



1.8×10^6 known

E. O. Wilson:
The Diversity of Life

$10^7 - 10^8$?

Hierarchical Classification

- Originally by Linnaeus
- Based on outward form
- Now can be checked with genetic analysis
- Lower levels imply closer relationship
- Higher levels are more inclusive
- Top level is now the domain:
  - archaea, eubacteria, eukarya

Examples of Classification

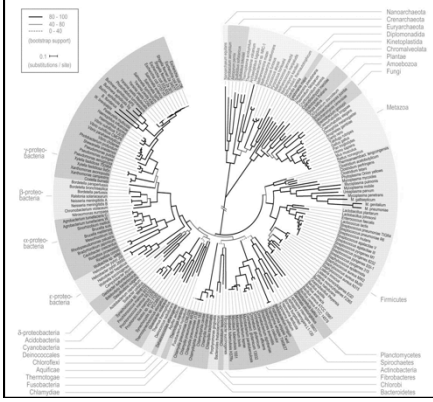
	Human Beings	Garlic
Domain	Eucarya	Eucarya
Kingdom	Animalia	Plantae
Phylum	Chordata	Angiospermophyta
Class	Mammalia	Monocotyledonheae
Order	Primates	Liliales
Family	Hominidae	Liliaceae
Genus	Homo	Allium
Species	Sapiens	Sativum

The Oldest Life (based on genetic analysis)

More phyla in sea (35) than on land (10)
Root of tree of life lies between Archaea
& Eubacteria - closer to Archaea

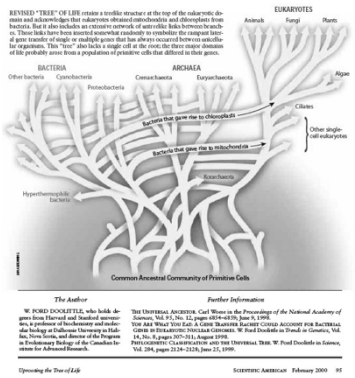
Evidence for life back to 3.8×10^9 yr ago when Earth was still being bombarded
Some challenges to oldest fossils; secure to
About 2.8×10^9 yr ago

Tree of Life



Ciccarelli et al. 2006
Science, 311, 1283

Web may be better metaphor than tree

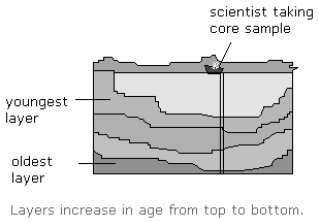


Lateral transfer of genes:
Very common among prokaryotes
Also in eukaryotic cell (organelles)

Fossils

Hard parts: bones, teeth, …
petrification ⟶ minerals
Molds ⟶ petrification (preserves soft parts)
Bacteria - stromatolites, microfossils
Isotopic ratios - characteristic of life

Dating Fossils



Relative Dating

Layers increase in age from top to bottom.

Radioactive decay ⟶ absolute dates

e.g. ^{14}C produced by cosmic rays

C.R. + ^{14}N ⟶ ^{14}C ⟶ ^{14}N

Works to $\lesssim$ 60,000 yr 1/2 in 5,730 yr

For older fossils, get date of layers above & below from volcanos -

e.g. ^{40}K ⟶ ^{40}Ar, …

Decay of Radioactive Atoms

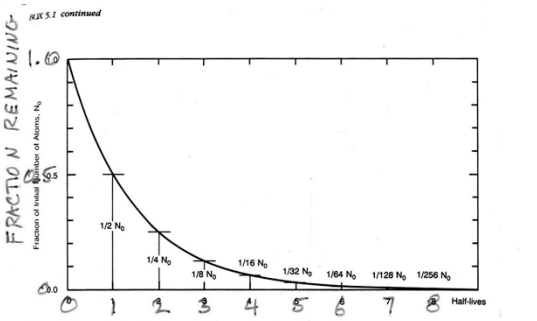
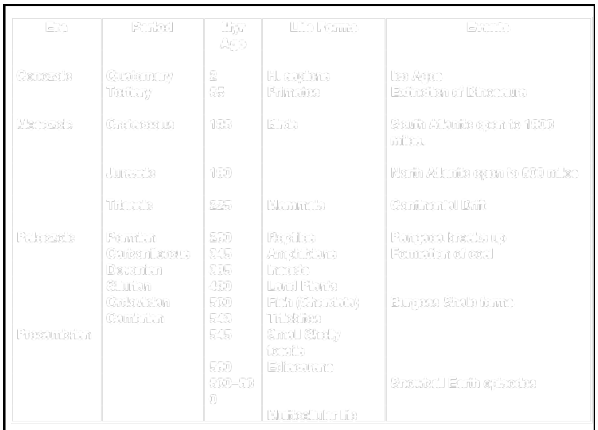


Figure A. Decay of radioactive atoms. At time zero, there is a given number of radioactive atoms, N_0. The atoms decay into their offspring products at rates such that after one halflife, half the N_0 atoms remain; after two halflives one-quarter of the N_0 atoms remain; and so forth.



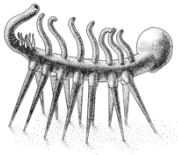
Fossils from Burgess Shale ~ 530 Myr Ago

126 | Wonderful Life (S.J. Gould)

3.21. *Opabinia*, showing the frontal nozzle with terminal claw, five eyes on the head, body sections with gills on top, and the tail piece in three segments. Drawn by Marianne Collins.

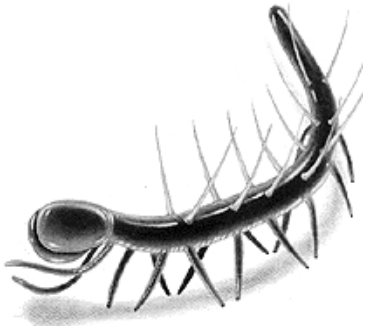
Many basic body plans (phyla) tried out in Cambrian; some did not survive; never attempted again.

154 | Wonderful Life



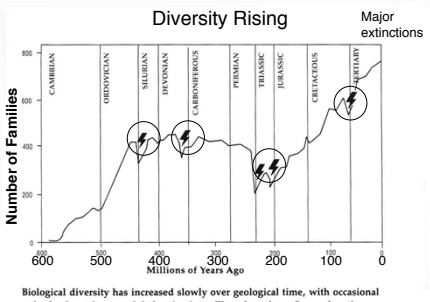
3.34. *Hallucigenia*, supported by its seven pairs of struts, stands on the sea floor. Drawn by Marianne Collins.

Correct Version of Hallucigenia



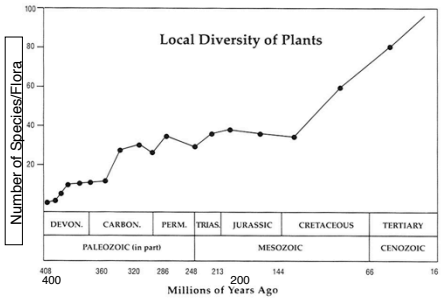
Diversity Rising

Major extinctions



Biological diversity has increased slowly over geological time, with occasional setbacks through mass global extinctions. There have been five such extinctions so far, indicated here by lightning flashes. The data given are for families (groups of related species) of marine organisms. A sixth major decline is now underway as a result of human activity.

E. O. Wilson:
The Diversity of Life



The average number of plant species found in local floras has risen steadily since the invasion of the land by plants 400 million years ago. The increase reflects a growing complexity in terrestrial ecosystems around the world.

E. O. Wilson:
The Diversity of Life

Summary of Fossil Record

- Simple organisms first, more complex later
- Prokaryotes, eukaryotes, multi-cellular
- Not deterministic “progress”
- Recent (last 150 Myr) rise in diversity caused by flowering plants and insect hosts
  - Some organisms become more complex
  - Many stay about the same
- Increase in diversity and a “left wall of minimal complexity”

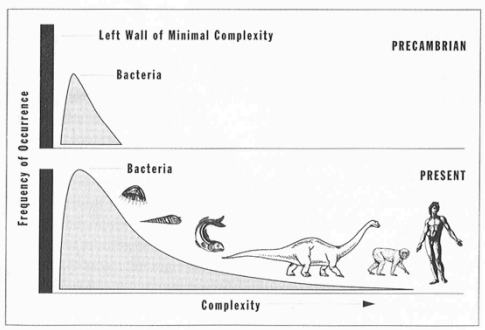


FIGURE 29
The frequency distribution for life's complexity becomes increasingly right skewed through time, but the bacterial mode never alters.

S. J. Gould

Theory of Evolution

Developed independently by Darwin and Wallace

Based on earlier ideas, but key feature was the role of selection

Two Key ingredients:

1. Random, inheritable variations
2. Natural Selection (competition for scarce resources produces "survival of the fittest")

1. Mutation is ultimate source of variation (but sexual reproduction produces great variation without many mutations)
2. Selection

   Organism level ⟶ species gradually evolves

   Species level ⟶ (speciation + extinction)

   "Life" evolves

Topics:

Sexual Reproduction

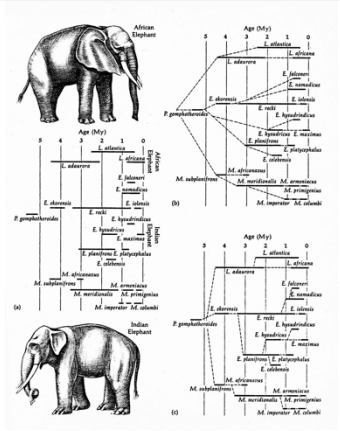
Gradualism vs. Punctuated Equilibrium

Speciation: the role of geographical isolation

Ecological niches

Why Sex?
(Or why do males exist?)

- Sexual reproduction (meiosis) allows more variation
  - Allows favorable mutations from two lines to combine
  - Protects against harmful mutations
- But, if only females, more gene copies, more efficient reproduction
  - Short term fitness might favor asexual
- Recent studies in water fleas indicate that protection against harmful mutations is key feature
- "Males are allowed to exist after all, because they help females get rid of deleterious mutations."
  - Science, 311, 960 (Feb. 17, 2006)



Elephants and relatives

Gradualist

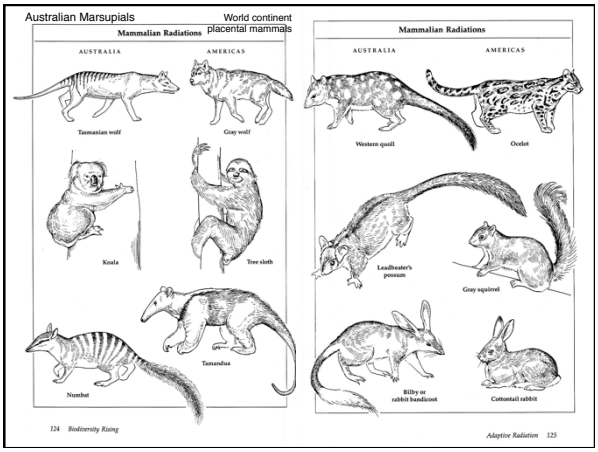
Punctuated Equilibrium

Speciation

- Darwin's "Origin of Species" did not explain
- Modern synthesis – Ernst Mayr
  - Geographic isolation
    - Islands
    - Mountaintops
  - Genetic drift
  - Varieties no longer interfertile: new species
- Adapting to different, but close environments
  - Hybrids are not well adapted

Ecological Niches

- "Niche" (a way of making a living)
  - Different food source
  - Different microclimate
  - Species diversity high when environment is complex
- Convergence
  - With long geographic isolation
  - Find similar types of animals
  - From very different evolutionary sources



Statements about Evolution

True or False (& Why?)

1. People who move to the south and adapt to hot weather are an example of evolution
2. Almost all species that ever lived are now extinct
3. Extinction represents a failure of evolution
4. A natural catastrophe, like an asteroid impact or an ice age, is needed to cause natural selection
5. Evolution always selects more complex, intelligent organisms for survival
6. Major diversification of surviving groups usually follows a mass extinction

Evolution: Theory or Fact?

- Facts
  - fossils and ages are facts
  - Order of origins of groups are facts
  - Genetic relationships are facts
- Theory (explanation of facts)
  - Variations and selection
  - Theory makes predictions
  - Predictions are checked
  - Theory is refined

IF Intelligent Design were a scientific theory…

- Assume a silicon chip designed life on Earth
- Would such a theory predict:
  - Increase in complexity with time in fossil record?
  - Continued speciation?
  - Vestigial legs in whales?
  - Genomes full of genes from other organisms? … and full of non-coding DNA?

Evolution and Religion

- Vatican Conference on Evolution
  - Mar 3-7, 2009
  - On occasion of 150 years since Origin of Species
  - Explore compatibility
- http://www.evolution-rome2009.net/

The Origin of Intelligence

The Origin of Intelligence

f_i : Fraction of life-bearing planets where Intelligence develops

What is intelligence?
Propose: "The ability to model the world, including the organism itself"

⇒ Intelligence as continuum
related to complexity of organism
milestone: human-level intelligence

Information as Measure of Intelligence

Evolution of intelligence ~ increase in information
DNA: model of organism, the program
A quantitative measure: # of bits of information

Bit: Information in the answer to a yes/no question

e.g.,	Purines	Pyrimidines
	Adenine (A)	Cytosine (C)
	Guanine (G)	Thymine (T)

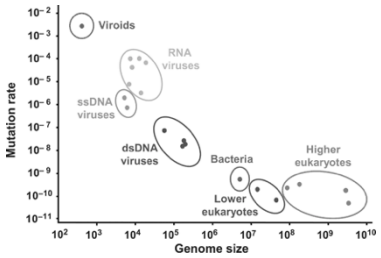
Information Content

Unit	# of Bits	# of Pages	# of Books
1 base	2		
1 codon	6		
Virus	$\sim 10^3$	1	
Bacterium	10^6	1000	
Amoeba	5×10^8		500
H. Sapiens*	6×10^9		small library

*~ 2% codes for proteins
⇒ 1.2×10^8 bits

Evolution produced Increase in information

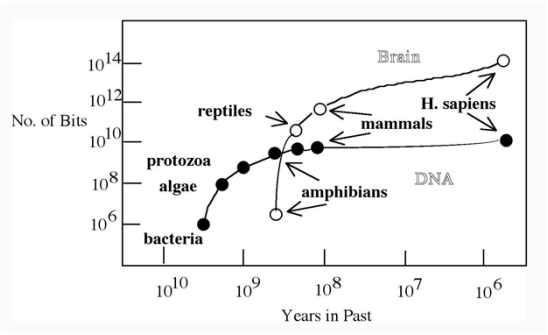
Information stored in DNA limited by fidelity of Replication. The bigger the genome, the smaller the mutation rate must be.



Gago et al. 2009, Science, 323, 1308

Further Complications…

- Humans make about 90,000 kinds of protein
- Now it seems we have only 21,000 genes
- What's going on?
- One gene can lead to different proteins
  - The mRNA is edited to remove introns
  - Sometimes exons are left out or introns in
  - Splicing controls gene expression
  - More common in more complex organisms



Based on Sagan

Dragons of Eden

Why Brains?

To get more than 10^{10} bits (or 10^{8}?), need extra-genetic storage

Neurons led to brains

How is information stored in brains?

Not entirely clear

Neuron fires or not: 1 bit/neuron

Yes or No

Brains are Different

Neuron firing controlled by many (~10^3) inputs - synapses

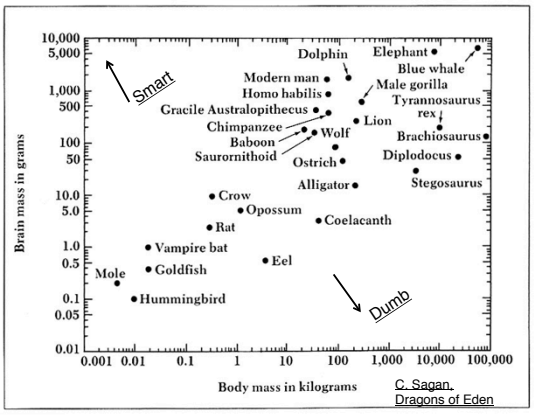
An **analog** computer ⇒ Hard to count

~ 10^{11} neurons, 10^{14} synapses

Corresponds to 20×10^6 books = NY public library

Surrogate Measure:

Brain size or Brain mass/body mass



C. Sagan, Dragons of Eden