Genetic Evidence for Evolution

http://www.biologycorner.com/resources/DNA-colored.gif
Outline

- Expectations from evolution
- Basics of genetics
- Ubiquitous proteins and DNA sequences
- Evolution in the lab
- Speciation in nature

NOTE: many slides in the four evolution lectures obtained from Web sources: Ken Miller [“Hot Science, Cool Talks” at UT Austin], Elizabeth Saunders, Carl Wozniak, Caltech Bio 1
The Basic Idea

• Darwin had no concept of genetics
• Therefore, genetic tests subject evolution to a whole new set of possible falsifications
• How does it do?
Evidence for Evolution - Comparative Morphology

Why use the same skeletal plan for these very different appendages?
Why do embryos of different animals pass through a similar developmental stage?

Recent discoveries of the conservation of molecular mechanisms of development are even more compelling.
First let’s think about what we expect from evolution
The Tree of Life

- Standard, somewhat misleading depiction

The Tree of Life

- A more accurate, modern version...
- Three domains
- Idea: some universal common ancestor from which all life descended
- What does this imply?

http://nai.arc.nasa.gov/seminars/68_Rivera/tree.jpg
Expectations of Common Descent

• Evolution does not invent new things from scratch. It has to make minor changes in existing structures
• In fact, expect non-optimal structures in many cases
• Examples?
Giant Panda’s Thumb

Not a real thumb. Not opposable like ours. Adaptation of a tiny bone in hand.

Used to strip bamboo. Inefficient!

www.athro.com/evo
The Appendix

No obvious use, at least now.

People get along fine without one!

But if it bursts, it can be fatal (Houdini 1926)
Our optic nerves block part of our retinas, leading to blind spots. Octopus eyes don’t have this flaw.
But what about at the genetic level?
Genetic basics: DNA

- DNA = set of blueprints! contains instructions needed to construct other components of cells, e.g., proteins, RNA
- Double helix
  In humans, 1m long!!
- Four bases: A, T, G, C
  A with T, G with C
- Code is read by copying stretches of DNA into the related nucleic acid RNA transcription

http://www.biologycorner.com/resources/DNA-colored.gif
Genetic basics: DNA
Amino Acids & Proteins

• Amino acids link to create proteins
• Amino acids = *amine group* (NH or NH$_2$) + *carboxylic acid group* (COOH) + *side chain* (for each amino acid)
• Triplets code for amino acids, e.g., TGT,TGC=cysteine
  - 4x4x4 = 64 triplets = 64 genetic “words” in genetic code
  - Multiple triplets code for same amino acid (redundancy)
• Most organisms construct proteins from the same set of 20 amino acids → common ancestor!
• Living cells use only the *left-handed* versions of amino acids to build proteins
  → common ancestor!

http://www.answersingenesis.org/images/chirality-rgb.jpg
Is DNA the Basis for Life Everywhere in the Universe?

• We don’t know, but probably not
• Very early, it is thought that a different type of molecule (RNA) was genetic basis
• Maybe many such candidate molecules
• In any case, randomness of evolution means that even if aliens have DNA, it is likely to be much different in specifics
DNA and Common Descent

- Mutations happen gradually
- Therefore, common descent predicts that related organisms will have related amino acid sequences and base sequences even if it is not functionally required

http://evolution.berkeley.edu/evosite/evo101/images/dna-mutation.gif
Ubiquitous Proteins

- All organisms have them
- Perform very basic life functions
- Example: Cyt c made of $10^2$ amino acids
- Oxygen transport
- About $10^{93}$ functional variants; about $10^{135}$ total
- Functionally, no reason to be similar
- Evolution demands it

What do the data say?

http://www.eiu.edu/~eiuchem/faculty/tremaincytc.png
Evolutionary Prediction Supported

Amino acids reveal evolution

<table>
<thead>
<tr>
<th>Organism</th>
<th>Number of amino acid differences from humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chimpanzee</td>
<td>0</td>
</tr>
<tr>
<td>Rhesus monkey</td>
<td>1</td>
</tr>
<tr>
<td>Rabbit</td>
<td>9</td>
</tr>
<tr>
<td>Cow</td>
<td>10</td>
</tr>
<tr>
<td>Pigeon</td>
<td>12</td>
</tr>
<tr>
<td>Bullfrog</td>
<td>20</td>
</tr>
<tr>
<td>Fruit fly</td>
<td>24</td>
</tr>
<tr>
<td>Wheat germ</td>
<td>37</td>
</tr>
<tr>
<td>Yeast</td>
<td>42</td>
</tr>
</tbody>
</table>

(out of 104)
Functional Subtlety?

• Could it be that similar animals have similar precise needs for cyt c? e.g., fish and dolphins, birds and bats?
• No!
• As predicted by common descent, humans and dolphins are closer than dolphins and sharks; humans and bats closer than bats and birds
• Evolutionary prediction strongly verified
Additional Test: DNA Sequence

- On average, 3 triplets code for each amino acid
- Cyt c = 104 amino acids
- Thus $3^{104} \approx 4 \times 10^{49}$ exactly equivalent sequences for cyt c
- No reason for similarity other than common descent
- What do data say?

http://plato.stanford.edu/entries/information-biological/GeneticCode.png
Conservation at the Molecular Level

Why else should different organisms possess related genes?

Why does the degree of relationship of genes match their degree of relationship established by other methods?

$3 \times 10^4 = 312$ bases total
Comparative Genomic (DNA) Evidence was Decisive

Chimp genetic code opens human frontiers
Genome comparison reveals many similarities — and crucial differences

By Alan Boyle
Science editor
MSNBC
Updated: 4:20 p.m. ET Sept. 1, 2005

Scientists unleashed a torrent of new information about humans and chimpanzees on Wednesday when two teams of biologists reported that DNA sequences are identical in the two species. This appears to contain clues to how humans and chimpanzees relate to other relatives in the animal kingdom.

"We're really looking at an incredibly significant story," said University of Washington geneticist Robert Waterston, senior author of a study in the journal Nature presenting the draft of the chimpanzee genome.

"More than a century ago Darwin and Huxley posited that humans share recent common ancestors with the African great apes. Modern molecular studies have spectacularly confirmed this prediction and have refined the relationships, showing that the common chimpanzee (Pan troglodytes) and bonobo (Pan paniscus) are our closest living evolutionary relatives."
Human Chromosomes (coiled DNA) (23 pairs = 46)
Testing the Evolutionary Hypothesis of Common Ancestry

Chromosome numbers in the great apes:

- human (Homo) 46
- chimpanzee (Pan) 48
- gorilla (Gorilla) 48
- orangutan (Pogo) 48

**Testable prediction:** If these organisms share common ancestry, the human genome must contain a pair of fused chromosomes.
Chromosome numbers in the great apes (Hominidae):

- human (Homo) 46
- chimpanzee (Pan) 48
- gorilla (Gorilla) 48
- orangutan (Pogo) 48

Testable prediction: The marks of that fusion must appear in one of the human chromosomes.
Chromosome 2 is unique to the human lineage of evolution, having emerged as a result of head-to-head fusion of two chromosomes that remained separate in other primates.

Perspective

• Humans, chimps are different e.g., we’re much smarter
• No reason to be ashamed of common ancestry with chimps! Remember, current apes aren’t our ancestors; they are more like cousins
• Rapid changes (brain size) can occur with small changes in genome; complicated
Evolutionary Principles in Practice: The AIDS “Cocktail”

- Why is there a plunge in US deaths since 1995? Still terrible, but better...
- AIDS caused by virus (HIV) Reproduces fast $\Rightarrow$ Adjusts quickly (via mutations)
- Evolution says: can’t make many mutations at once if each is unhelpful So, three drugs at once
- Has held up so far...

Evolution in the Lab (1988 – present)

- Richard Lenski
  Michigan State Univ.
- Start: cloned E. coli bacteria
  Genetically identical!
- In test tube, feed for a day,
  remove, repeat...
  >50,000 generations (2010)
- Results?
  Genetic diversity
  More fit for environment
  Multi-stage mutation

http://uanews.ua.edu/anews2005/sep05/images/lenski_300.jpg
Change in Relative Fitness

Put ancestral + evolved strains in same flask.

Wait...

Evolved strain is much more competitive in environment.
Origin of Novelty

• Test tubes involve citrate as well as glucose
  But E. coli bacteria can’t metabolize citrate

• Many generations passed...

• In generation #31,500, strain evolved that can metabolize citrate

• Discovered previous “potentiating” mutations (neutral drift, but allowed later co-opting of mutations)

• Just as expected!
Evolution in Nature: Antibiotic Resistance

• “Old standbys” (penicillin, streptomycin, etc.) don’t work as well as they used to

• Why? Bacteria have evolved to resist them

• Evolution is accelerated by overuse of antibiotics in livestock
  Gives bacteria more adaptive chances!

• This is why you **finish** an antibiotic regimen
  Otherwise, remaining bugs are more resistant!
Evolution of pesticide resistance
Using Evolution to Combat Pests

- Bt (bacillus t...) pesticide = biological alternative to a pesticide
  Allele is recessive
- If spray all, resistance spreads fast
- If leave refuge unsprayed, breeding reduces number of resistant insects

http://evolution.berkeley.edu/evolibrary/images/relevance/refugia.gif
Evolution and Genetic Diversity

• 1800s: “lumper” potatoes (clones) grown for Irish
• 1840s: potato blight hits, all potatoes susceptible
• 1 in 8 Irish died of starvation during this period
• Genetic diversity is key to surviving diseases

http://evolution.berkeley.edu/evolibrary/article/0_0_0/agriculture_02
Recent Low-Diversity Examples

• 1970: >$1 billion in single-variety corn crops lost due to fungus
• 1980s: >2 million acres of grapevine in CA had to be replanted due to insects; single variety of grapevine root
• Our normal bananas are genetically identical to each other; ripe for disease! Already killed off a variety in 1960s
Speciation: http://www.sfgate.com/cgi-bin/object/article?f=/c/a/2001/03/26/MN172778.DTL&o=0
Summary

• Genetic evidence strongly supports evolution
• Mechanism is simple and powerful enough to occur anywhere in universe, but details will no doubt differ
• But what are the conditions for life to originate and survive, possibly to intelligence? More speculative, but we’ll give it a try!