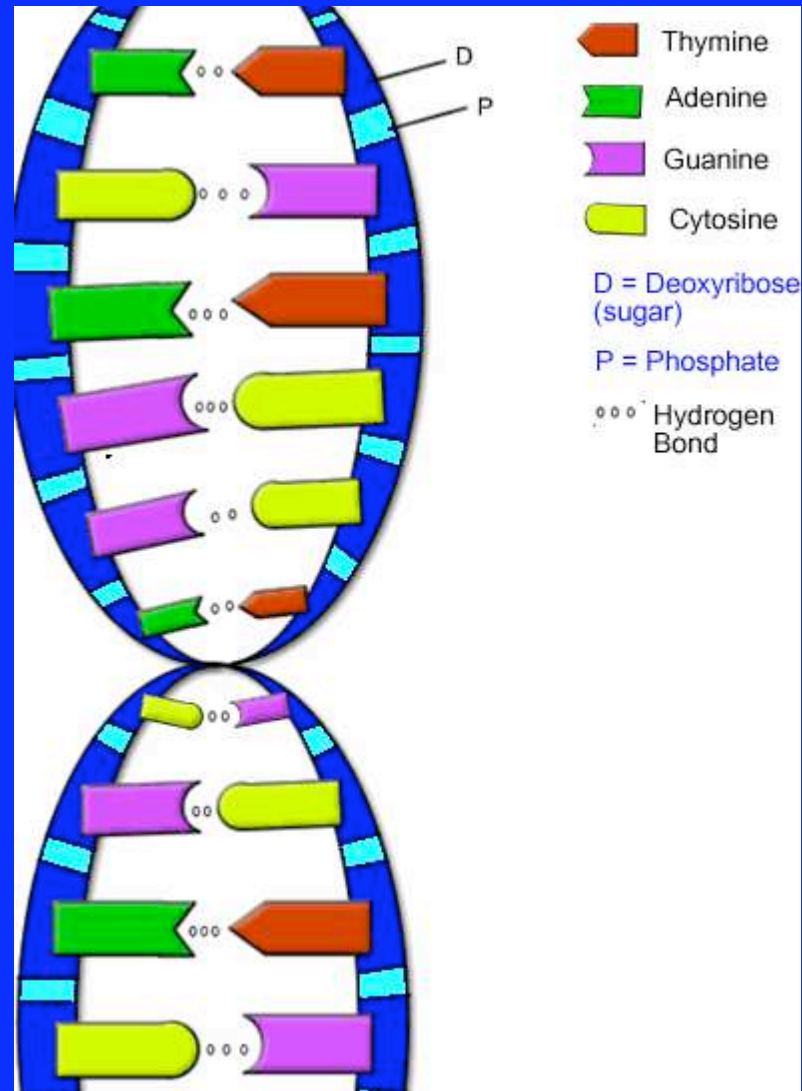


# Genetic Evidence for Evolution



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

# Outline

- Evidence for evolution from microbiology
- 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

# Midterm: Open or Closed Book?

- My preference is closed book, closed notes  
Much easier exam!  
Focuses on knowledge, not look-up skills
- If class has strong preference for open-book, we can do that

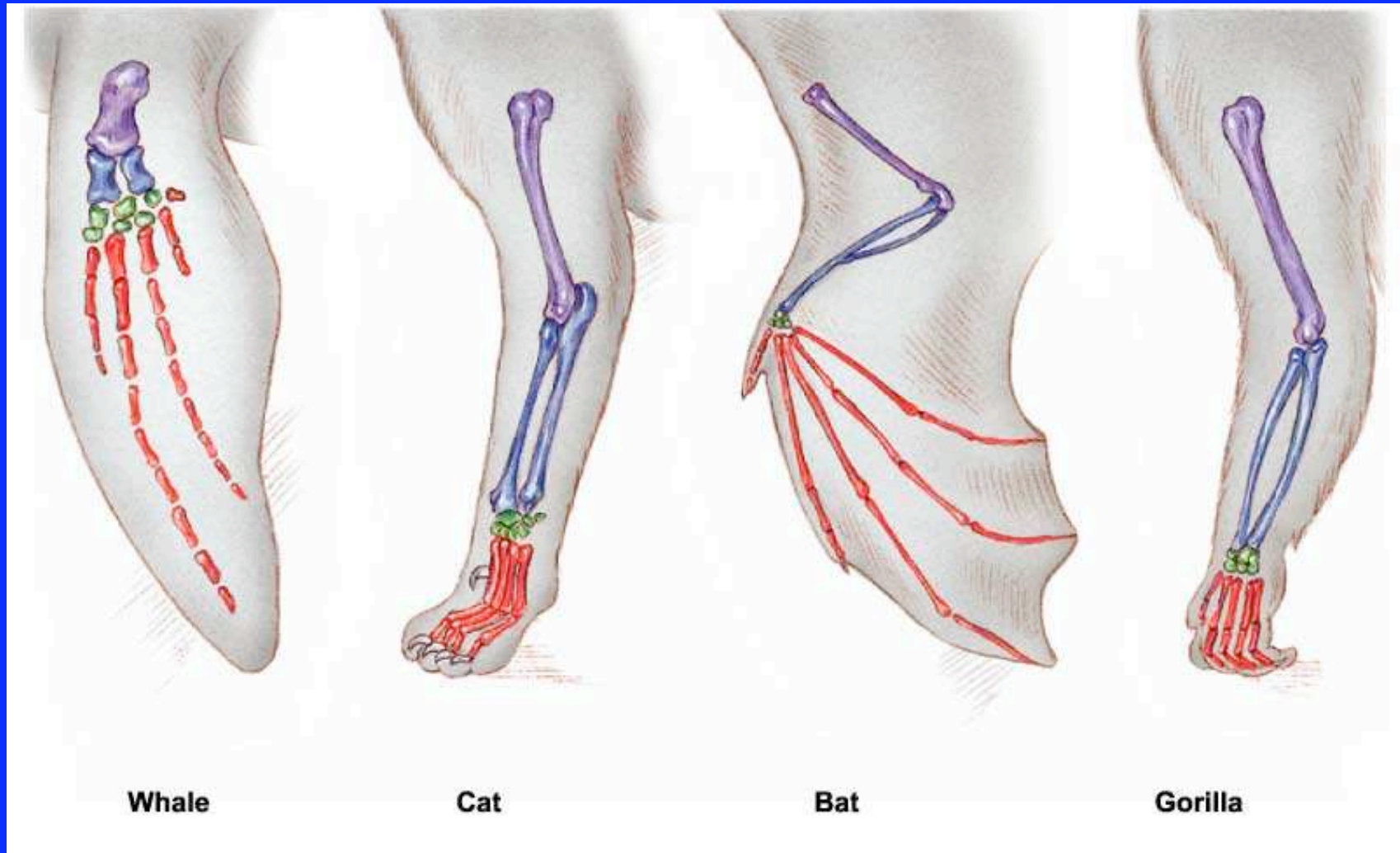
# Breaking News: Water on Moon!

- Data from three spacecraft, including UMd's EPOXI
- Spectra clearly indicate water and OH
- But (from UMd's Lori Feaga):  
“You would have to scrape the area of a football field to get one quart of water”
- Bring your own supplies :)

# The Basic Idea

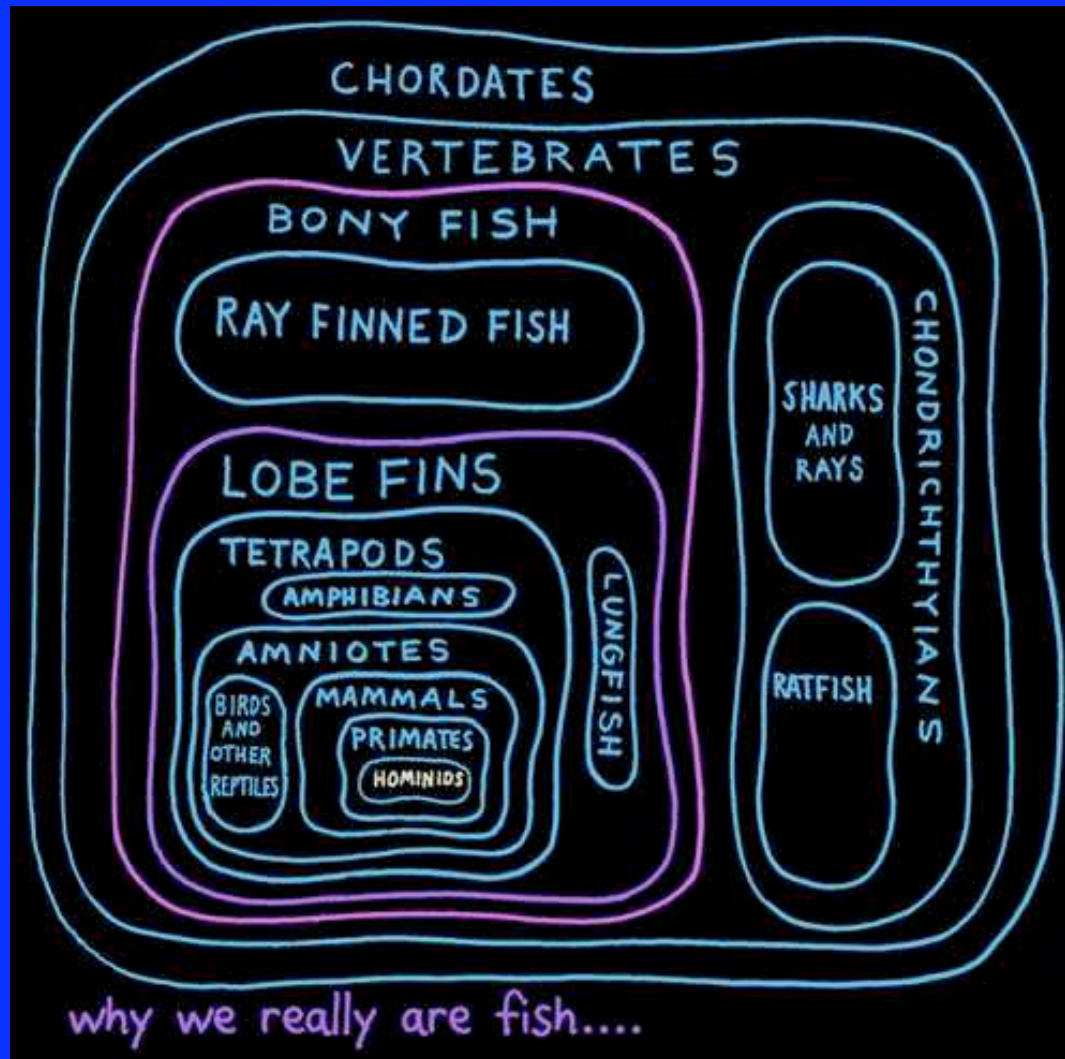
- Darwin had no concept of genetics
- Therefore, genetic tests subject evolution to a whole new set of possible falsifications
- How does it do?

## Evidence for Evolution - Comparative Morphology



Why use the same skeletal plan for these very different appendages?

# Your Inner Fish (Shubin)

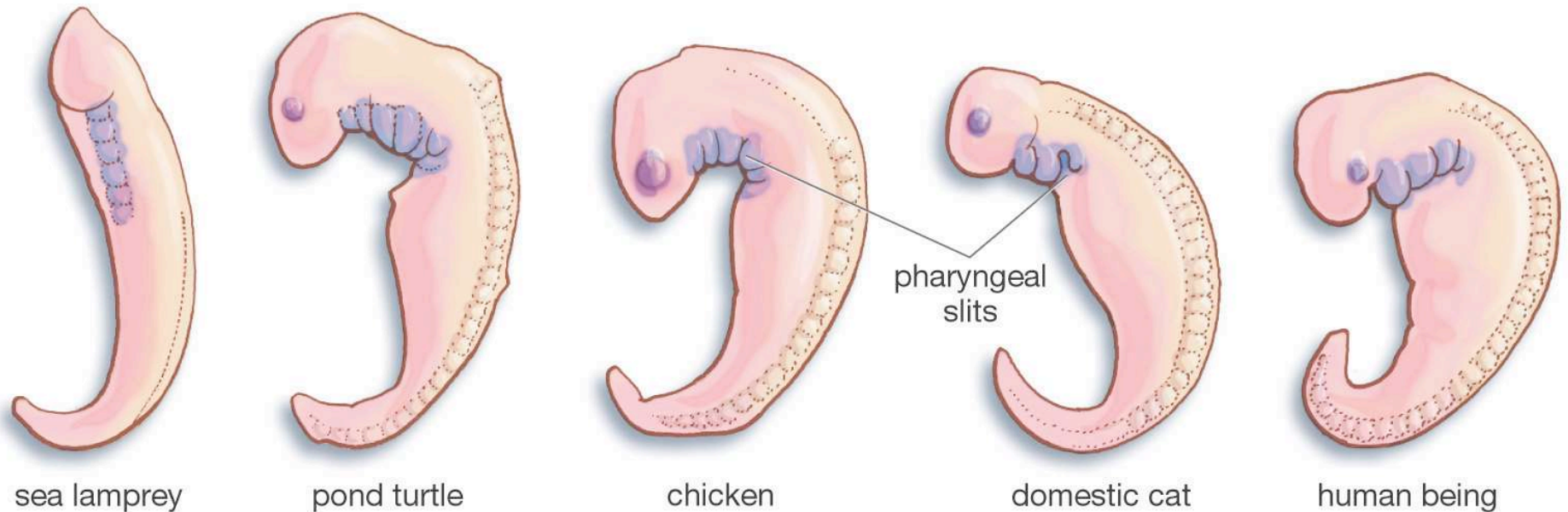


<http://www.hmnh.org/galleries/ichtheology/devonian/WeAreFishVennDiagram.jpg>



# Evidence for Evolution - Comparative Embryology

Pharyngeal slits exist in these five vertebrate animals ...



... evidence that all five evolved from a common ancestor.

**Why do embryos of different animals pass through a similar developmental stage?**

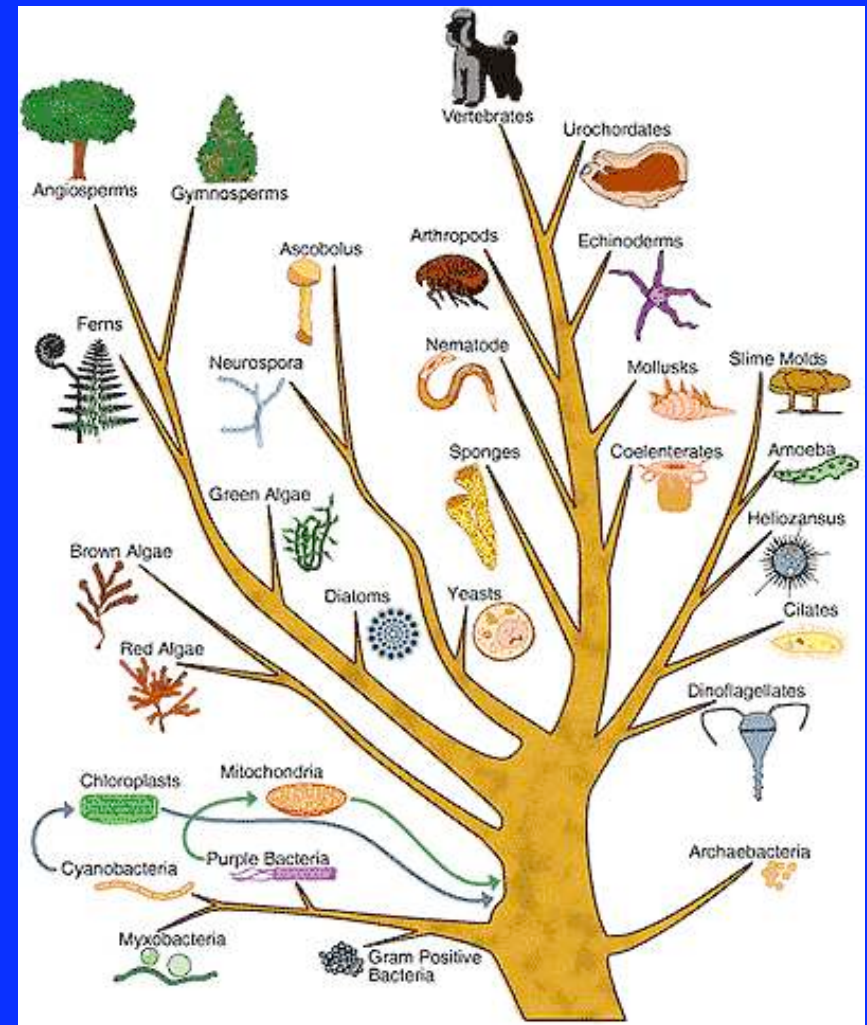
Recent discoveries of the conservation of molecular mechanisms of development are even more compelling.



First let's think about what we expect from evolution

# The Tree of Life

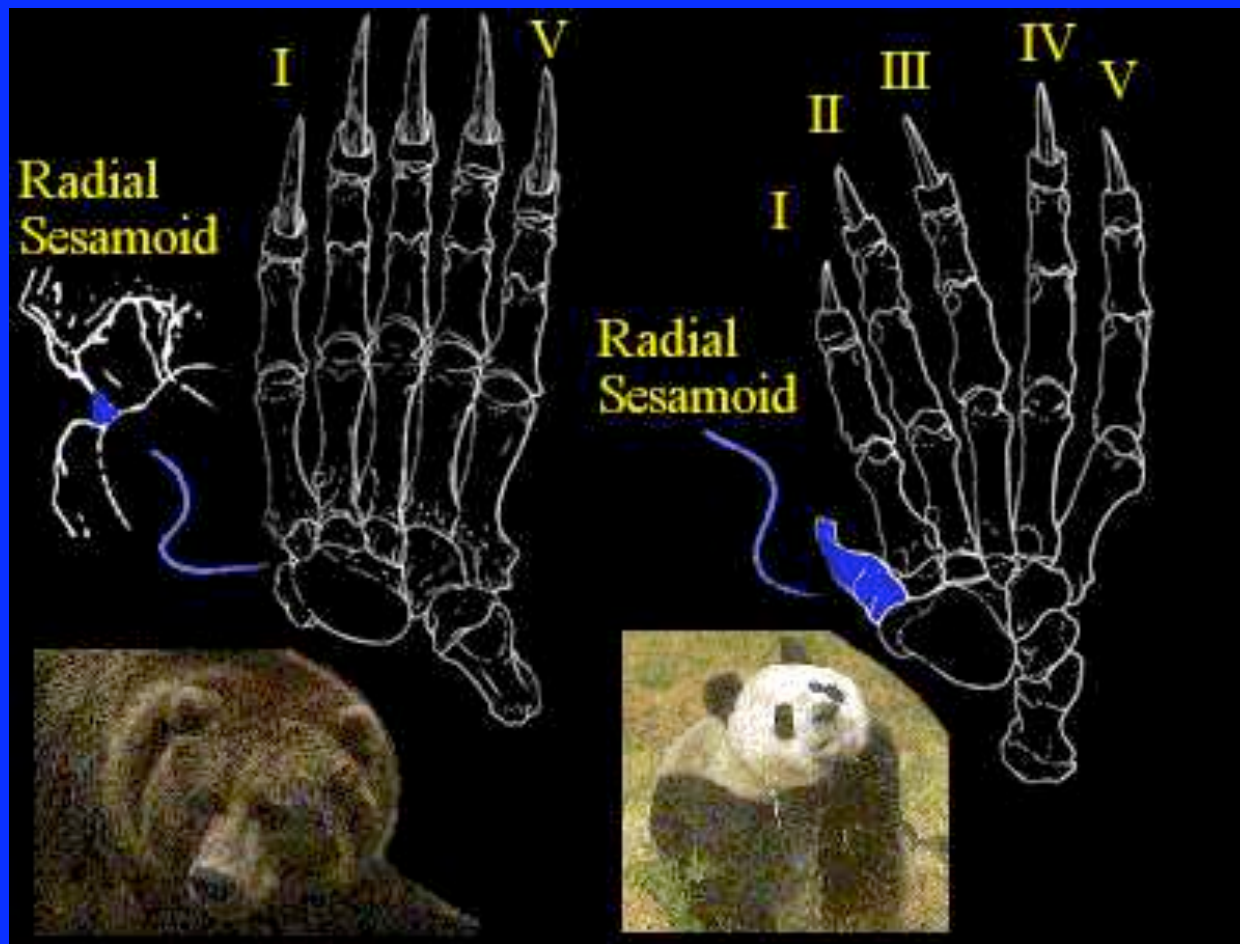
- Standard, somewhat misleading depiction
- Idea: some universal common ancestor from which all life descended
- What does this imply?



# 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



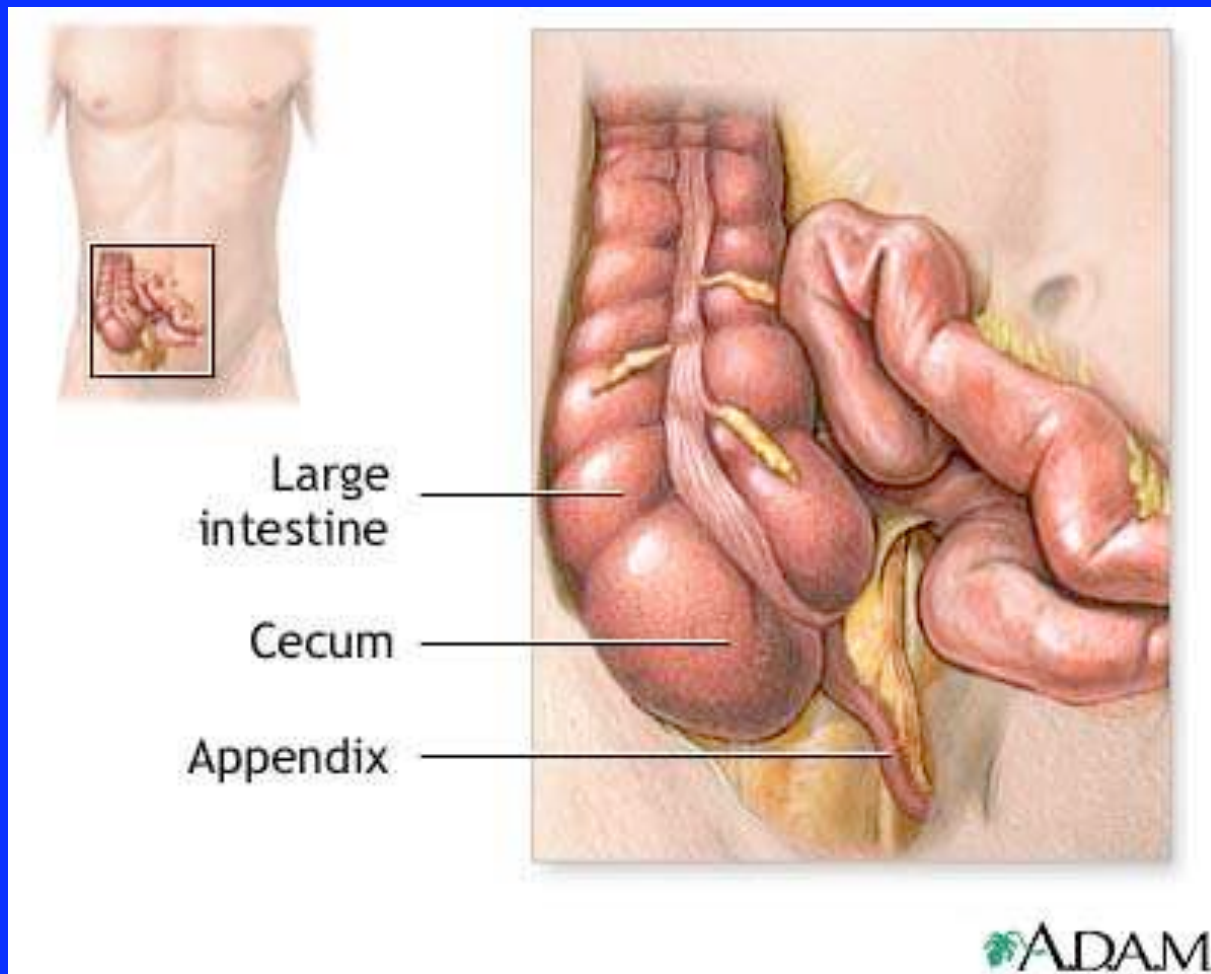
Not a real thumb.  
Adaptation of a  
tiny bone in hand.

Used to strip  
bamboo.

Inefficient!

[www.athro.com/evo](http://www.athro.com/evo)

# The Appendix



No obvious use,  
at least now.

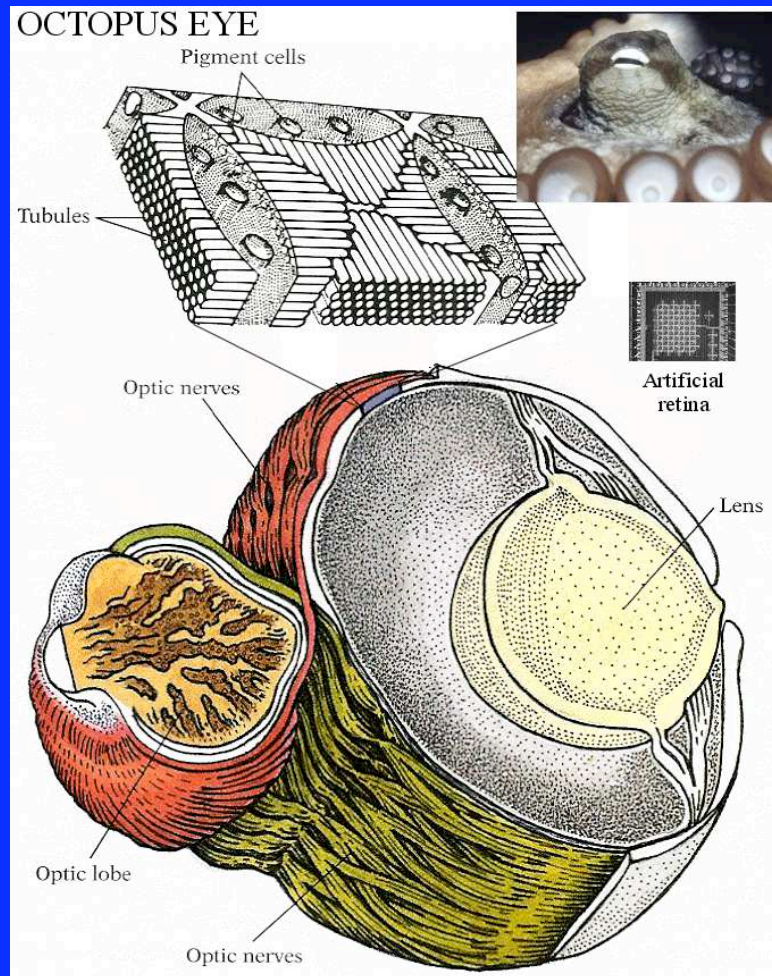
I get along fine  
without one!

If bursts, can  
be fatal  
(Houdini)

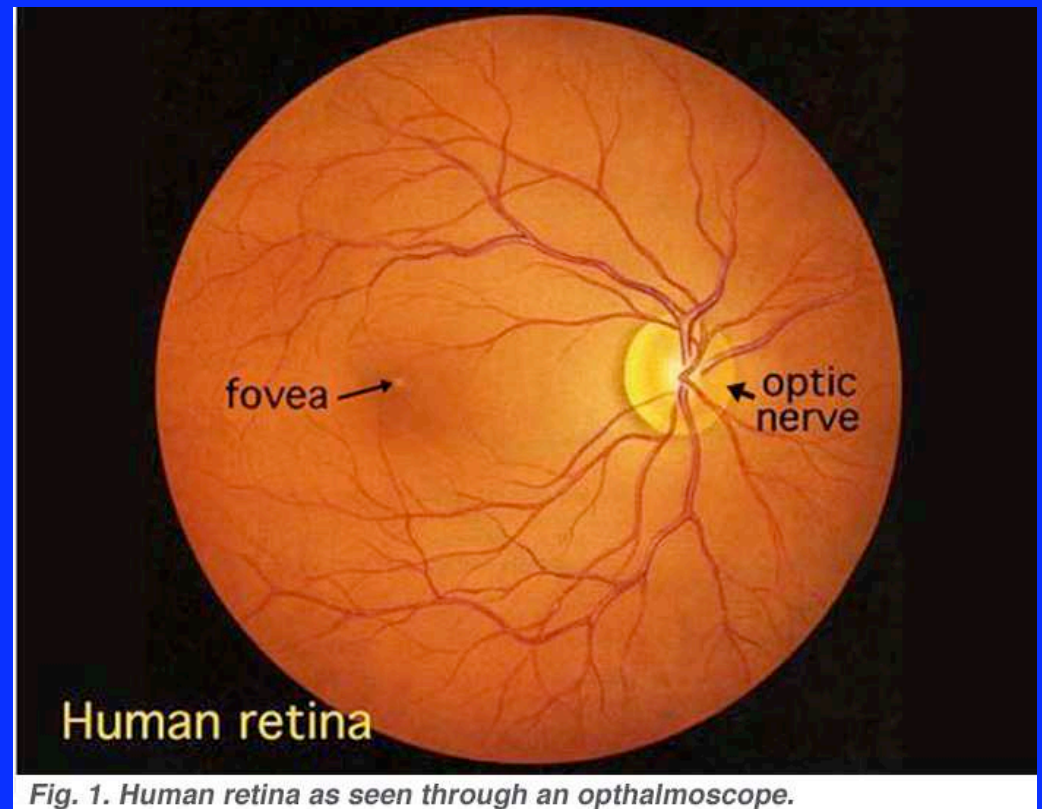


# Structure of the Eye

<http://cas.bellarmine.edu/tietjen/Laboratories/Eye004.gif>



<http://webvision.med.utah.edu/imageswv/huretina.jpeg>



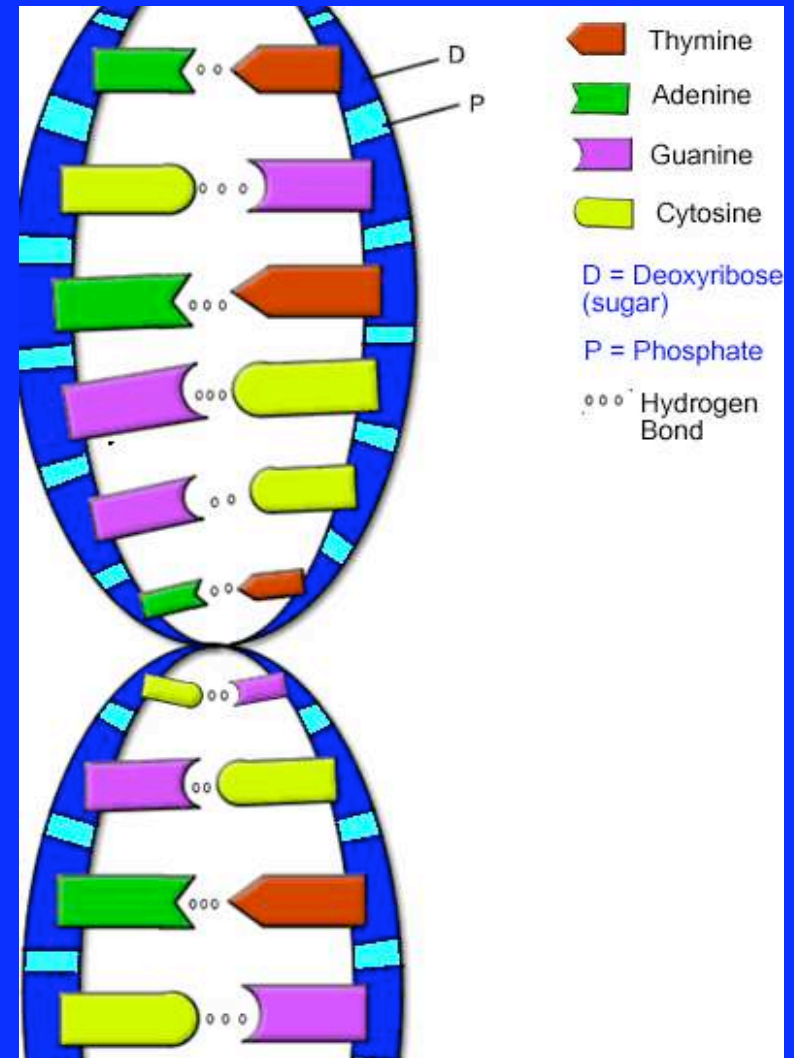
Our optic nerves block part of our retinas, leading to blind spots. Octopus eyes don't have this flaw<sup>14</sup>

But what about at the  
genetic level?



# Genetic basics: DNA

- Double helix  
In humans, 1m long!!
- Four bases: A,T,G,C  
A with T, G with C
- Triplets code for amino acids, e.g.,  
TGT,TGC=cysteine  
20 amino acids  
4x4x4 triplets  
Multiple triplets code for same amino acid
- Amino acids link to make proteins



# Is DNA the Basis for Life Everywhere in the Universe?

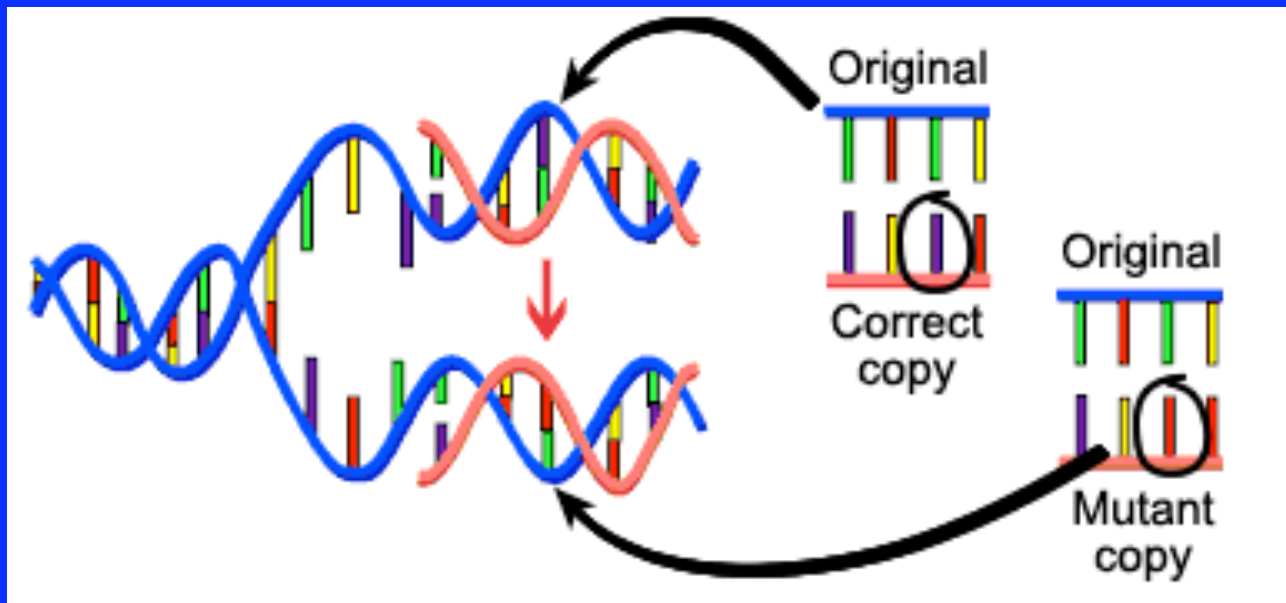
- We don't know, but probably not
- Very early, thought that a different type of molecule (RNA) was genetic basis
- Maybe many such candidate molecules
- In any case, randomness of evolution means that even if aliens have DNA, it is likely to be much different in specifics

# Current Research: Epigenetics

- Gradually being realized that external factors may affect gene expression
- Example: differentiation of stem cells
- Mechanisms studied include effects of shapes, addition of methyl groups to DNA
- I wonder if this will eventually provide yet another way to test common descent...

# DNA and Common Descent

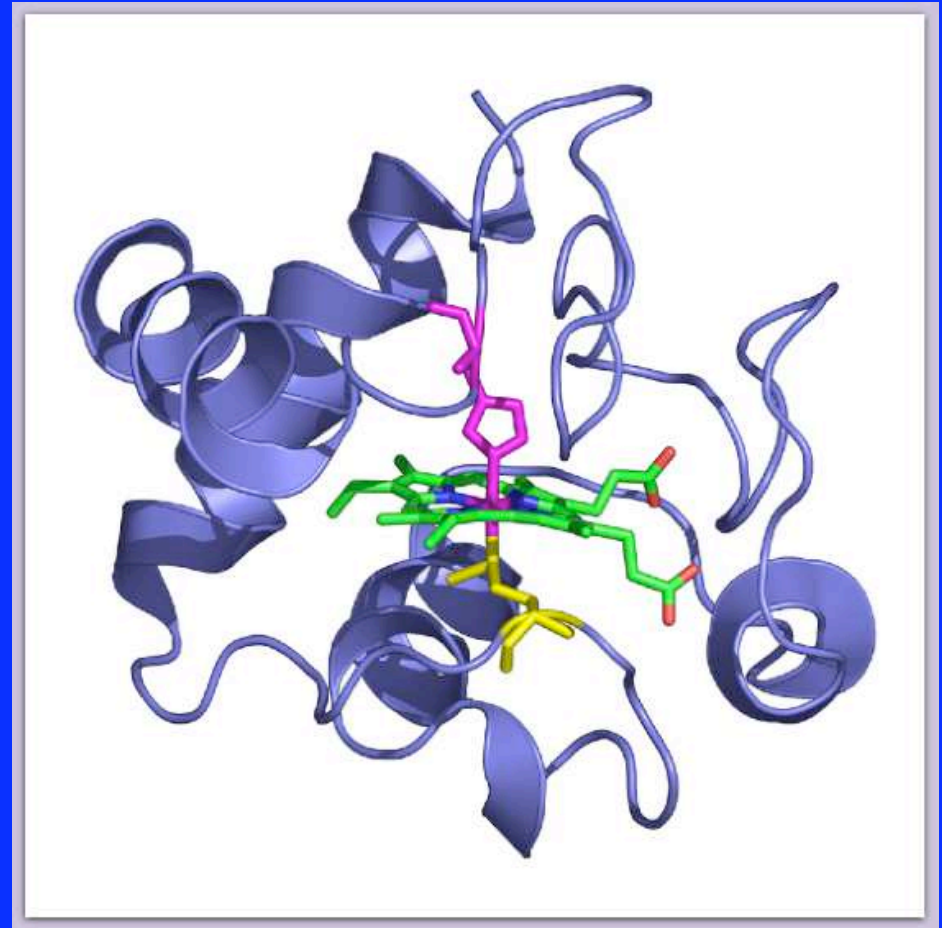
- Mutations happen gradually
- Therefore, common descent predicts that related organisms will have related amino acid sequences and base sequences even if not functionally required



# Ubiquitous Proteins

## Cytochrome c

- Perform same function for all organisms
- Example: Cyt c  
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?







# Evolutionary Prediction Supported

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

## Amino acids reveal evolution

### Cytochrome c Evolution

	Organism	Number of amino acid differences from humans
	Chimpanzee	0
	Rhesus monkey	1
	Rabbit	9
	Cow	10
	Pigeon	12
	Bullfrog	20
	Fruit fly	24
	Wheat germ	37
	Yeast	42

A

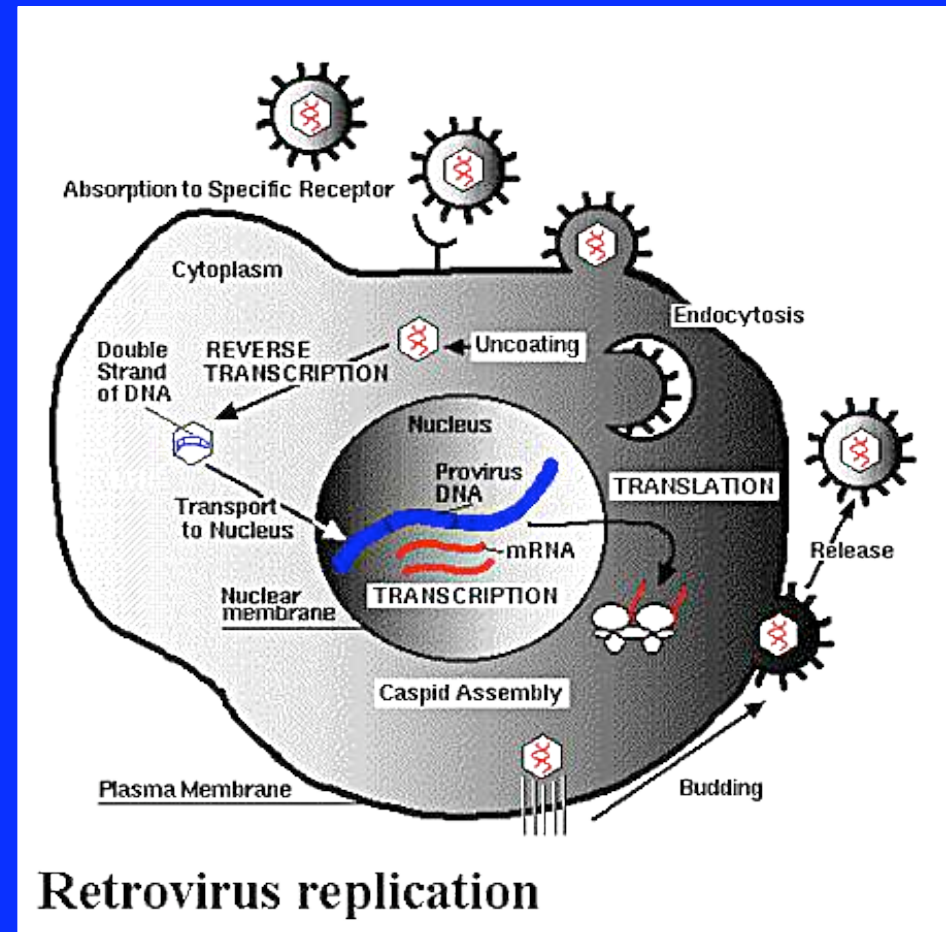
# Functional Subtlety?

- 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



# Endogenous Retroviruses

- Some viruses can, over time, incorporate themselves in our DNA  
**8% of human genome!**
- Not selected for, no functional effect
- But sequences and insertion points support common descent!



# Additional Test: DNA Sequence

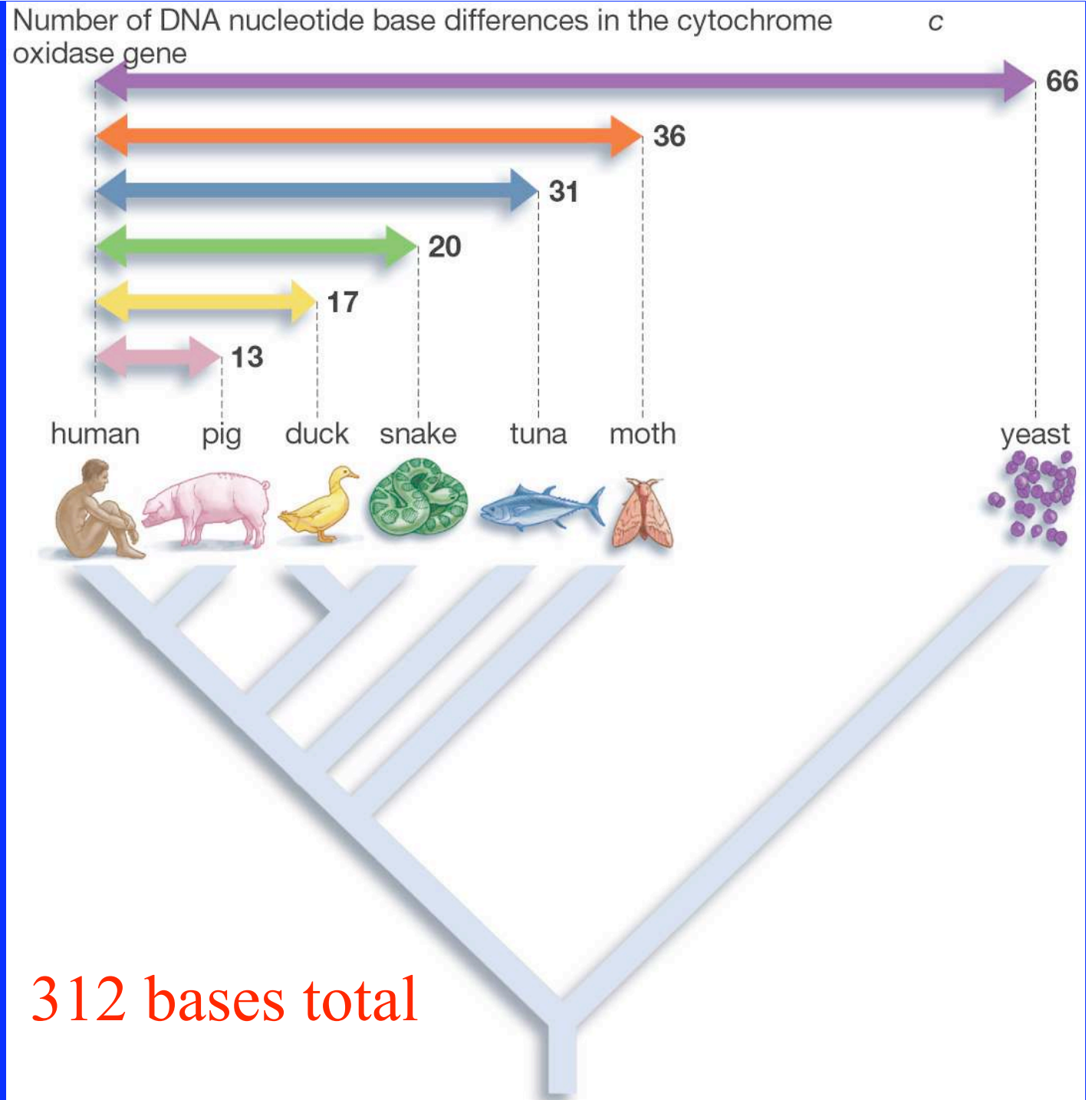
- On average, 3 triplets code for each amino acid
- Thus  $3^{104} \sim 4 \times 10^{49}$  *exactly equivalent* sequences for cyt c
- No reason but common descent for similarity
- What do data say?

		Second Letter				
		T	C	A	G	
First Letter	T	TTT } Phe TTC } TTA } Leu TTG }	TCT } TCC } Ser TCA } TCG }	TAT } Tyr TAC } TAA Stop TAG Stop	TGT } Cys TGC } TGA Stop TGG Trp	T C A G
	C	CTT } CTC } Leu CTA } CTG }	CCT } CCC } Pro CCA } CCG }	CAT } His CAC } CAA Gln CAG }	CGT } CGC } Arg CGA } CGG }	T C A G
	A	ATT } ATC } Ile ATA } ATG Met	ACT } ACC } Thr ACA } ACG }	AAT } Asn AAC } AAA Lys AAG }	AGT } Ser AGC } AGA } Arg AGG }	T C A G
	G	GTT } GTC } Val GTA } GTG }	GCT } GCC } Ala GCA } GCG }	GAT } Asp GAC } GAA Glu GAG }	GGT } GGC } Gly GGA } GGG }	T C A G

## 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?



# Comparative Genomic 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 Monday when they revealed that DNA sequences are identical. The findings appear to contain clues to how humans and their closest relatives in the animal kingdom evolved.

"We're really looking at an incredible discovery," 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."*

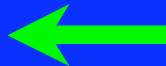




# Testing the Evolutionary Hypothesis of Common Ancestry

Chromosome numbers in the great apes:

human ( <i>Homo</i> )	46
chimpanzee ( <i>Pan</i> )	48
gorilla ( <i>Gorilla</i> )	48
orangutan ( <i>Pongo</i> )	48

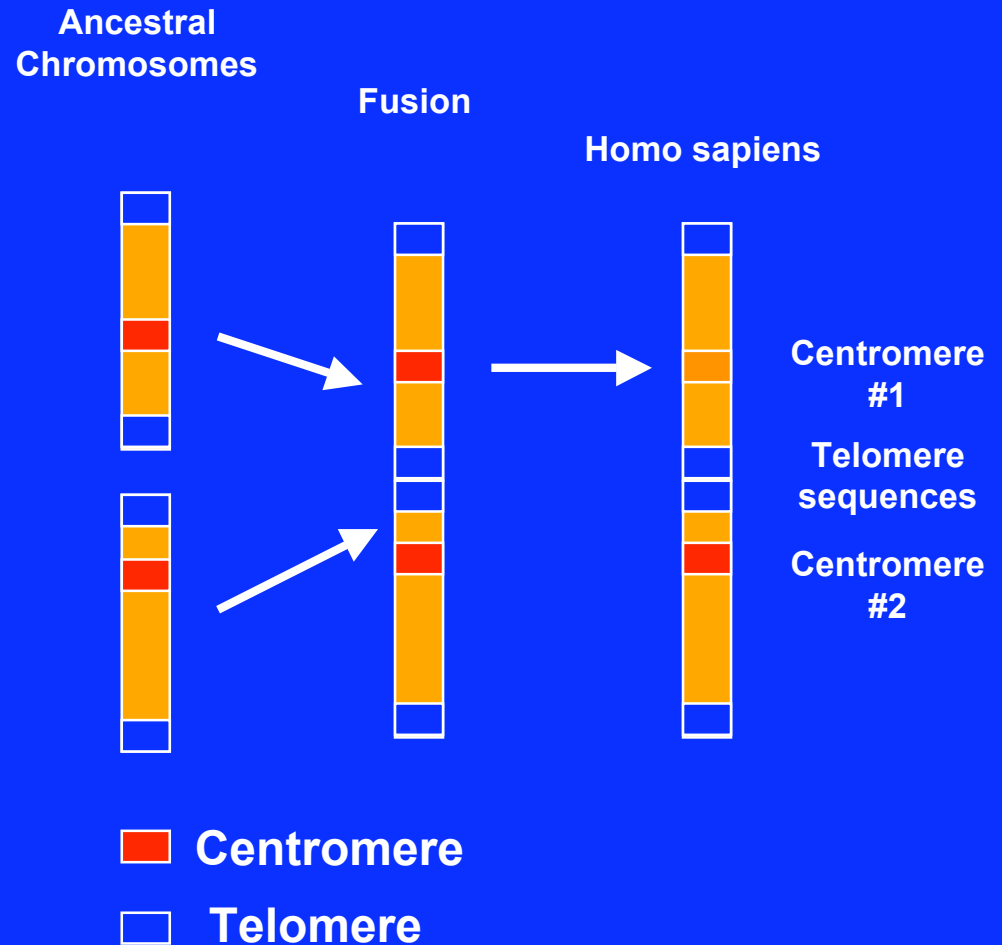


**Testable prediction:** If these organisms share common ancestry, the human genome must contain a fused chromosome.



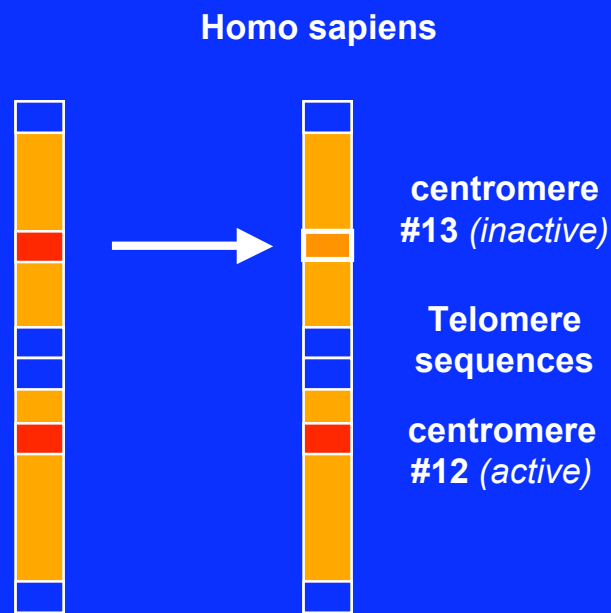
## Chromosome numbers in the great apes (Hominidae):

human (Homo)	46
chimpanzee (Pan)	48
gorilla (Gorilla)	48
orangutan (Pongo)	48



**Testable prediction:** The marks of that fusion must appear in one of the human chromosomes.

# Human Chromosome #2 shows the exact point at which this fusion took place



Chromosome 2 is unique to the human lineage of evolution, having emerged as a result of head-to-head fusion of two acrocentric chromosomes that remained separate in other primates.

**Hillier *et al* (2005)** “Generation and Annotation of the DNA sequences of human chromosomes 2 and 4,” *Nature* 434: 724-731.

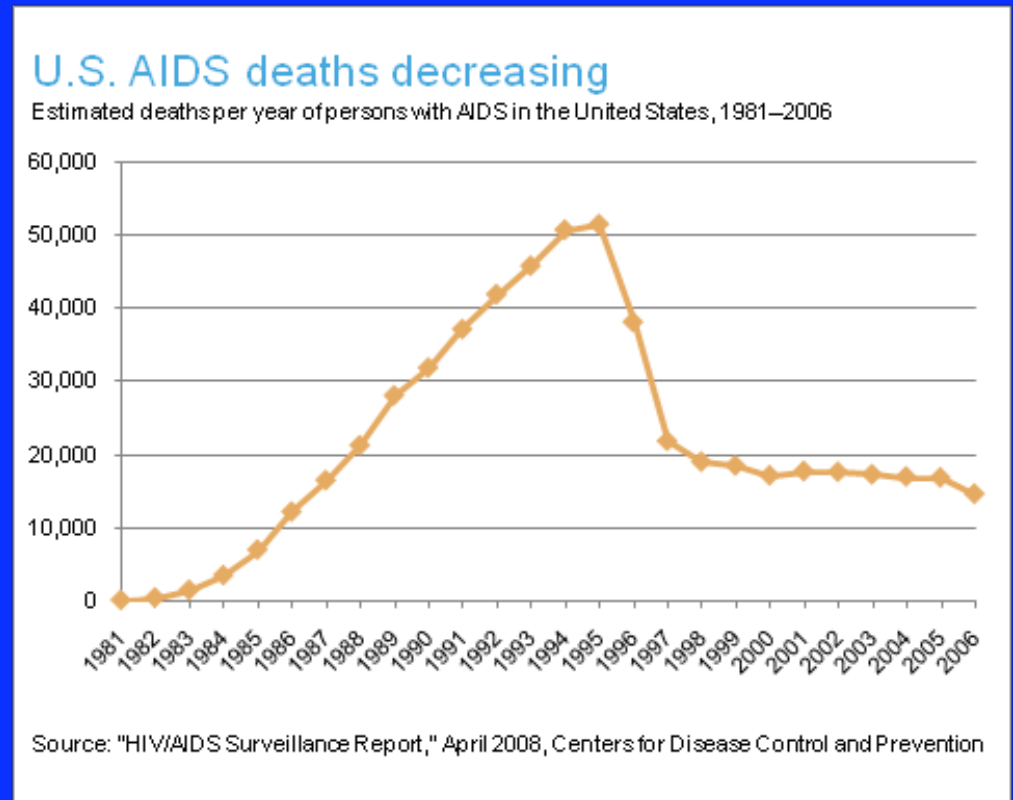


# Perspective

- 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

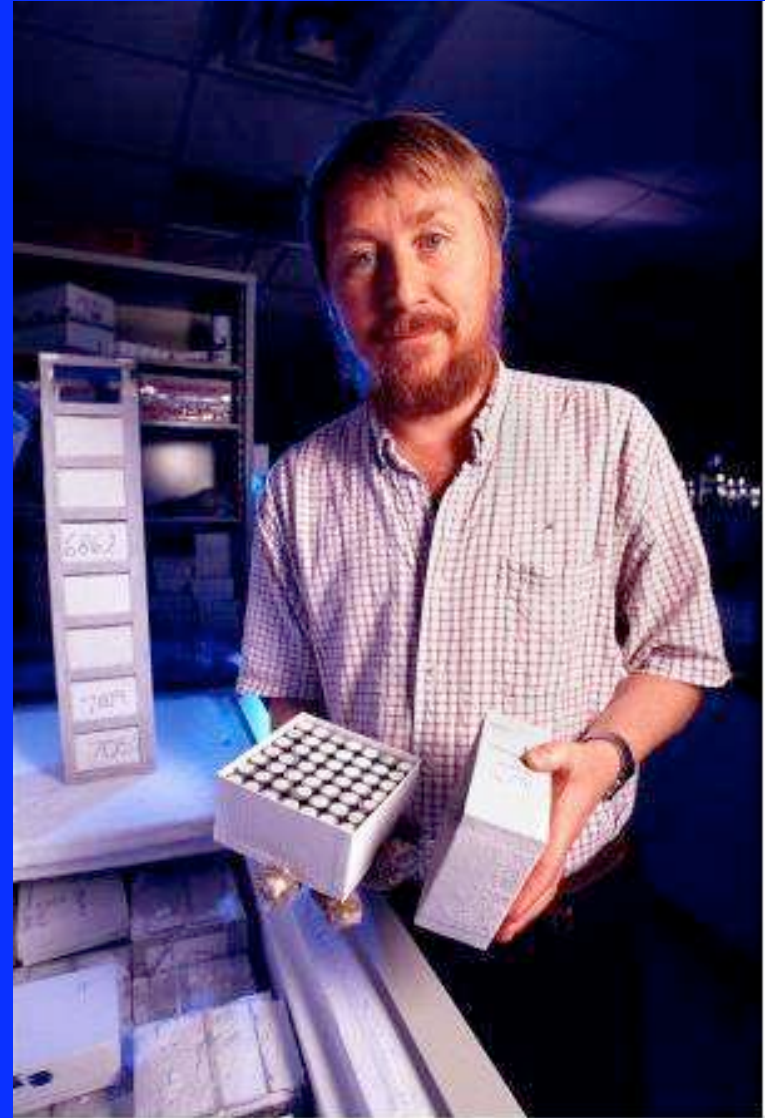
- Why plunge in US deaths?  
Still terrible, but...
- AIDS caused by virus  
Reproduces fast  
Adjusts quickly
- Evolution says: can't make many mutations at once if each unhelpful  
So, three drugs at once
- Has held up so far...



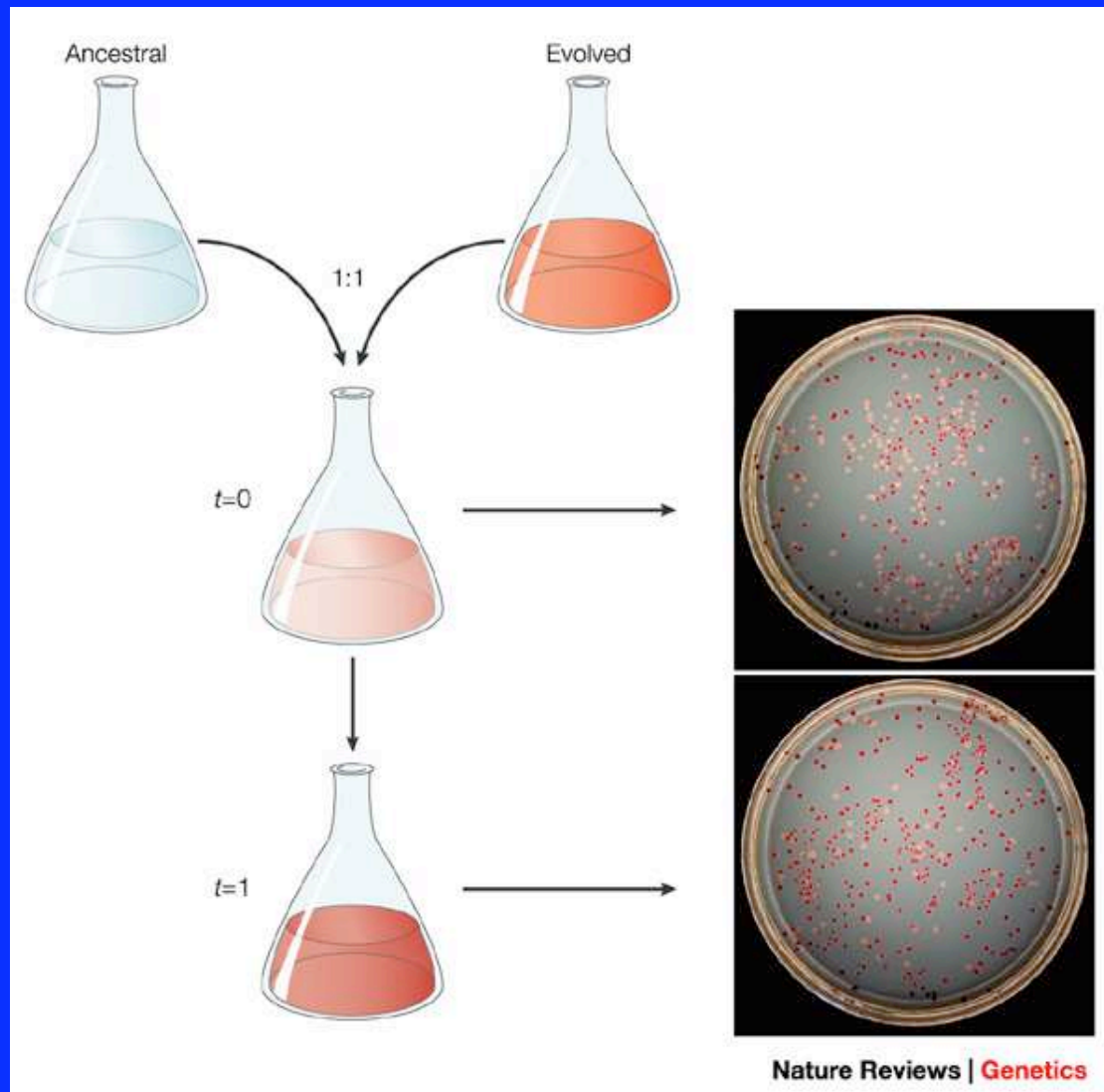
[http://www.publicagenda.org/files/charts/ff\\_healthcare\\_us\\_aids\\_deaths\\_decreasing.png](http://www.publicagenda.org/files/charts/ff_healthcare_us_aids_deaths_decreasing.png)

# Evolution in the Lab

- Richard Lenski  
Michigan State Univ.
- Start: cloned E. coli  
Genetically identical!
- In test tube, feed for day, remove, repeat...  
>40,000 generations
- Results?  
Genetic diversity  
More fit for environ.  
Multi-stage mutation



# Change in Relative Fitness



Put ancestral,  
evolved strains  
in same flask.

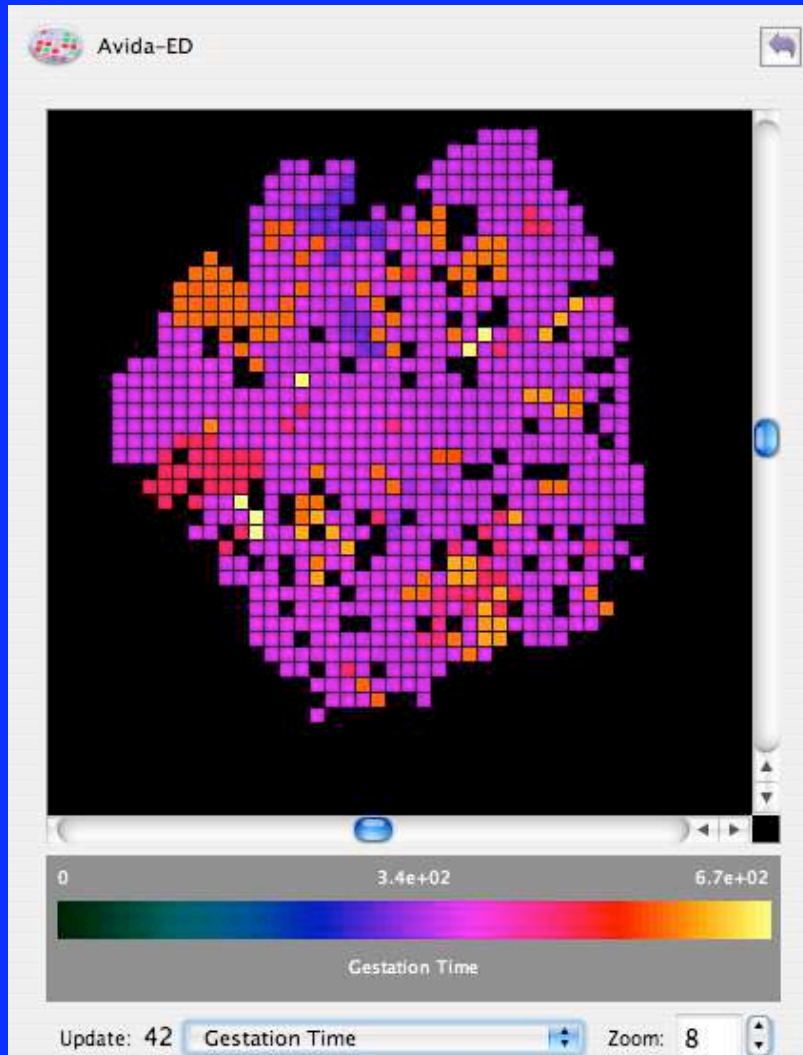
Wait...

Evolved strain is  
much more  
competitive  
in environment

# Origin of Novelty

- Test tubes involve citrate as well as glucose  
But *E. coli* 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!

# Digital Evolution



Lenski and crew also work on digital evolution. Computer code that can mutate, modify, reproduce, compete, without user involvement. Can thus follow all steps. Have seen novelties originate.

# Evolution in Nature: Antibiotic Resistance

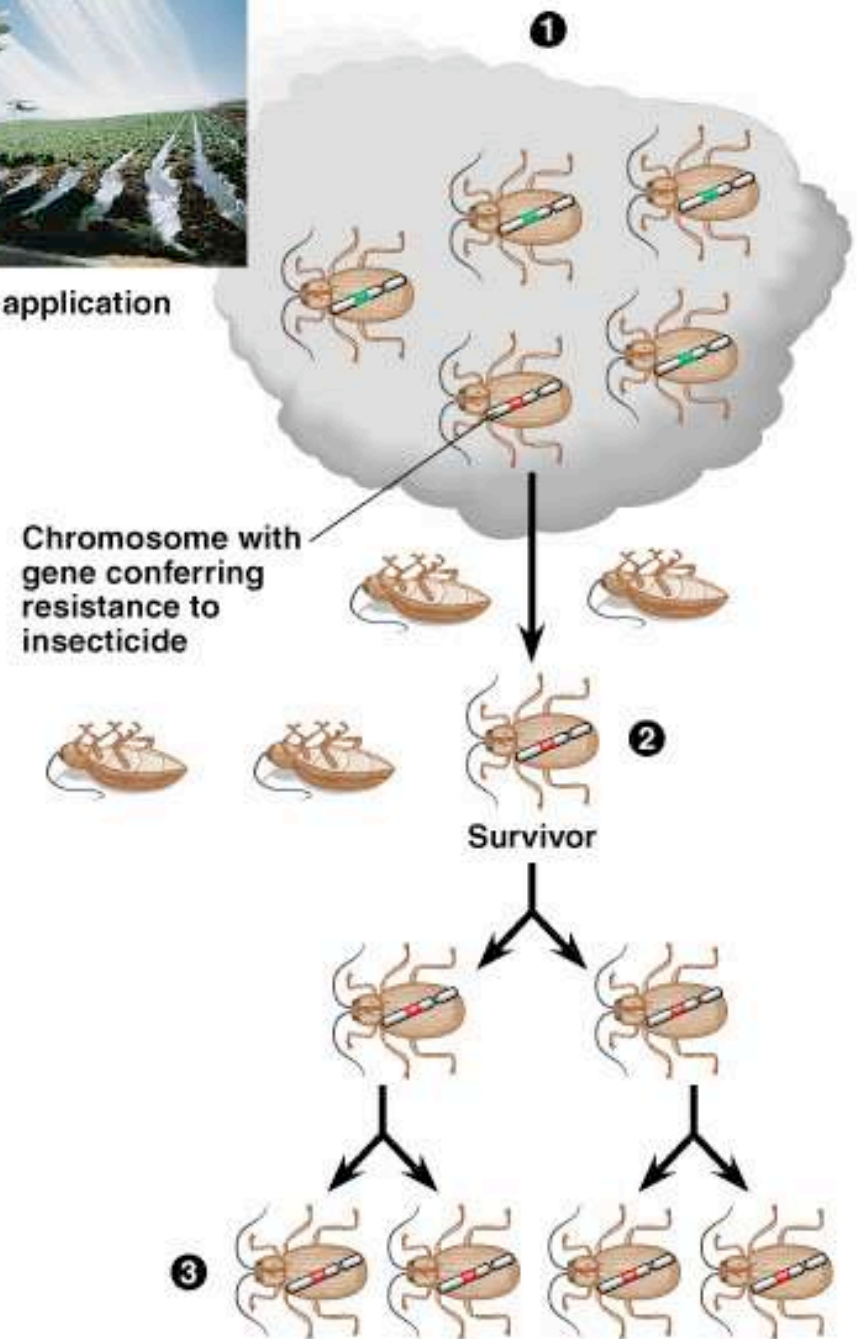
- “Old standbys” (penicillin, streptomycin, etc.) don’t work as well as they used to
- Why? Bacteria have evolved to resist them
- Evolution is accelerated by overuse of antibiotics in livestock  
Gives bacteria more adaptive chances!
- This is why you *finish* an antibiotic regimen  
Otherwise, remaining bugs more resistant!



# Evolution of pesticide resistance

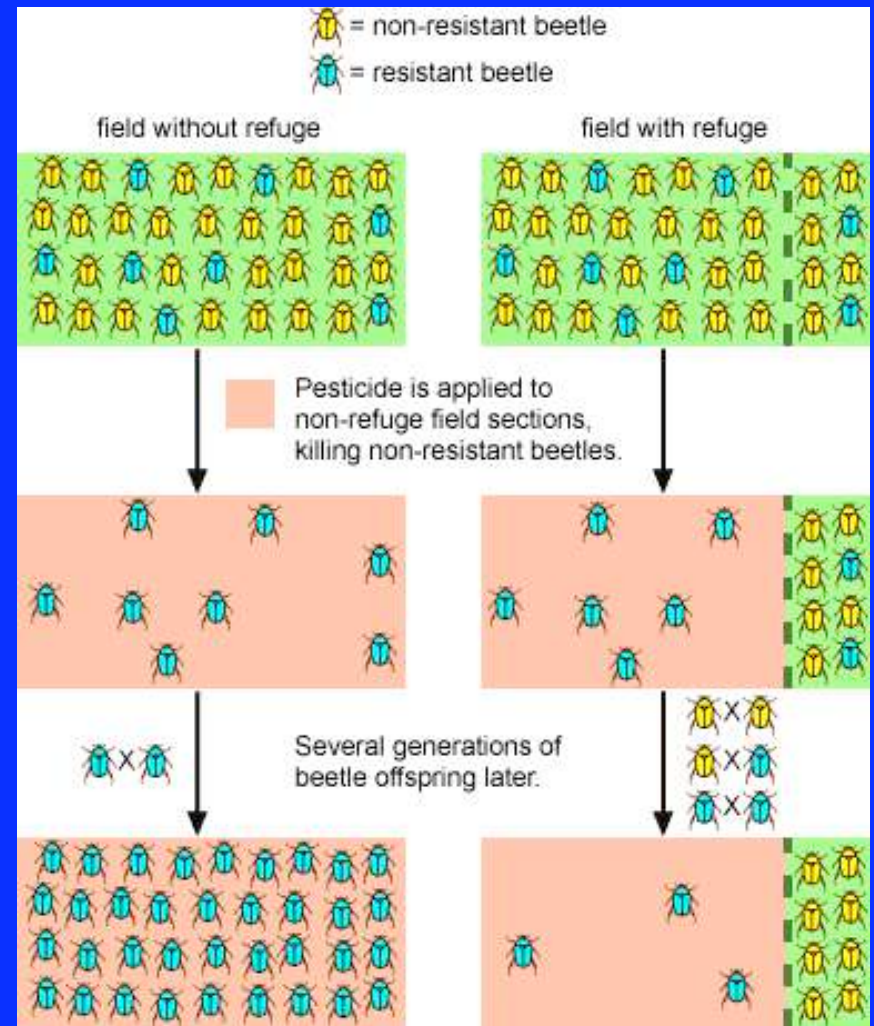


Insecticide application



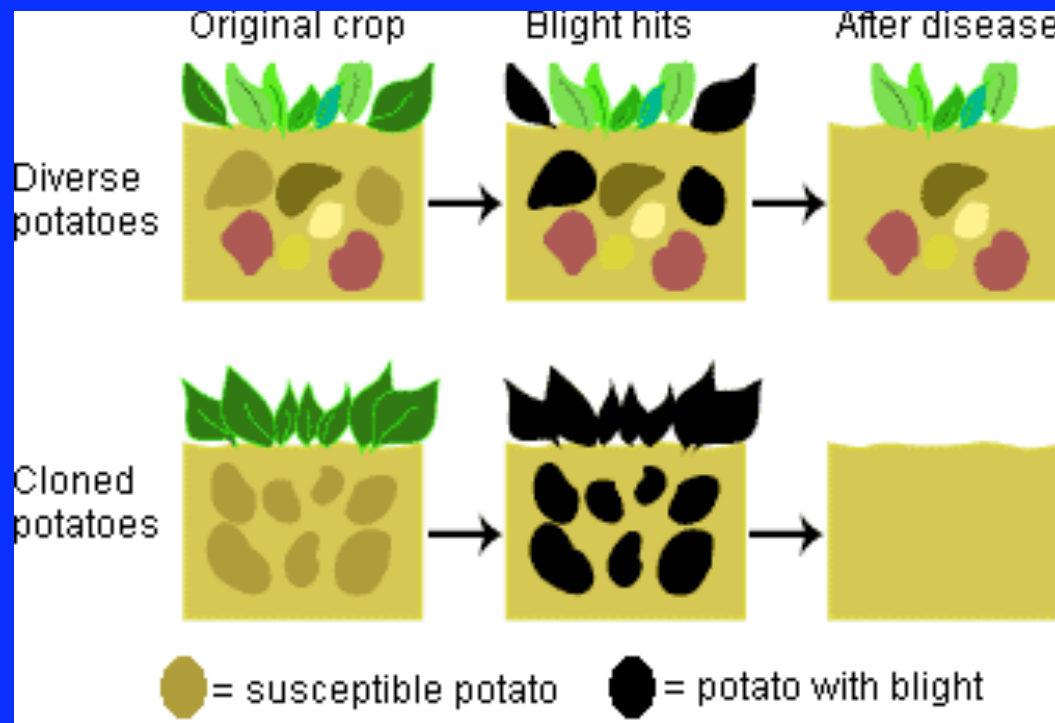
# Using Evolution to Combat Pests

- Bt pesticide  
Allele is recessive
- If spray all, resistance spreads fast
- If leave refuge unsprayed, breeding reduces number of resistant insects



# Evolution and Genetic Diversity

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



[http://evolution.berkeley.edu/evolibrary/article/0\\_0\\_0/agriculture\\_02](http://evolution.berkeley.edu/evolibrary/article/0_0_0/agriculture_02)

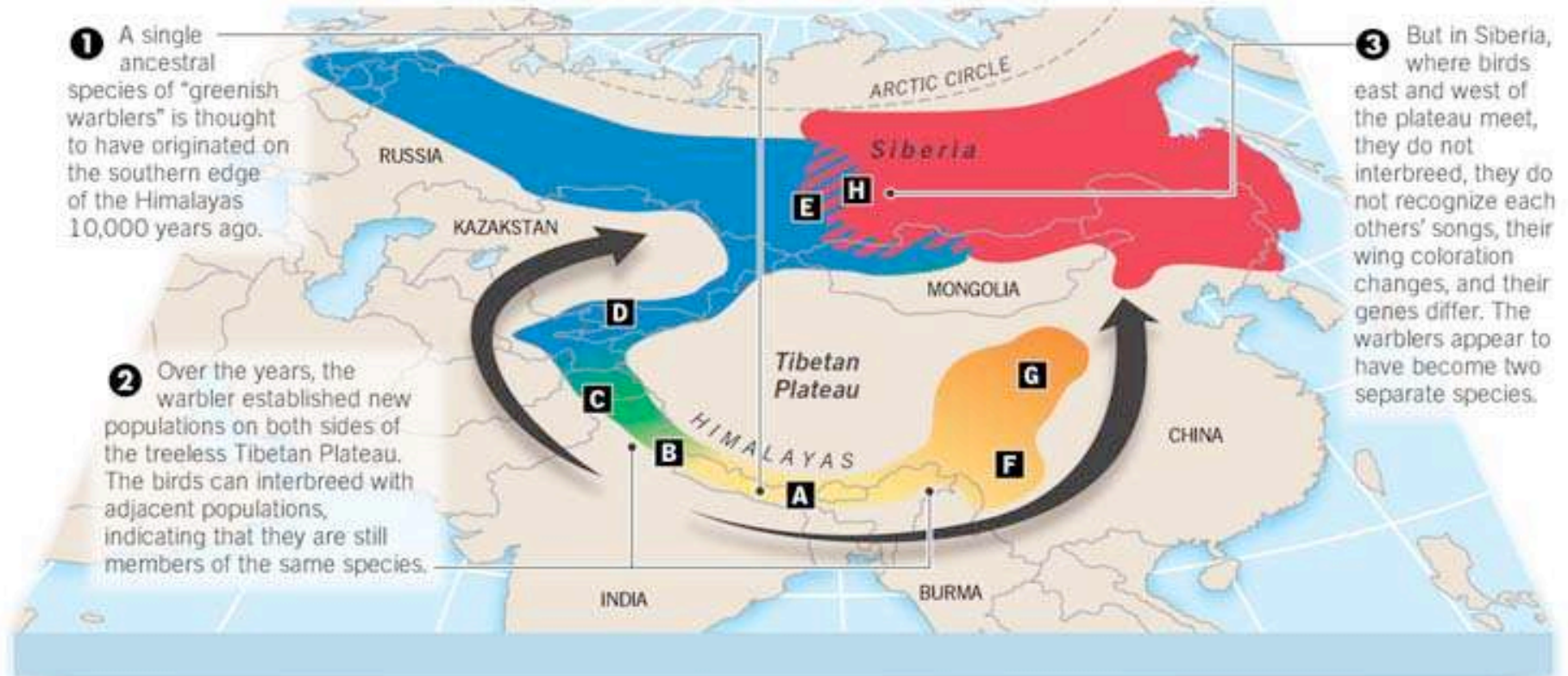
# Recent Low-Diversity Examples

- 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*



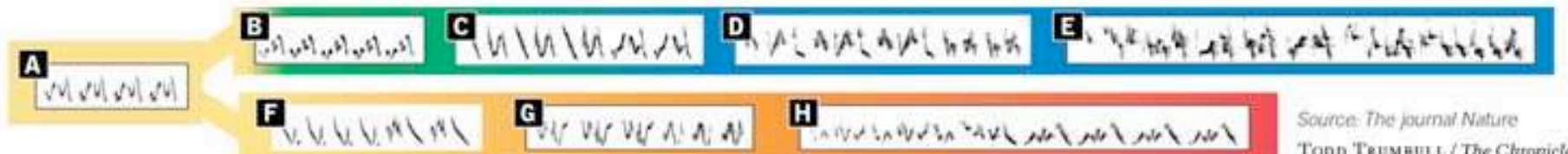
## Tracing the Evolution of Species

Biologists have discovered two populations of Eurasian songbirds in Siberia that show the strongest evidence yet of having evolved from a single ancestral species into two distinct ones. The map below shows the present ranges of the birds around the Tibetan Plateau, with gradations of color indicating where gradual changes have evolved between one subspecies and another.



### Singing a new song

Sound spectrograms show how the warblers' songs at various locations on the map (A through H) become more complex until, where the two populations occupy the same range (at E and H), they can no longer recognize each others' songs.



Source: The journal Nature  
TODD TRUMBULL / The Chronicle

**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
- What about fossil evidence? What can we say about evolution over times much greater than we can investigate directly?