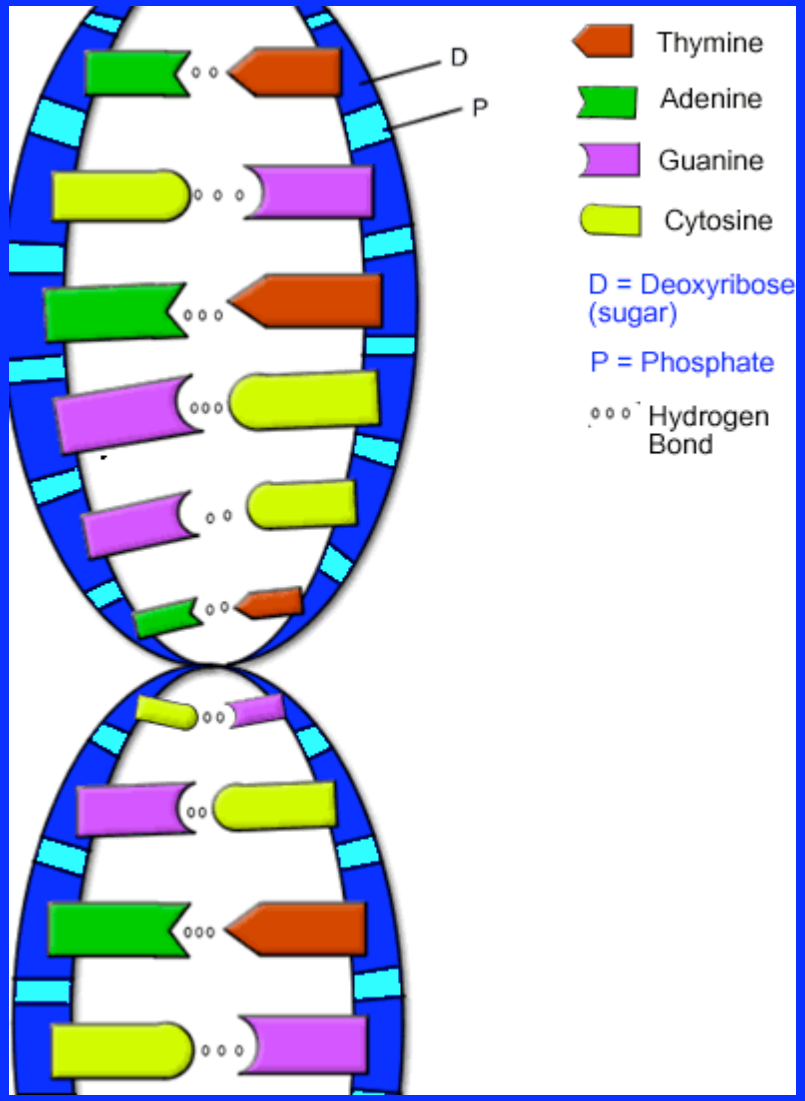
Genetic Evidence for Evolution



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

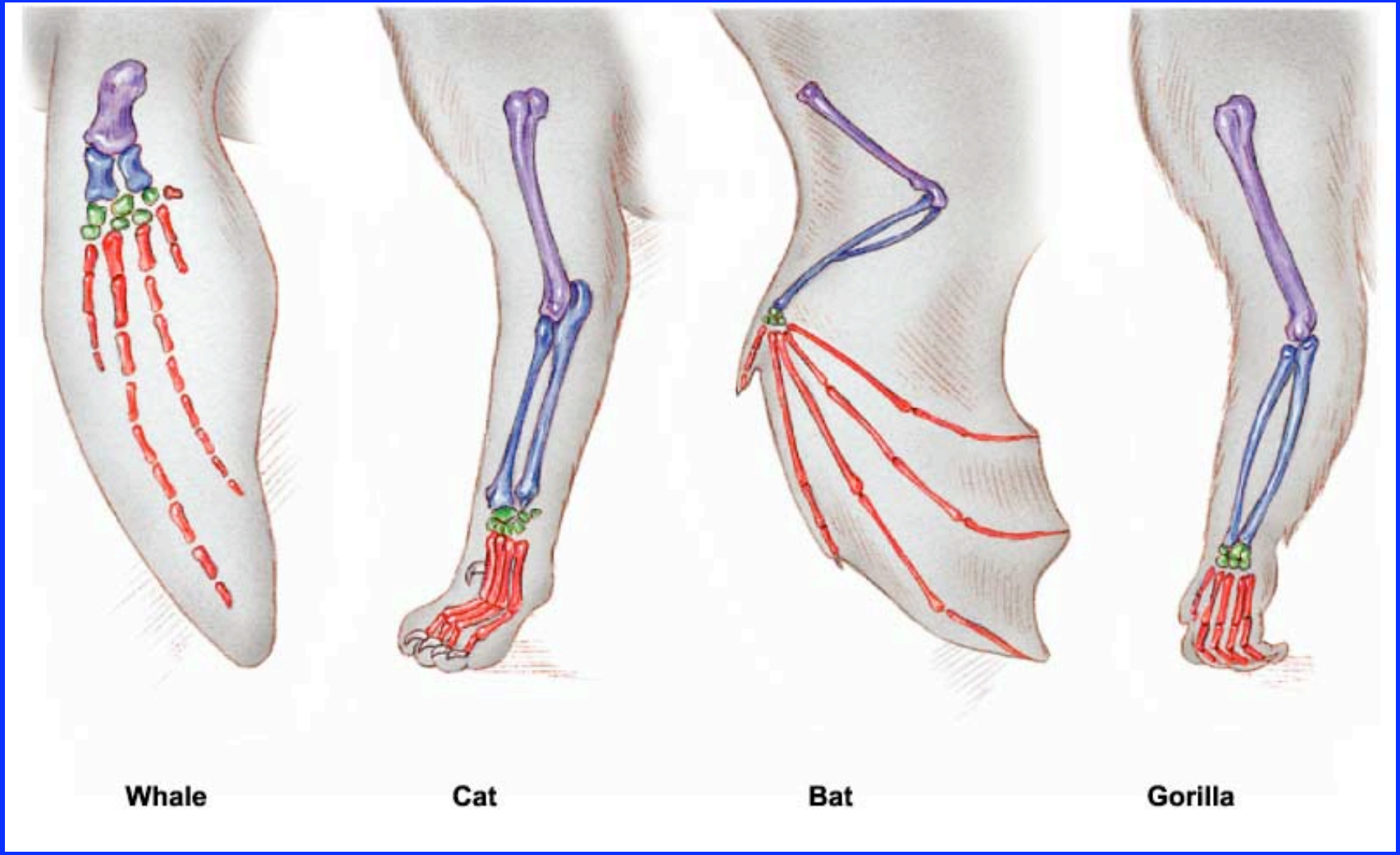
Breaking News: Water on Moon!

- 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

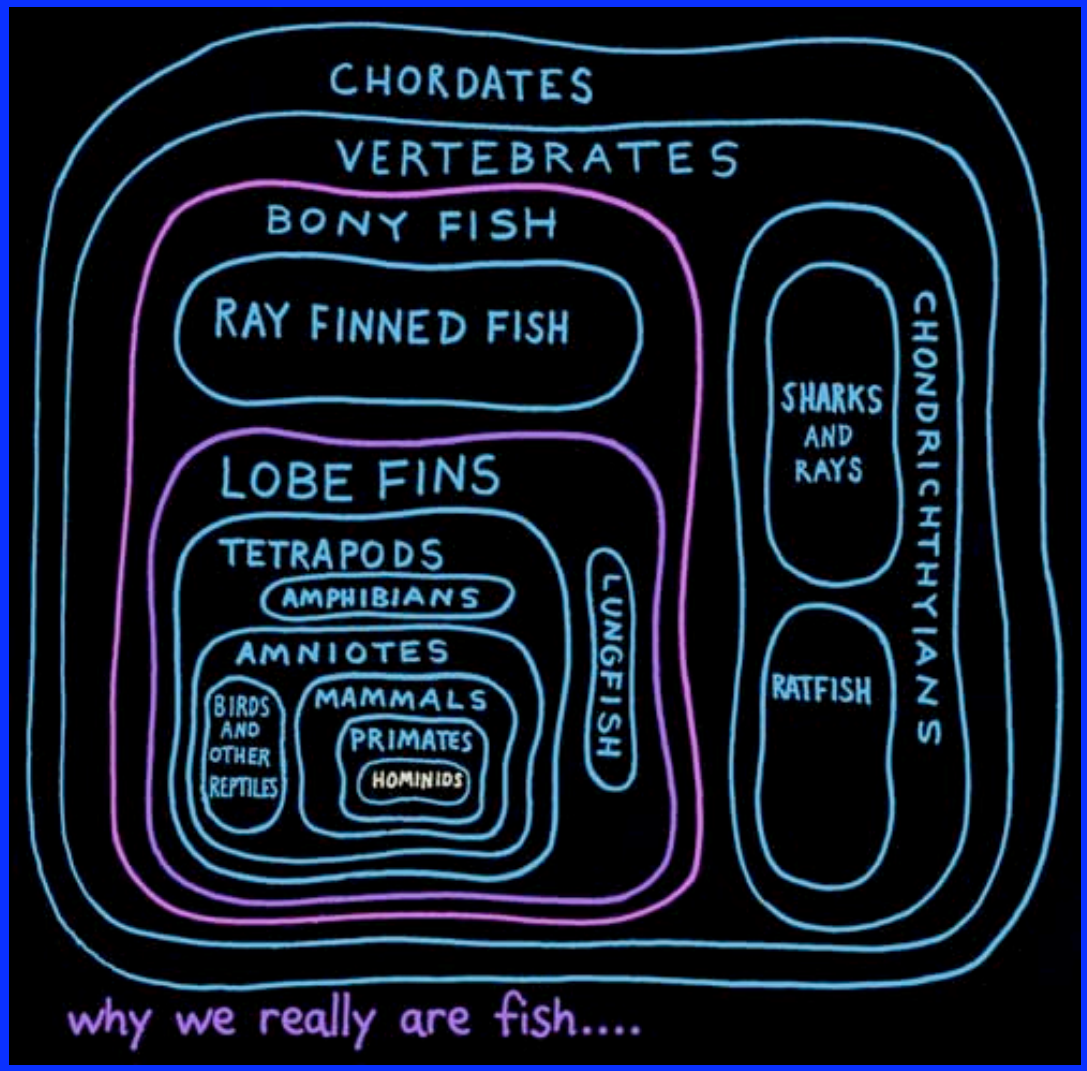
- Darwin had no concept of genetics
- Therefore, genetic tests subject evolution to a whole new set of possible falsifications
- How does it do?

Evidence for Evolution - Comparative Morphology



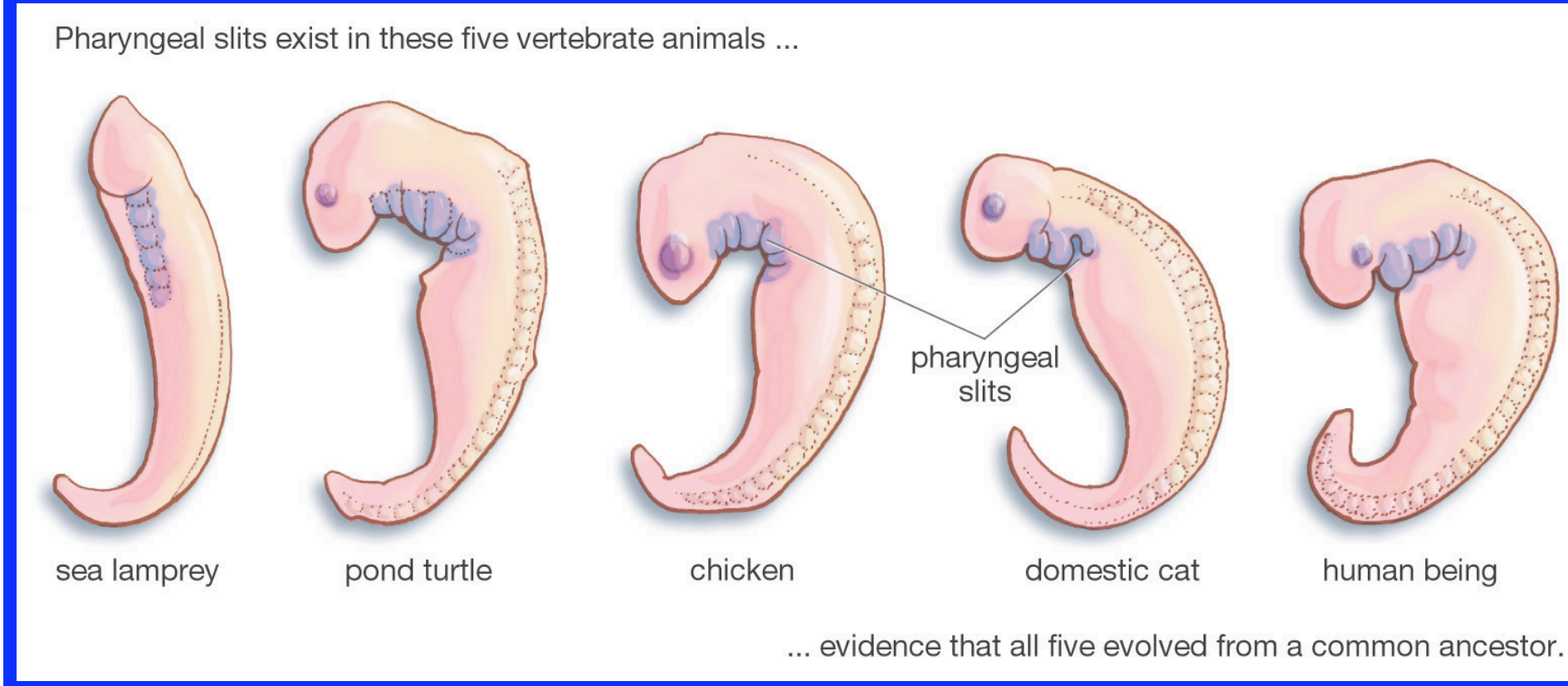
Why use the same skeletal plan for these very different appendages?

Your Inner Fish (Shubin)



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

Evidence for Evolution - Comparative Embryology



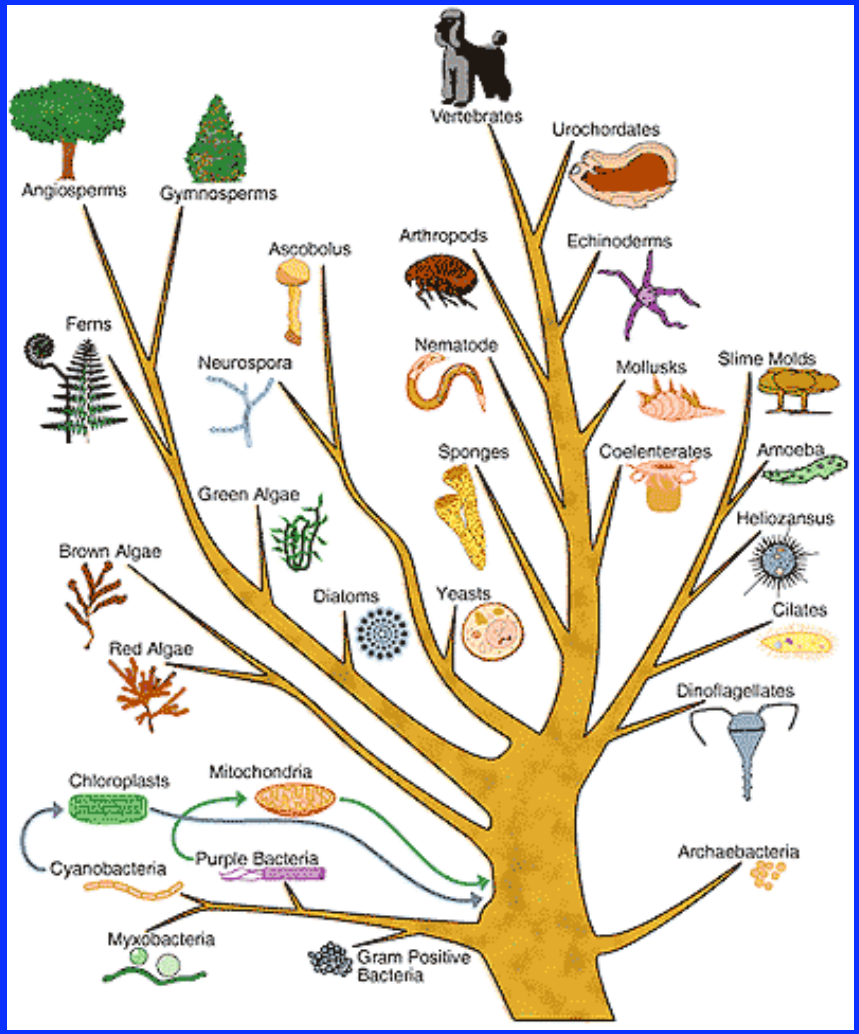
Why do embryos of different animals pass through a similar developmental stage?

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?

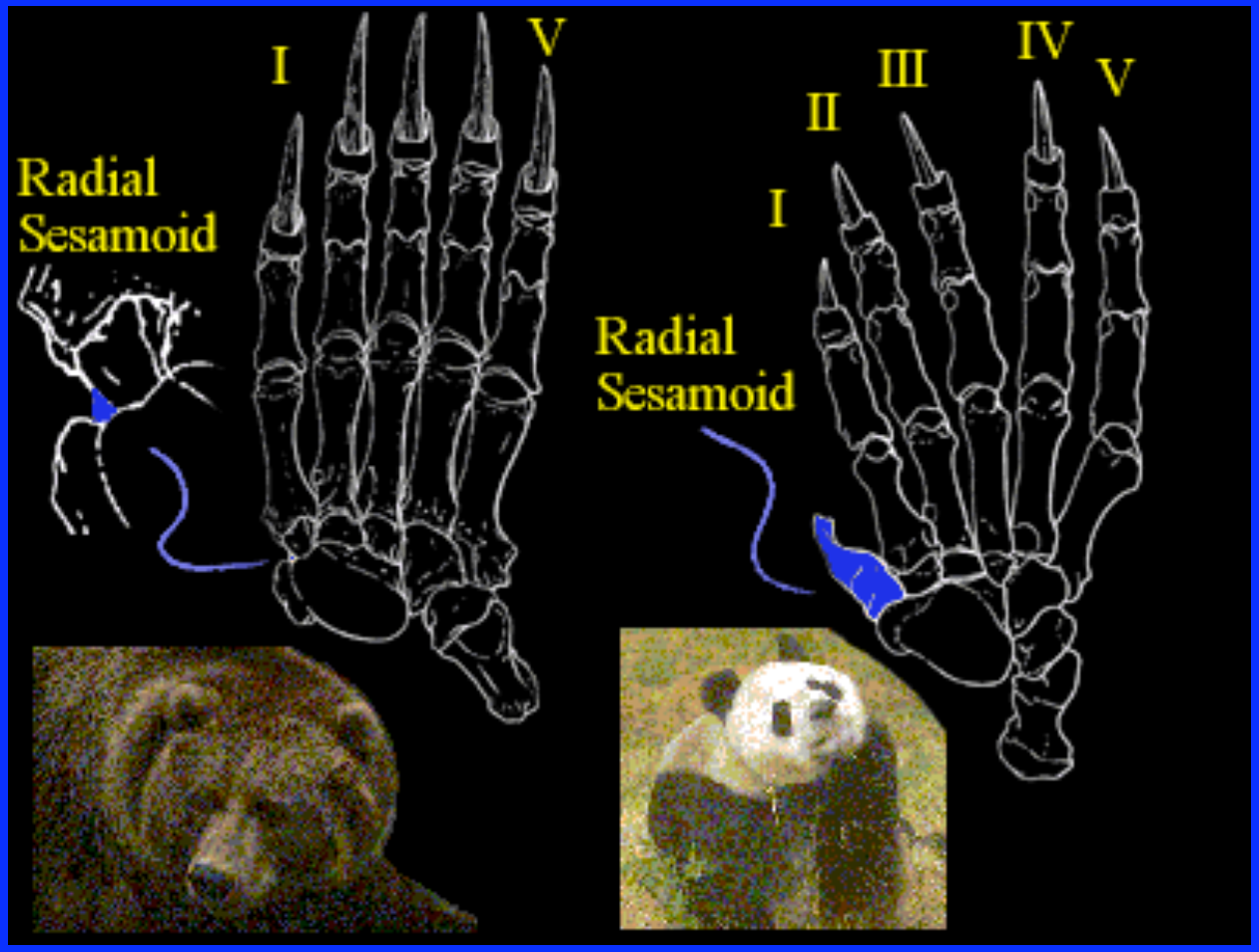


http://www.nbii.gov/portal/server.pt/gateway/PTARGS_0_2_3846_404_1617_43/http%3B/public-content%3B7087/publishedcontent/publish/ecological_issues/genetic_biodiversity/phylogenetic_trees_intro/tree.gi

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



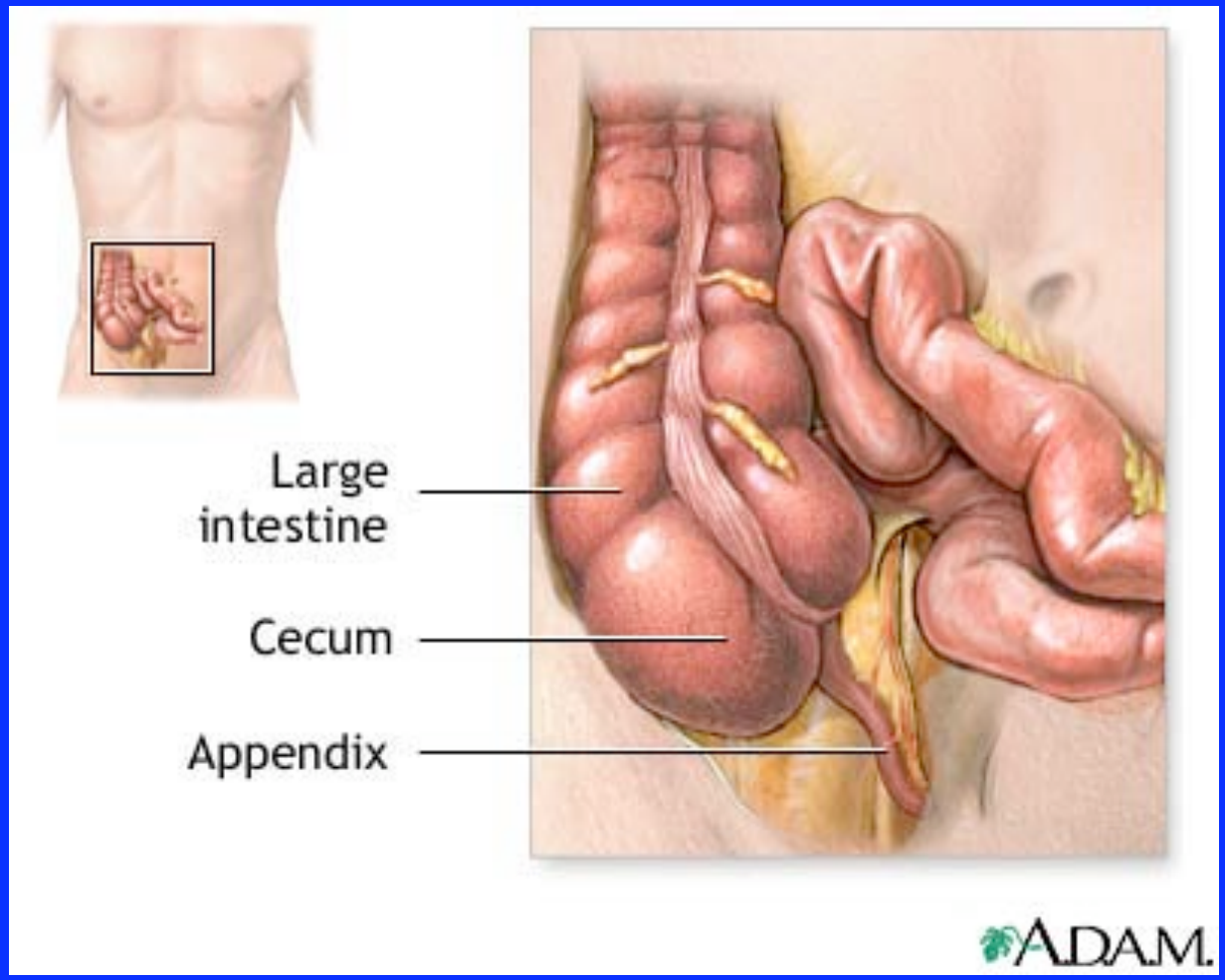
Not a real thumb. Adaptation of a tiny bone in hand.

Used to strip bamboo.

Inefficient!

www.athro.com/evo

The Appendix



No obvious use, at least now.

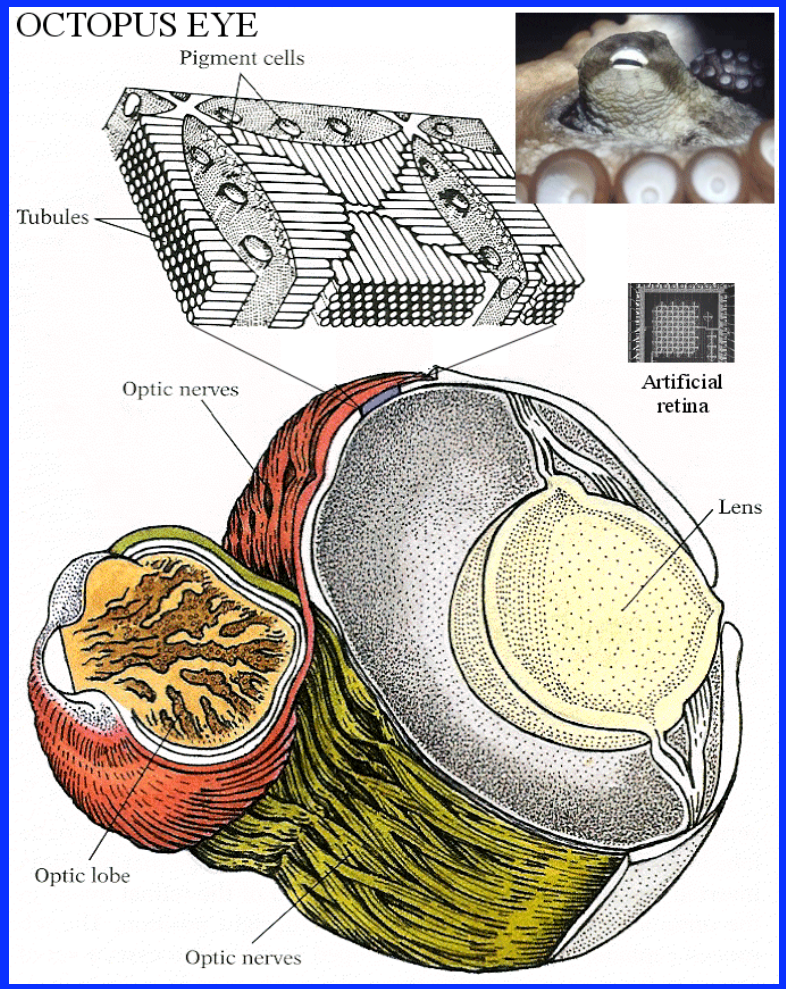
I get along fine without one!

If bursts, can be fatal (Houdini)

http://www.nlm.nih.gov/MEDLINEPLUS/ency/images/ency/fullsize/1128.jpg

Structure of the Eye

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



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

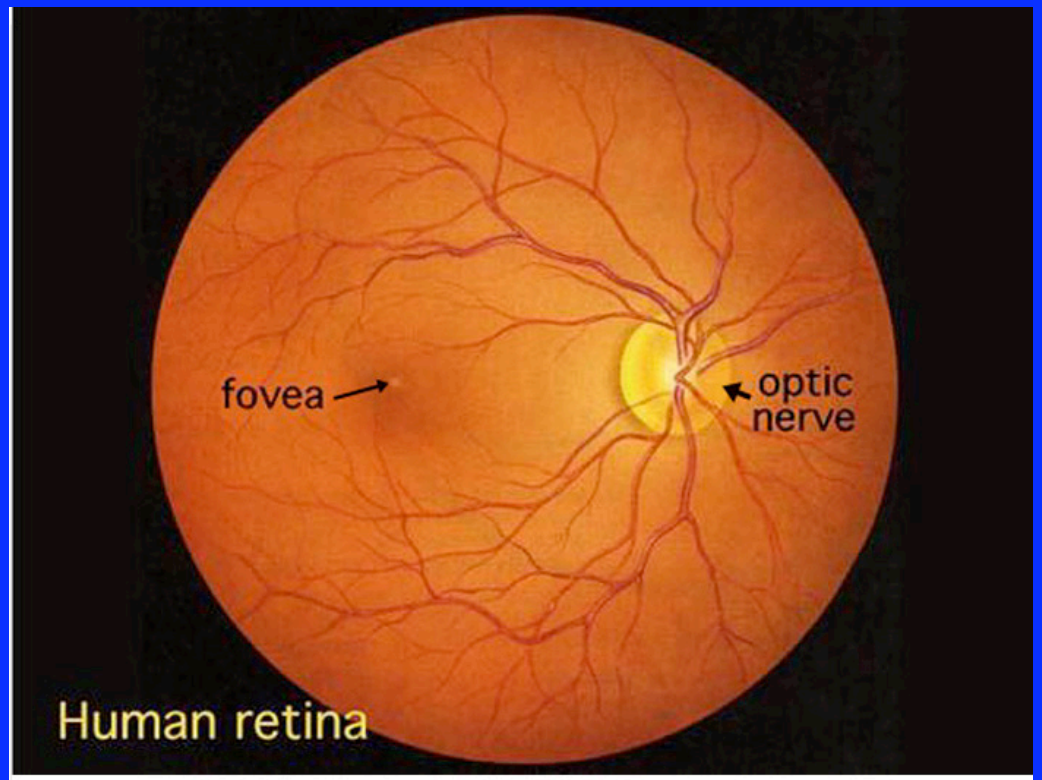


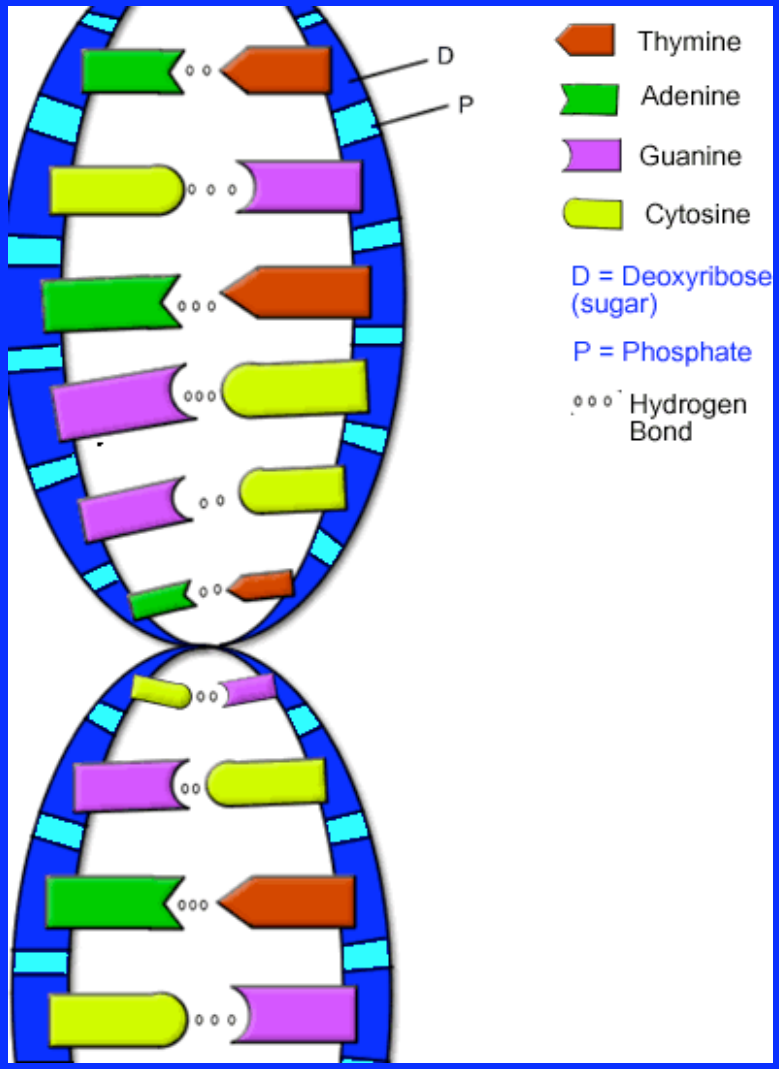
Fig. 1. Human retina as seen through an opthalmoscope.

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

- 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



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

Is DNA the Basis for Life Everywhere in the Universe?

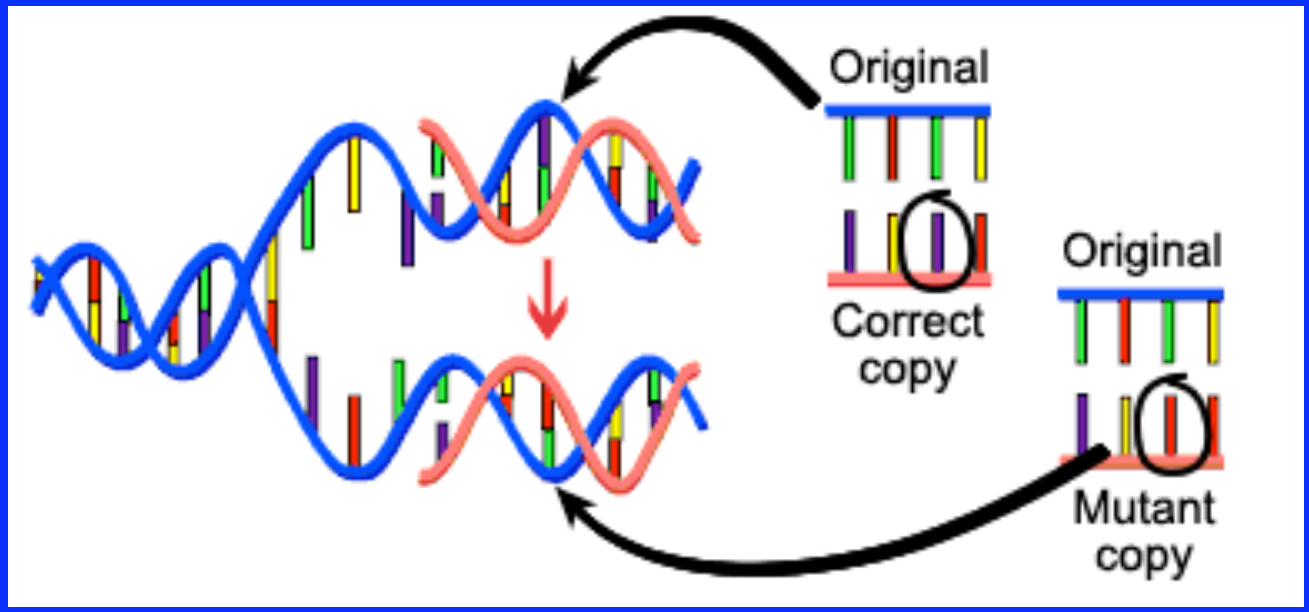
- We don't know, but probably not
- Very early, thought that a different type of molecule (RNA) was genetic basis
- Maybe many such candidate molecules
- In any case, randomness of evolution means that even if aliens have DNA, it is likely to be much different in specifics

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

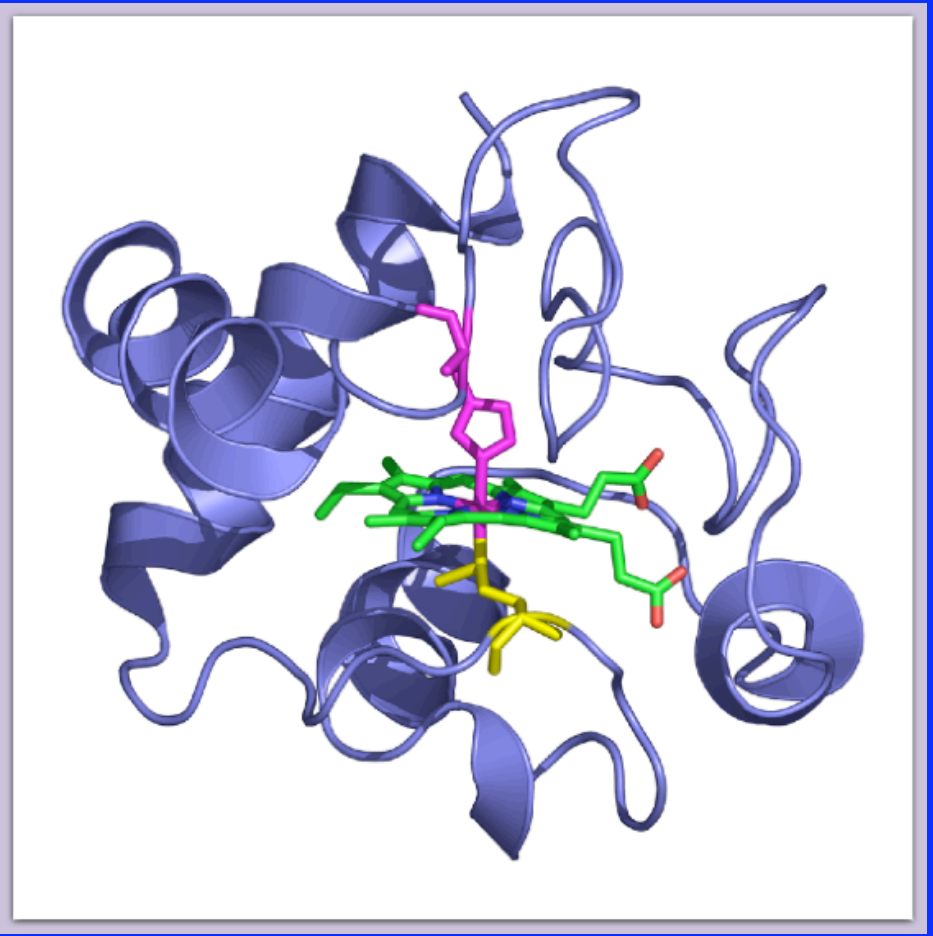


http://evolution.berkeley.edu/evosite/evo101/images/dna-mutation.gif

Ubiquitous Proteins

- 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?

Cytochrome c



http://www.eiu.edu/~eiuchem/faculty/tremain/cytc.png

Evolutionary Prediction Supported

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

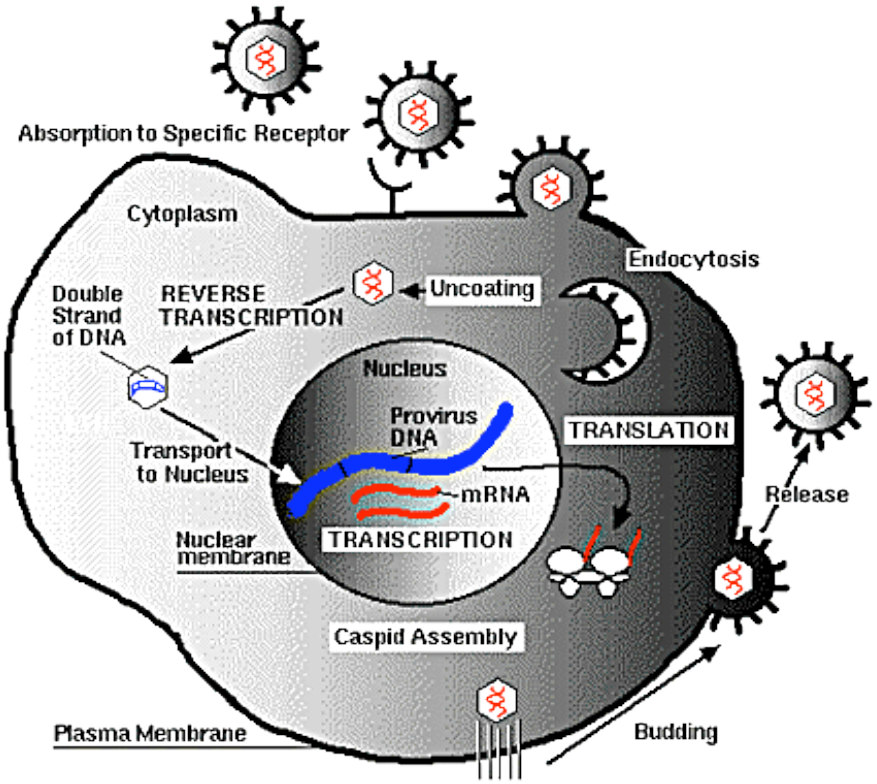
A

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!

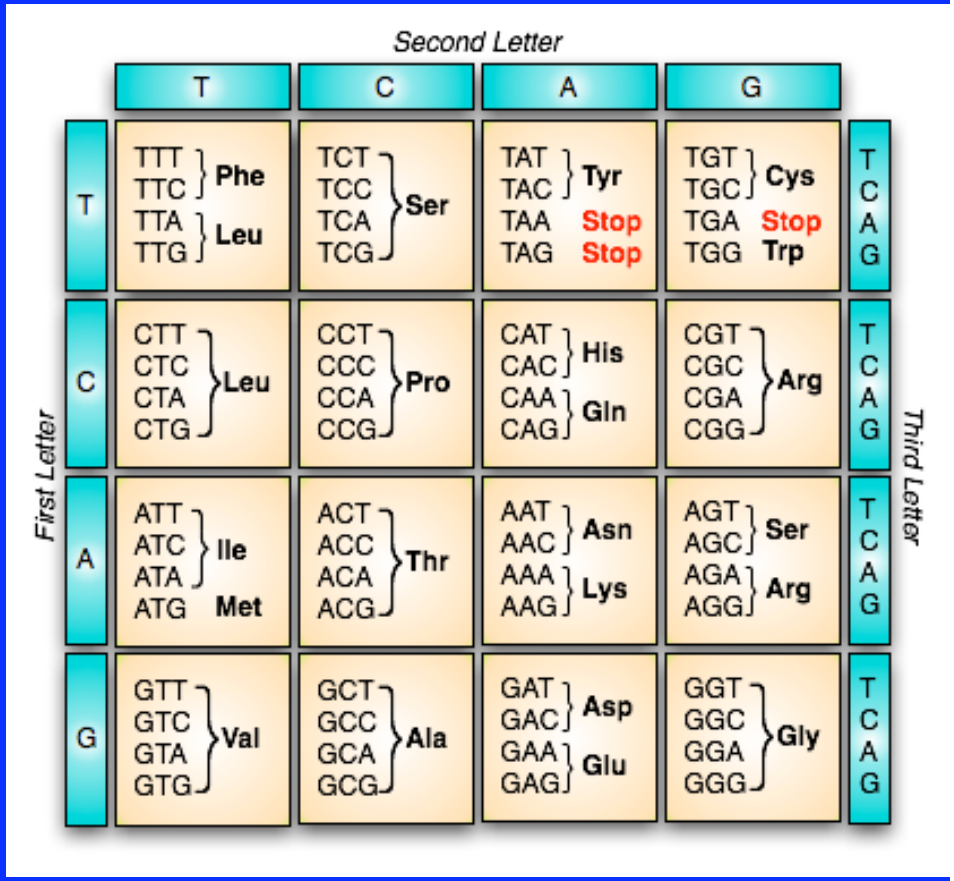


Retrovirus replication

http://www.wellesley.edu/Chemistry/Chem101/hiv/retrovirus.gif

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?

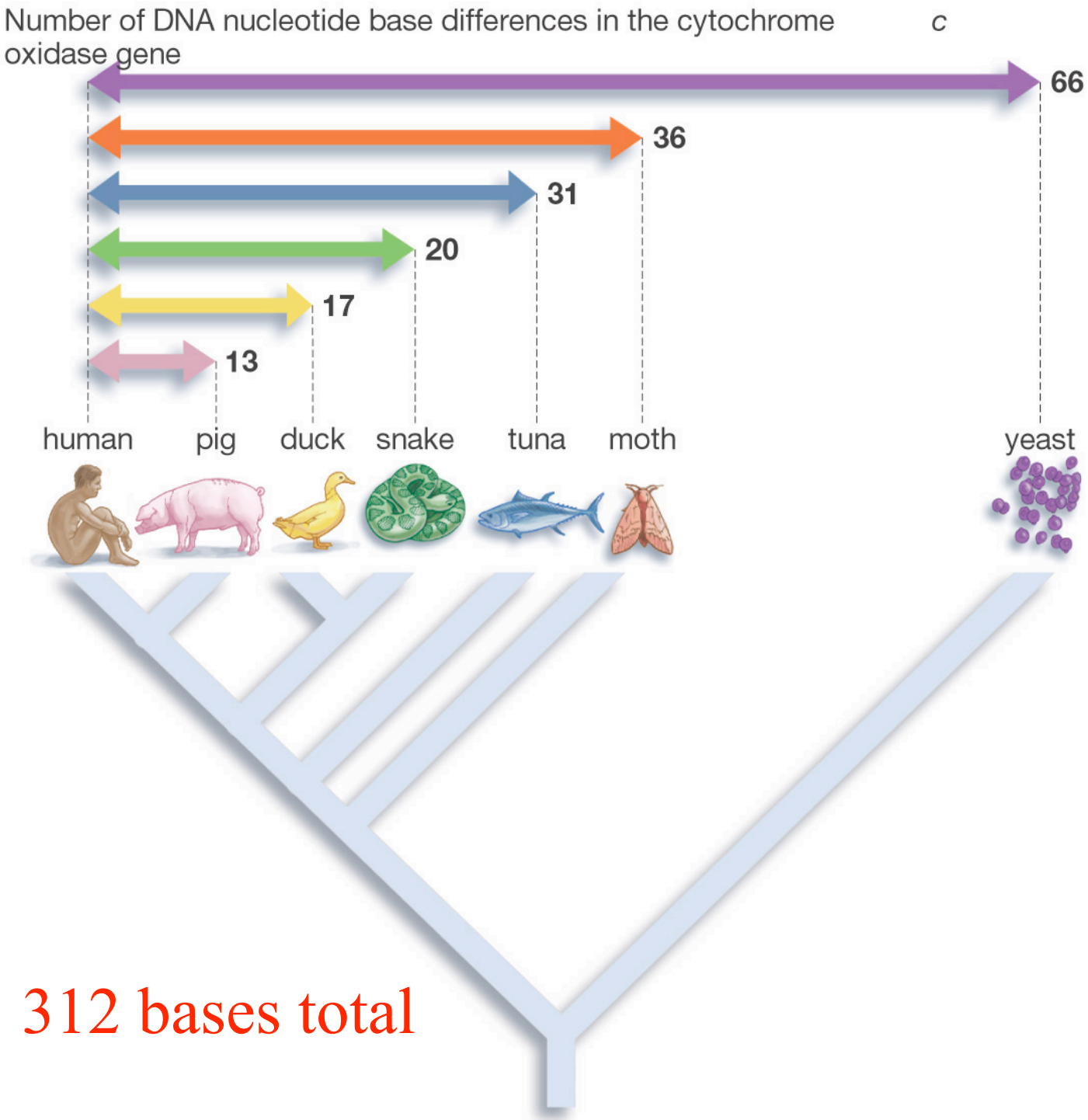


http://plato.stanford.edu/entries/information-biological/GeneticCode.png

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?



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
humans and chimpanzees on
DNA sequences are identical.
appears to contain clues to h
relatives in the animal kingdo

"We're really looking at an in
spectacular," 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

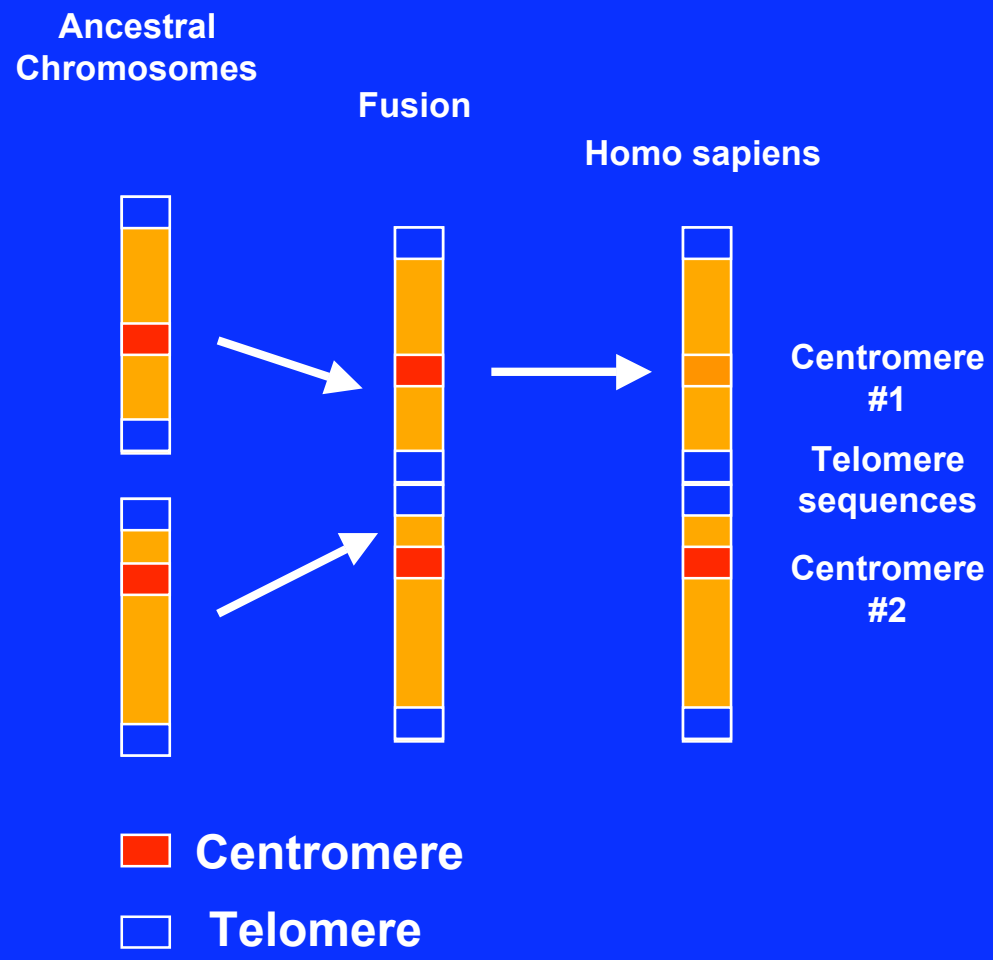
Chromosome numbers in the great apes:

human (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 fused chromosome.

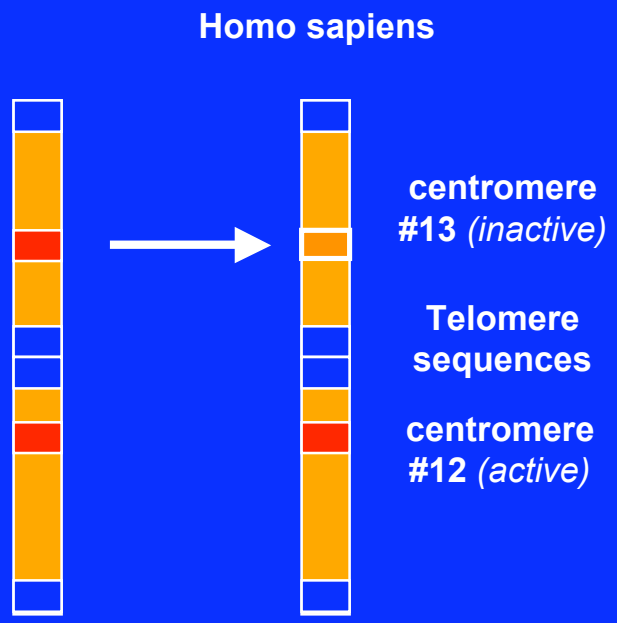
Chromosome numbers in the great apes (Hominidae):

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.

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.

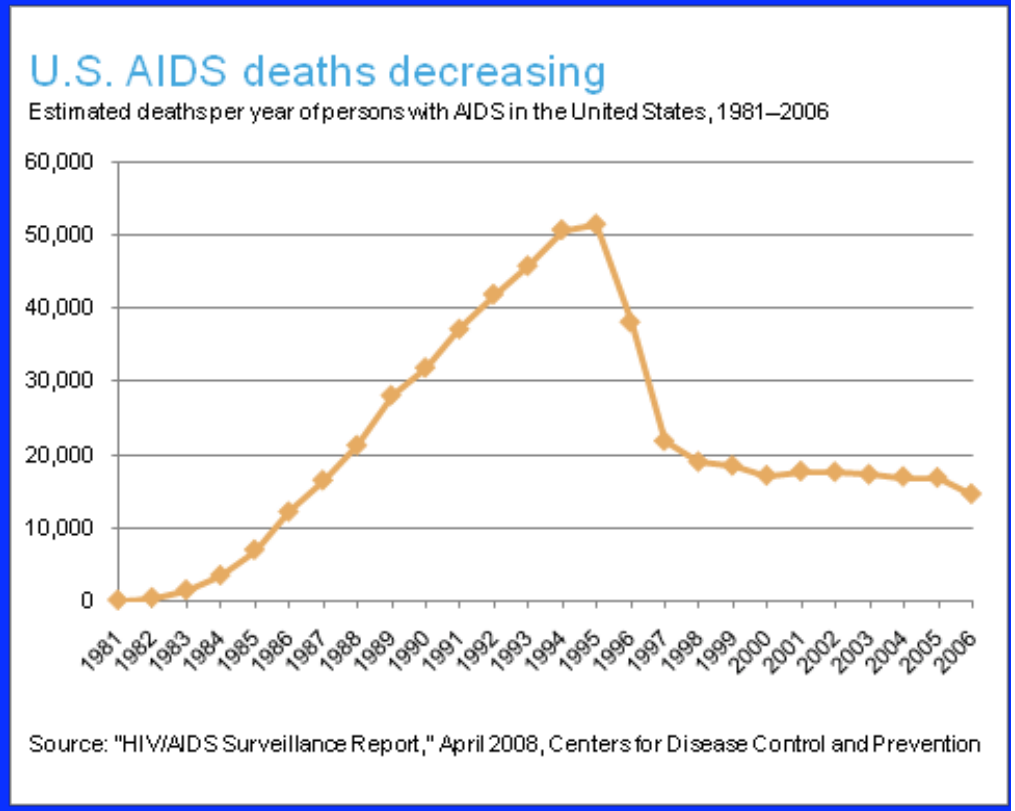
Hillier *et al* (2005) "Generation and Annotation of the DNA sequences of human chromosomes 2 and 4," Nature 434: 724-731.

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

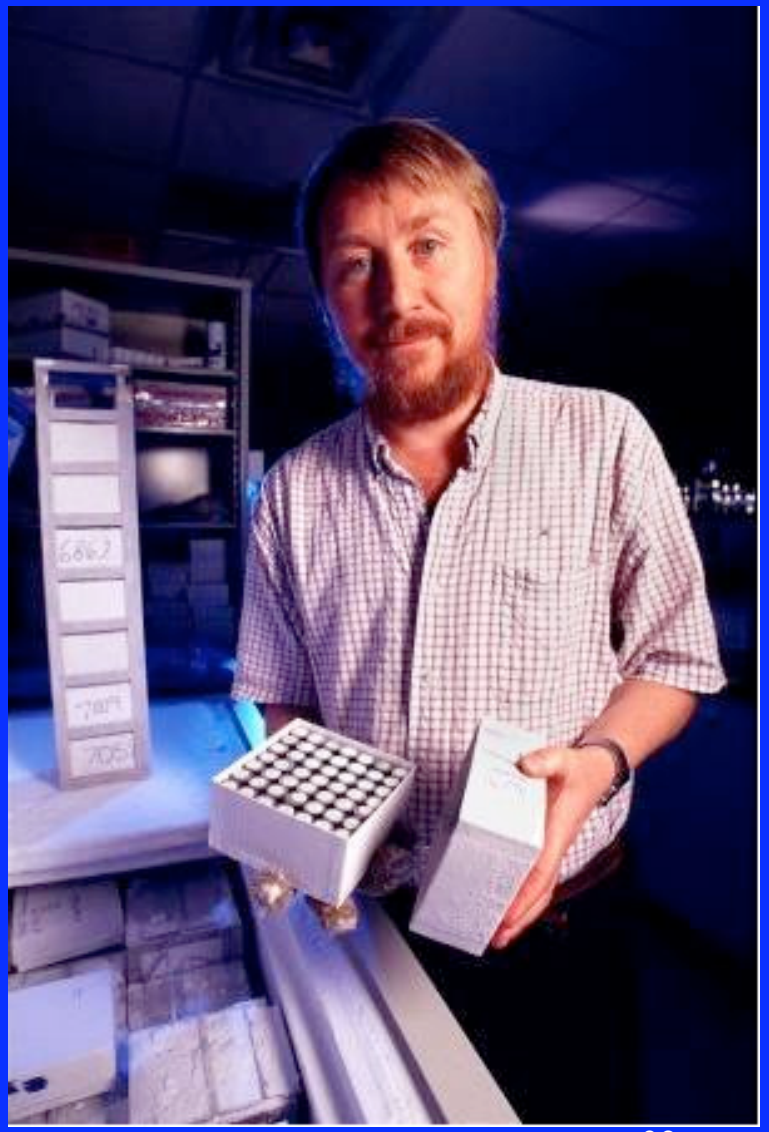
- Why plunge in US deaths?
  Still terrible, but...
- AIDS caused by virus
  Reproduces fast
  Adjusts quickly
- Evolution says: can't make many mutations at once if each unhelpful
  So, three drugs at once
- Has held up so far...



http://www.publicagenda.org/files/charts/ff_healthcare_us_aids_deaths_decreasing.png

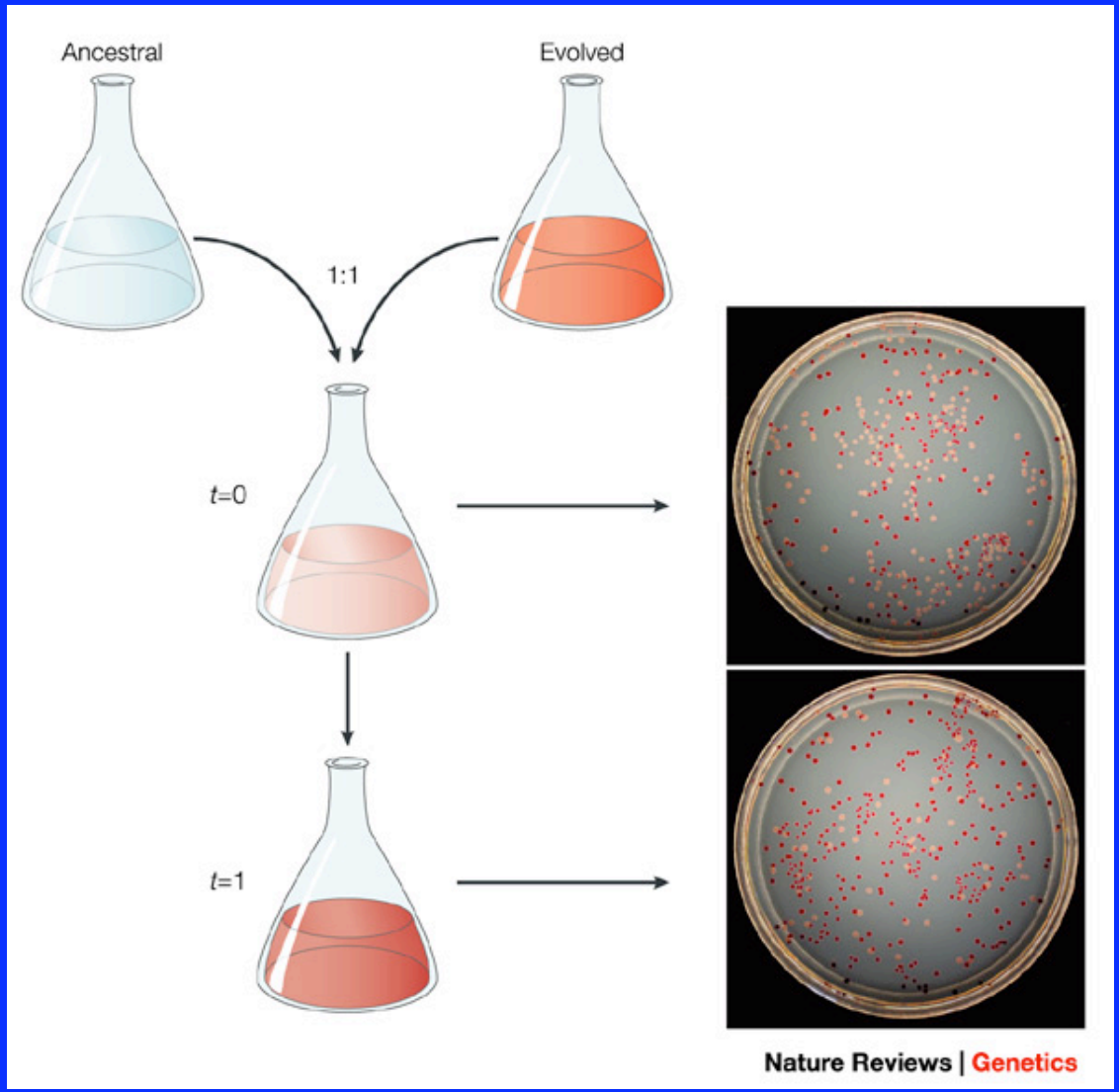
Evolution in the Lab

- 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



http://uanews.ua.edu/anews2005/sep05/images/lenski_300.jpg

Change in Relative Fitness



Put ancestral, evolved strains in same flask.

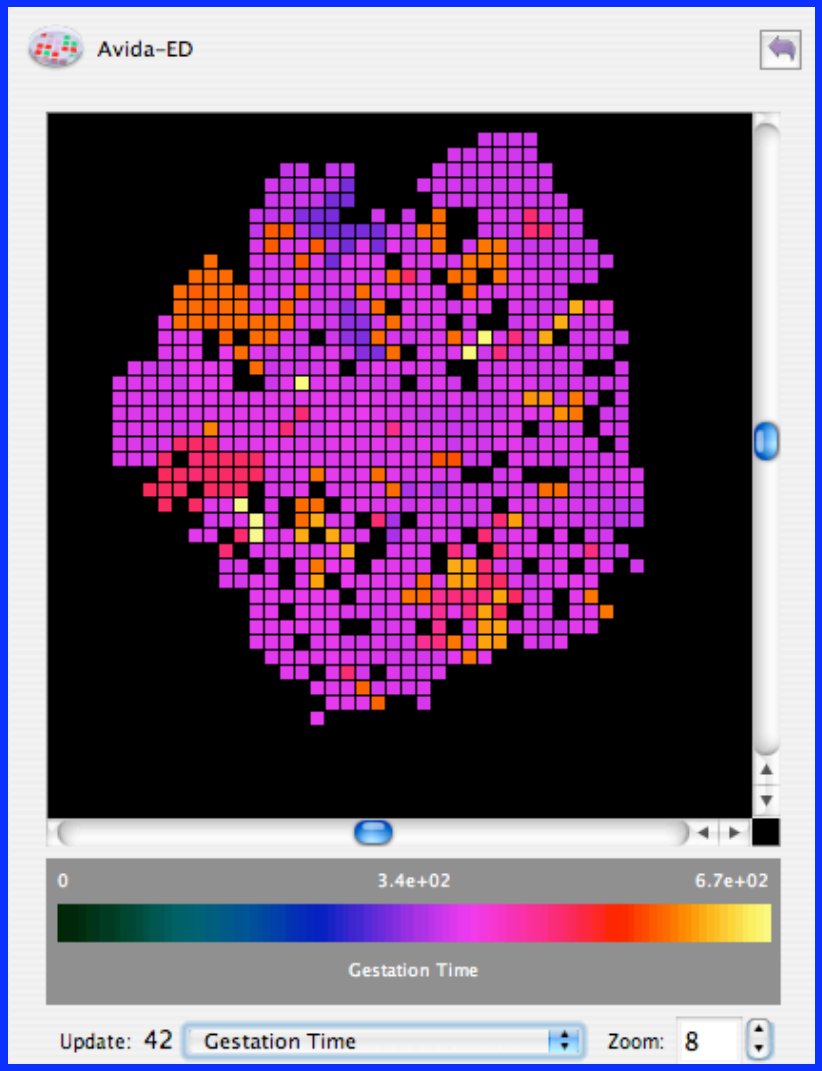
Wait...

Evolved strain is much more competitive in environment

Origin of Novelty

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



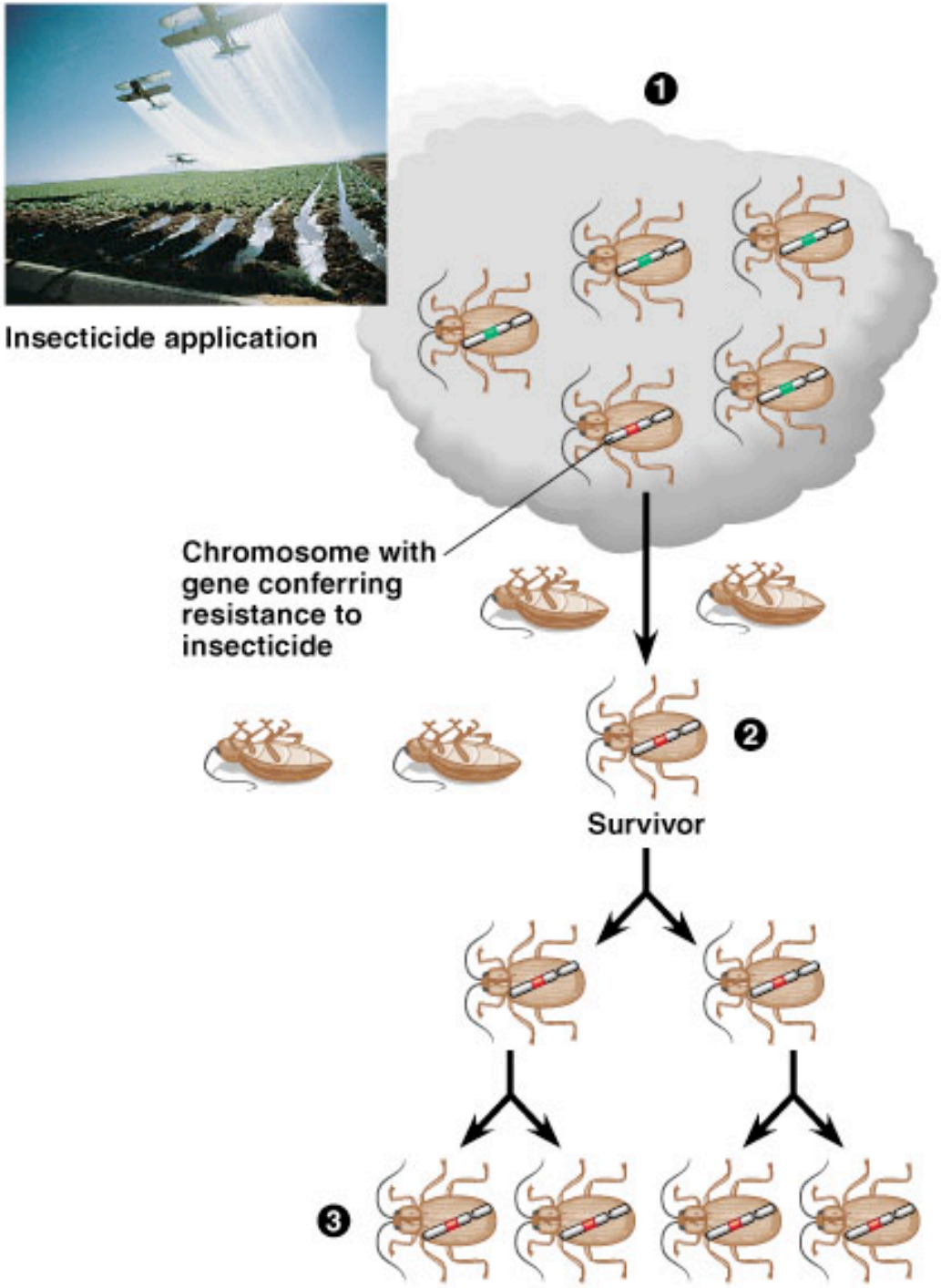
http://www.bioquest.org/products/images/PetriDish.png

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

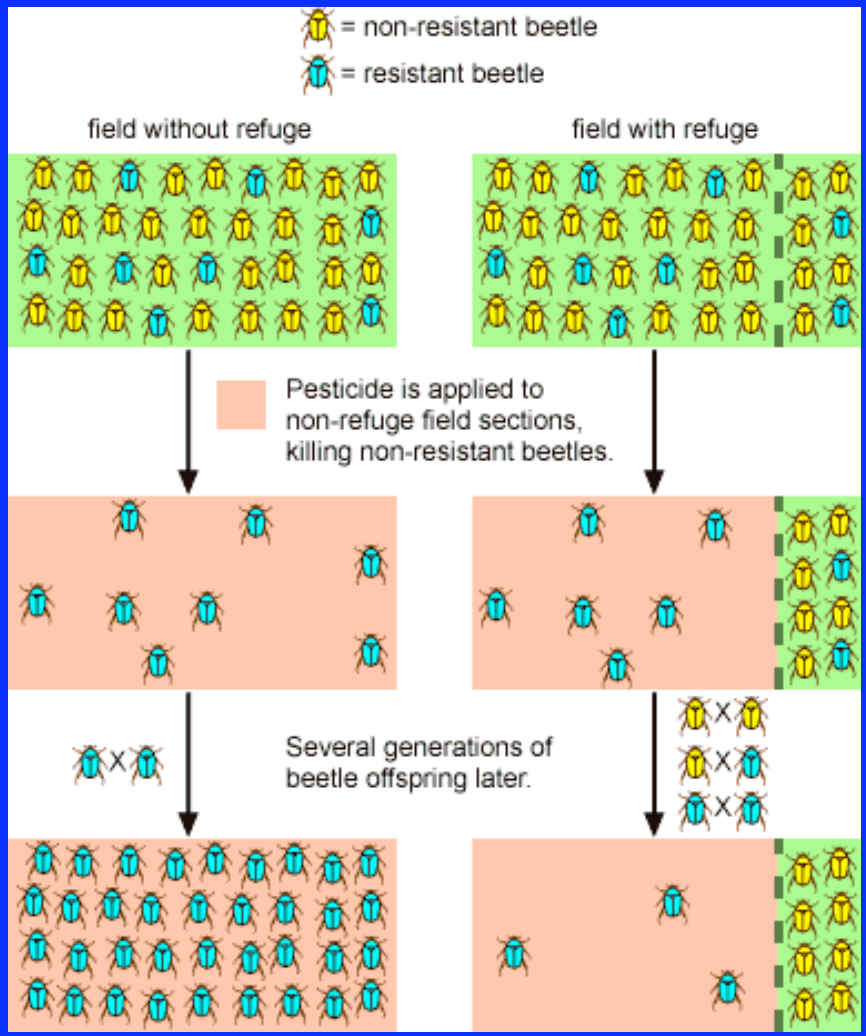
- "Old standbys" (penicillin, streptomycin, etc.) don't work as well as they used to
- Why? Bacteria have evolved to resist them
- Evolution is accelerated by overuse of antibiotics in livestock
  Gives bacteria more adaptive chances!
- This is why you ***finish*** an antibiotic regimen
  Otherwise,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

Evolution of pesticide resistance



Using Evolution to Combat Pests

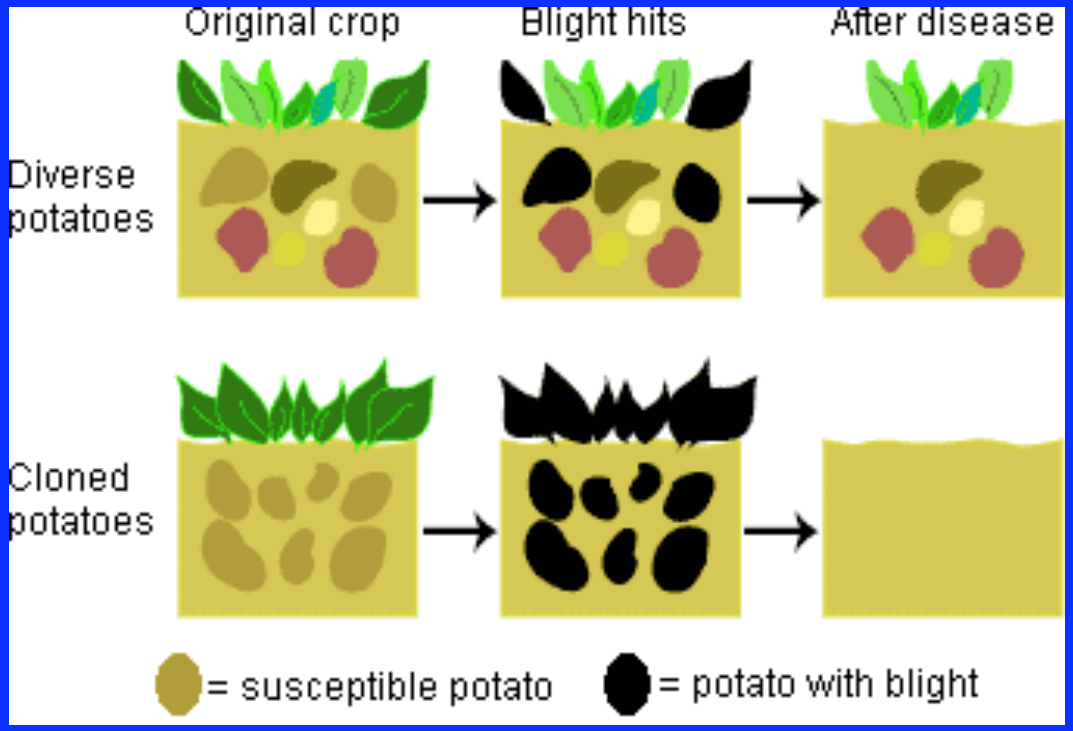
- Bt pesticide
  Allele is recessive
- If spray all, resistance spreads fast
- If leave refuge unsprayed, breeding reduces number of resistant insects



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 during this period
- Genetic diversity is key to surviving diseases



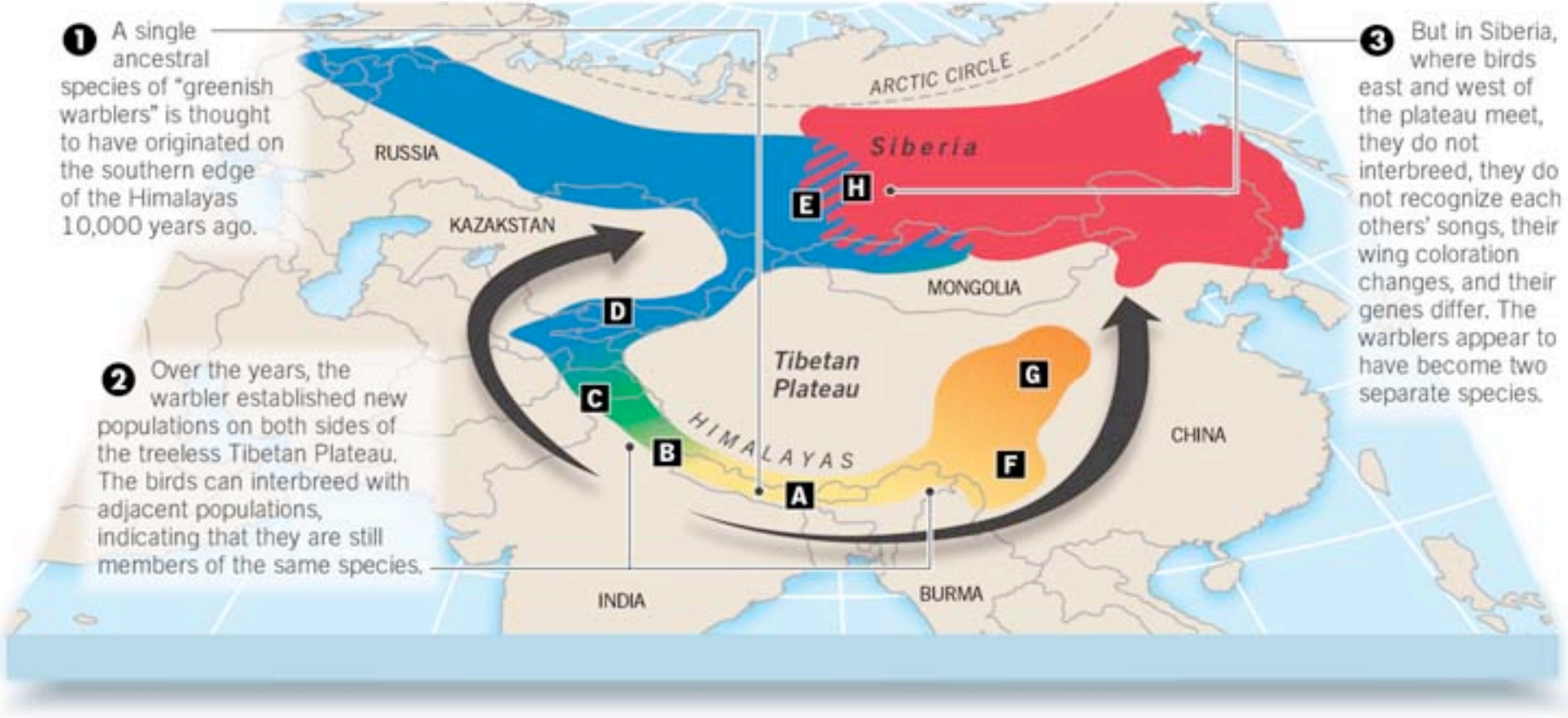
http://evolution.berkeley.edu/evolibrary/article/0_0_0/agriculture_02

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

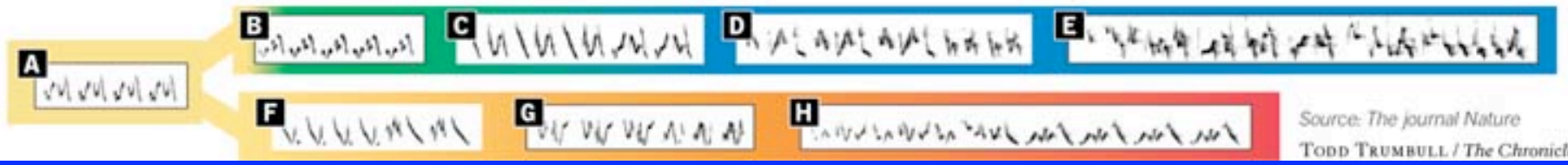
Tracing the Evolution of Species

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?