Evolution:
The foundational concept of biology

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Additional material in full pdf file of this talk:

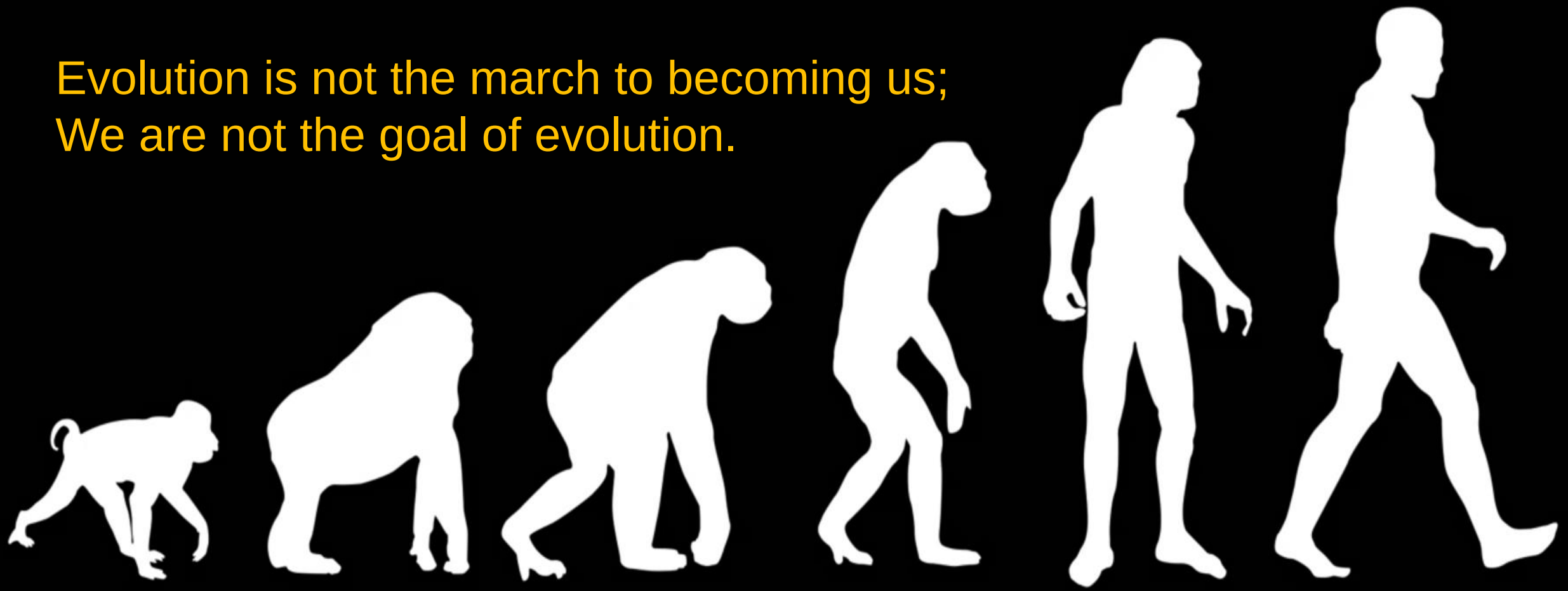
- Explanation of Phylogenies
- Science section
- Creationism vs science
- How to speak about evolution: words matter
- Natural Selection sweeps
- Co-evolution

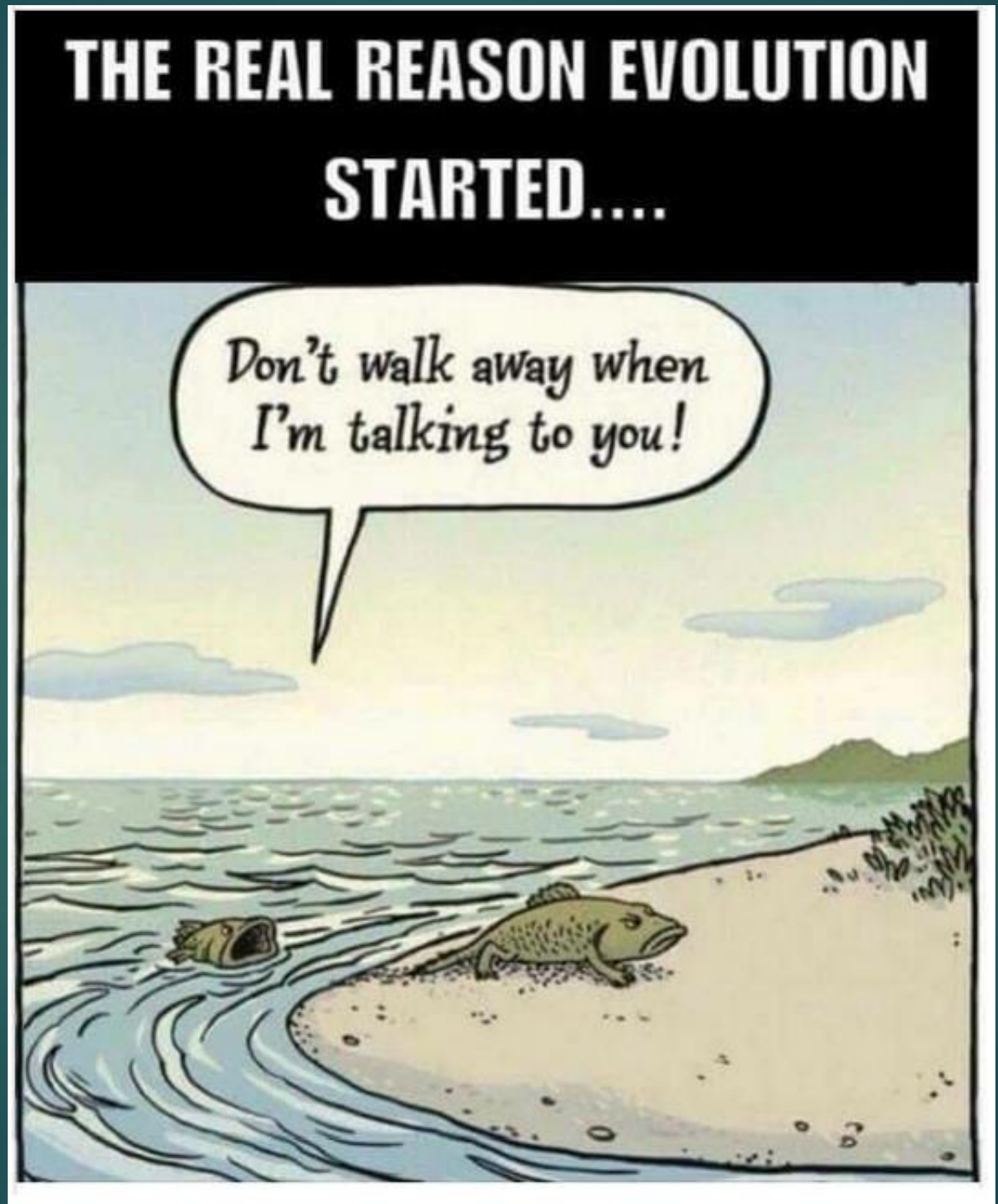
Evolution pre-test

- Do you believe in evolution?
  - You should not “believe” in evolution!
- What is the primary driver of evolution?
  - Reproductive success
- If we descend from apes, why are they still around?
  - Because we do not descend from apes, but from fish.
- Do the bulk of genetic differences between chimpanzees and humans lie in the ~20,000 protein-coding genes?
  - No. They are in the gene regulatory genes (“junk genes”)

Evolution is not a line that ends in you

Evolution is not the march to becoming us;
We are not the goal of evolution.




THE REAL REASON EVOLUTION STARTED....
Don't walk away when I'm talking to you!

Evolution

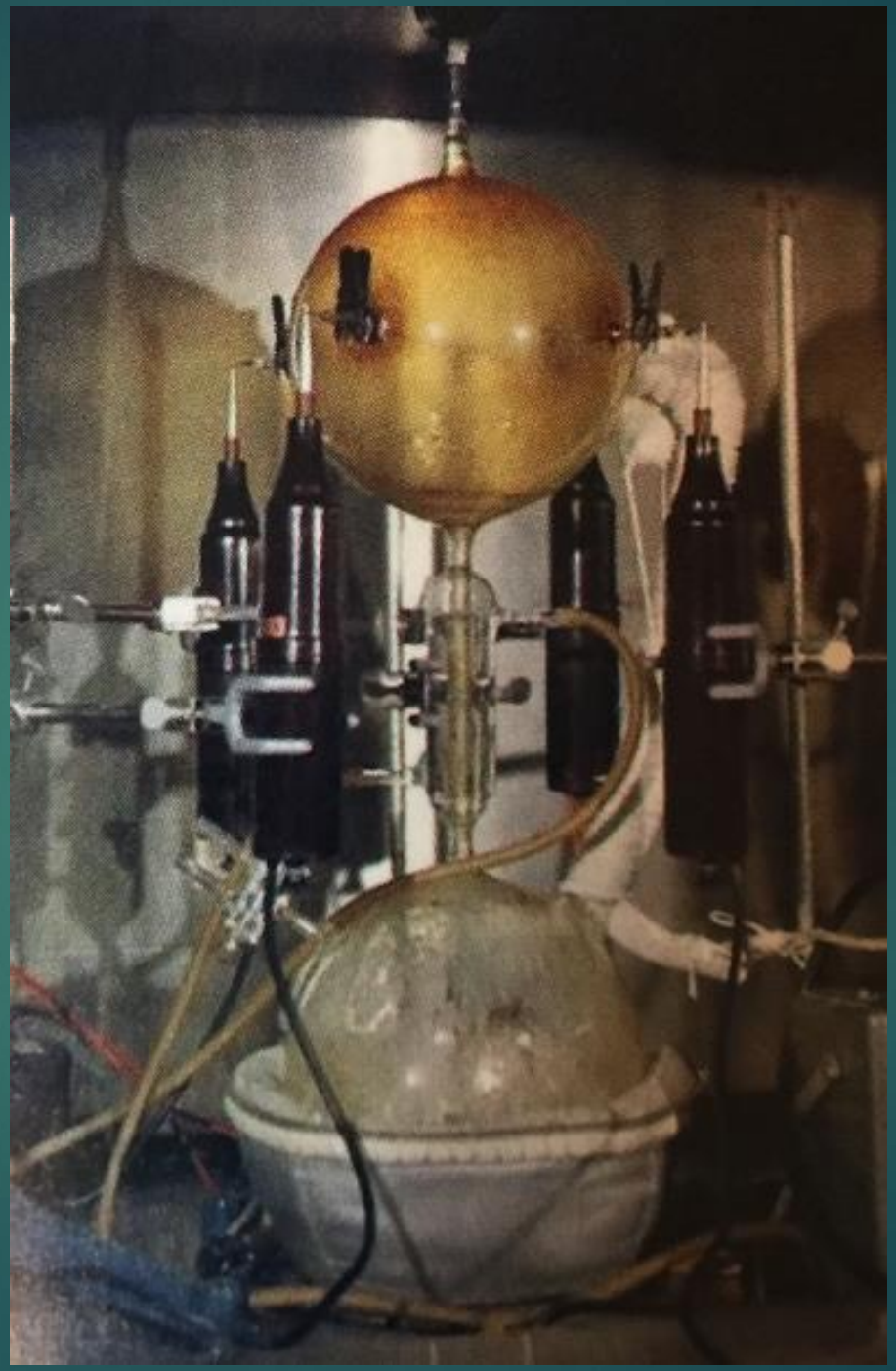
- Evolution is biological change over time.
- All living species—including humans—evolved from ancestral species, from a common ancestor.
- The major process responsible for the evolution of adaptive change is natural selection.
- Natural selection is about survival to reproduce.
- Natural selection is blind; it is not directional.
- Evolution doesn’t follow a straight line. It’s bushy.
- None of our ancestors were trying to be us.
- Our evolutionary history is littered with many branches, experiments, adaptations, and dead ends.
- Today, all species of *Homo* have disappeared except for one: us.

Chemical Origin of Life

Miller–Urey experiment, 1952

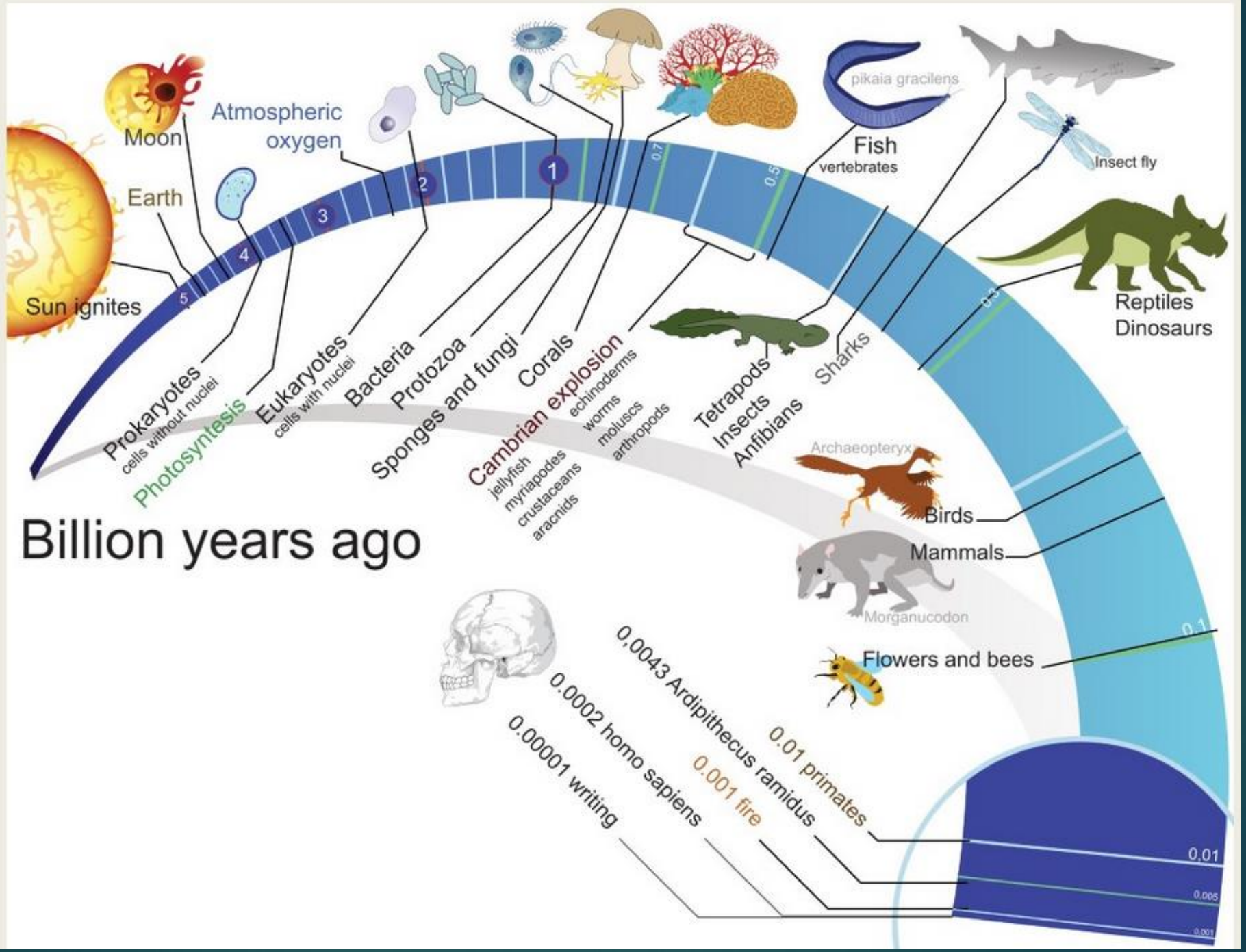
Used water (H_2O), methane (CH_4), ammonia (NH_3), and hydrogen (H_2).

Electrical jolts produced 20+ amino acids

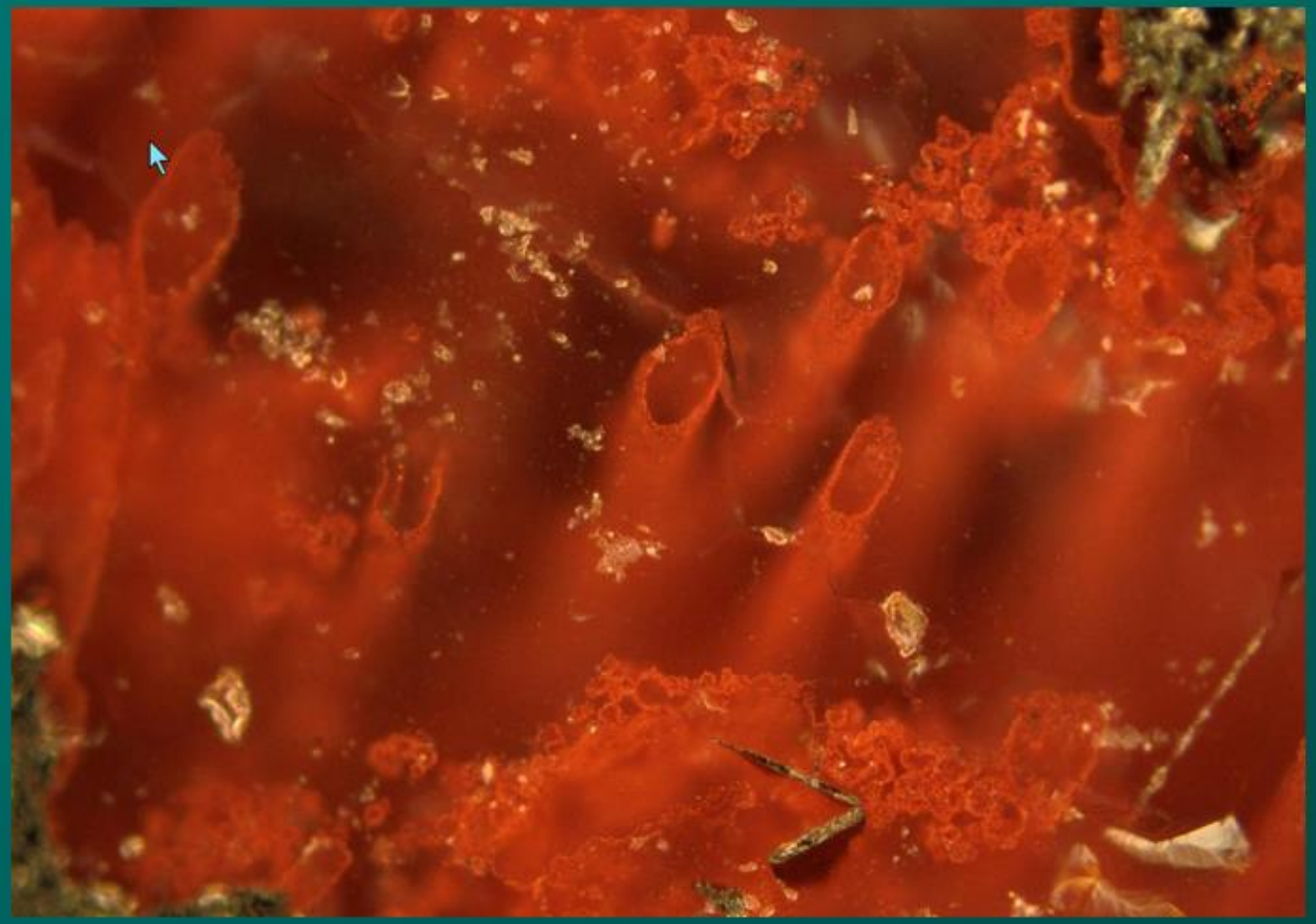


Origin of Life: basic chemistry can create living cells

- No formal scientific explanation of origin of life currently exists
- All life comes from common ancestor; life forms get simpler the older they are
- But they were not created by biological evolution, which depends on reproduction
- Origin of life depends on properties of chemistry; chemistry of life is organized into metabolic pathways (orderly chemical reactions)
- Living cells are made of special molecules (amino acids, sugars); can create genes, proteins, cell membranes; 52 have been found in meteorites
- 1828 – creation of urea (pee) via chemical reactions; evidence that life could emerge from nonliving chemistry
- Chemical evolution: simple molecules + energy can create more complex molecules; can create self assembly into more complex molecules (hollow spheres like membranes, tall structures like proto RNA)
- If it can happen on earth, then also elsewhere in universe
- In 2016, 355 genes inferred to have been present in LUCA


Moon
Atmospheric oxygen
Earth
Sun ignites
Prokaryotes
cells without nuclei
Photosyntesis
Eukaryotes
cells with nuclei
Bacteria
Protozoa
Sponges and fungi
Corals
Cambrian explosion
jellyfish
myriapodes
crustaceans
aracnids
echinoderms
worms
moluscs
arthropods
Tetrapods
Insects
Anfibians
pikaia gracilens
Fish
vertebrates
Sharks
Insect fly
Reptiles
Dinosaurs
Archaeopteryx
Birds
Mammals
Morganucodon
Flowers and bees
Billion years ago
0.0043 Ardipithecus ramidus
0.0002 homo sapiens
0.00001 writing
0.01 primates
0.001 fire
1
2
3
4
5
0.7
0.5
0.3
0.1
0.01
0.005
0.001

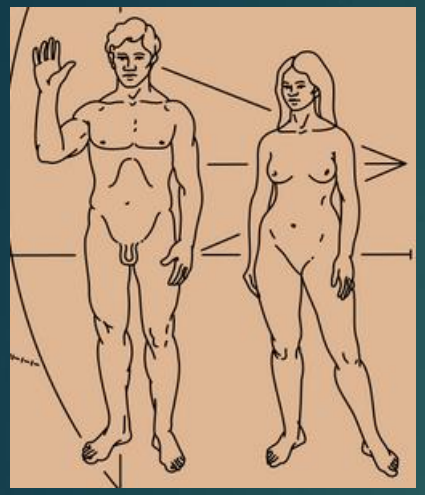
Life at 4.28 Ba?: just 300 Ka after formation of planet



4.28 billion year old iron-rich tubes from Northern Quebec may be the oldest known fossils on the planet.

Matthew S. Dodd, et al., 2017

How Much of Your DNA You Share with:



99.9%

Neandertals 99.7%

98.4%

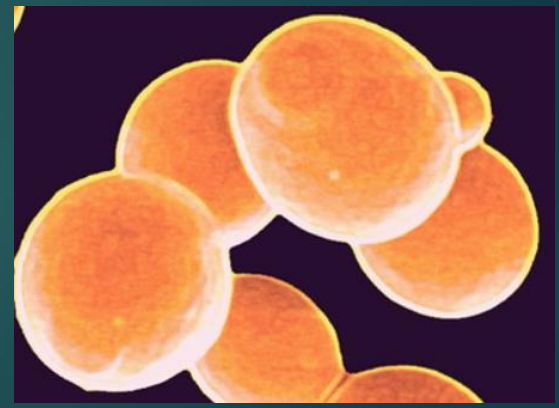
92%

70%

60%

50%

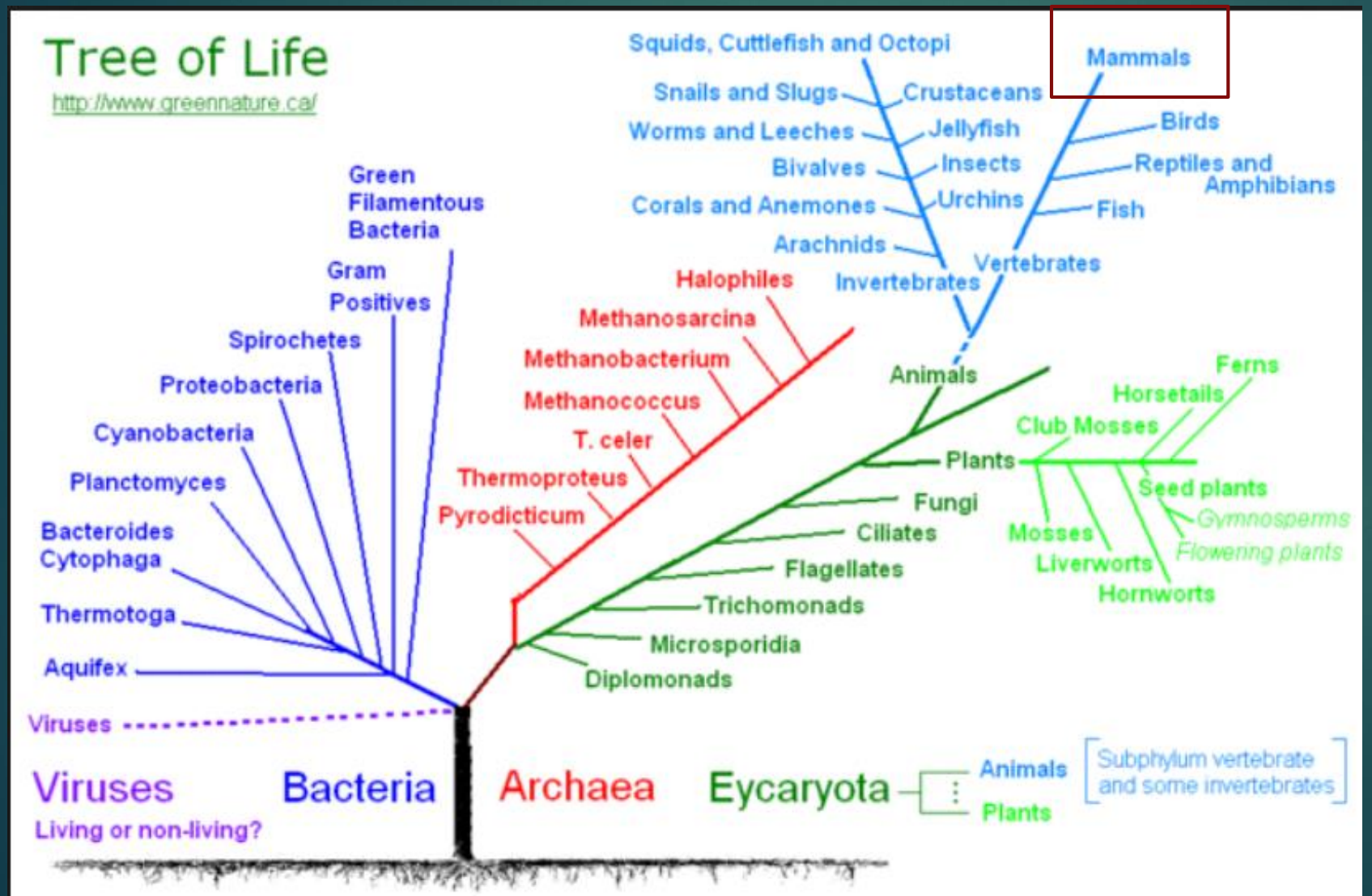
You are related to every living creature on planet earth



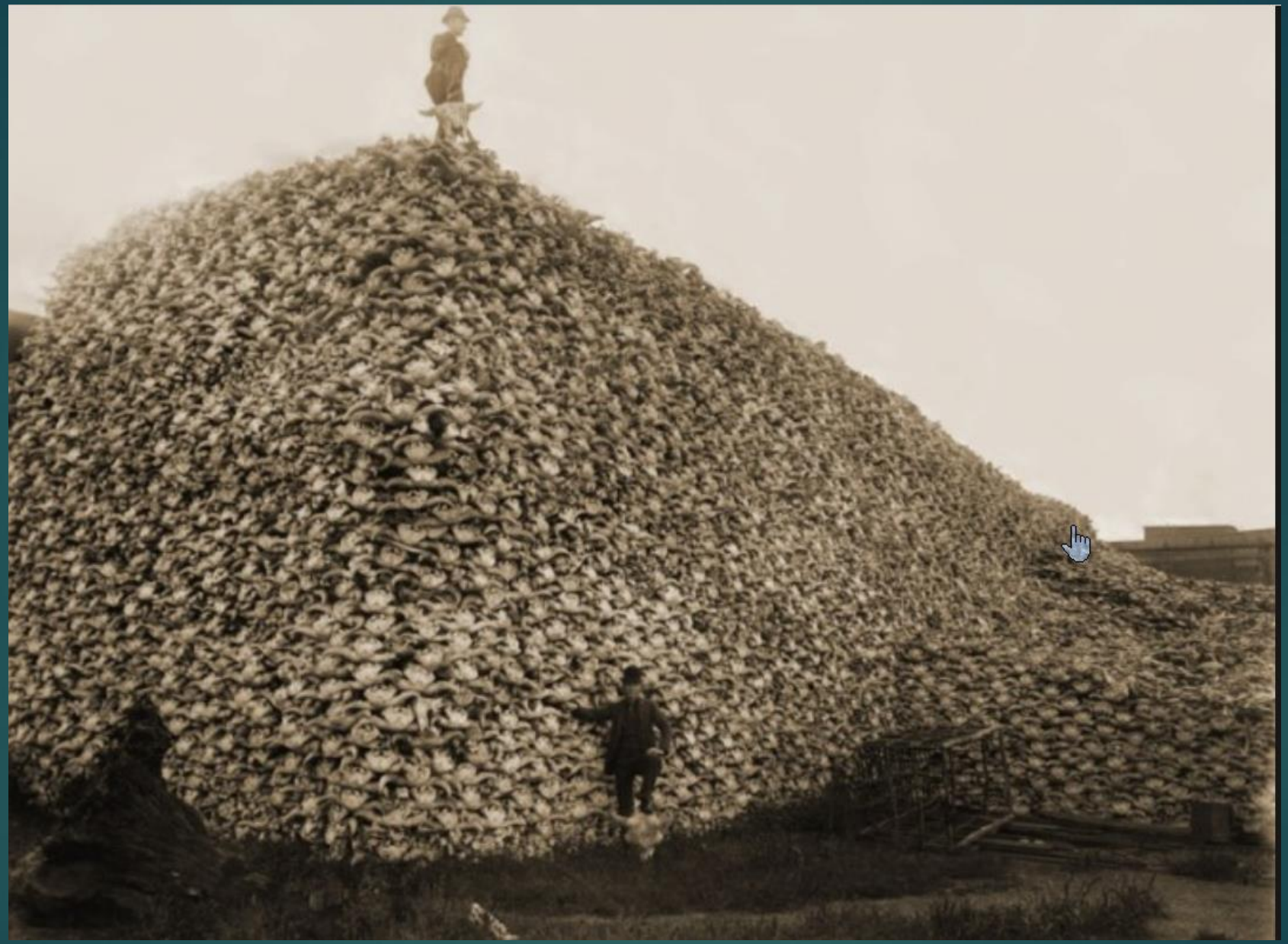
Yeast = 26%

https://www.quora.com/What-percentage-of-human-DNA-is-shared-with-other-things

Vast Diversity of Life on Earth:
8.7 +/- 1 Million species



Only 1.2 million species have been described -
86% of existing species on Earth and 91% of species in the ocean still await description



Extinction is part of evolution: Buffalo skulls in 1870, for fertilizer

Evolution is adaptation and extinction

- 2016: Largest analysis of microbial data: 99.999 percent of all species remain undiscovered - Earth could contain nearly 1 trillion species (incl. microorganisms), with only .0001 of 1 percent now identified
- How many species on earth have gone extinct?
- 99.99%
- The average species "lifespan" is about 1 million years
- 85-97% of all animals have not fossilized
- Only 250,000 species that have been identified in the fossil record of land animals

The utter weirdness and a perfect example of Evolution:

Naked Mole Rat

The utter weirdness and uniqueness of Evolution: Naked Mole Rats

- 30 year lifespan; buck teeth that can move independently; live in deserts of E. Africa; eat widely dispersed root vegetables
- Large colonies of 300; nest chambers, community bathrooms
- Rigid hierarchy: a queen, 3 male consorts, everyone else soldiers, or root hunting workers; no pain sensitivity; typically live for 3 years
- Can survive for 5 hours in air that contains only 5% oxygen; normal 21% Ox; no other mammal could survive in their chambers
- Entirely ectothermic (cold-blooded); have abandoned thermoregulation; only mammals where body temperature fluctuates with environment, cold blooded like reptiles; hemoglobin which is much stickier for Ox; suspended animation with low movement & lower heart beat when Ox low; only mammal to switch from glucose to fructose metabolism (without Ox) like plant
- Resistance to cancer and oxygen deprivation

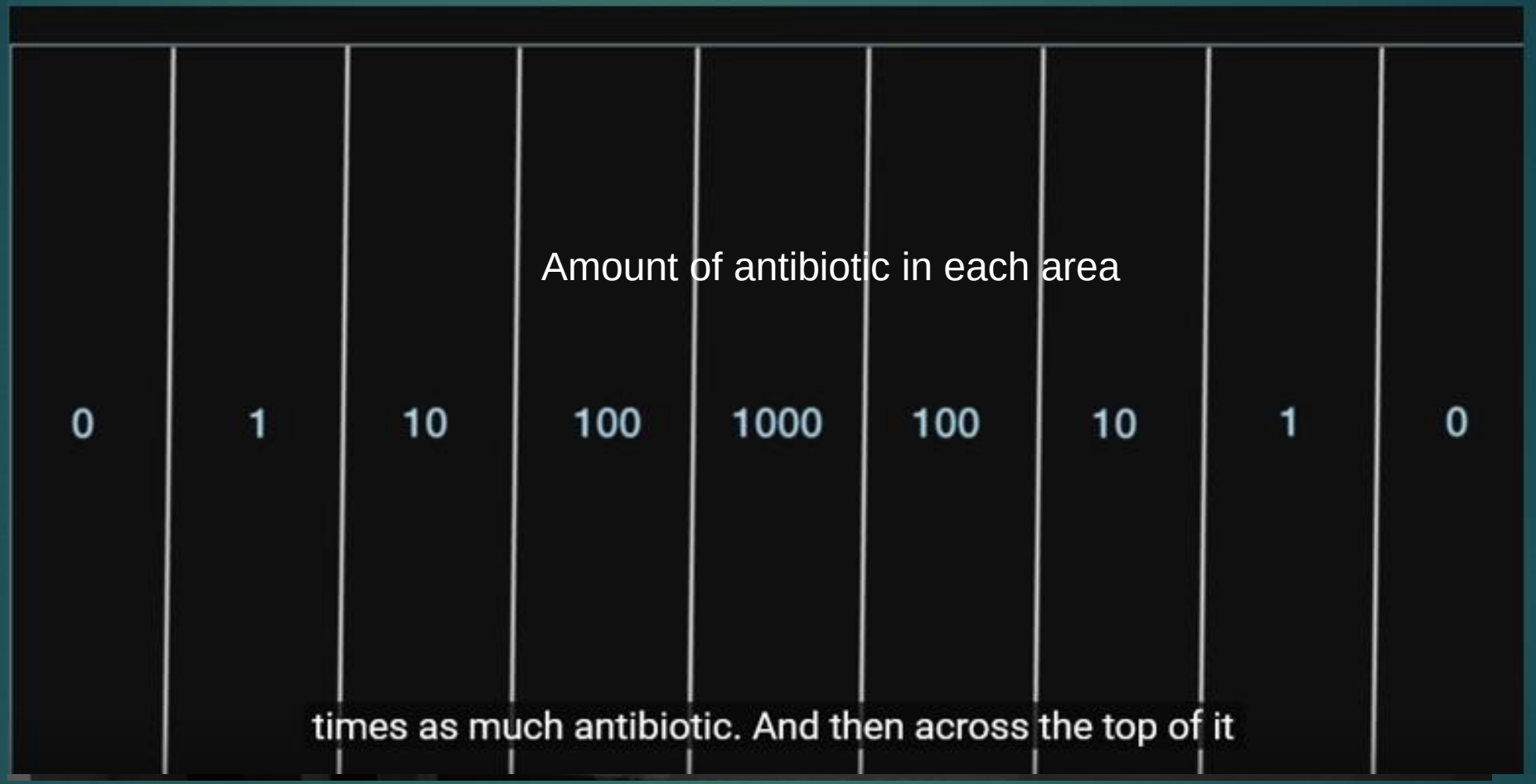
Reason for atheism

- Parasitoid wasps influenced the thinking of Charles Darwin about religion.
- In an 1860 letter to the American naturalist Asa Gray, Darwin wrote:
  - " I own that I cannot see as plainly as others do, and as I should wish to do, evidence of design and beneficence on all sides of us. There seems to me too much misery in the world. I cannot persuade myself that a beneficent and omnipotent God would have designedly created parasitic wasps with the express intention of their feeding within the living bodies of Caterpillars. “(On the Origin of Species, Chapter 7, page 218.)

- The paleontologist Donald Prothero notes that religiously-minded people of the Victorian era, including Darwin, were horrified by this instance of evident cruelty in nature, particularly noticeable in the Ichneumonidae.
- 100,000 species

Caterpillar infected by parasitoid wasp

Evolution of antibiotic resistance in real time in a 2'x4' petri dish



E. coli

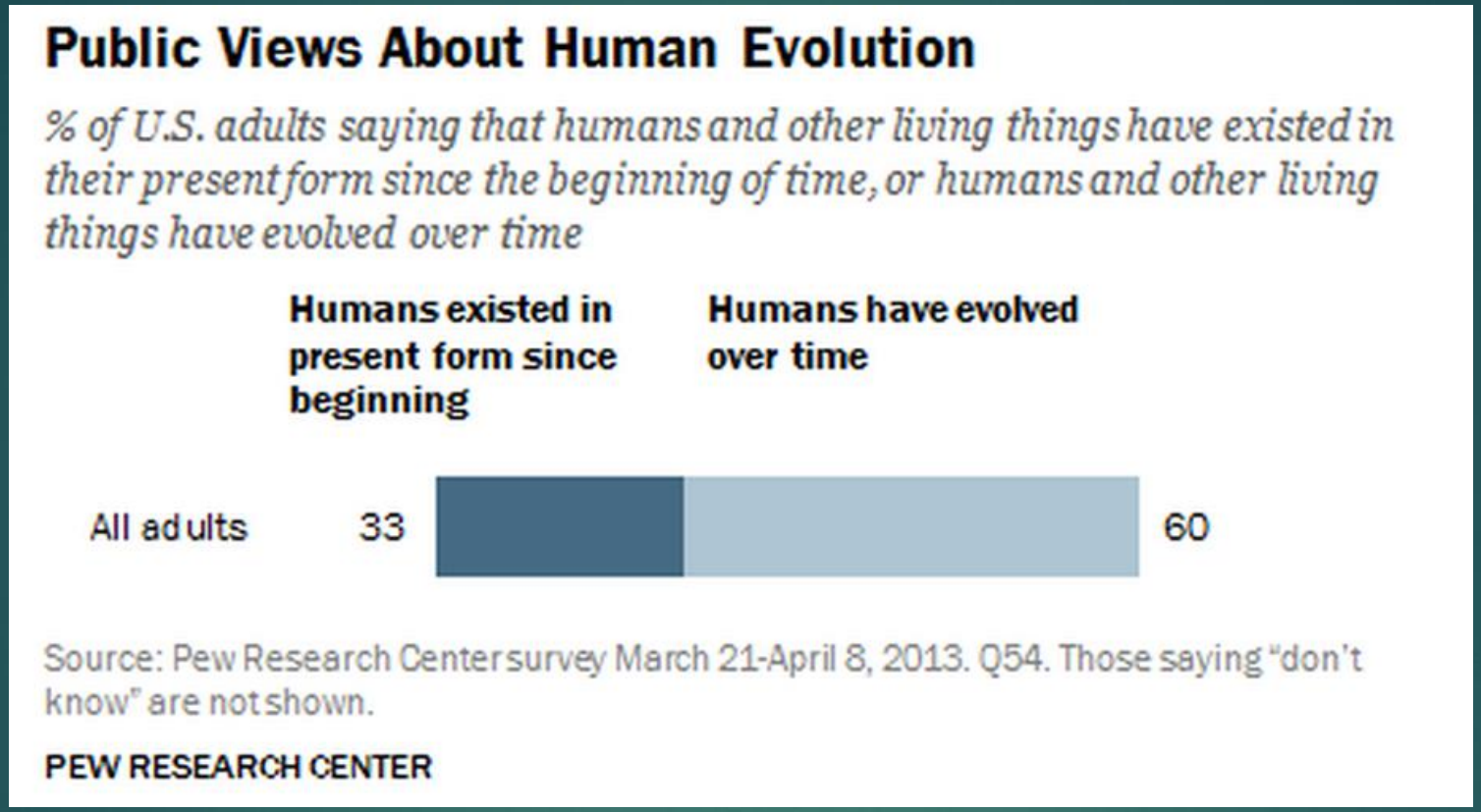
Harvard Medical School and Technion-Israel Institute of Technology: Bacteria (white) grow up to the boundary where they can no longer survive. Mutants, capable of surviving the higher concentration of antibiotic, appear and invade the new band. Subsequent steps require further mutations.

Michael Baym et al., Science, 2016

Evolution is a fact: Bacterial resistance development in 11 days

Reveals how bacteria develop resistance to increasingly higher doses of antibiotics in a matter of 11 days.;
Antibiotics*:* trimethoprim (TMP) or ciprofloxacin (CPR)

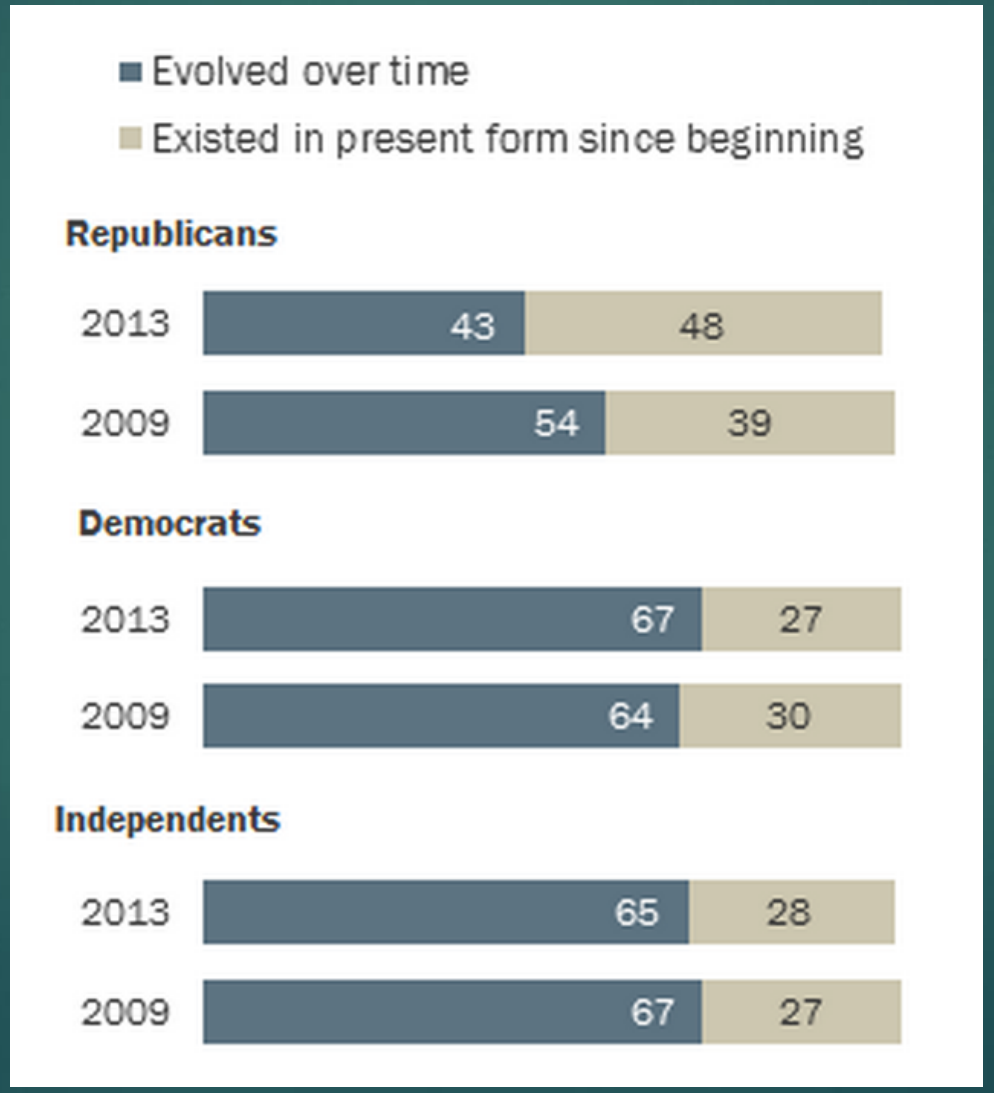
Only 60% Accept Human Evolution



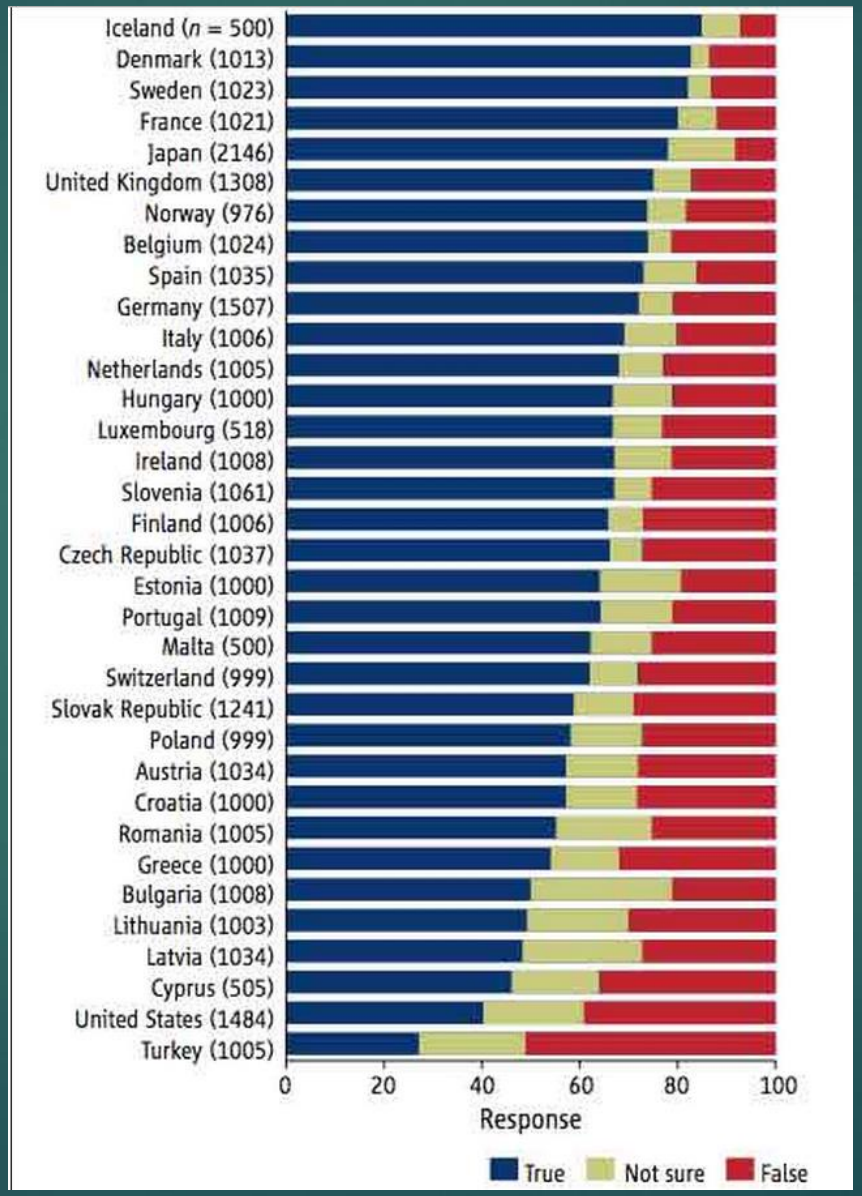
99.9 percent of scientists accept evolution

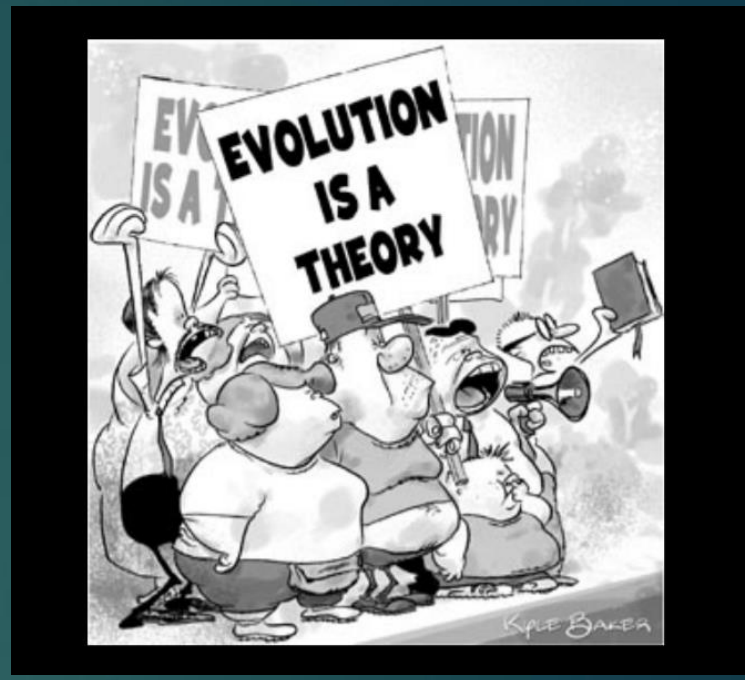
Fewer than 30 percent of high school teachers take an adamant pro-evolutionary stance on the topic; 13% teach creationism.

By Political party: Have humans evolved?
Democrats – (67%) Yes; Republicans – (48%) No



Belief in Evolution by Country: USA is 33rd of 34 Countries





Those damn facts…

- As Daniel Patrick Moynihan famously said:
  - *“Everyone is entitled to his own opinion, but not to his own facts.”*
- Herbert Spencer:
  - *“Those who cavalierly reject the Theory of Evolution, as not adequately supported by facts, seem quite to forget that their own theory is supported by no facts at all.”*
- Or Thomas Huxley:
  - *“The great tragedy of science is the slaying of a beautiful hypothesis by an ugly fact.”*

Darwin’s Idea: Evolution

Chapters of *The Origin of Species*, 1869 ed.

- 1 Variation under domestication
- 2 Variation under nature
- 3 Struggle for existence
- 4 Natural Selection or Survival of Fittest
- 5 Laws of Variation
- 6 Difficulties of the theory
- 7 Objections to Theory of Natural Selection
- 8 Instinct
- 9 Hybridism
- 10 Imperfection of geological record
- 11 Geological succession of organic beings
- 12 & 13 Geographical distribution
- 14 Mutual affinities of organic beings: morphology, embryology, rudimentary organs
- 15 Recapitulation

Brief summary of the *Origin of Species*

- Plants and animals under domestication show astonishing variation. This variation is due to artificial selection by the breeder. The same variation is shown by nature. We see an inevitable struggle for existence because more offspring are produced in each generation than can survive. This struggle is fiercest in same species by those exploiting the same resources. Variants which are better suited to their environment will have a better chance of surviving, as will their offspring, whenever the variation is inherited. By analogy with artificial selection, this principle is called natural selection.
- Similarly, sexual selection is driven by struggles of the same sex in the same species. If some environment is not well occupied, natural selection will preserve individuals that vary in the right direction, cumulatively and so slowly that we cannot see it in action.

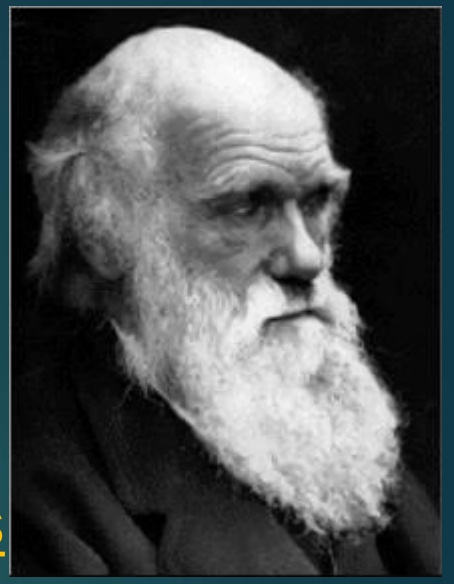
Brief summary of the *Origin of Species 2*

- The affinities of all living organisms can be represented as a great tree, which fills crust of the Earth with its dead and broken branches (extinct species), and covers the surface with its ever branching and beautiful ramifications (living species). Our ignorance of the causes & laws of variation is profound, but natural selection soldiers on. We often do not see transitional forms because newer better forms out-compete older ones, but gradations can be seen in nature (simple to complex eyes). It is unclear why hybrids between species are often sterile.
- Geological time is vast and the fossil record so imperfect that we can scarcely expect to find transitional fossils. But the theory of descent with modification provides the best explanation for extinction and for the succession of the same types of organisms within the same areas. It is the best explanation for (1) curiosities of the geographical distribution of living organisms (old and new world differences or differences of islands),

Brief summary of the *Origin of Species 3*

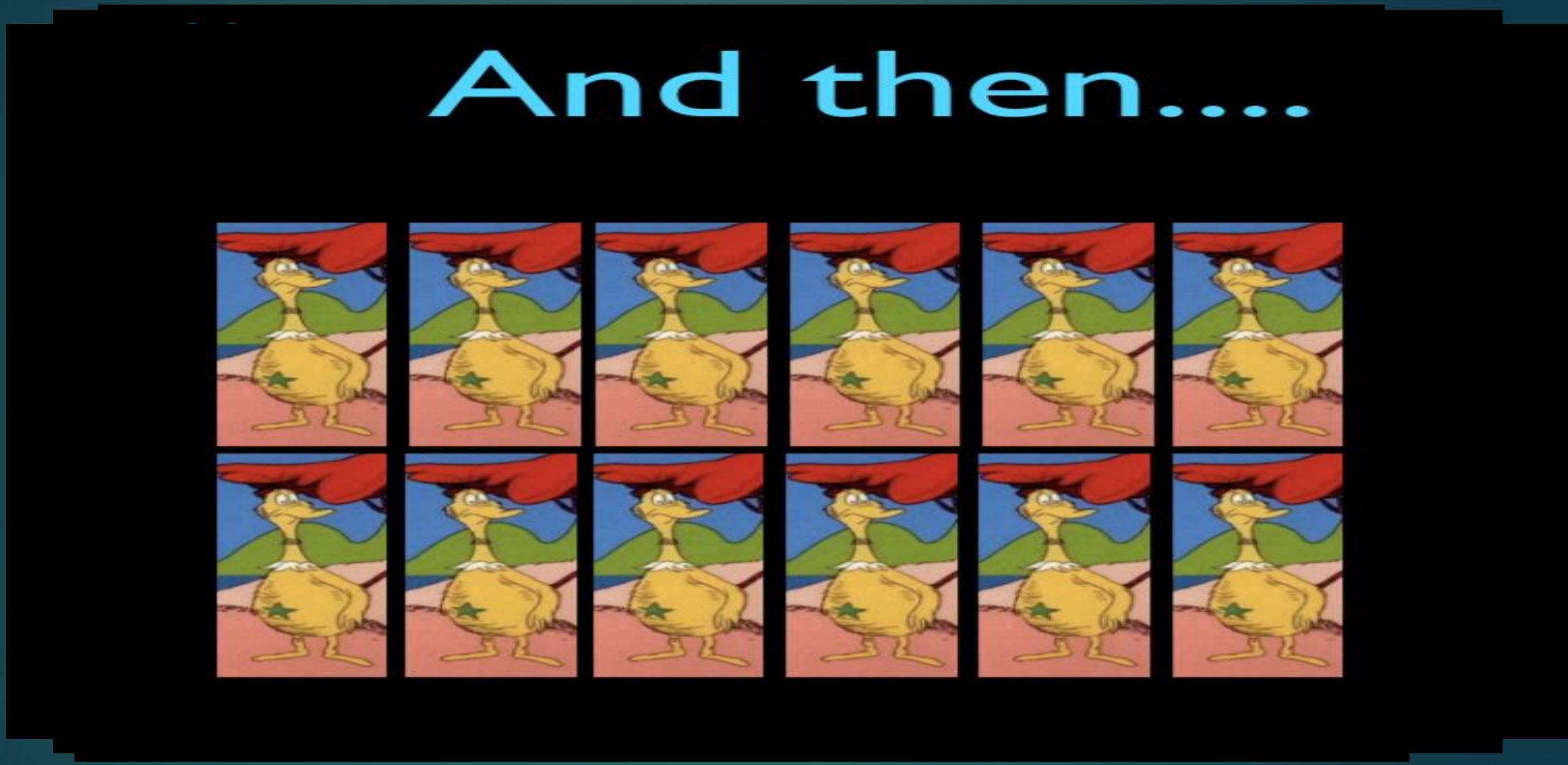
- (2) natural taxonomic hierarchy of groups within groups; (3) morphological and embryological similarities in form unrelated to function (similar bones in wings, legs, flippers, etc.); and (4) rudimentary organs. Although it stretches the imagination, descent with modification powered by natural selection is the inevitable consequence of the facts in front of us. It provides a nobler vision of the origin of species than special creation, and its creative power makes biology much grander and more interesting than the fixed laws and repetitive planetary orbits of physics.
- Big 5 ideas: variation, mutability of species, common descent, natural selection, gradualism

Evolution for Beginners



- Biology does not make sense without the concept of evolution.
- Evolution is the idea that all living things arose from a single common ancestor in the distant past and that life continues to diversify today as new species appear.
- Evolution explains why we can classify organisms into different groups (because some organisms are more closely related than others).
- Evolution explains why the cells of all organisms use the same kind of biochemical machinery (because all life shares a common ancestor & related DNA.)

Natural Selection at work



Evolution is a fact

- By definition, you do not “believe” in something if is true beyond a shadow of a doubt.
- Evolution is a fact, not a belief.
- The amount of biodiversity on earth (all animals, fish, plants, bacteria, etc.) is the fact of evolution.
- So if someone asks: “Do you believe in evolution, “ they are framing it wrong. That’s like asking “Do you believe in blue? Or Do you believe in gravity.

Evolution 2

- You don’t believe in evolution
- You either understand it or you do not.
- It is the fundamental fact in all biology.
- Examples of evolution:
  - Variety of dogs
  - Large strawberries
  - Seedless watermelons
  - Skin color
  - Size of pigs
  - Genetically modified plants (GMOs)
  - All Plants
  - All animals
  - All life on earth
  - You

What did Darwin did not know: DNA & Genes

- DNA (Deoxyribonucleic acid) is a molecule, made from 4 types of nucleotides (A, C, T, G)
- Gene is a sequence of DNA made up of specific sequence of Ns that codes for something, i.e. eye color
- Genes can create 20 amino acids which can create millions of specifically shaped proteins – cells – tissues – organ - organism
- ~20K human protein-coding genes; 2% of DNA; non-coding DNA = 98%
- Non-coding DNA produces RNA, gene expression, transcription of proteins, telomeres

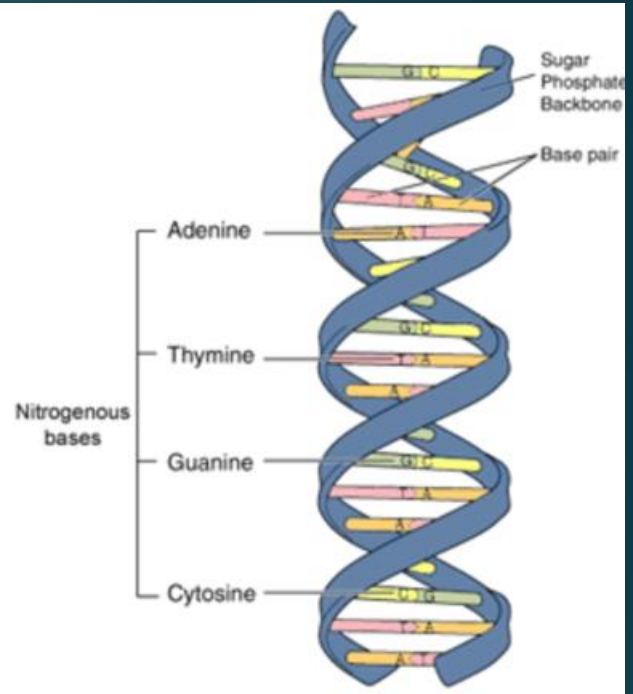


Image adapted from: National Human Genome Research Institute.

The DNA double helix showing base pairs

Each nucleus has 1.8 meters of DNA

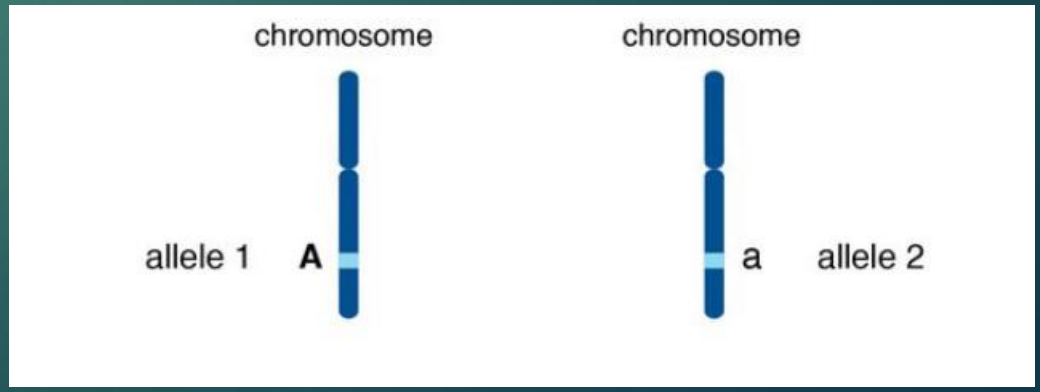
www.dnalc.org

What is a gene? an allele?

- A gene is a segment of DNA found on a chromosome. One version (allele) of the same gene comes from each parent.

- Genes are passed on from parents to offspring; get 1 allele from each parent. You have 2 alleles for each trait you have.

- Allele = different versions of a trait in a gene (1 from Mom, 1 from Dad); one of two alternative forms of a gene, found at the same place on a chromosome.
  - Example: brown vs blue eyes



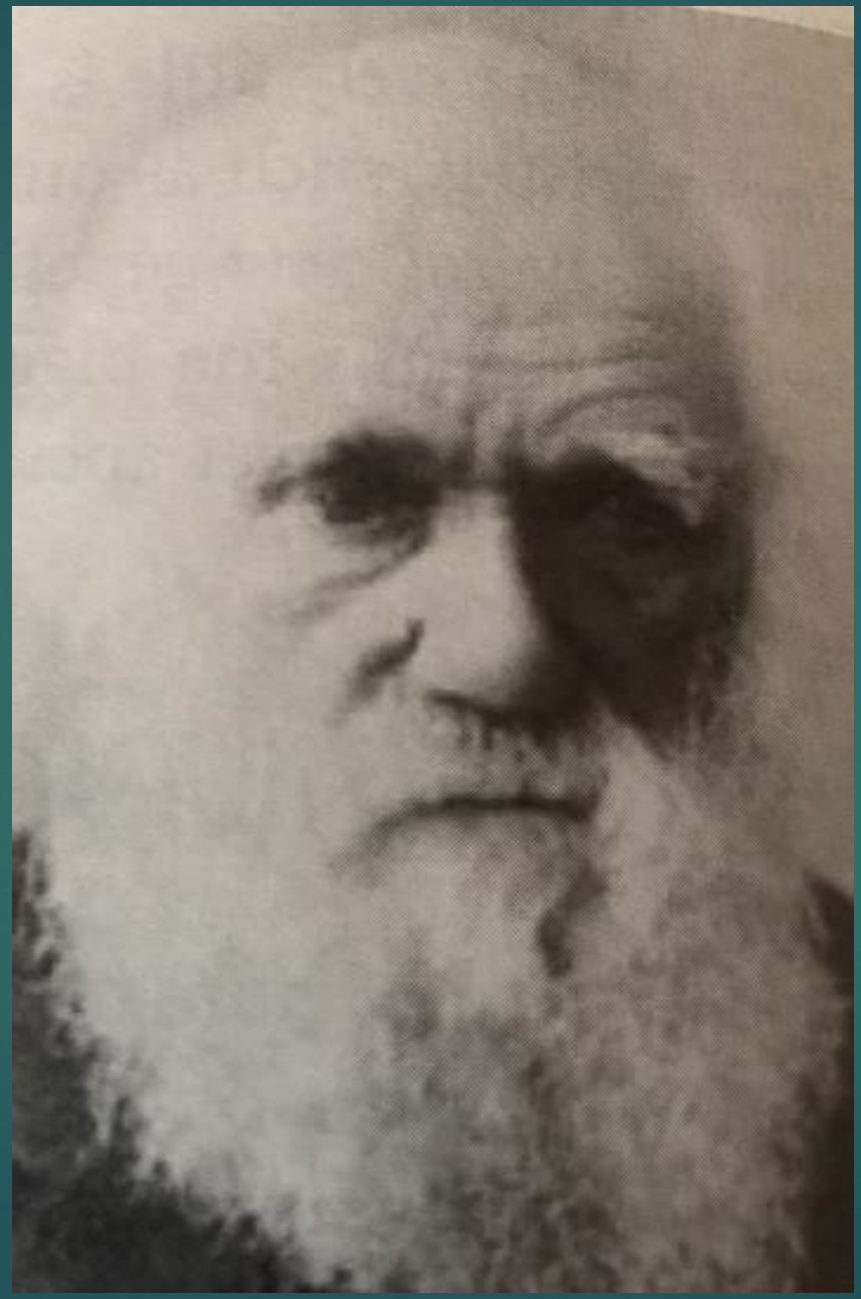
Evolution

- Darwin: Descent with modification via natural selection

- Evolution is nothing more than a fairly simple way of understanding what is unquestionably a real fact:
  - There is vast diversity of life on earth
  - Living things evolve to better survive & reproduce in their environment
  - All life on earth is related through their common descent via DNA.

- Evolution only occurs when there is a change in gene frequency (proportion of a population that carries one type of variant, or allele, at a locus) within a population over time.

Great Apes

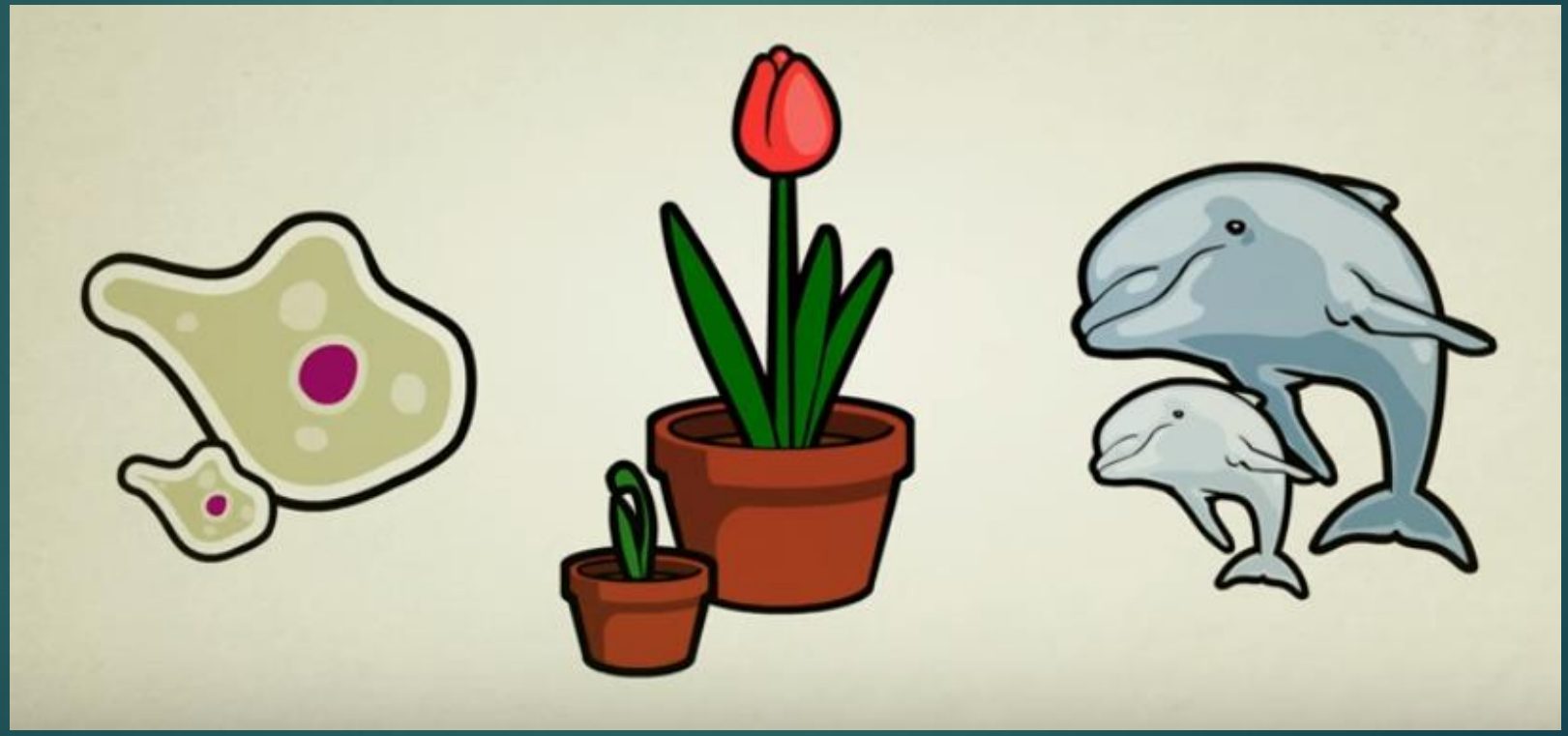


Darwin’s tagged finches from Galapagos

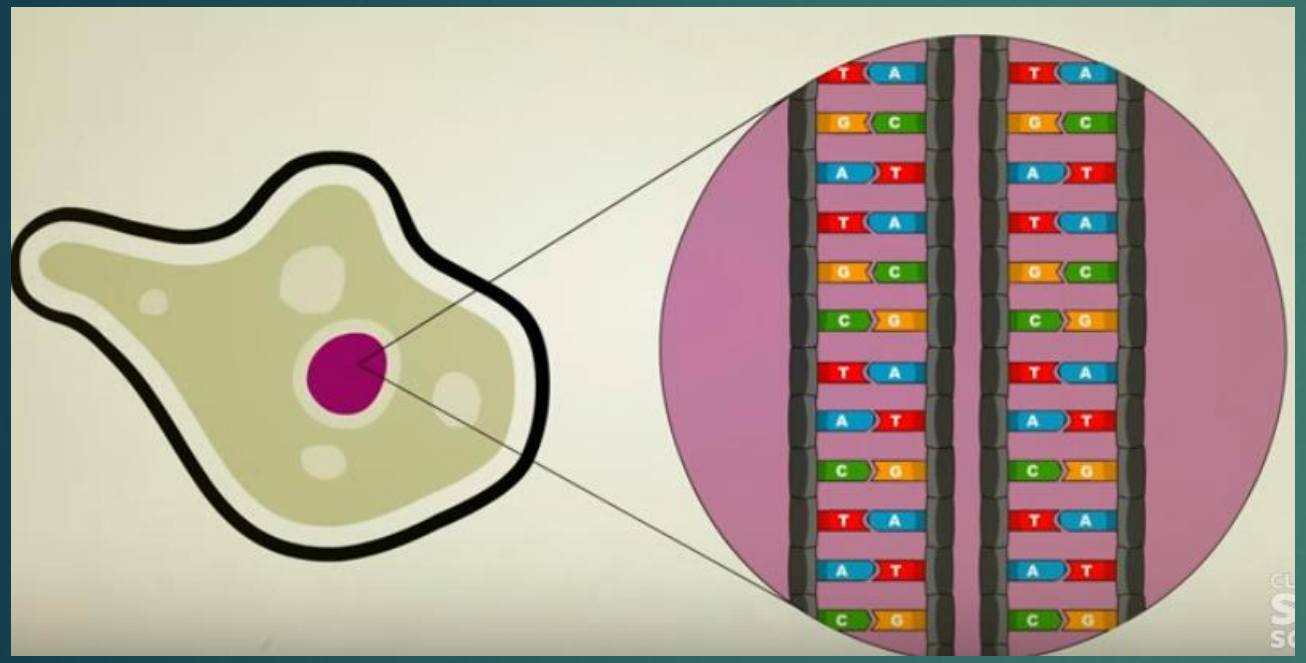
But Alfred Wallace’s were more colorful.

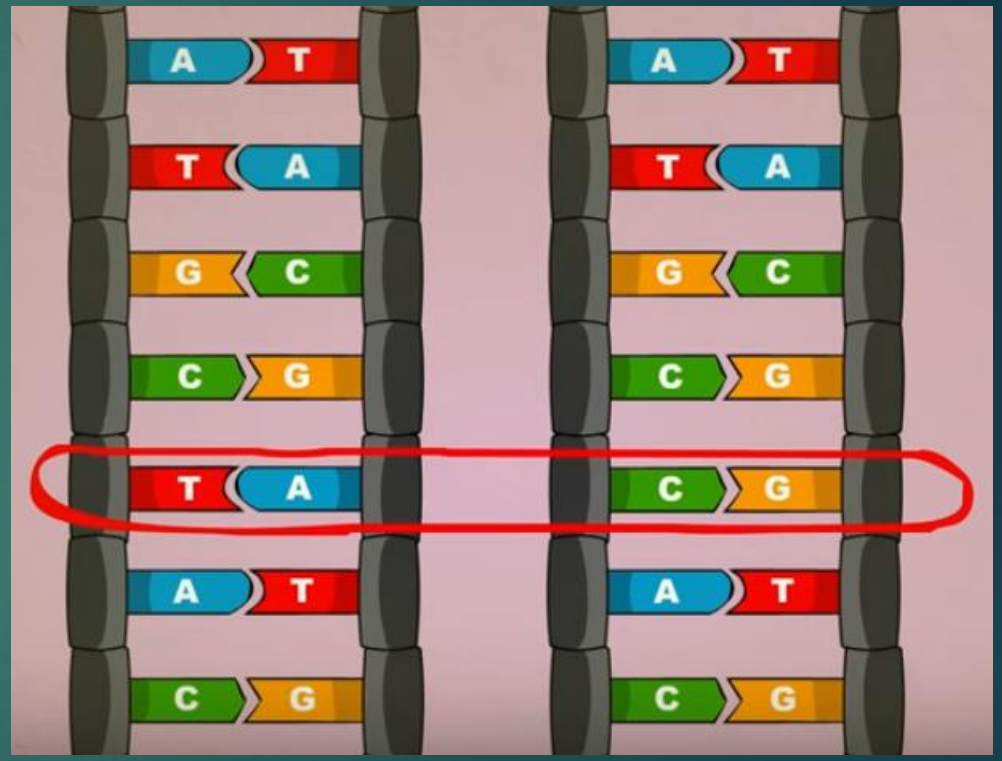
What is evolution

- Any change in heritable traits within a population across generations
- Reproduction required: All organisms make copies of themselves



We reproduce by copying our DNA;
but errors can occur = DNA mutation

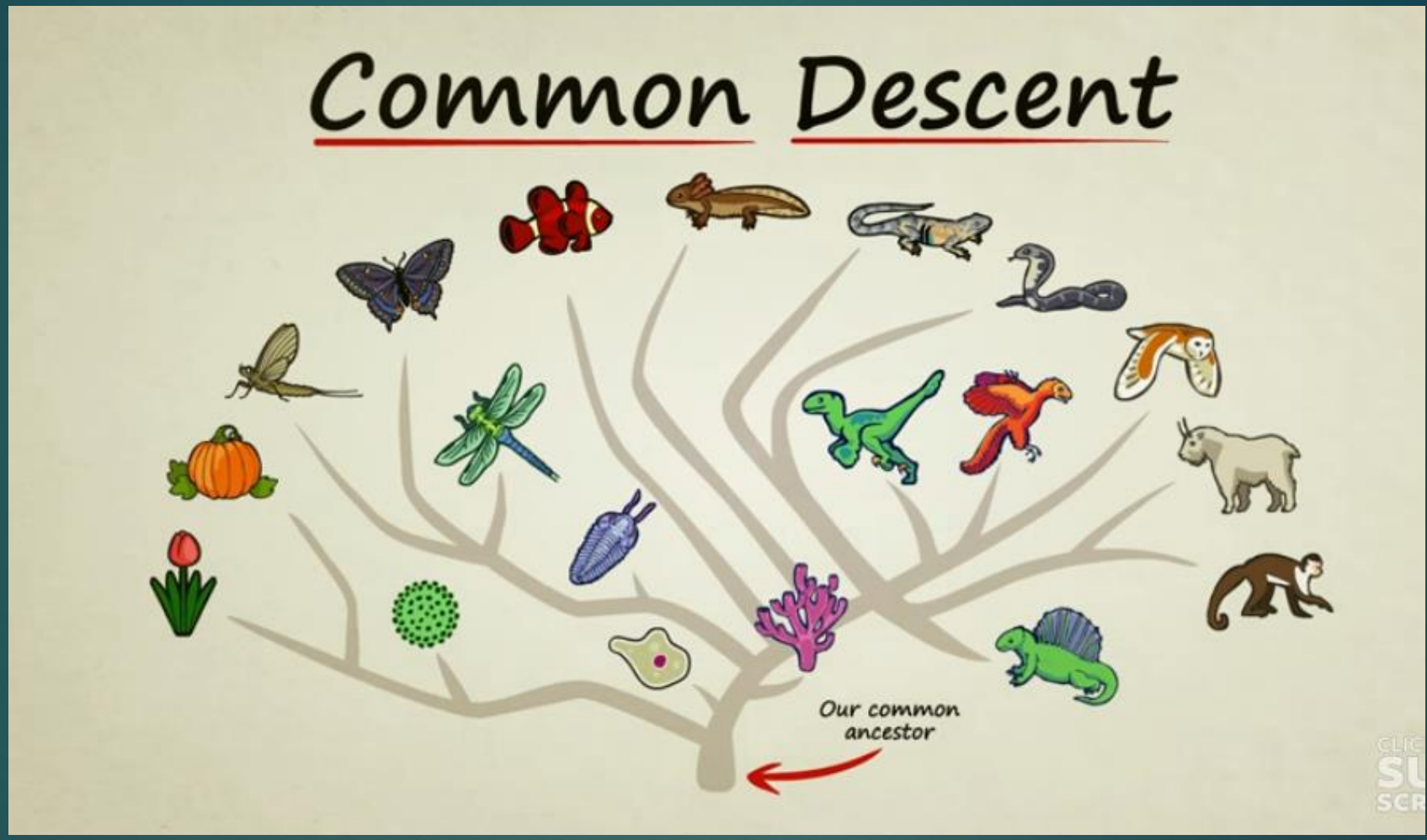




Small variations accrue over generations

Descent with Modification

When parents have children, children look and behave differently from parents and from each other; due to chromosome recombination and random genetic mutation



Common Descent is a conclusion based on massive collection of facts:
Fossils, DNA, comparative anatomy, biochemistry, & species distribution

Islands are sources of unique specimens; but often different islands have specimens that act and look similar to nearby islands

Selective breeding: farmers breed wild boars into current pigs

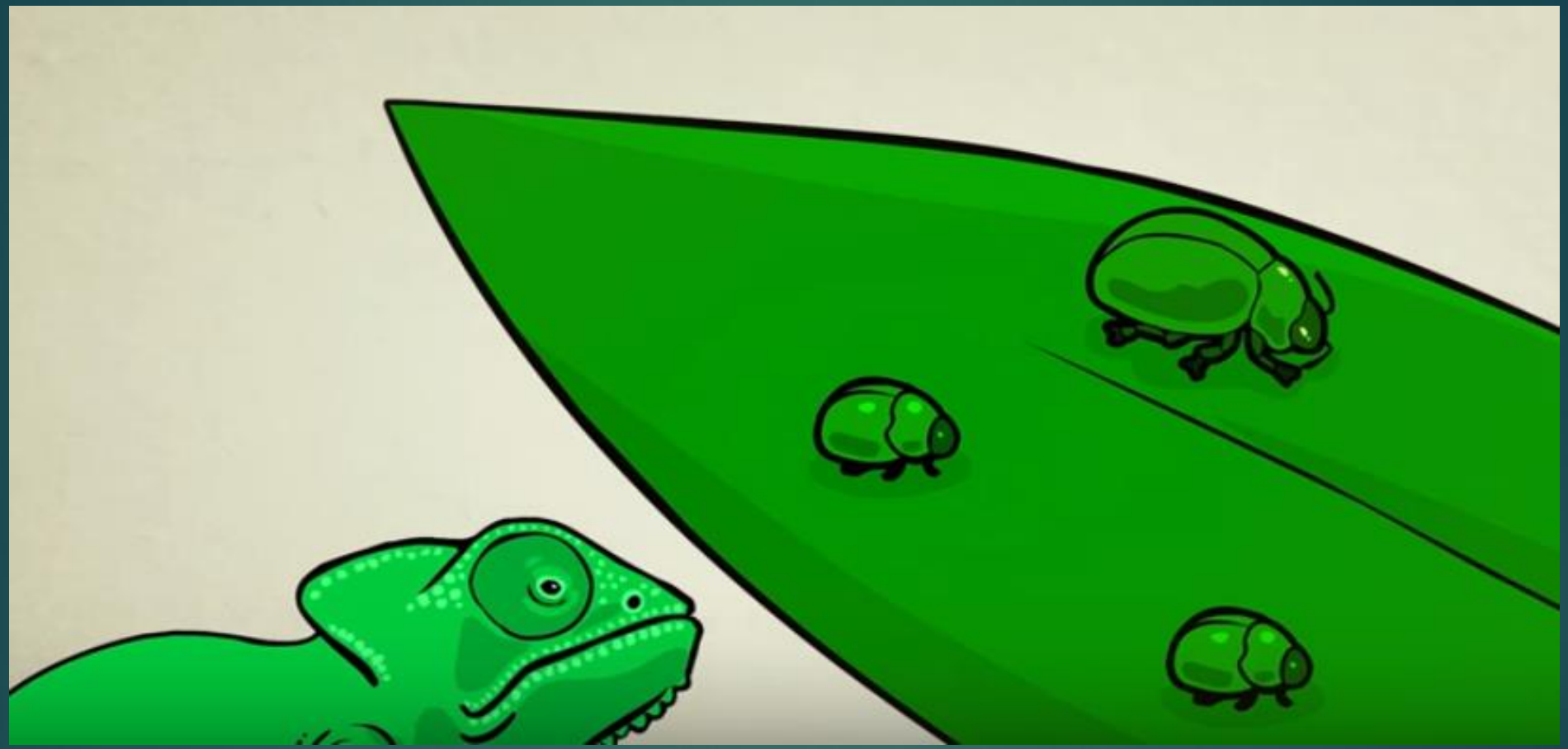
Farmer creates nothing: simply picks from variation he finds

Artificial selection: The mustard family, Brassicaceae

Contains some 338 genera and more than 3,700 species

Origin = wild mustard plant: Arugula, cauliflower, cabbage, kale, garden cress, bok choy, broccoli, Brussels sprouts, collard, rutabaga, horseradish

Nature itself is capable of selection;
this process = Natural Selection



Nature “chooses” from existing variation; those which are more adaptable to local environment, get to reproduce; others do not

Elements of the theory of evolution

- All species are capable of producing offspring faster than the food supply increases; there will be a struggle for existence
- All living things show variation
- Favorable variations will offer an advantage in the struggle for existence
- These variations, when heritable will be passed on to the next generation and will increase in frequency over time, changing the population

Method of evolution

- Only how evolution works (the mechanism) is currently a scientific question.
- Natural selection is the currently accepted scientific explanation of the method of evolution (Wallace & Darwin)
- Darwin:
  - Malthus: all animals multiple until they can't survive
  - Immense variation in these groups due to:
    - Mutations in DNA in sex cells (only ones that are evolutionarily significant) and
    - Parental recombination: Randomness of which parental chromosomes recombine, and crossing over of parts of chromosomes produce immense variation
  - Natural selection: Differential survival of variants in a particular environment; more successful reproduction with greater adaption (not necessarily strength or intelligence)

Natural Selection: Organisms that are best adapted to an environment *survive* and *reproduce* more than others

- Natural selection is the process by which random evolutionary changes are selected for by nature in a consistent non-random way
- Nature decides which traits to keep: those that confer fitness
- Positive changes add up over multiple generations; negative traits are removed
- Variation precedes selection. As Dawkins has said, natural selection is the non-random survival of random variants.
- Through this simple, ongoing, process, nature can produce "*endless forms most beautiful and most wonderful*"

Natural selection

- Requirement:
  - Variation must exist *a priori* in order for natural selection to act, i.e. natural selection does not create a variant but it 'prefers' it. Evolution always tweaks last year's model. It is a tinkerer, not an inventor.

- Natural Selection = mechanism for evolutionary change favoring the survival and reproduction of some organisms over others because of their biological characteristics.

- "It is not the most intellectual of the species that survives; it is not the strongest that survives; but the species that survives is the one that is able best to adapt and adjust to the changing environment in which it finds itself." Leon C. Megginson

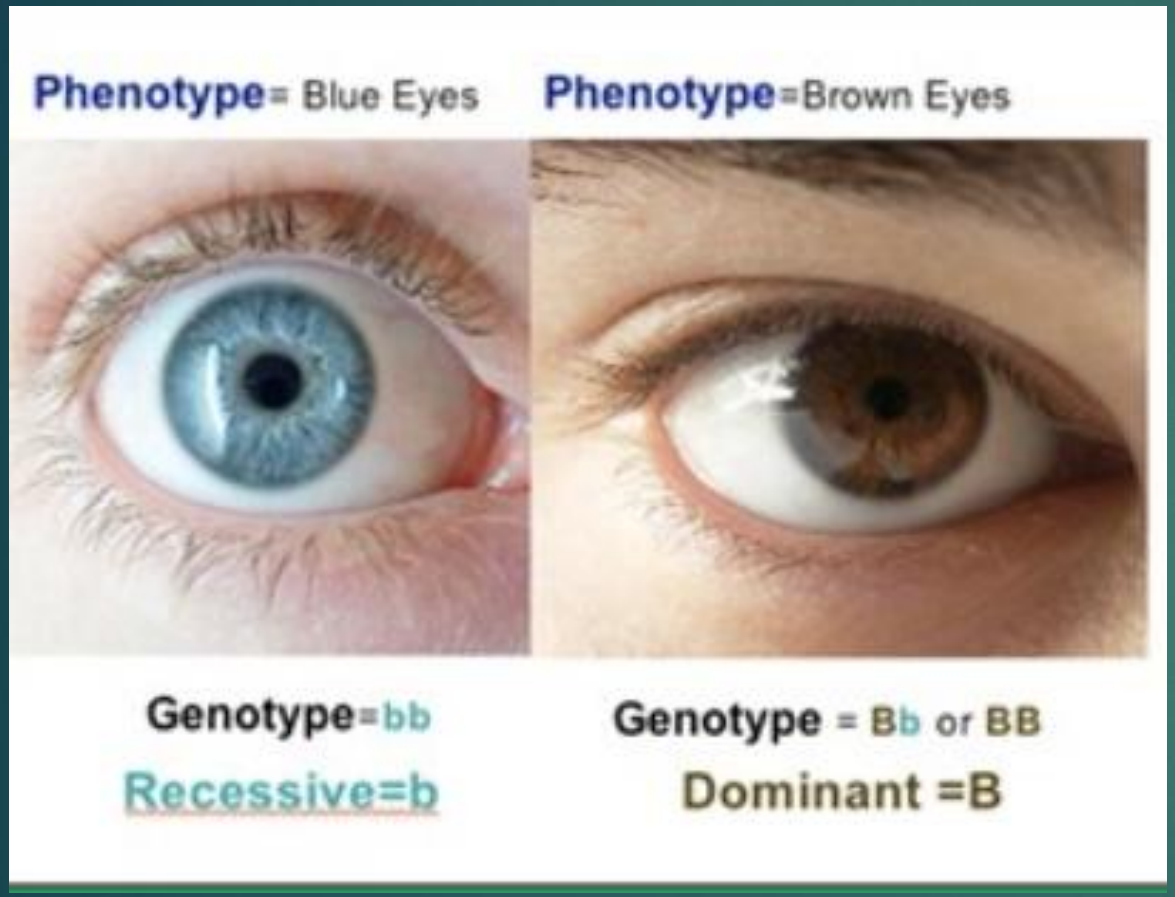
NS: phenotype, genotype, and environment.

- Phenotype:
  - the observable characteristics of an organism
  - can be anatomical, biochemical, or behavioral
  - natural selection works on phenotypes
  - Phenotype = produced by genotype + environment

- Genotype:
  - the genetic makeup of an individual, its DNA, genes

- Environment: So how natural selection operates is specific at any given time to a given phenotype within a given environment. If you change the environment, you might change how natural selection is acting on an organism. A mutation (lactose tolerance) only was favored when environment had cows and cheese.

Phenotypes and Genotypes



Phenotype: your observable traits, i.e. actual eye color; how an organism appears

Genotype: combination of alleles that you inherited from parents and that cause your phenotype

A tiger in the wild does not care about your genes; it only cares about how fast you are

Populations evolve

- Individual survival and reproduction depends on whether it has genes that produce traits that are well adapted to its environment.

- Individual organisms do not evolve: The ontogeny (development) of an individual is not considered evolution

- Only populations evolve: The changes in populations that are considered evolutionary are those that are heritable via the genetic material from one generation to the next.

Douglas J. Futuyma in *Evolution*, 2017

- Darwin's Theory of Natural Selection occurs in four steps:
  - 1 - Overproduction
  - 2 - Variation
  - 3 - Competition
  - 4 - Selection

1. Overproduction

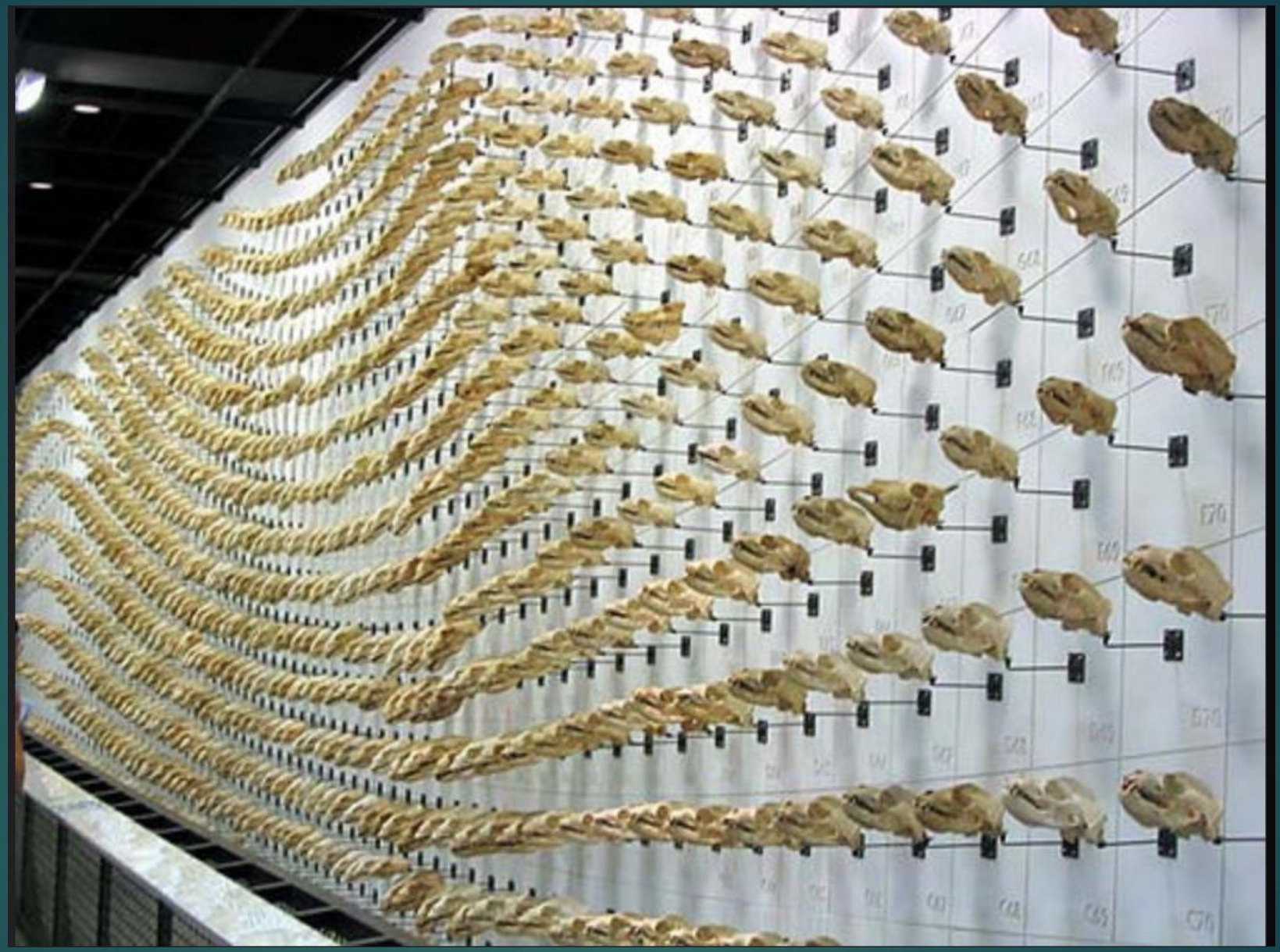
- Each species produces more offspring that can survive

2. Variation

- Each individual has a unique combination of inherited traits (phenotype).
  - Adaptation: an inherited trait that increases an organism's chances of survival

Variation

20,000
Butterfly
caterpillars



California Academy of Science: 5000 sea lion skulls

Why is Variation Important?

- Because the environment changes.

- The more variation within a species, the more likely it will survive
  - Ex: If everyone is the same, they are all vulnerable to the same environmental changes or diseases

- The more variation of different types of species in an habitat, the more likely at least some will survive
  - Ex: Dinosaurs replaced by mammals
  - i.e. drug resistance development in HIV virus; billions of copies in a body

3. Competition

- Individuals compete for limited resources:
  - Food, water, space, mates

- Natural selection occurs through "Survival of the fittest"
  - Fitness: the ability to survive and reproduce
  - "Best adapted" = as well adapted as your competitors; squeaking by, being good enough, or adequate enough
  - Natural selection's only criterion is that something works, not that it works as well as it might. Botched jobs are common.
  - Fitness Success: if you reproduce, you have succeeded

4. Selection

- The individuals with the most adaptable traits will survive and have the opportunity to pass on it's traits to offspring.

- Principle of local adaptation: in a particular location, a trait may help you survive better

- Natural selection acts on the phenotype (physical characteristics), not the genotype (genetic makeup)
  - Ex: When a predator finds its prey, it is due to the prey's physical characteristics, like color or slow speed, not the alleles (BB, Bb)

- Evolution occurs when adaptive traits build up in a population and nonadaptive traits are eliminated by the death of the individuals.

Light vs dark mouse color advantage: depends on color of rock

1 letter mutation

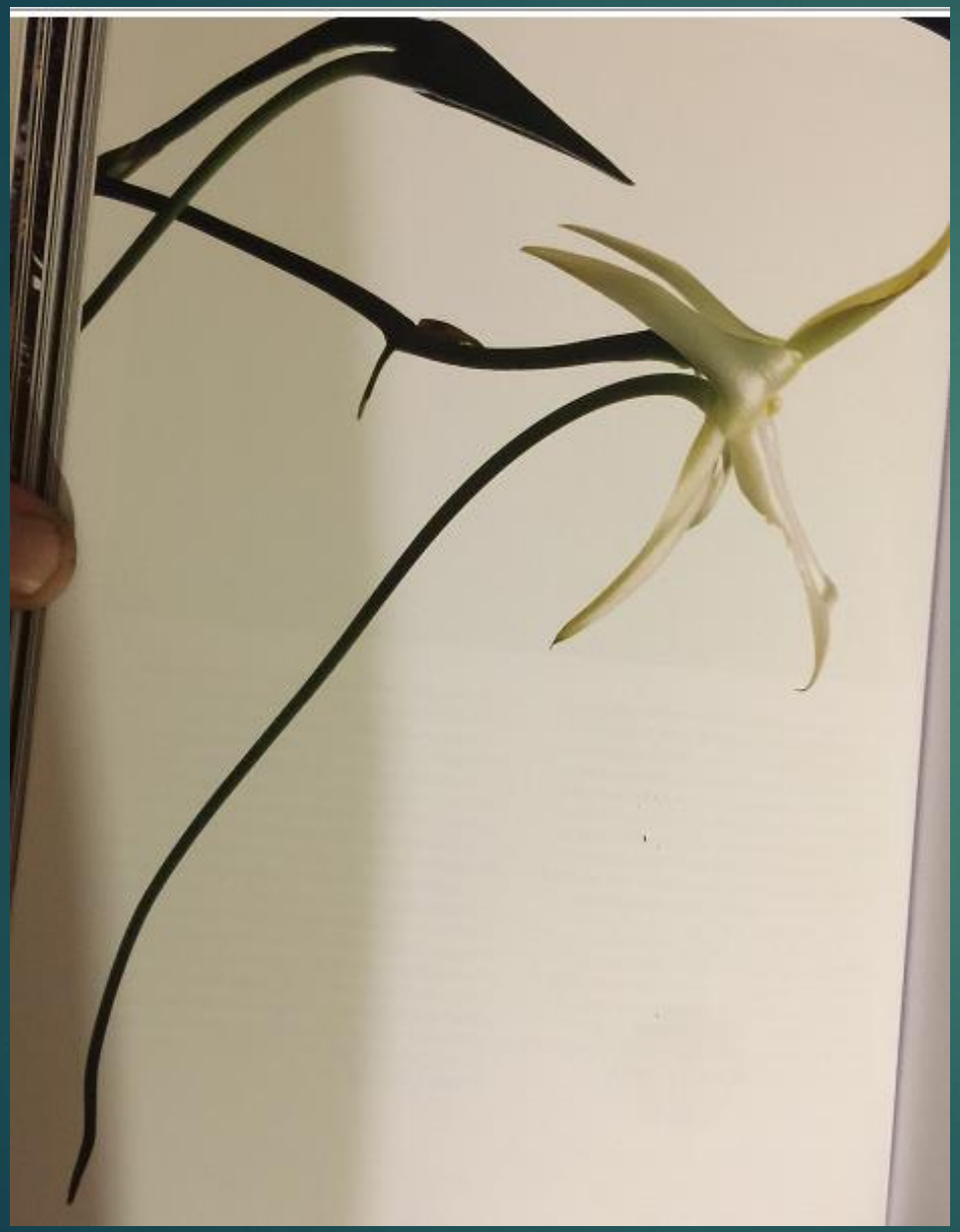
Darwin: “Good Heavens what insect can suck it”– Co-evolution

- Darwin received a Madagascar orchid (*Angraecum sesquipedale)* with 11 inch nectar r… …nce in 1862 of a moth with

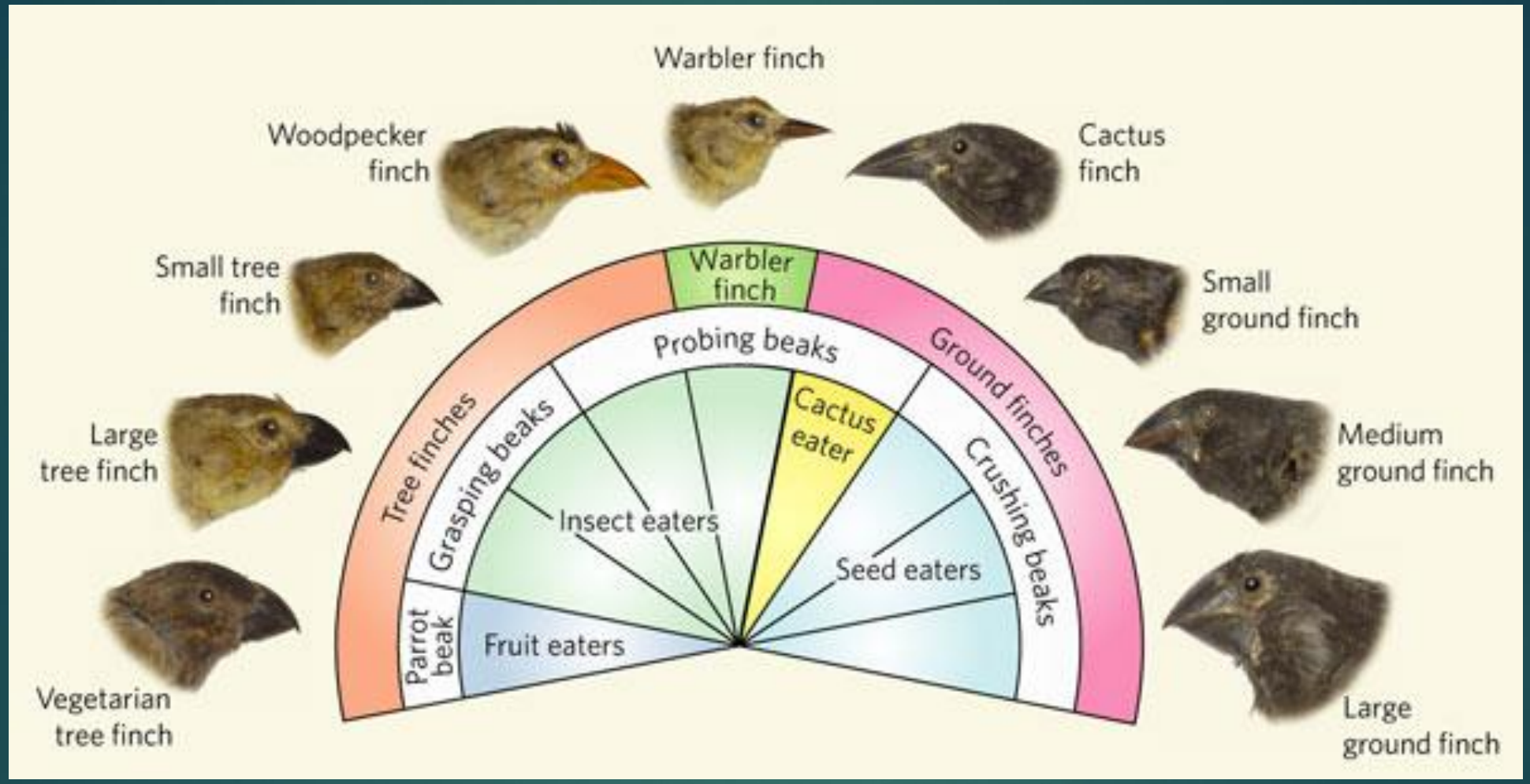
The sphinx moth (*Xanthop*… discovered in 1903; photo i… Co-evolution: pollination or…

JOSEPH ARDITTI, et al., 20…2

Natural Selection: A Darwin tale of a proboscis



Darwin's Finches



Finches with uniquely adapted beaks related to unique foods on each Galapagos island; All descended from 1 ancestral finch which flew there from South America
Applied this idea of descent with modification to all of life, the tree of life concept

Evidence of possibility of fast evolution

- Grants showed in their studies of Galapagos finches, small beaks can change into large beaks in a single generation, depending on climate conditions and the type of food to be found

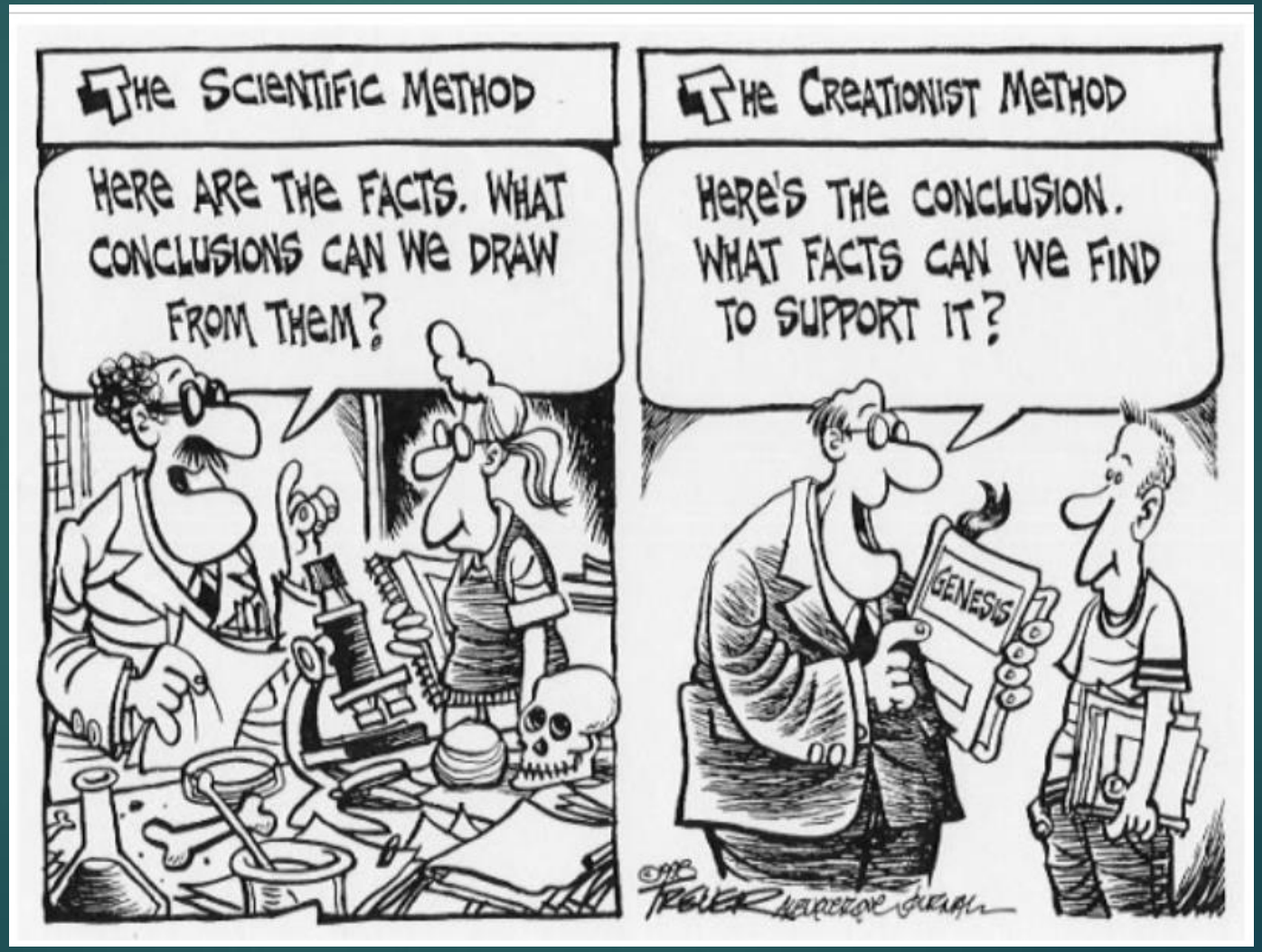
- But those rapid changes aren't often permanent. Changes in vegetation could mean that large beaks become a handicap.

- But to enable fast evolution, you must have enough genetic variation present in the underlying gene pool for selection to work upon.

Evolution of Evolutionary Theory after Darwin

- Darwin could not explain how variation was maintained
  - Darwin did not know: genetics, DNA
  - Assumed blending inheritance
  - Could not explain evolution beyond original range of variation
- Acceptance of Darwinian mechanisms awaited rediscovery of Mendelian genetics
- Eventually inclusion of genetics evolutionary theory in the Modern Synthesis (1930-1950)
- Evo-Devo (1980-present): role of development in evolution, i.e. Hox genes

Science and Creationism



What is Science?

- The word *science* comes from the Latin "scientia," *meaning* knowledge.
- Science is the pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence. It is fundamentally a way of knowing, a methodology.
- Falsifiability is fundamental to science: “No amount of experimentation can ever prove me right; a single experiment can prove me wrong." —Albert Einstein
- A scientific theory is empirical, and is always open to falsification if new evidence is presented. No scientific theory is ever considered strictly certain as science accepts the concept of fallibility.
- JBS Haldane: there would be a falsification of the theory of evolution if we found a fossil rabbit or a horse along with a trilobite in Pre-Cambrian.

What about God?

- My experience with a crying 12 year old boy at the Academy
- Science has nothing to say about God, not out of rejection, but merely because there is no way of scientifically studying or ascertaining a theological truth, i.e. existence of a deity.
- Percy Bysshe Shelley: “God is a hypothesis, and, as such, stands in need of proof: the onus probandi [burden of proof] rests on the theist.”
- For some people, unfortunately, the only way of dealing with their conflict is to deny the evidence for evolution altogether.

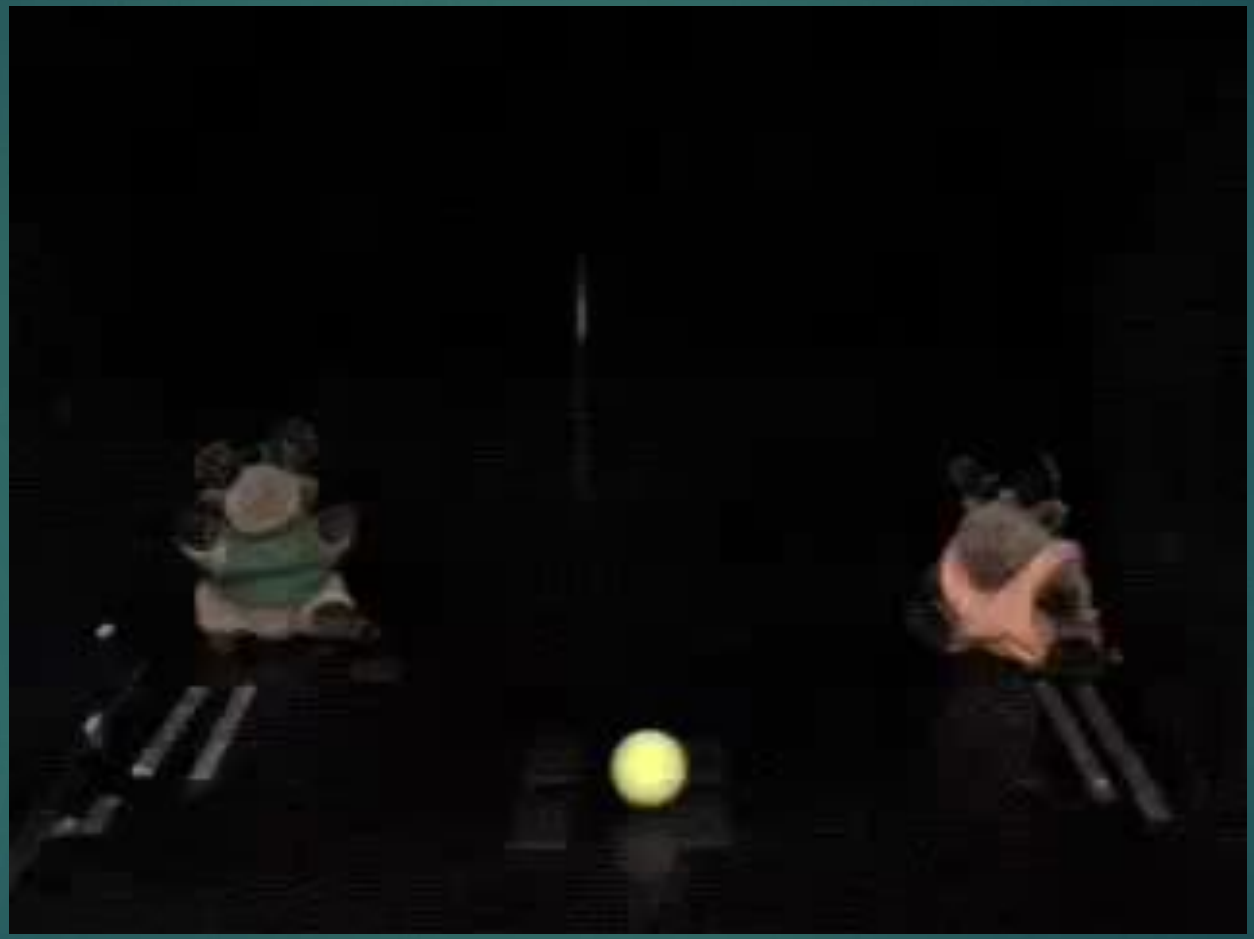
What about God?

- Many argue that if there is no God, there is no basis for morality.

- Arthur C. Clark: “One of the great tragedies of mankind is that morality has been hijacked by religion. So now people assume that religion and morality have a necessary connection. But the basis of morality is really very simple and doesn’t require religion at all. It’s this: “Don’t do unto anybody else what you wouldn’t like to be done to you.” It seems to me that that’s all there is to it.”

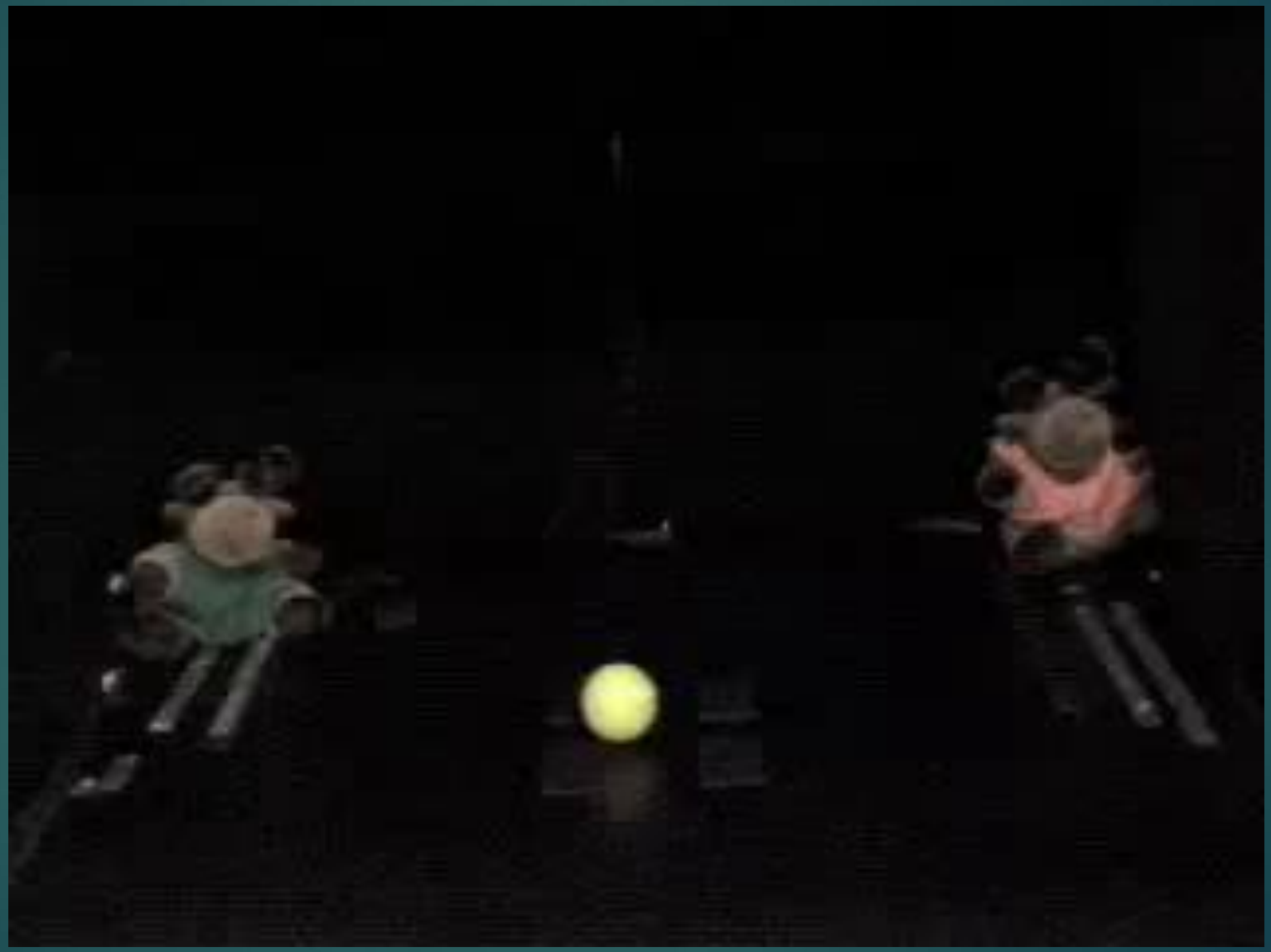
- See:
  - *Faith* vs. Fact – Jerry Coyne
  - *God's Word or Human Reason?: An Inside Perspective on Creationism*. 2016 - Kane, J., Willoughby, E., Keesey, T.

A Lesson in the origins of Morality: Puppets who share



Hamlin, J.K., & Wynn, K. (2011).

Puppets who are not pro-social



3 & 8 month old infants prefer prosocial to antisocial others

- The babies were next given a choice between taking a treat away from the “nice” puppet or the “naughty” one. Infants consistently removed the treat from the naughty puppet. Sone also smacked them as well.
- 3 to 8 month old toddlers direct positive behaviors toward prosocial others & negative behaviors toward antisocial others. Humans are an evolutionarily social species.

Hamlin, J.K., & Wynn, K. (2011).

Kitzmiller v. Dover, 2005: Teaching ID is unconstitutional

- 2005 the landmark legal case *Kitzmiller v. Dover* in Harrisburg, Pa., set binding precedent that the teaching of intelligent design in U.S. public schools is unconstitutional because the idea is fundamentally religious, not scientific.

- Decision transcript: https://www.documentcloud.org/documents/2426499-kitzmiller-v-dover-decision.html

- Galileo Galilei: “I do not feel obliged to believe that the same God who has endowed us with sense, reason, and intellect, has intended us not to use them.”

Misconceptions of evolution and natural selection

- Bigger is better
- Newer is better
- Faster is better
- Natural selection always works
- Evolution has a direction or goal
- Natural selection always produces perfect structures
- All structures are adaptive

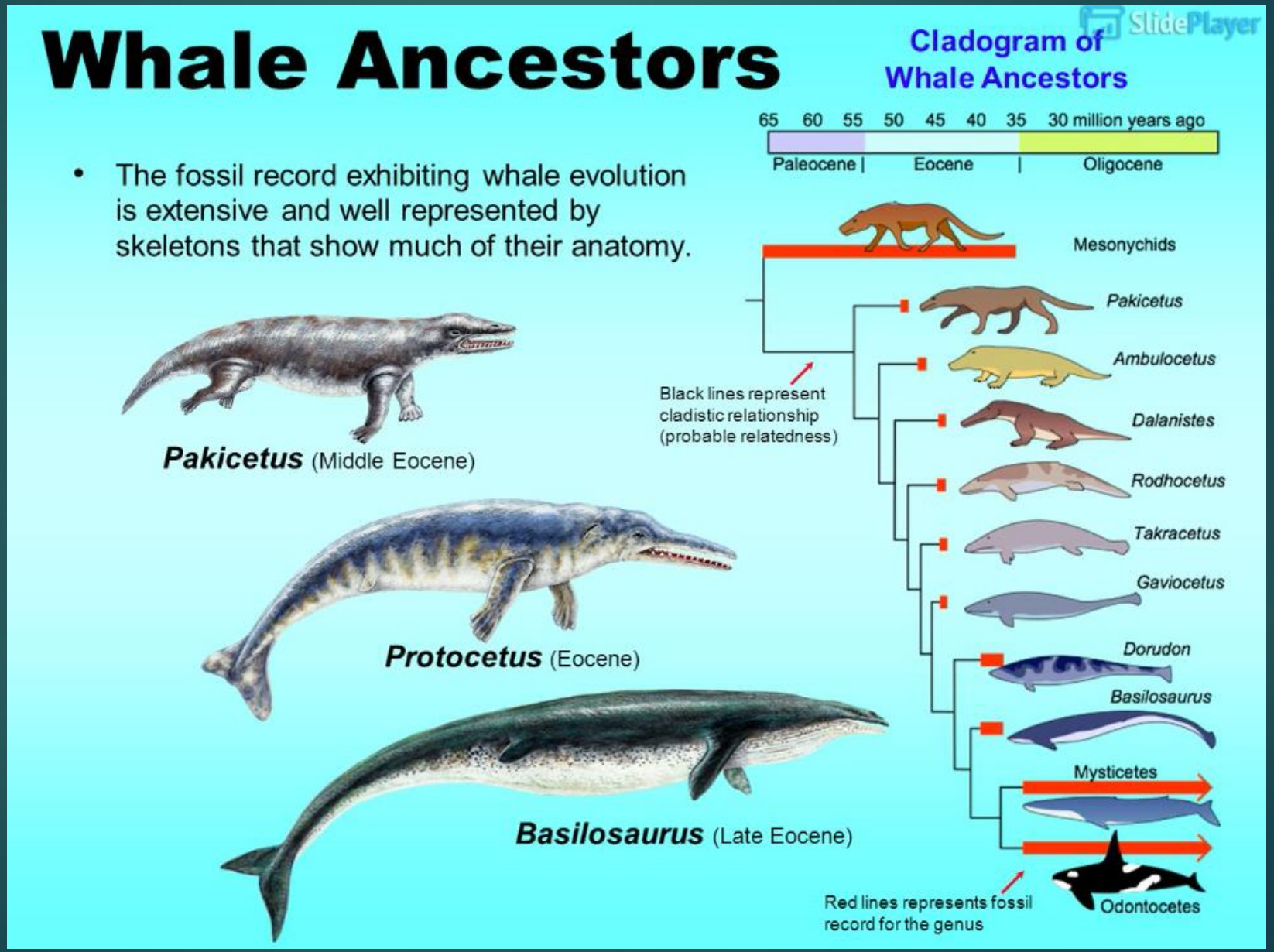
Basic premises for this discussion

- Evolution is not a belief system. It is a scientific hypothesis: a rational acceptance of evidence that can be falsified. It has no role in defining religion or religious beliefs. It is based on evidence.
- Evolution is a theory…but you don't get any better than that in science
- There is a lot of religious contention about evolution, but not among scientists or scientific organizations.
- Creationists do not accept evolution.
- 99.9% of scientists believe there is overwhelming evidence of evolution.

What is the Evidence for evolution

- From many different areas of biology:
- **1 Comparative Anatomy.** Species may share similar physical features because the feature was present in a common ancestor (homologous structures, Vestigial Organs).
- **2 Embryology.** Similarity in early forms of development
- **3 Molecular biology.** DNA and the genetic code reflect the shared ancestry of life. DNA comparisons can show how related species are.
- **4 Fossils.** Fossils document the existence of now-extinct past species that are related to present-day species.
- **5 Biogeography.** Spatial distribution of species: The global patterns of distribution of organisms and the unique features of island species reflect evolution and geological change.
- **6 Direct observation.** We can directly observe small-scale evolution in organisms with short lifecycles (e.g., pesticide-resistant insects).

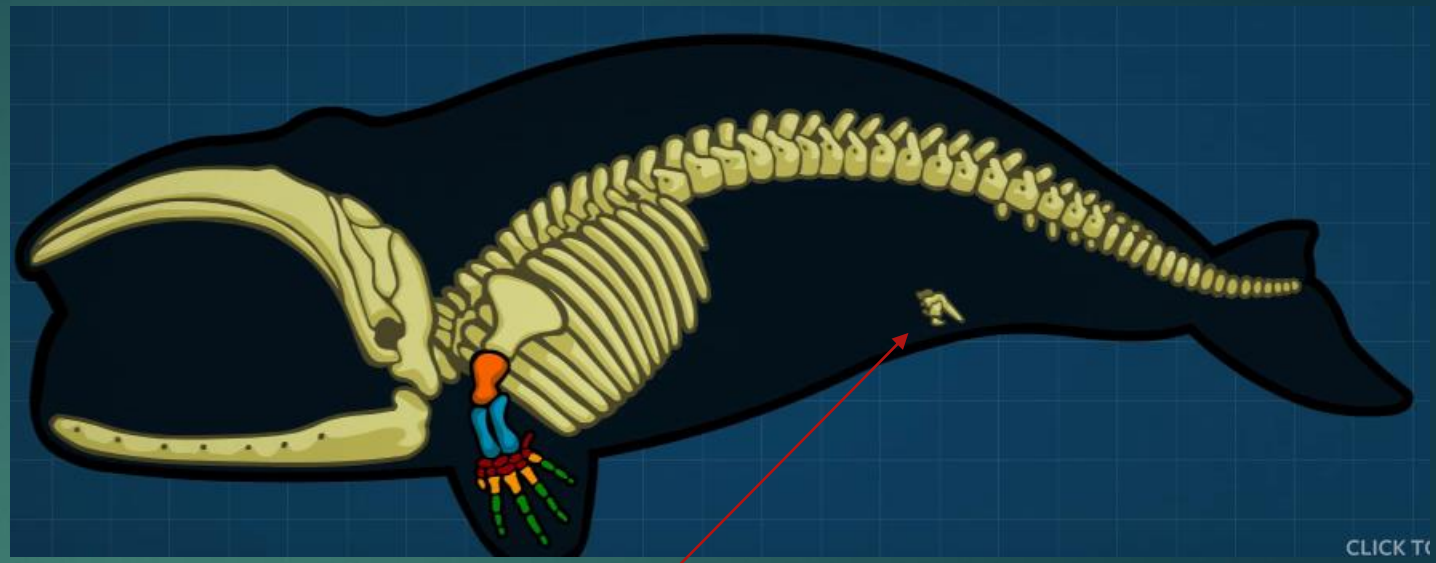
A Whale of a Tale: Lots of transitional evidence of their evolution

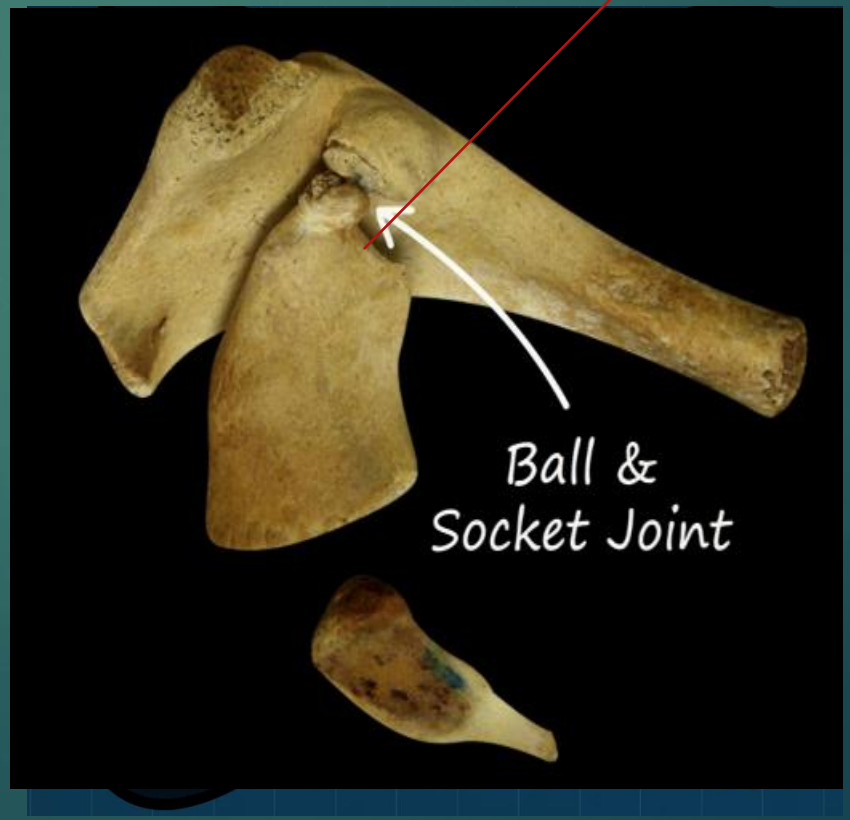


Whales are mammals:

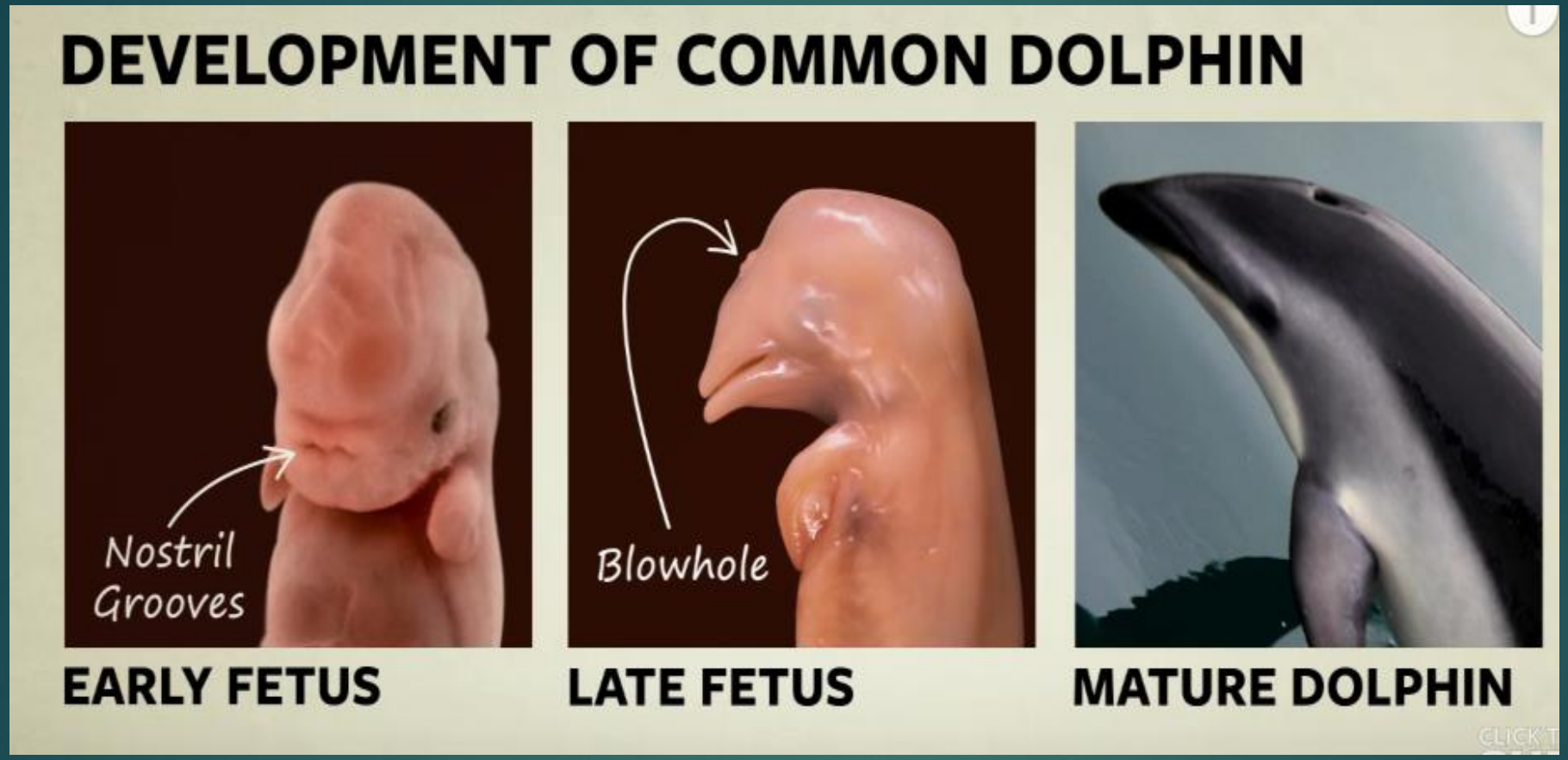
Comparative anatomy

- Placenta
- Give live birth
- Feed milk to young
- Warm blooded (97ºF)
- No gills; have lungs
- Blowholes = modified nose
- Hair
- Fin = hand - arm, wrist, hand
  - 1-2-5 sequence
- Vestigial leg bones
- Swim with up-down motion



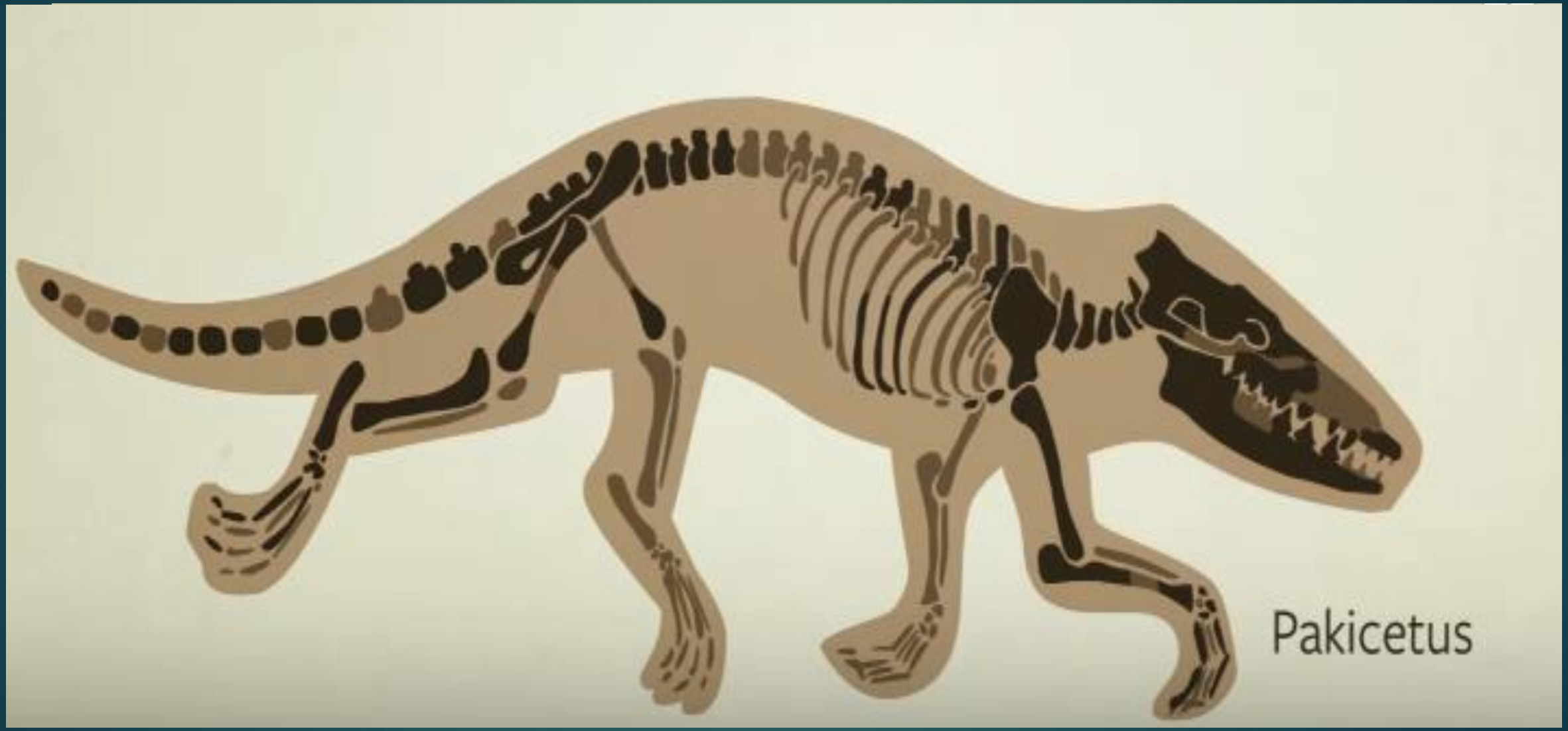


Whales: Embryology

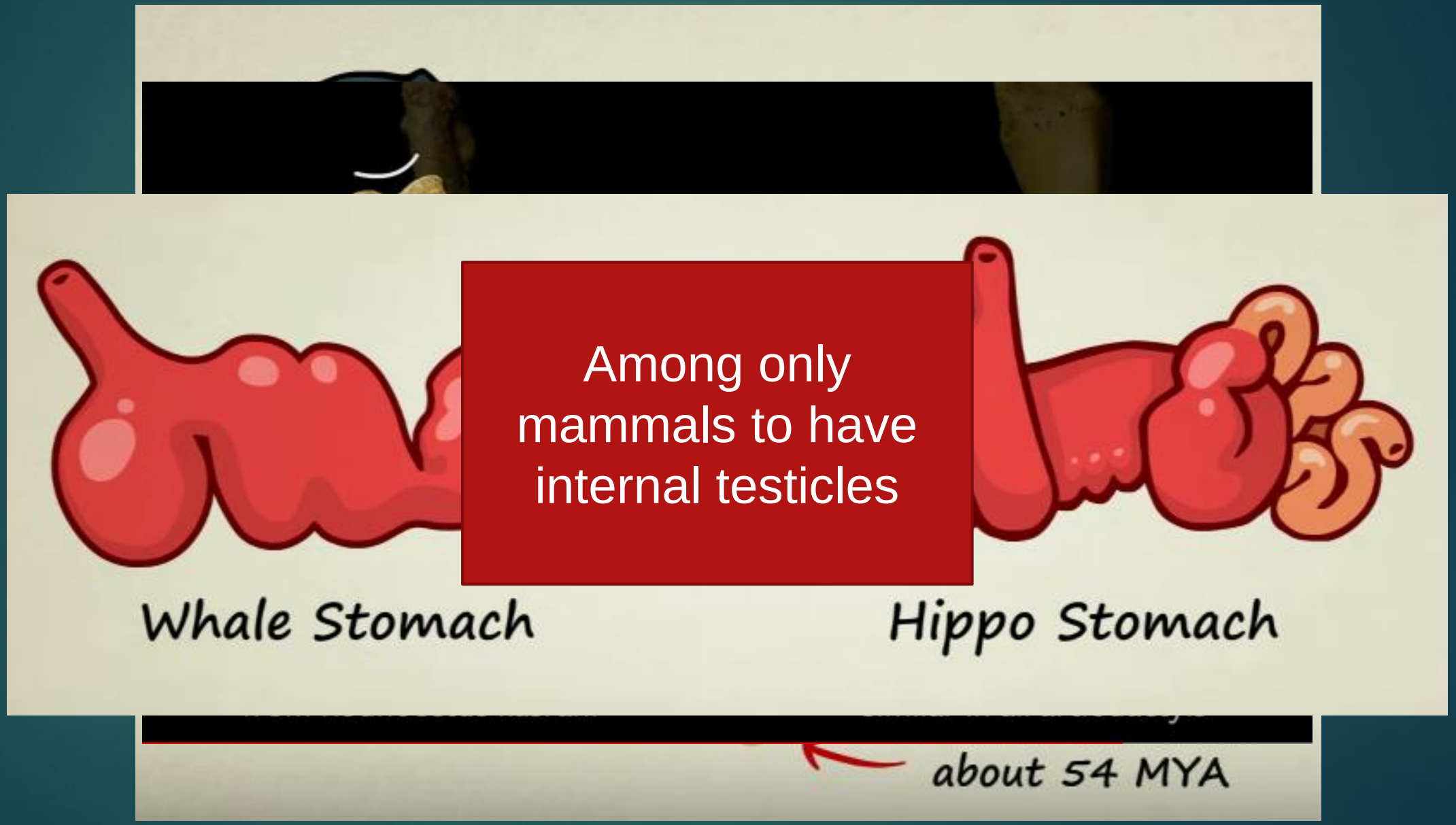


Evolution of nostril placement:
Ancestry of whales were once land animals

Whales: Fossil Record – whales evolved from land mammal



Whales: DNA evidence – What is closest species?



Evidence of Evolution: 1 - Morphology: shared similarities in form

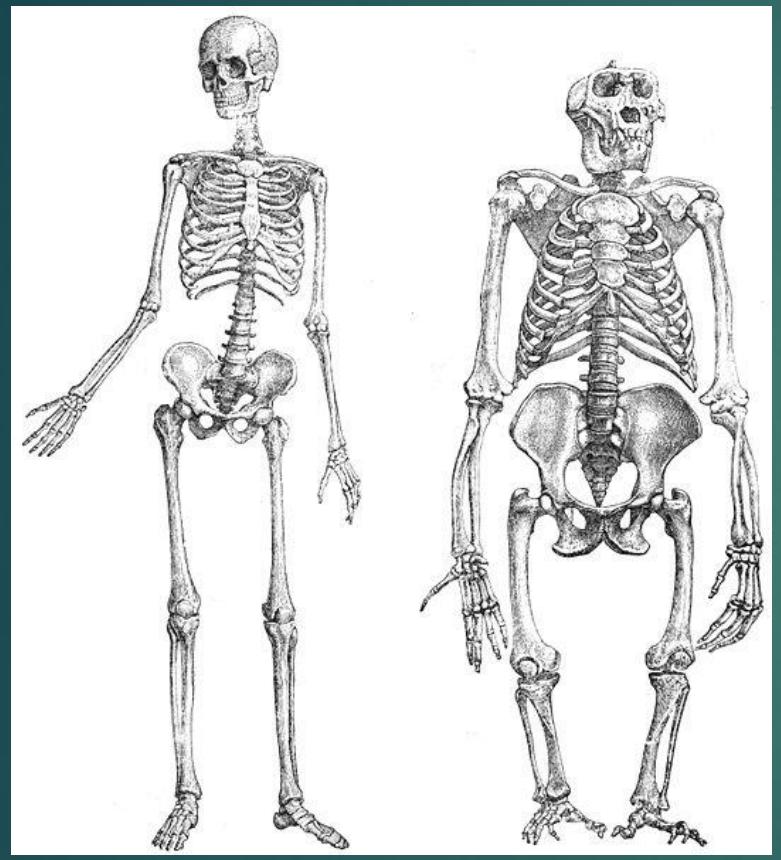
- Linnaeus showed how species could be systematically classified, according to their shared similarities of form, i.e. 4 legs

- Richard Owen made a major contribution by advancing the concept of homologies:
  - superficially different, but fundamentally similar, versions of a single organ or trait, shared by dissimilar species, i.e. pendactyl hand

- Darwin, with a nod to Owen's "most interesting work," supplied the answer to existence of homologies: common descent, as shaped by natural selection

- The number of shared characteristics between any one species and another indicates how recently those two species have diverged from a shared lineage.

1 - Comparative Anatomy – bilateral symmetry



Human and Gorilla

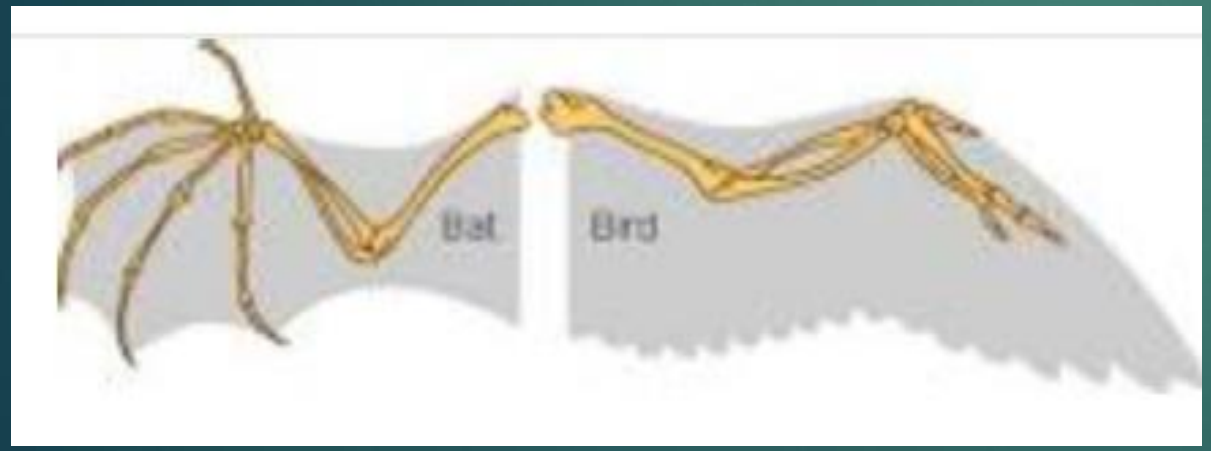
- The skeleton of humans and gorillas are very similar suggesting they shared a recent common ancestor, but very different from the more distantly related woodlouse…

- yet all have a common shared characteristic: bilateral symmetry

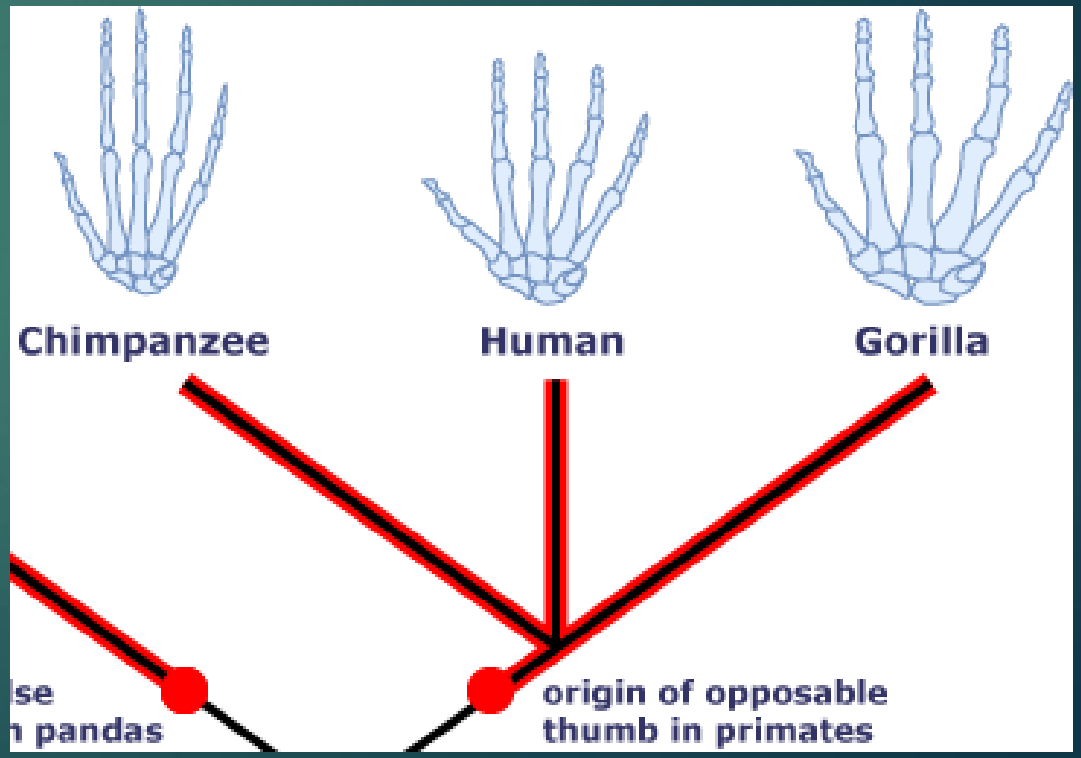
Woodlouse

Homology and Analogy

- IN both cases, similarity in traits
- Similarities can be due to
  - shared evolutionary past (homology – opposable thumb in primates)
  - or common function (analogy – bat & bird wing)



Convergent Evolution



Common solutions for common problems:

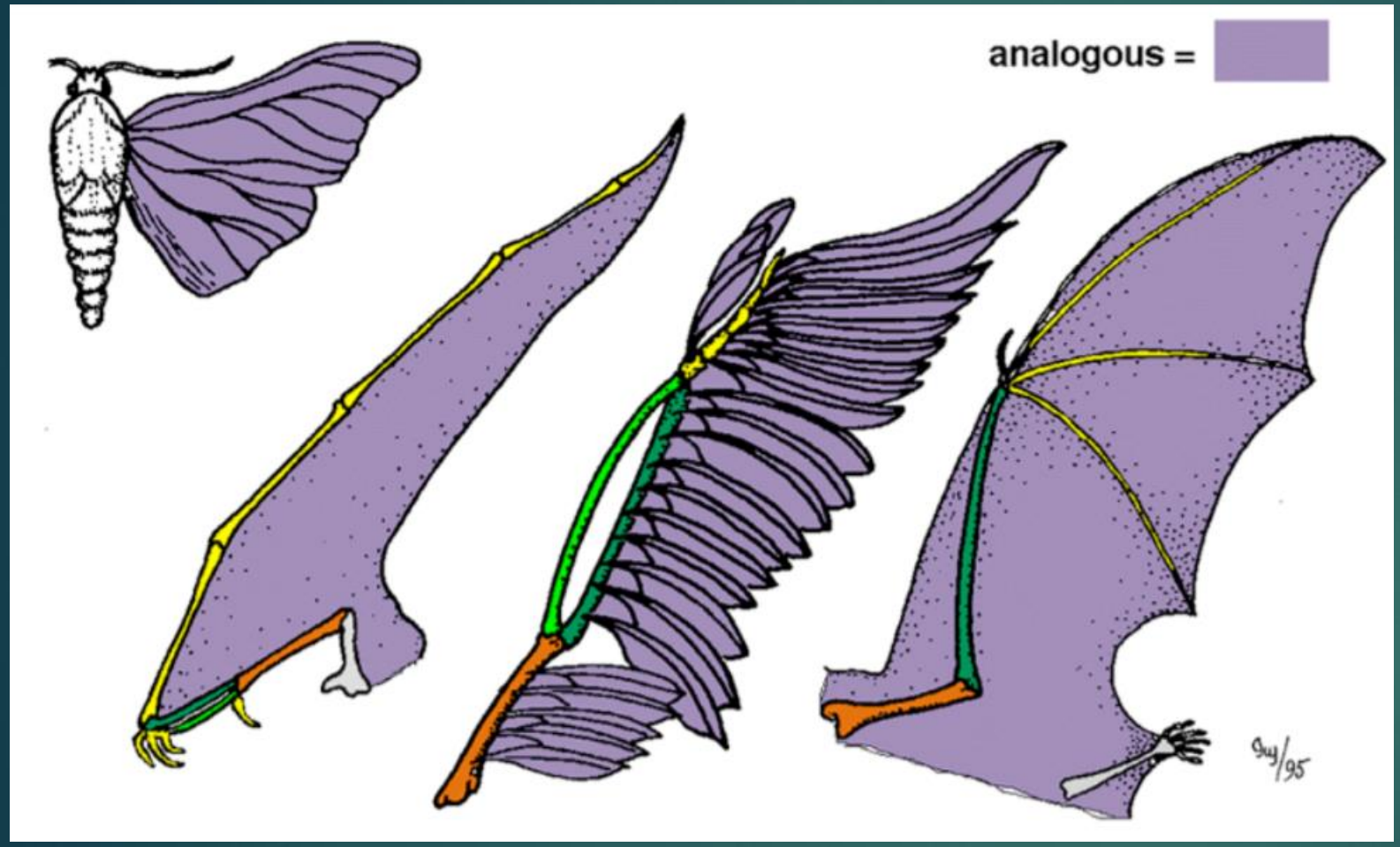
Analogous Structures via Convergent Evolution

- Not all physical features that look alike are due to common ancestry.

- Instead, some physical similarities are Analogous: they evolved independently in different organisms because the organisms lived in similar environments or experienced similar selective pressures. They have a common function, i. e. a wing.

- This process is called convergent evolution. (To *converge* means to come together, like two lines meeting at a point.)

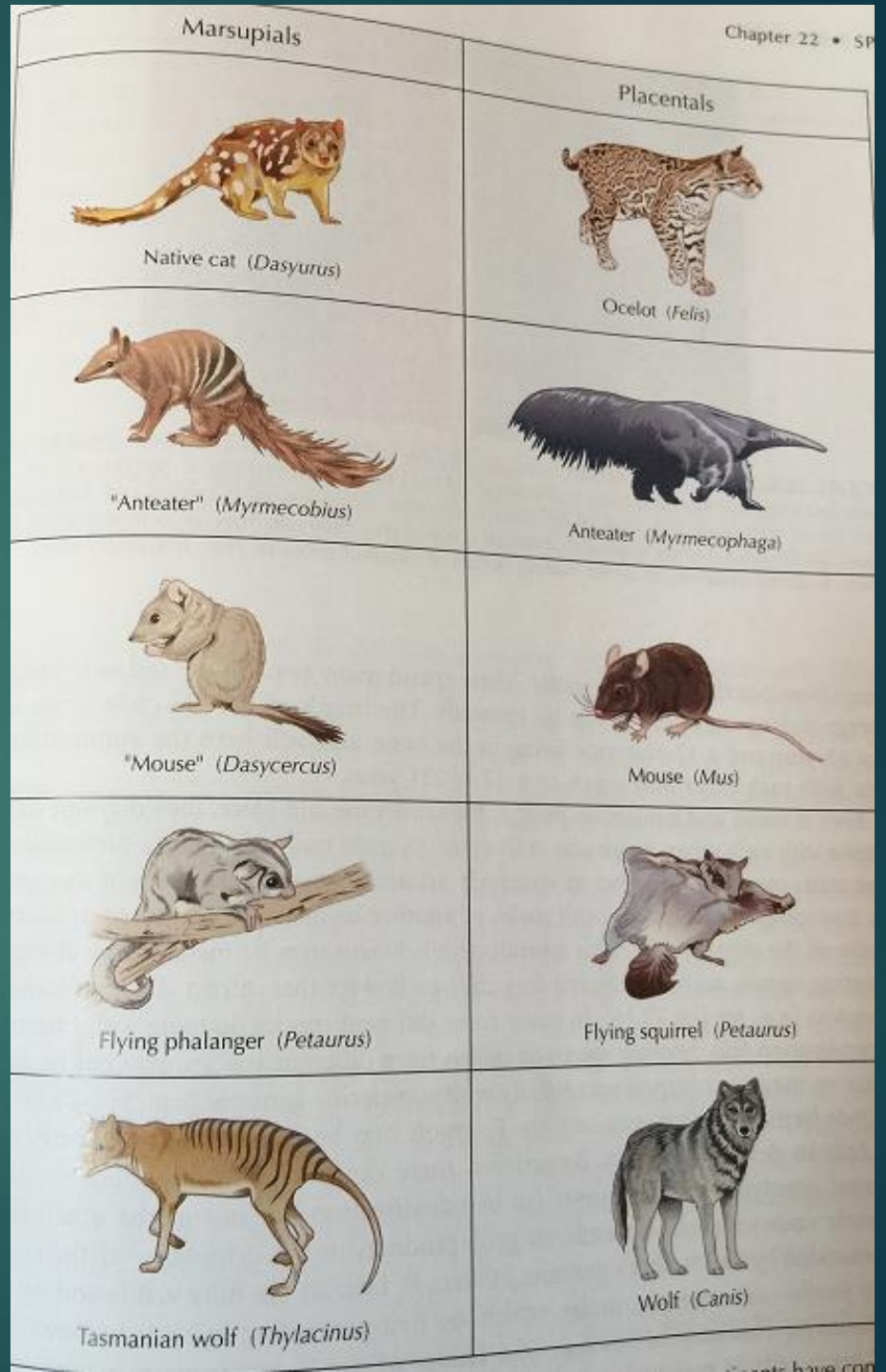
Analogous Structures – no shared ancestor, similar function



- A bird's wing and a bat's wing are considered analogous structures.
- Analogous structures are those that are similar between two organisms due to shared function.
- Though bird and bat wings are analogous as wings, but are homologous as forelimbs.

Convergent Evolution

- Despite evolving in geographic isolation, the marsupials of Australia have evolved many analogous features of placental mammals in the rest of the world.
- Each area had a functional form of cat, mouse, squirrel, wolf

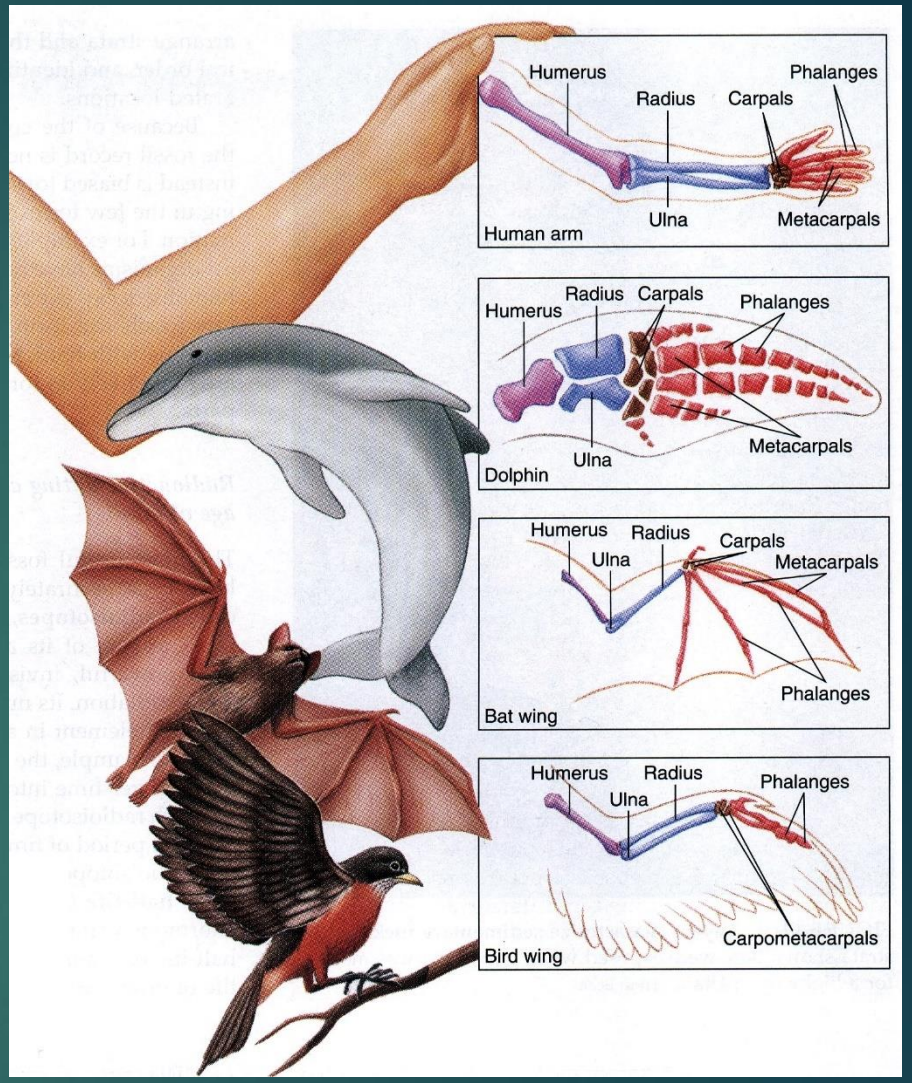


Homologous Body Structures

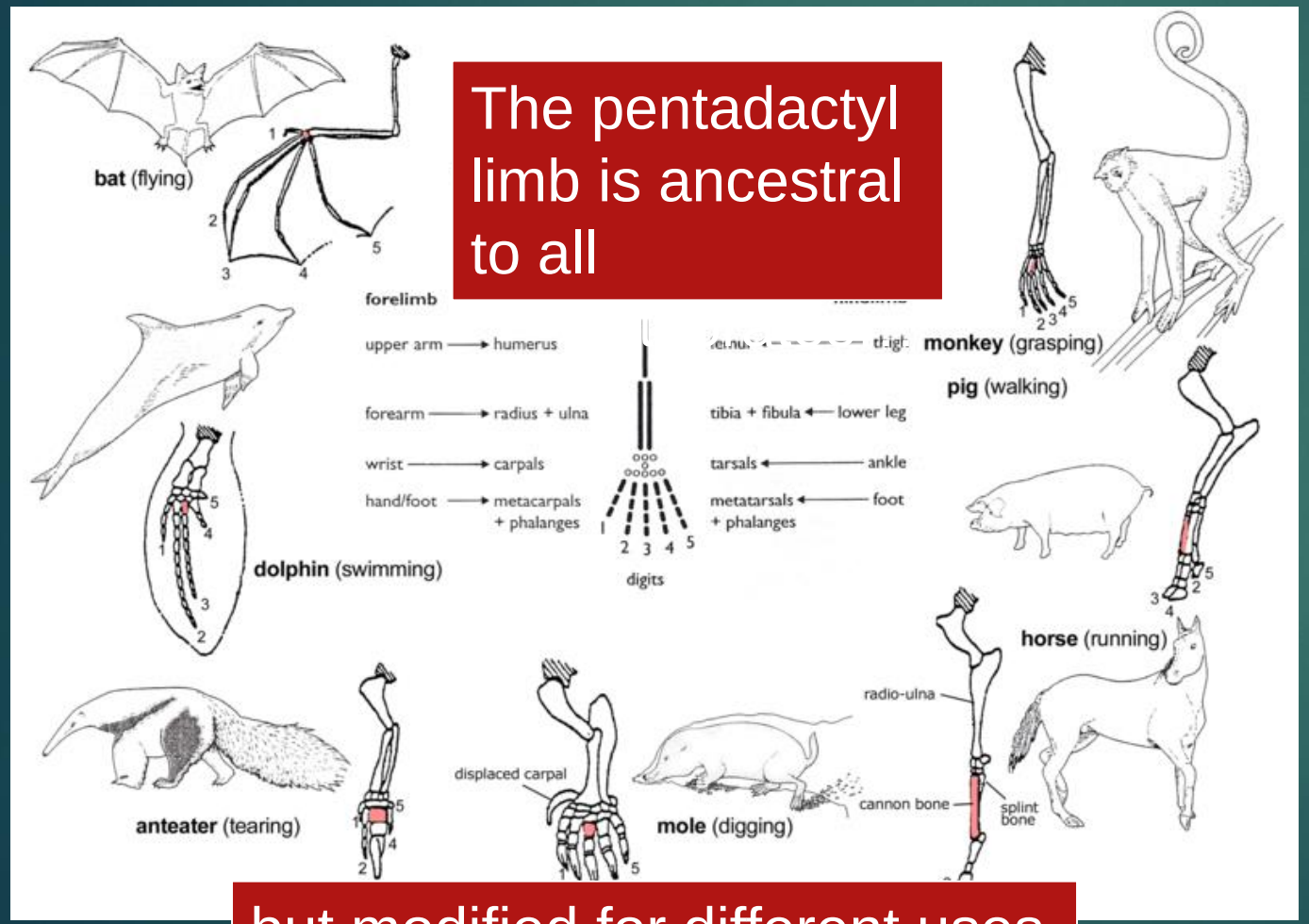
- **Homologous Body Structures**: similar anatomy in different types of animals because of common ancestry

- Physical features shared due to evolutionary history (a common ancestor) are said to be **homologous**.

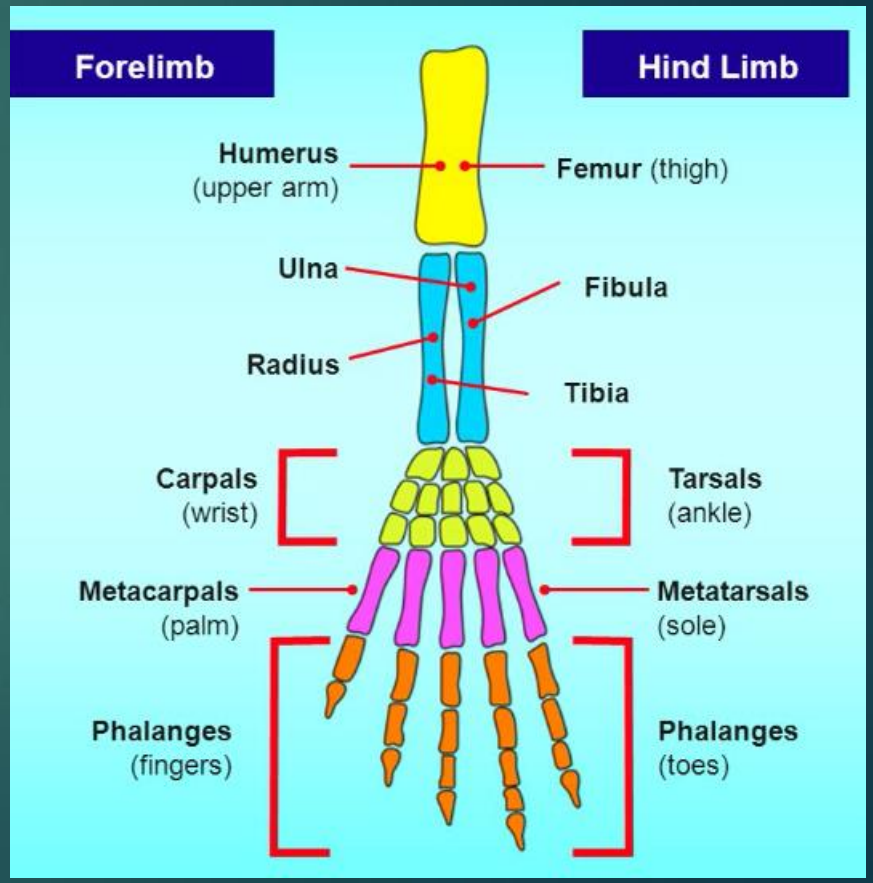
- But they look different because they have adapted to function in different environments



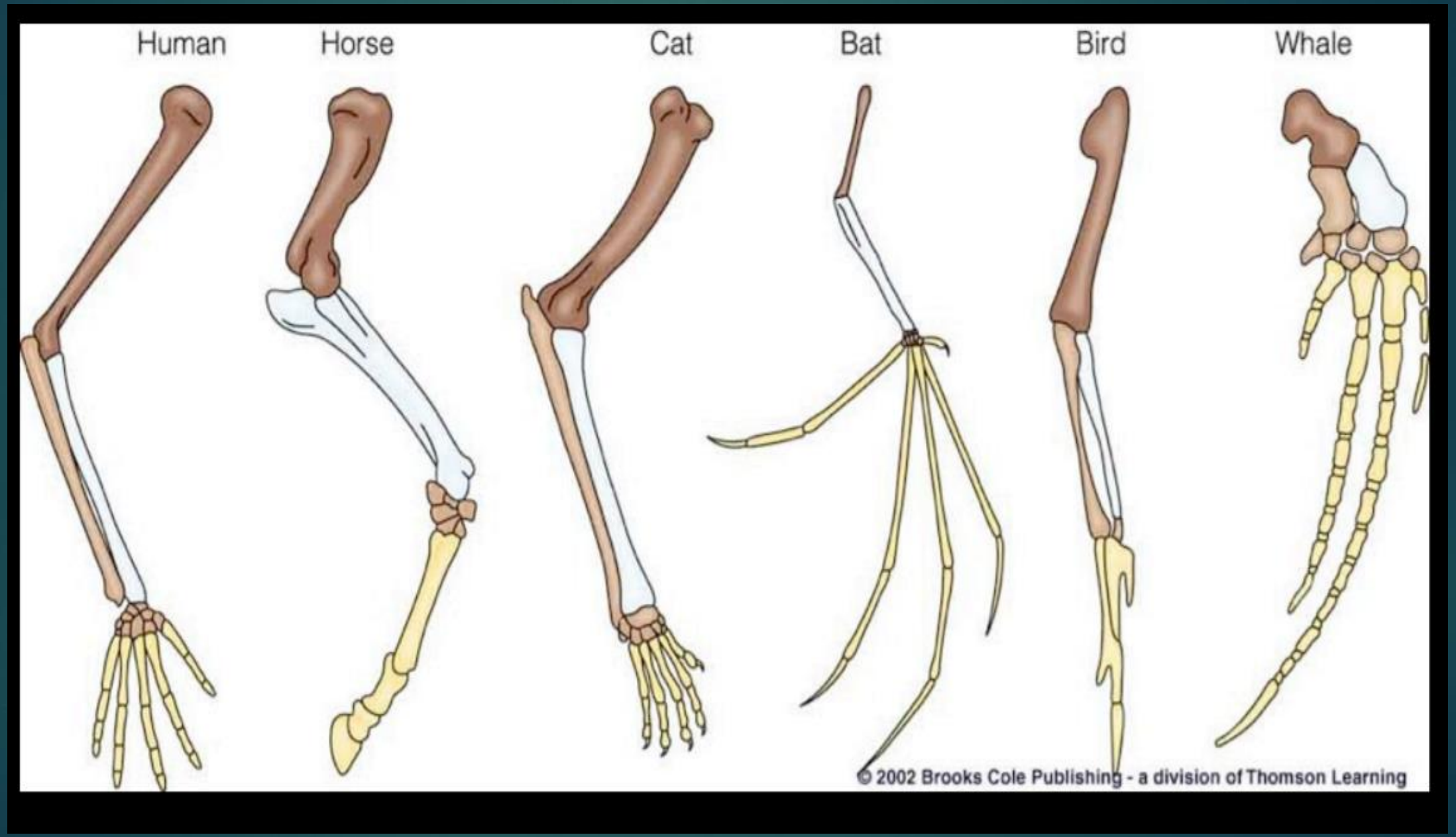
Evidence: Homology: an ancestral anatomical feature that has subsequently been modified in its descendants for a specific function. Indicate adaptive radiation (adapted to different niche).



Pentadactyl limb



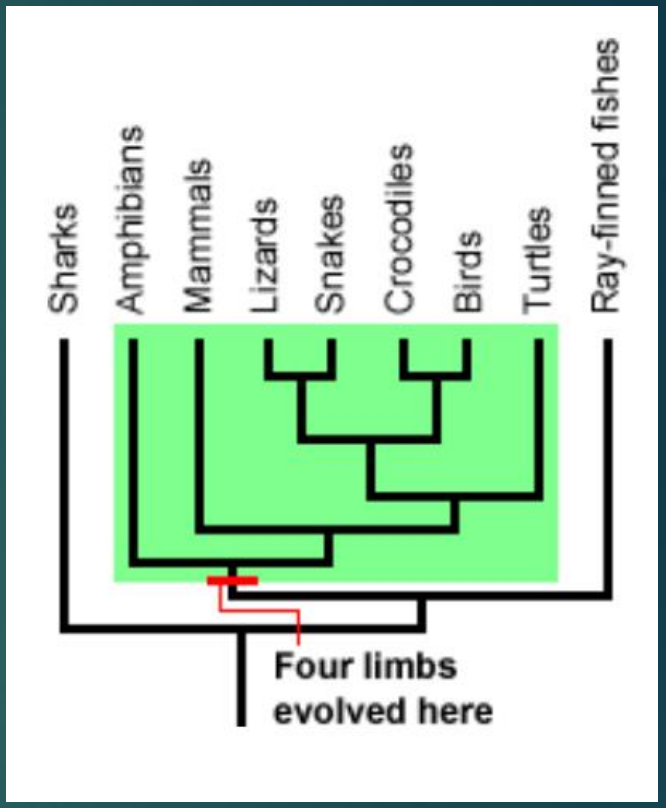
Homologous Body Structures: *bones = 1, 2, wrist, 5 digits*



- Egyptian fruit bat, whose translucent wings beautifully display the skeleton’s homology with our hand
- Skeleton view of a bat

Taxonomic Classification: Shared derived characteristics

- ANCESTRAL (not “primitive”) - the state seen in both the distant ancestor and current species i.e. being bipedal
- DERIVED - something new that has changed since the recent ancestor, i.e. large brain
- A shared character is one that two lineages have in common, (i.e. fur)
- A derived character is trait that the current organism has, and previous one didn’t; one that evolved in the lineage leading up to a clade (branch) and that sets members of that clade apart from other individuals.
- Shared derived characters can be used to group organisms into taxonomic clades (a group of organisms believed to have evolved from a common ancestor).
  - For example, amphibians, turtles, lizards, snakes, crocodiles, birds and mammals all have, or historically had, four limbs.

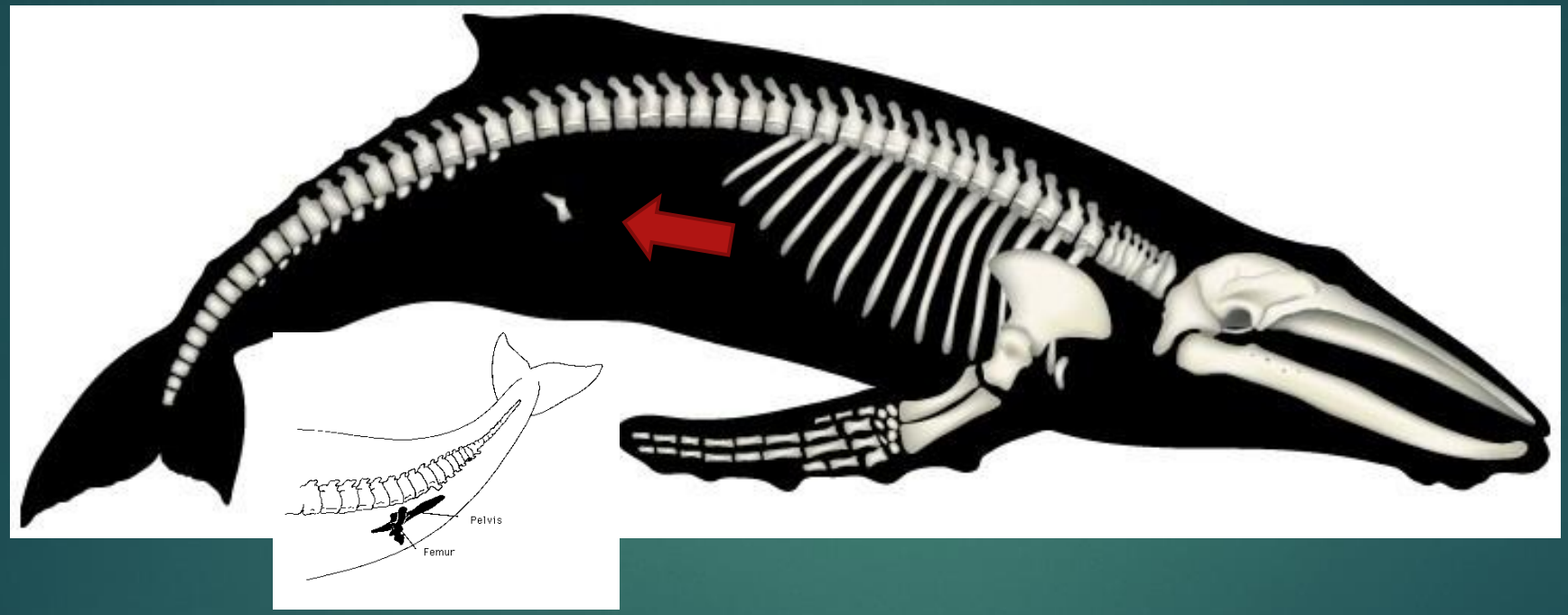


Evidence: Vestigial Characteristics

- Vestigial characteristics: An organ present in an organism which is reduced in size or has no current use. Degenerate structures that no longer perform the same function as in the past; small, tolerable evolutionary imperfections:
  - Darwin: Vestigial structures stand as evolutionary evidence of common ancestry
  - male mammals (including human males) have nipples (we all start out female)
  - snakes (notably boa constrictors) have the rudiments of a pelvis and tiny legs buried inside their sleek profiles; one lobe of the lung is vestigial
  - certain species of flightless beetle have wings, sealed beneath wing covers that never open
  - Wings of kiwi are tiny vestiges and useless.
  - Vestigial eyes of burrowing or cave animals are no longer used for vision
  - The human coccyx (tail bone) is a much reduced version of an ancestral tail; also appendix
  - Sinus cavities in humans have their drainage hole in the top (were in front when quadruped); wisdom teeth; palmer grasp in infants

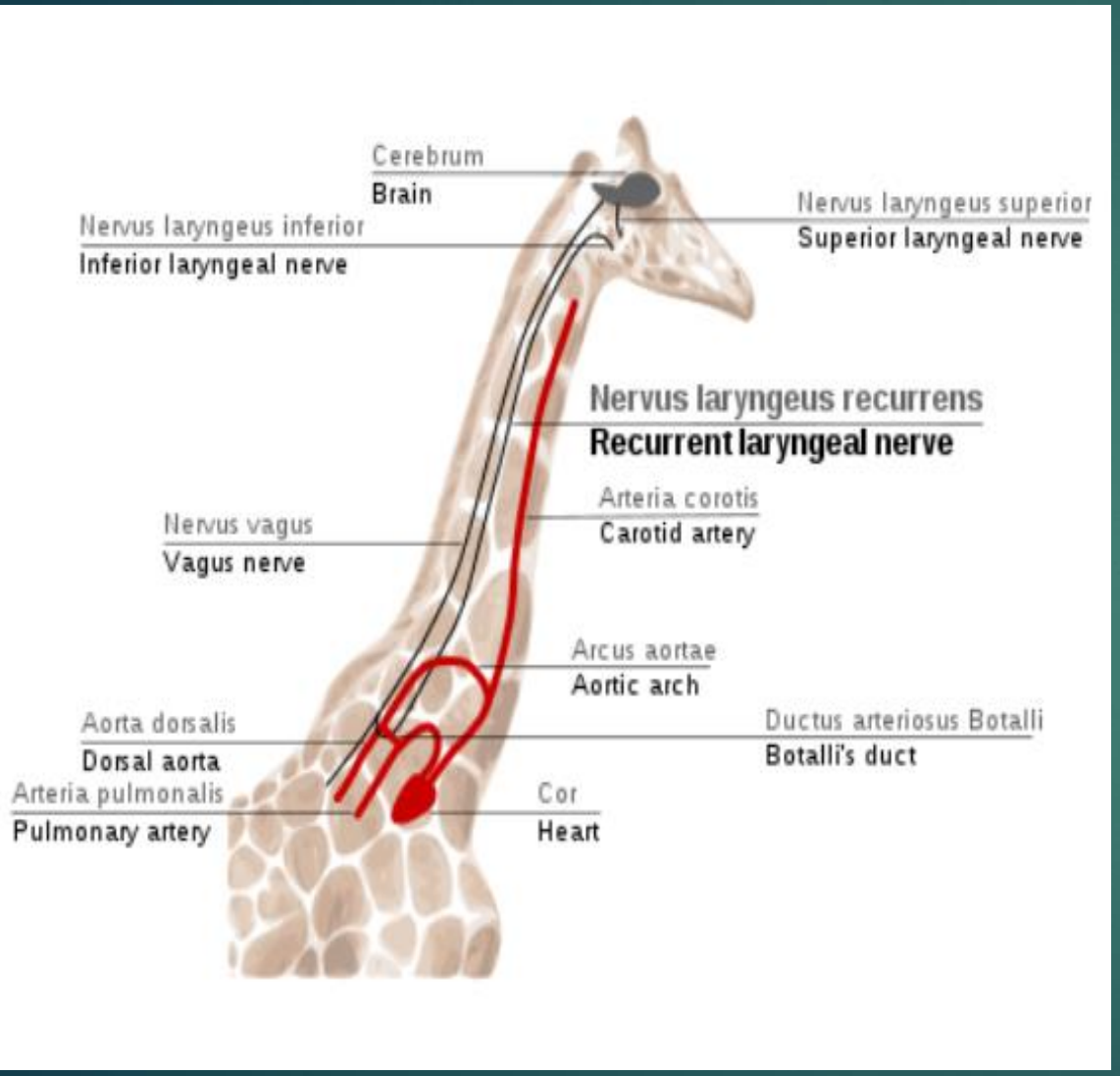
Vestigial Structures

- Vestigial Structures: “leftover” traces of evolution that serve no current purpose



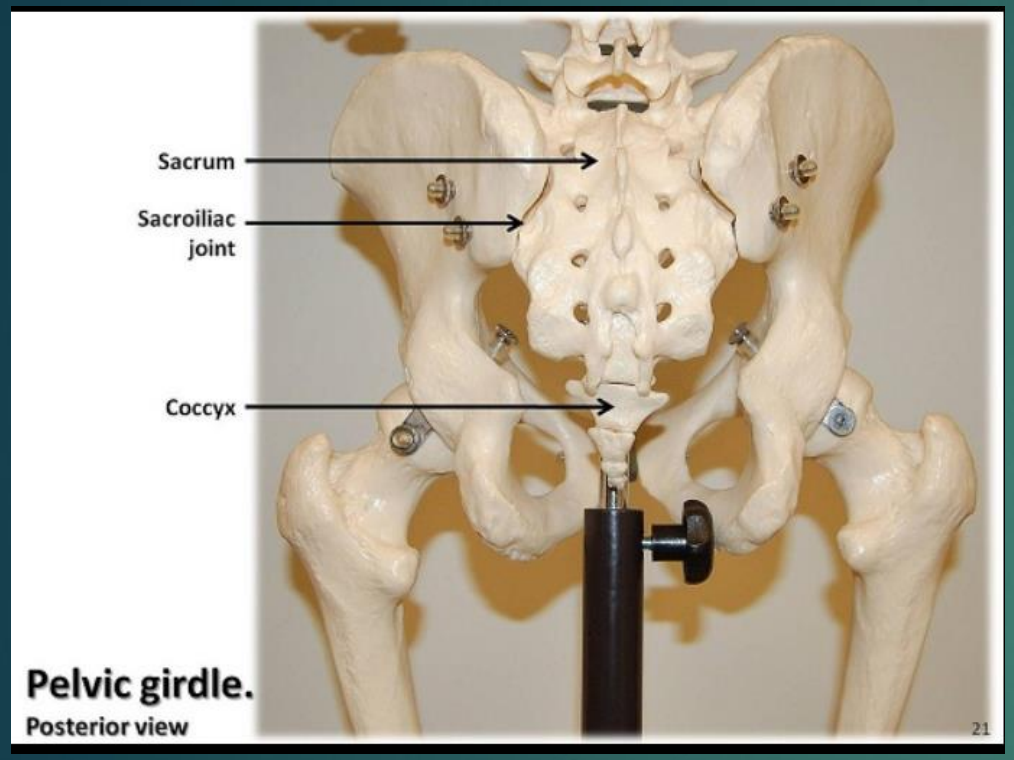
i.e. the hind leg bones of whales;

Laryngeal Nerve in Giraffes & Humans



- Although the most direct route for this nerve is just a few inches, it may be up to 13 feet long in giraffes as it goes all the way down the neck, loops back, and comes all the way back up again.
- This nerve takes a similarly crazy route in humans too.
- The nerve is long because our fish ancestors had no neck, and the nerve looped around a gill arch that developmentally becomes the dorsal aorta in mammals.

Coccyx & Goosebumps

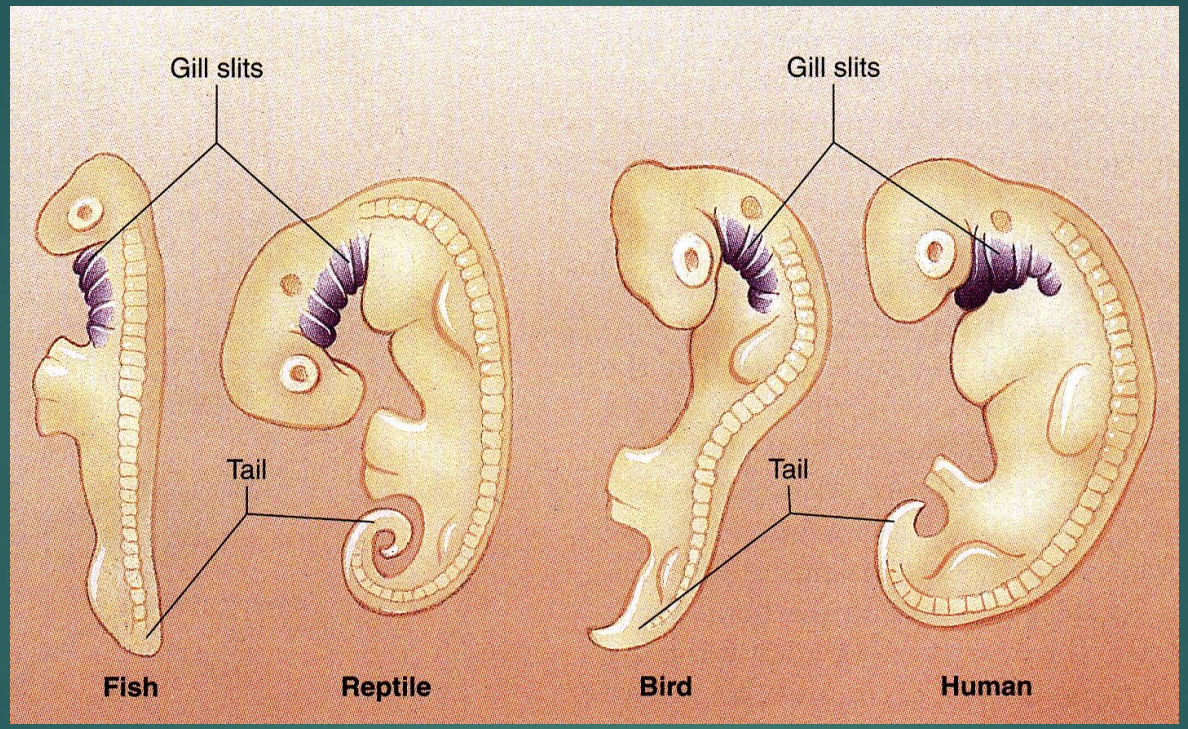


The tailbone is the final segment of the vertebral column in tailless primates, all that remains from our ancestors' tails. Today it serves as an attachment point for muscles and something to sit on.

These bumps on our bare skin occur in cold weather or when experiencing fear. In our ancestors they would cause the fur to rise up, increasing insulation against the cold and increasing the appearance of size against threats.

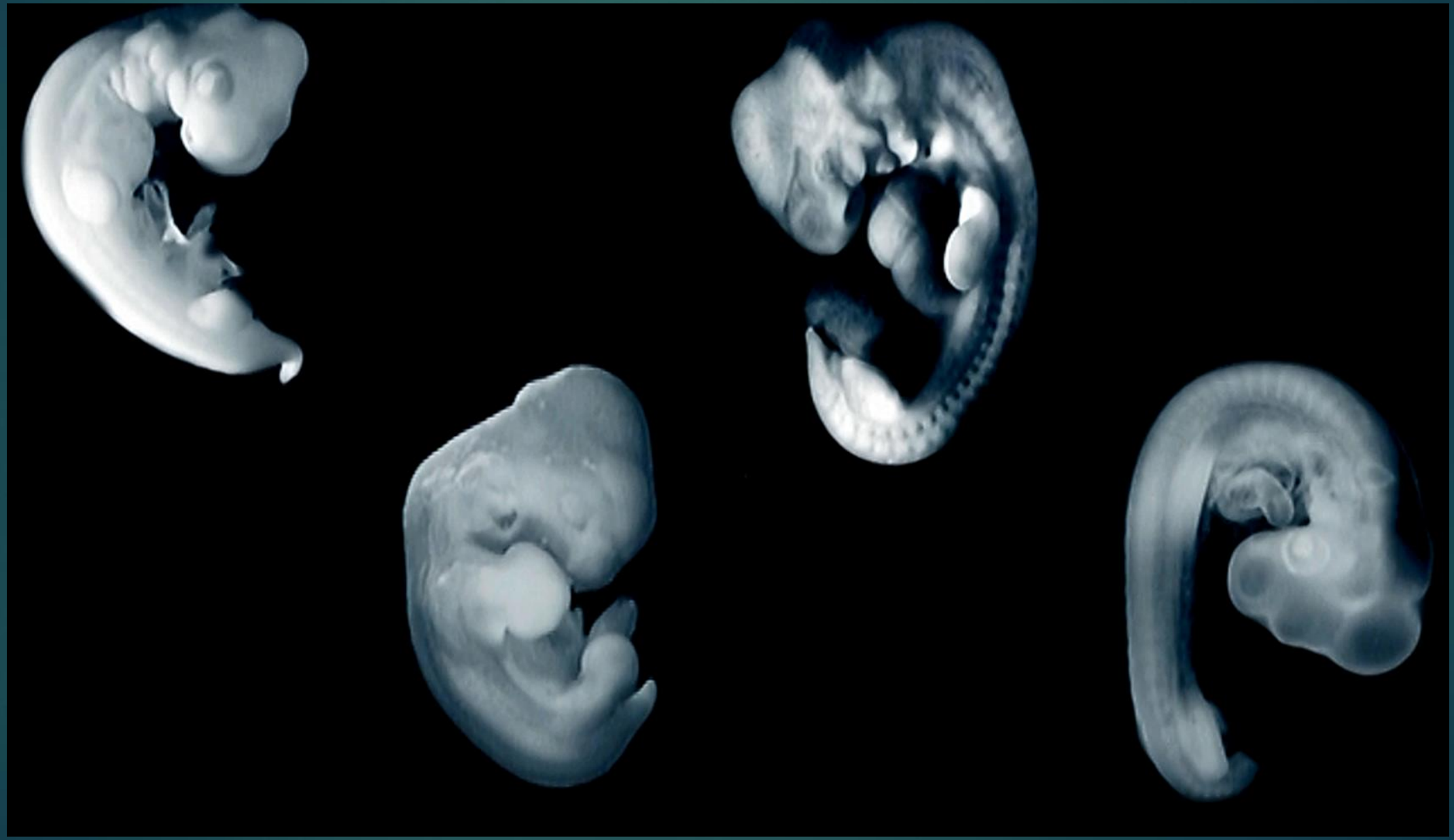
2 - Embryology

- Embryology: embryos of all vertebrates are very similar in early development



- Embryos are where all the action is in terms of diversification
- Use same set of key genes to build bodies

Human, chicken, turtle, bat? Start off so similar & end up so different.



Later: turtle, bat, human, chicken

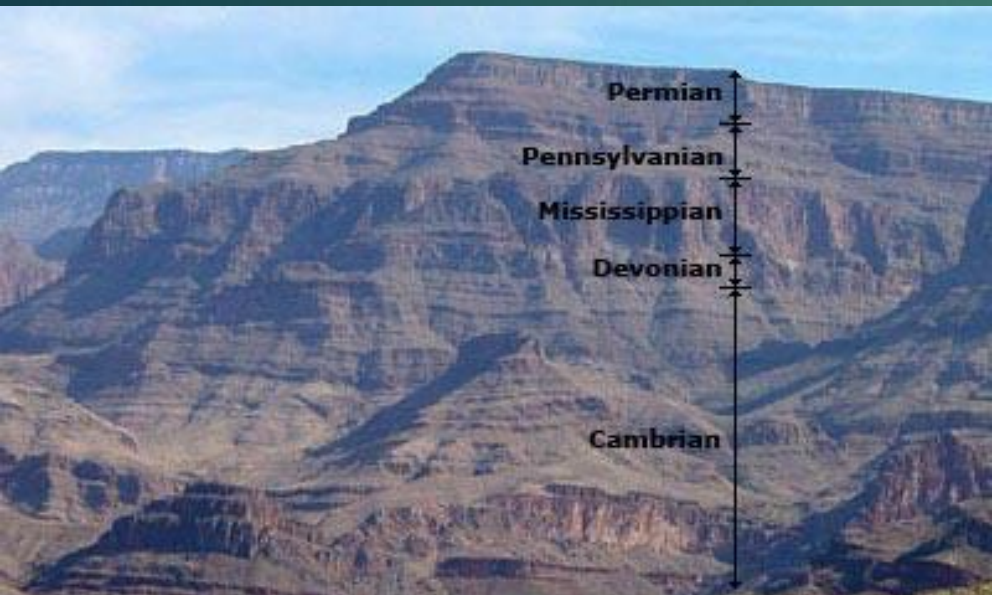
Embryos do temporarily take on the characteristics of their ancestral species, such as human embryos having gill arches, a tail, eyes on the sides of the head, a tube-shaped heart, and ear-bones in the jaw during development, all of which vanish in later development.

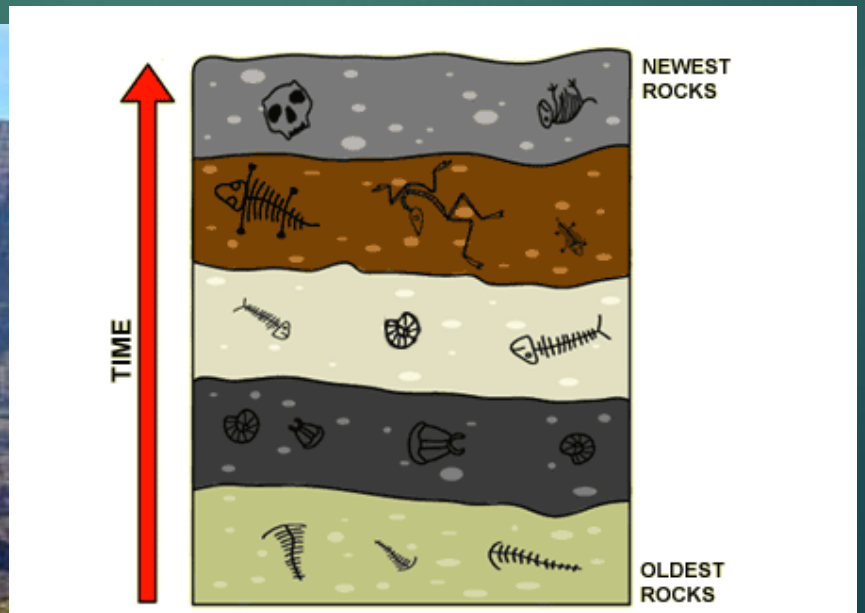
Evidence 3 - Molecular analysis: Proof of Common Descent

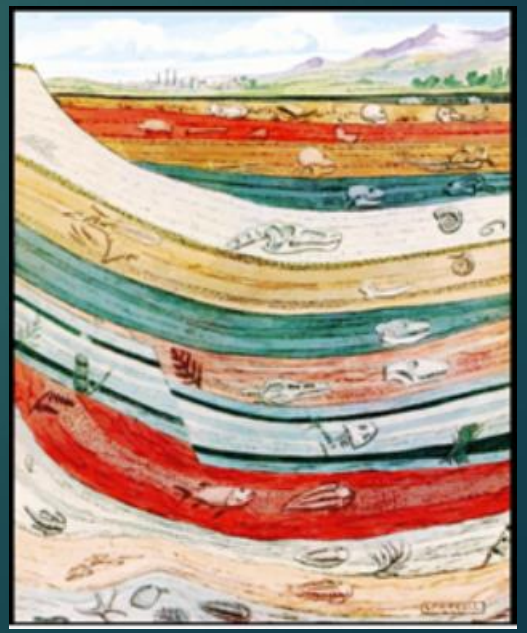
- DNA hybridization: unzip DNA from 2 species and recombine to form hybrid DNA; amount of heat it takes to separate hybridized DNA is measure of how similar DNA is, i.e. New world vultures & storks; When single strands of DNA from humans and chimps are combined, they combine almost perfectly.
- Amino Acid Analysis: compare sequences of amino acids mutations in certain proteins between 2 species, i.e. hemoglobin; fewer number of mutations in amino acids leads to greater species similarity; chimps & humans have identical amino acids; gibbons have 3 less
- Protein analysis: Immunology indirectly measures degree of similarity of proteins in different species; greater the similarity between humans and blood of other species, greater the antibody-antigen reaction; can determine evolutionary relationship of 2 species, i.e. phylogeny of tree frogs
- DNA sequencing: extract genome of a species & compare species, i.e. humans and chimps share 98.4%; humans and Neandertals share 99.7%

Evidence of Evolution: 4 - The Fossil Record

- Fossils: a record of the history of life on Earth
- **Fossils** are the petrified remains of previously living organisms or their traces, dating from the distant past.
- The fossil record is not complete or unbroken: most organisms never fossilize
- Organisms that do fossilize are rarely found by humans.
- Nonetheless, the fossils that humans have collected offer unique insights into evolution over long timescales.





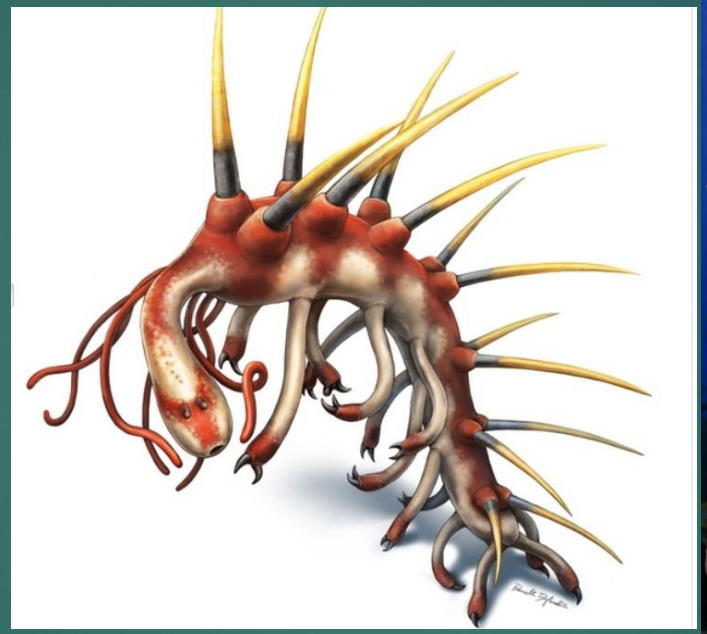


Fossils

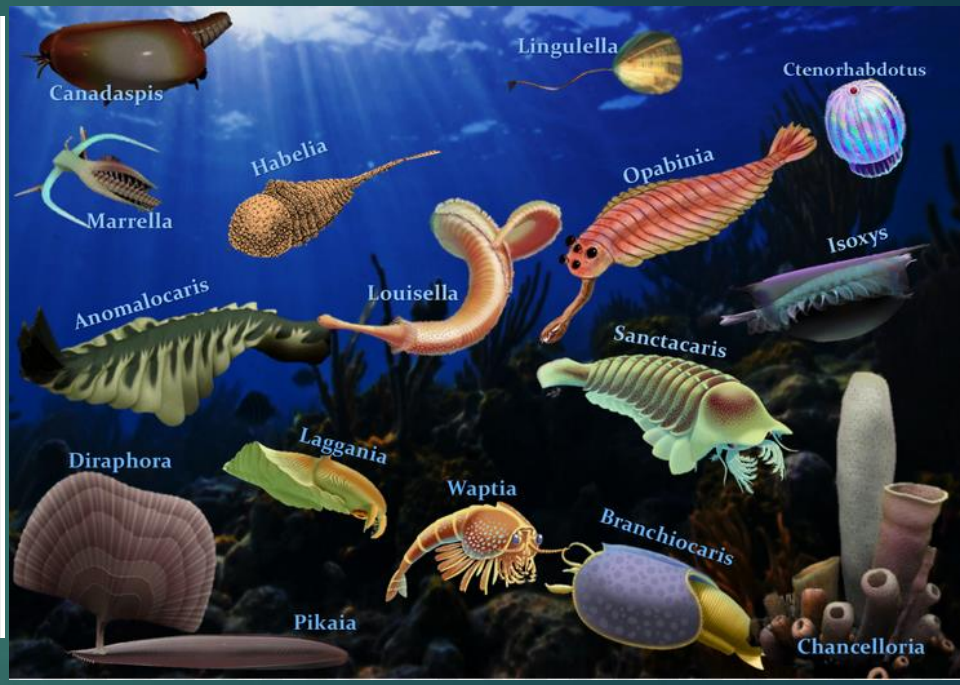
- Paleontology reveals a clustering pattern in the dimension of time.
  - The vertical column of geologic strata, laid down by sedimentary processes over the eons,
  - lightly peppered with fossils,
  - represents a tangible record showing which species lived when.
- Younger layers of rock lie atop more ancient ones, as do the animal and plant fossils in that strata.
- What Darwin noticed about this record is that closely allied species tend to be found adjacent to one another in successive strata.
- One species endures for millions of years and then makes its last appearance; just above, a similar but not identical species replaces it.

Evolution's Big Bang = Cambrian Explosion: The first blood bath – first arms war; Predation requires nervous systems

Anomalocaris: up to 2 meters



Hallucigenia

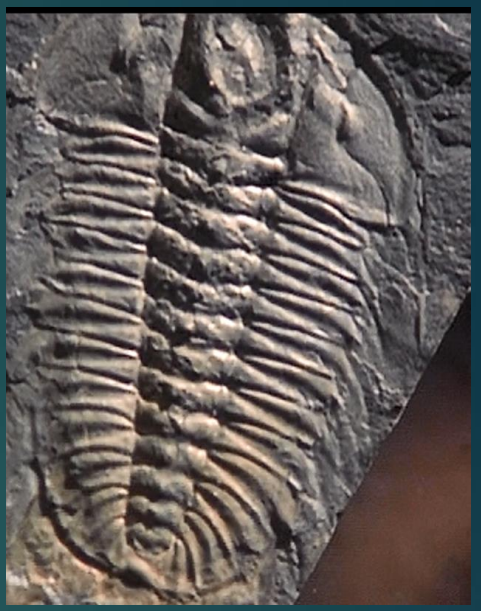


Bilaterians: bilateral animals — body plans that have a left and right side, a top and bottom, and a mouth and anus. Mostly predators.

Origin of Animals

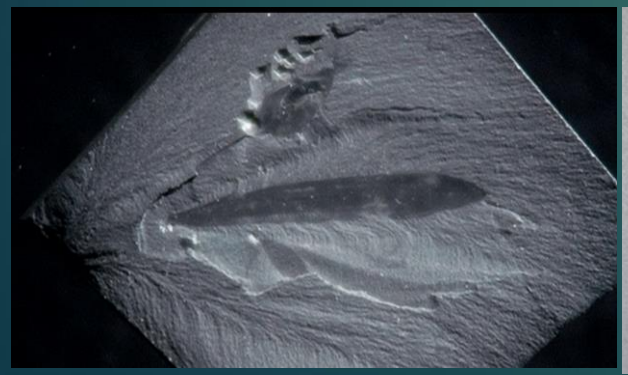
- Appear 570 Ma in Cambrian explosion

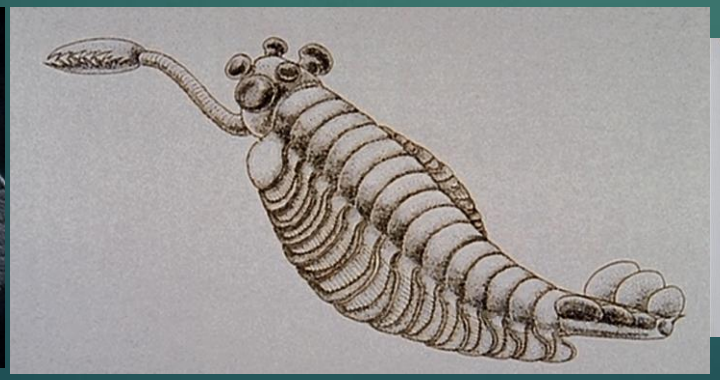
- Charles Walcott discovered Burgess Shale in 1909; result of catastrophic mudslide; 60,000 fossils

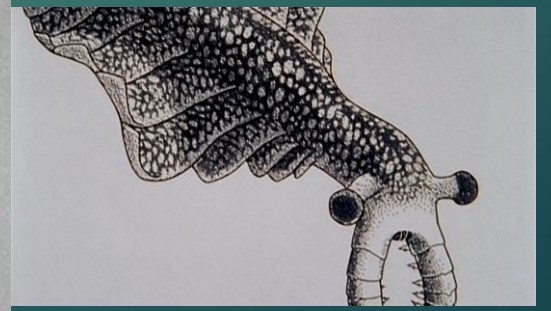


- All animal phyla appeared; 75% still with us; No new phyla since; All current body plans were present then

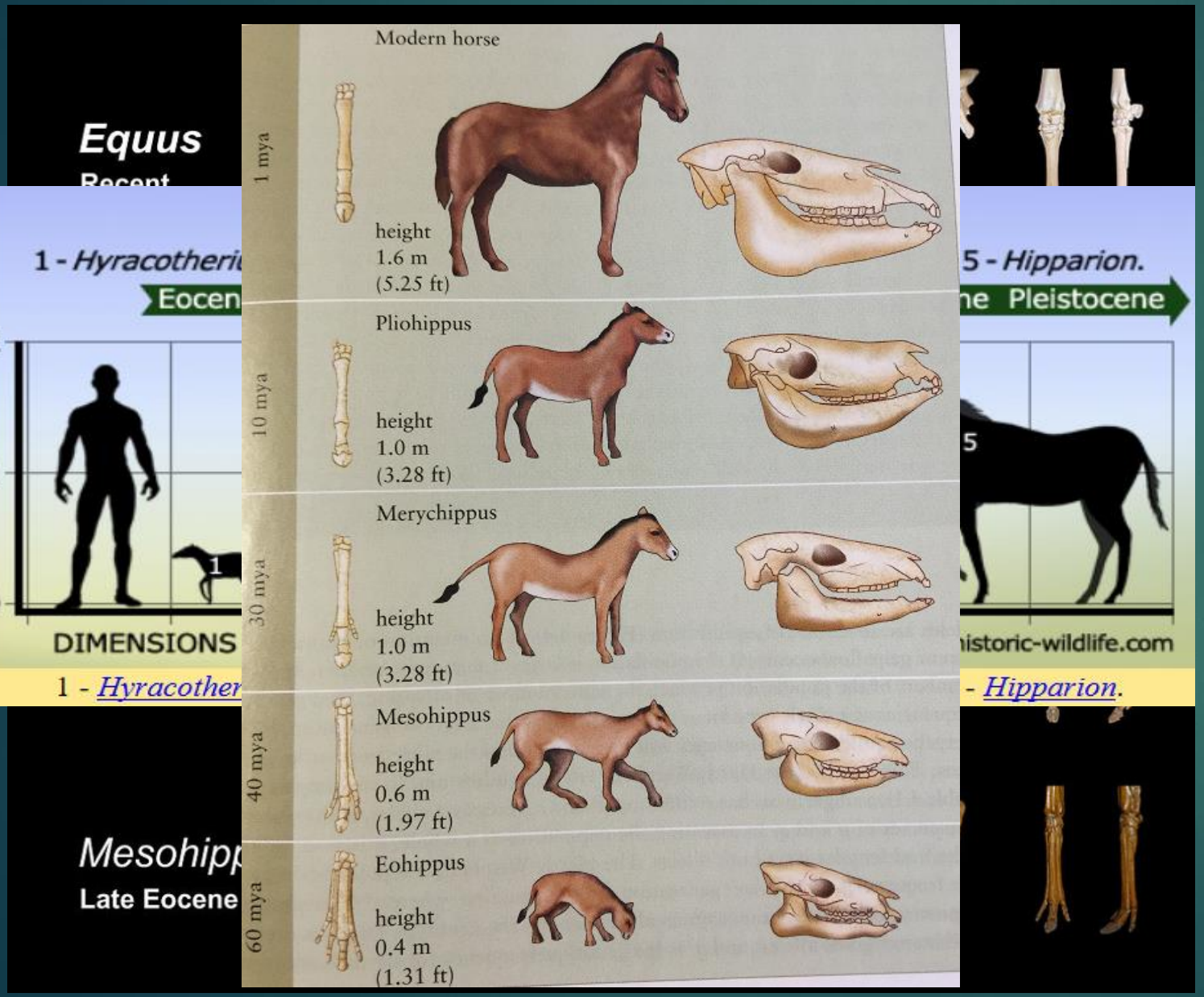
- Trilobites (arthropod); strange creatures, i.e. *Hallucigenia*







Fossil record of evolution of the horse



- Fossils document the existence of now-extinct species, showing that different organisms have lived on Earth during different periods of the planet's history.
- They can also help scientists reconstruct the evolutionary histories of present-day species.
- For instance, some of the best-studied fossils are of the horse lineage

Evidence: Transitional fossils: show the intermediate stages

- Many fossils show a clear transition from one species, or group, to another.

- Archaeopteryx was found in Germany in 1861. It share many characteristics with both dinosaurs and birds.

- It provides good evidence that birds arose from dinosaur ancestors

en.wikipedia.org/wiki/Image:Archaeopteryx_lithographica_paris.JPG

Transitional forms

- Not “missing links” (chain of being reference)
- Evolutionary transitions between taxonomic groups (i.e. fish to amphibians)
- Transitional forms appear in the fossil record as organisms that resemble an ancestral form, but possess derived features characteristic of a newly emerging taxonomic group
- Examples: Archaeopteryx, Tiktaalik (fish with tetrapod features)
- All living creatures and all fossils are 'transitional'.

Neil Shubin: *Your Inner Fish* - Tiktaalik

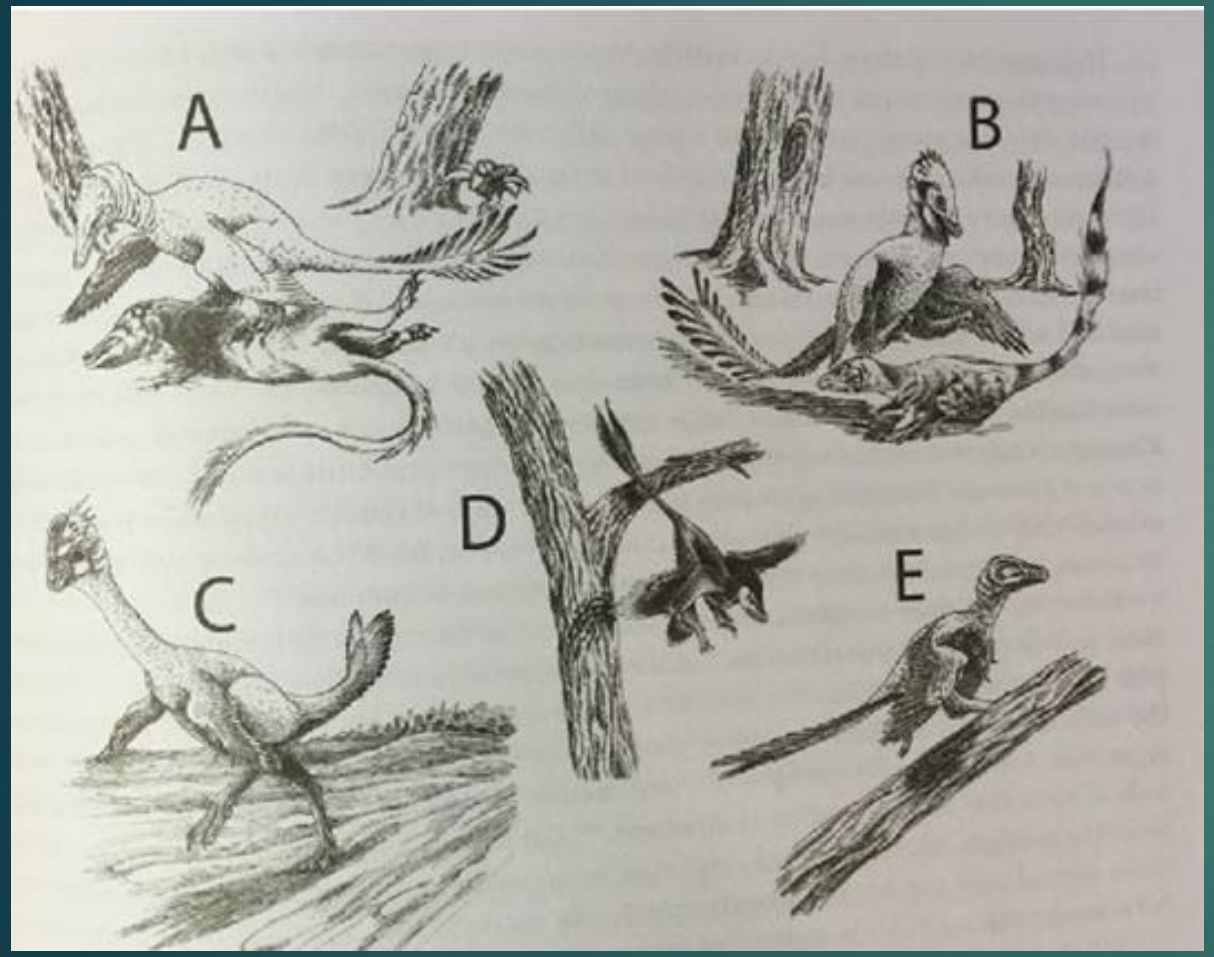
- 375 Ma - prior, only fish; after, animals that walked
- Near north pole: flat headed lobe finned fish, with eyes on top
- Tiktaalik: perfect transitional form for conversion from fish to amphibian
- oxygen-poor shallow-water habitats
- First tetrapod 1-2-5 pentadactyl limb

Lobe-finned fish: 395 Ma

Early tetrapod: 365 Ma

Modern Amphibian

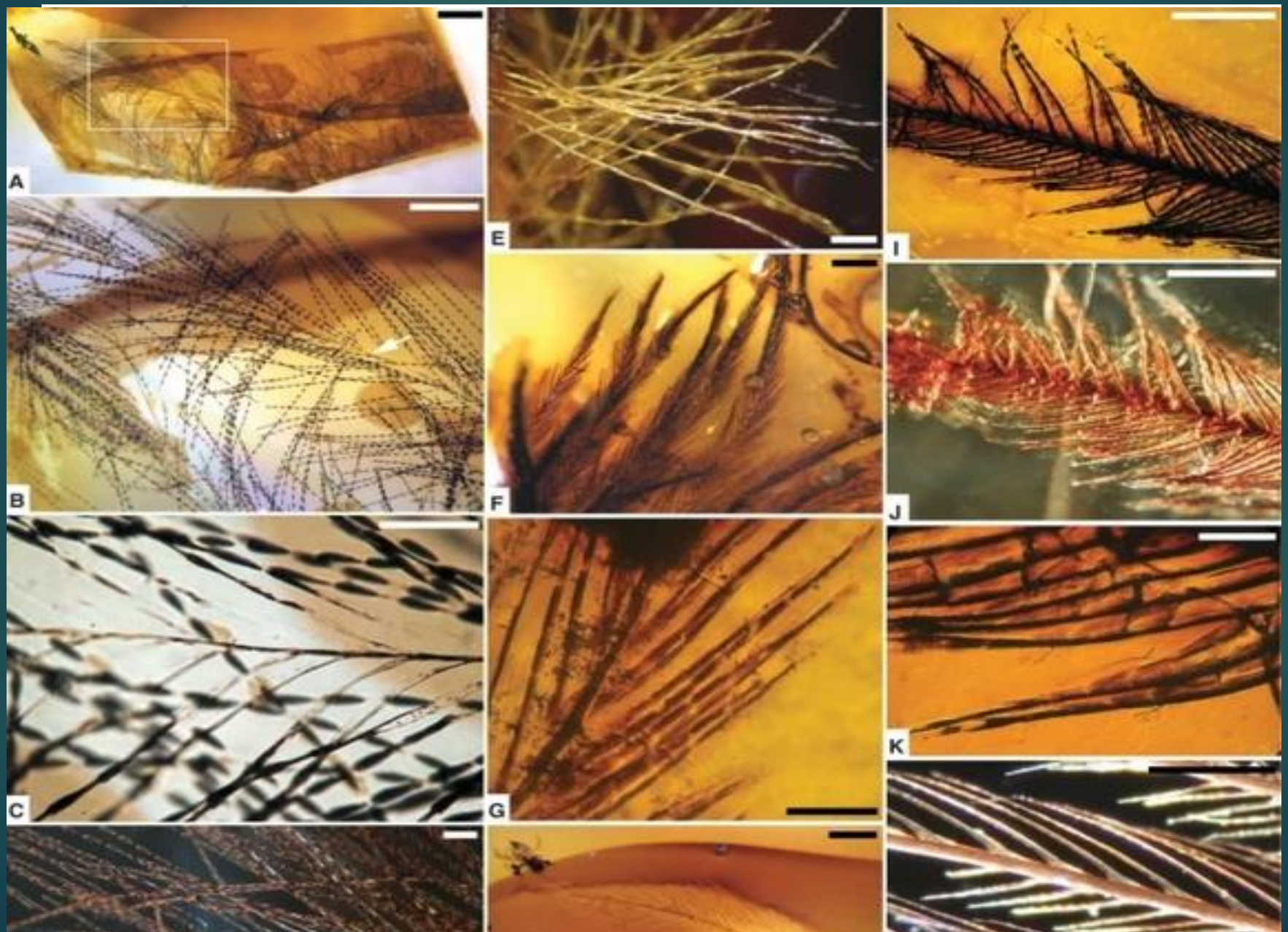
Evolution of flying



- Potential steps: 5 aerodynamic functions that wings could have served in feathered dinosaurs; each of which is used by at least 1 modern bird:
- A. Flapping in order to keep balanced while holding prey
- B. Using their wings to steer themselves midair when leaping to attack
- C. Flapping to steer or produce thrust while running
- D. Using wing to glide out of trees
- E. Using force of wingbeat to *press themselves against a steep surface* while climbing it

Wings must have been exaptations; they were used by the ancestor for one function, and became useful for flight among the descendants

Velociraptors = turkey size, but feathered (unlike Jurassic Park)



FEATHER EXPERIMENTS

The fossils of feathered nonavian dinosaurs (the three at left) and early birds (at right) from northeast China's Liaoning Province are all about 125 million years old, but they show different approaches to feathers and flight. Because they lived at the same time, sorting out stages in the evolution of flight is difficult.

Sinosauropteryx
Colorful banding in the tail feathers suggests they were for camouflage or communication.

Caudipteryx
Broad feathers in running dinosaurs may have provided bursts of speed or been simply for display.

Microraptor
This dromaeosaur's feathered legs may have acted like airfoils, providing lift for gliding from trees.

Jeholornis
This early bird was likely a powerful flier. Its long tail could have been used as a rudder or an airfoil.

Pedopenna to *Anchiornis* to *Scansoriopteryx* to *Archaeopteryx* to *Confuciusornis* to *Sinosauropteryx* to *Eoalulavis* to *Ichthyornis*

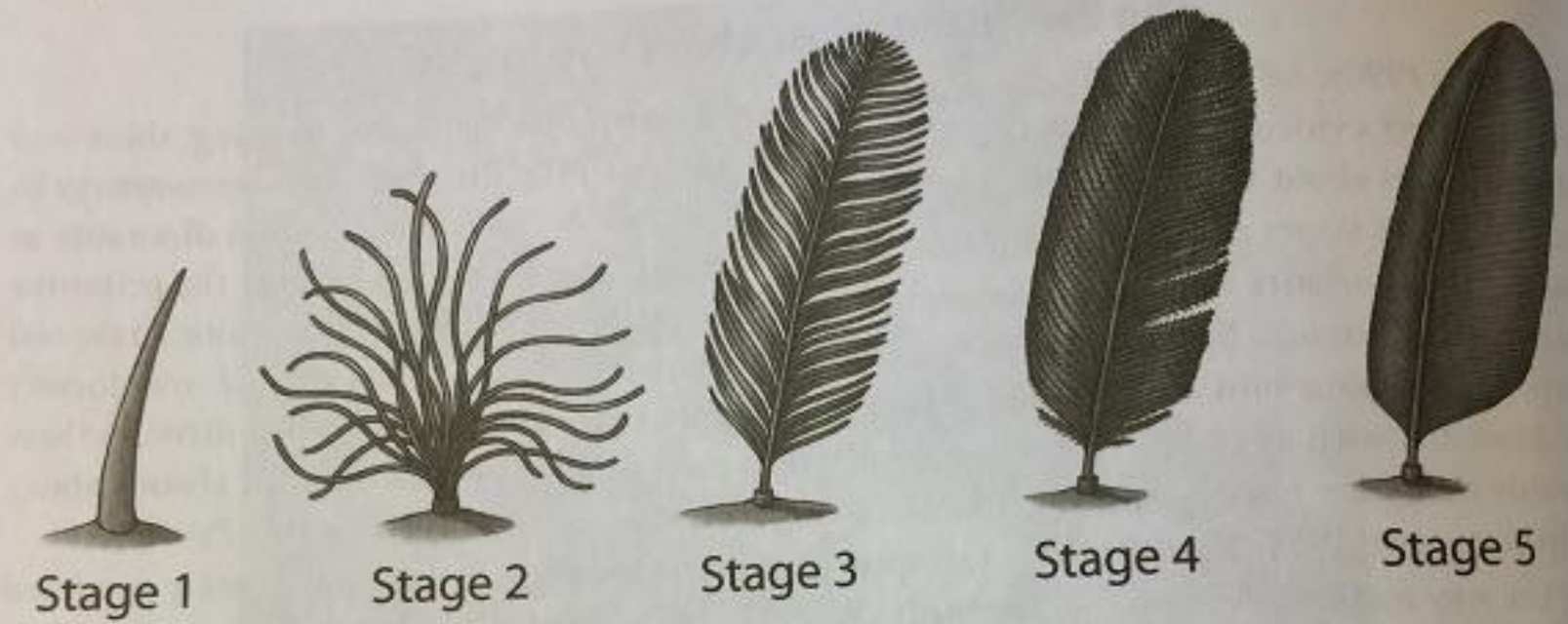


Figure 4.13: Five stages in the evolution of feathers, based on a 1999 paper by Richard Prum. Each of these stages is now known from at least one feathered dinosaur fossil. Like this:

Stage 1—simple fibers
Hollow unbranched fibers, with no barbs or barbules.

Stage 2—bundles of fibers
Groups of unbranched fibers, with each group attaching to a central point.

Stage 3—unbranched barbs
Rows of unbranched barbs along a central shaft.

Stage 4—barbs and barbules
Rows of barbs attached to a central shaft, which branch further into barbules.

Stage 5—fully-developed flight feathers
Barbs and interlocking barbules; asymmetrical shape.

Transitional form: Synapsid (“mammal-like reptiles”) to Mammals

Protoclepsydrops to *Archaeothyris* to *Clepsydrops* to *Dimetrodon* to *Procynosuchus* to *Thrinaxodon* to *Morganucodon* to *Yanoconodon*.

Oldest foss

▲ *Repenomamos giganticus*, compared with the skeleton of a modern tree shrew. *R giganticus* was more than a metre long, and ocassionally fed on baby dinosaurs. Photograph: Wei Gao/IVPP

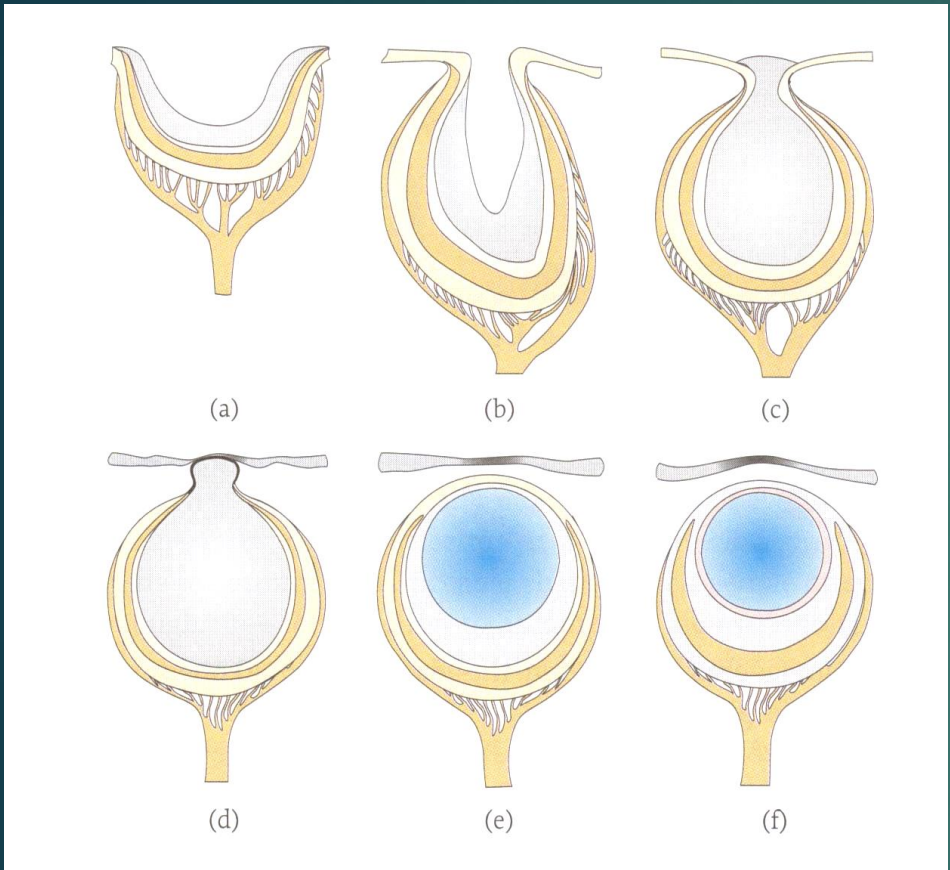
Agilodoc

Night tim ects.

Argument from design: the eye

- In 1802 theologian William Paley wrote that if one finds a pocket watch in a field, the most reasonable conclusion is that someone dropped it, not that natural forces created it there. By analogy, Paley argued, the complex structures of living things must be the handiwork of direct, divine invention.
- Darwin wrote *On the Origin of Species* as an answer to Paley: he explained how natural forces of selection, acting on inherited features, could gradually shape the evolution of complex organic structures.
- Darwin suggested that even “incomplete” eyes might confer benefits (such as helping creatures orient toward light) and thereby survive for further evolutionary refinement.
- Biology has vindicated Darwin: researchers have identified primitive eyes and light-sensing organs throughout the animal kingdom and have even tracked the evolutionary history of eyes through comparative genetics.

Selection of small intermediate steps for complex organs



Living gastropod mollusks illustrate intermediate steps between eye cup and camera-type eye

1. Many invertebrates have a simple light-sensitive spot (a). (e.g., drop in light as signal of predator nearby).
2. Light-sensitive cells in a depression [(a) eye pit of limpet] additional info about direction of change in light intensity.
3. Depression could get deeper, each step favored because better directional info [(b) eye cup of Beyrich's split shell]
4. If it gets deep enough, could form images on light-sensitive tissue, like pinhole cameras form images on photographic film [(c) pinhole eye of California abalone]
5. Transparent cover [(d) closed eye of turban shell] might be favored because protect from parasites and mechanical damage
6. Lens could evolve through gradual changes in transparent cover or through modification of internal structures [(e) Atlantic dog whelk]

Human eye contain imperfections due to it's evolution, i.e. retinal tear/detachment; blind-spot because nerve comes thru hole

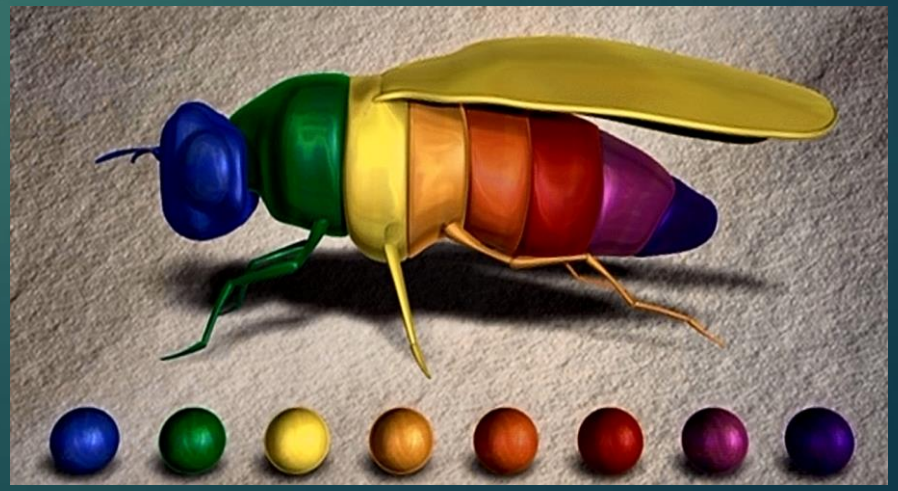
Estimate of 500 K to evolve: cup eye, constriction of lens, addition of water all increase sharpness of focus

Evolved some 50 to 100 times,

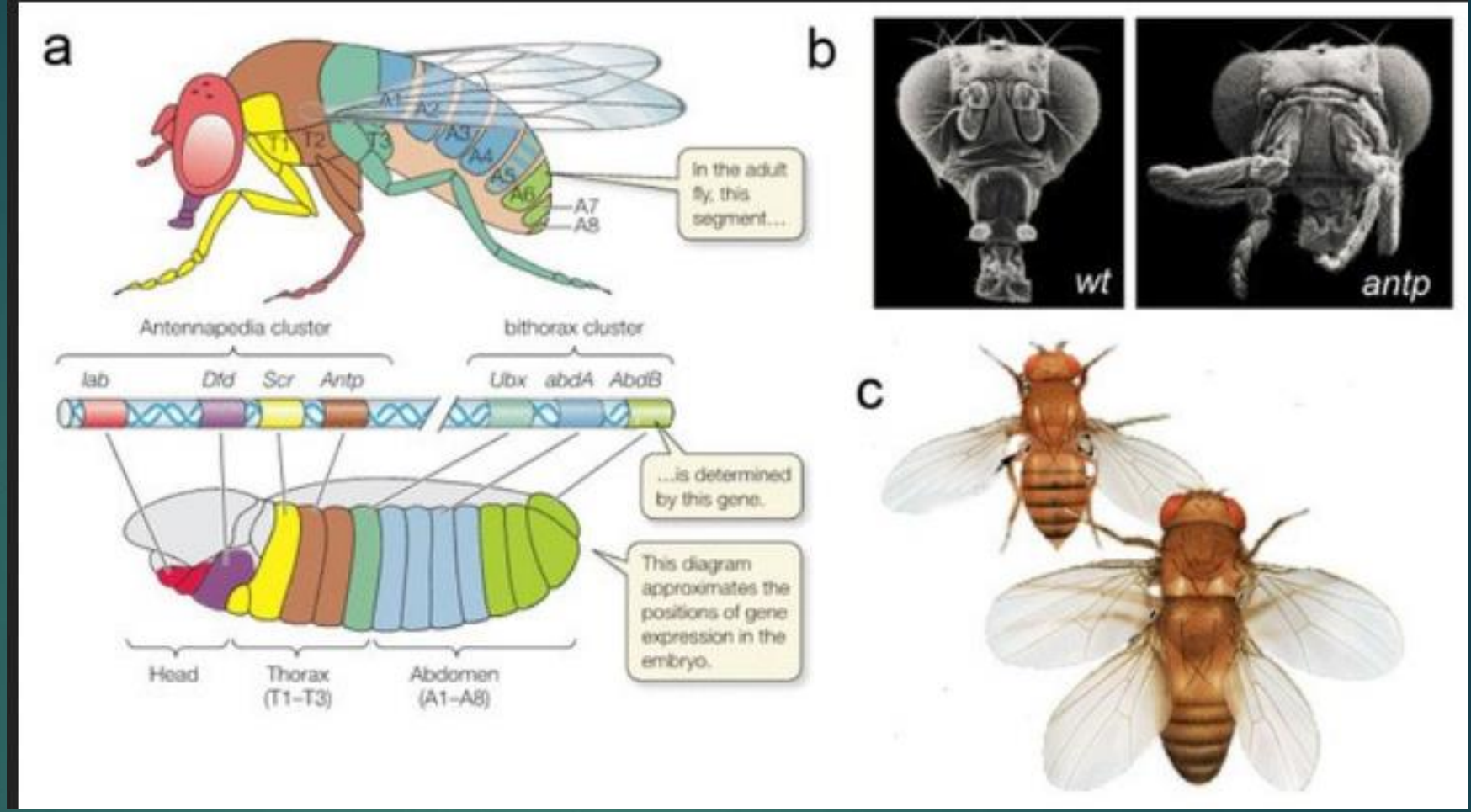
Evolution the tinkerer

- Evolution does not tinker with bodies, but with the recipe, the machinery that builds bodies: the genes
- William Vincent: noted wrong body segments in animal development; examples of deformed animals with segments in wrong place (legs, 6 fingers); random errors might be fuel for evolution
- Edward B. Lewis, Cal Tech: discovered highly conserved single Hox genes which are arranged in the same order on the chromosomes as the body segments they control (homeobox – 8 basic genes)
- Walter Gehring: replaced fruit fly eye segment gene with similar mouse gene; fruit fly eye was produced
- 600 M old set of genes; from LCA of basal animal; before sea urchins


Legs in the wrong place

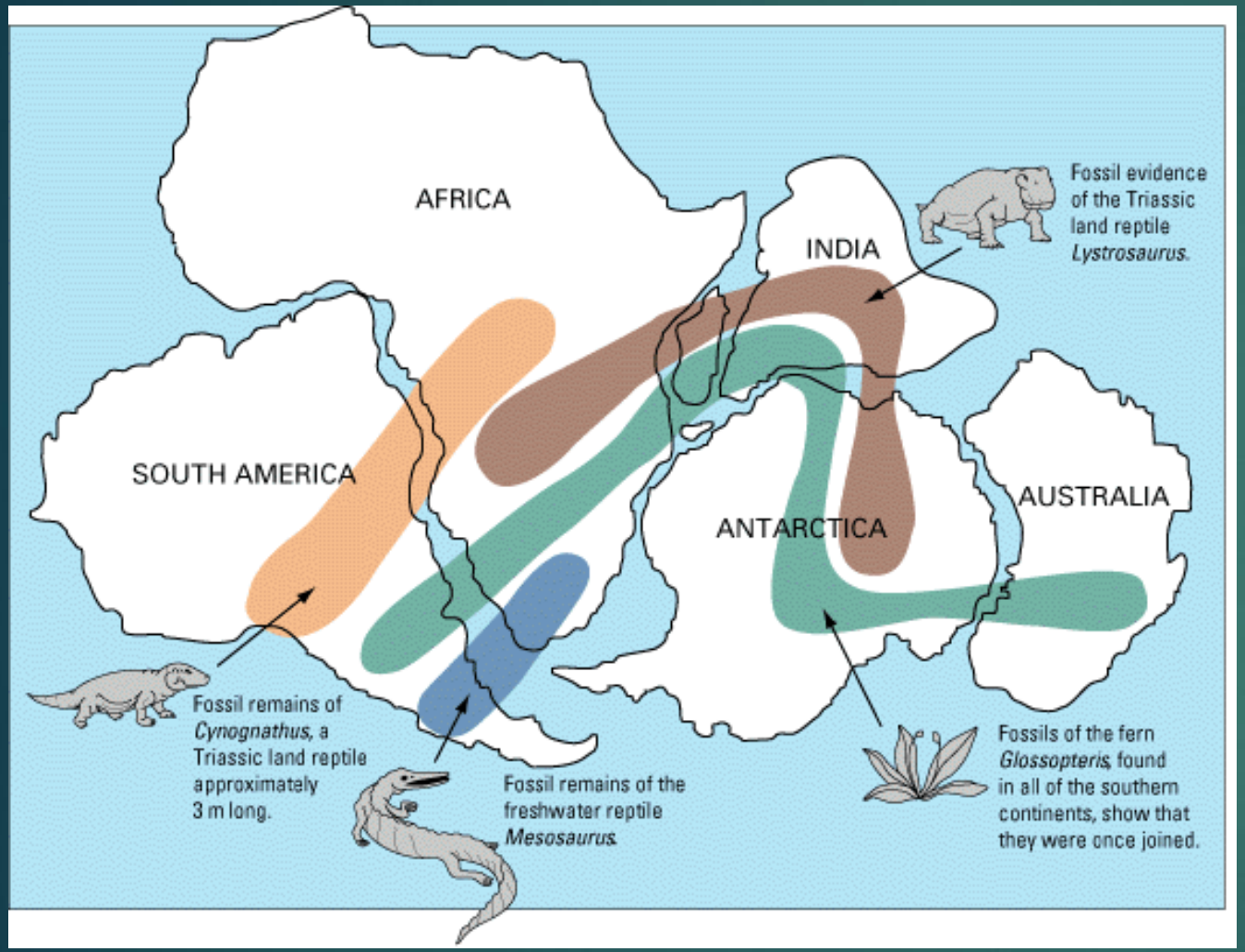


Hox Genes



Hox genes provide for the basic blueprint of all segmented life, such as arthropods, insects, and organisms with backbones. They define what, if anything, should grow out of each segment of the body plan. Mutations in hox genes can replace antennae with legs, as in the above photo of a fly, or give humans a sixth finger, but they also make it much easier for species to mutate in useful ways to produce body plans adapted to a wide variety of environments.

Evidence for Evolution: 5 - Biogeography: Tectonic Plates



Evidence for both Pangaea & for evolution

- Why is geographical proximity a better predictor of biological similarity than similarity of climate?
- Because geography reflects genealogy: closely related species are often found close together geographically

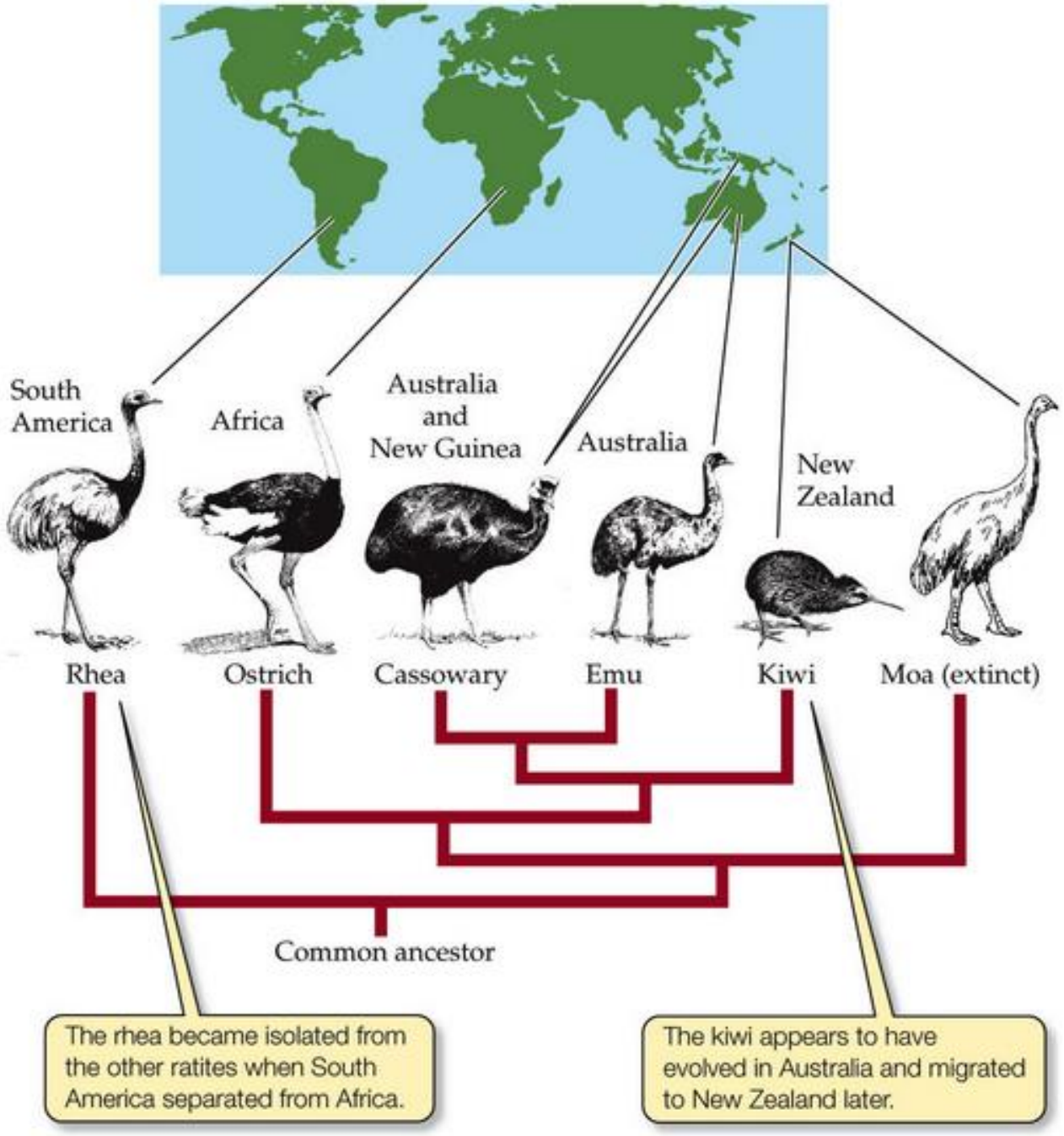
Biogeography: species distribution

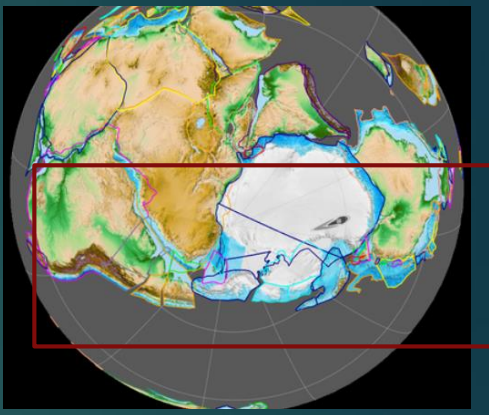
- The geographic distribution of organisms on Earth follows patterns that are best explained by evolutionary comment descent, in combination with the movement of tectonic plates over geological time.
  - Groupings of organisms that had already evolved before the breakup of the supercontinent Pangaea (about 200 Ma) tend to be distributed worldwide.
  - In contrast, animals that evolved after the breakup tend to appear uniquely in smaller regions of Earth. For instance, there are unique groups of plants and animals on northern and southern continents that can be traced to the split of Pangaea into two supercontinents (Laurasia in the north, Gondwana in the south).
- Similar species occur nearby in space because they have descended from common ancestors.

Biogeography: Islands

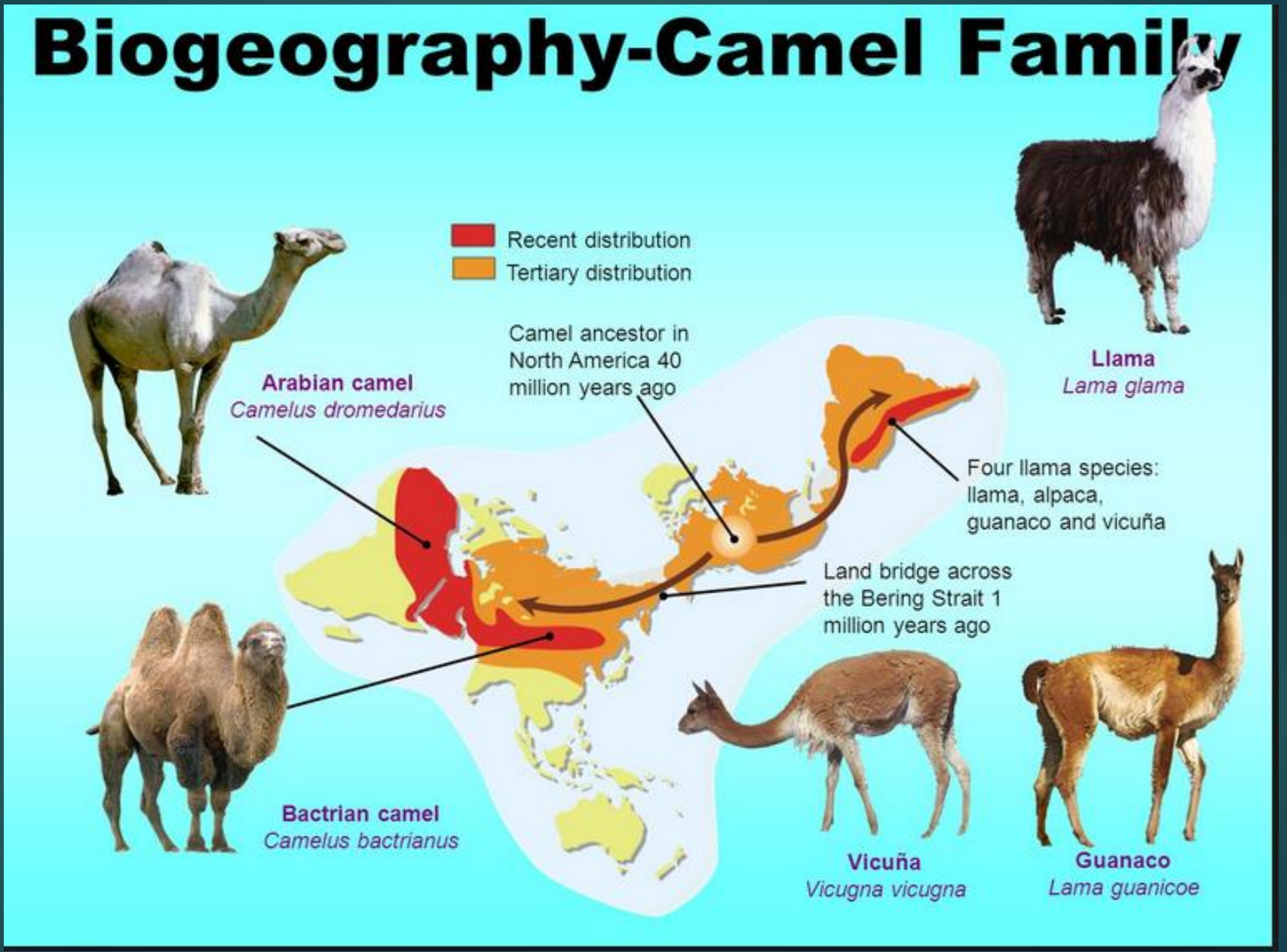
- The evolution of unique species on islands is another example of how evolution and geography intersect.
  - Most of the mammal species in Australia are marsupials (carry young in a pouch), while most mammal species elsewhere in the world are placental (nourish young through a placenta). Australia's marsupial species are very diverse and fill a wide range of ecological roles. Because Australia was isolated by water for millions of years, these species were able to evolve without competition from (or exchange with) mammal species elsewhere in the world.
  - The marsupials of Australia, Darwin's finches in the Galápagos, and many species on the Hawaiian Islands are unique to their island settings, but have distant relationships to ancestral species on mainlands.

Evolution of flightless birds



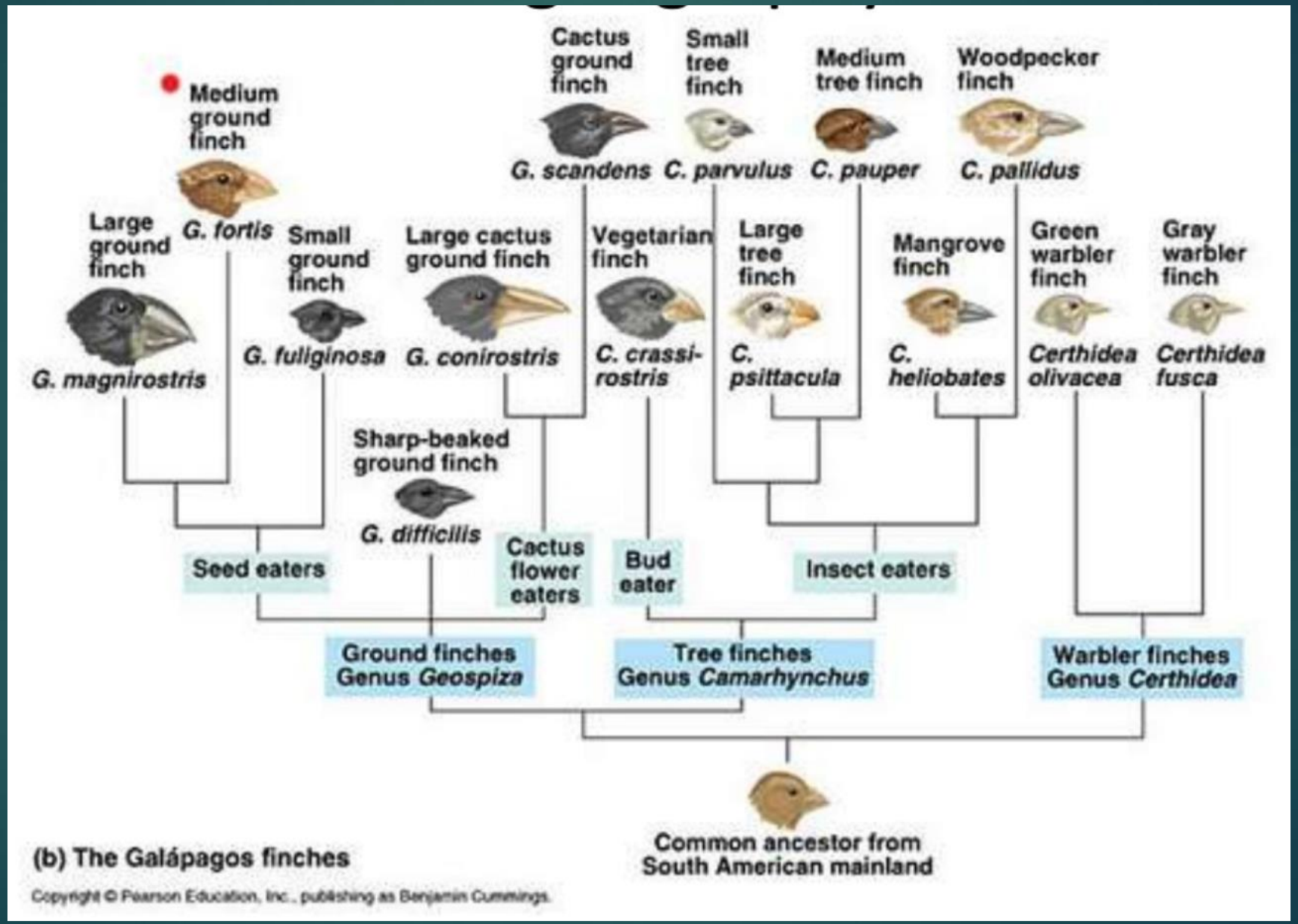


LCA from Gondwana during the Late Cretaceous



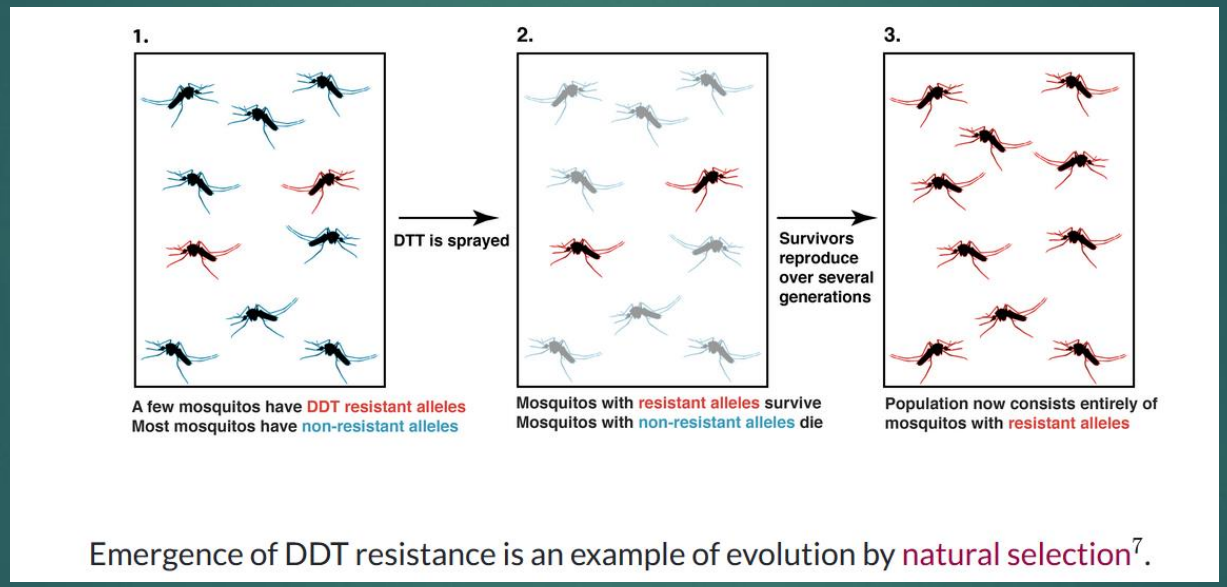
No surviving camel species on their continent of origin, North America

Biogeography: Galapagos Finches



Evidence for Evolution: 6 - Direct observation of microevolution

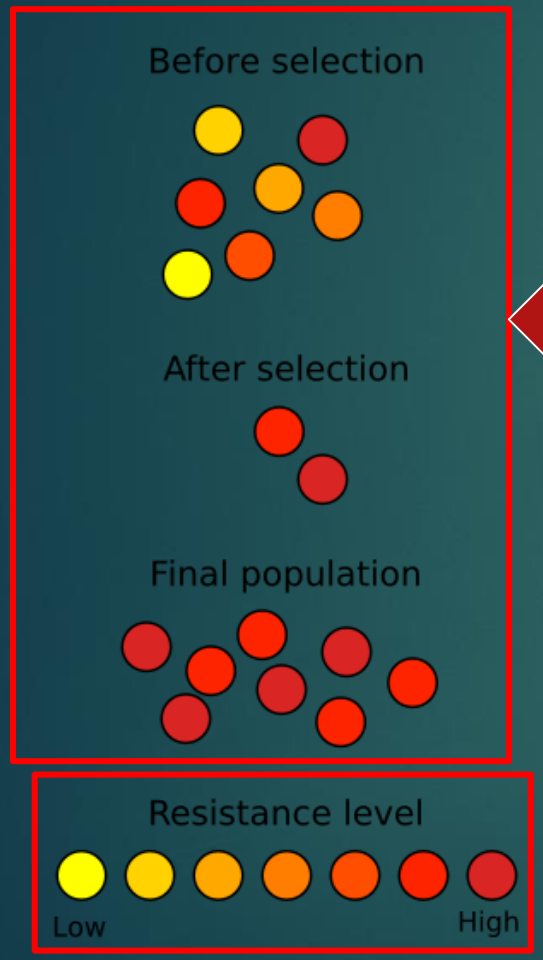
- In some cases, the evidence for evolution is that we can see it taking place around us! Important modern-day examples of evolution include the emergence of drug-resistant bacteria and pesticide-resistant insects.



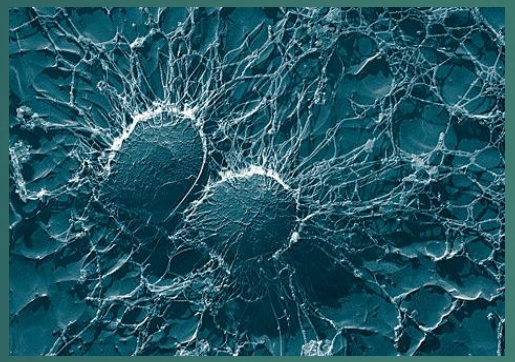
Emergence of DDT resistance is an example of evolution by natural selection[7].

Bacteria and viruses, which have even larger population sizes and shorter lifecycles, can evolve resistance to drugs very rapidly, as in antibiotic-resistant bacteria and drug-resistant HIV. There's no better or more immediate evidence supporting the Darwinian theory than this process of development of resistance.

Antibiotic resistance: new generation of bacteria in 30 minutes (96 generations in 2 days)



Staphylococcus



- We are all familiar with the way that certain bacteria can become resistant to antibiotics
- This is an example of natural selection in action. The antibiotic acts as an environmental pressure. It weeds out those bacteria with low resistance and only those with high resistance survive to reproduce.

Penicillin – 1943; first resistant strains of *Staphylococcus* – 1947; Methicillin – 1960; resistance by 1980; Vancomycin - 1972, resistance by 2002; equal to evolution of the horse

C. Lee Ventola, 2015

Bed Bugs, Pesticide Resistance, and Cancer

Fruit flies, houseflies, rats, mosquitoes, and Colorado potato beetles are among some of the species observed to evolve a resistance to a variety of pesticides.

Cancer: One of the reasons cancer is so difficult to treat is because the disease evolves through natural selection to grow more resistant to treatments.

Bad News: overall number of bacterial infections remained relatively constant between 2002 and 2014, rising from 13.5 million to 14.3 million annually, the proportion that were antibiotic resistant rose dramatically, from 5% to 11.0%.

Figure 3. Number of Antibacterial New Drug

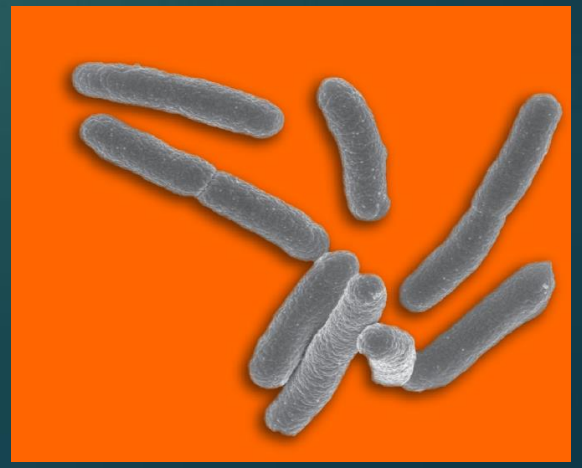
2000: 5%

2014: 11%

Classic Example: Pepper Moths during Industrial Era in England

Richard Lenski and E. coli: Life evolves

- Since 1988, he has grown 12 colonies of E. coli from a single ancestor strain. 7 generations a day.
- Since then, over 50,000 generations (in 2010) of E. coli
- Complete frozen fossil record = Frozen every 500 generations
  = study has provided evidence of how evolution actually occurs.
- 1 of the populations developed the ability to utilize citrate as a nutrient
- Your gut = harbor something like a billion E. coli at this very moment



Importance of Evolution: explains biological reality

- Fish are shrinking in size: if larger fish are caught & eaten, smaller ones are tossed back, within 4 years smaller fish will reproduce more
- Where did HIV come from: patient zero in 1980s; LCA of variants was 1966; multiple variants across world; incl. apes; LCA of HIV in 1900 between chimps and humans; hunter in Cameron got virus from cutting himself from infected chimp
- Why are grasslands turning into deserts: as human populations increase, grazers begin to disappear due to hunting & loss of habitat; in seasonally dry places, grasslands depend on grazers, which till land with their feet, fertilize with dung & urine, and remove excess vegetation so seeds can grow
- Other examples: Pesticide & antibiotic resistance, invasive species on islands, flu overcoming immune defenses, new flu strains, pine tree diversity, albatrosses not defending vs mice, change fish size without genetic mediation, elephant trunks are shrinking, why toxic animals are brightly colored, temperature sex determination, toxicity of rough skinned newt, potato famines, risks of monocultures, shrinking ram horns, curing malaria, failure of mouse tested drugs in humans, disappearance of western pond turtle, curing cholera,

Does the evidence for evolution really exist?

- In short, overwhelmingly.
- Numerous examples of discovery of predicted intermediate forms, genetic similarity studies, and new molecular mapping have only further confirmed the theory
- There are no cases where evolution has been found to be false

Further evidence for evolution websites

- Talk Origins has a much more erudite list 29+ Evidences for Macroevolution.
- Dr. George Johnson's Backgrounders has a step by step walkthrough of the evidence in plain English.
- Wikipedia has an extensive page outlining the evidence for common descent
- Ryan Somma: http://ideonexus.com/2012/02/12/101-reasons-why-evolution-is-true/

4 Forces of evolution

- The evolutionary forces that can change allele frequencies over time:
- • Mutation
- • Gene Flow
- • Genetic Drift
- • Natural Selection
- All 4 forces, or a subset, can act at the same time

The evolutionary forces that can change allele frequencies over time

- 1 Mutation: any heritable change in structure of DNA
  - Introduces a new genetic variant, initially at very low frequency (humans have ~36 mutations at birth; 30-year-old parents, on average, inherit 11 new mutations from the mother, 45 from the father.)

- 2 Gene flow: exchange of genes between 2 populations
  - An individual moves into a new population and reproduces there
    - New genes are introduced into a population
    - Gene flow makes 2 populations more similar; if less gene flow, populations become more unique
    - Without gene flow → reproductive isolation → genetic divergence → speciation

The evolutionary forces that can change allele frequencies over time 2

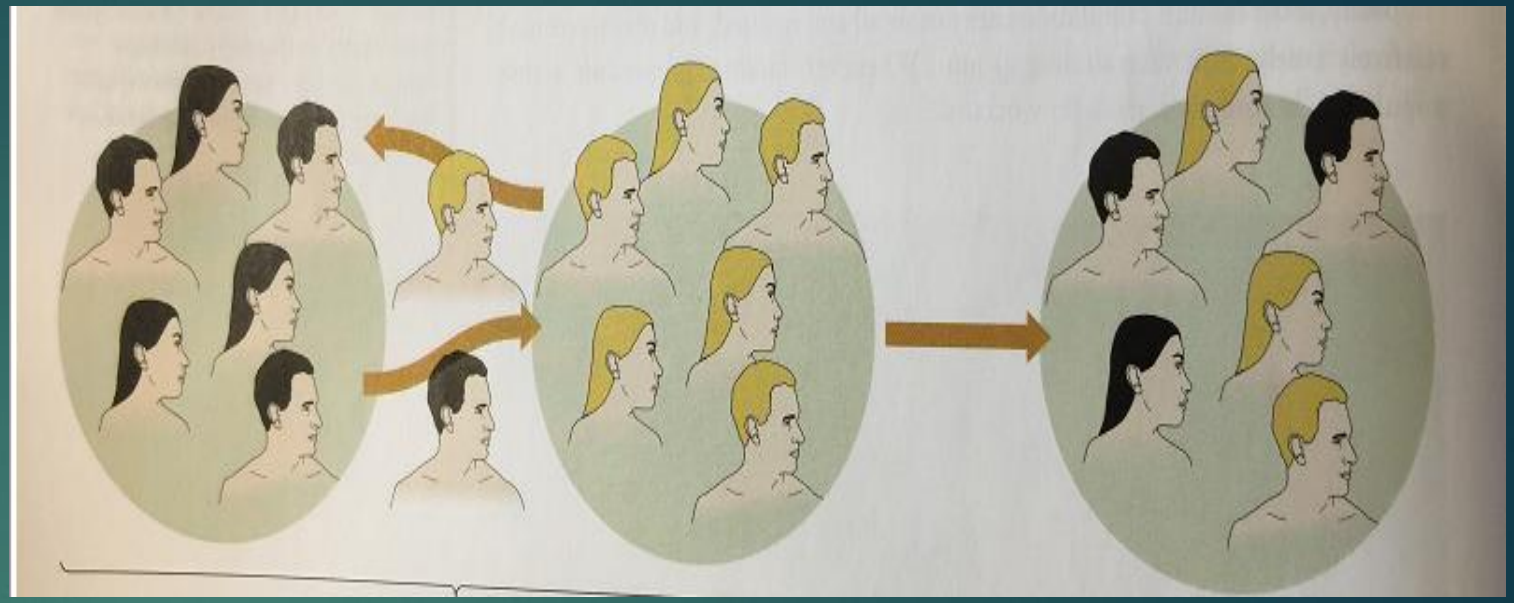
- 3 Genetic drift: genetic change due to chance
  - Random change in allele frequency from generation to generation.
  - Genetic drift results from the sampling error inherent in the transmission of gametes by individuals in a finite population.

- 4 Natural selection: nature favors traits that enhance survival & reproduction
  - Alleles that increase fitness (survivability) exhibit an increase in frequency
  - Alleles that decrease fitness exhibit a decrease in frequency

Evolutionary Force 1 - Mutation: a change in DNA

- The genes in cells are under constant mutation pressure from radiation, viruses, chemicals, and copying errors.
- Mutations can be beneficial, neutral, or harmful for the organism.
- Mutations are random: Mutations do not "try" to supply what the organism "needs."
- Not all mutations matter to evolution: if they happen in somatic genes; only germline (egg or sperm) mutations count
- In some ways, mutation is the most basic and fundamental force of evolutionary change

Evolutionary Force 2 - Gene Flow: Migration



Gene flow is the process of any movement of individuals, and/or the genetic material they carry, from one population to another; i.e. pollen being blown to a new destination, or people moving to new cities

i.e. some brown beetles might have joined a population of green beetles. That would make genes for brown coloration more frequent in the green beetle population than they were before the brown beetles migrated into it.

Gene Flow (gene migration)

- Gene Flow – movement of genes between populations. Gain or loss of alleles from a population due to migration of fertile individuals or from the transfer of gametes

- Gene flow increases the variability of the gene pool by adding new alleles

- Tends to reduce differences between populations

- Gene flow opposes the effects of mutation, natural selection, and genetic drift

Introgression or gene flow?

- What do we call genetic contribution from Neandertals?
  - If Neanderthals were simply a different population, related to modern humans, we might call it simply gene flow.

- But if they are different species-- not Homo sapiens neanderthalensis, but Homo neanderthalensis-- then you wouldn't call it gene flow.
We would call it introgression, the movement of genetic material from one species to another.

- So was it gene flow between two populations or introgression between two species? Need more data.

Evolutionary Force 3 - Genetic drift – random chance

- In each generation, some individuals may, just by chance, leave behind a few more descendants (and genes, of course!) than other individuals.

- The genes of the next generation will be the genes of the "lucky" individuals, not necessarily the healthier or "better" individuals. That, in a nutshell, is genetic drift. It happens to ALL populations — there's no avoiding the vagaries of chance.

Genetic drift affects the genetic makeup of the population but, unlike natural selection, through an entirely random process. So although genetic drift is a mechanism of evolution, it doesn't work to produce adaptations.

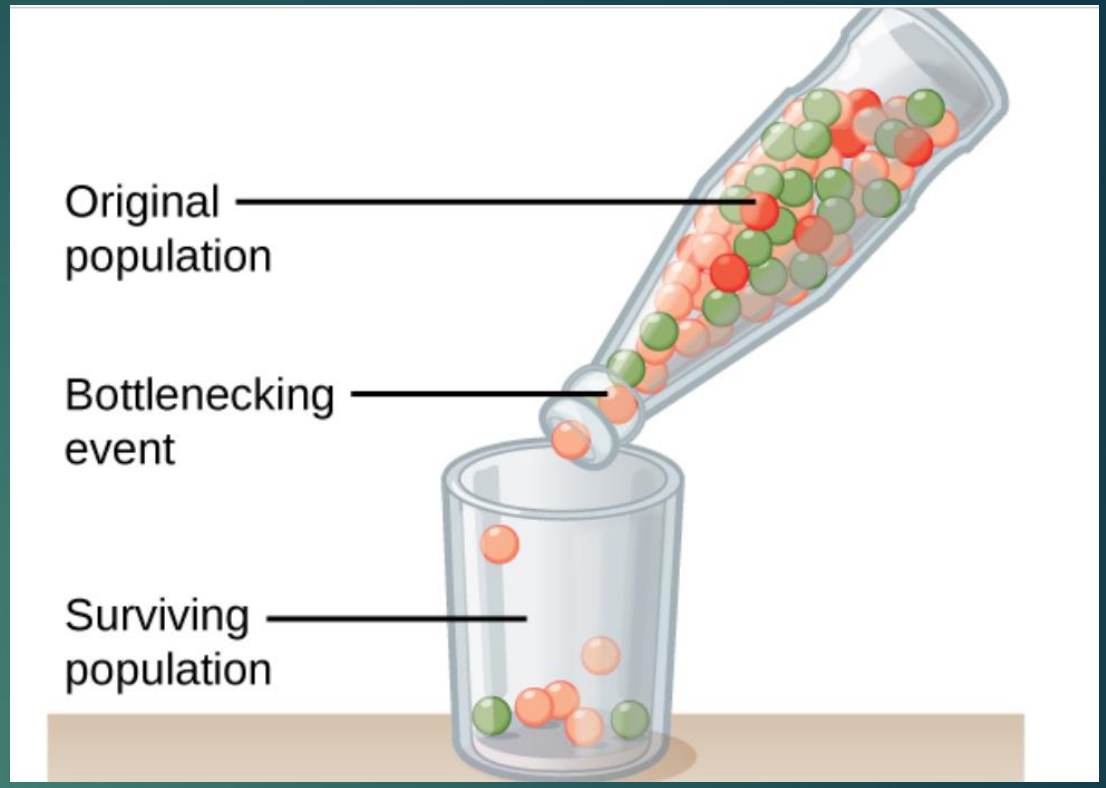
Genetic drift:

- Imagine that in one generation, two brown beetles happened to have four offspring survive to reproduce.
- Several green beetles were killed when someone stepped on them and had no offspring.
- The next generation would have a few more brown beetles than the previous generation — but just by chance.
- These chance changes from generation to generation are known as genetic drift.

Genetic Drift: stronger effect in smaller populations

- Random changes in allele frequencies over time; aimless, not adaptive, because it is by chance alone
- Unlike natural selection, genetic drift does not depend on an allele's beneficial or harmful effects.
- Effect is greatest in small populations – leads to loss of genetic diversity
  - Allele will become more or less prevalent in small populations
- A decrease in population size will increase effect of genetic drift. Drift is common in two population events:
  - genetic bottlenecks
  - founder events

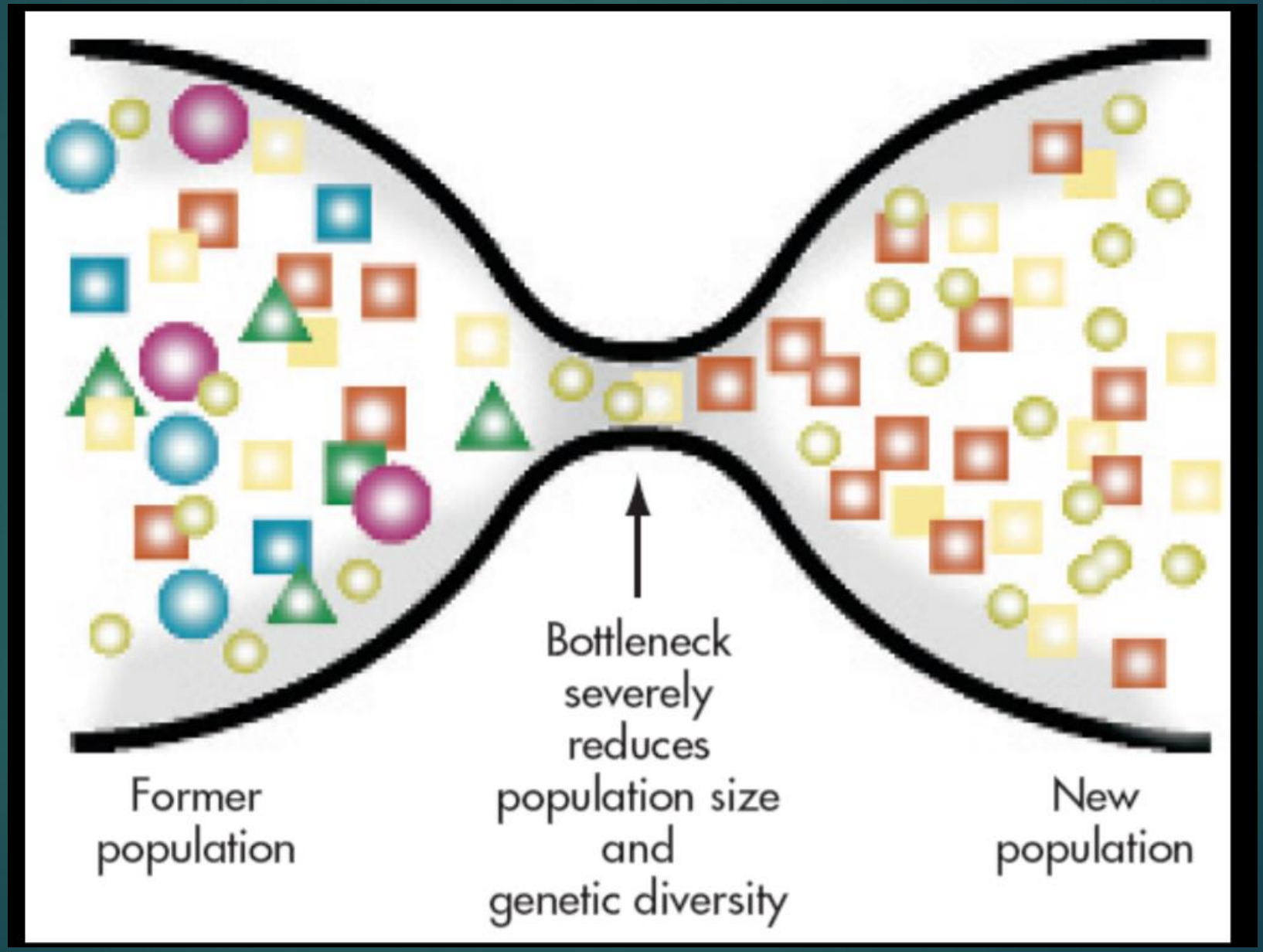
Genetic drift: Bottleneck effect



- Bottleneck effect = event which significantly reduces population size, i.e. habitat destruction, genocide:
- Original population contains larger genetic diversity, i.e. Africa
- If bottleneck occurs, surviving population has less genetic diversity (fewer alleles; higher level of genetic drift due to smaller population)
- Genetic evidence of African bottleneck circa 70 Ka, left 2000 humans

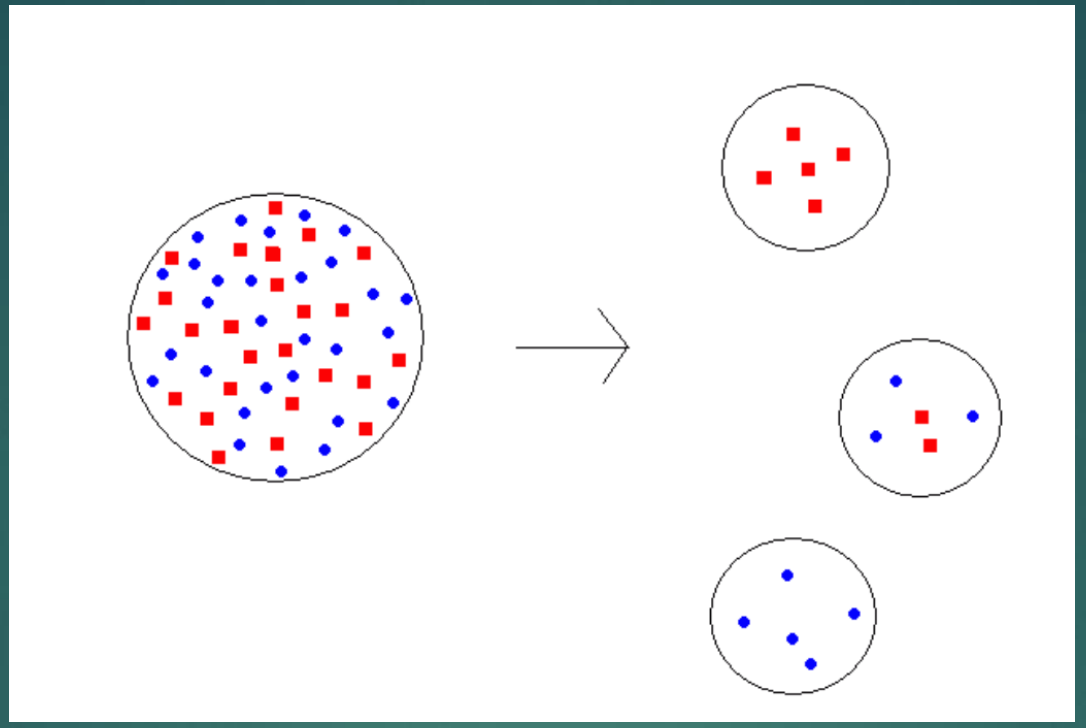
Genetic Drift - Bottleneck

6 types:
Blue
Purple
Orange
Dark Green
Light Green
Yellow



Only 3 types:
No:
Blue
Purple
Dark Green

Genetic Drift: Founder effect (a form of bottleneck)



- **Founder effect** is the loss of genetic variation that occurs when a new population is established by a very small number of individuals from a larger population. Result of migrations.
- The original population (left) could give rise to different founder populations (right).
- Africa has greatest genetic variation, because of longer time for mutations. All migrations that left had less genetic variability due to founder effect.

Evolutionary Force 4 – Natural Selection

- NS = only those organisms that are best adapted to their environment tend to survive and transmit their genetic characters in increasing numbers to succeeding generations, while those less adapted tend to be eliminated.

- NS = process by which heritable traits increase an organism's chances of survival and reproduction

- Example: the shape of finches' beaks on the Galapagos Islands has tracked weather patterns: after droughts, the finch population has deeper, stronger beaks that let them eat tougher seeds.

Natural Selection

- 1- There is variation in traits: brown & green beetles; Some variations are more successful than others, leading to a change in the entire population over time
- 2 - There is differential reproduction - not all individuals get to reproduce to their full potential: green beetles, but not brown beetles, get eaten by birds; brown beetles reproduce, green don't
- 3 - There is heredity - The surviving brown beetles have brown baby beetles because this trait has a genetic basis.
- 4 - End result: Brown coloration allows the beetle to have more offspring & becomes more common in the population

Natural selection

- Erroneous thinking that evolution is random because some elements of its process are random.
- Mutation itself is random with respect to outcome
- Genetic drift is also random. Genetic drift is driven by the frequency of a trait within a given population, not necessarily by how likely or how advantageous that trait is within that given population.
- Natural selection is not random. Natural selection acts in a specific direction. It takes a population from its starting point and moves it to areas of higher fitness, assuming those areas are available to it

Evolution

- Evolution does not progress toward an ultimate or proximate goal (Gould 1989).

- Evolution has no goals, & has nothing to do with effort. Natural selection has no foresight, directionality, or intentionality.

- Evolution is not "going somewhere"; it just describes changes in inherited traits over time. Occasionally, and perhaps inevitably, this change results in increases in biological complexity, but to interpret this as "progress" is to misunderstand the mechanism.

- The action of selection is only something we can understand after the fact...it is not a forward looking process.

Natural selection

- The language that we use to describe natural selection, including that word "selection," suggests that selection is an active force, that there's some outside force that's choosing this to be a favored variant and predicting that it's going to be more likely.

- But that actually reverses the course of action. In one example, one notes that red individuals are more frequent in future generations; they were better able to reproduce and survive. But they aren't better able to reproduce and survive because they're red.

- There isn't some future plan that is trying to unfold. Rather, the properties of the moment help shape the properties of the future. In this case, how selection is acting now determines what the properties of our population might look like in future generations.

Fitness

- Fitness describes how good a particular genotype is at leaving offspring in the next generation relative to how good other genotypes are at it.
- So if brown beetles consistently leave more offspring than green beetles because of their color, you'd say that the brown beetles had a higher fitness.
- Of course, fitness is a relative thing. A genotype's fitness depends on the environment in which the organism lives. The fittest genotype during an ice age (i.e. more body fat), for example, is probably not the fittest genotype once the ice age is over.
- The fittest individual is not necessarily the strongest, fastest, or biggest. It depends on adaptability to a certain environment. A genotype's fitness includes its ability to survive, find a mate, produce offspring — and ultimately leave its genes in the next generation.

Sexual Selection

- A form of Natural Selection
- Asexual reproduction = produces clones
- Sexual selection: improves a species ability to survive by constantly varying the traits of offspring, making it more likely that some will be able to survive a dramatic environmental change such as drought or famine.
- Two types:
  - intrasexual selection – male to male competition for access to females; increases biological weaponry & behaviors (antlers, tusks)
  - Intersexual selection – males compete for attention of females: peacock's tail

Evolution

- NS keeps around traits that are furthering organism's survival and reproduction today, not traits that might come in handy a million years from now. Evolution is a kind of Zen. No striving, no trying. Just use what happens to be useful now.

- There are no species that are more highly evolved than another one.

- Evolutionary fitness: fitting the circumstances of one's life, best matching your environment, "survival of best matching"; can survive and reproduce in its environment;

What is a species?

- Species: An interbreeding group of animals or plants that are reproductively isolated though anatomy, ecology, behavior, or geographic distribution from all other such groups

- Biggest gene pool possible under natural conditions.

- There are lots of places where it is difficult to apply this definition, i. e. asexual reproduction, hybrids

- Speciation is a lineage-splitting event that produces two or more separate species.

Species Concepts

- Biological species concept: Defines species as interbreeding population that is reproductively isolated from other such populations.
- Evolutionary species concept: Defines species as evolutionary lineages with their own unique identity.
- Ecological species concept: Defines species based on the uniqueness of their ecological niche.
- Recognition species concept: Defines species based on unique traits or behaviors that allow members of one species to identify each other for mating.

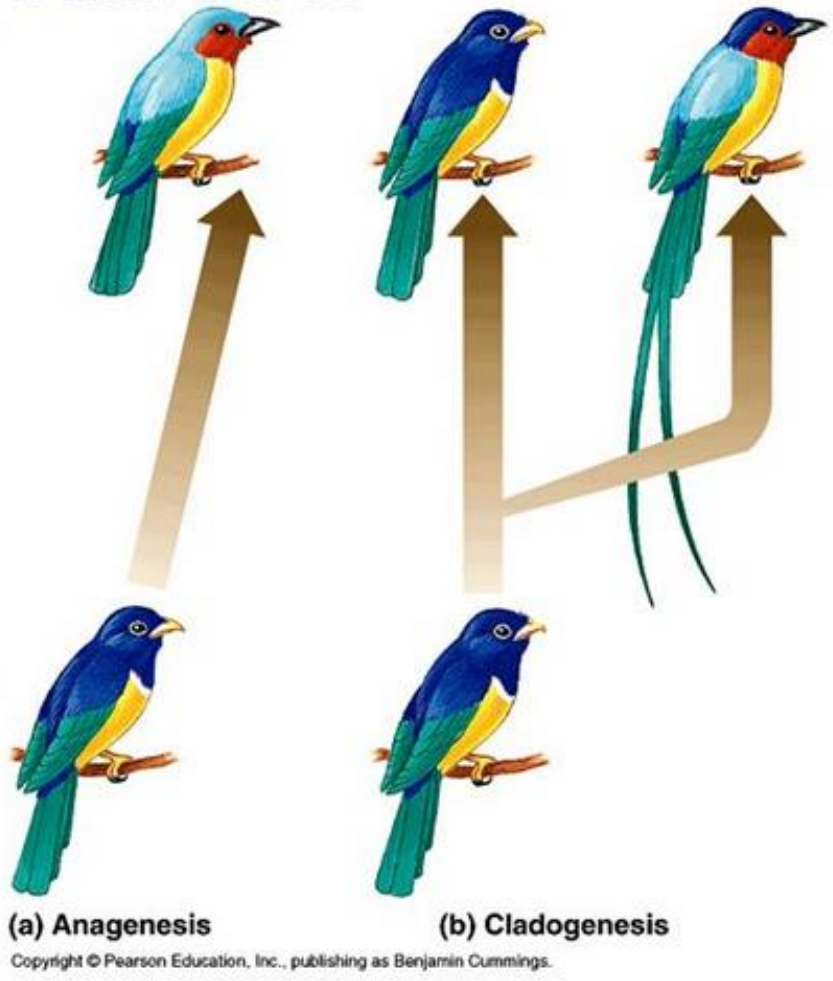
One Species: Theridon grallator

These “happy face” spiders *look* different, but since they can interbreed, they are considered the same species: *Theridion grallator*.

Modes of Evolutionary Change

Patterns of speciation

- **Anagenesis**: phyletic evolution, accumulation of heritable change in population
- **Cladogenesis**: branching evolution (basis for biological diversity)



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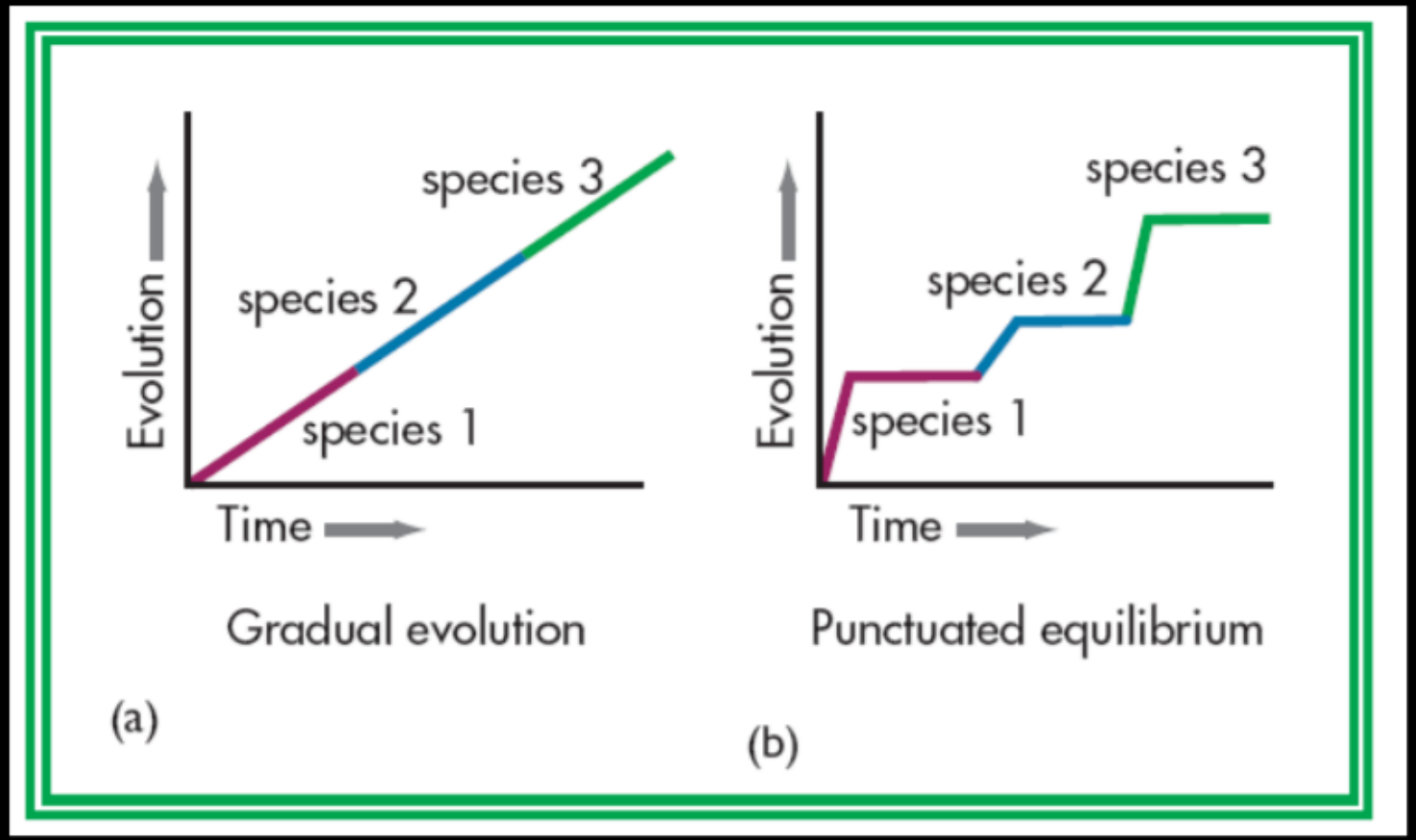
Tempo of Speciation?

- Gradualism?
- Punctuated Equilibrium?



The Species Problem

- Generally speaking, different species don't have fertile descendants. Given Neandertal DNA in modern humans, N & MH clearly interbred. But weren't N & MH separate species? Doesn't a species, by definition, breed only with others of that species?
- The question of how to define a species has divided researchers for centuries. Darwin's words in *On the Origin of Species* still hold: "No one definition has satisfied all naturalists."
- Most scientists use the biological species concept proposed by Ernst Mayr: "groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups."
- Svante Pääbo dodges the species question & refers to N, MHs, D as "populations". He considers species discussion "a sterile academic endeavor"

Species Problem

- If you apply Mayr's definition strictly, then N, D, & MHs must be considered Homo sapiens. This is John Hawks position. A minority view.
- Morphological differences between MH and N are significant, greater than in all MHs, per J. Hublin. In the real world, he says, Mayr's concept doesn't holdup.
- There are 330 closely related species of mammals that interbreed, and at least 30% can produce fertile hybrids. 10 percent of all animal species are known to hybridize
- Low levels of interbreeding between N, H, Ds suggest that either archaic people mated with moderns only rarely or their hybrid offspring had low fitness and so produced few viable offspring.

Species problem

- The N & MH hybrids proved to be fertile for the simple reason that the two species shared sufficient genetic similarity for it to be possible, without genetic complications arising in the hybrid species that would render it sterile.
- X chromosome in MHs is almost devoid of Neanderthal DNA. The Y-chromosome of male Neanderthals proved to be unviable in hybrids; only the female MH hybrids proved to be fertile.
- Female modern humans and male Neandertals were not fully compatible and male Neandertals may have had problems with sperm production.
- The answer still depends on how you define a species. Ernst Mayr: “Are species realities of nature or are they simply theoretical constructs of the human mind?”

Microevolution & Macroevolution

- Microevolution is change at individual species level; changes within a species that aren't drastic enough to create an entirely new species; no speciation; caused by the 4 evolutionary processes

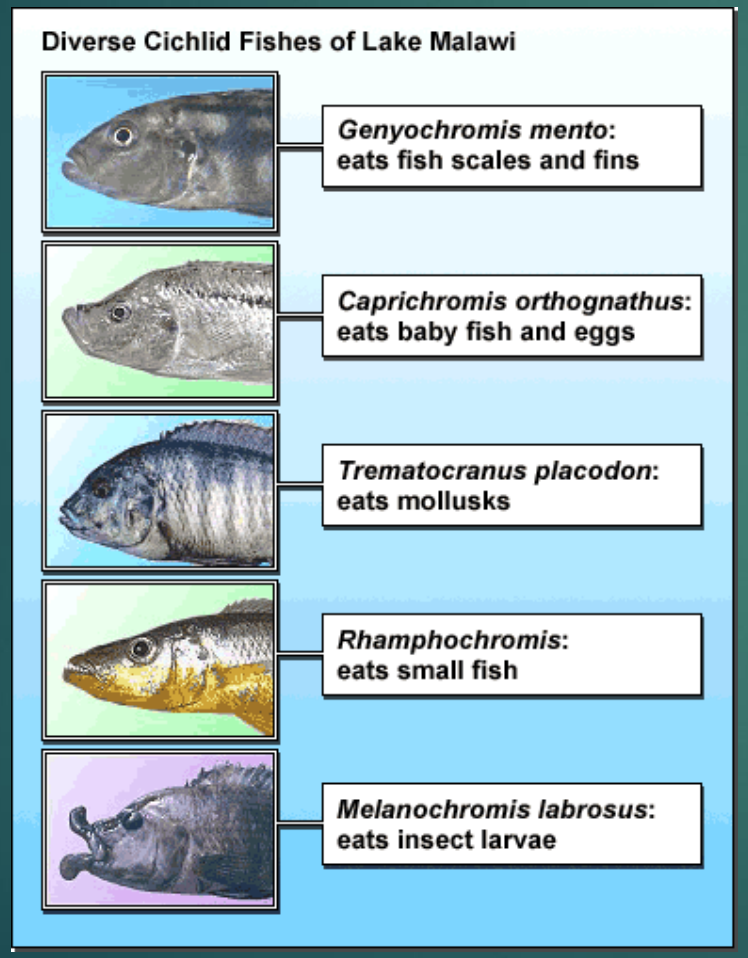
- Microevolution (evolutionary change below the level of the species); observed in human timescale; i.e. peppered moth, evolution of bacterial resistance

- Macroevolution (change above the level of the species); cumulative effect of these small changes over a long period of time - may lead to speciation, i.e. evidence from fossils, Galapagos finches

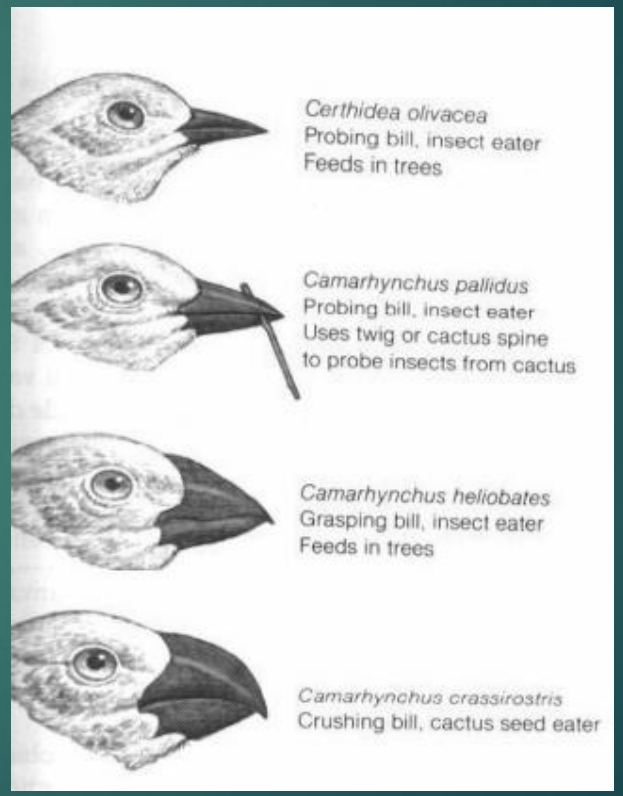
- Microevolution is a change in gene frequency in a population and a population is a group of organisms that share a common gene pool — like all the individuals of one beetle species living on a particular mountaintop.

- There is no difference between macroevolution and microevolution. Macroevolution is merely a collection of microevolution events.

Speciation: Adaptive Radiation – An example of Divergent Evolution



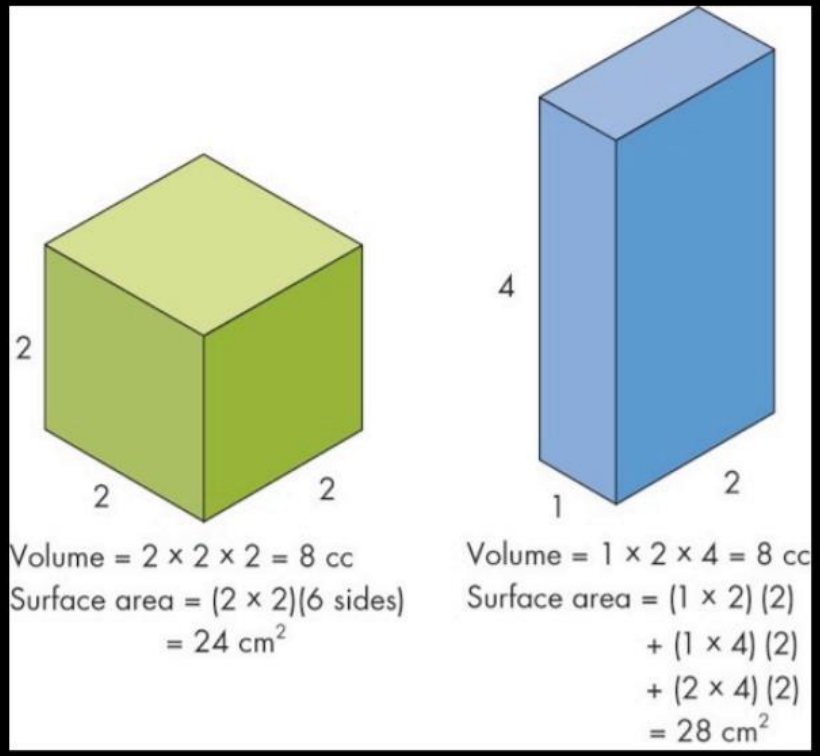
http://evolution.berkeley.edu/evolibrary/home.php



http://www.vanderbilt.edu/AnS/english/Clayton/Galapago_finches.gif

Bergman and Allen

Heat and Cold



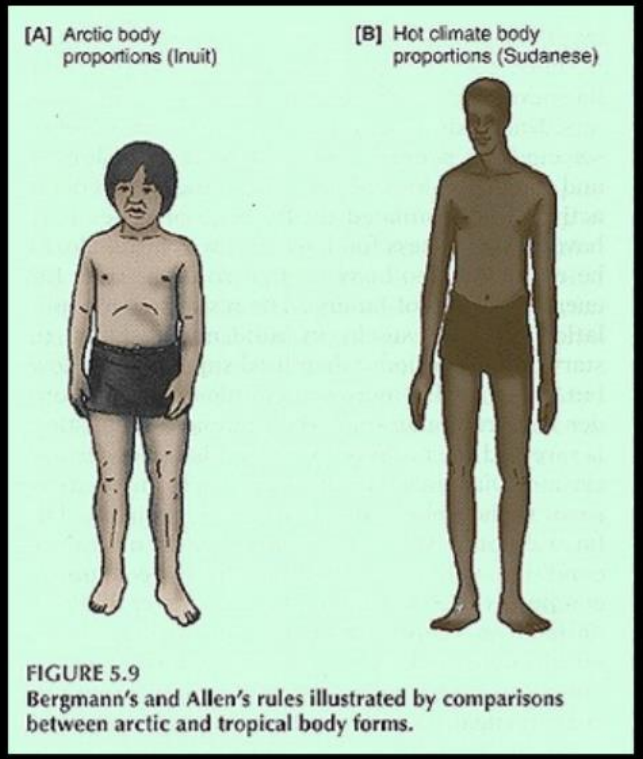


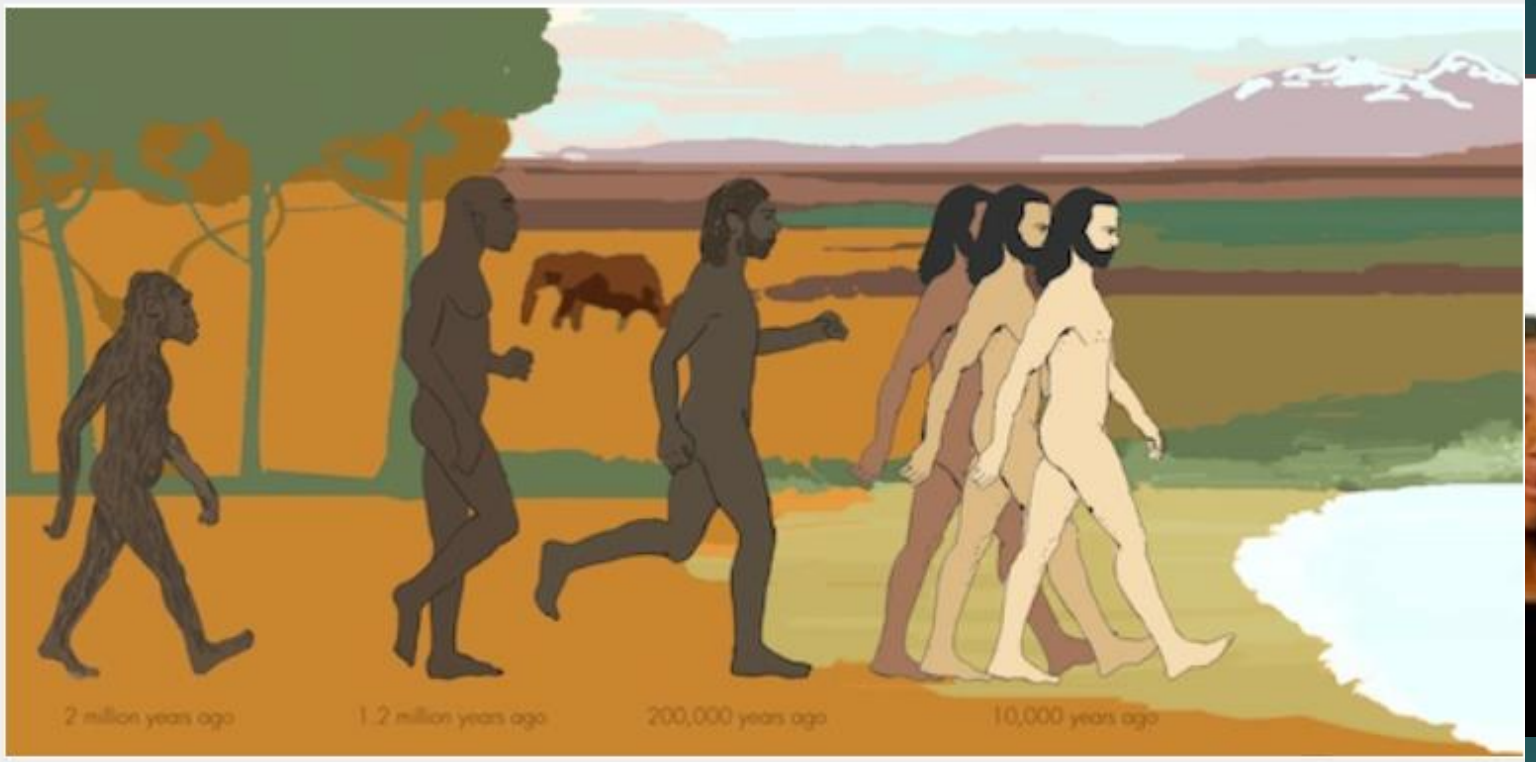
FIGURE 5.9
Bergmann's and Allen's rules illustrated by comparisons between arctic and tropical body forms.

Each human population in general has all the same alleles as other human populations, just at different frequencies

Bergmann and Allen's rules predict that the body shape in a cold environment will be short and stocky & tall and thin in heat

Body shape in a cold environment will be short & stocky; tall & thin in heat

Latitude is the key to skin color evolution

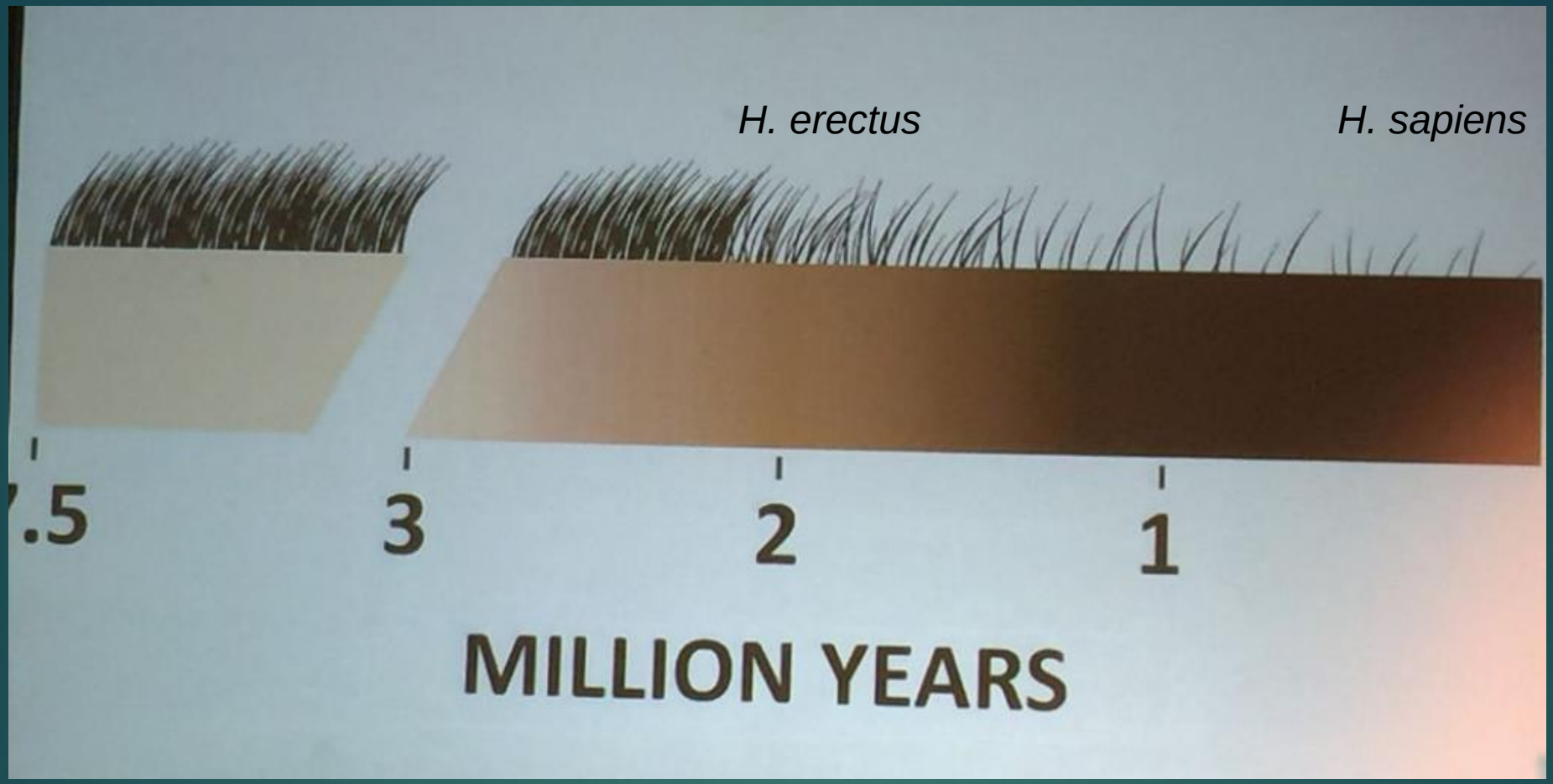


Human evolution from the equatorial African forests to the temperate zone.
Illustration by Jessica C. Kraft

No single gene determines such characteristics as skin color; No significant differences in body organs in humans, only in body parts that interact with the environment (skin, eyes); cannot predict where someone came from based on inner organs

- Skin color varies according to latitude and therefore by the intensity of incident ultraviolet light.
- Populations closer to the equator have darker skin; those further away, lighter skin. Has nothing to do with “race” = a non-biological concept.

Nina Jablonski: Skin Color & Hair & Human Evolution



Light skin has only developed in Northern latitudes in last 10 Ka

Living Color: The Biological and Social Meaning of Human Skin Color by Nina Jablonski

Only Skin Deep

- Skin color variations are adaptive traits that correlate closely to geographic latitude and the sun's ultraviolet radiation. Vitamin D levels in the body played a key role in the evolution of our species' skin color.

- Darker skin pigmentation (more melanin produced in the skin) developed as body's protection:
  - Loss of body hair led to the development of dark skin pigmentation; original condition for the genus *Homo;* eumelanin is natural sun screen
  - Against UVB radiation & DNA damage
  - Prevents folate depletion (failure of normal embryogenesis and spermatogenesis; esp. neural tube development)
- Lighter skin pigmentation (depigmentation)
  - Very high correlation between UV radiation and skin color; the weaker the sunlight is in a geographic region, the lighter the indigenous people's skin is. Lighter skin is 6x more efficient at making Vitamin D from UVB ray
  - Adapted to environments of low UV radiation
  - Production of more Vitamin D (calcium absorption for healthy bones, anti-rickets, anti-CA, MS)
  - Has superior antimicrobial defense

Remember:

Evolution is the foundation of all biology!

Online anatomy

- Eskeletons: http://eskeletons.org/
- Comparative anatomy: http://eskeletons.org/compant

Downloads

- www.charlesjvellaphd.com
- Lecture Pdfs in:
  - 2018 OLLI: Human Evolution: The First 150 Years of Discovery