Evolution: The foundational concept of biology

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Additional material in full pdf file of this talk:

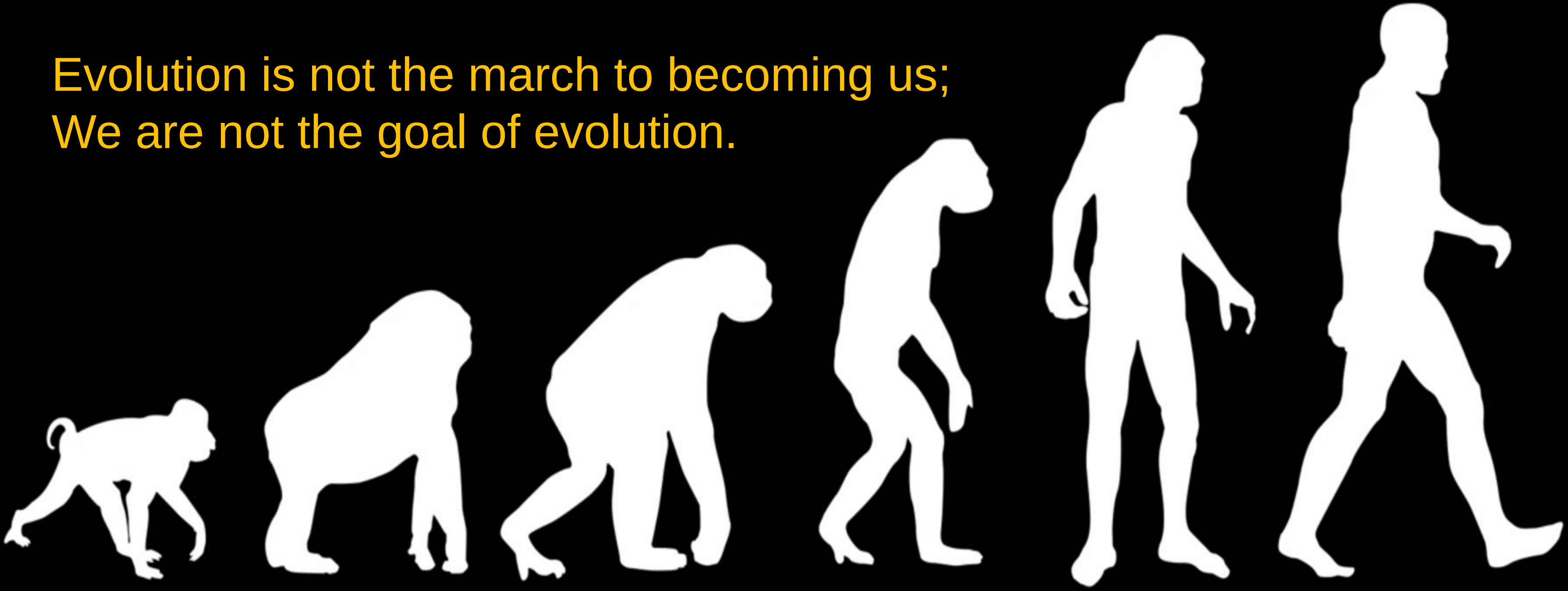
- Explanation of Phylogenies
- Science section
- Creationism vs science
- How to speak about evolution: words matter
- Natural Selection sweeps
- Co-evolution

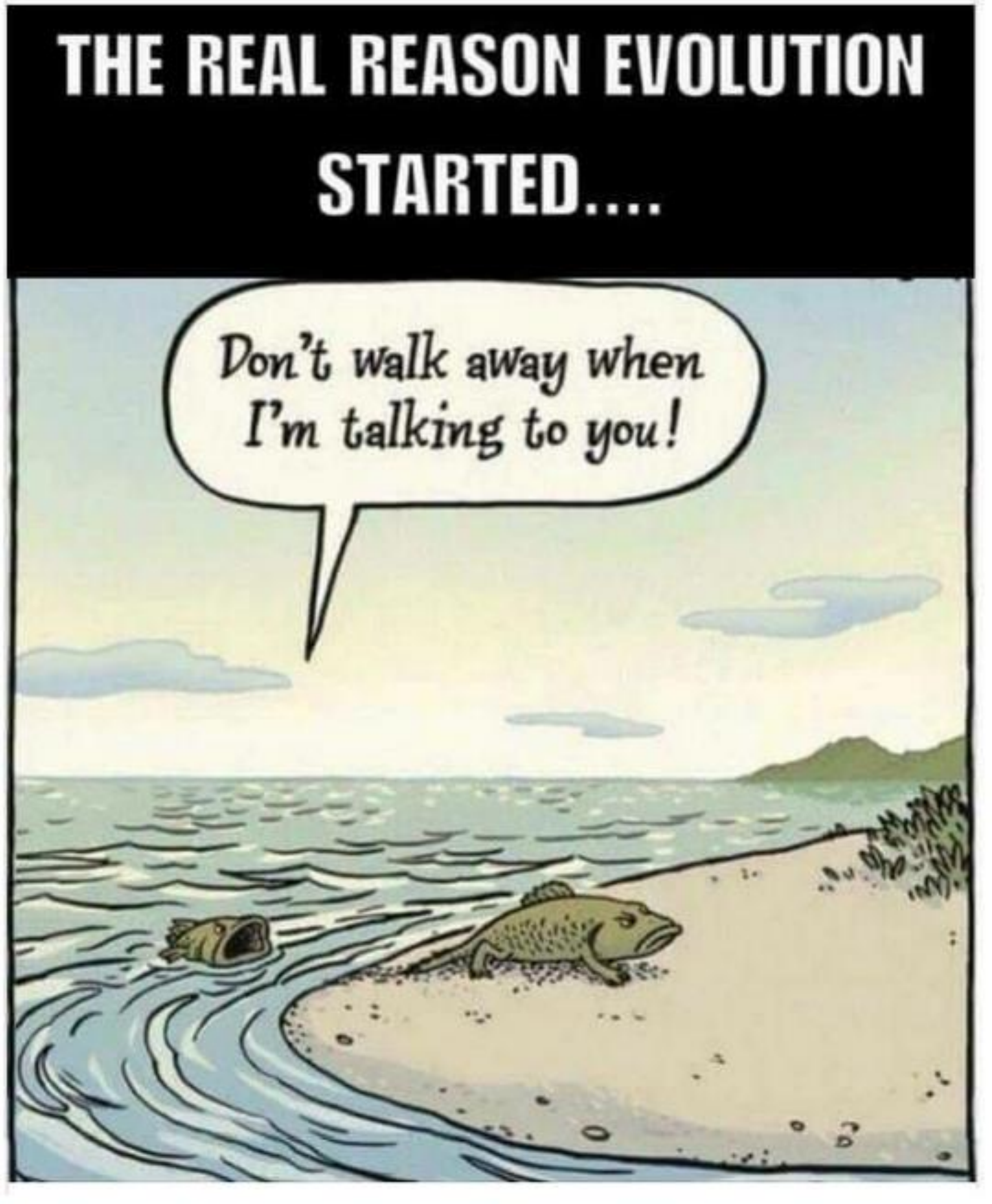
Evolution pre-test

- 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

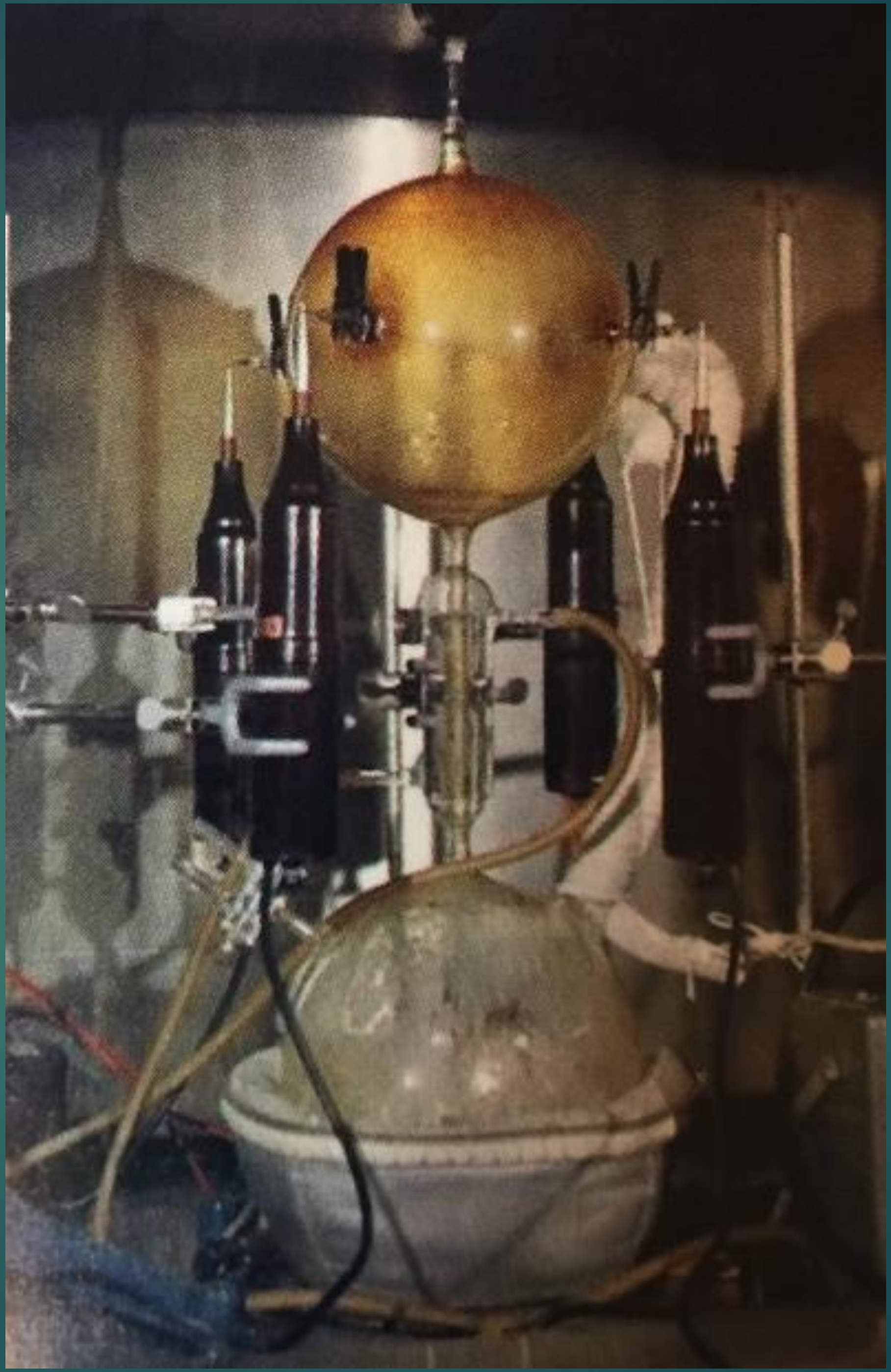
- Evolution is biological change over time.
- All living species—including humans—evolved from ancestral species, from a common ancestor.
- The major process responsible for the evolution of adaptive change is natural selection.
- Natural selection is about survival to reproduce.
- Natural selection 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

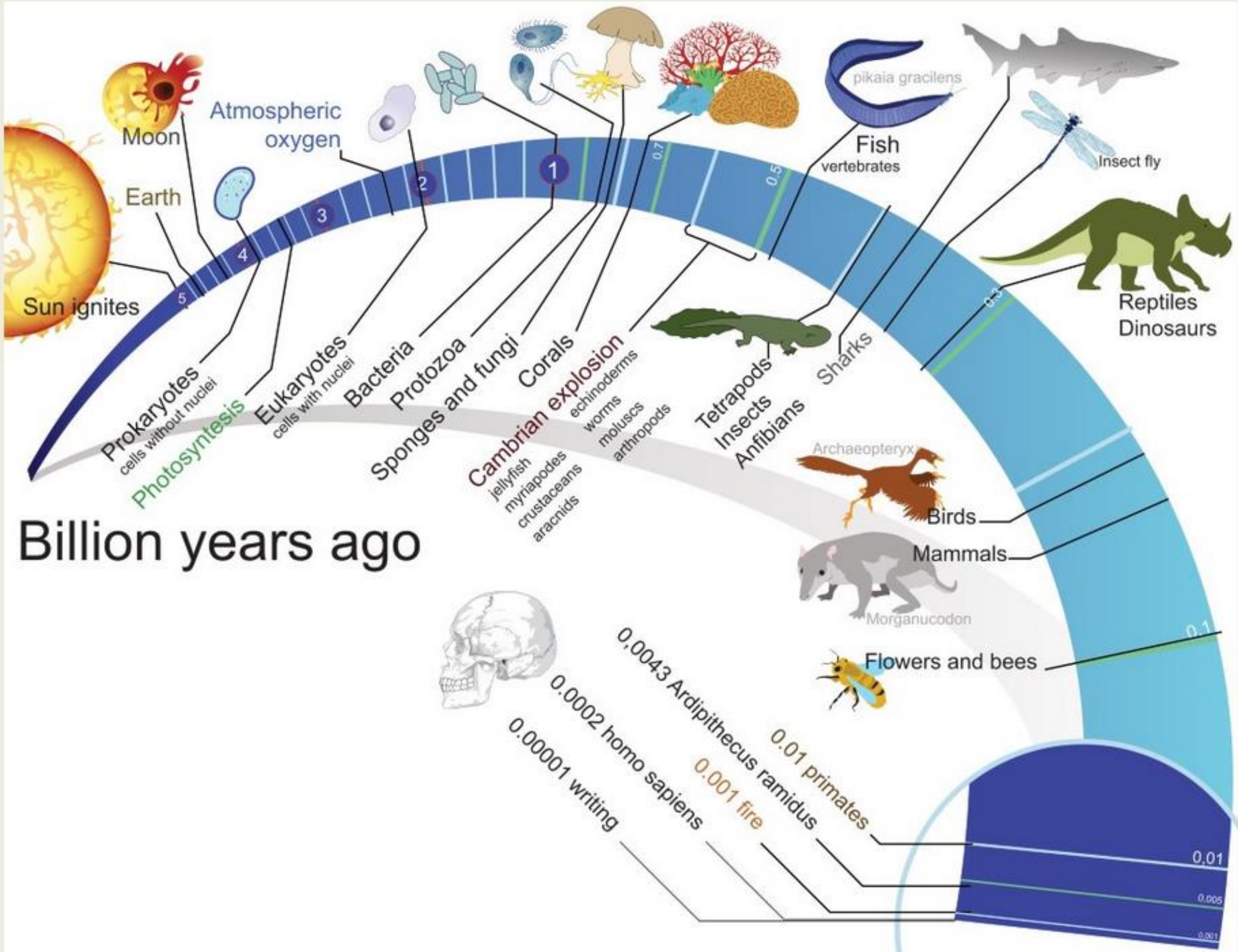
Used water (H_2O), methane (CH_4), ammonia (NH_3), and hydrogen (H_2).

Electrical jolts produced 20+ amino acids



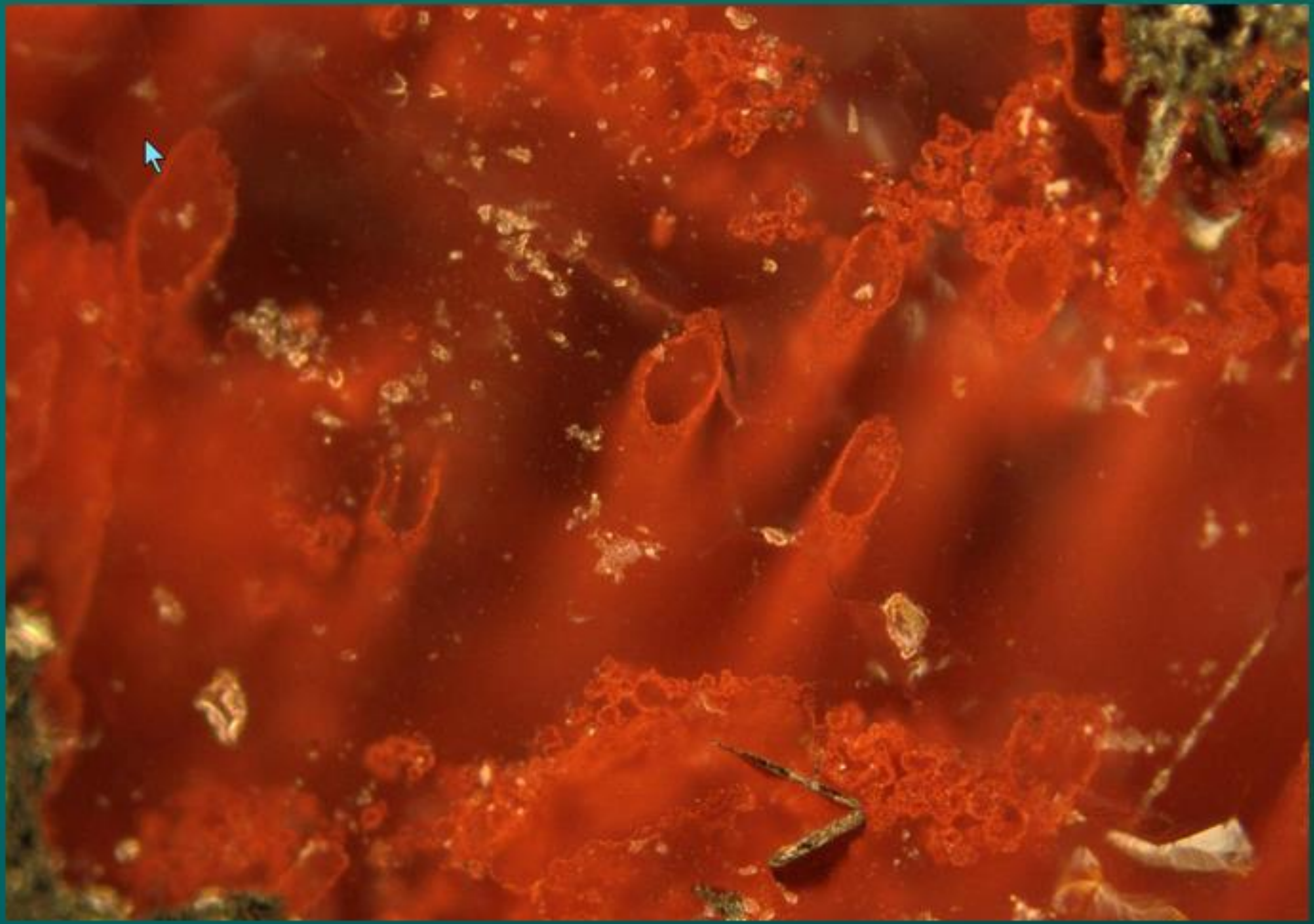
Origin of Life: basic chemistry can create living cells

- 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



Billion years ago
Sun ignites
Earth
Moon
Atmospheric oxygen
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
pikaia gracilens
Fish
vertebrates
Tetrapods
Insects
Anfibians
Sharks
Insect fly
Reptiles
Dinosaurs
Archaeopteryx
Birds
Mammals
Morganucodon
Flowers and bees
0,0043 Ardipithecus ramidus
0.01 primates
0.001 fire
0.0002 homo sapiens
0.00001 writing
5
4
3
2
1
0.7
0.5
0.3
0.1
0,01
0,005
0,001

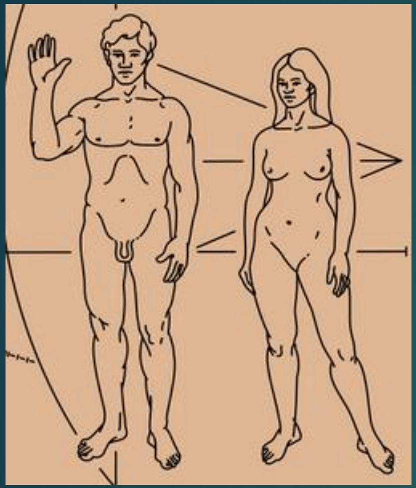
Life at 4.28 Ba?: just 300 Ka after formation of planet



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%

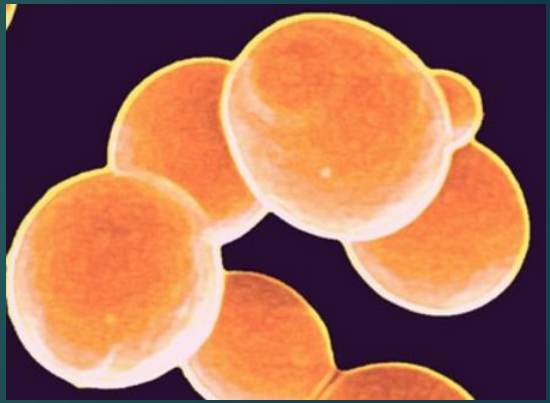
92%

70%

60%

50%

You are related to every living creature on planet earth



Yeast = 26%

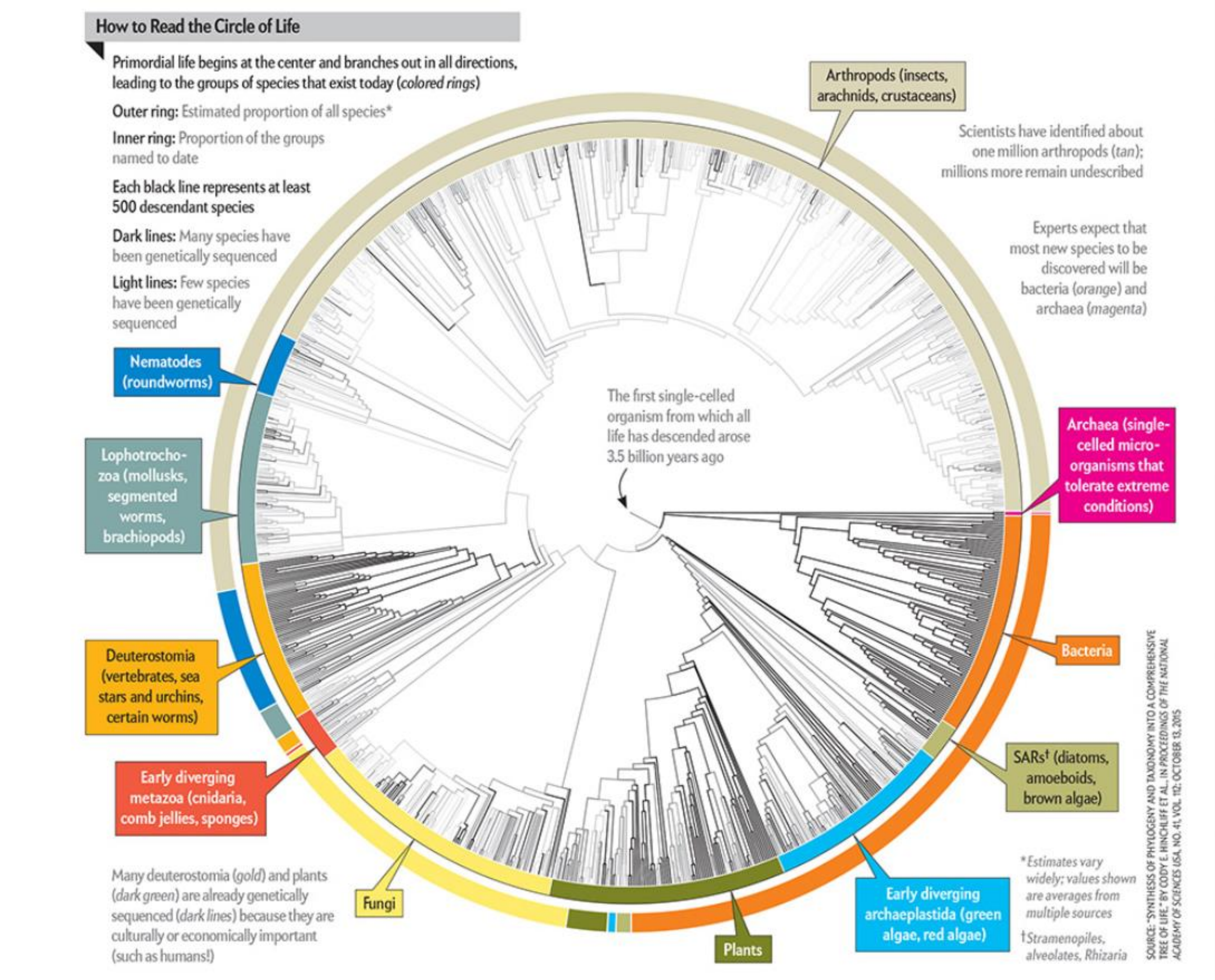
https://www.quora.com/What-percentage-of-human-DNA-is-shared-with-other-things

Evolution is complex

~8.7 million (±1.3 million) eukaryotic (nucleus within a membrane) species globally

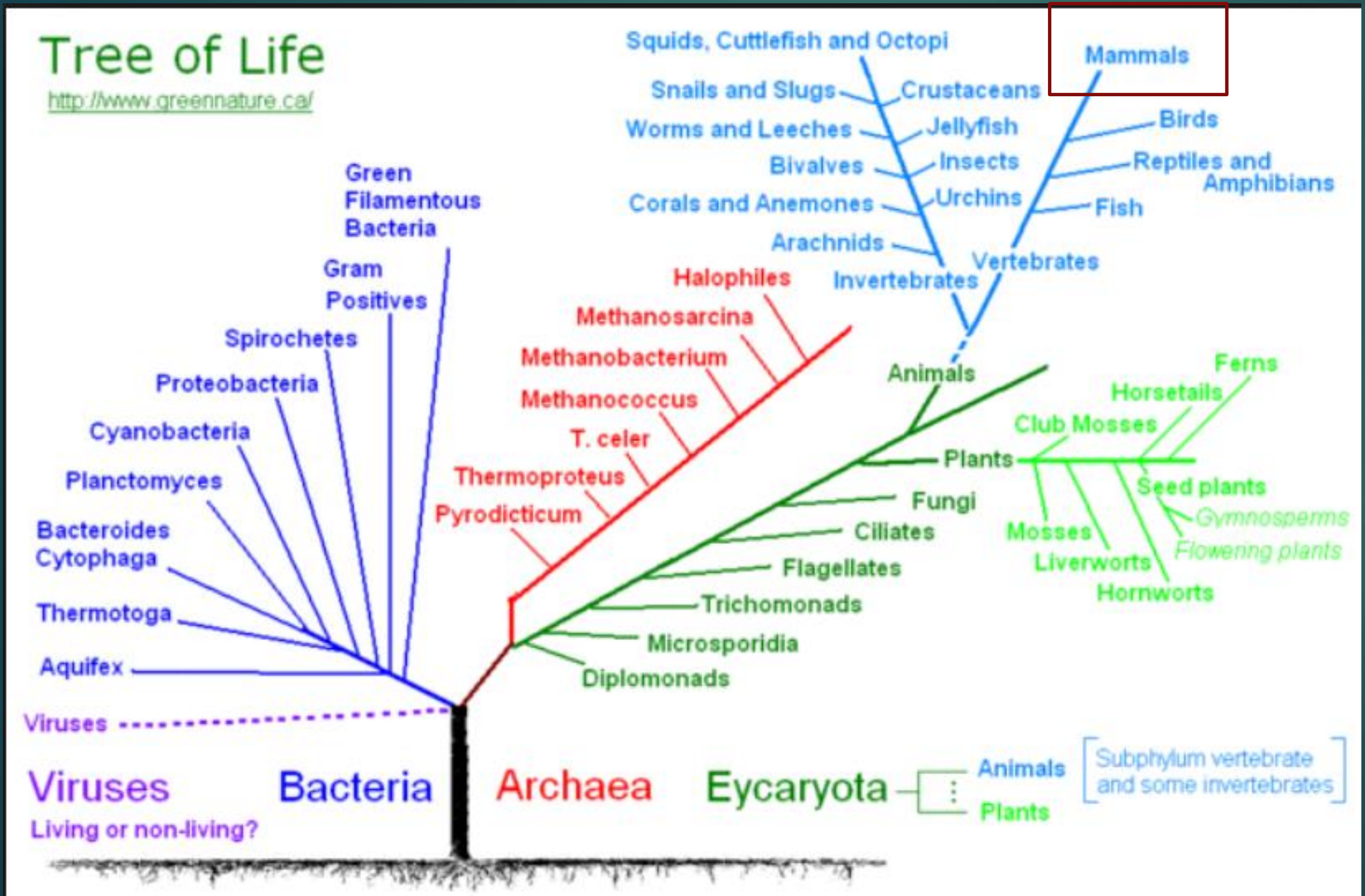
~2.2 million (±0.18 million) marine

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



http://www.opentreeoflife.org/

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



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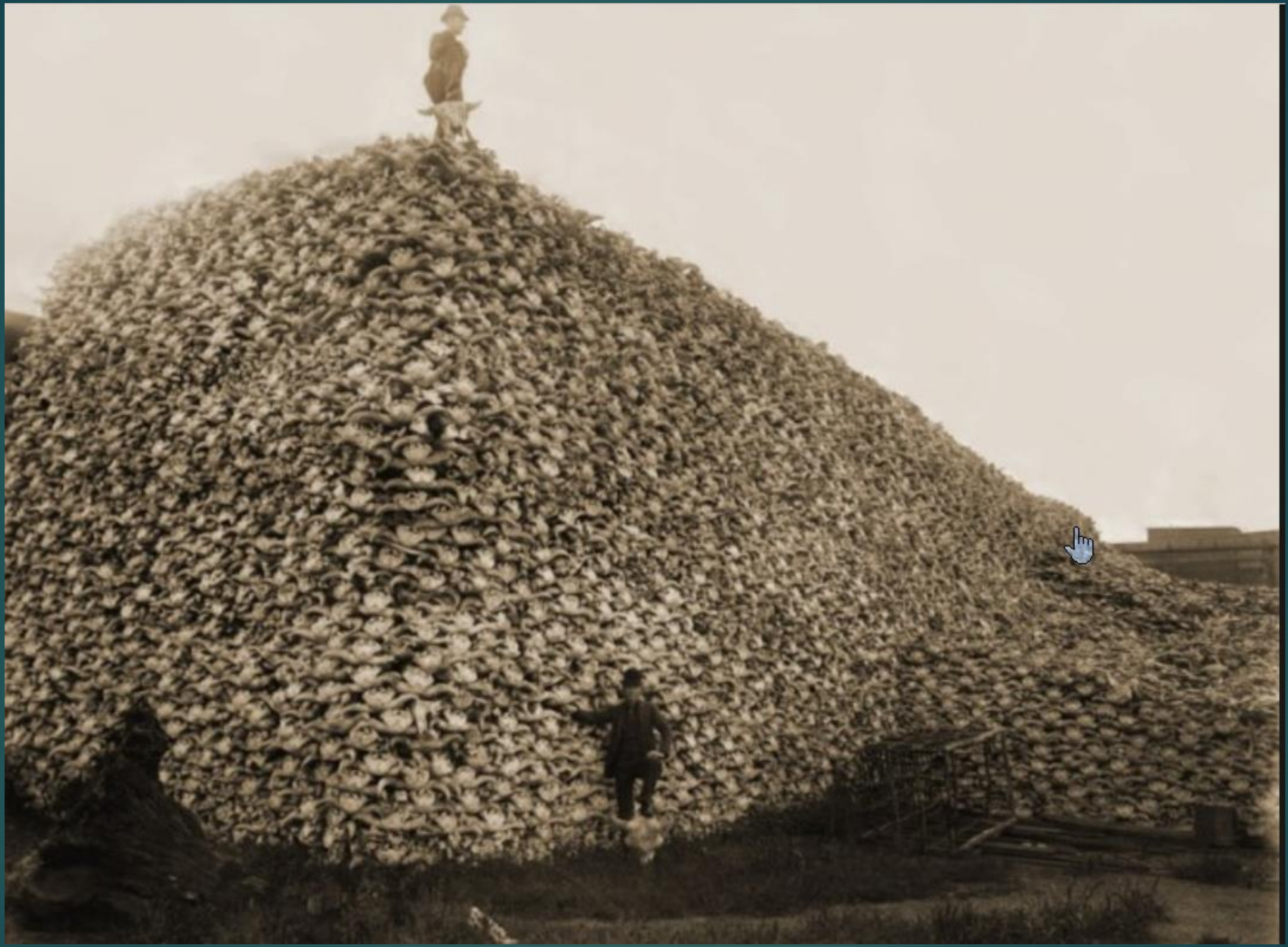


Extinction is part of evolution: Buffalo skulls in 1870, for fertilizer

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

Extinction

- 5 mass extinctions in last 500 K:
  - End Ordovician, 444 million years ago, 86% of species lost
  - Late Devonian, 375 million years ago, 75% of species lost
  - End Permian, 251 million years ago, 96% of species lost
  - End Triassic, 200 million years ago, 80% of species lost
  - End Cretaceous, K-T Event, 66 million years ago, 76% of all species lost; end of dinosaurs, rise of mammals
  - Causes: methane releases, flood basalt eruptions/volcanos, climate change, impact events
- Post extinction world is ripe for significant diversification; took 20 My for first dinosaurs to evolve after Triassic extinction; mammals are shrew like

6th Mass Extinction: Current

- 35 Ma: first monkeys and apes
- 6th Mass Extinction: rate of extinction has increased 1,000 to 10,000 times higher than the *natural extinction rate*.
- Habitat destruction, global warming are leading causes
- Biological invasions (Hawaii: 1000 native plants, 1000 invader species; invading snake eats bird eggs; no longer pollinate native plants); rats; goats on Galapagos; N Dakota leafy spurge kills native grasses – flea beetle brought in to fight it
- Deforestation

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

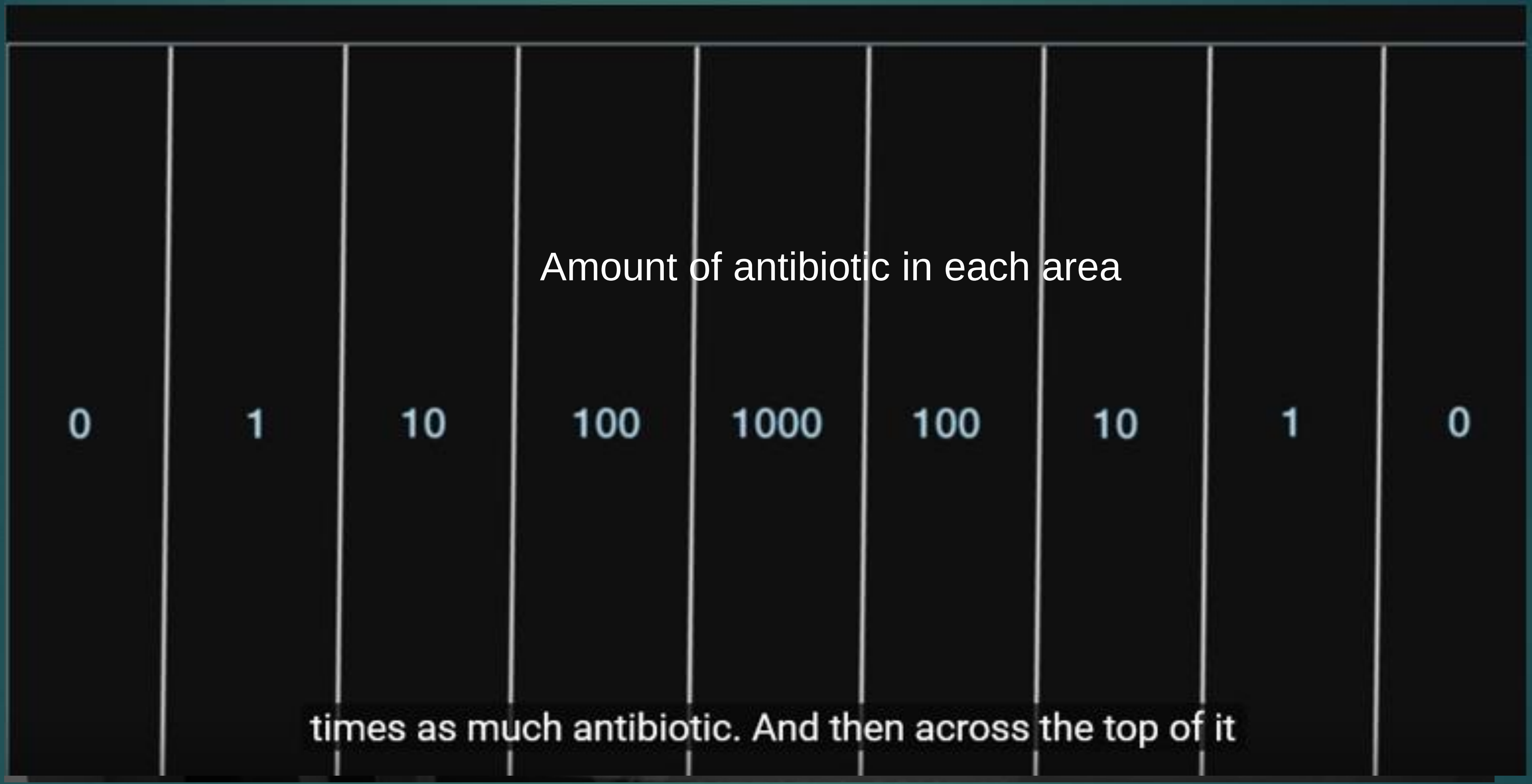








Evolution of antibiotic resistance in real time in a 2'x4' petri dish

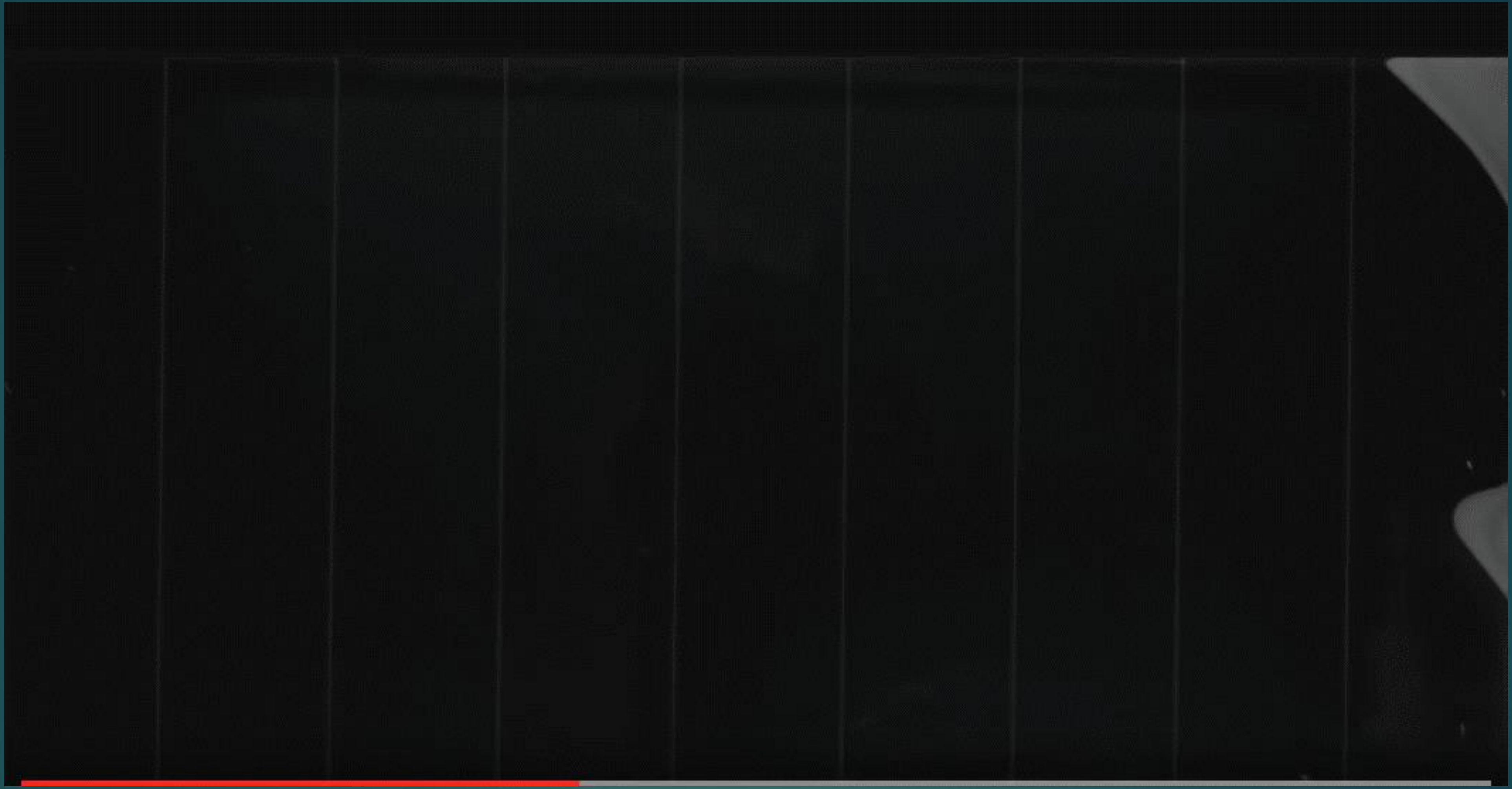


E. coli

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

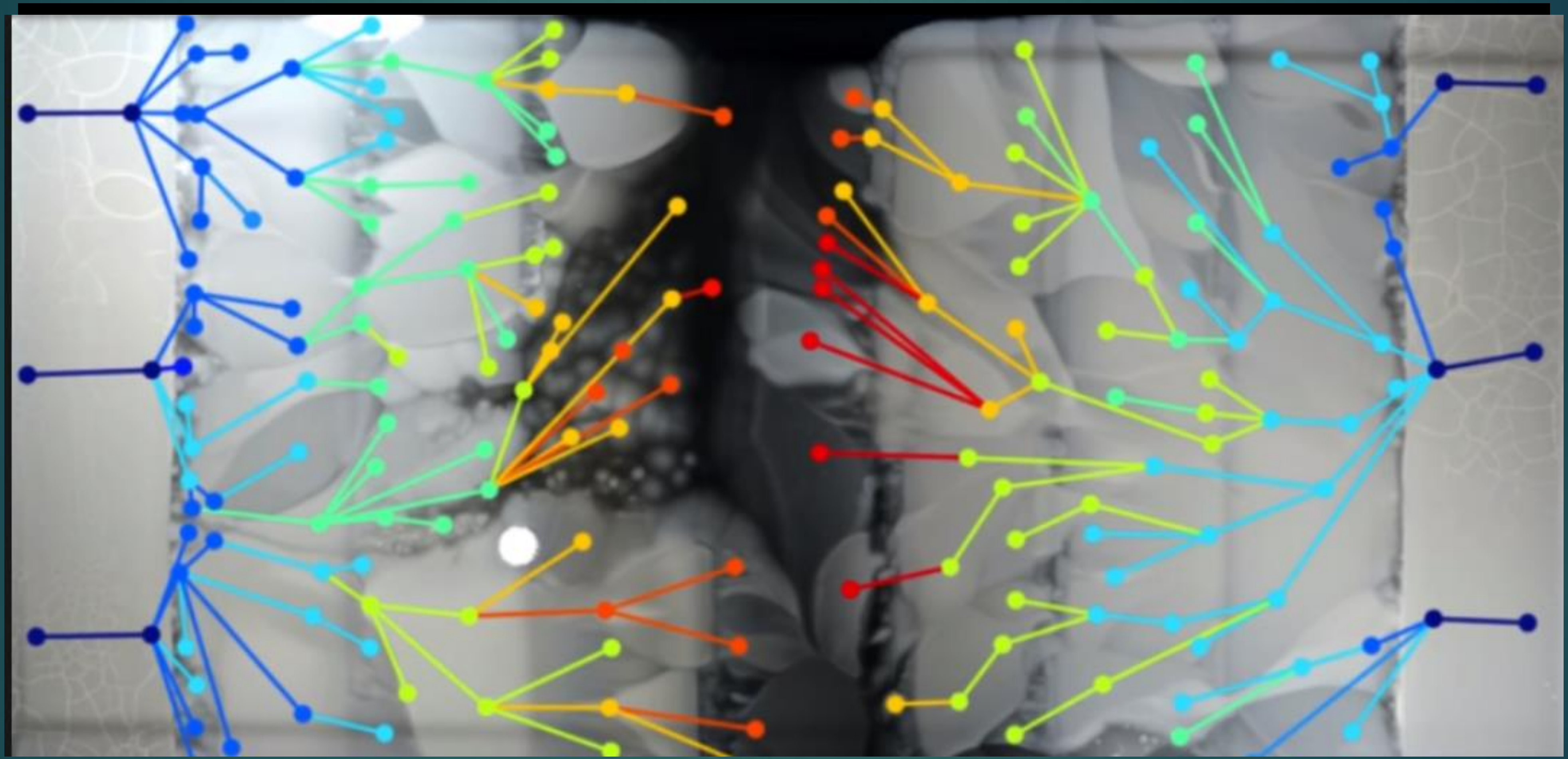
Evolution is a fact: Bacterial resistance development in 11 days



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

Bacteria evolves antibiotic resistance in 11 days

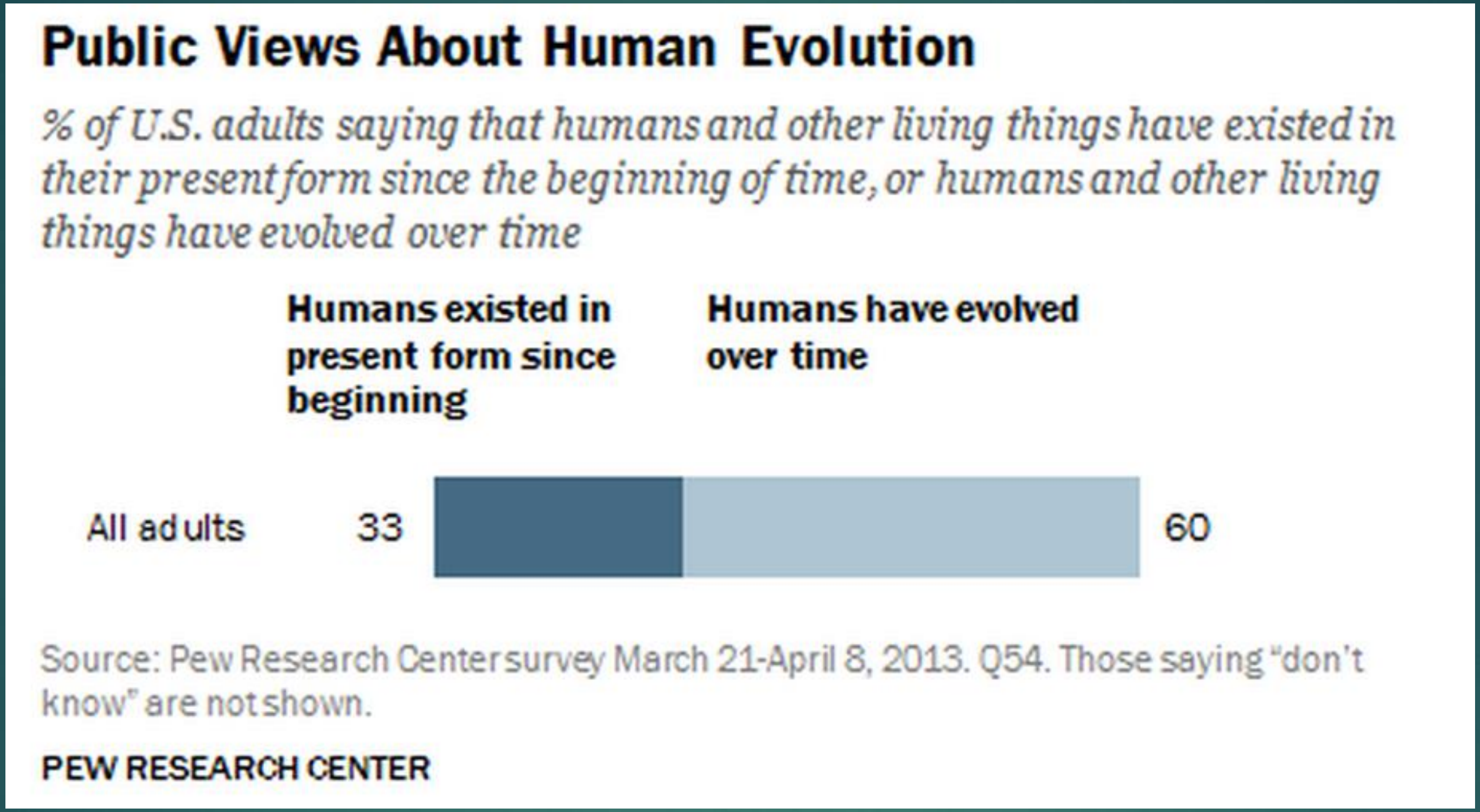
After about 11 days, resistance to over 1000 times as much antibiotic as was originally toxic evolves.



0 1 10 100 1000 100 10 1 0 amount of antibiotic

Human equivalent = 2000 years

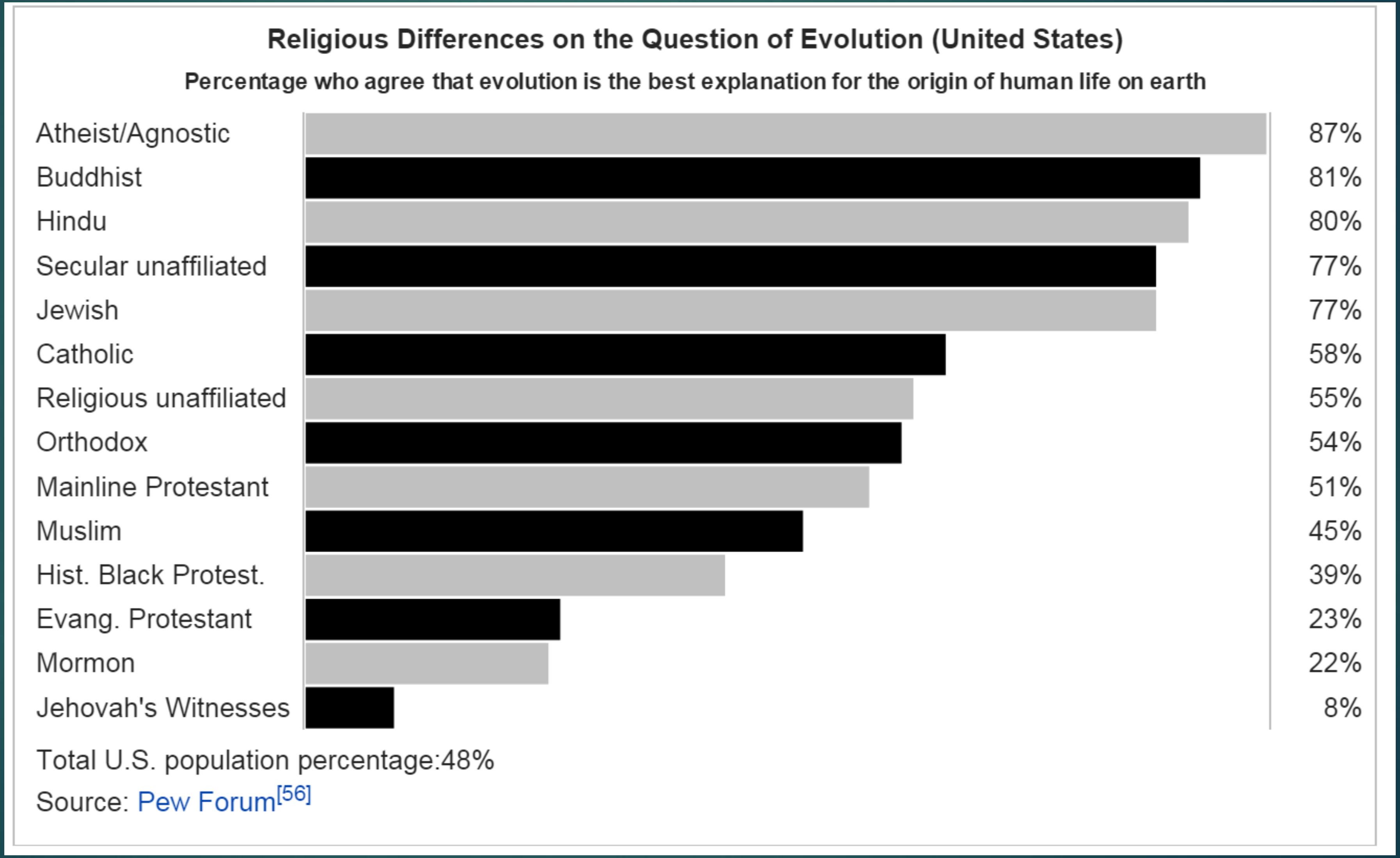
Only 60% Accept Human Evolution in USA



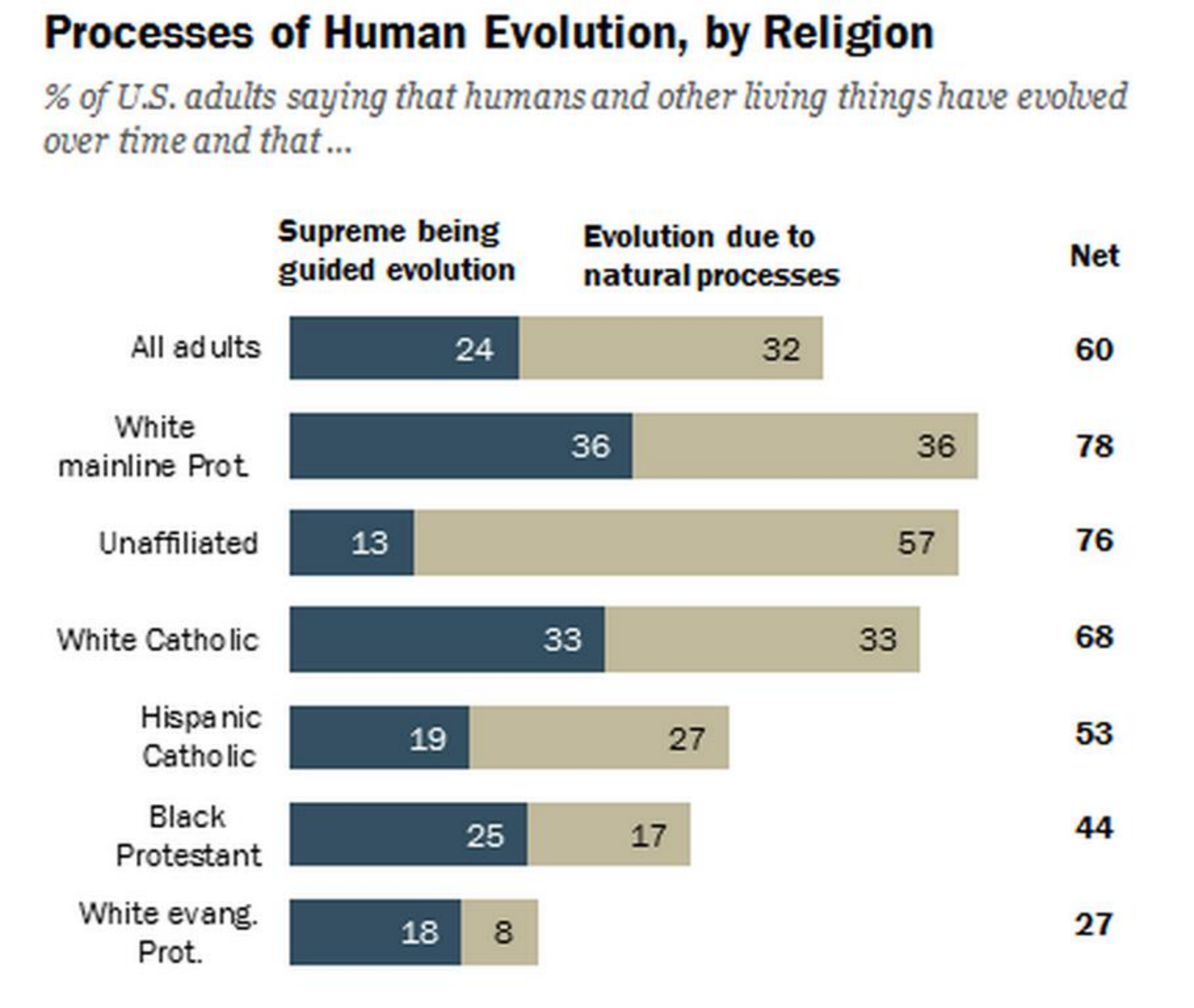
99.9 percent of scientists accept evolution

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

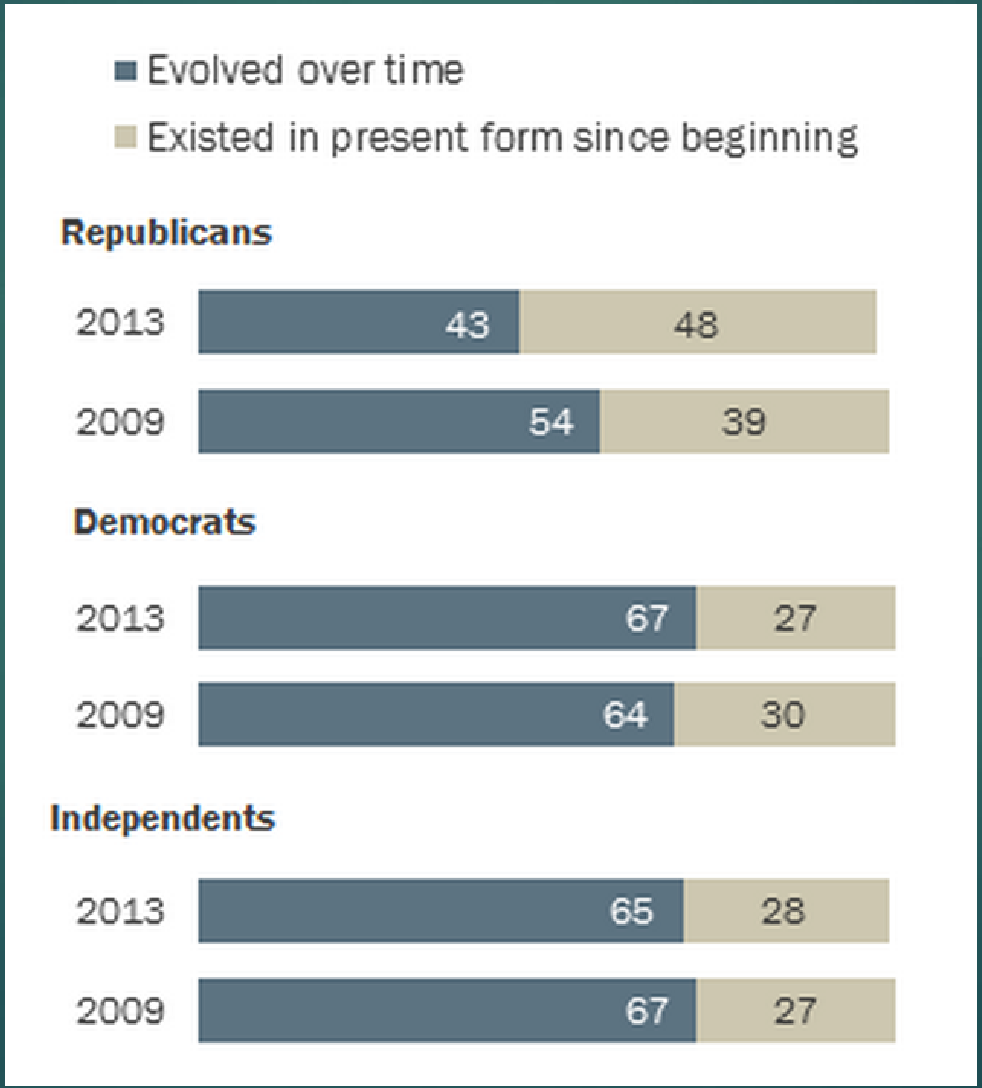
Acceptance of Evolution:
Most accepting: Atheists; Least accepting: Jehovah Witnesses



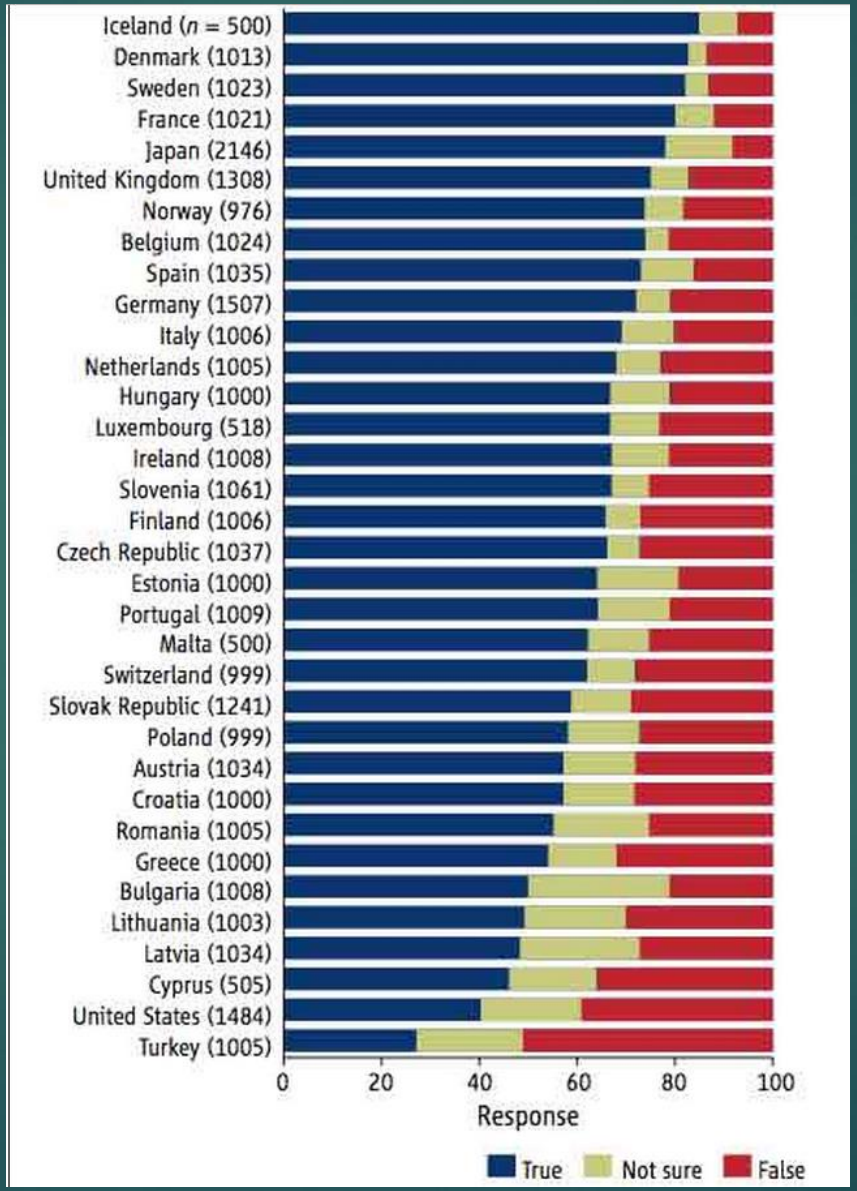
Is God (24%) driving evolution or Evolution due to natural processes (32%)



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

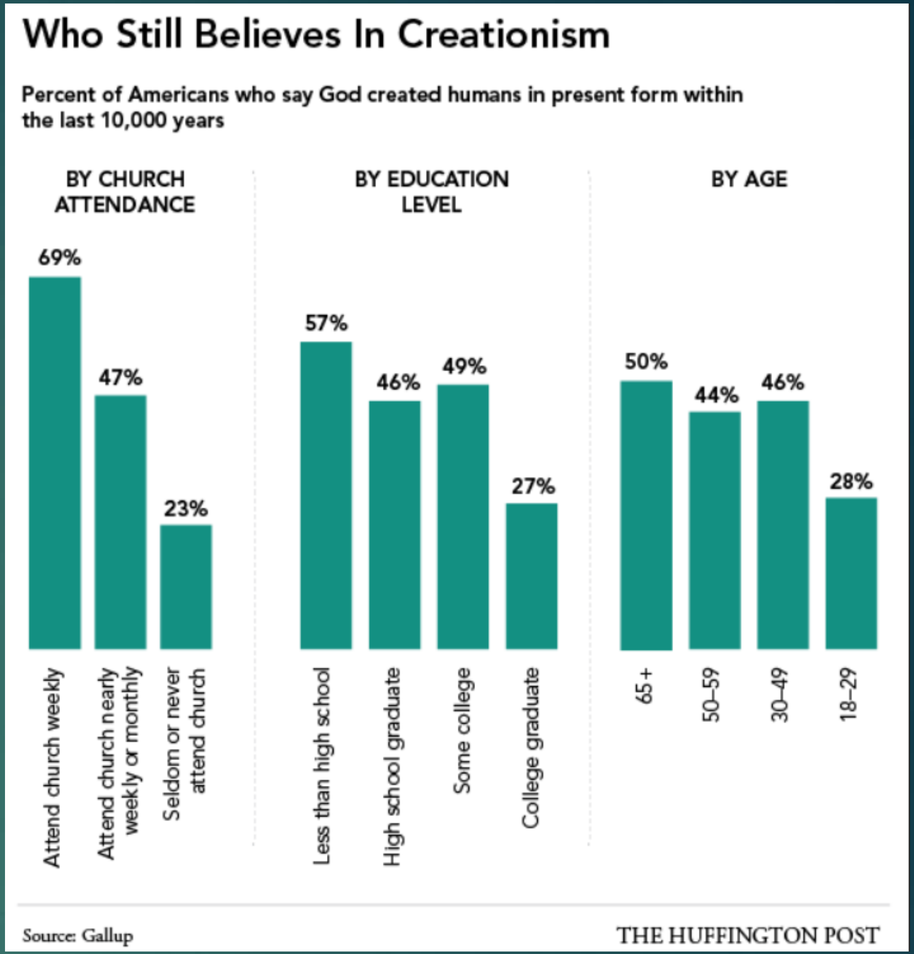


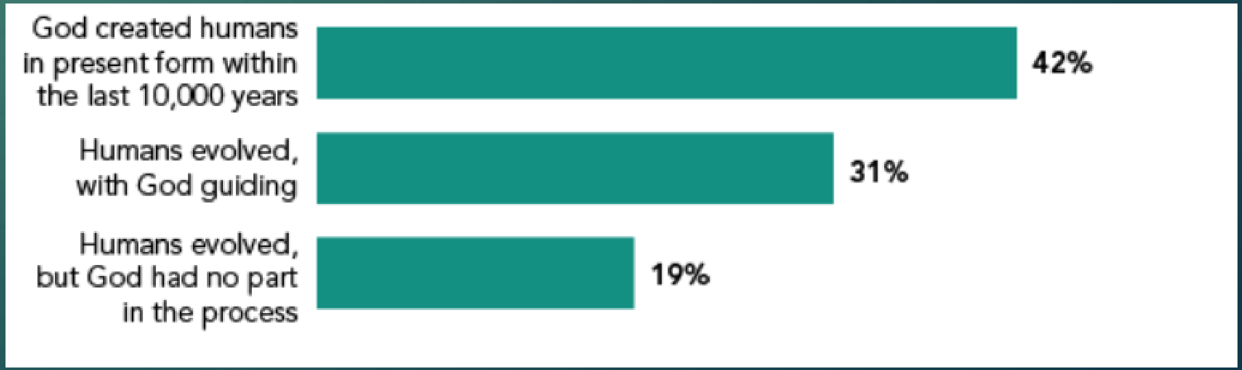
Belief in Evolution by Country: USA is 33rd of 34 Countries



Acceptance of Evolution

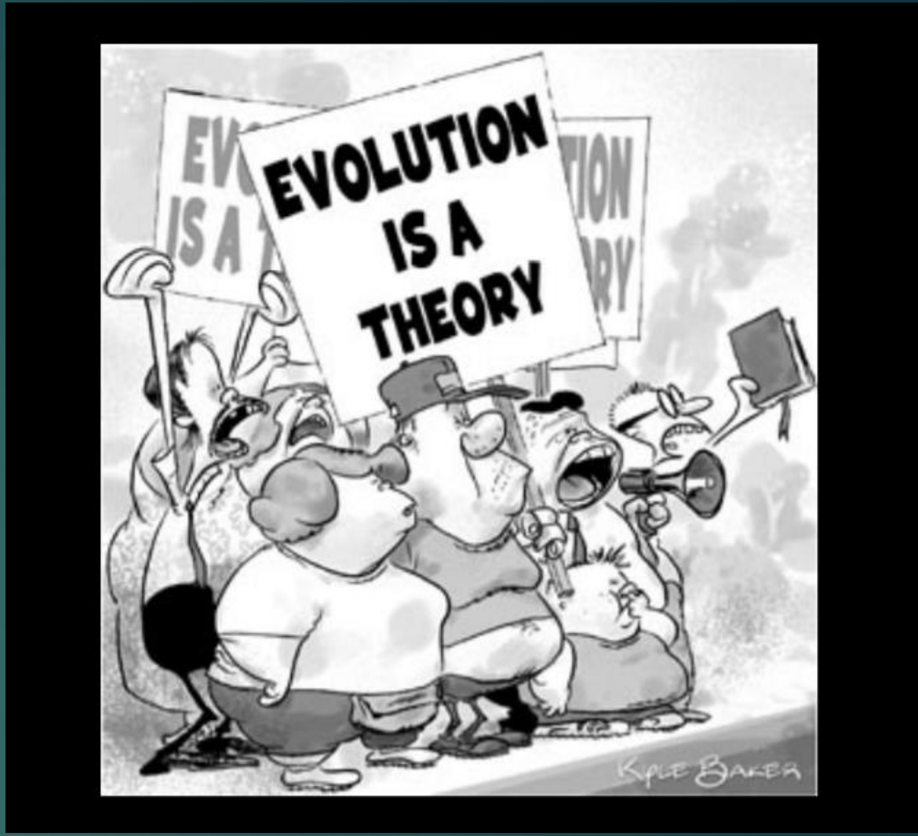
- Approximately 50% of the U.S. population thinks evolution does (or did) not occur.
- While 99.9 percent of scientists accept evolution, 40-**50 percent** of college students do not accept evolution and believe it to be 'just' a theory."
- Most accepting: non-Church attenders, college educated, below age 29





Teaching evolution

- The majority of high-school biology teachers don't take a solid stance on evolution with their students, mostly to avoid conflicts
- Fewer than 30 percent of teachers take an adamant pro-evolutionary stance on the topic.
- Also, 13 percent of these teachers advocate creationism in their classrooms.



https://www.livescience.com/11656-13-biology-teachers-advocate-creationism-class.html

2018 study: Ideological Antecedents of Science Acceptance and Rejection

- 3 studies of US adults—including an analysis of large-scale survey data
- Science understanding is associated with vaccine and GM food acceptance
- Political conservatism best predicts climate change skepticism (economic cost of compliance).
- Religiosity best predicts vaccination skepticism.
- GM food skepticism is depends on science knowledge.
- Religious conservatives consistently display a low faith in science and an unwillingness to support science.

Bastiaan T. Rutjens, et al., 2018

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

Darwin’s Dangerous Idea

Darwin presumed that populations of individuals changed over time, and, in 1844, he developed the concept of the driving force for evolution. It wasn’t until 1859 that he published his idea.

“I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection.”

—Charles Darwin from "The Origin of Species“, 1859

<u>Broader theory</u>: Given enough time, and innumerable minute changes, anything can evolve by natural processes; Without outside interventions. Whether raising of mountains, evolution of stars, or the creation of new species…

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.

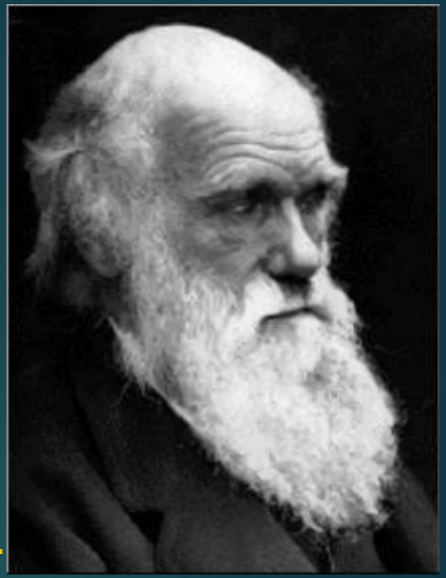
Brief summary of the *Origin of Species 2*

- 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



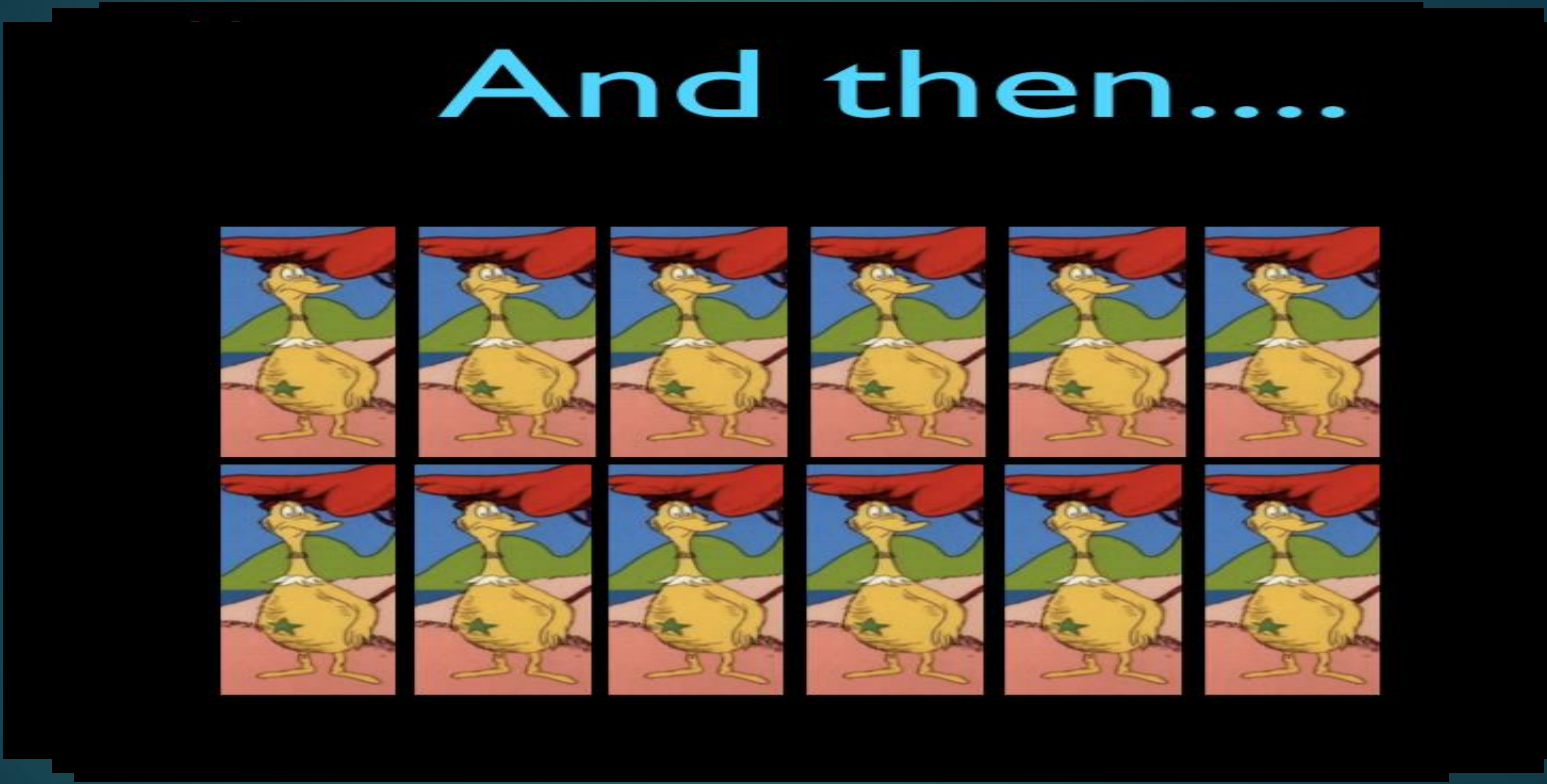
- Biology does not make sense without the concept of evolution.

- 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.

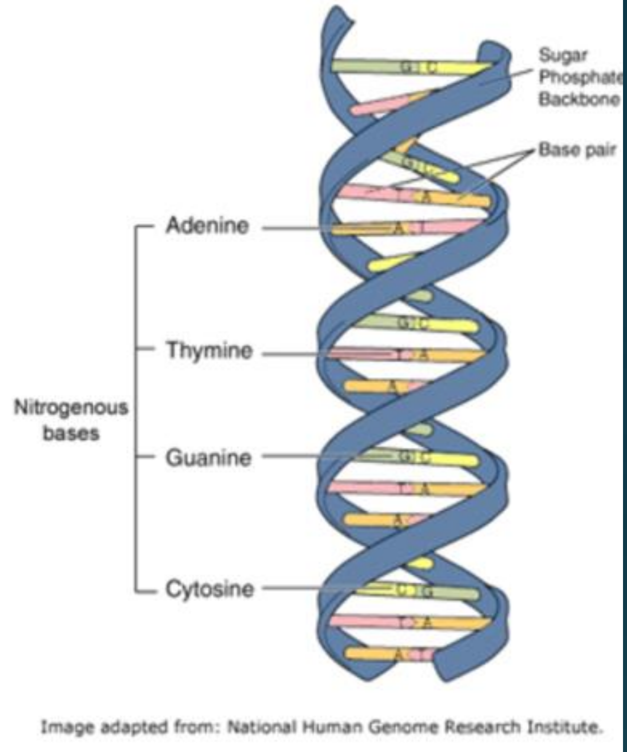
- It is the fundamental fact in all biology.

- 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



The DNA double helix showing base pairs

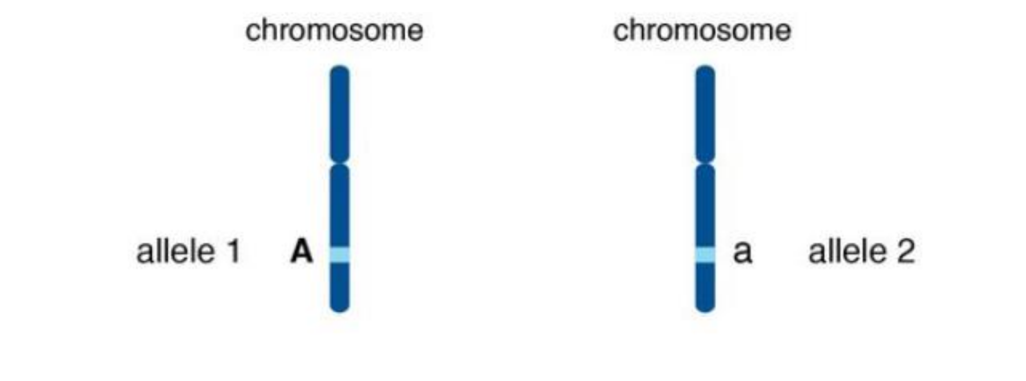
Each nucleus has 1.8 meters of DNA

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.

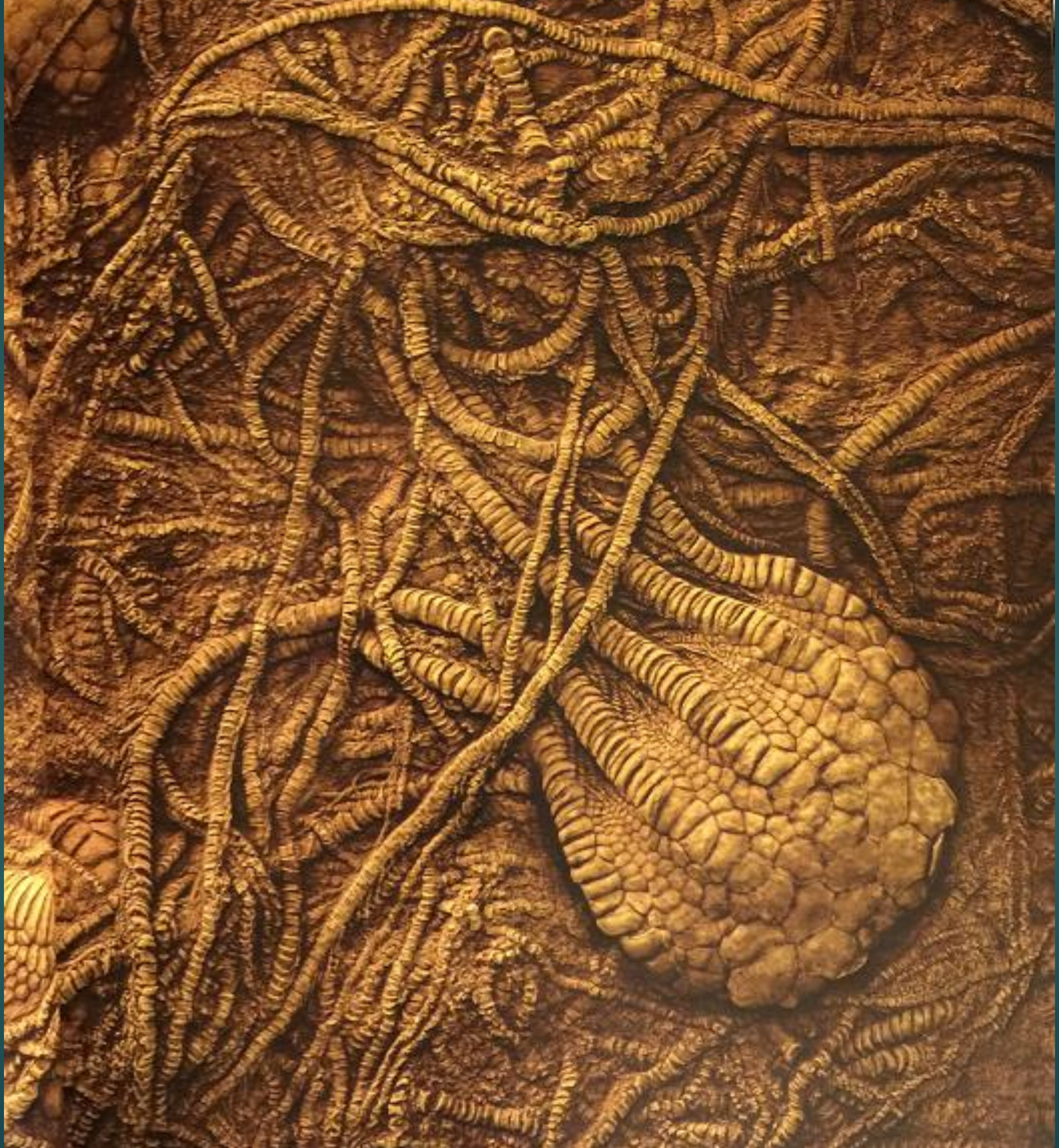
What is evolution?

Darwin: Descent with modification via natural selection

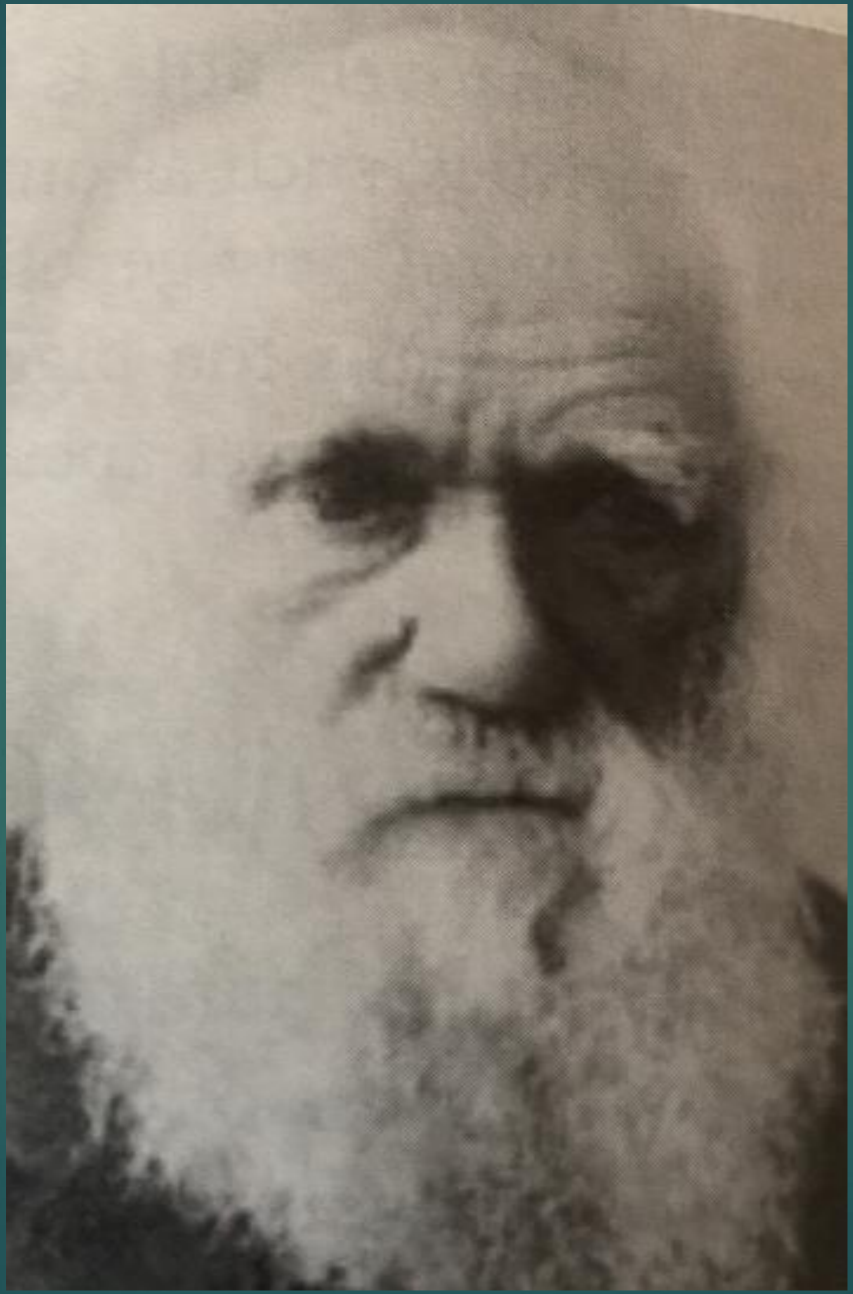
"Evolution: any change in the frequency of alleles within a gene pool from one generation to the next." - Helena Curtis and N. Sue Barnes, *Biology*, 5th ed. 1989, p.974

- Another definition: heritable change in a population through time.


Polish Lynx
Nicobar



Great Apes



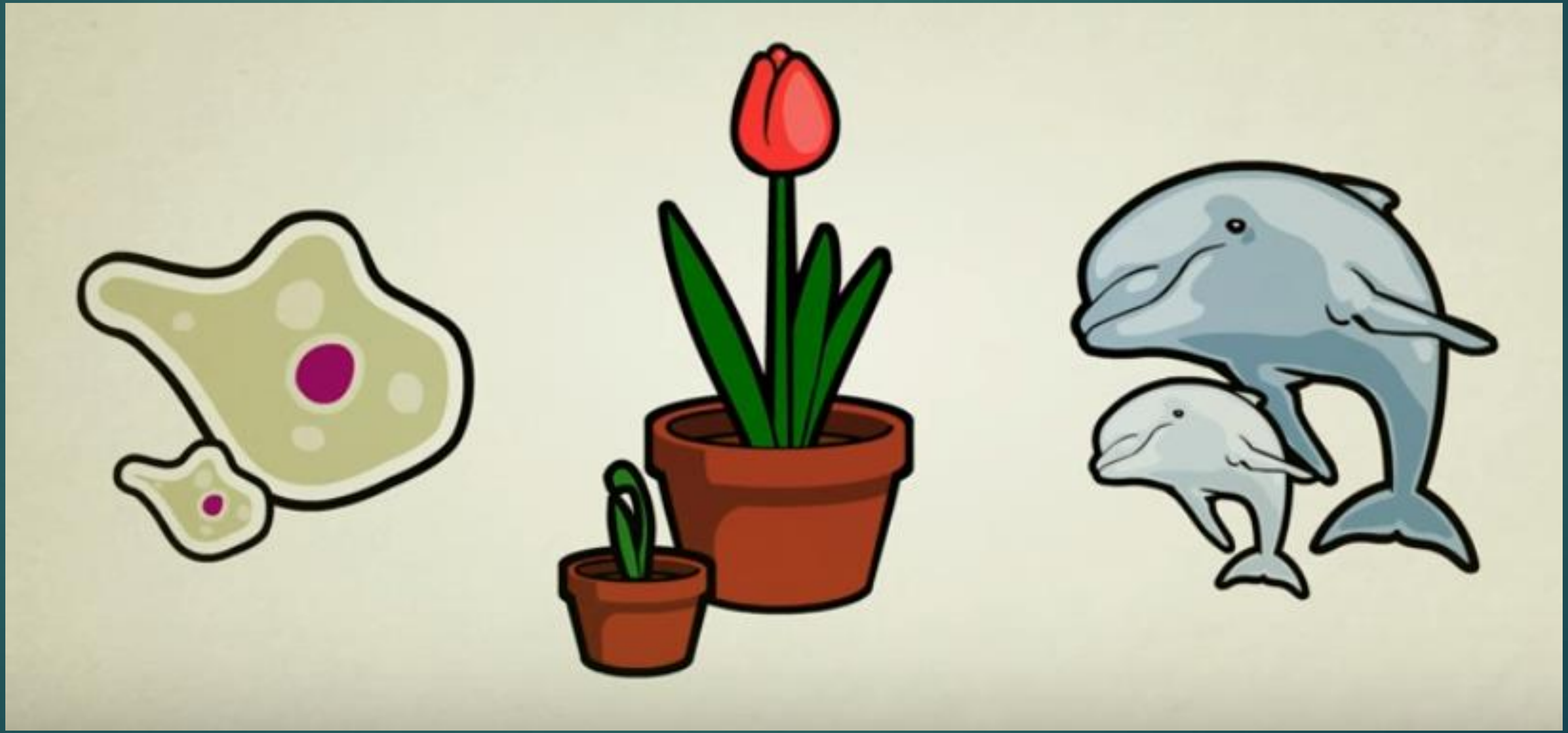
Darwin’s tagged finches from Galapagos

But Alfred Wallace’s were more colorful.

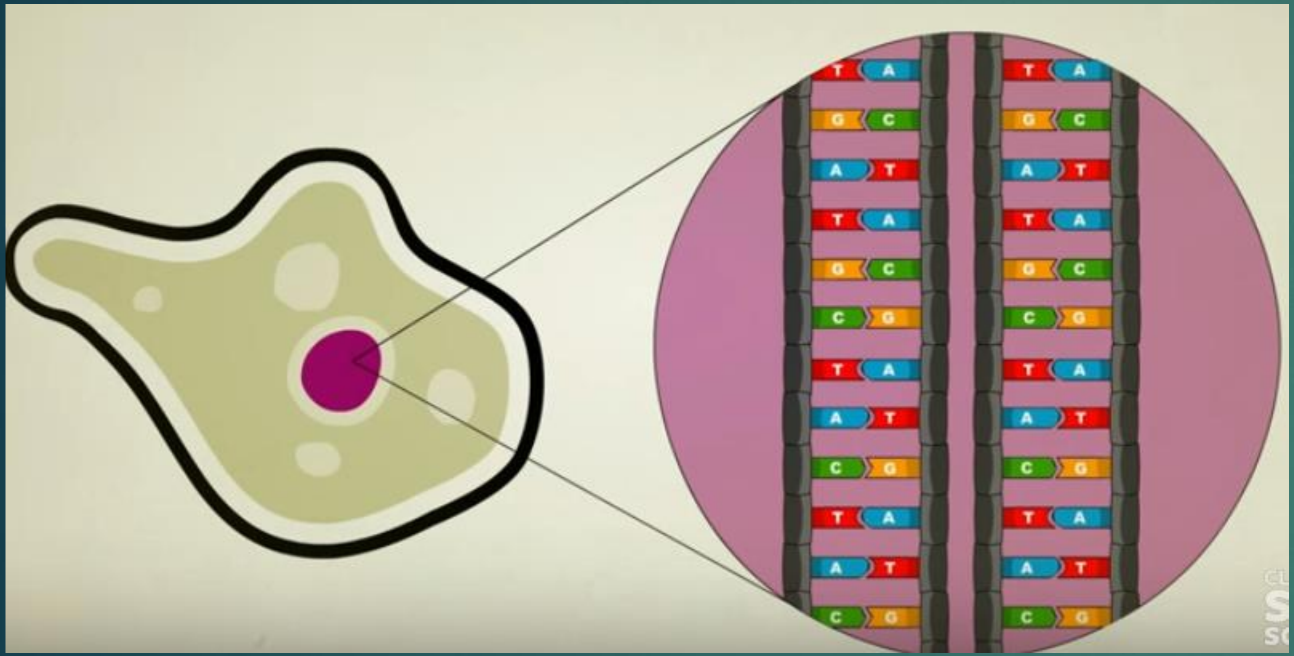
Wallace found more colorful birds

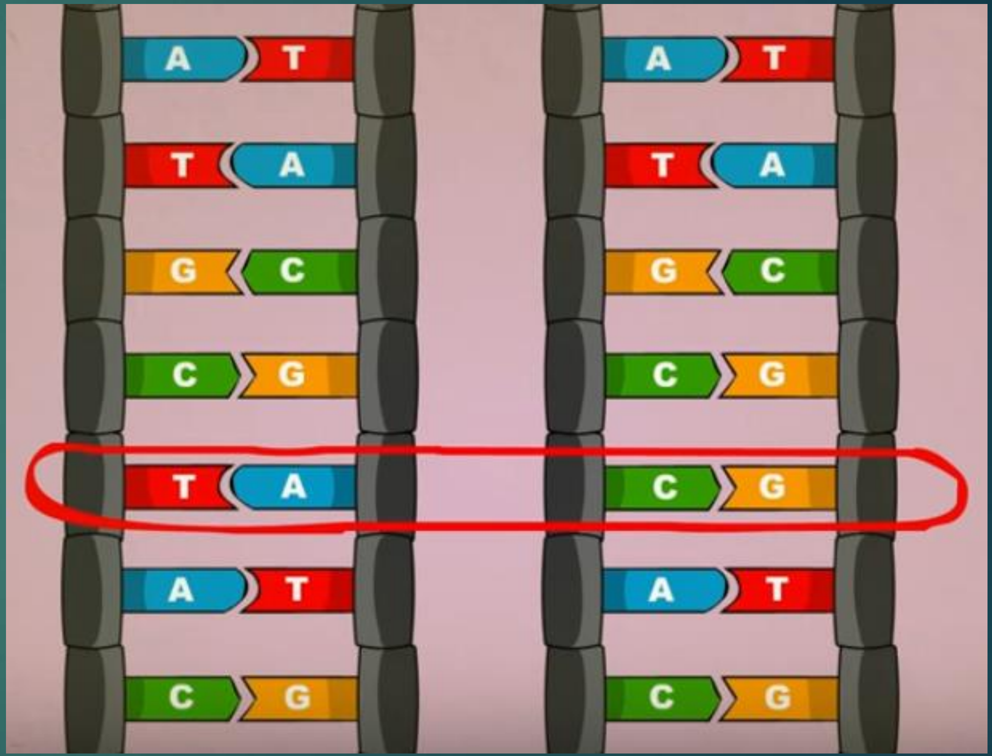
What is evolution

- 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

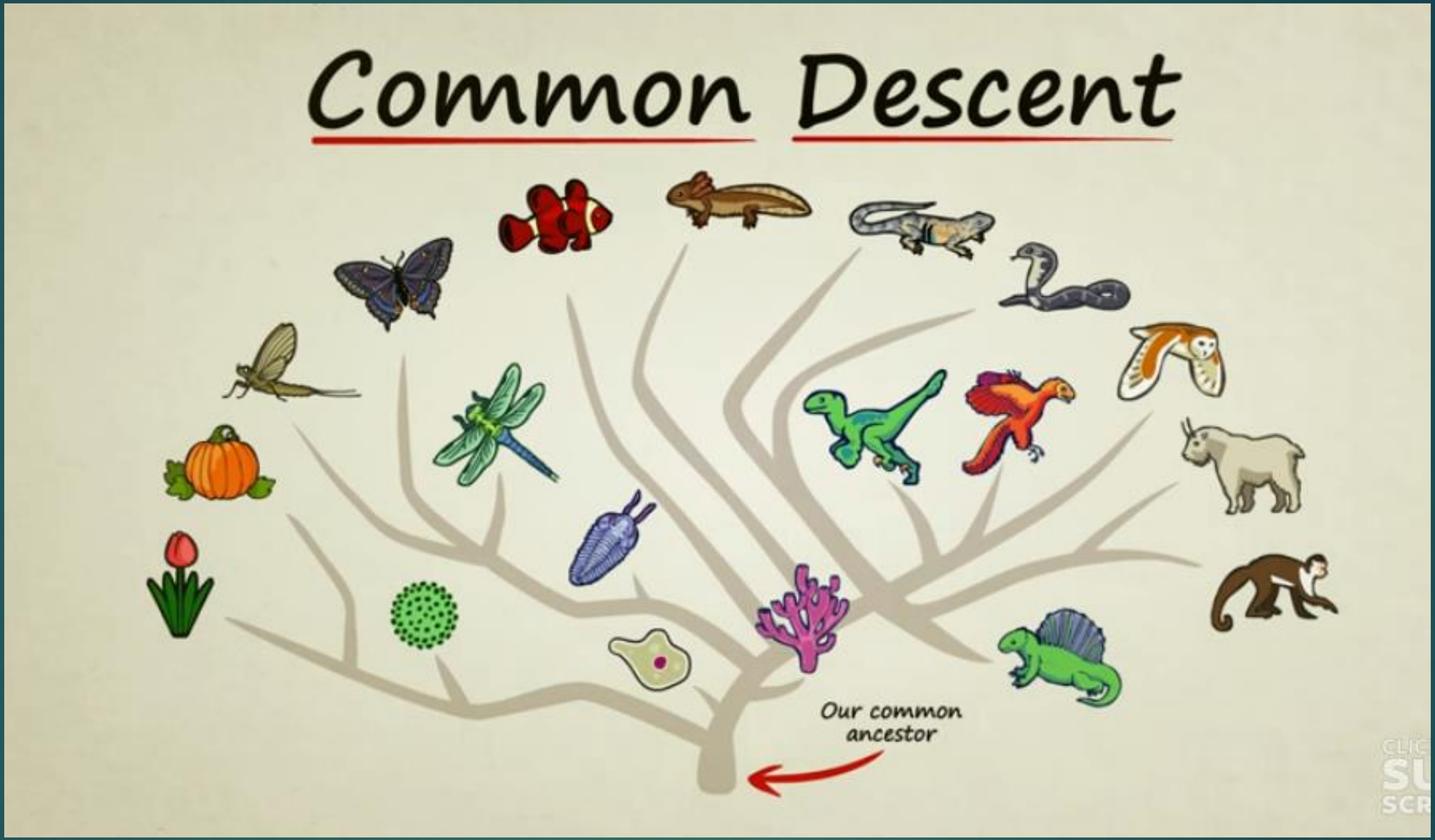




Small variations accrue over generations

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

Theory of natural selection was answer to a problem:

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

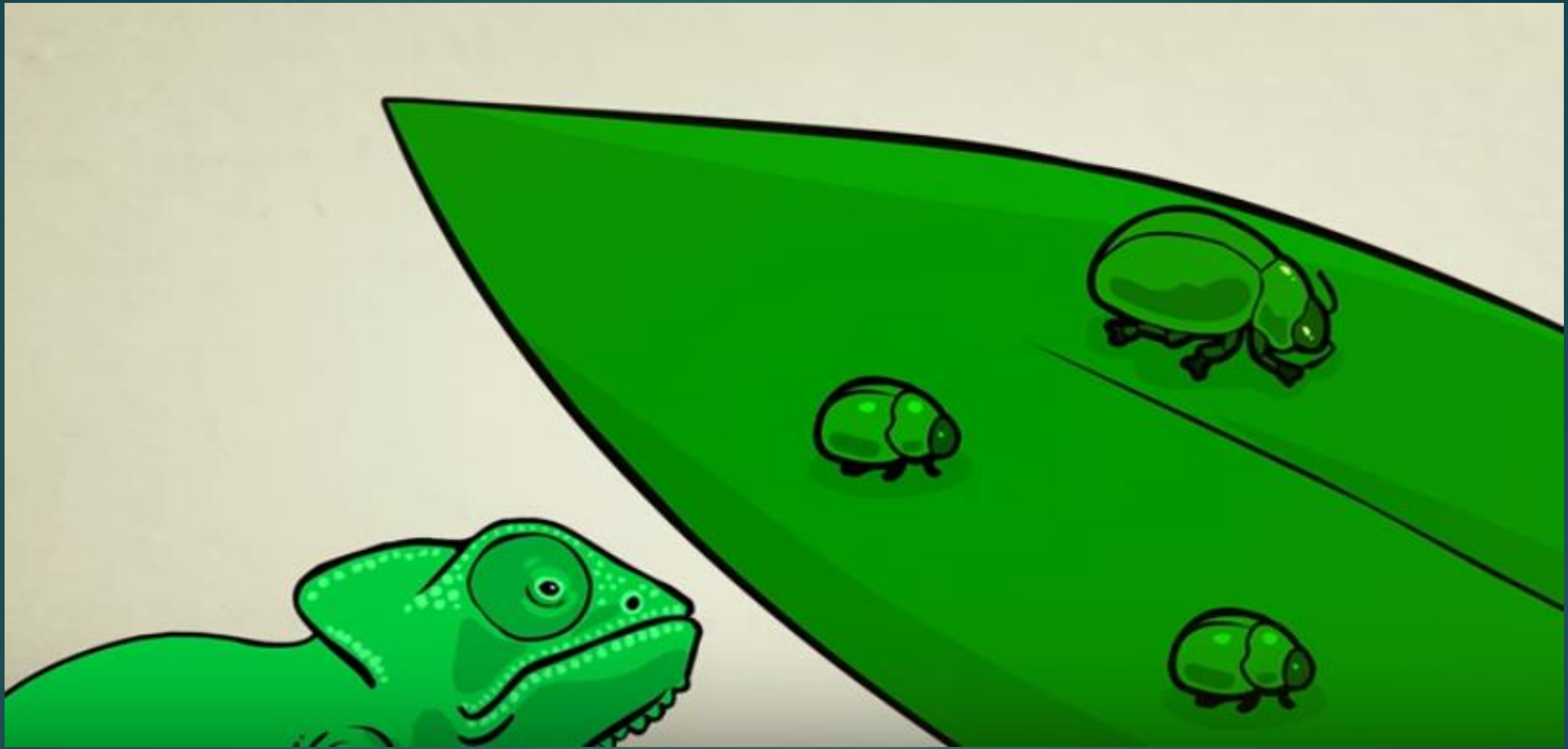
Artificial selection: The mustard family, Brassicaceae

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

2 - Evolution by natural selection

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.

- Genotype: inherited package of an organism; DNA and developmental plan

- Phenotype: What you see of an organism; anything that we can observe, measure, or record about an organism. It reflects not just the genotype but how that genotype has developed through time. The downstream development of the genotype. We generally think of natural selection as acting on the phenotype. We generally think of natural selection as shaping phenotypes, and thereby indirectly shaping genotypes.

- 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. i.e. milk digestion: changes in the genotype that changed the adult phenotype that allowed for the digestion of milk, suddenly became favored. A mutation (lactose tolerance) only was favored when environment had cows and cheese.

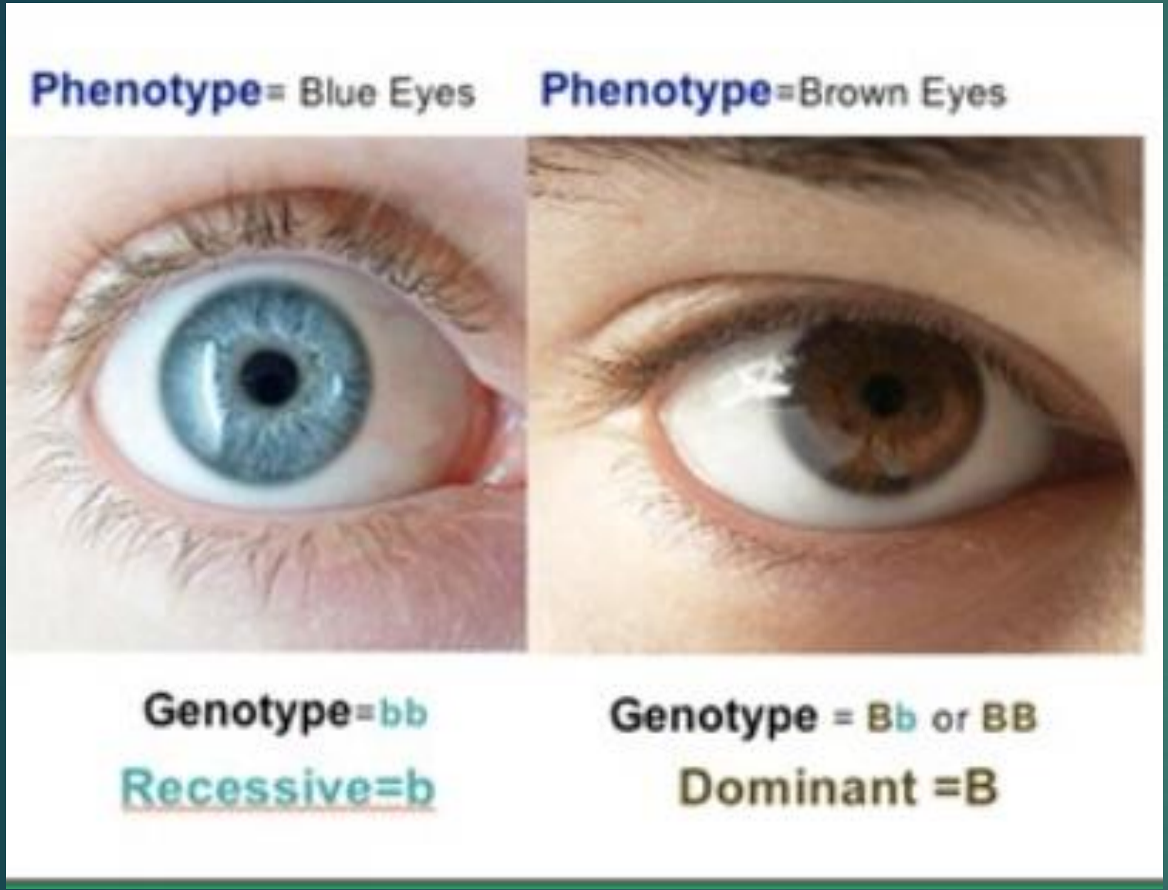
NS: phenotype, genotype, and environment.

- 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

Evolution is not random; nor is Natural selection

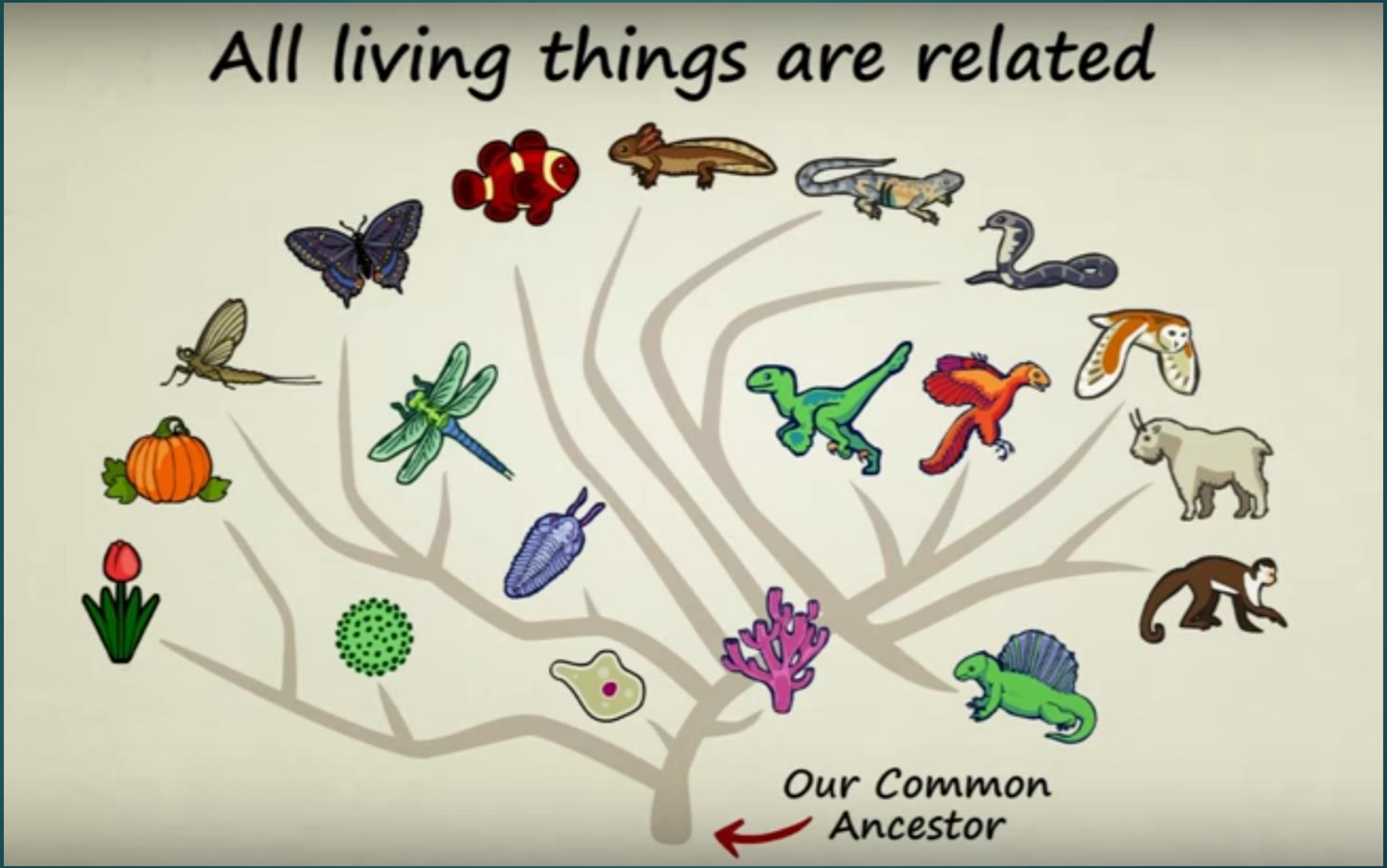
- Evolution is not a random process.

- The genetic variation on which natural selection acts may occur randomly, but natural selection itself is not random at all.

- Heritable variation is generated spontaneously by random processes of mutation and recombination. Arises in same way in either the absence or presence of selection.

- Variation precedes selection. As Dawkins has said, natural selection is the non-random survival of random variants.

1 - All life is related by common descent



https://www.youtube.com/watch?v=lIEoO5KdPvg

Evolution

- **Evolution (descent with modification)** is the change in heritable traits of biological populations over successive generations.
- Evolutionary processes give rise to diversity at every level of biological organization.
- All life on Earth originated through common descent from a last universal ancestor that lived approximately 3.5–3.8 billion years ago.
- It is a random process. There is no innate progress. There is no purpose in evolution.

Evolution Basics

- Through completely natural processes, living things evolve to better survive and reproduce in their specific environments
- All living things on earth are evolutionarily related in a single evolutionary tree, evolving from common ancestor

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

Evolution as tweaks

- Evolution works through the randomness of mutations followed by the non-randomness of selection, all of this acting on a body form with an established structure that can be modified only through small tweaks and tugs.
- Evolution is a tinkerer: uses the old to make the new
- There many examples of poor design in evolution: near sightedness, inoperative GULO gene that would produce Vitamin C
- The argument from poor design goes back to Darwin himself and we've discovered thousands of more examples since then. Poor design is definitely evidence for an evolutionary past,

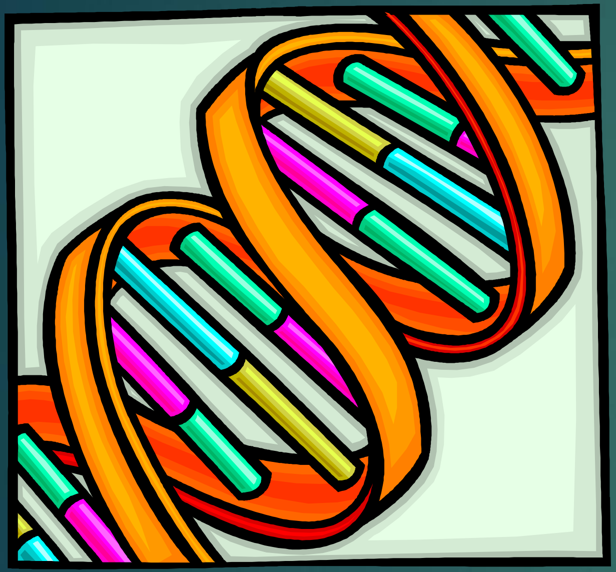
Evolution

- Evolution by natural selection is a process inferred from three facts about populations:
  - 1) more offspring are produced than can possibly survive,
  - 2) traits vary among individuals, leading to different rates of survival and reproduction, and
  - 3) trait differences are heritable.
- Excess population growth drives the competitive struggle. Because less successful competitors produce fewer surviving offspring, the useless or negative variations tend to disappear, whereas the useful variations tend to be perpetuated and gradually magnified throughout a population.
- Evolution does not happen to individuals – it happens to populations of organisms
- It is a random process. There is no innate progress. There is no purpose in evolution.

Theory of Evolution

- Two big ideas, not just one, are at issue:
  - the evolution of all species, as a historical phenomenon; a question of what happened
  - natural selection, as the main mechanism causing that phenomenon; a question of how
- The gist of the concept is that small, random, heritable differences among individuals result in different chances of survival and reproduction—success for some, death without offspring for others—and that this natural culling leads to significant changes in shape, size, strength, armament, color, biochemistry, and behavior among the descendants.

Natural Selection:



- Darwin knew nothing of genes, but what he did have were two observations and a little inference that provided the motive force for evolution.
- Darwin did not understand mechanism of inheritance

Natural Selection: 2 observations

Observation 1: Organisms generally have more offspring than can survive to adulthood.

Observation 2: Offspring are not identical. There is variation in their appearance, size, and other characteristics.

Inference: Those organisms that are better adapted to their environment have a greater likelihood of surviving to adulthood and passing these characteristics on to their offspring.

Darwin’s Postulates

- Infinite ability of populations to grow, but finite ability of environments to support growth

- Within populations, organisms vary in ways that affect ability to survive and reproduce

- Variations are transmitted from parents to offspring

- Natural selection – evolution by variation and selective retention; because resources are finite & because of random variation, some individuals will be better than others at accessing those resources & will produce more surviving offspring in same species; advantage = increase in animal’s “fitness”

Theory of Evolution

- Darwin's assumptions:
  - Life was old
  - Life started out with one or few simple organisms and evolved into all life today
  - Natural selection was process that produced new change

- Evolution: The process of change over time
  - Specifically, a change in the frequency of a gene or allele in a population over time

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

- "Best adapted" = "as well adapted as your competitors"; Natural selection's only criterion is that something works, not that it works as well as it might. Botched jobs are common.

- 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 <u>unique combination of inherited traits (phenotype)</u>.
  - Adaptation: an inherited trait that increases an organism's chances of survival

Variation

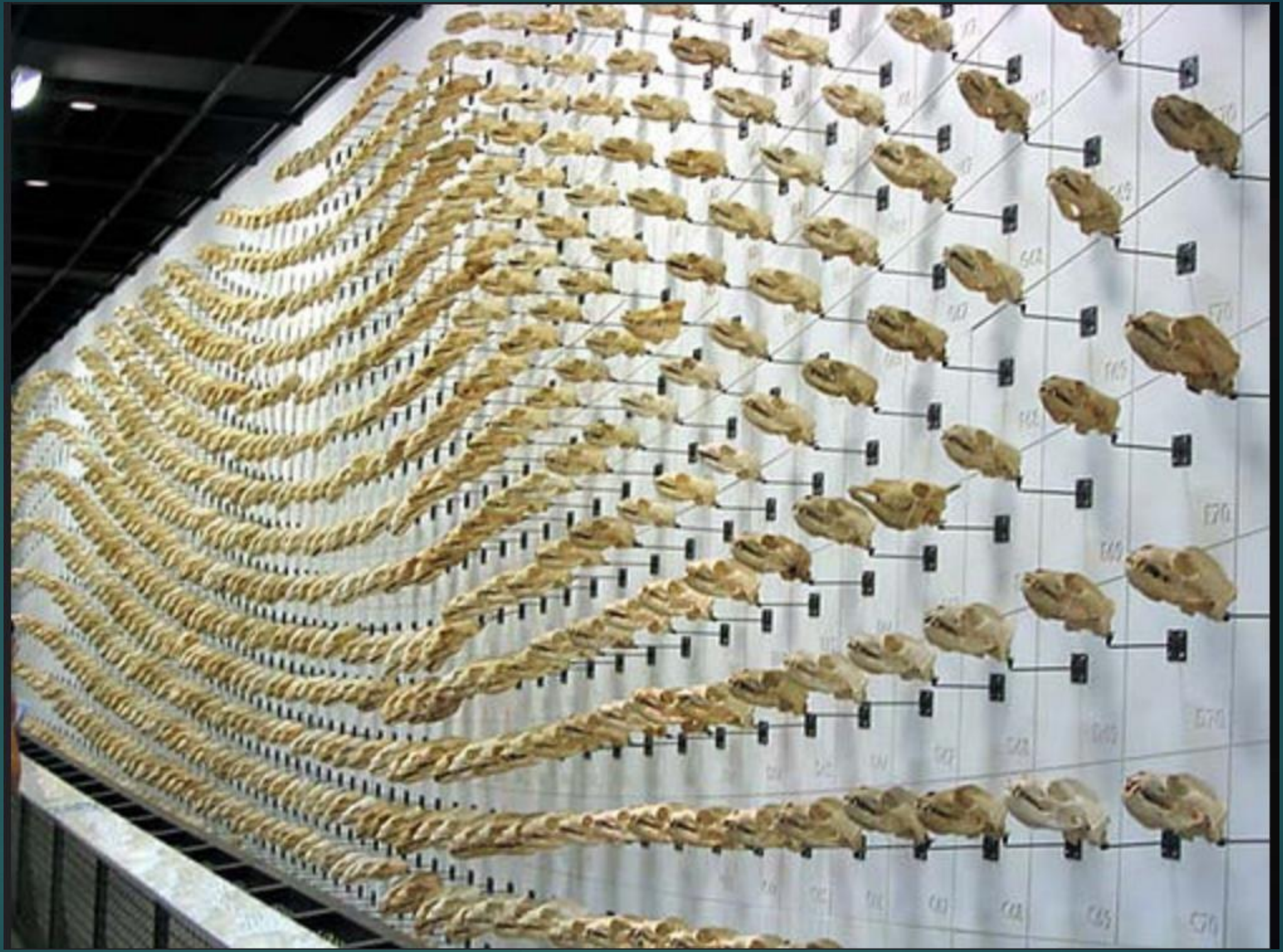
- Nevertheless, some mutations will persist and increase genetic variation within a population.

- Variants of a particular gene are known as alleles.

For example, the one of the genes for hair color comprises brown/blonde alleles.

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

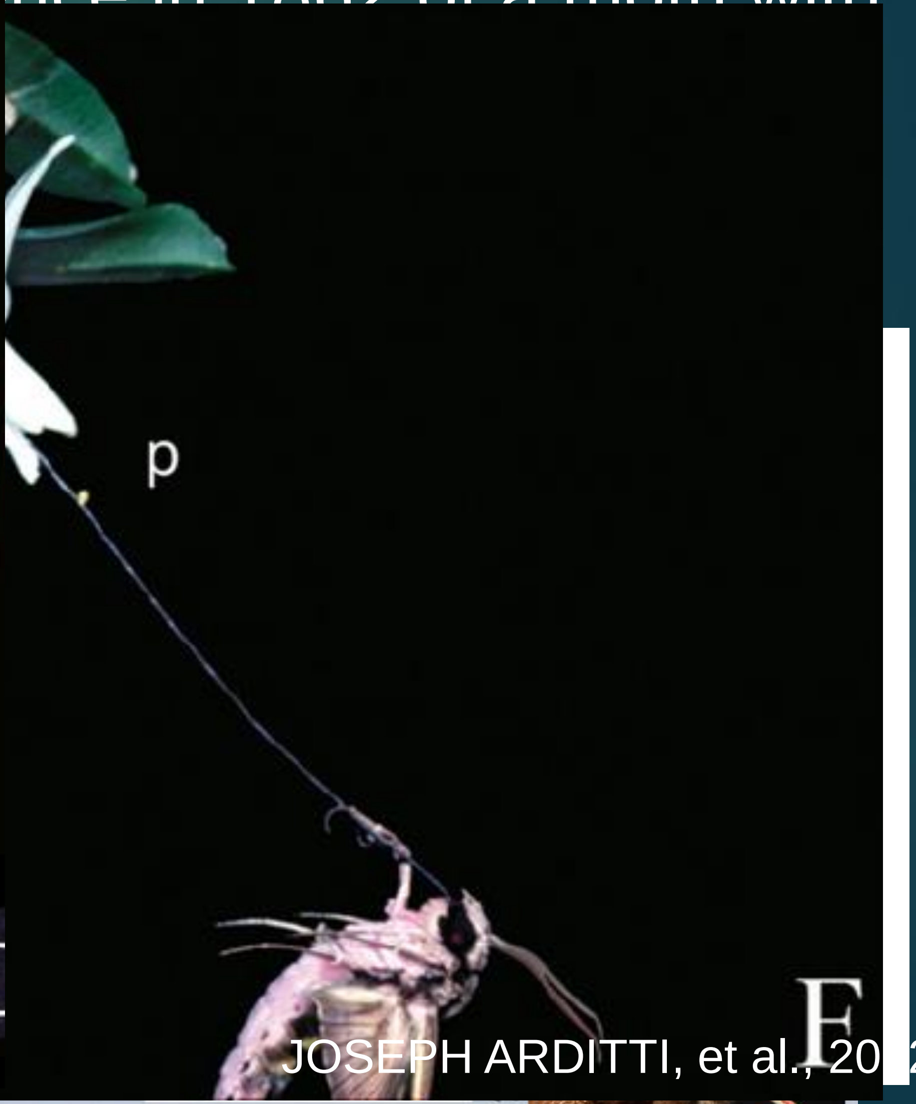
- The individuals with the most adaptable traits will survive and have the opportunity to pass on it’s traits to offspring.
- Principle of local adaptation: in a particular location, a trait may help you survive better
- Natural selection acts on the phenotype (physical characteristics), not the genotype (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

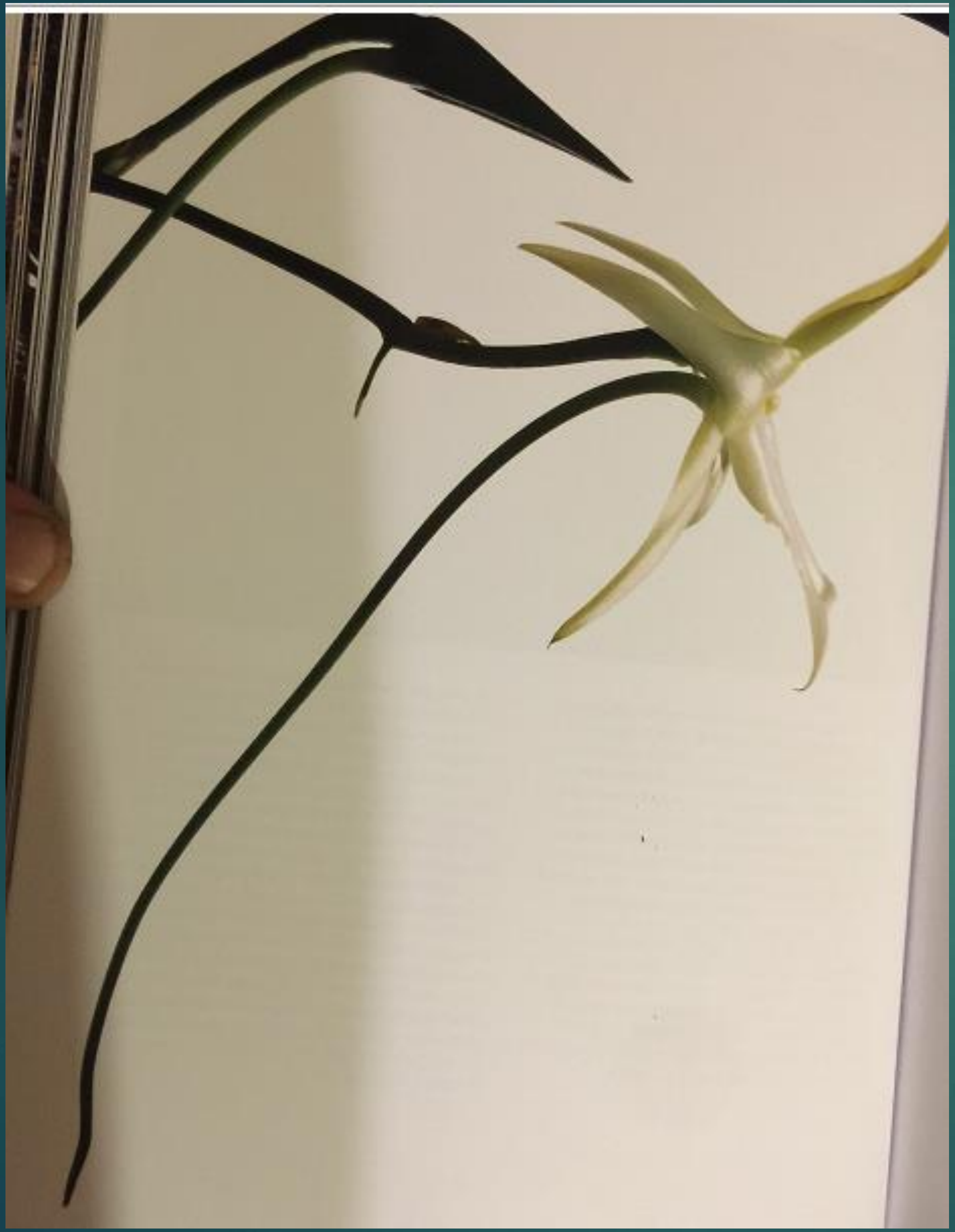
- Darwin received a Madagascar orchid (*Angraecum sesquipedale)* with 11 inch nectar r… …nce in 1862 of a moth with



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

JOSEPH ARDITTI, et al., 20[illegible]2

Natural Selection: A Darwin tale of a proboscis

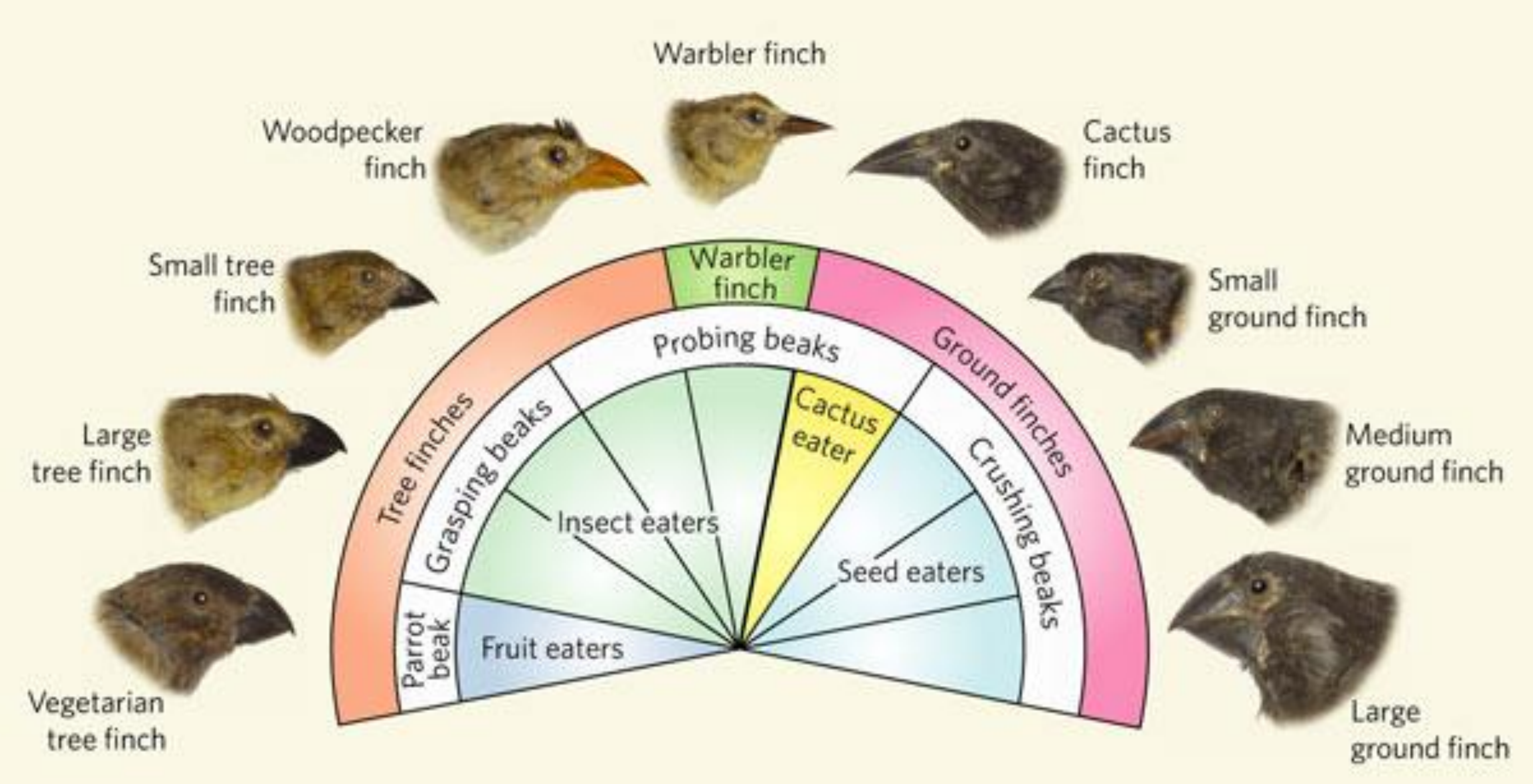


Descent with Modification

- Descent with Modification – each living species has descended, with changes, from other species over time.

- Common Descent – all living organisms are related to one another

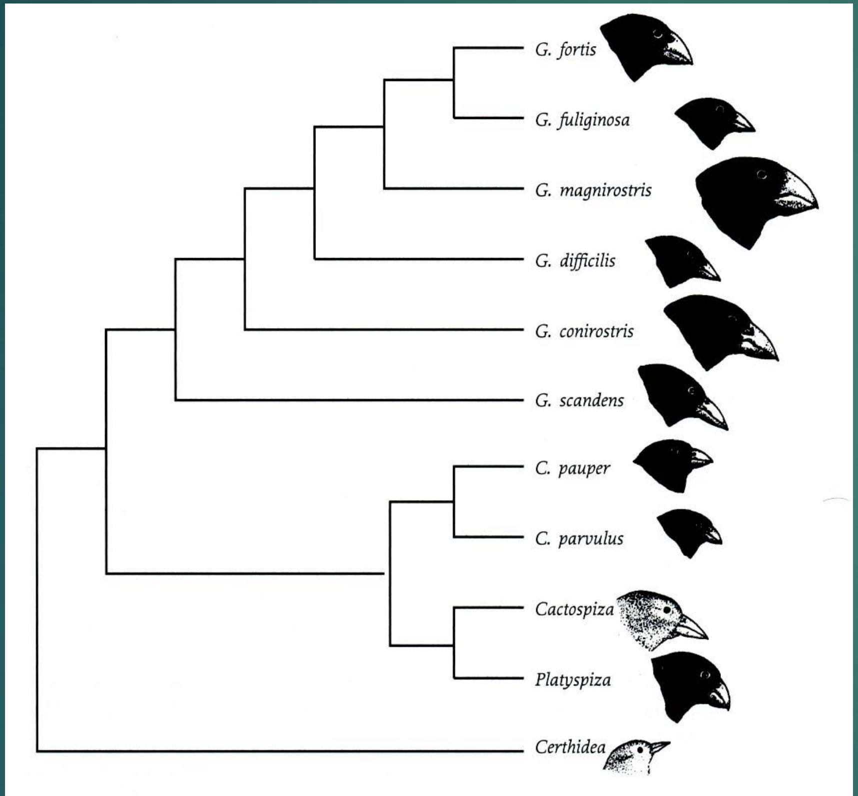
Darwin's Finches



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

Some of the Finches of the Galapagos

Rates of Evolutionary Change



- 14 living species in Galápagos
- All descended from single species within last half million years

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.

Don’t need millennia: examples of rapid evolution

- Mosquitoes that colonized the London Underground in 1863 are now new species
-
- Chinook salmon from Alaska to California needed just a human generation to become smaller and shorter-lived due to commercial fishing in the 1920s
- Risk of Death: within four years (6-8 generations) — male guppies had significantly changed their reproductive patterns when put in a stream without predators; when predators are introduced, the guppies adapted by maturing at an earlier age. “The risk of death alters the ways organisms allocate resources for survival

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

What Darwin did not know: Genetics

- From 1856-63, a monk called Gregor Mendel cultivated 29,000 pea plants to investigate how evolution worked i.e., how characteristics were passed down the generations.

- He figured out the basic principles of genetics. He showed that offspring received characteristics from both parents, but only the dominant characteristic trait was expressed. Mendel's work only came to light in 1900, long after his death

en.wikipedia.org/wiki/Image:Mendel.png
en.wikipedia.org/wiki/Image:Doperwt_rijserwt_peulen_Pisum_sativum.jpg

Science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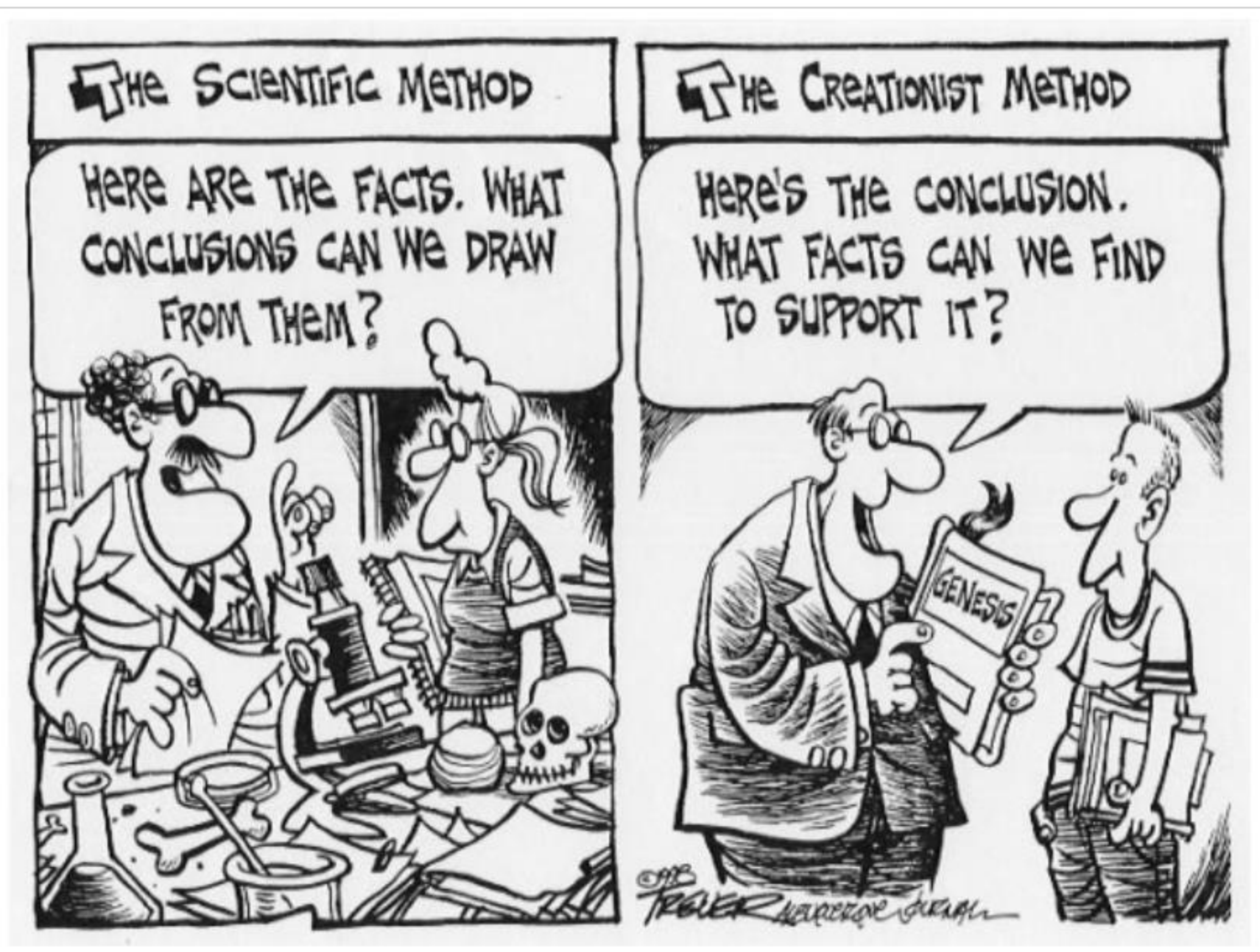
undsci.berkeley.edu

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.

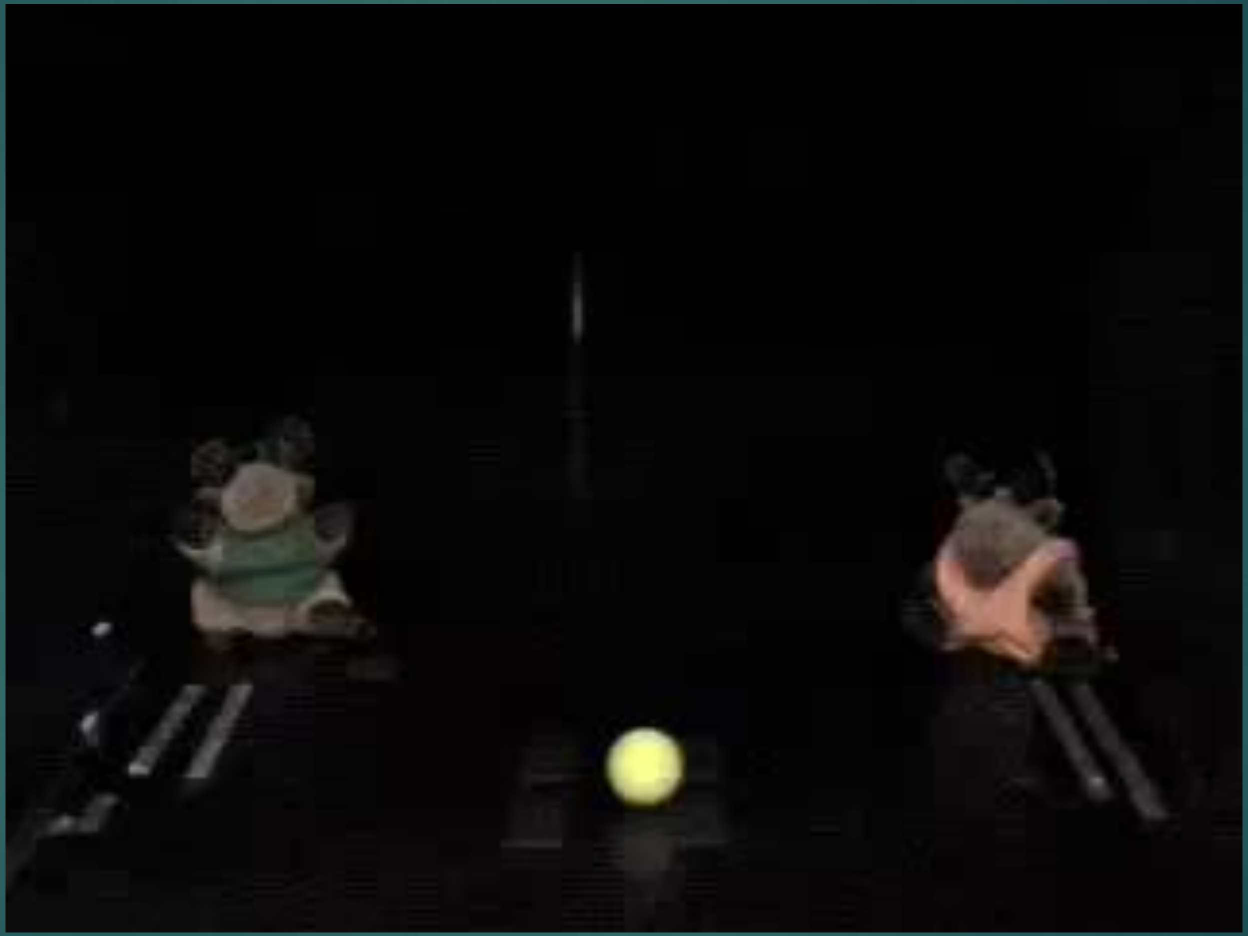
What about God?

- 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.”

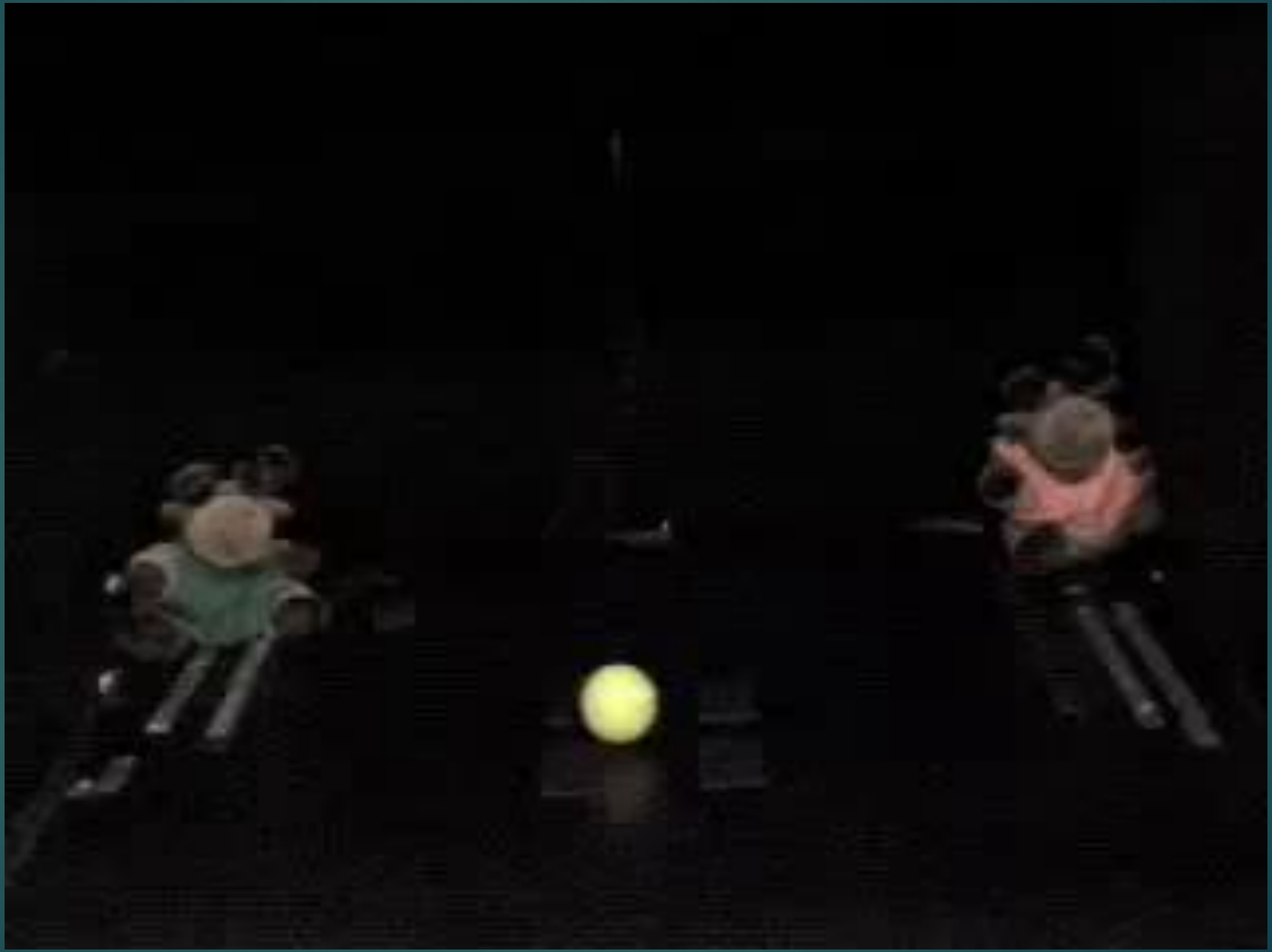
- See:
  - *Faith vs. Fact* – Jerry Coyne
  - *God's Word or Human Reason?: An Inside Perspective on Creationism*. 2016 - Kane, J., Willoughby, E., Keesey, T.

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).

Infants have innate moral sense

- Moral sense of right (preferring helping puppets) and wrong (rejecting hurting puppets) emerges in toddlers between three and 10 months of age, far too early to attribute to learning and culture.
- In Bloom's laboratory, a one-year-old baby watched puppets enact a morality play.
- One puppet rolled a ball to a second puppet, who passed the ball back. The first puppet then rolled the ball to a different puppet, who ran off with the ball. The baby was next given a choice between taking a treat away from the "nice" puppet or the "naughty" one.
- As Bloom predicted, the infant removed the treat from the naughty puppet—which is what most babies do in this experiment.
- But for this little moralist, removing a positive reinforcement (the treat) was not enough. "The boy then leaned over and smacked this puppet on the head,"

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."

Creationist Claims

- "Evolution is only a theory"

- Actually, evolution is both a fact and a theory
  - Fact is "an observation that has been repeatedly confirmed and for all practical purposes is accepted as 'true.'", i.e. fossil record
  - According to the National Academy of Sciences (NAS), a scientific theory is "a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses."
  - No amount of validation changes a theory into a law, which is a descriptive generalization about nature.
  - So when scientists talk about the theory of evolution—or the atomic theory or the theory of relativity, for that matter—they are not expressing reservations about its truth.

Evolution and the Vatican

- 1950: Pope Pius XII – Evolution is a valid scientific approach to the development of humans
- 1996: Pope John Paul II reiterates this
- 2008: The theory of evolution is compatible with the Bible
- Theistic evolution: accepts evolution as a scientific theory and sees no reason why God could not have used a natural evolutionary process in the forming of human species

Creationist Claims

- "Evolution is unscientific, because it is not testable or falsifiable."
  - Microevolution (changes within species over time) and macroevolution (how taxonomic groups above the level of species change - Fossil record and DNA – relationships of organisms)
  - Predictions: progressively less apelike and more modern humans in fossil record & none during era of dinosaurs
  - Scientific publications disputing evolution are all but nonexistent; few antievolution manuscripts are even submitted to scientific journals.

  - "Living things must be products of intelligent design, because natural selection could not produce some complex beings."
  - Evolution of camera-type eye
  - Convergent evolution (unrelated organism develop trait due to similar environmental need)

Misconceptions about evolution

- Everything is an adaptation produced by natural selection: male nipples = along for ride on selected DNA section
- Natural selection is the only means of evolution: 100 mutations in embryo, genetic drift
- Natural selection leads to ever-greater complexity: cave fish lose their eyes
- Evolution produces creatures perfectly adapted to their environment: You don’t have to be perfectly adapted to survive, you just have to be as well adapted as your competitors. Evolution is far more likely to reshape existing structures than to throw up novel ones. The lobed fins of early fish eventually became our fingers.
- Evolution always promotes the survival of species: evolution sometimes results in individuals or populations becoming less fit and may occasionally even lead to extinction. Detrimental mutations may accumulate faster than natural selection can eliminate them

Example of potential extinction: In 1991, South Africa eradicated feral cats *Felis catus* on its sub-Antarctic Marion Island. Result:

A "scalped" Light-mantled Sooty Albatross on Marion Island; & invasive Marion Island House Mouse which feeds on albatross at night. With no instinctual fear of this mouse, albatross will sit passively while mouse nibbles into its flesh until bird dies

Misconceptions about evolution 2

- <u>It doesn’t matter if people do not understand evolution</u>: any modern society which bases major decisions on superstition rather than reality is heading for disaster; S Africa denies HIV

- <u>“Survival of the fittest” justifies “everyone for themselves”</u>: *The* “fittest” can be the most loving and selfless, not the most aggressive and violent. Fitness may mean the best camouflaged or the most fertile to the cleverest or the most cooperative

Creationist myths:

Evolution must be wrong because the Bible is inerrant
Accepting evolution undermines morality
Evolutionary theory leads to racism and genocide
Religion and evolution are incompatible
Half a wing is no use to anyone
Evolutionary science is not predictive
Evolution cannot be disproved so is not science
Evolution is just so unlikely o produce complex life forms
Evolution is an entirely random process
Mutations can only destroy information, not create it
Darwin is the ultimate authority on evolution
The bacterial flagellum is irreducibly complex
Yet more creationist misconceptions
Evolution violates the second law of thermodynamics

Responses to Creationism

- New Scientist Response: https://www.newscientist.com/article/dn13620-evolution-24-myths-and-misconceptions/

- Mark Isaac: http://www.talkorigins.org/indexcc/list.html

- *The Counter-Creationism Handbook* - Mark Isaac
- *God's Word or Human Reason? An Inside Perspective on Creationism* – J. Kane, E. Willoughby, T. Michael Keesey

- *Science on Trial: The Case for Evolution* - Douglas J. Futuyma

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 <u>not a belief system</u>. It is a <u>scientific hypothesis: a rational acceptance of evidence that can be falsified</u>. It has no role in defining religion or religious beliefs. It is based on evidence.

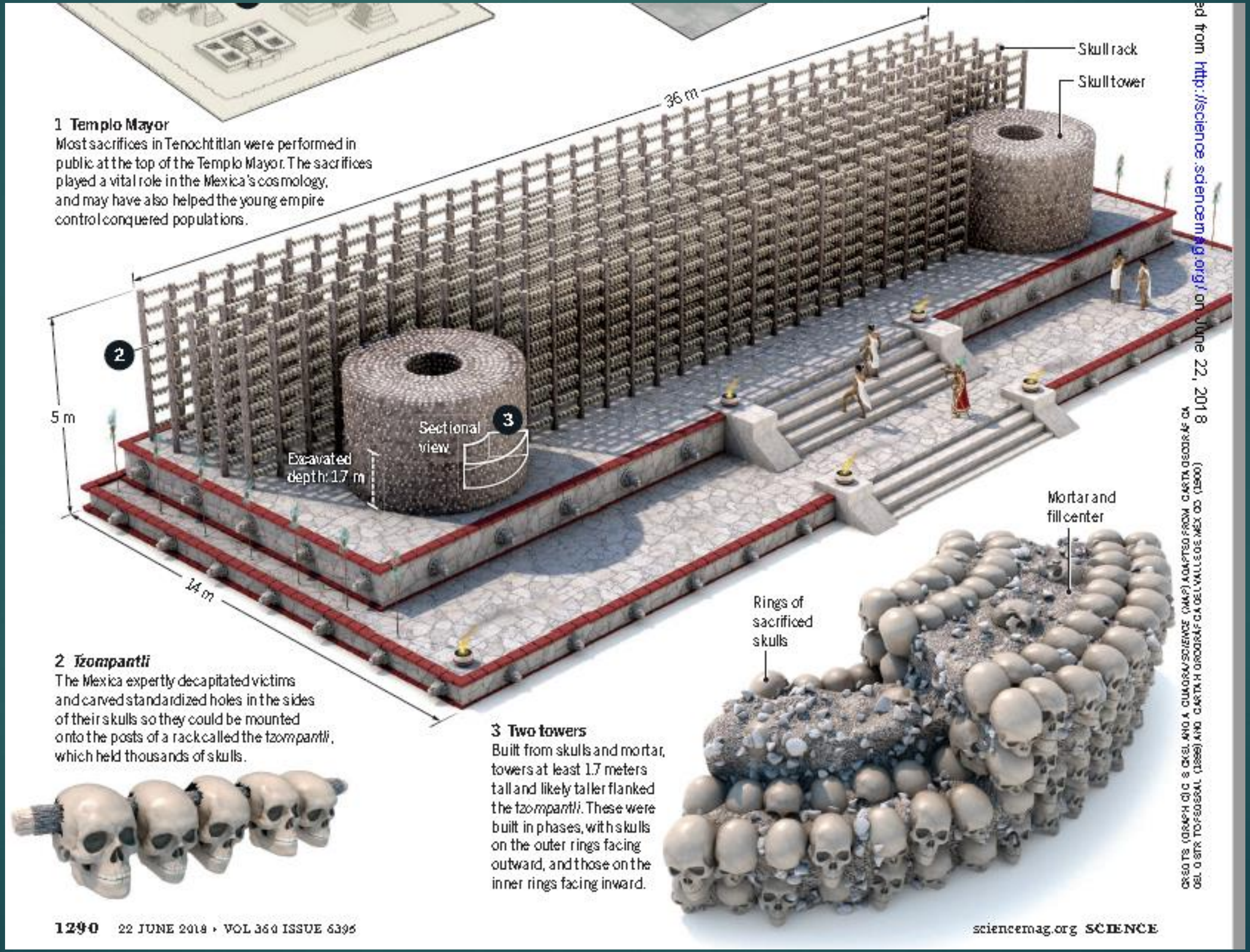
- <u>Evolution is a theory…but you don't get any better than that in science</u>

- <u>There is a lot of religious contention about evolution, but not among scientists or scientific organizations</u>.

- Creationists do not accept evolution.

- 99.9% of scientists believe there is overwhelming evidence of evolution.

We have evolved: The Aztec at Tenochtitlan's *tzompantli & belief* of it *as* a sign of life and regeneration



National Geographic, June 2018

Evidence of evolution

- Bird wings are modified arms and claws; bird evolution from dinosaurs
- Bats have wings based on 5 fingered hand
- Chimps share 98% of DNA with humans
- Mammals evolved from reptile like creatures, who evolved from amphibians, who evolved from fish like creatures, who evolved from segmented worms

Darwin's evidence for evolution

- The evidence that Darwin presented for evolution mostly fell within four categories:
  - biogeography (species distribution)
  - paleontology (fossils)
  - embryology
  - morphology

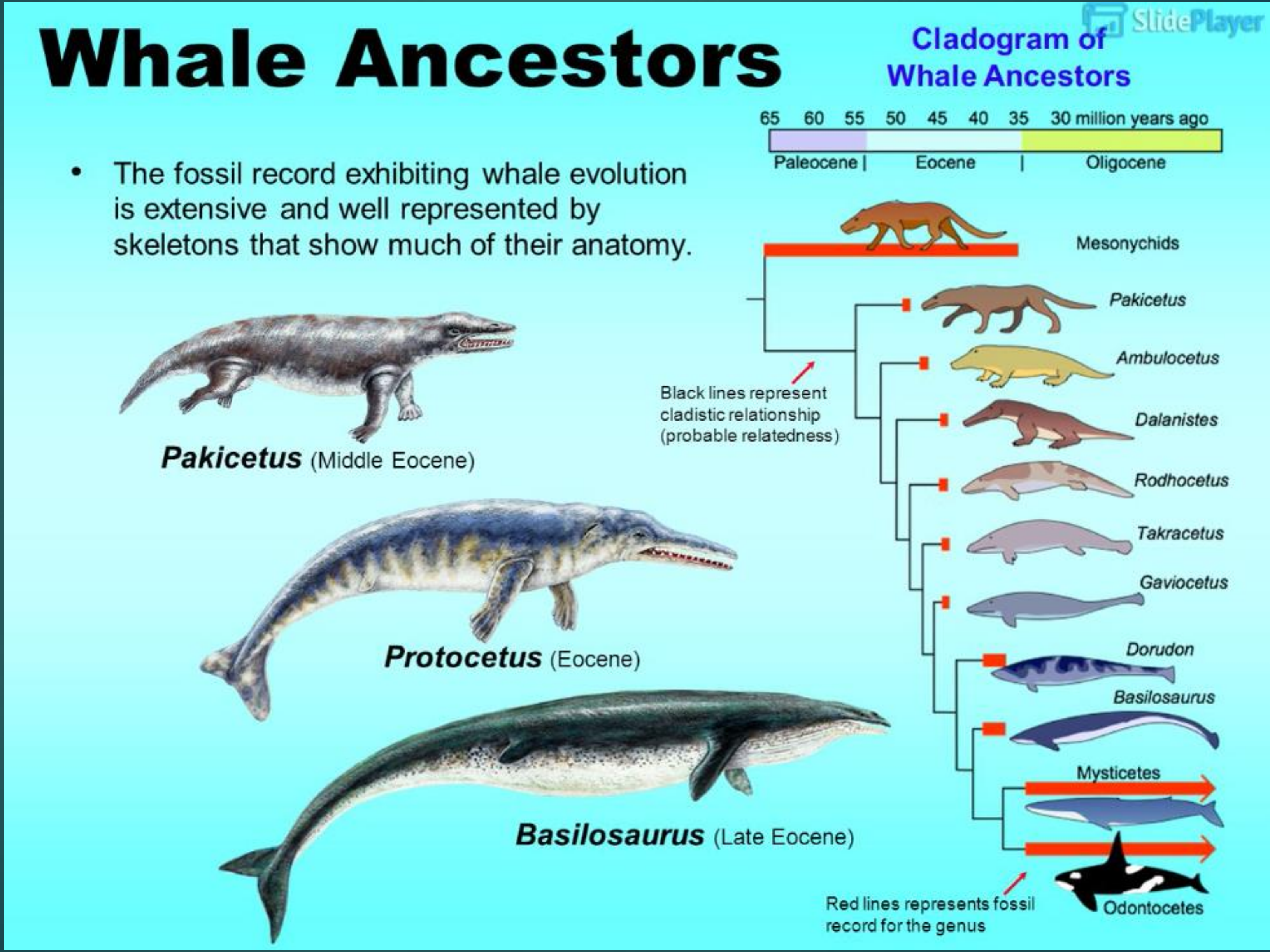
What is the Evidence for evolution

- 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).

Evidence of Evolution

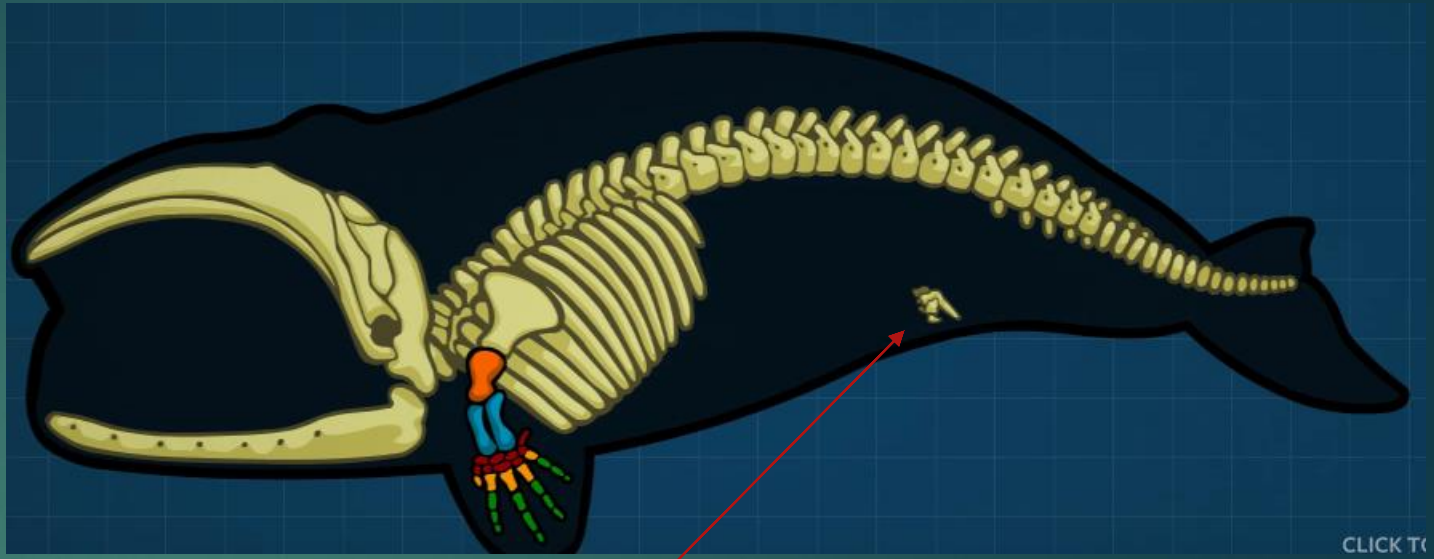
- Multiple independent lines of evidence:
    - Comparative anatomy: similarities of form
    - Embryology & development
    - Fossil Record
    - DNA Comparisons
    - Species Distribution = biogeography
    - Evolution Observed

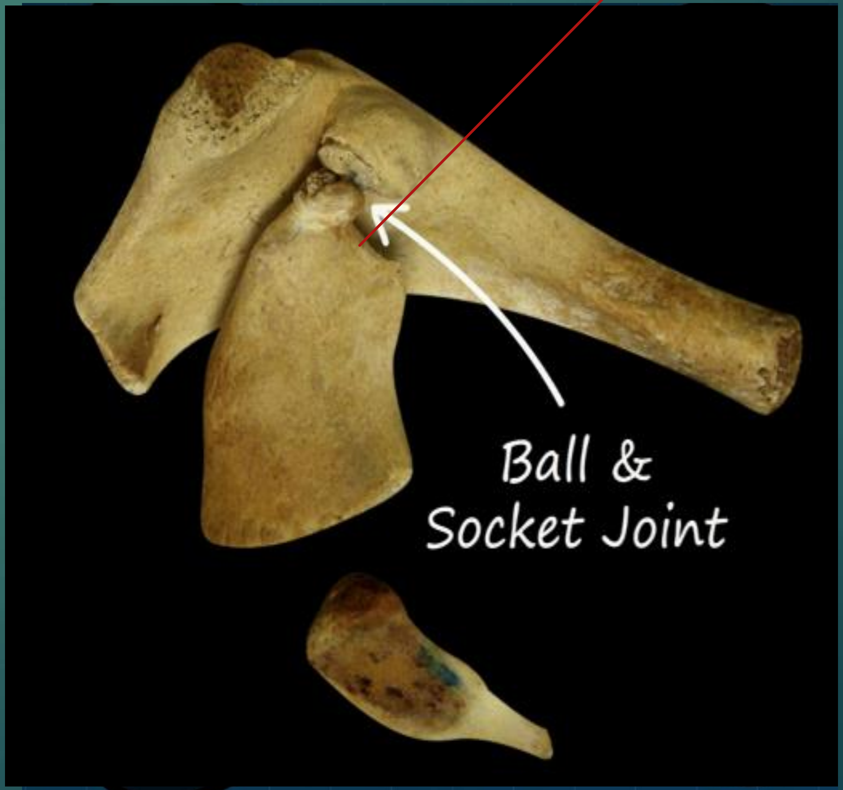
A Whale of a Tale: Lots of transitional evidence of their evolution



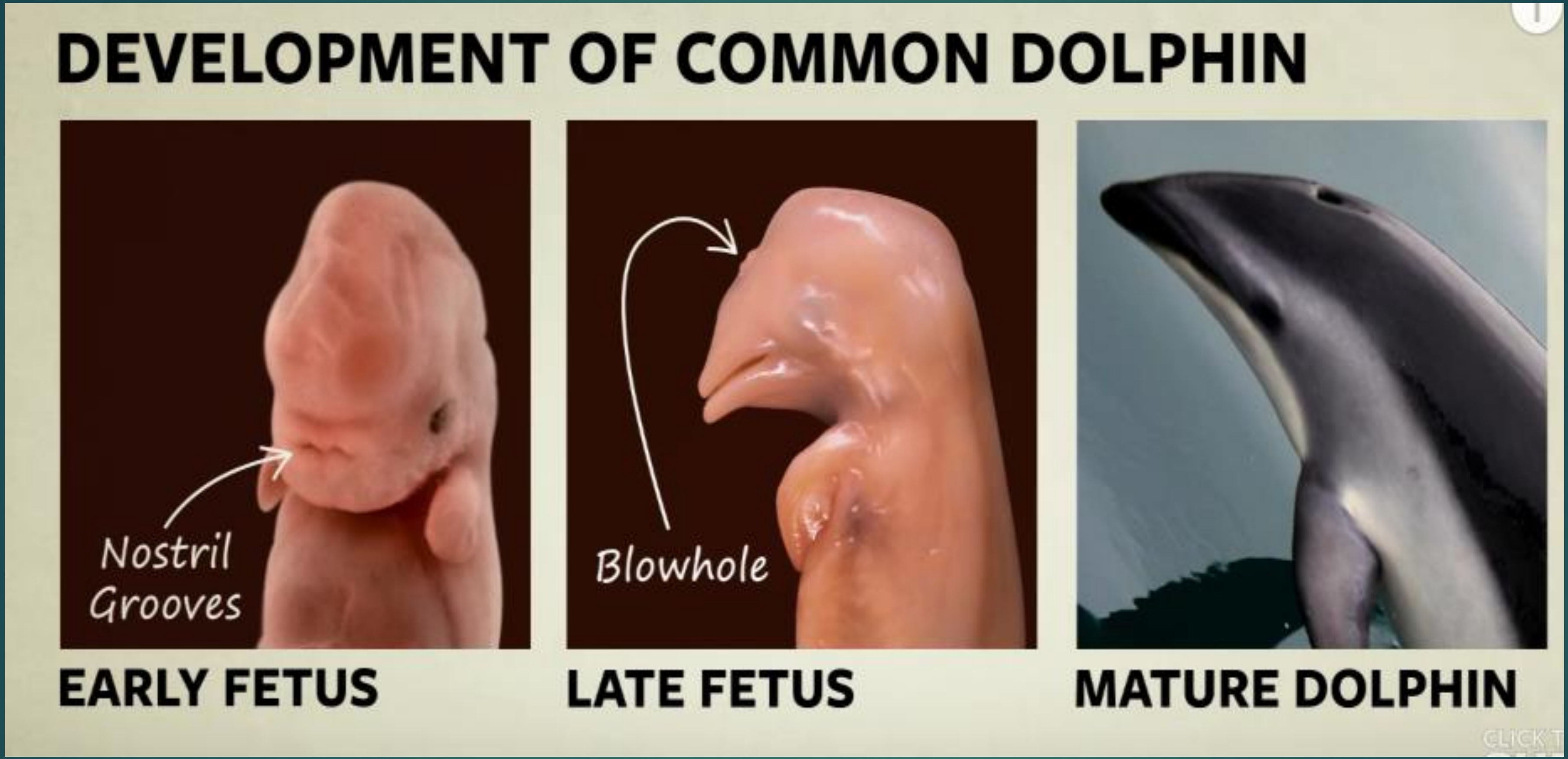
Whales are mammals:
Comparative anatomy

- 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

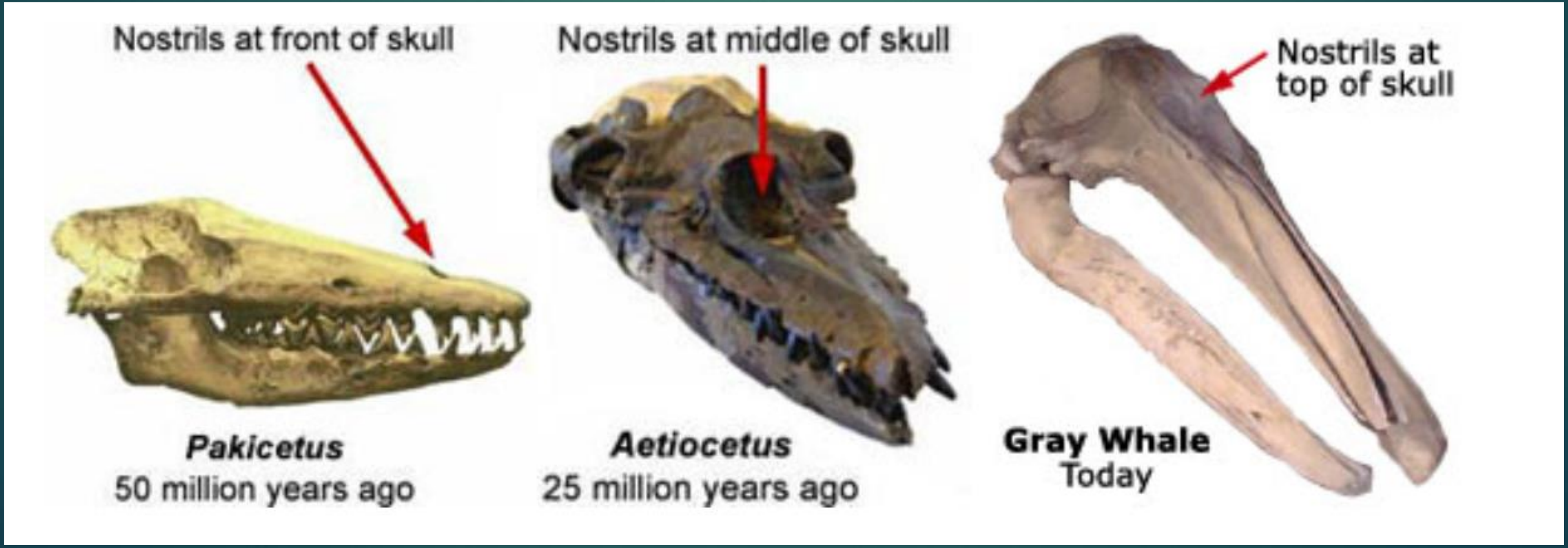


Evolution of nostril placement:
Ancestry of whales were once land animals

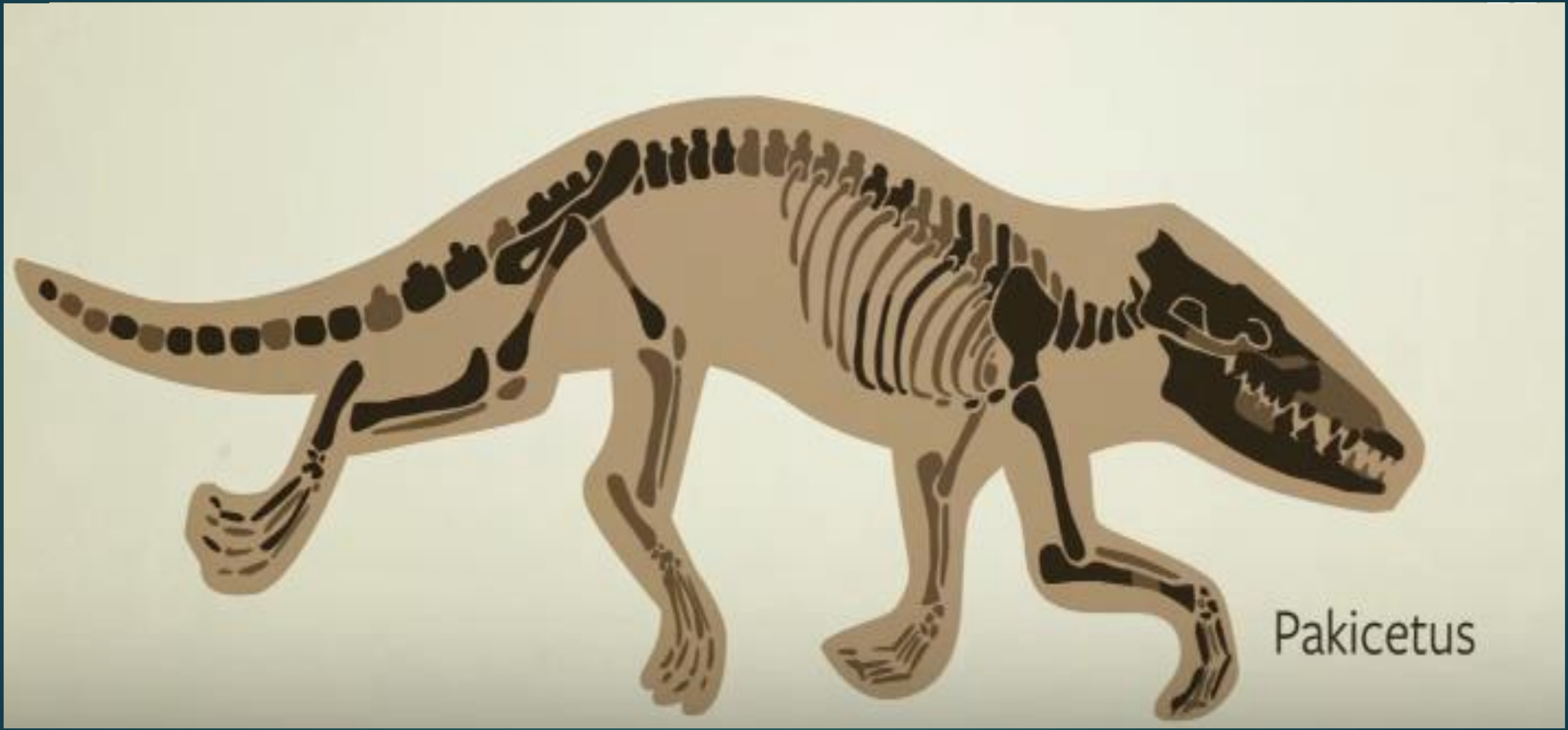
Transitional Forms

Pakicetus: 50 Ma; land mammal

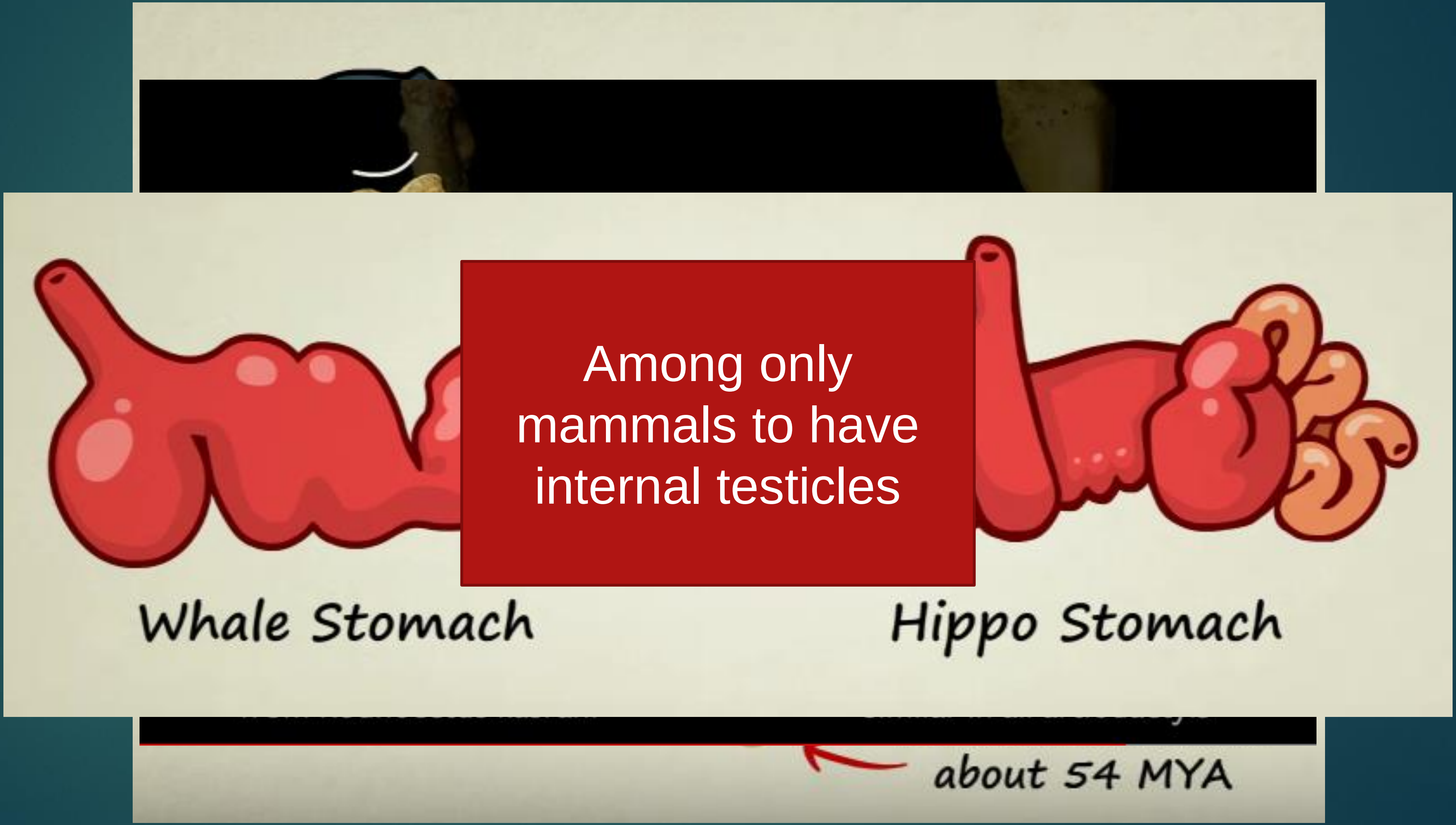
- Basilosaurid = 40 Ma, complete set of leg bones



Whales: Fossil Record – whales evolved from land mammal



Whales: DNA evidence – What is closest species?

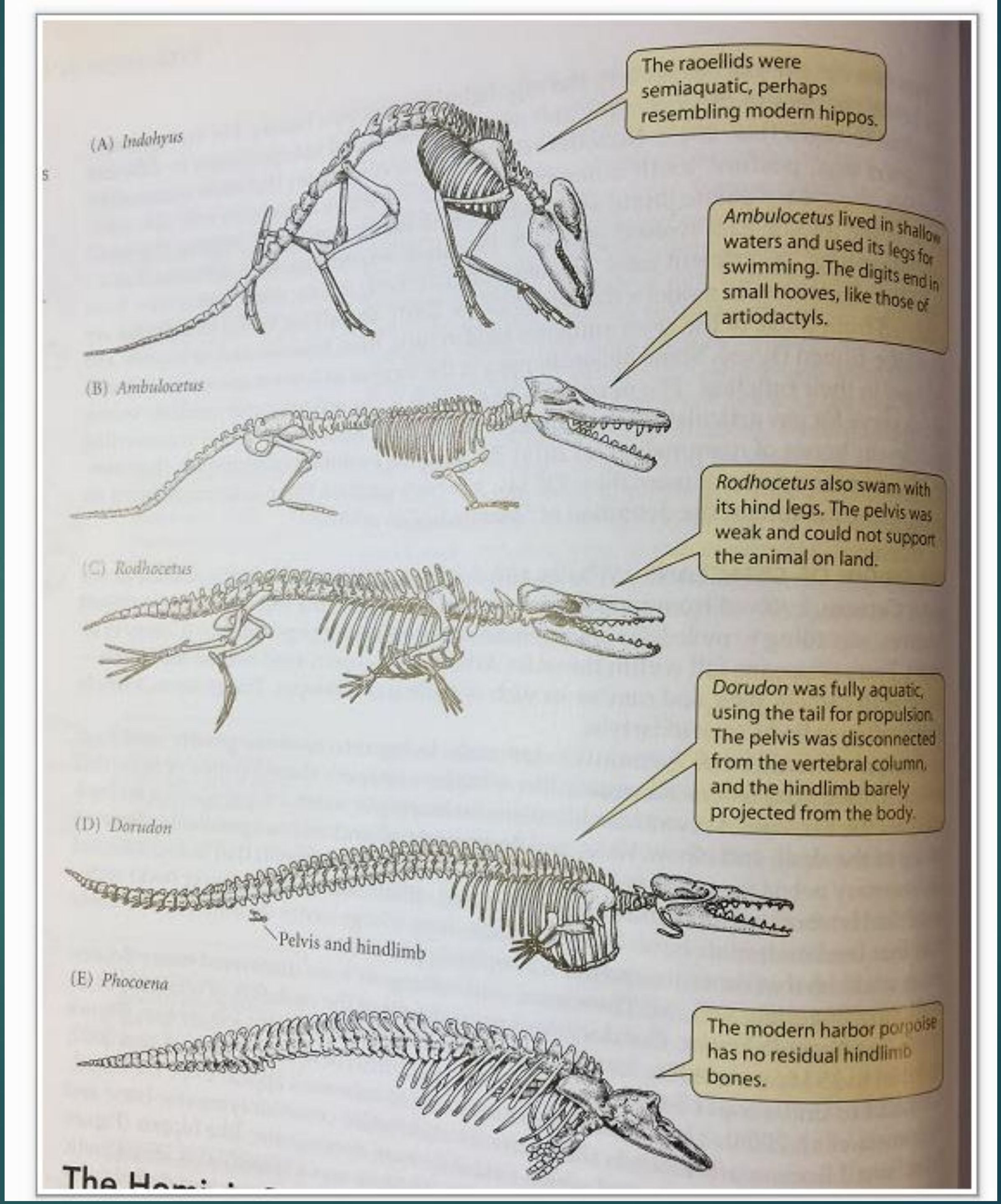


Among only mammals to have internal testicles

Cetaceans

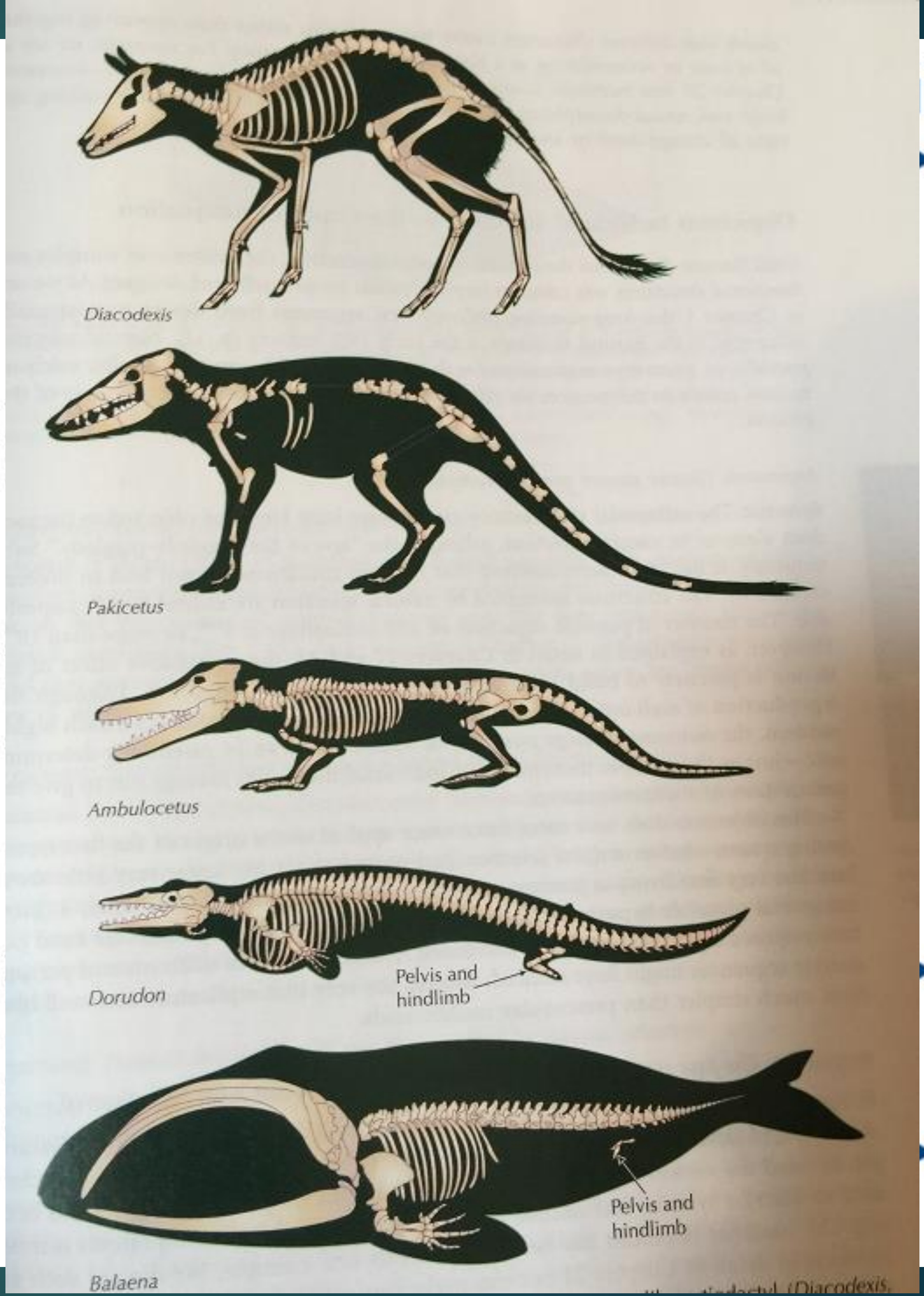
- Whales, dolphins, porpoises
- Evolution from ancient 4 legged land animal
- Comparative anatomy: have placentas, give live birth, milk to young, warm blooded, lungs not gills, 2 nasal passages, hair; arm, wrist, hand 1-2-5 sequence; hip, thigh, shin bones in back
- Embryology: arm & leg buds, 2 nostril grooves
- Fossils: intermediate species basilosaurid at 30-40 Ma has nasal opening midway up snout bones (at end in modern fox, at top in whale); hip, leg, ankle, toe bones present; Maiacetus at 47 Ma has full leg; Pakicetus walked in water; many intermediate species
- But whales did not descend from a group of carnivorous Eocene mammals known as mesonychids; the match to those Eocene carnivores might be close, but not close enough. DNA hybridization and other tests suggested that whales had descended from artiodactyls (that is, even-toed herbivores, such as antelopes and hippos), not from meateating mesonychids. Philip D. Gingerich found an anklebone, from a four-legged whale dating back 47 million years, that closely resembled the homologus anklebone in an artiodactyls. Suddenly he realized how closely whales are related to antelopes.
- DNA: whales most closely related to hippopotamus; both evolved from MCA at 54 Ma; both share double pulley ankle; give birth under water, multichambered stomachs like herbivores, only animals with internal testicles

Transitional whales



Transitional Forms: Whale evolution from land mammal

- Early wolf like creature – Pakicetus
- 40 Ma a lagoon of Mediterranean Sea (then 100 miles south); Valley of whales in Sahara desert (100 sq. miles)
- Fish swim by flexing from side to side; mammals by undulating their spines up and down
- *Pakicetus* to *Ambulocetus* to *Kutchicetus* to *Artiocetus* to *Dorudon* to *Aetiocetus* to *Basilosaurus* to *Eurhinodelphis* to *Mammalodon*.



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.

Comparative Anatomy

- Morphology was the "very soul" of natural history, according to Darwin. Living creatures can be easily sorted into a hierarchy of categories based on which anatomical characters they share and which they don't (See any zoo).

- Such a pattern of tiered resemblances—groups of similar species nested within broader groupings, and all descending from a single source reflect unbroken descent from common ancestors.

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

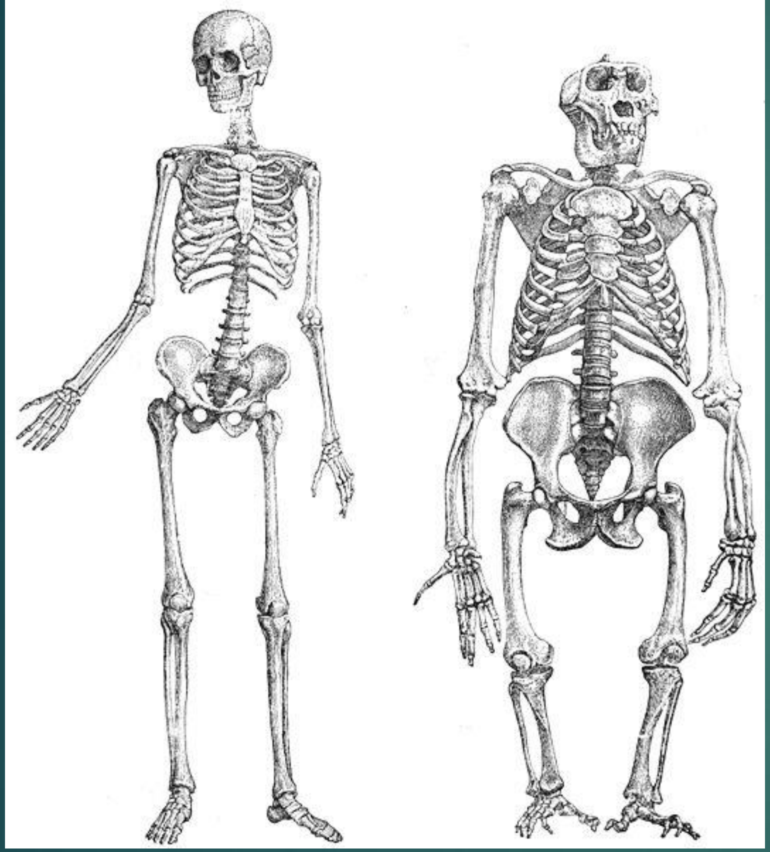
1 - Comparative anatomy

- Similar anatomical forms imply common descent.

- <u>Formation of new species</u> <u>can be inferred from shared sets of morphological traits, i.e. fossils</u>

- <u>These shared traits are more similar among species that share a more recent common ancestor</u>, and can <u>be used to reconstruct a biological tree for that species</u>

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

Shared features of form = common descent

- These shared features suggest that all living things are descended from a common ancestor, and that this ancestor had DNA as its genetic material, used the genetic code, and expressed its genes by transcription (into RNA) and translation (into protein).

- <u>Present-day organisms all share these features</u> because they were "inherited" from the ancestor (and because any big changes in this basic machinery would have broken the basic functionality of cells).

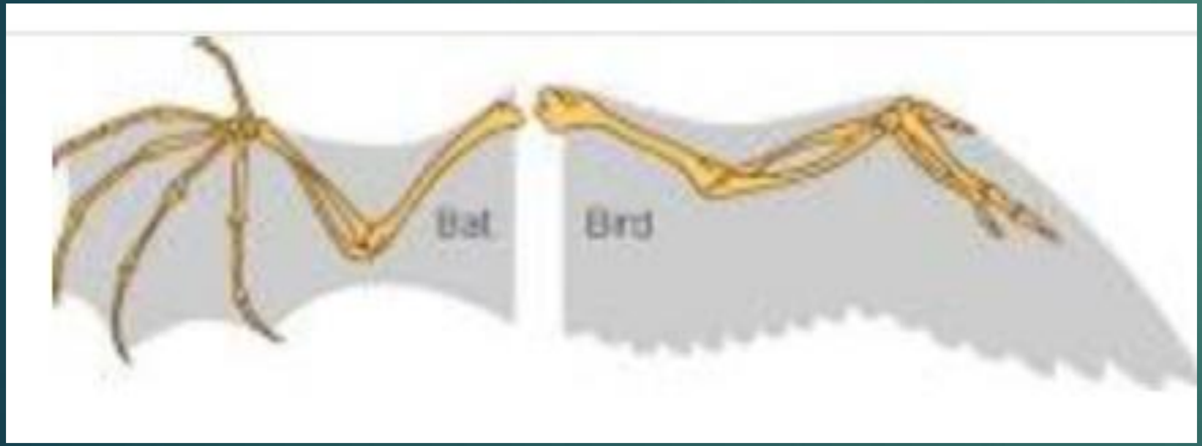
Similarity due to…

- Similarity of form due to:
  - Common ancestor had a trait they share
  - They have both changed from a common ancestor in a similar way
  - They are unrelated but have been subject to similar evolutionary forces

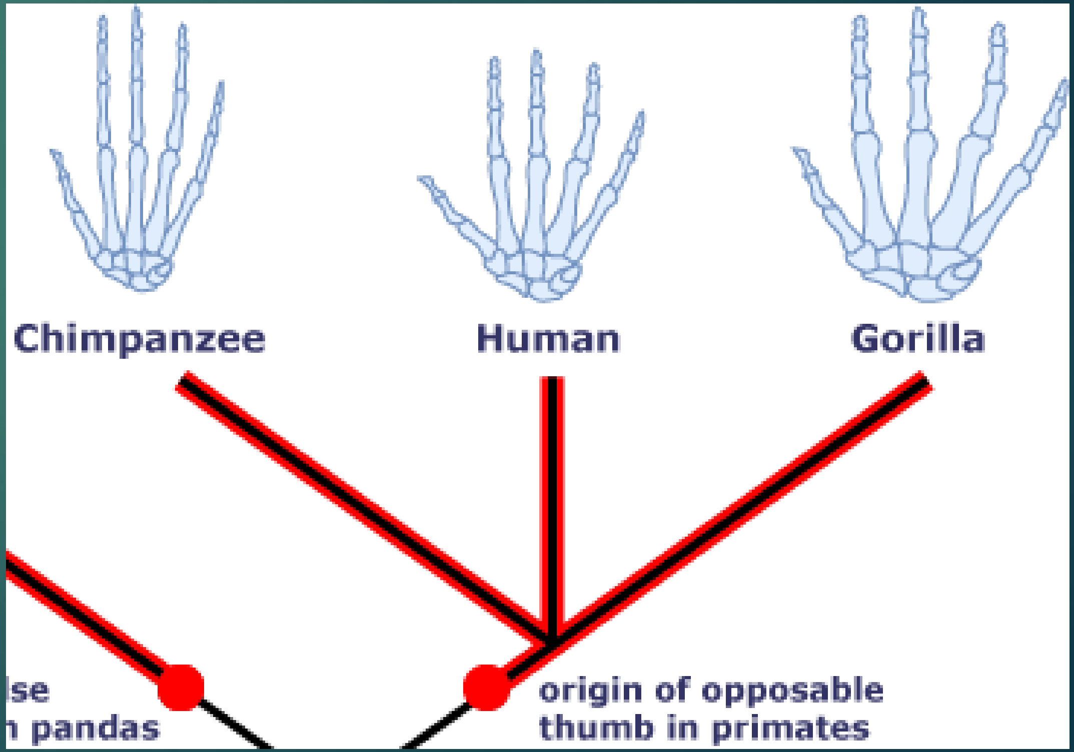
- How do you determine similarity in organisms?
  - • Homologous vs analogous traits
  - • Ancestral (not “Primitive”) vs derived traits

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)



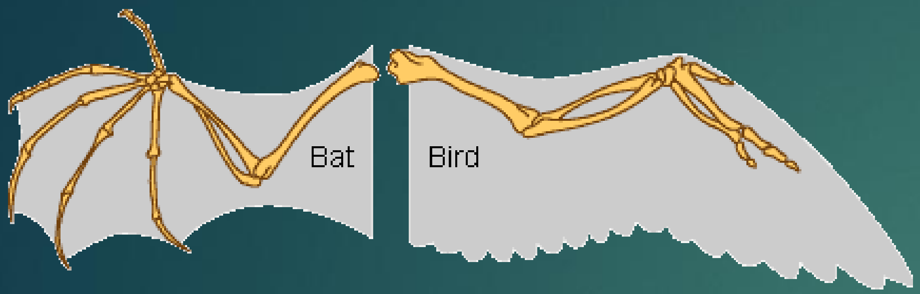
Convergent Evolution

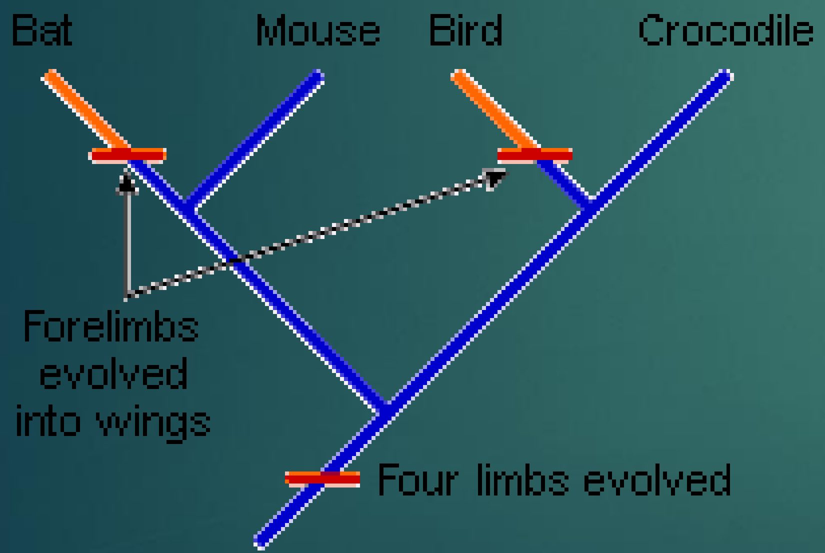


Common solutions for common problems:
Analogous Structures via Convergent Evolution

- 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.)

Convergent Evolution – What is an example?

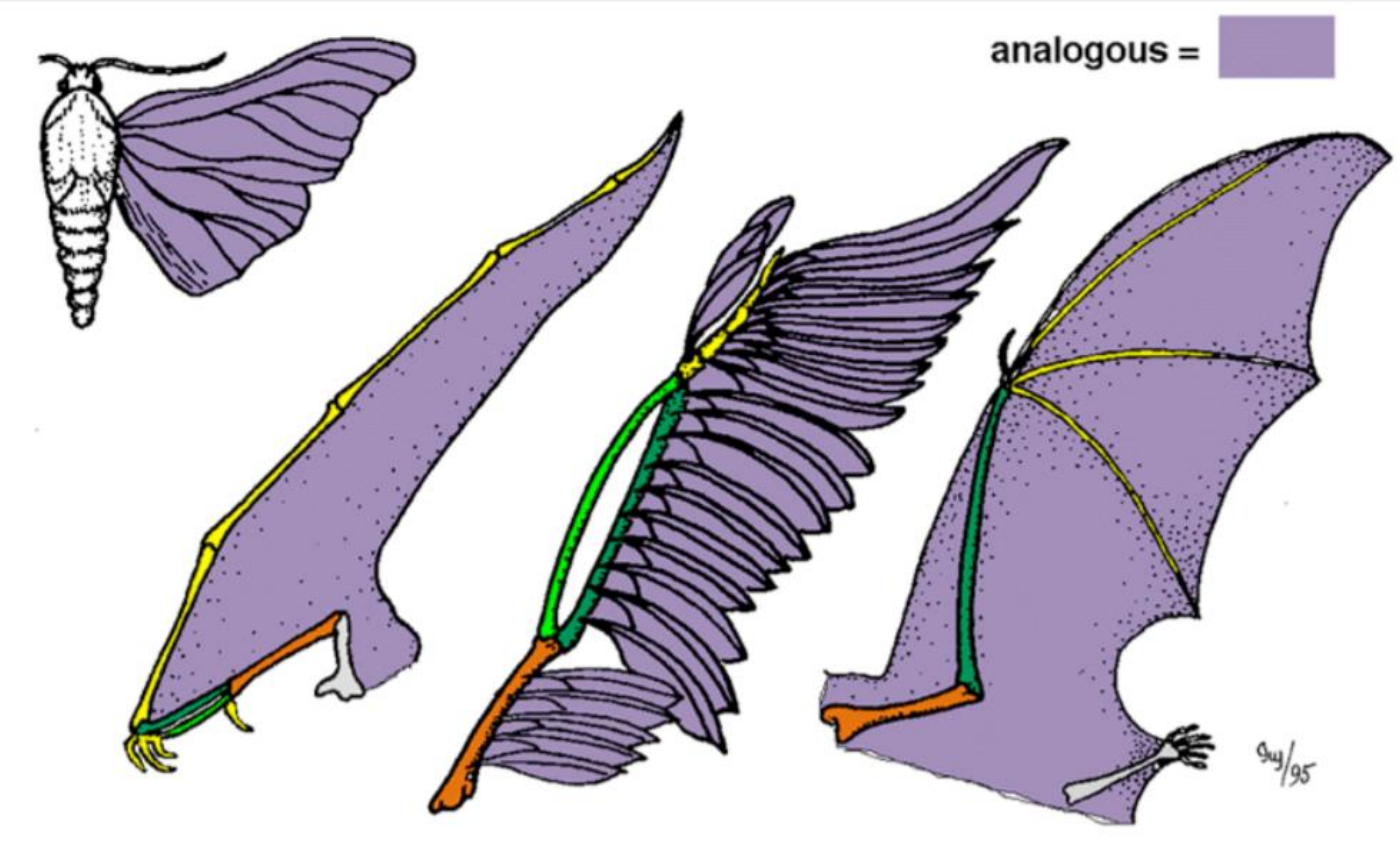




- Bird and bat wings are analogous — that is, they have separate evolutionary origins, but are superficially similar because they have both experienced natural selection that shaped them to play a key role in flight. Analogies are the result of convergent evolution.
- Though bird and bat wings are analogous as wings, but are homologous as forelimbs.

- Birds and bats did not inherit wings from a common ancestor with wings, but they did inherit forelimbs from a common ancestor with forelimbs.

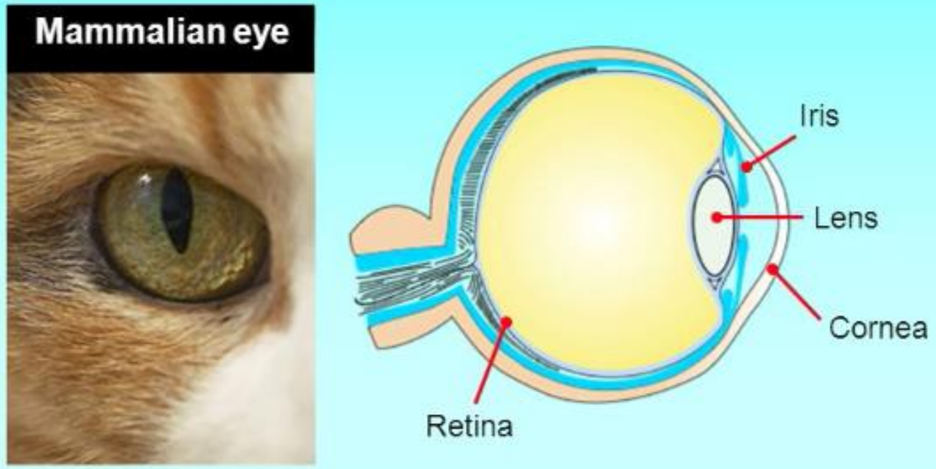
Analogous Structures – no shared ancestor, similar function

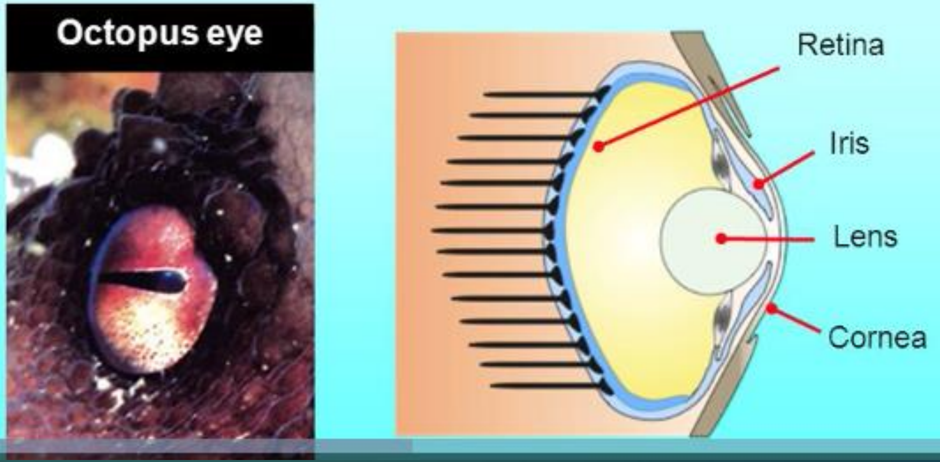


- A bird's wing and a bat's wing are considered analogous structures.
- Analogous structures are those that are similar between two organisms due to shared function.
- Though bird and bat wings are analogous as wings, but are homologous as forelimbs.

Analogy in Eye Structure

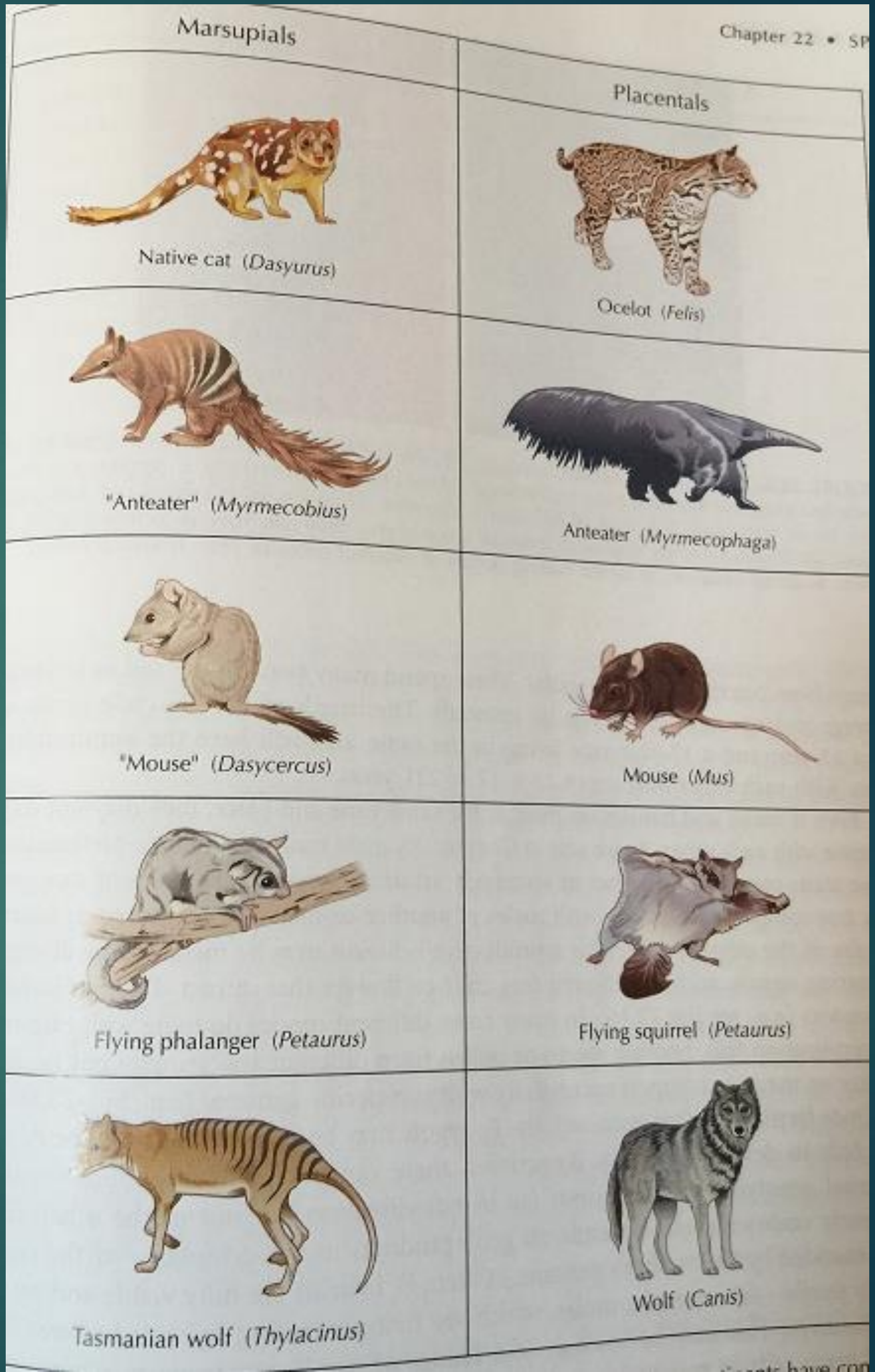
- Eyes in cephalopods (such as octopus) and mammals have the same function and are structurally similar, but have **evolved from different origins**.





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



Parallel Evolution

The most informative similarities are….

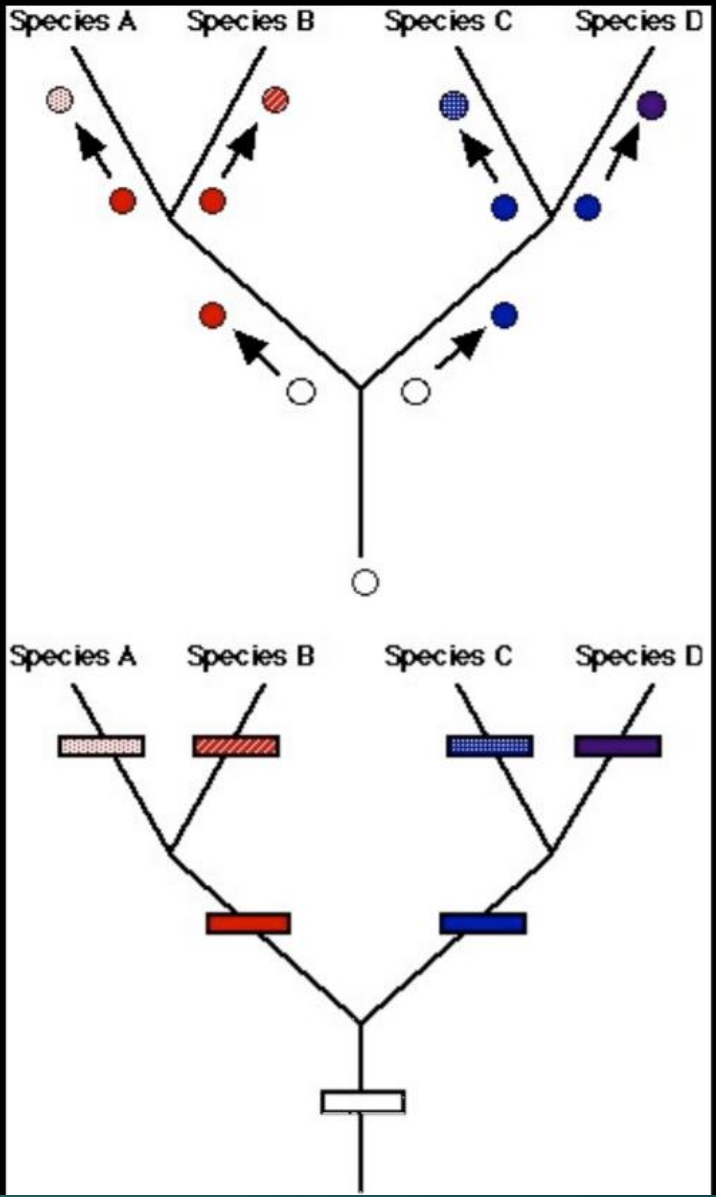
- • Shared homologies
- • Shared due to:
  - • a change since the ancestor (Derived)

Derived Traits

- Heritable traits that can be compared across organisms include physical characteristics (morphology), genetic sequences, and behavioral traits.
- • ANCESTRAL (not "primitive") - the state seen in the distant ancestor, i.e. bipedal
- • DERIVED - something new that has changed since the recent ancestor, i.e. large brain
- • SHARED DERIVED - specific character states shared in common between 2 forms and most useful in making evolutionary interpretations; sets members of that clade apart from other individuals, i.e. four limbs →vertebrates
- The traits that are most useful in determining relationships between organisms are shared derived homologous traits
- Shared-derived characteristics are most useful for determining relationships via principle of PARSIMONY, which says that the fewer evolutionary steps, the more likely the tree.

Shared-Derived traits suggest a shared evolutionary past

Shared-Derived traits indicated a shared adaptive pattern

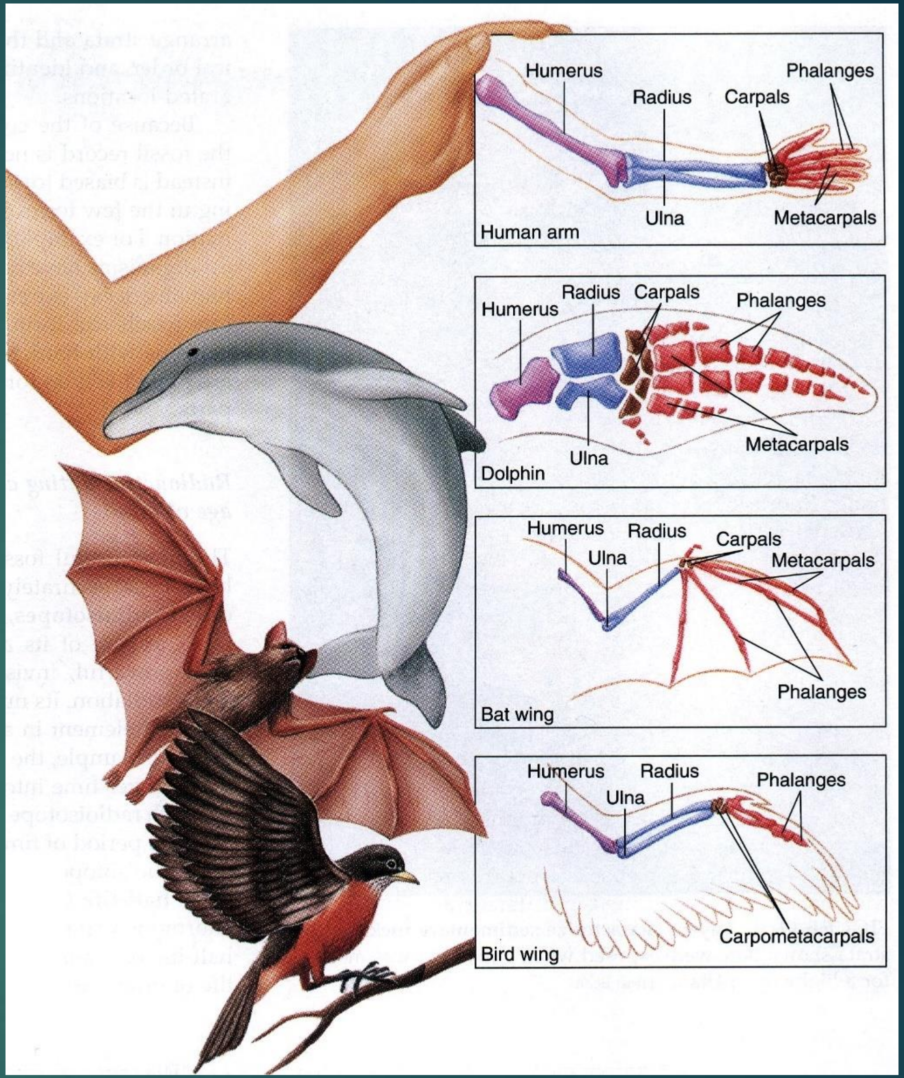


Homologous Body Structures

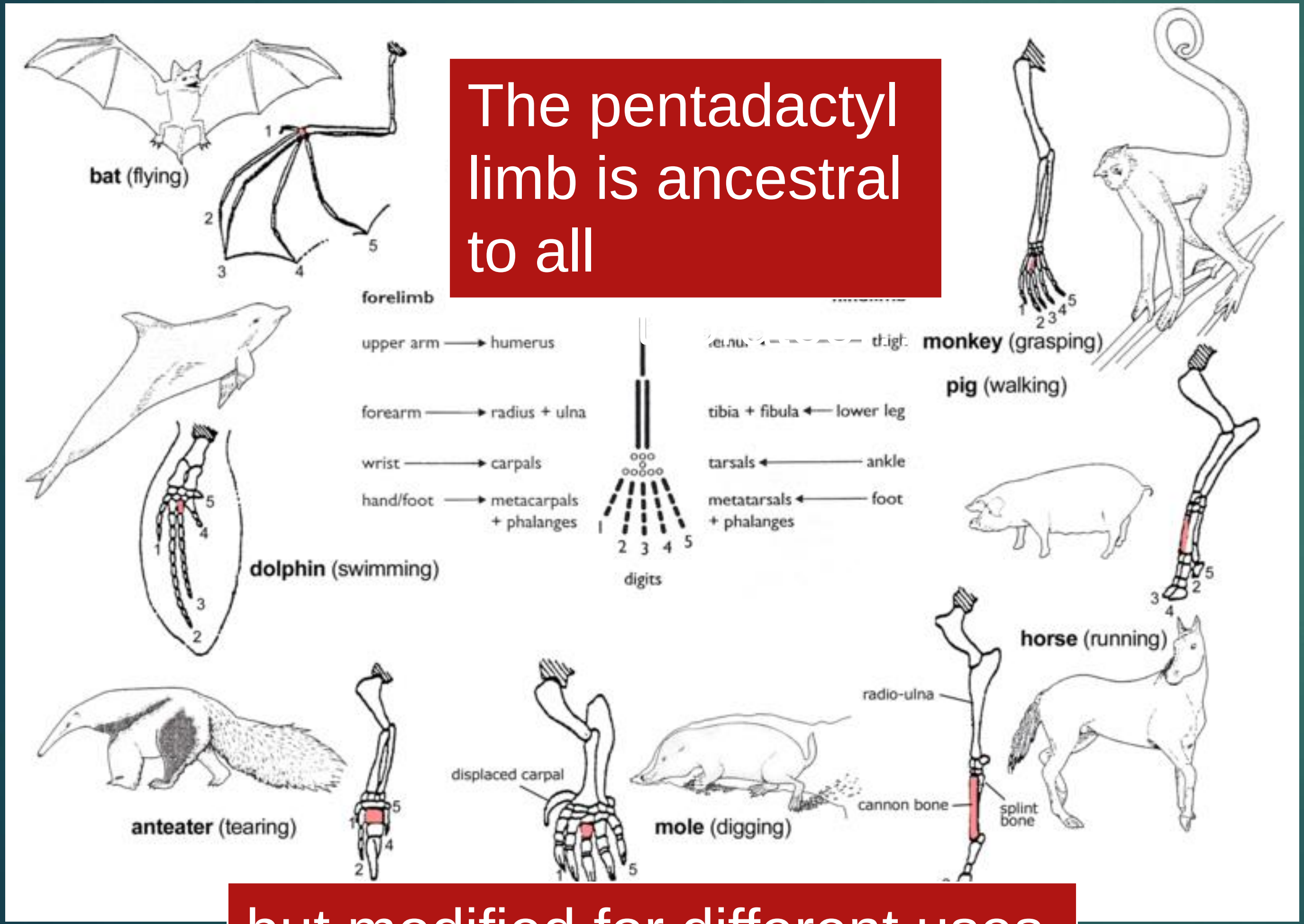
- **Homologous Body Structures**: similar anatomy in different types of animals because of common ancestry

- 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



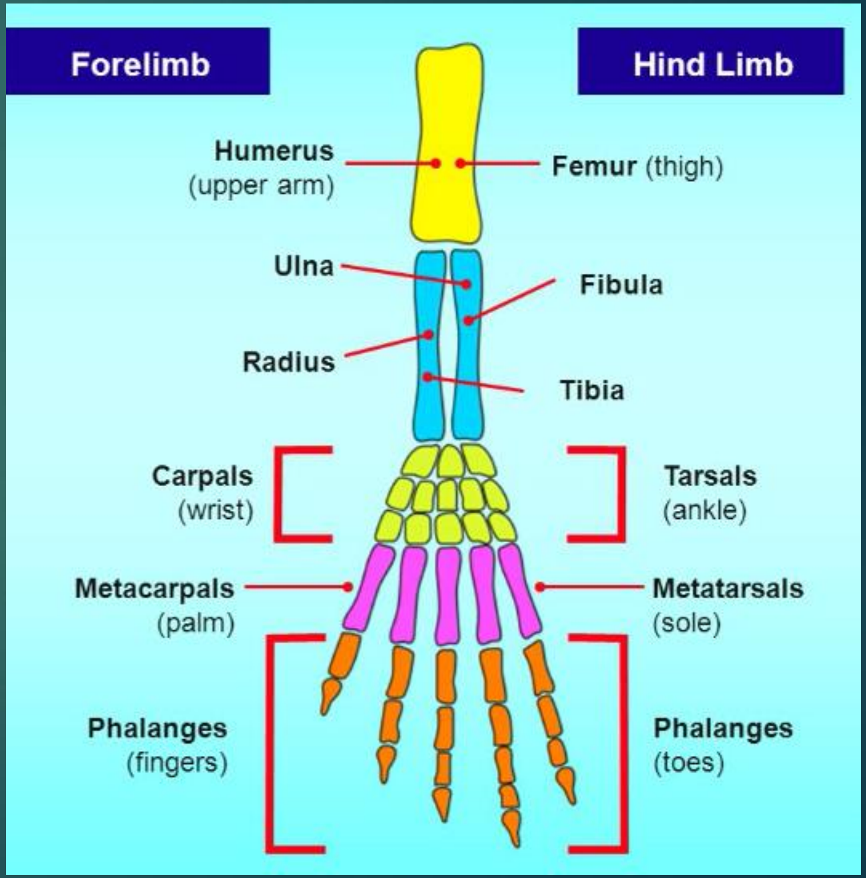
Evidence: Homology: an ancestral anatomical feature that has subsequently been modified in its descendants for a specific function. Indicate adaptive radiation (adapted to different niche).



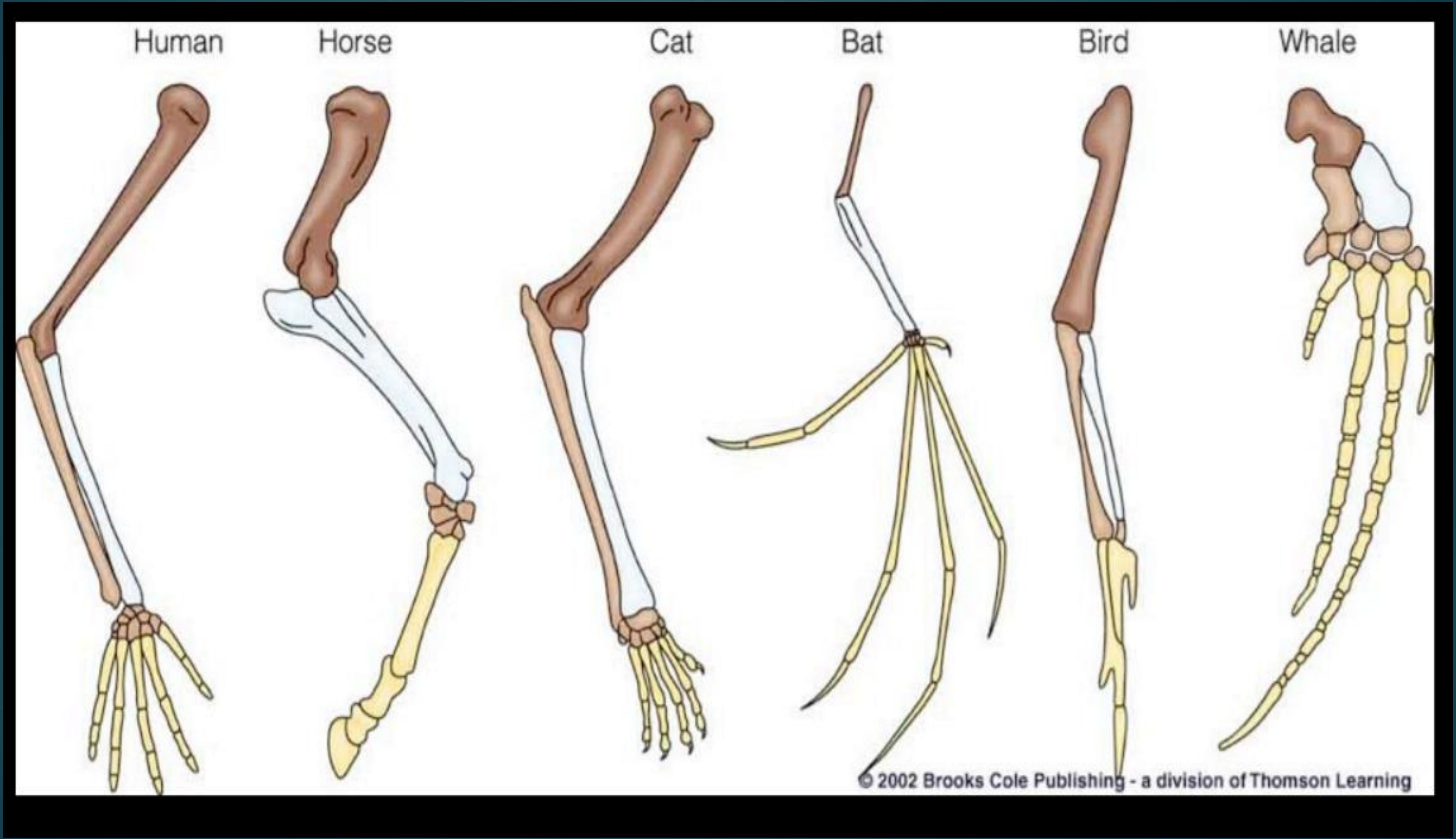
The pentadactyl limb is ancestral to all

but modified for different uses

Pentadactyl limb



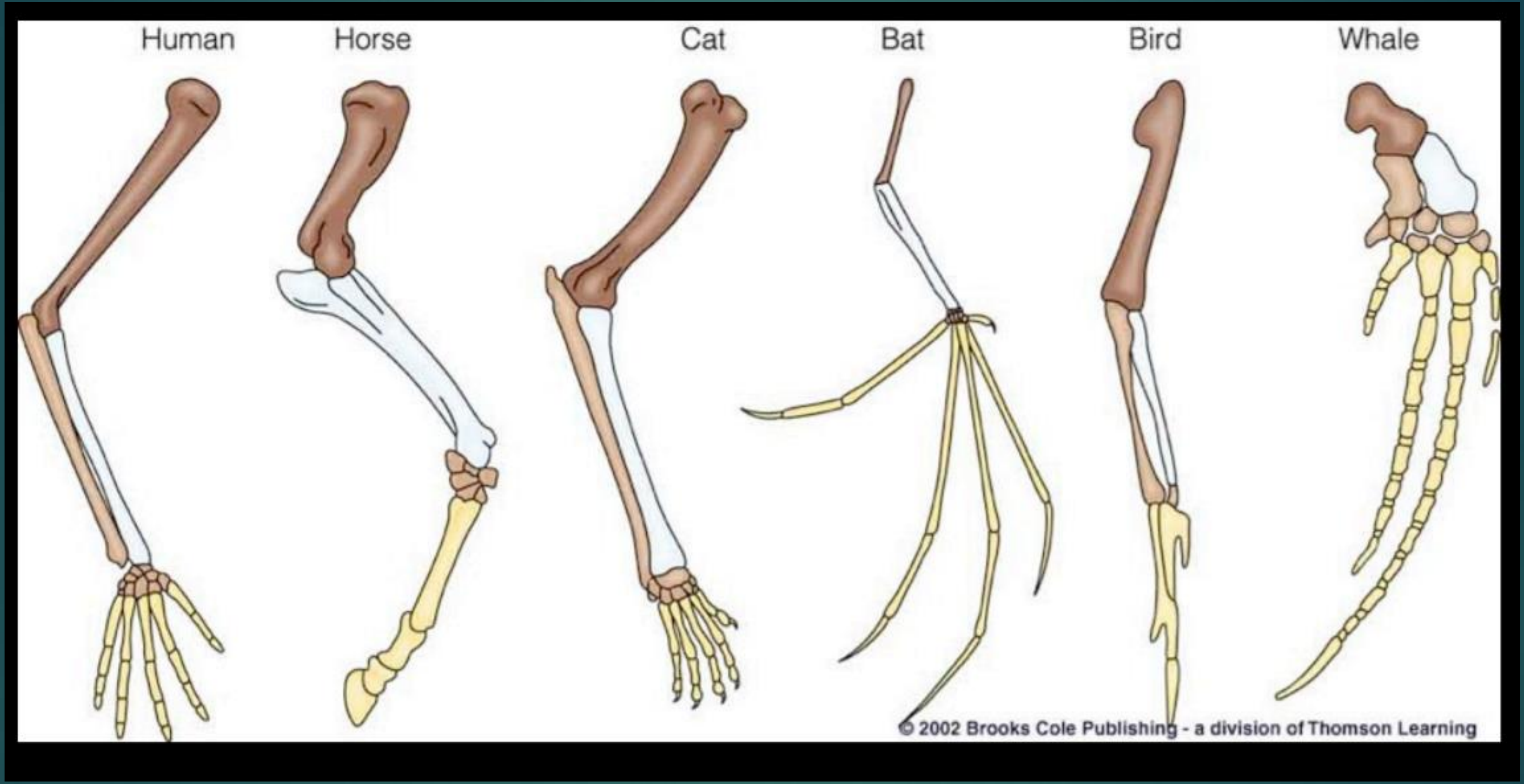
Homologous Body Structures: *bones = 1, 2, wrist, 5 digits*



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

- Skeleton view of a bat

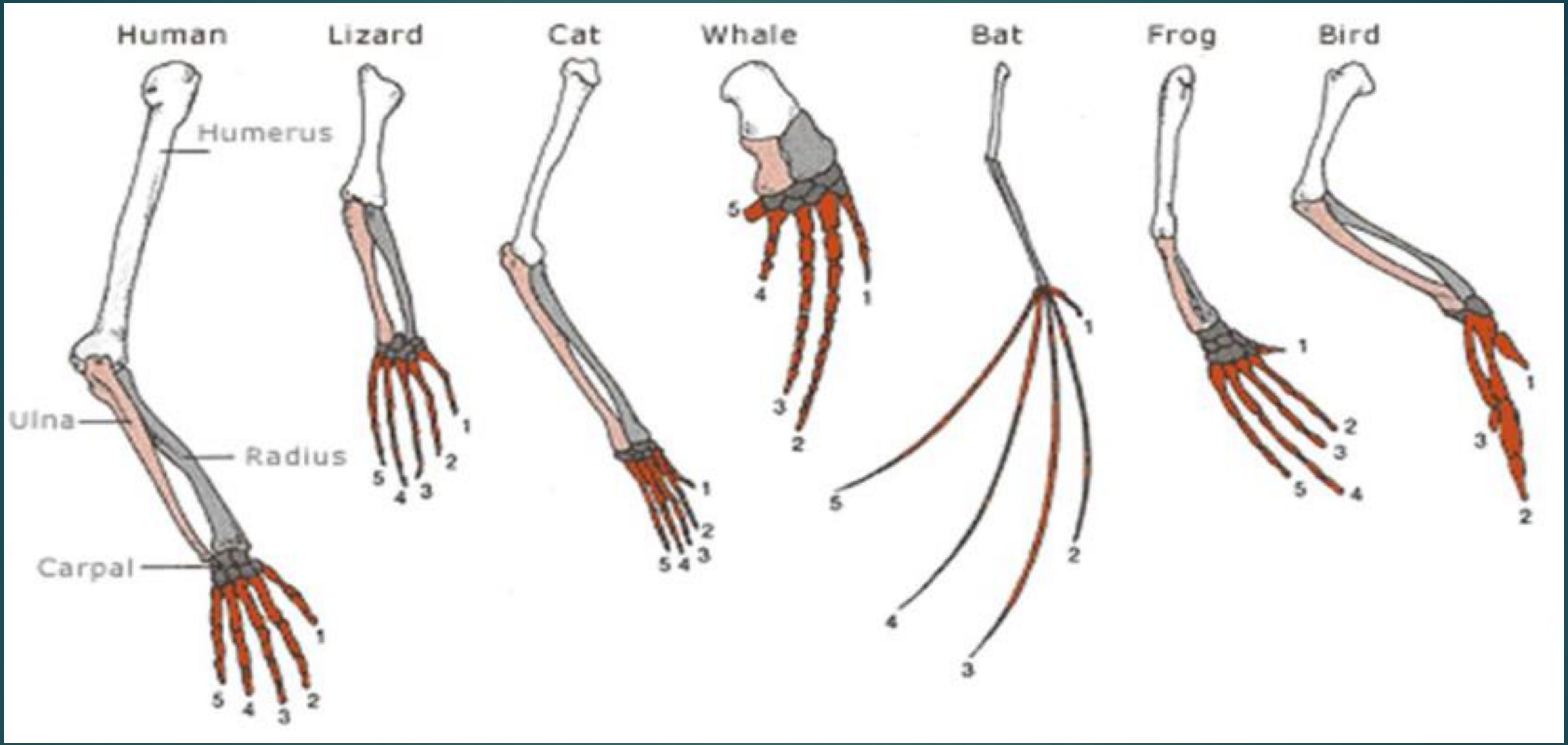
Homologous structures: 1-2-5 bones – common ancestor



The bat’s wing, seal’s flipper, cat’s paw, and human hand all have the same bones and muscles because they all share a common ancestor.

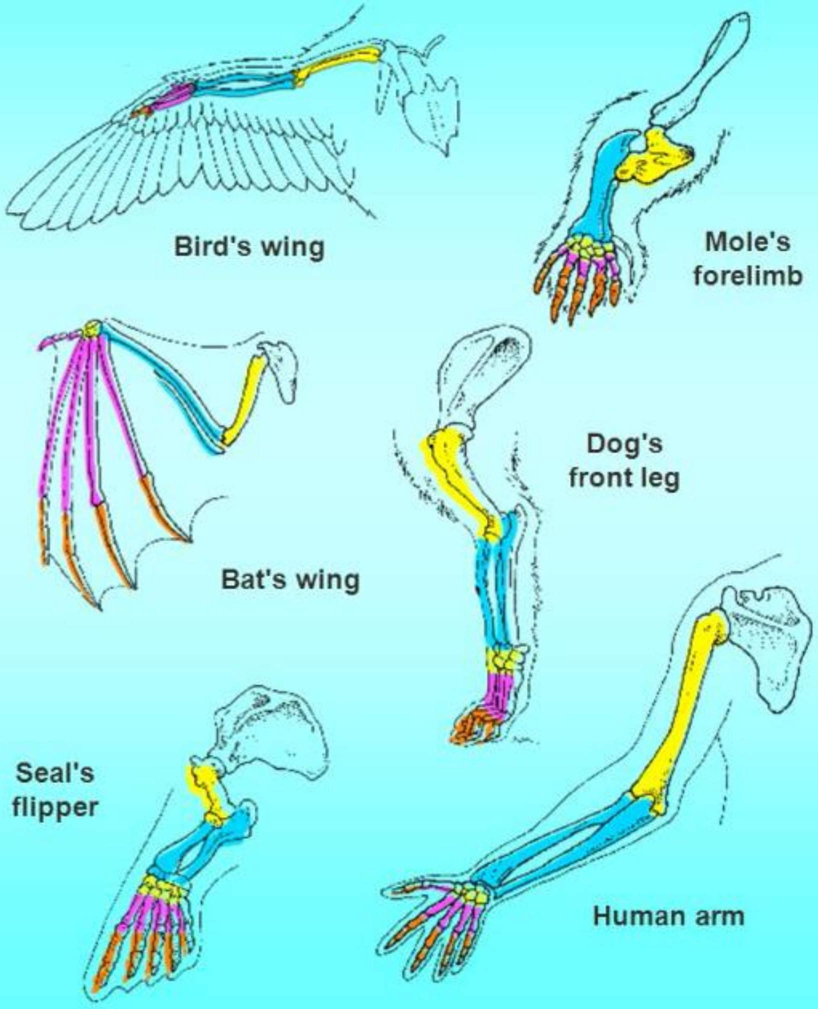
For example, giraffes have the same number of neck vertebrae as humans, seven.

Homologies

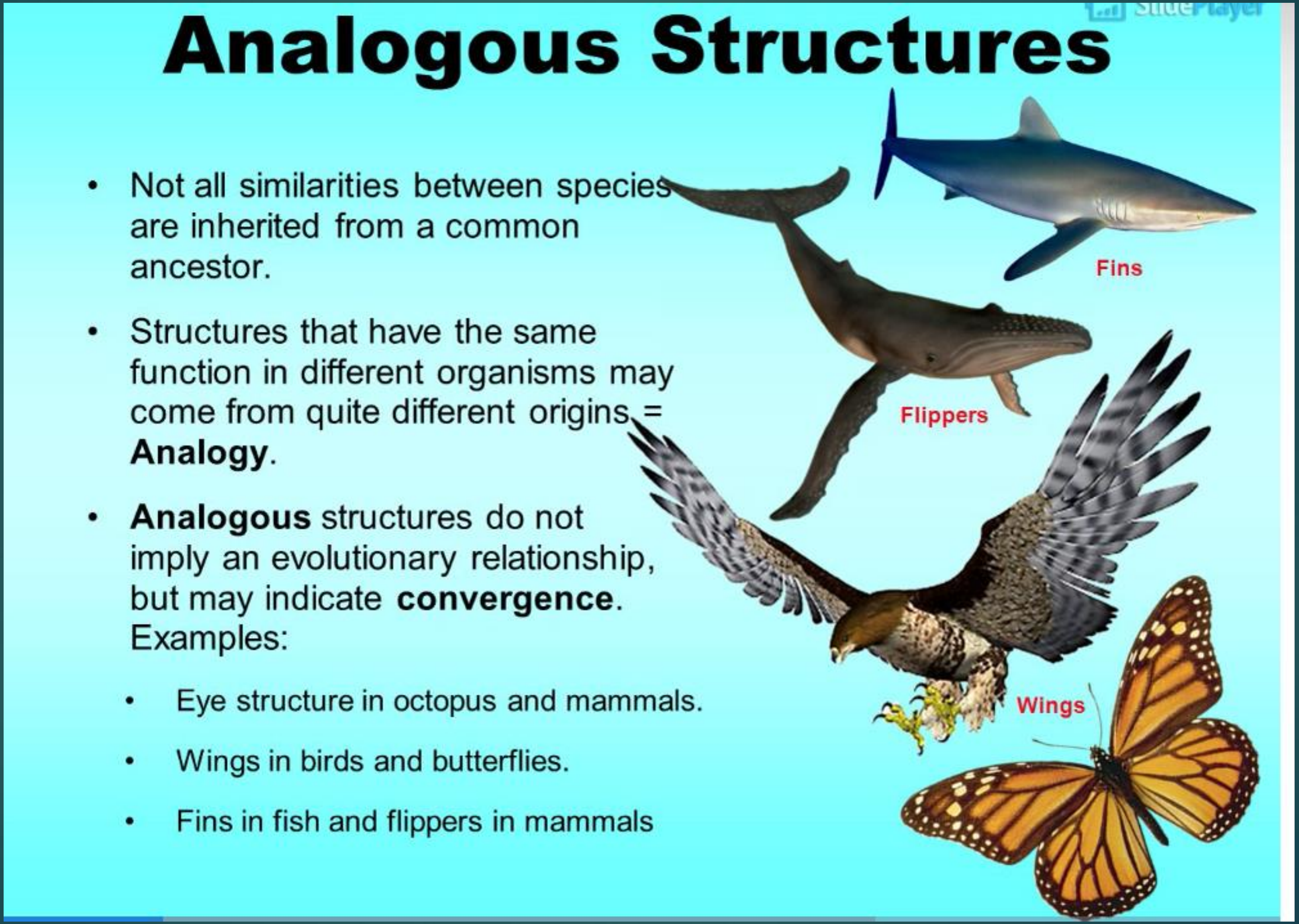

Human
Lizard
Cat
Whale
Bat
Frog
Bird
Humerus
Ulna
Radius
Carpal
1
2
3
4
5

Homologous Structures

- In many vertebrates, basic **pentadactyl** limb has been **highly modified** to serve specialized locomotory functions.
- Homologies also indicate adaptive radiation
- Basic limb plan adapted to meet needs of different niches.
- The same pattern of bones comprising the pentadactyl limb can be seen on each of these examples.



Comparative Anatomy



Homologous genes

- Biologists often compare the sequences of related genes found in different species (often called **homologous)** to figure out how those species are evolutionarily related to one another.
- The basic idea behind this approach is that two species have the "same" gene because they inherited it from a common ancestor. For instance, humans, cows, chickens, and chimpanzees all have a gene that encodes the hormone insulin, because this gene was already present in their last common ancestor.
- In general, the more DNA differences in homologous genes (or amino acid differences in the proteins they encode) between two species, the more distantly the species are related.
- For instance, human and chimpanzee insulin proteins are much more similar (about 98% identical) than human and chicken insulin proteins (about 64% identical), reflecting that humans and chimpanzees are more closely related than humans and chickens

Genes as homology

- The resemblance between human genes and those of mice also represents another form of homology, like the resemblance between a five-fingered hand and a five-toed paw.

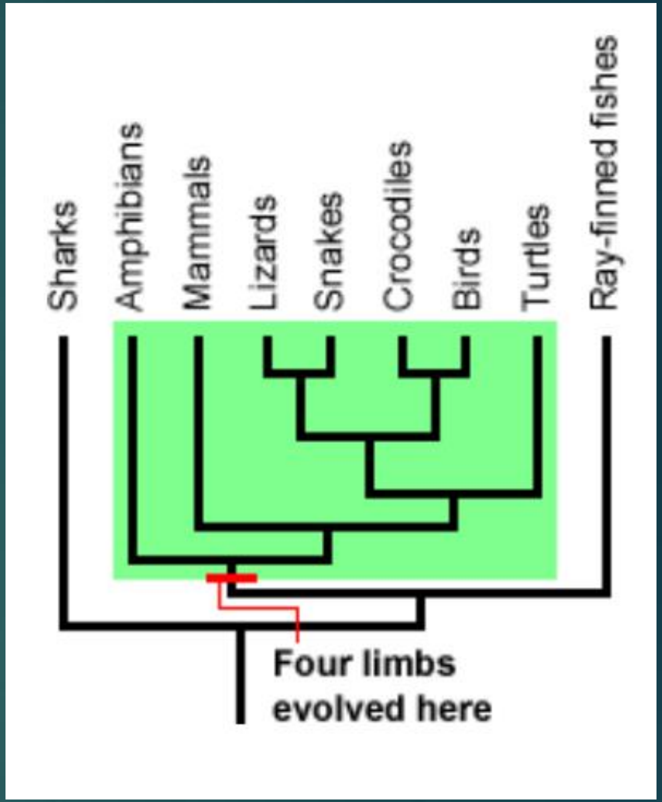
Taxonomic Classification: Shared derived characteristics

- ANCESTRAL (not "primitive") - the state seen in both the distant ancestor and current species i.e. being bipedal

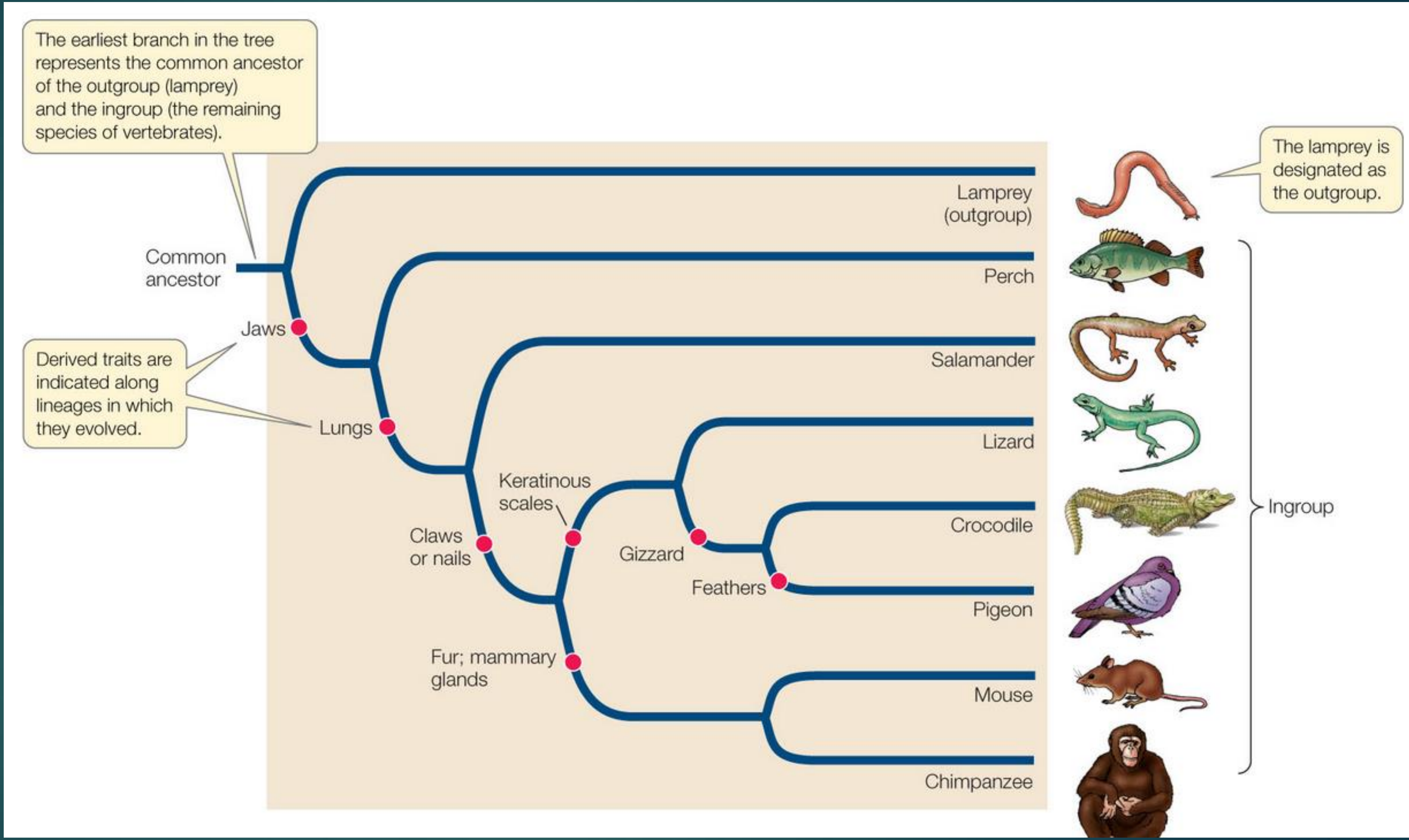
- DERIVED - something new that has changed since the recent ancestor, i.e. large brain

- 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.



Phylogeny



The earliest branch in the tree represents the common ancestor of the outgroup (lamprey) and the ingroup (the remaining species of vertebrates).
Common ancestor
Jaws
Derived traits are indicated along lineages in which they evolved.
Lungs
Claws or nails
Keratinous scales
Gizzard
Feathers
Fur; mammary glands
Lamprey (outgroup)
Perch
Salamander
Lizard
Crocodile
Pigeon
Mouse
Chimpanzee
The lamprey is designated as the outgroup.
Ingroup

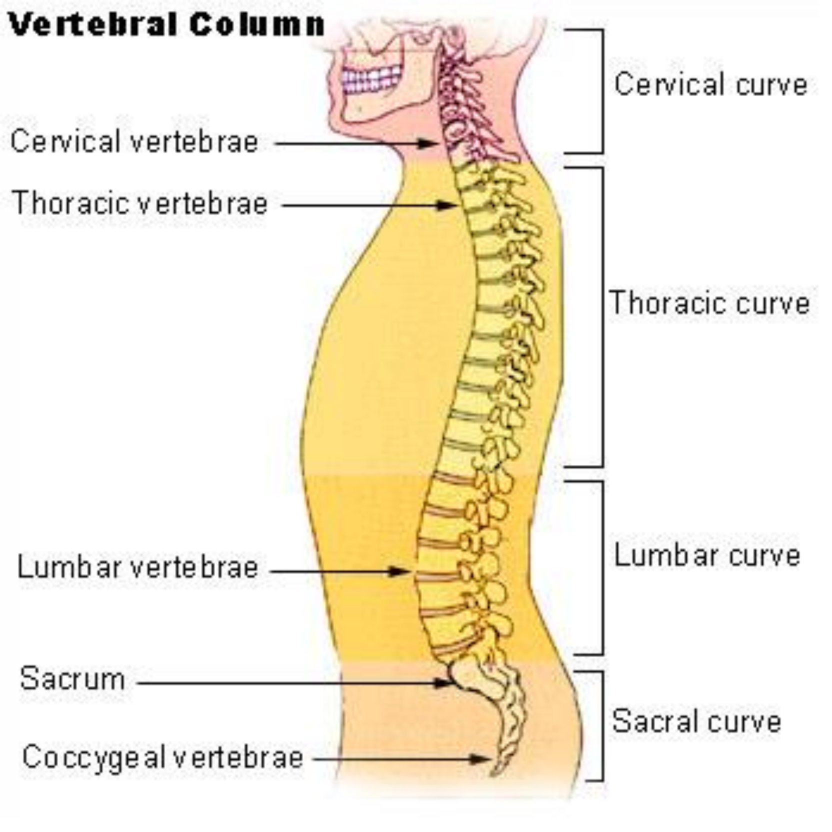
Evidence: Vestigial Characteristics

- 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 Organs

- Many organisms have degenerate structures that no longer perform the same function as in other organisms.
- These organs had a use in some ancestral form, but became redundant in later species.
- The selection pressure for complete loss is weak so the structures remain in a reduced form.
- Although vestigial organs apparently have little use, they may perform some secondary function.
- Examples:
  - Wings of kiwi are tiny vestiges and useless.
  - In snakes, one lobe of the lung is vestigial; is some species, there also vestiges of the pelvic girdle and hind limbs.
  - Vestigial eyes of burrowing animals are no longer used for vision.

Vestigial Structures

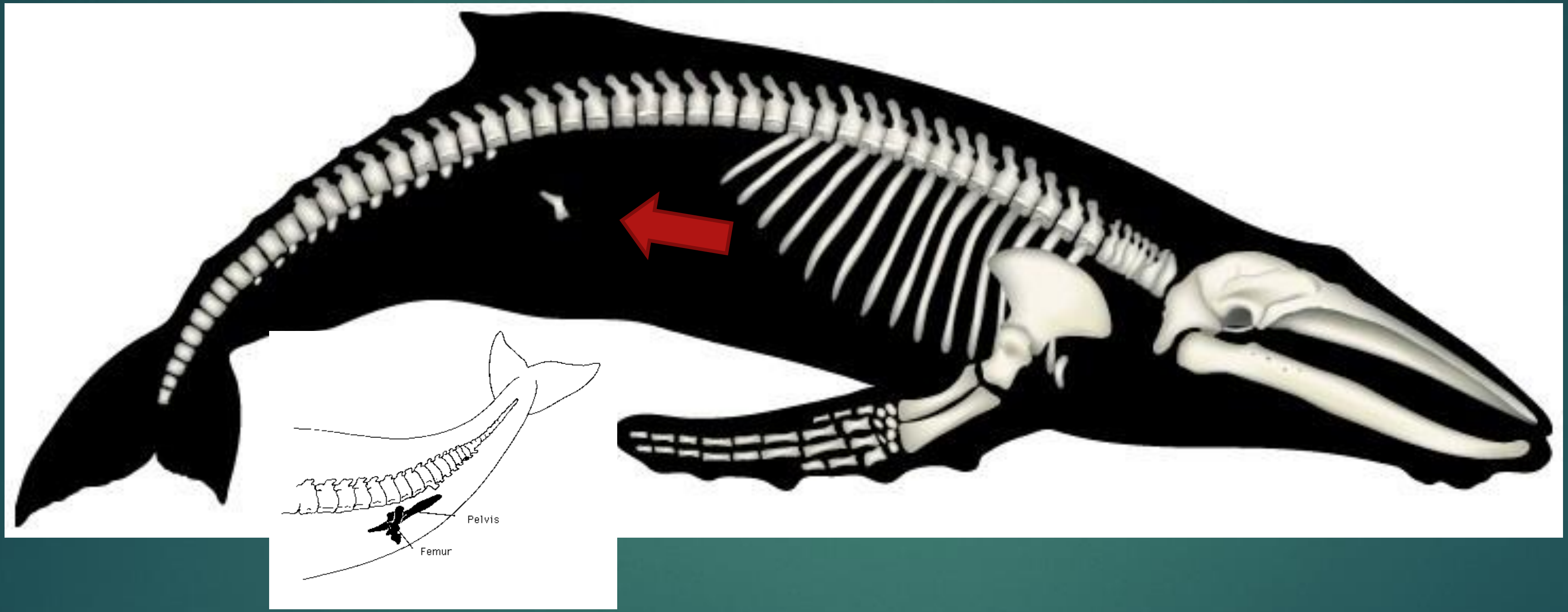


The coccyx is a vestigial tail

- As evolution progresses, some structures get side-lined as they are not longer of use. These are known as vestigial structures.
- The coccyx is a much reduced version of an ancestral tail, which was formerly adapted to aid balance and climbing.
- Another vestigial structure in humans is the appendix.

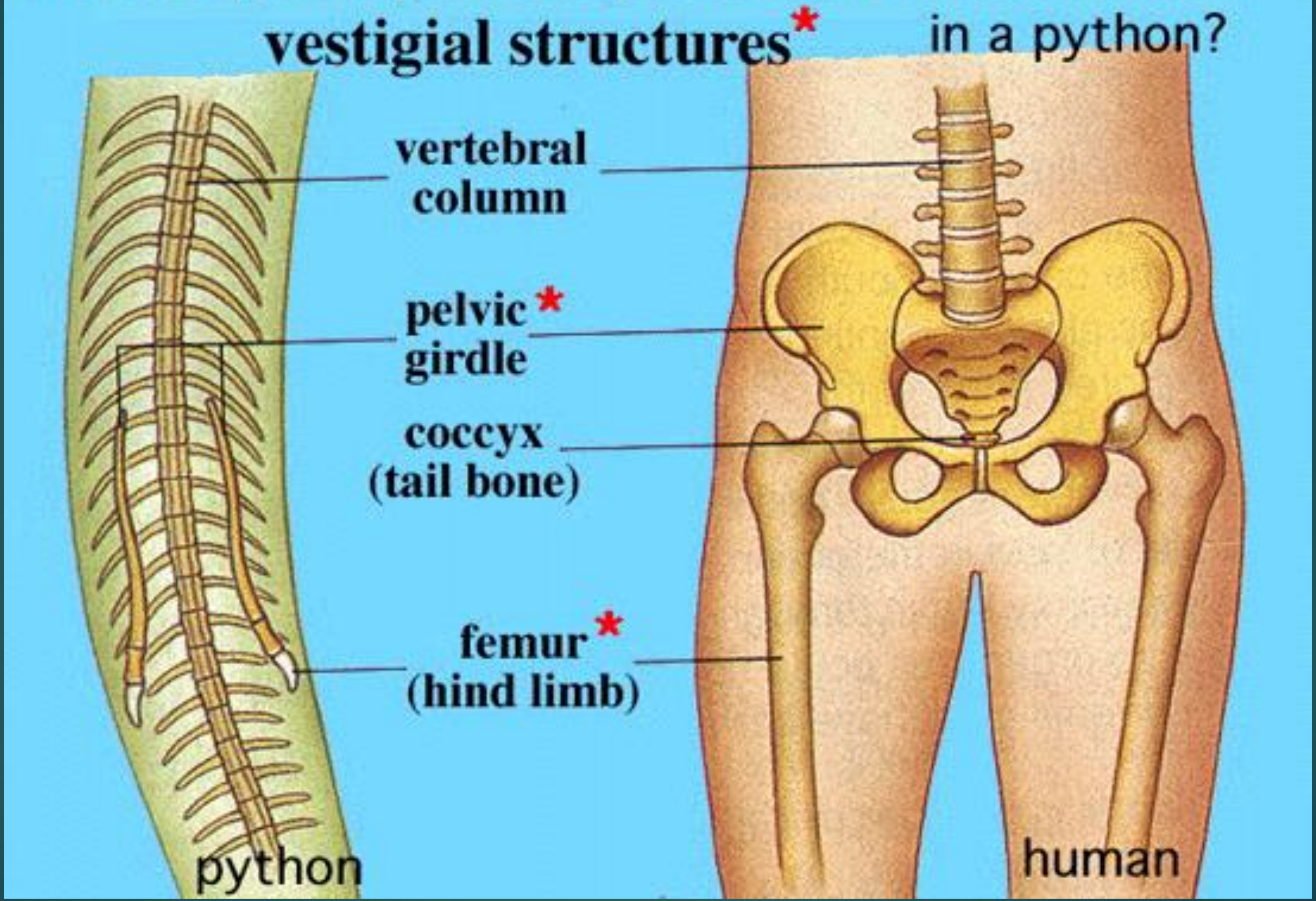
Vestigial Structures

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

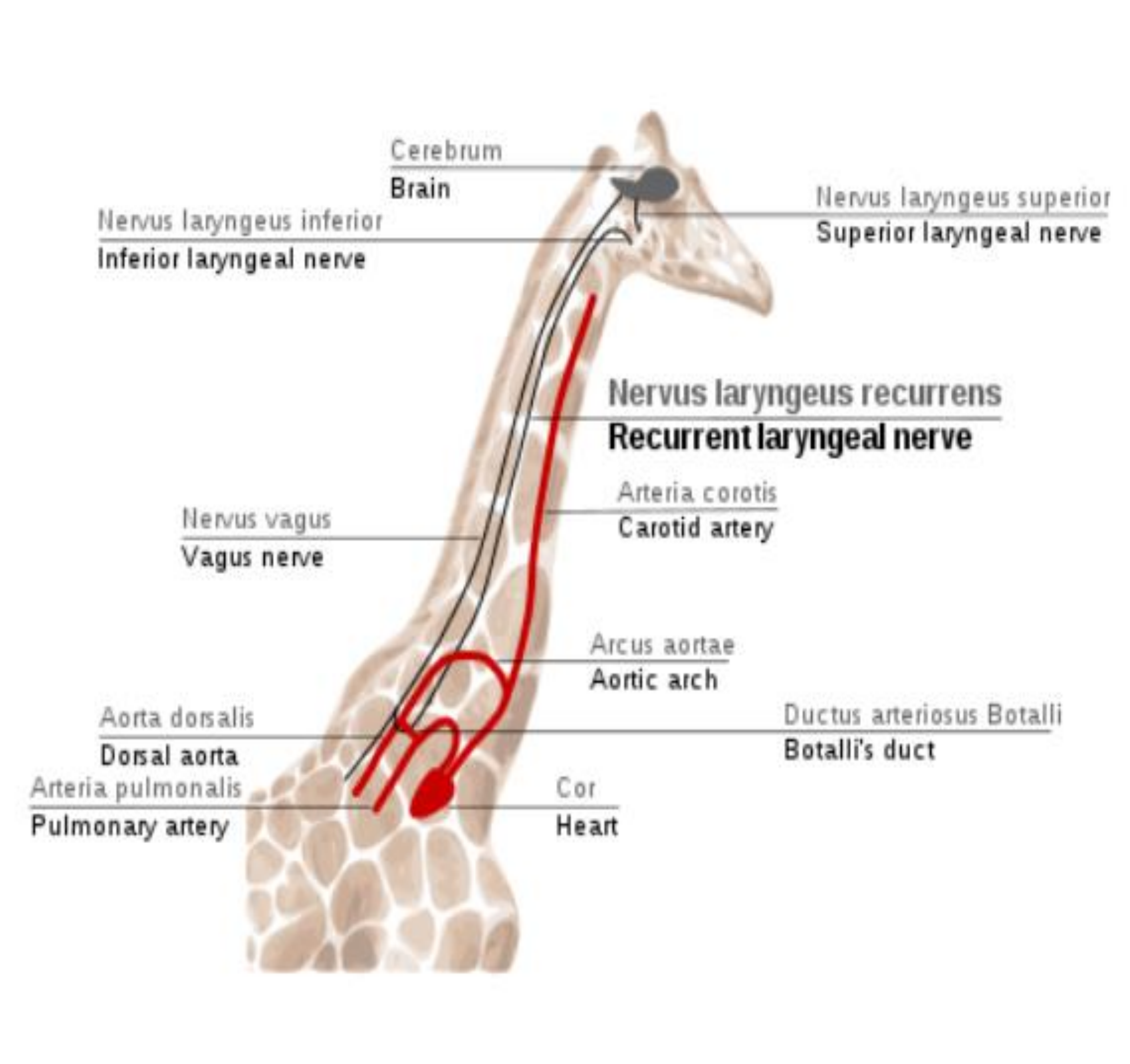


i.e. the hind leg bones of whales;

How do you explain the presence of these bones in a python?

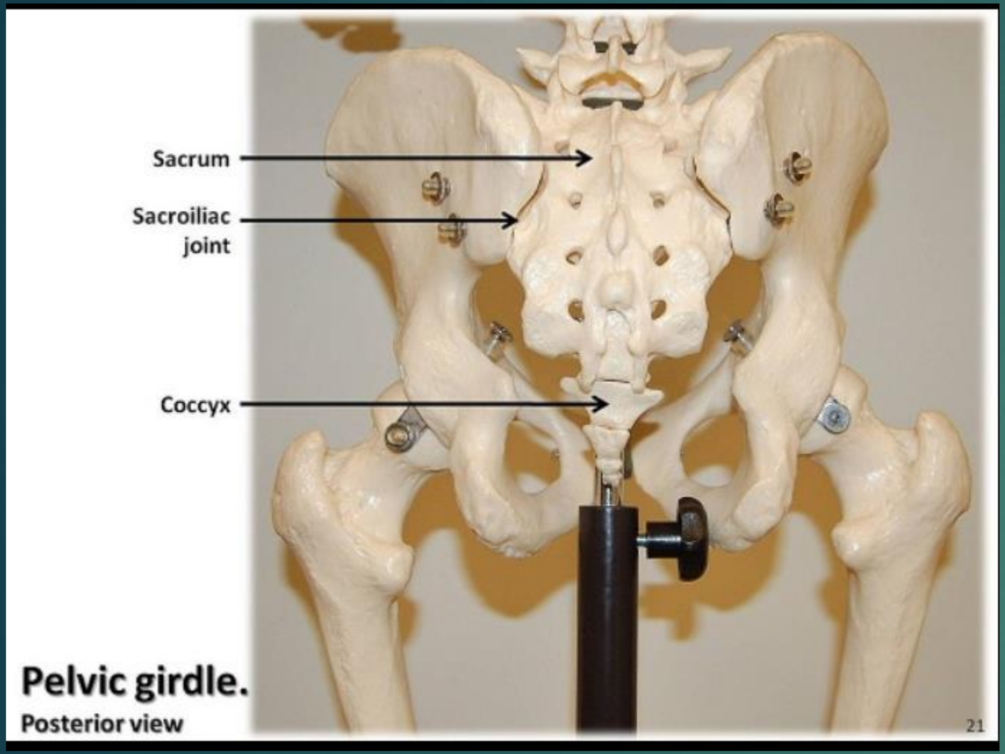


Laryngeal Nerve in Giraffes & Humans



- 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

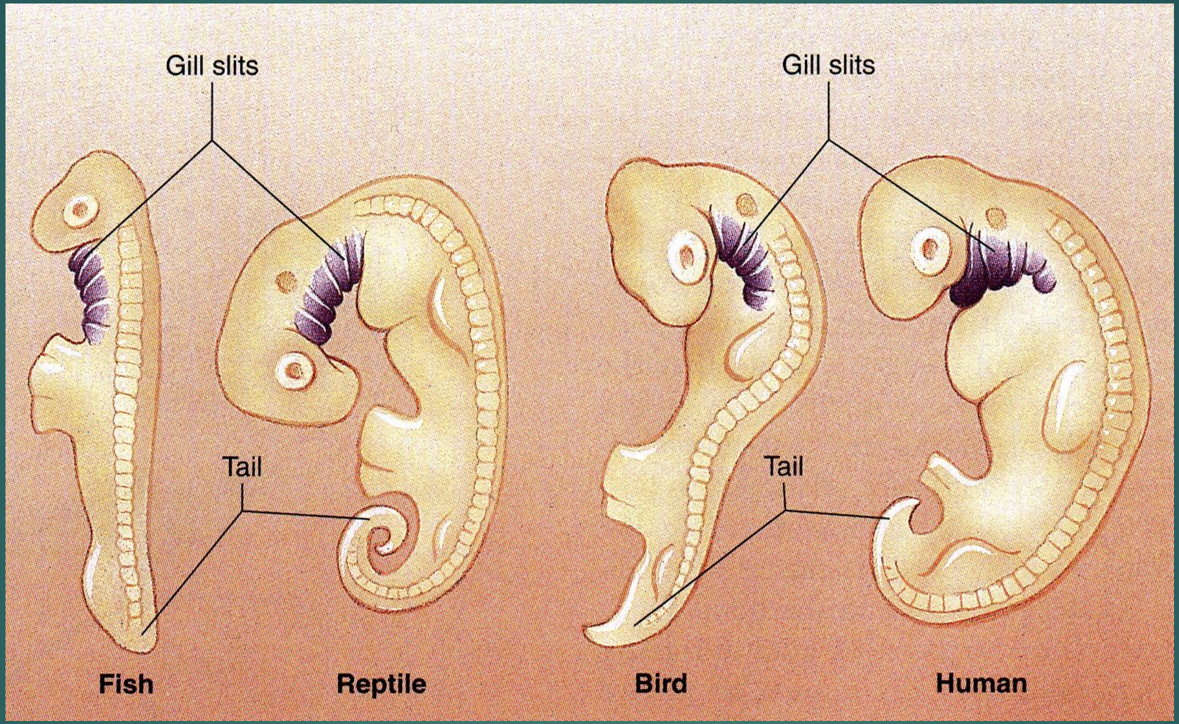


The tailbone is the final segment of the vertebral column in tailless primates, all that remains from our ancestors' tails. Today it serves as an attachment point for muscles and something to sit on.

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.

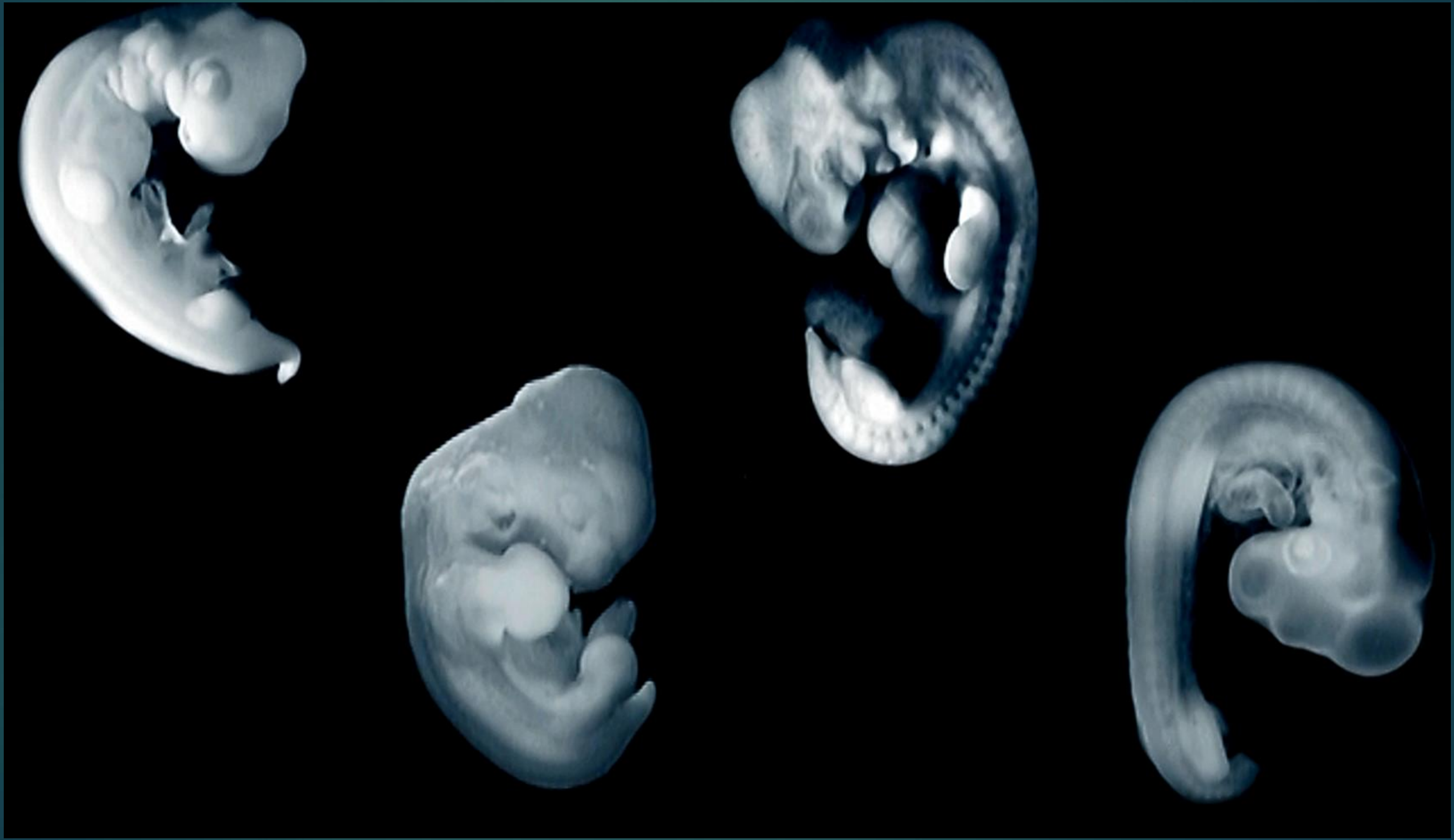
2 - Embryology

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

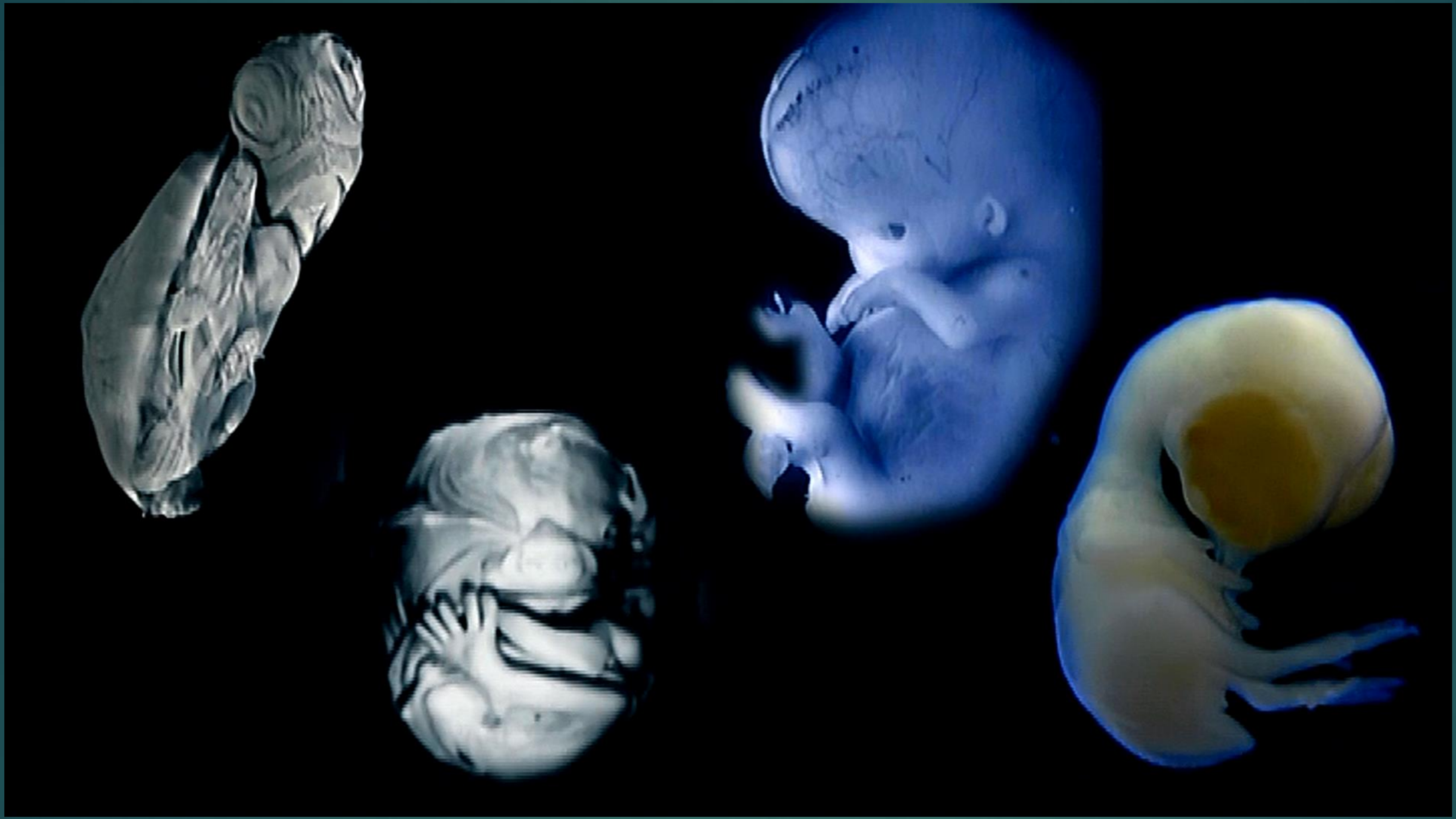


- Embryos are where all the action is in terms of diversification
- Use same set of key genes to build bodies

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



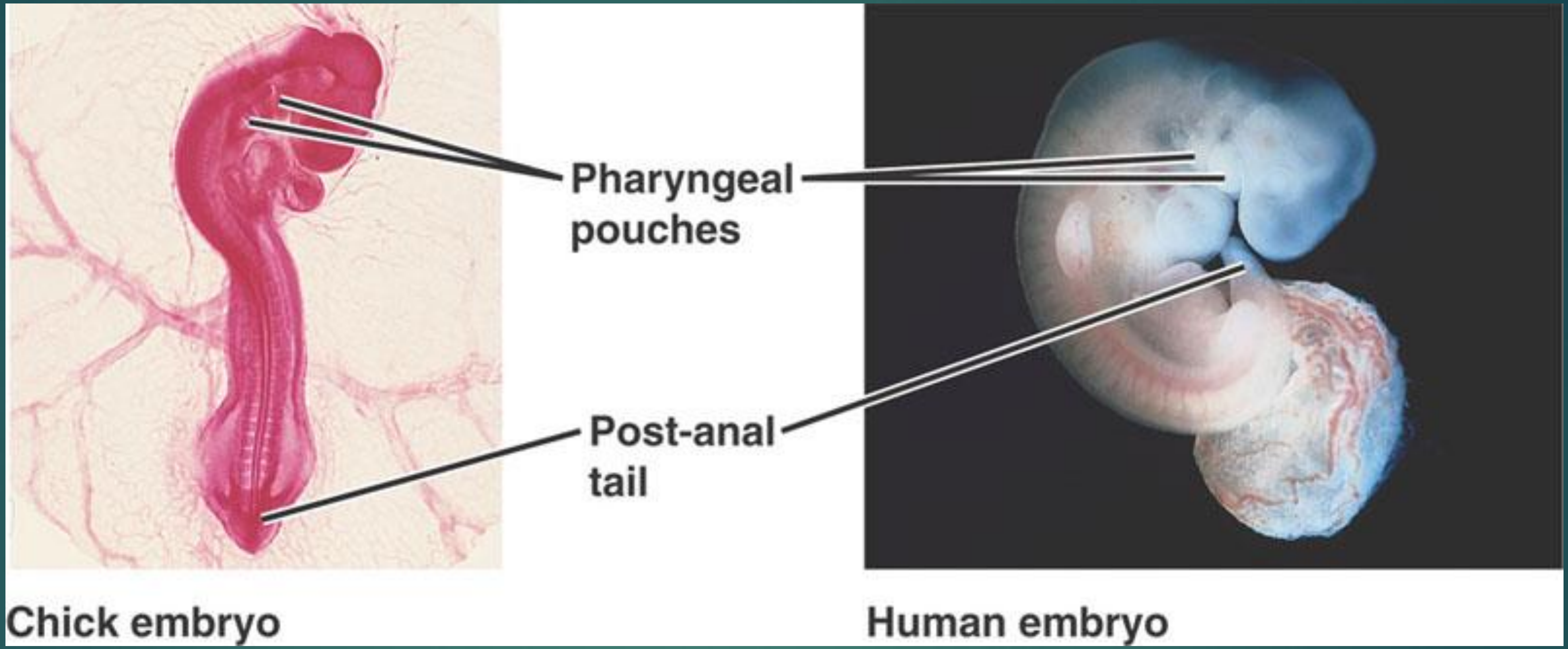
Later: turtle, bat, human, chicken



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.

Become gills in fish

Become bones of inner ear



Pharyngeal pouches

Other examples: legs in snake embryo; teeth in whale embryos

Indicates descent from prior form

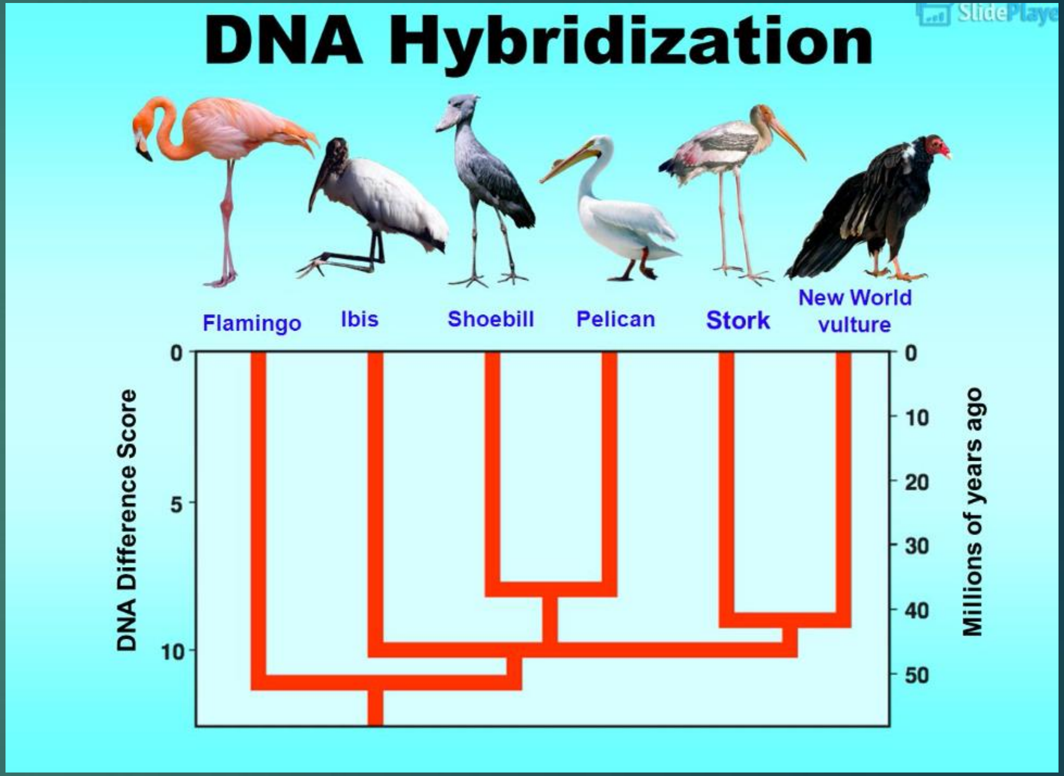
Evidence 3 - Molecular analysis: Proof of Common Descent

- 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%

Proof of Common Descent: 3 - Molecular analysis

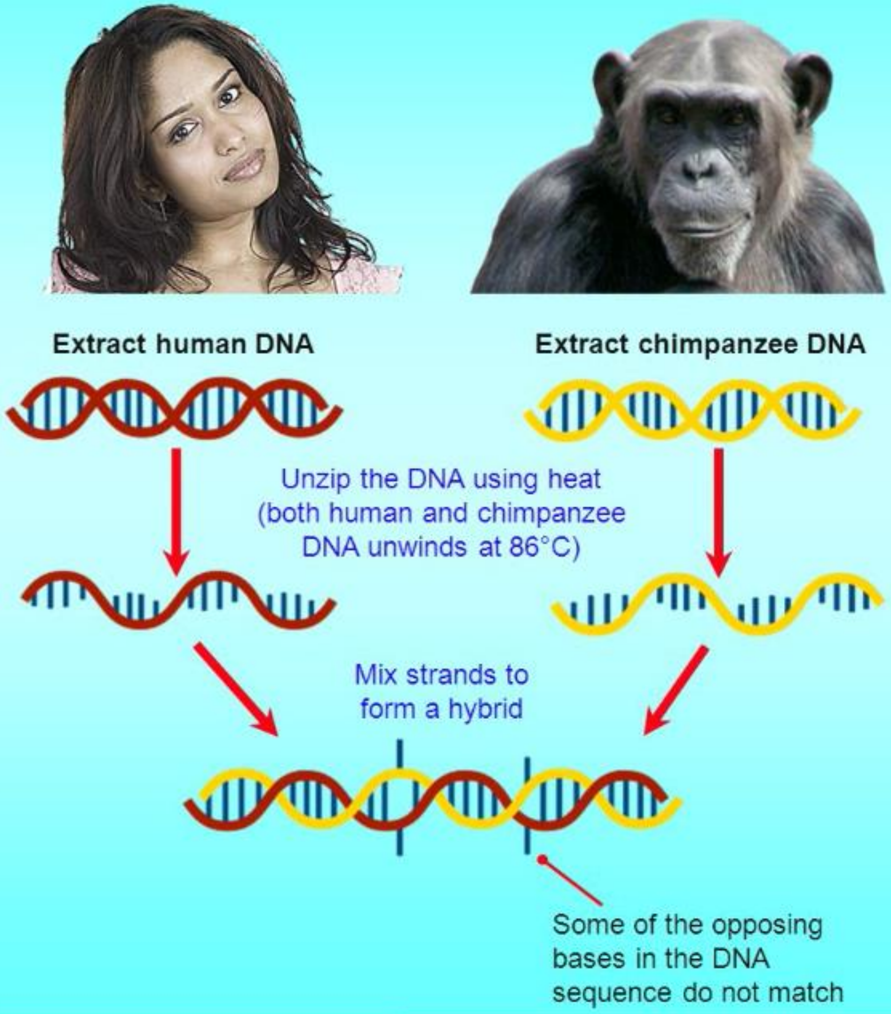
DNA Hybridization

- One way to reconstruct the evolutionary history of a species is using **DNA hybridization**.
    - In this technique, the DNA from different species is 'unzipped' and recombined to form **hybrid DNA**.
    - Heat can be used to separate the hybridized strands. The amount of heat required to do this is a measure of how similar the two DNA strands are (% bonding).
- **EXAMPLE**:
    - The relationships among the **New World vultures** and **storks** has been determined on the basis of DNA hybridization.



DNA Hybridization Method

- DNA is isolated from blood samples from each species:
  - Greater similarity in the DNA base sequences = stronger attraction between the two strands and harder to separate.
  - A crude measure of DNA relatedness can be achieved by measuring how hard it is to separate the hybrid DNA.
  - This is done by finding the temperature at which it unzips into single strands again (in this case it would be 83.6°C).



Genome analysis

DNA Sequencing

- Recent advanced techniques have enabled the sequence of DNA in different species to be determined.
- Species thought to be closely related on the basis of other evidence, were found to have a greater percentage of DNA sequences in common.
    - Humans and chimpanzees have a **97.6% similarity** in their DNA sequences and are very closely related.
    - An interesting finding was that the DNA of humans and chimpanzees is more closely matched than that of chimpanzees and gorillas.

Amino Acid Analysis

Amino Acid Sequencing

- Sequences of amino acids in certain proteins (e.g. **haemoglobin** and **cytochrome C**) have revealed great similarities and specific differences between species.
- Closely related species have proteins with similar amino acid sequences.
- Amino acid sequences are determined by **inherited genes** and differences are due to **mutations**.
- The degree of similarity of these proteins is determined by the number of mutations that have occurred. Distantly related species have had more time for differences to accumulate:
  - The greater the elapsed time since common ancestry, the greater the time for mutations to occur.
  - This in turn leads to a greater difference in amino acid sequences between species.

Amino Acid Sequencing

- Amino acid differences for beta-haemoglobin in **primates** compared to the human sequence:

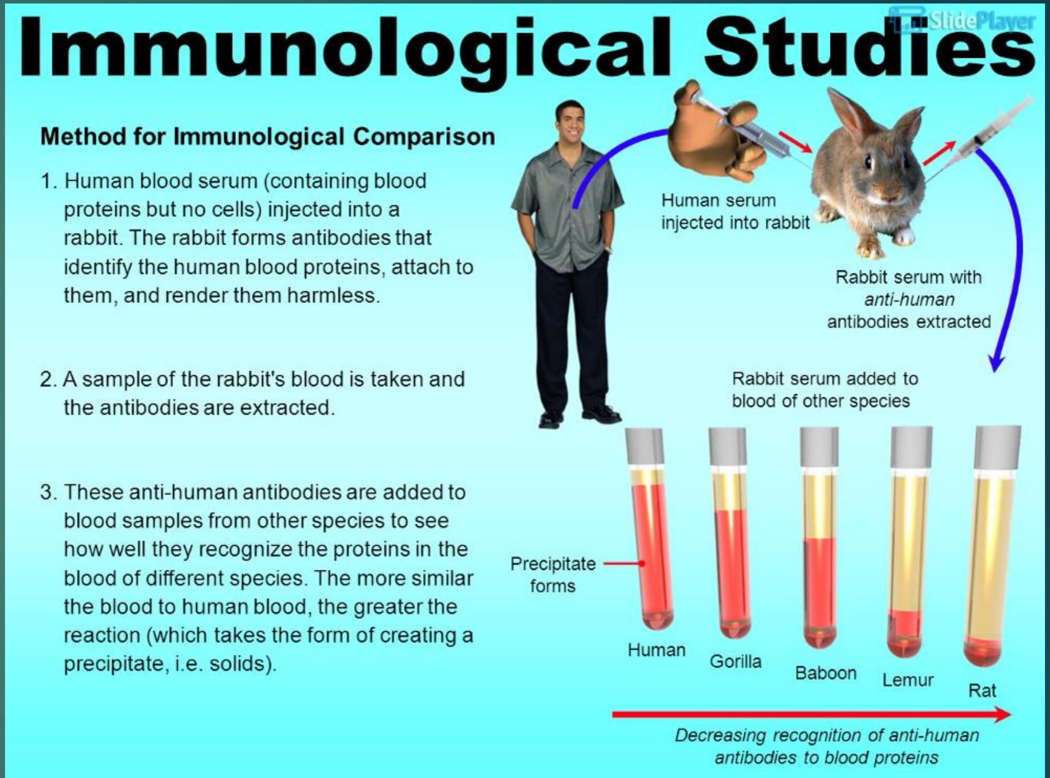
Primate	**No. of amino acids different from humans**	**Position of changed amino acids**
Chimpanzee	Identical	–
Gorilla	1	104
Gibbon	3	80 87 125
Rhesus monkey	8	9 13 33 50 76 87 104 125
Squirrel monkey	9	5 6 9 21 22 56 76 87 125

The 'position of changed amino acids' is the point in the protein, composed of 146 amino acids, at which a **different** amino acid occurs.

Protein Analysis

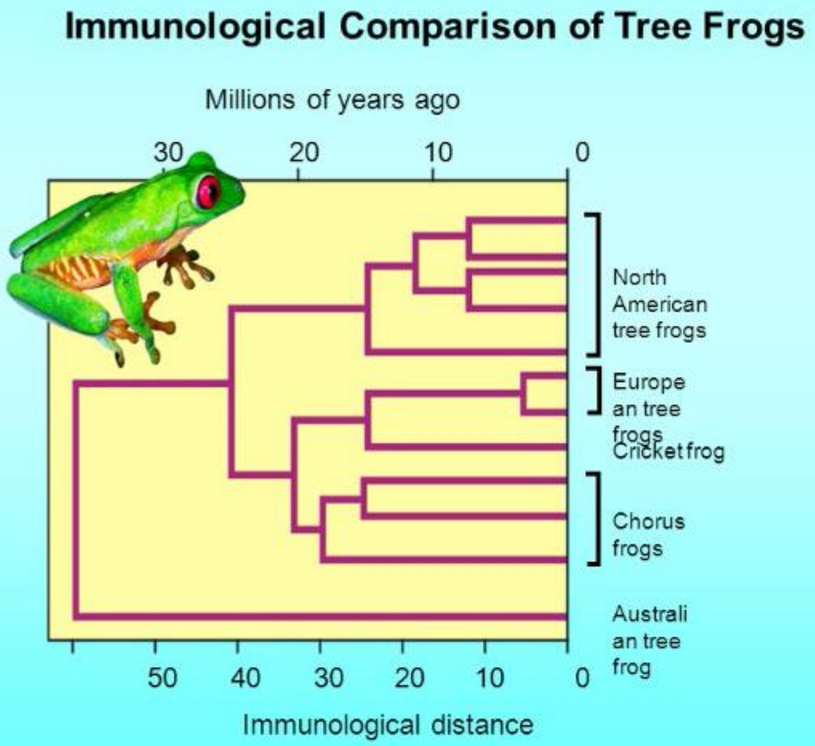
Immunological Techniques

- Immunology indirectly measures the degree of similarity of proteins in different species.
  - **EXAMPLE**: Anti-human antibodies are developed in a rabbit and added to the blood of other species.
  - The greater the similarity between humans and the blood of other species the greater the antibody-antigen reaction.

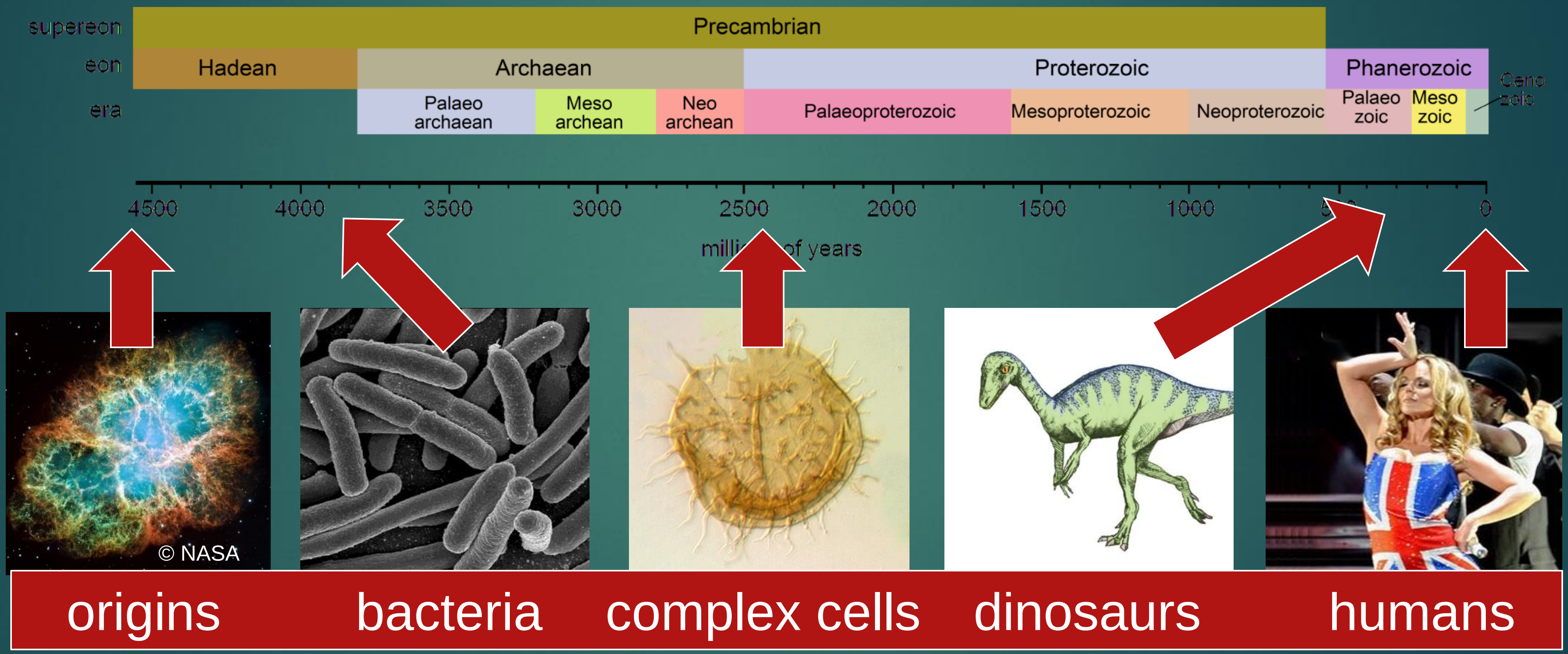


Immunological Evidence

- The evolutionary relationships of a large number of different animal groups have been established on the basis of **immunology**.
- The results support the phylogenies developed from other areas of biology: biogeography, comparative anatomy, morphological studies, and fossil evidence.
- **Example**: relatedness of tree frogs.
  - The phylogeny (evolutionary relationships) of tree frogs has been established by immunology.
  - The immunological distance is the number of amino acid substitutions between taxa.



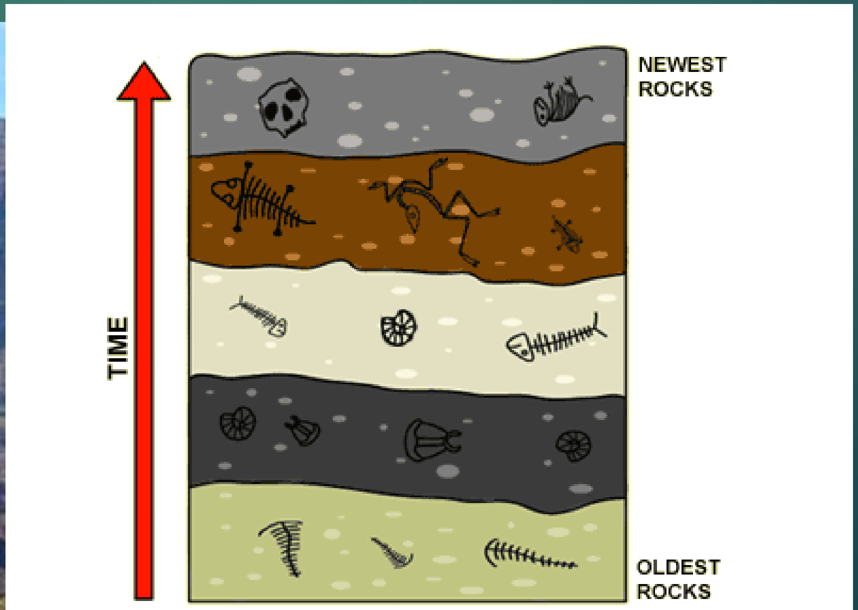
Evidence of Evolution: 4 - Fossil Record

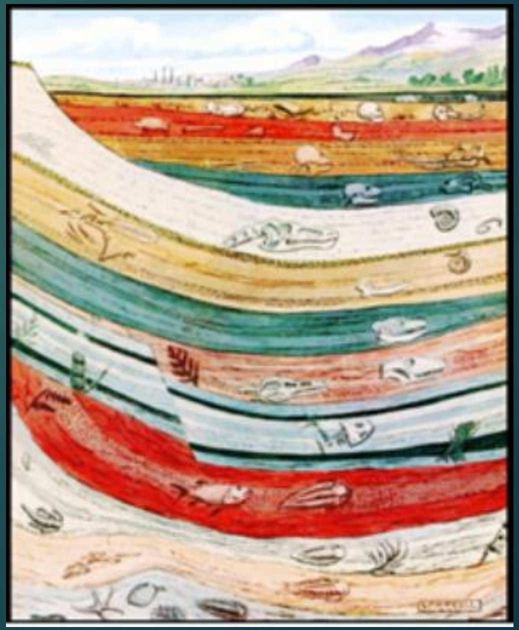


The fossil record: a sequence from simple bacteria to more complicated organisms through time and provides the most compelling evidence for evolution.

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.



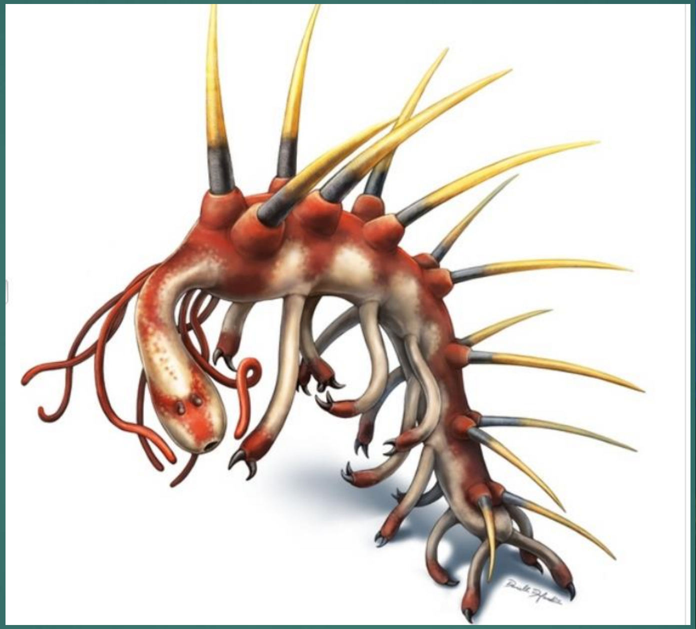


Fossils

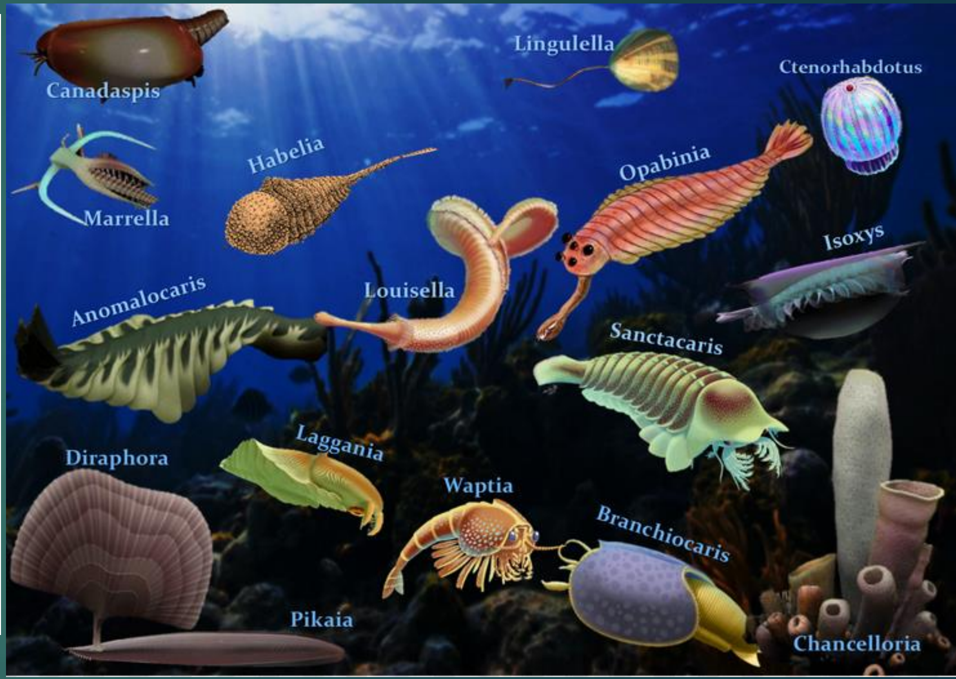
- Paleontology reveals a clustering pattern in the dimension of time.
  - The vertical column of geologic strata, laid down by sedimentary processes over the eons,
  - lightly peppered with fossils,
  - represents a tangible record showing which species lived when.
- Younger layers of rock lie atop more 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.

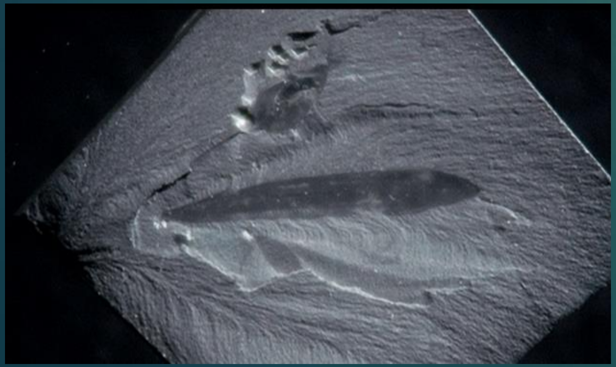
Origin of Animals

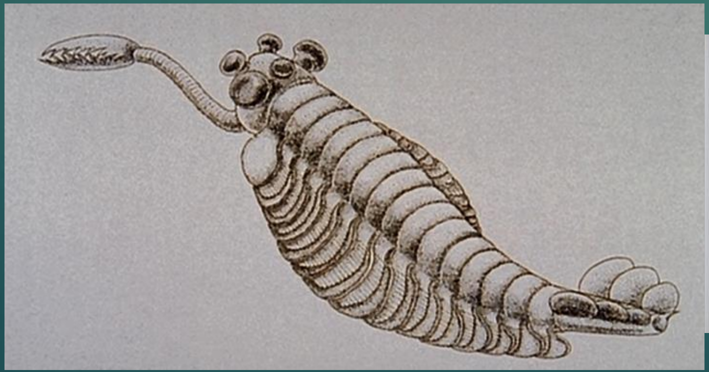
- Appear 570 Ma in Cambrian explosion

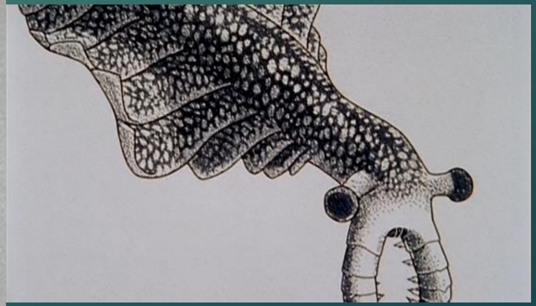
- Charles Walcott discovered Burgess Shale in 1909; result of catastrophic mudslide; 60,000 fossils

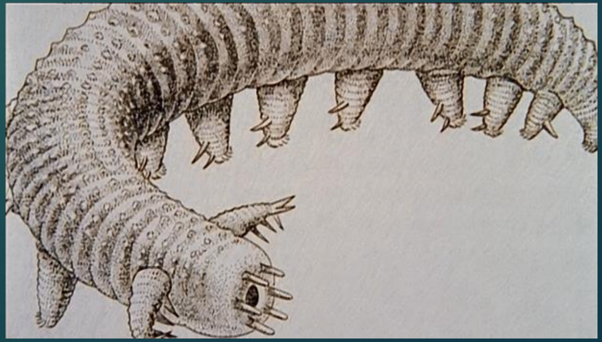
- All animal phyla appeared; 75% still with us; No new phyla since; All current body plans were present then

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









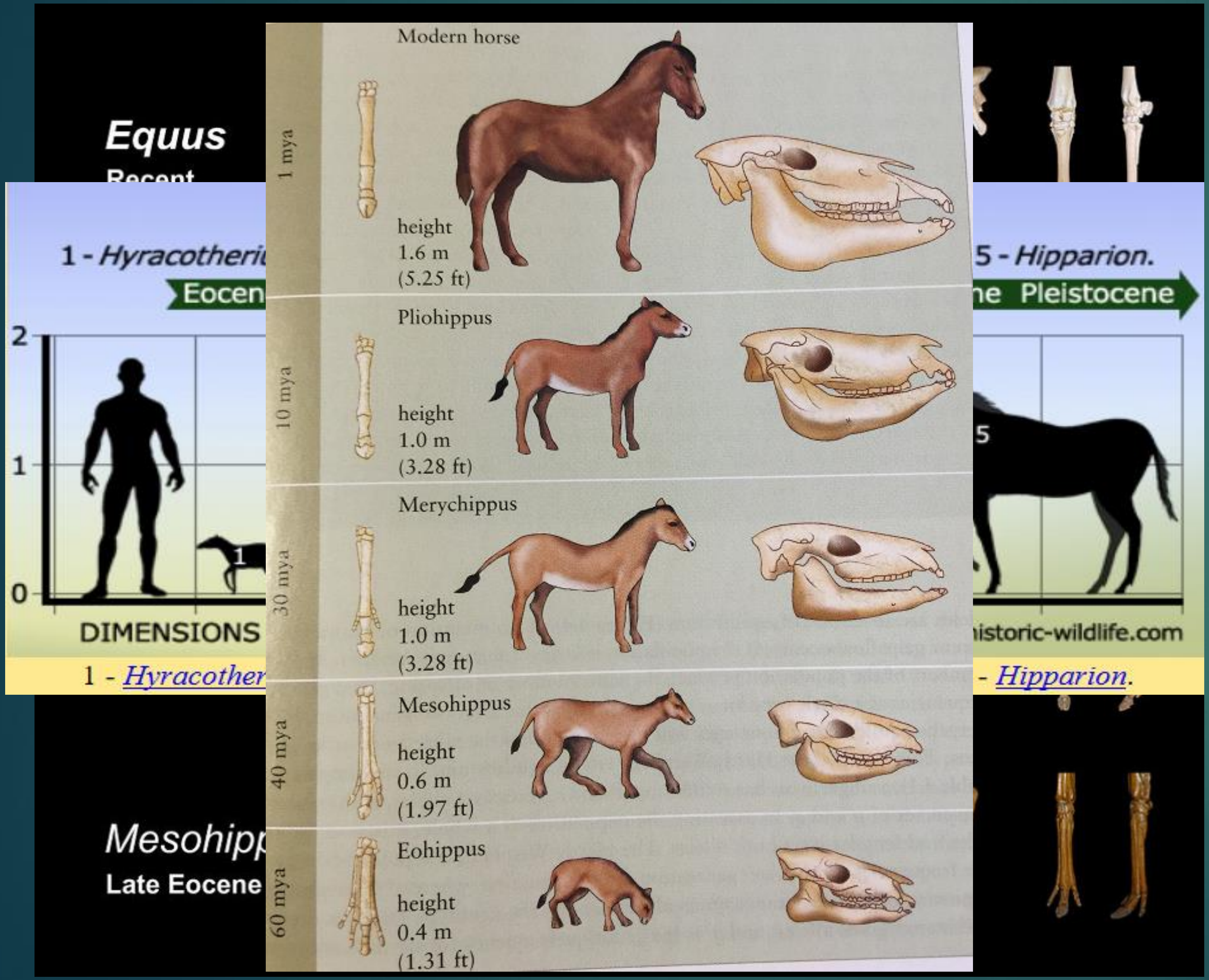
Cambrian Revolution: 542-580 Mya

- In 40 M years:
  - All animal phyla appeared
  - 75% still with us; No new phyla since
  - All used olfaction
  - No complex behavior before
  - After, complex sensory systems, especially in predators
  - Movement beyond just reaction to stimuli
  - Then ability to learn, ability to predict, ability to control
  - Cambrian bloodbath of predator eating predator that probably supplied the selective force necessary for the evolution of the first brains.
  - Development of olfactory navigational system, which could map spatial valences, lead to an arms race between predators and prey

Fossils

- In North America, for example, a vaguely horselike creature known as *Hyracotherium* was succeeded by *Orohippus,* then *Epihippus,* then *Mesohippus,* which in turn were succeeded by a variety of horse like American creatures.
- Some of them even galloped across the Bering land bridge into Asia, then onward to Europe and Africa. By five million years ago they had nearly all disappeared, leaving behind *Dinohippus,* which was succeeded by *Equus,* the modern genus of horse.
- Closely allied species succeed one another in prehistoric time, as well as living nearby in space, because they're related through evolutionary descent.
- JBS Haldane: there would be a falsification of the theory of evolution if we found a fossil rabbit in Pre-Cambrian, or a horse along with a trilobite.

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

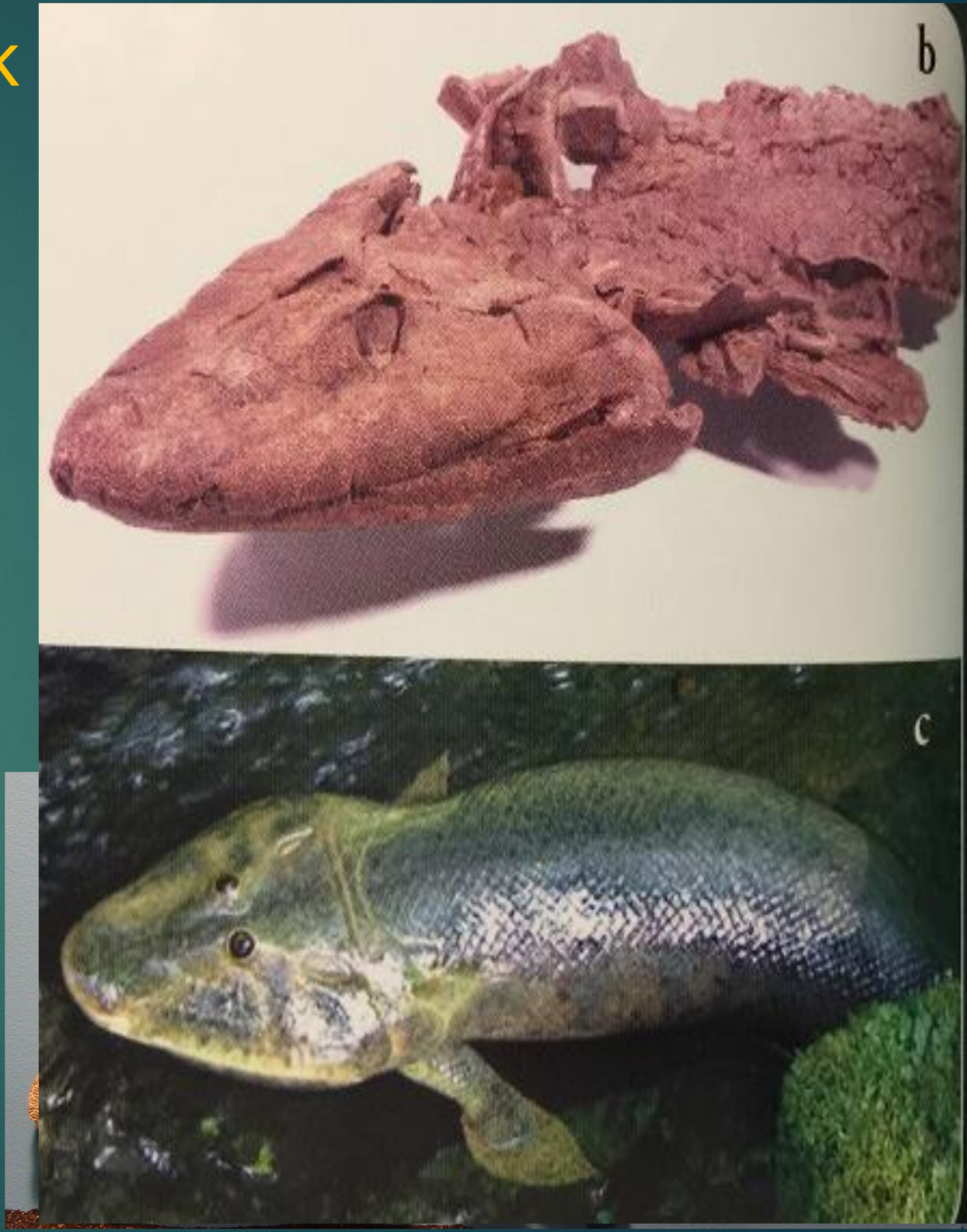
en.wikipedia.org/wiki/Image:Archaeopteryx_lithographica_paris.JPG

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



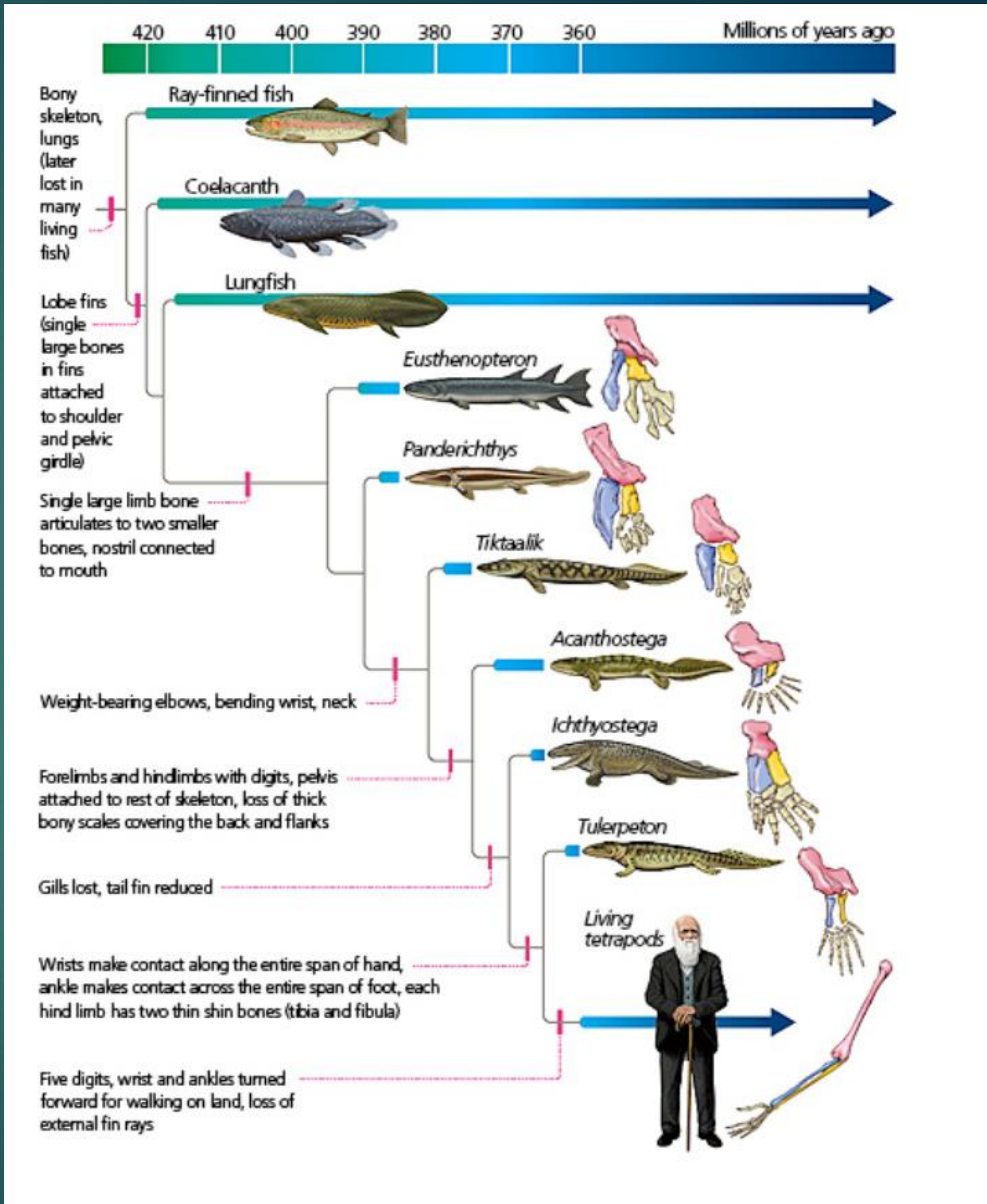
Lobe-finned fish: 395 Ma

Early tetrapod: 365 Ma

Modern Amphibian

Transition from water to land

- All land animals are tetrapods
- Old idea: fish came on land with fins & then developed legs;
- Current theory that fish first developed gills, fish-like tail, and paddle shaped fins while in the water (*Acanthostega, 370 Ma*) –



Transitional forms

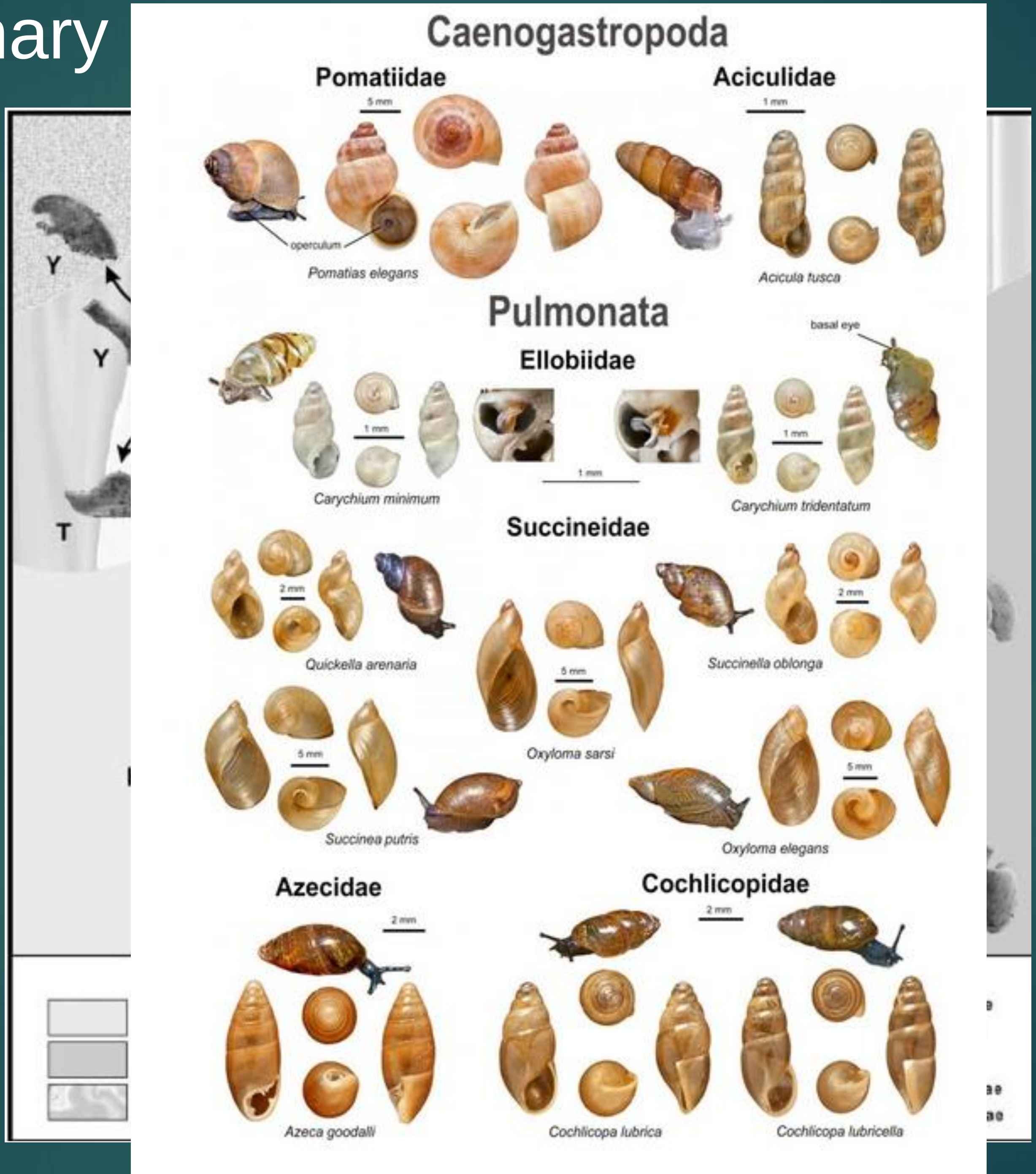
- Fish to tetrapods sequence: *Osteolepis* to *Eusthenopteron* to *Panderichthys* to *Tiktaalik* to *Elginerpeton* to *Ventastega* to *Acanthostega* to *Ichthyostega* to *Hynerpeton* to *Tulerpeton* to *Pederpes* to *Eryops*.

- Fossil seashells trace the evolution of various mollusks through millions of years.

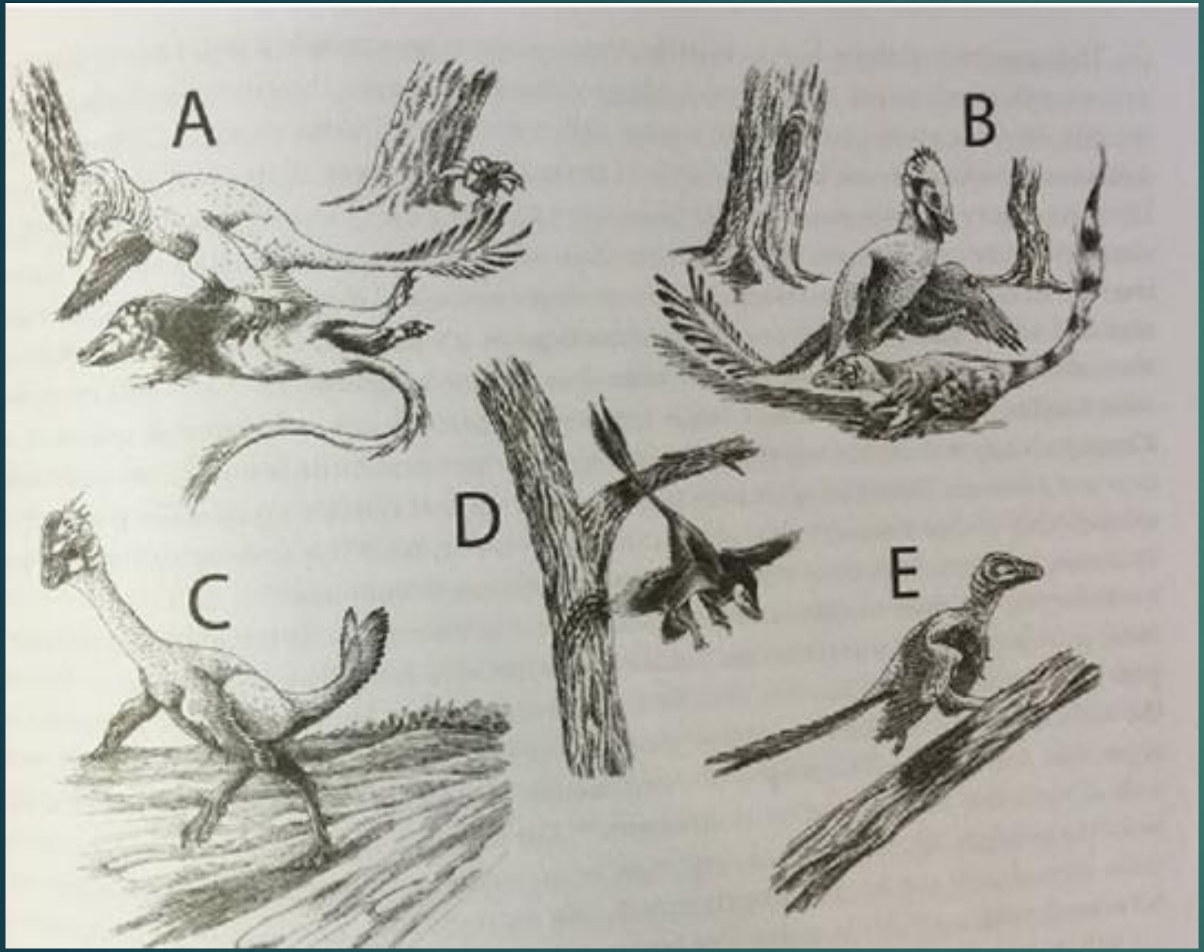
- Perhaps 20 or more hominins (not all of them our ancestors) fill the gap between Sahelanthropus at 7 Ma and modern humans.

- All organisms share most of the same genes, but as evolution predicts, the structures of these genes and their products diverge among species, in keeping with their evolutionary relationships.

Various evolutionary



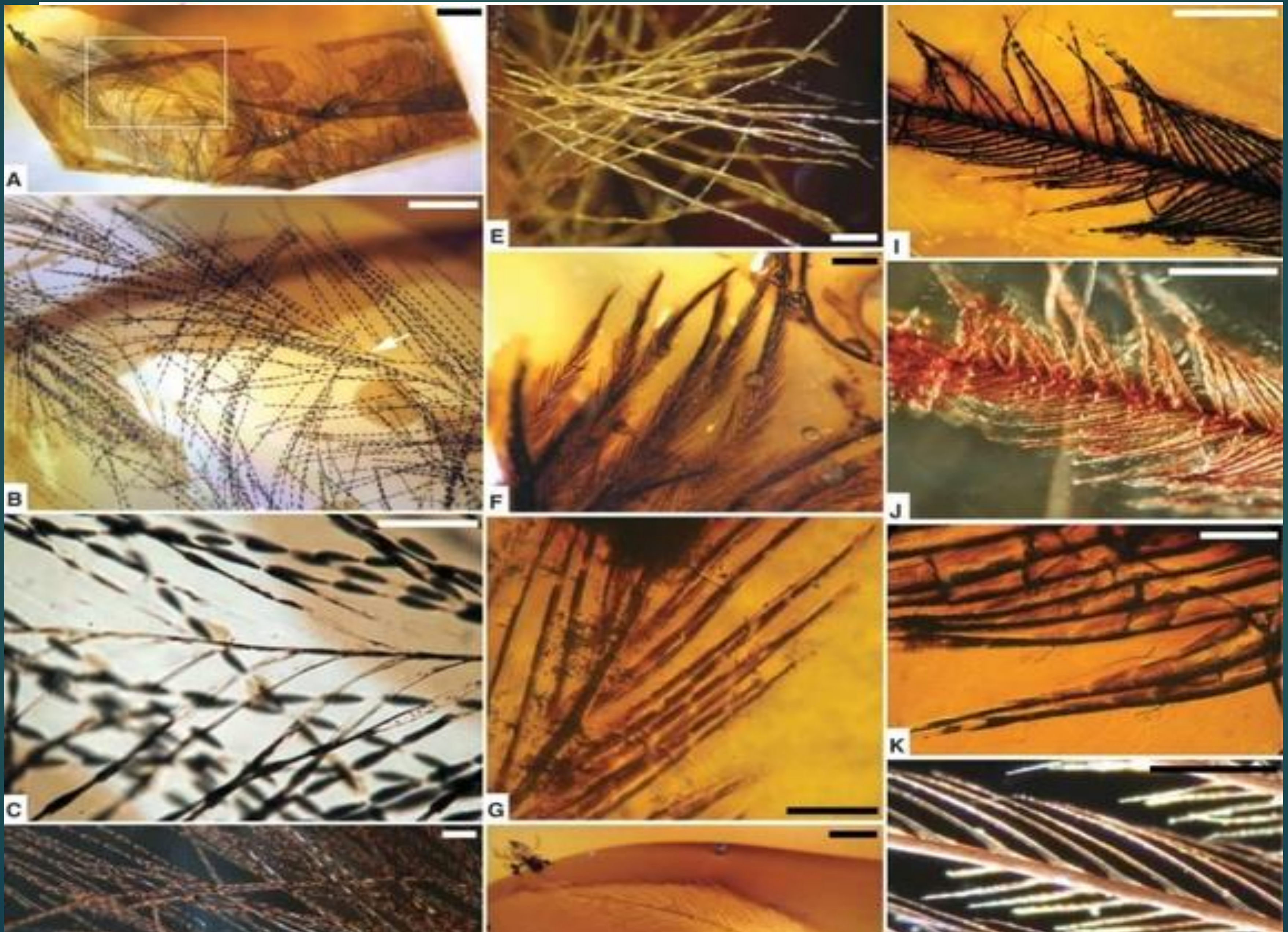
Evolution of flying

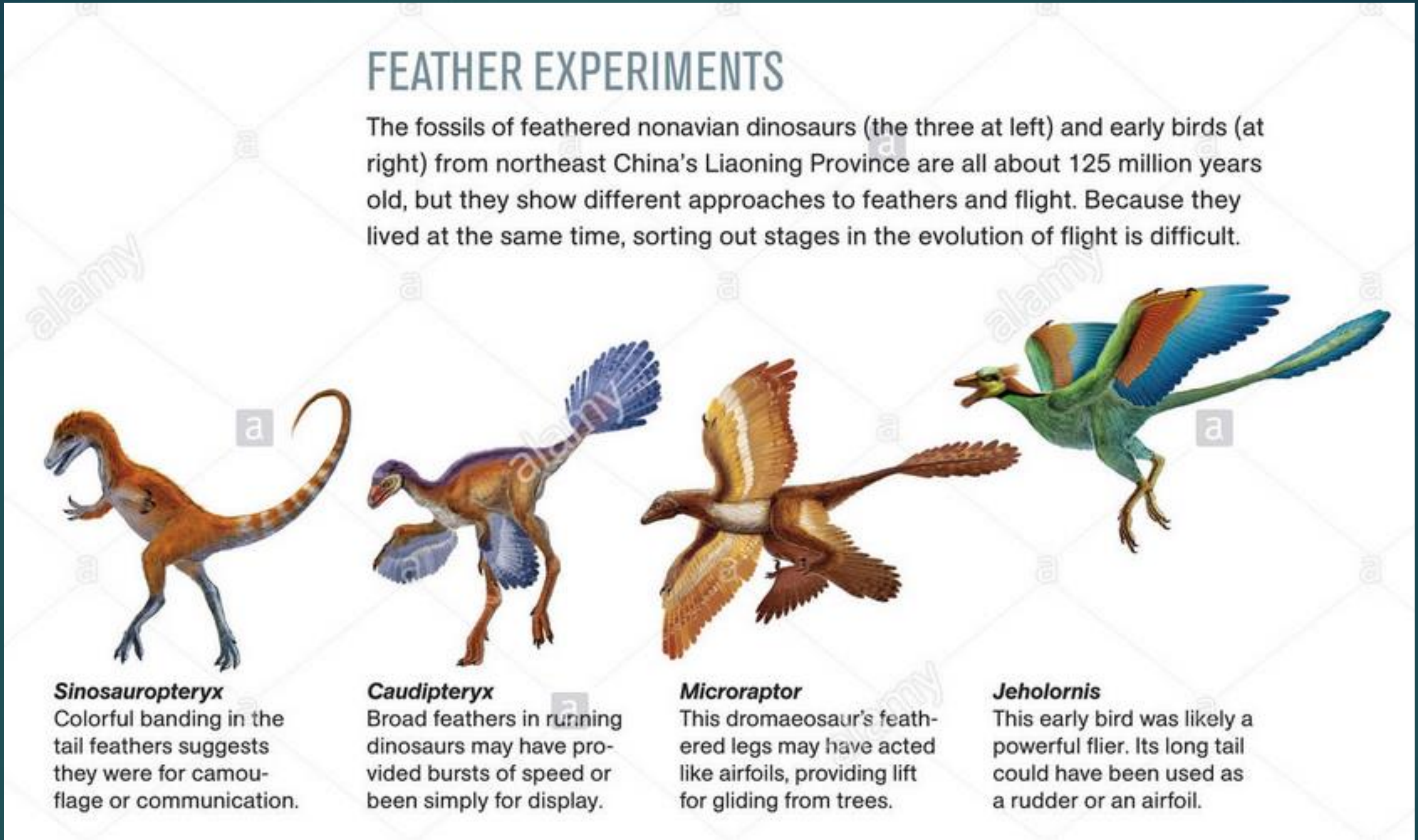


- Potential steps: 5 aerodynamic functions that wings could have served in feathered dinosaurs; <u>each of which is used by at least 1 modern bird</u>:
- A. <u>Flapping</u> in order to keep balanced while holding prey
- B. Using their wings to <u>steer</u> themselves midair when leaping to attack
- C. Flapping to <u>steer or produce thrust</u> while running
- D. Using wing to <u>glide out of trees</u>
- 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)





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*.

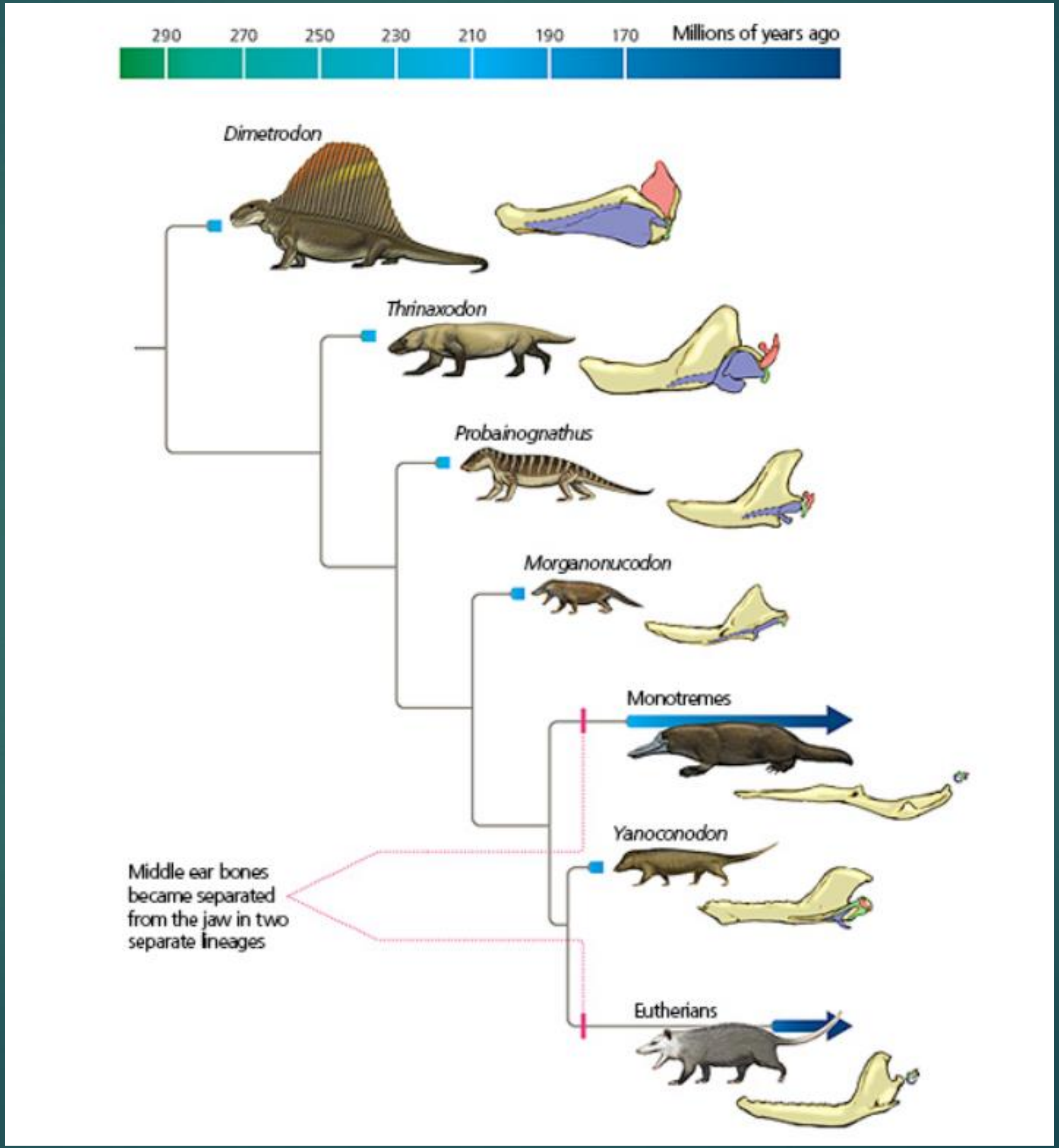
Oldest foss

▲ *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

Agilodoco

Night tim ects.

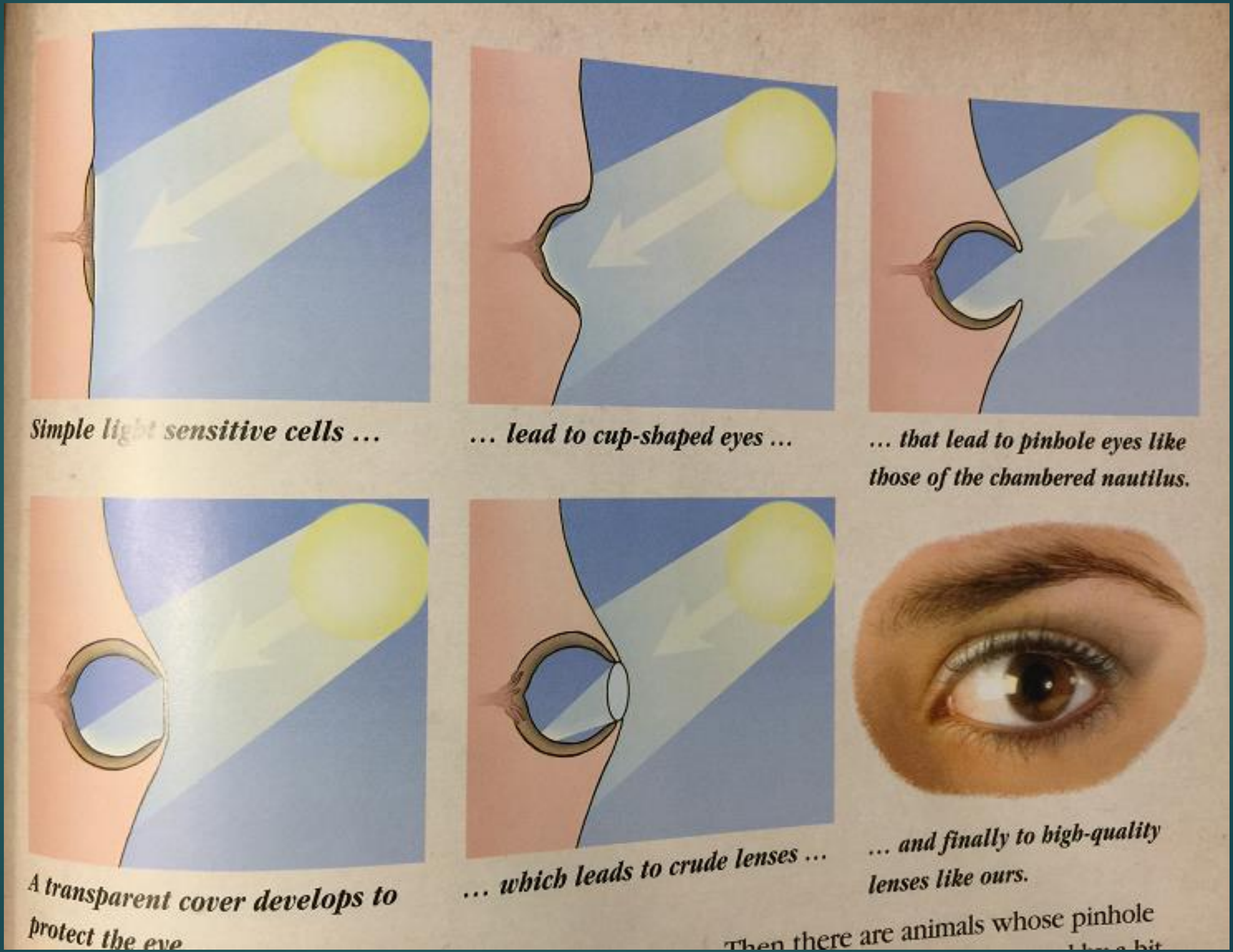
Reptile to mammals: jaw to ear bones



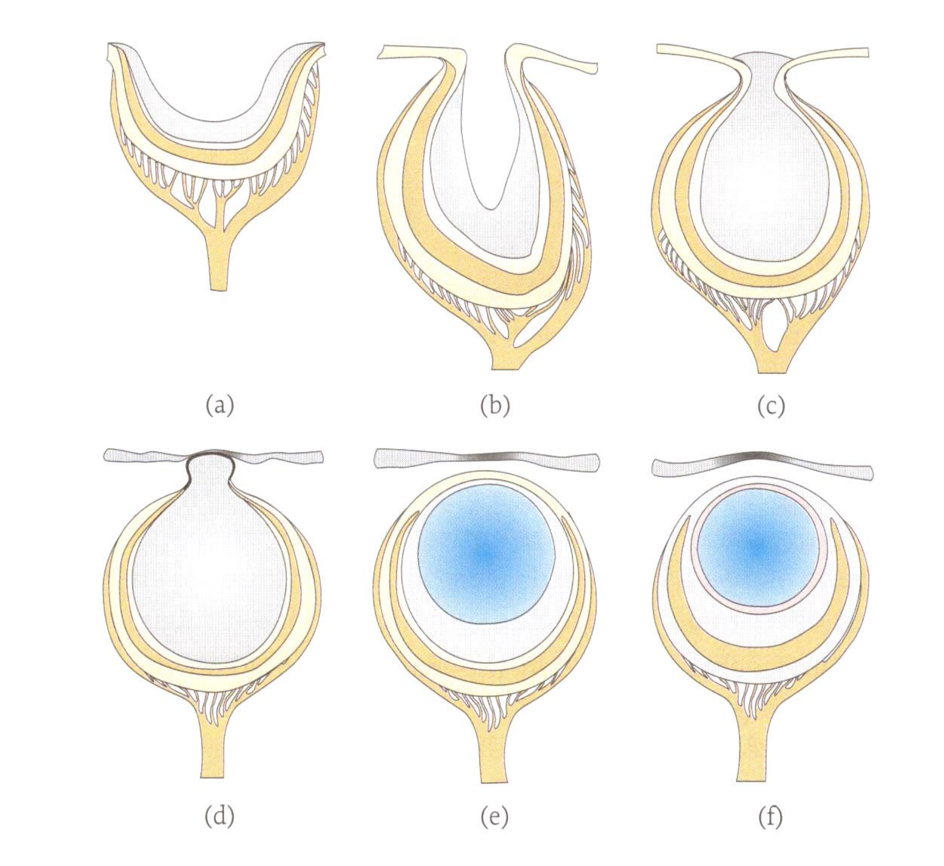
Argument from design: the eye

- 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.

How to evolve a complex eye



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]

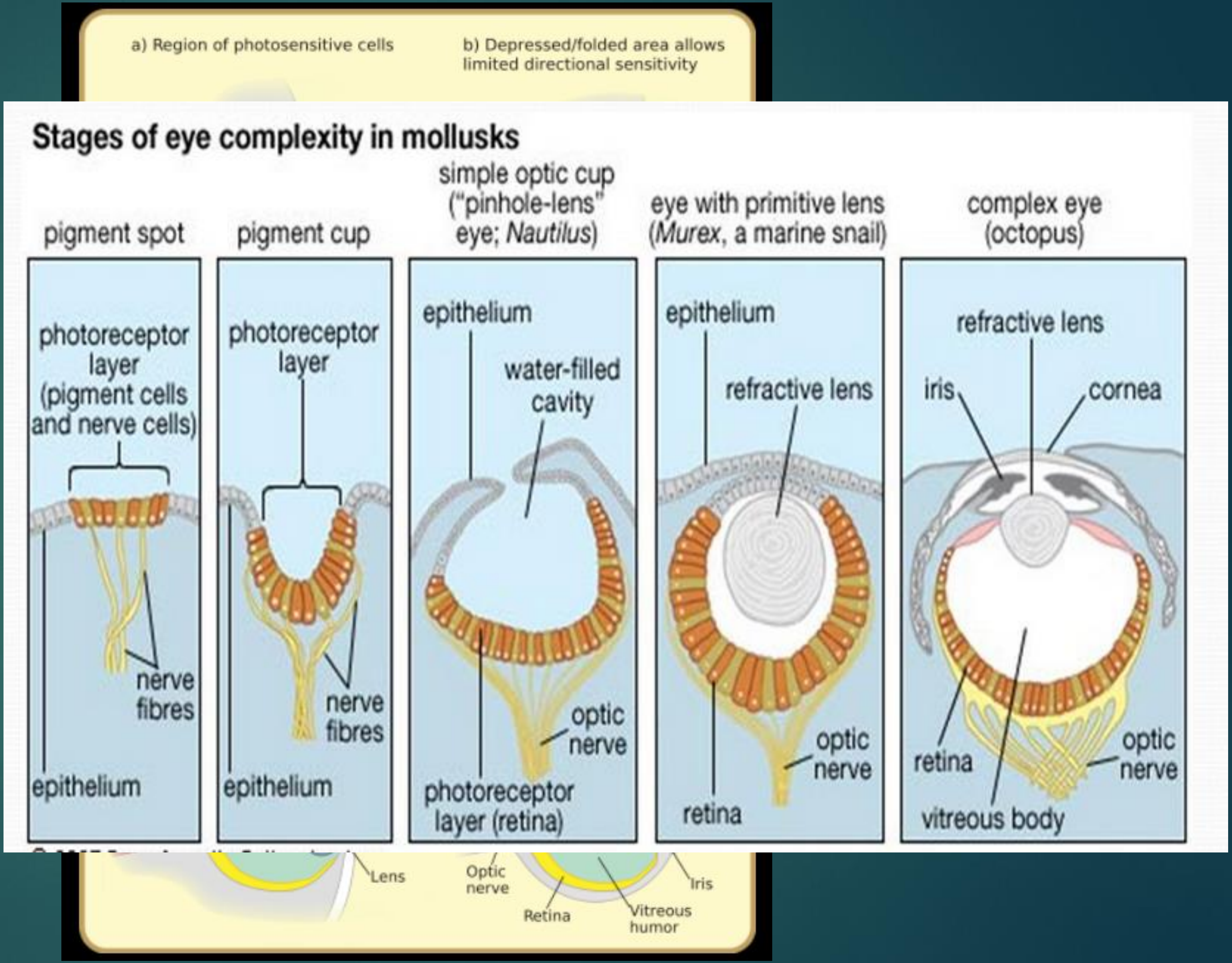
Human eye contain imperfections due to it's evolution, i.e. retinal tear/detachment; blind-spot because nerve comes thru hole

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,

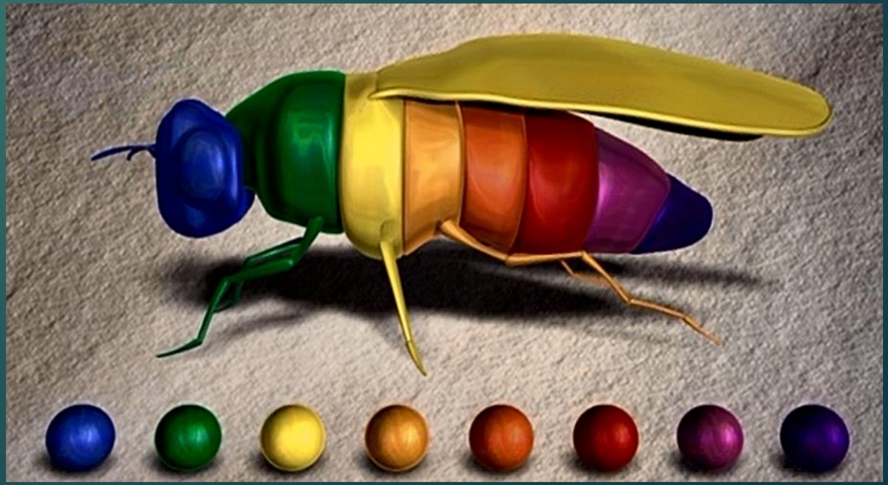
Eve: Basic to complex

- Complex image-forming eyes have evolved some 50 to 100 times,
- with the first eyes appearing in the fossil record 540 Ma

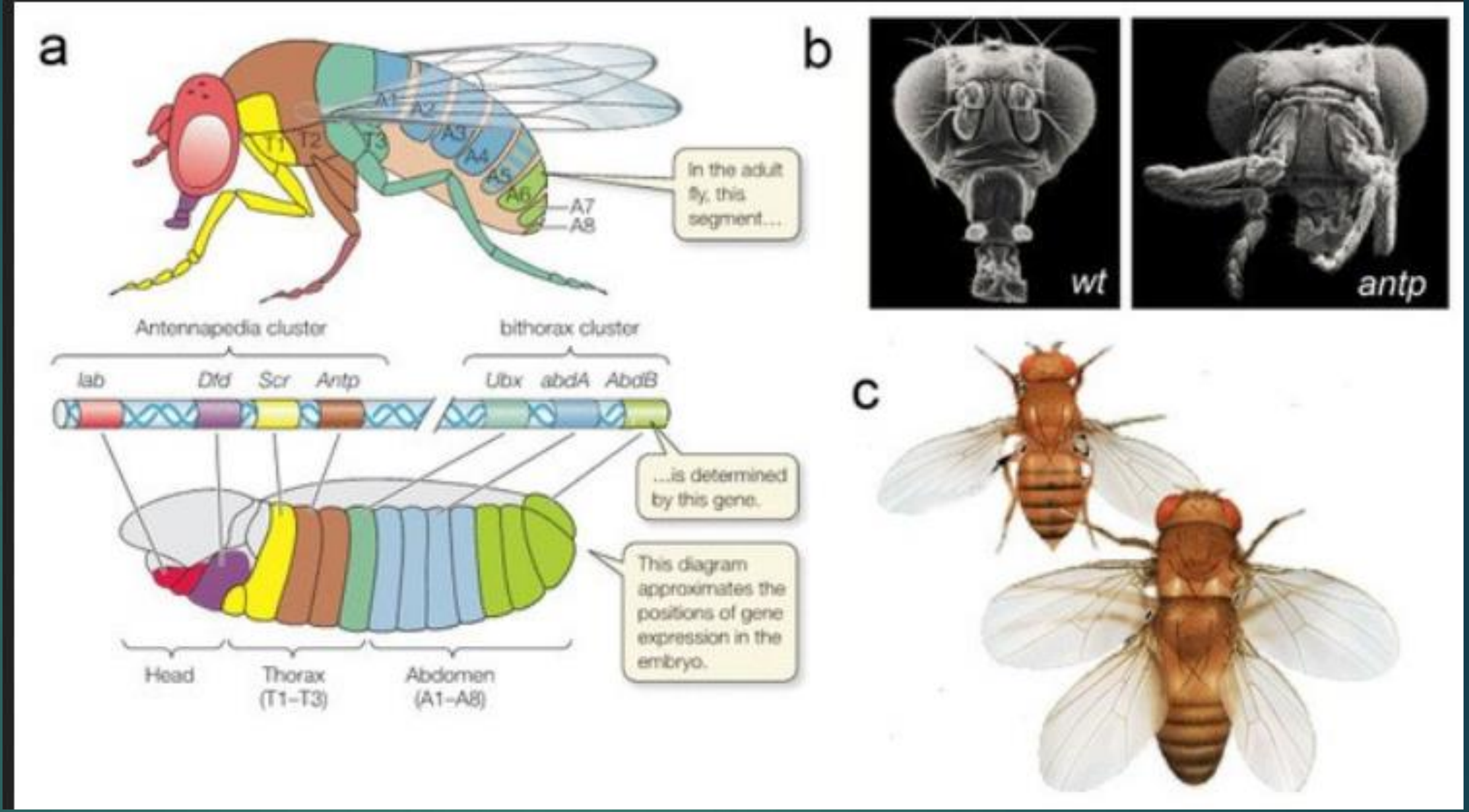


Evolution the tinkerer

- 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



Hox Genes

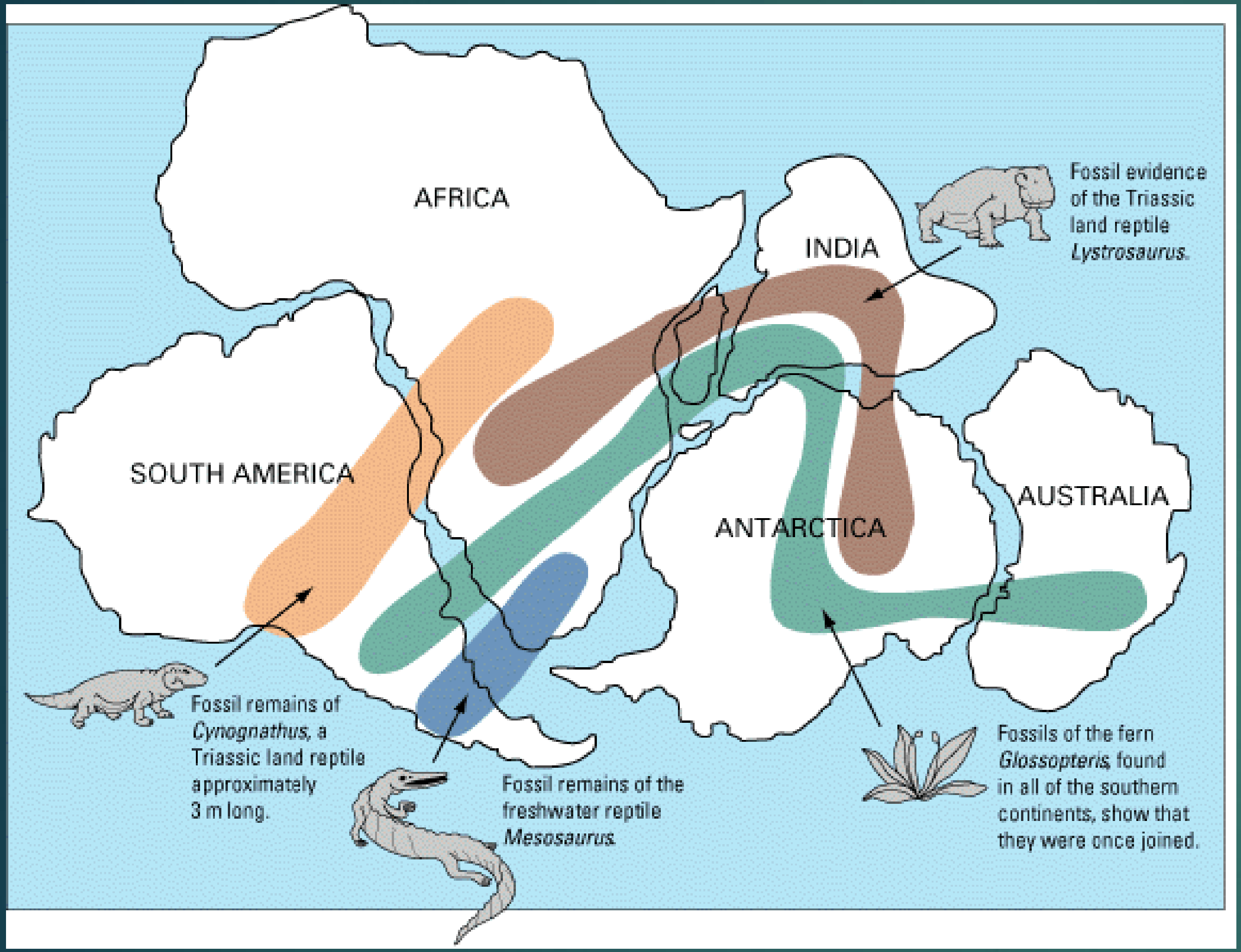


Hox genes provide for the basic blueprint of all segmented life, such as arthropods, insects, and organisms with backbones. They define what, if anything, should grow out of each segment of the body plan. Mutations in hox genes can replace antennae with legs, as in the above photo of a fly, or give humans 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.

Exaptation

- Exaptation (Stephen Jay Gould and Elisabeth Vrba): a trait's current use does not necessarily explain its historical origin. Not all is adaptation
- Describes a shift in the function of a trait during evolution.
- For example, a trait can evolve because it served one particular function, but subsequently it may come to serve another.
- Bird feathers are a classic example: initially they may have evolved for temperature regulation, but later were adapted for flight.
- Mammalian ear bones: repurposing of two of the three bones in the reptilian jaw to become the malleus and incus of the mammalian ear,

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

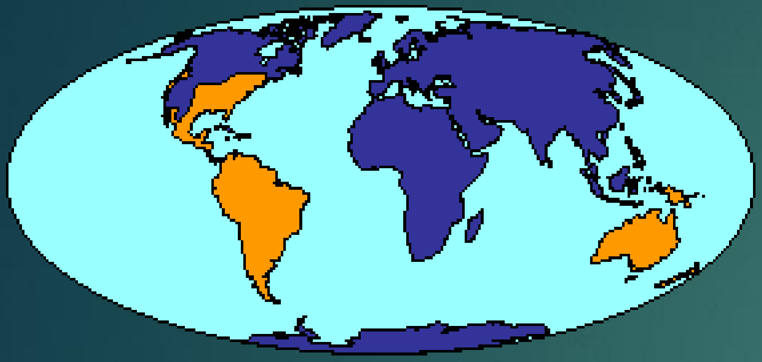
Biogeography: species distribution

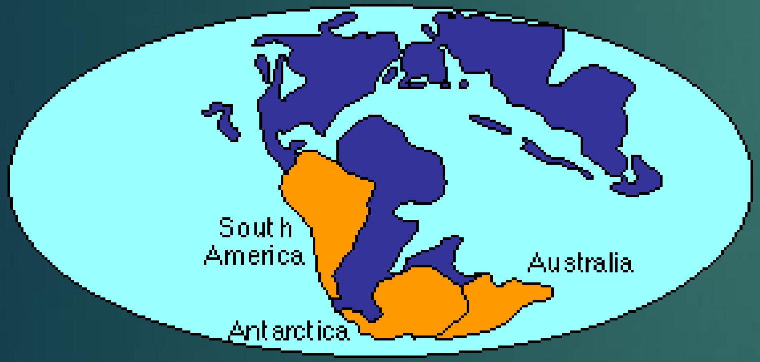
- The geographic distribution of organisms on Earth follows patterns that are best explained by evolutionary comment descent, in combination with the movement of tectonic plates over geological time.
  - Groupings of organisms that had already evolved before the breakup of the supercontinent Pangaea (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.

Biogeography

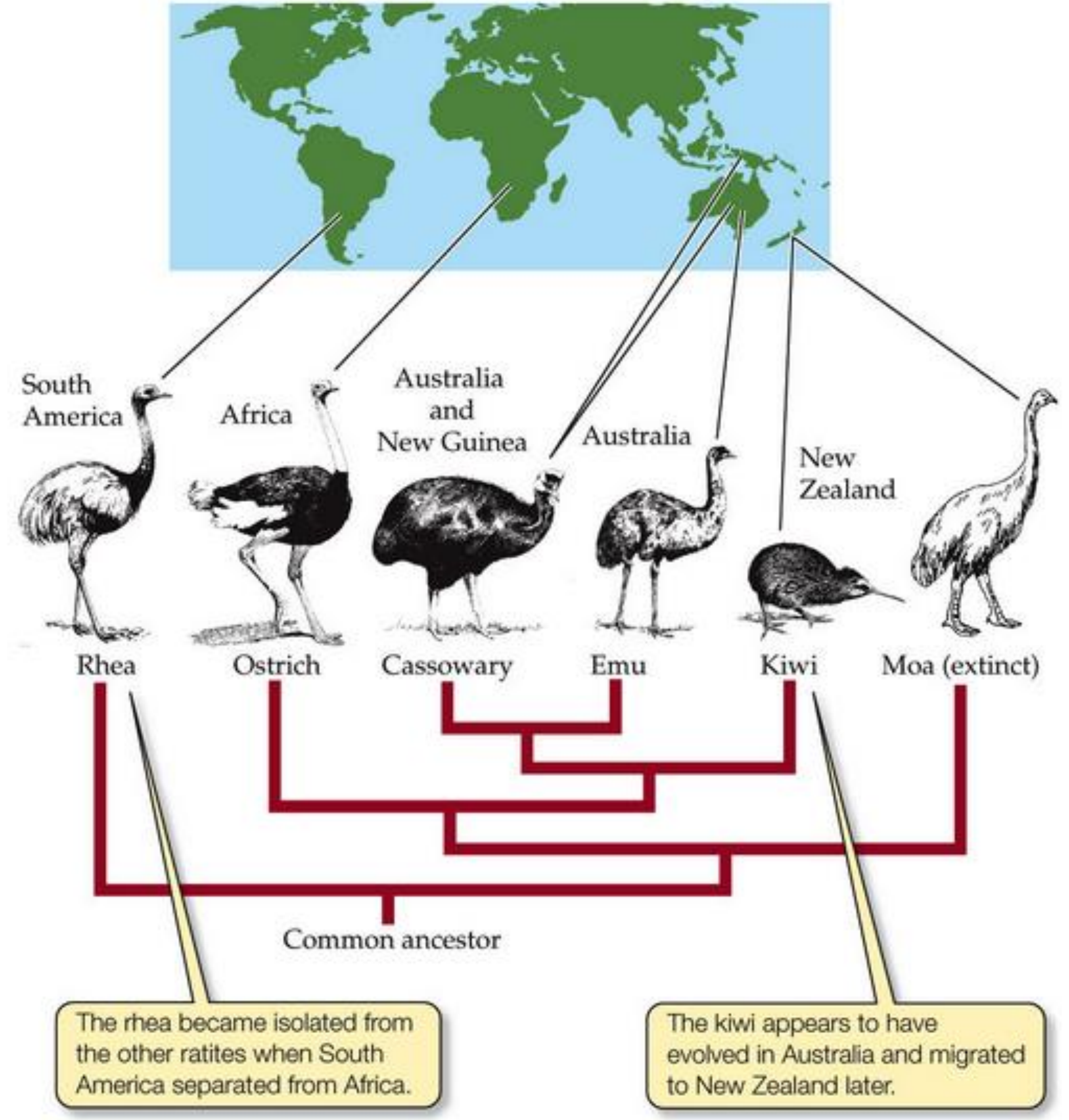


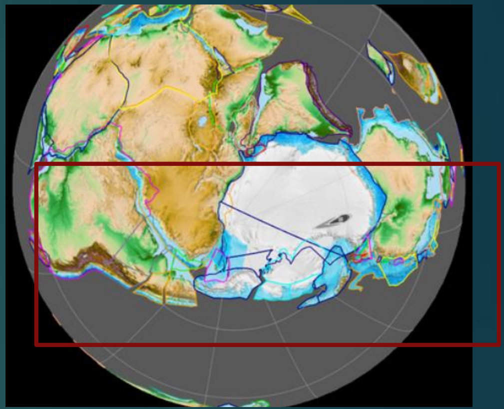


- Geographic spread of organisms also tells of their past evolution.
- Marsupials occur in two populations today in the Americas and Australia. Originated in N America, then S America, then Asia
- This shows the group evolved before the continents drifted apart (180 Ma)
- Found in Americas, Australia, Antarctica, South Africa

evolution.berkeley.edu/evosite/lines/IVCexperiments.shtml
en.wikipedia.org/wiki/Image:Kangaroo_and_joey03.jpg

Evolution of flightless birds





LCA from Gondwana during the Late Cretaceous

Biogeographical Evidence

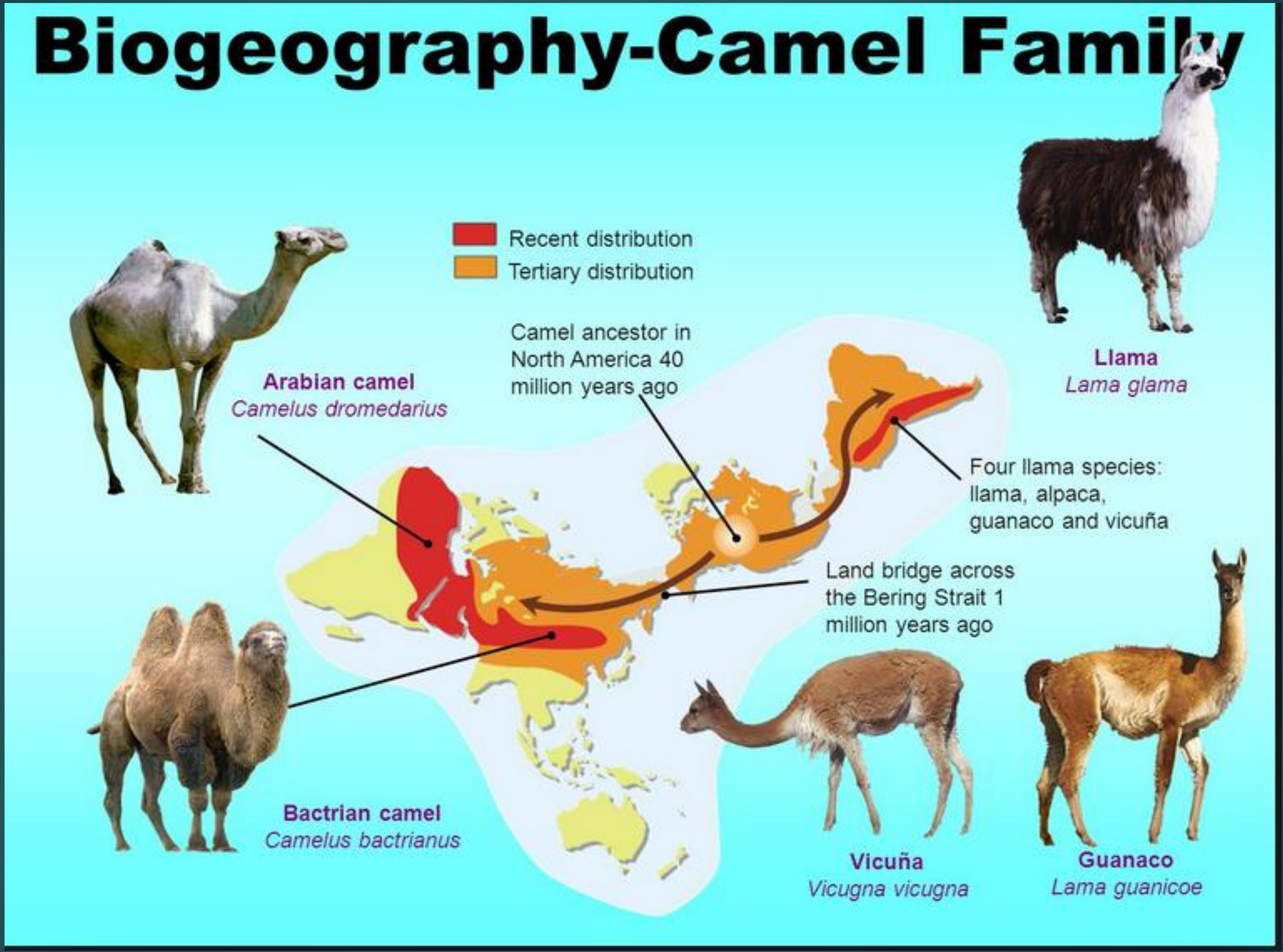
- The study of plant and animal distribution is called **biogeography**.
  - The basic principle of biogeography is that each plant and animal species **originated only once**. The place where this occurred is the **centre of origin**.
  - The **range of a species** can be very **restricted** or, as with humans, almost the whole world (**cosmopolitan**).
  - Regions that have been separated from the rest of the world for a long time (e.g. Madagascar, Australia, and New Zealand), often have **distinctive biota** comprising a large number of **endemic species** (species that are found nowhere else).

Biogeographical Evidence

- General principles for the dispersal and distribution of land animals are:
  - Closely related animals in different geographic areas probably had **no barrier** to dispersal in the past.
  - The most effective barrier to dispersal in land animals is **sea** (as when sea levels change).
  - The discontinuous distribution of modern species may be explained by **movement** out of the area they originally occupied, or by **extinction**.
- **Oceanic islands** often have species that are similar to, but distinct from, those on neighboring continents.
- The occurrence of these species suggests that they were island colonizers that evolved in isolation differently to their ancestors on the mainland.

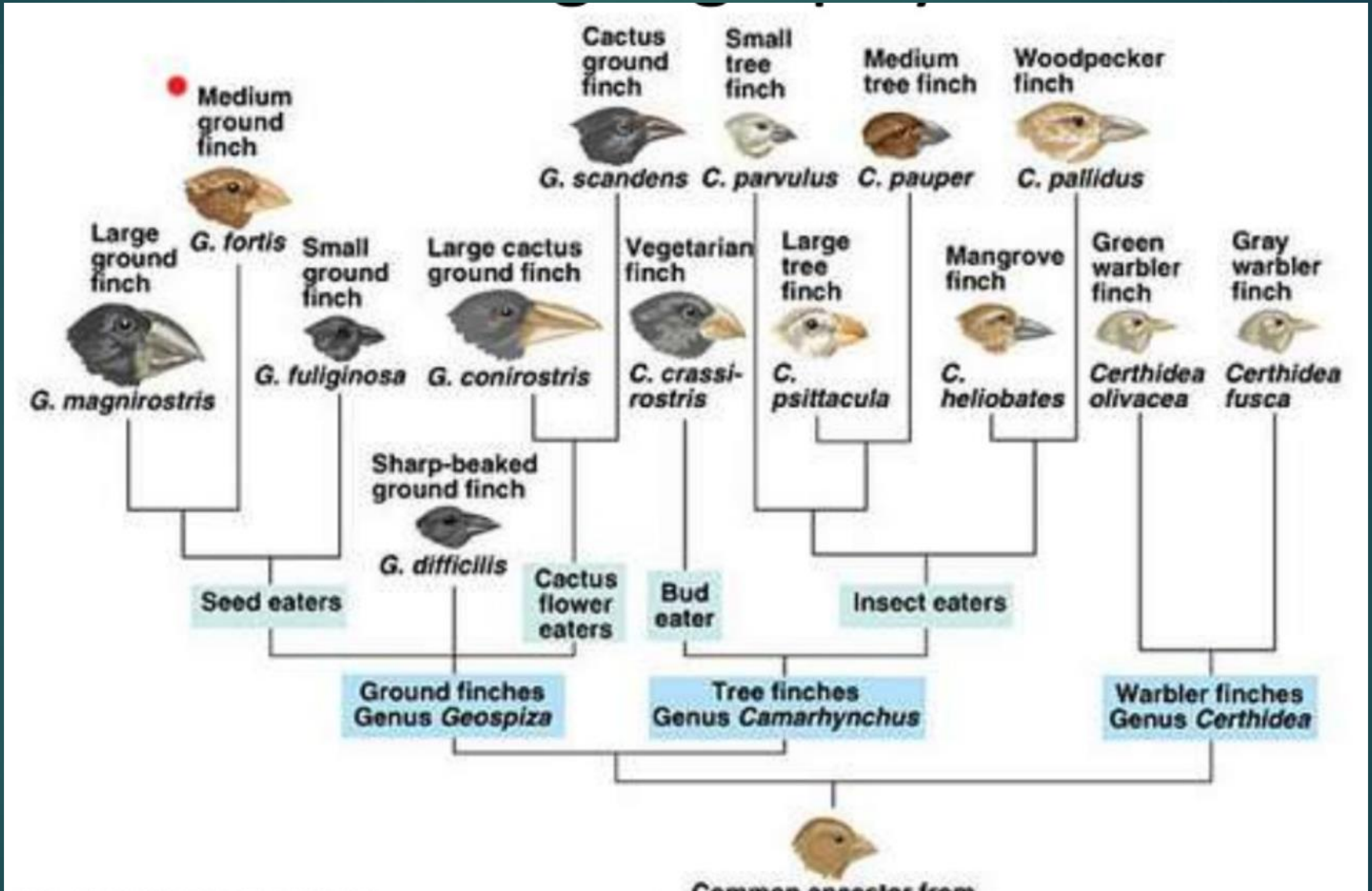
Biogeography-Camel Family

- The camel family comprises six modern-day species that have survived on three continents:
  - Arabian camel
  - Bactrian camel
  - Llama
  - Vicuña
  - Alpaca
  - Guanaco
- There are no surviving species on their continent of origin, North America, where they emerged about 40 million years ago and later dispersed to other continents.



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

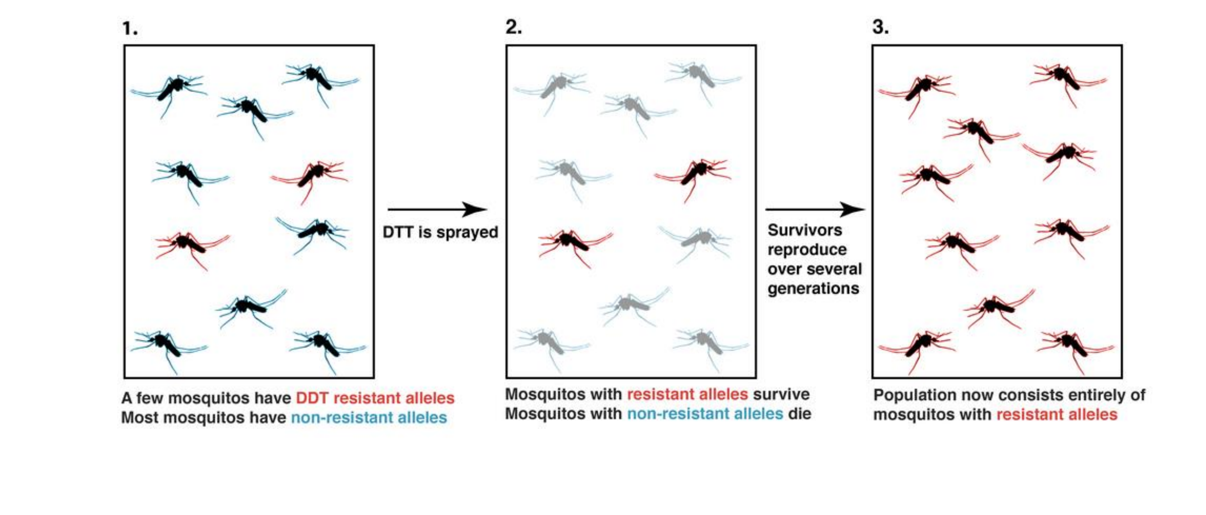
Biogeography: Galapagos Finches



(b) The Galápagos finches

Evidence for Evolution: 6 - Direct observation of microevolution

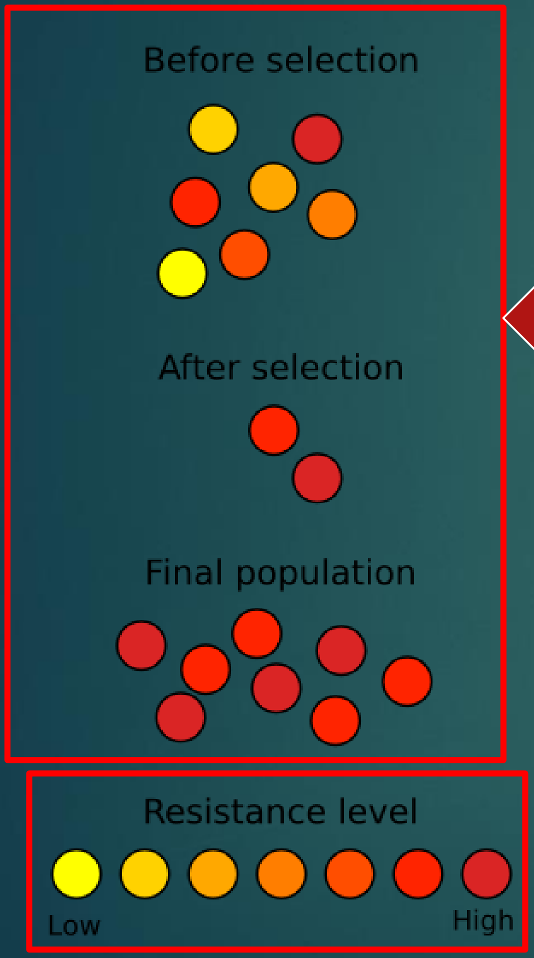
- In some cases, the evidence for evolution is that we can see it taking place around us! Important modern-day examples of evolution include the emergence of drug-resistant bacteria and pesticide-resistant insects.



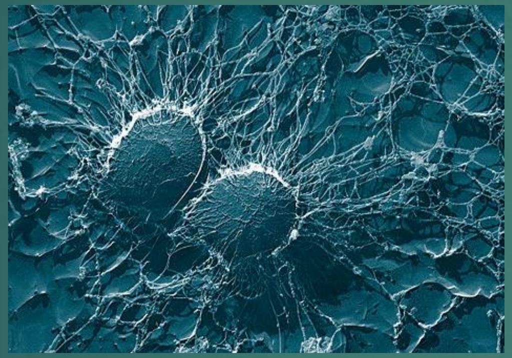
Emergence of DDT resistance is an example of evolution by natural selection[7].

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



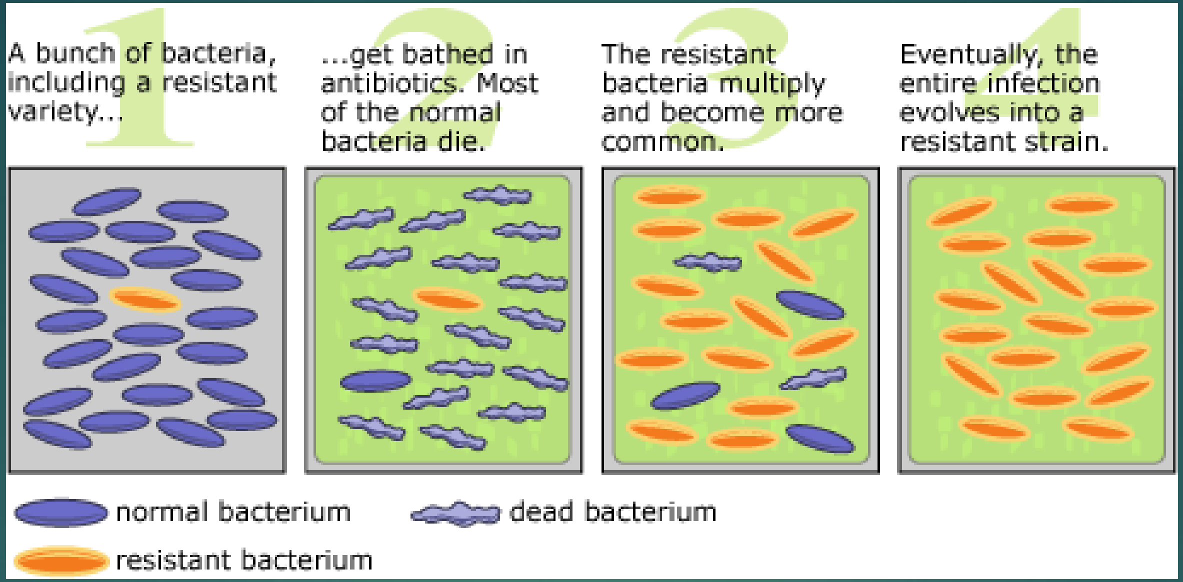
- We are all familiar with the way that certain bacteria can become resistant to antibiotics
- This is an example of natural selection in action. The antibiotic acts as an environmental pressure. It weeds out those bacteria with low resistance and only those with high resistance survive to reproduce.

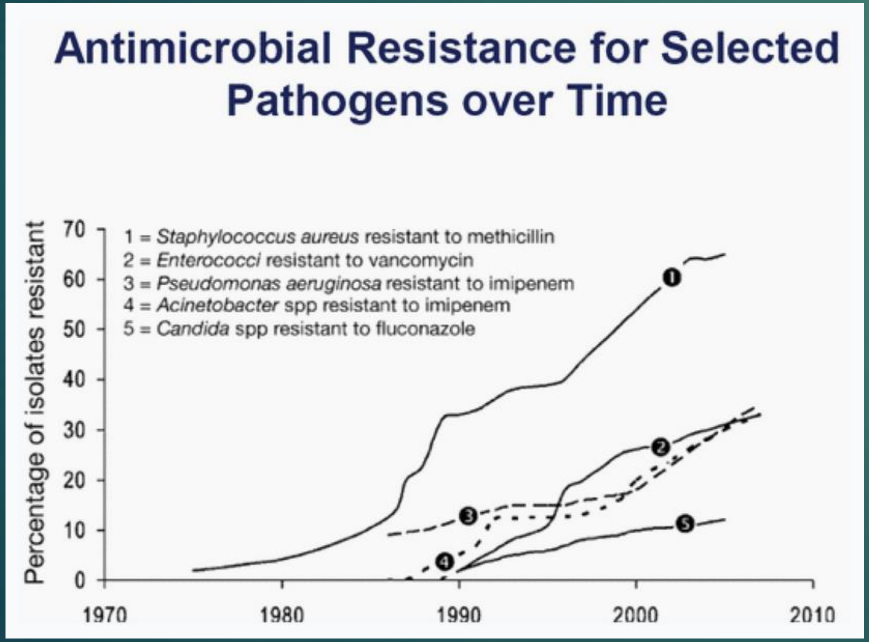
Penicillin – 1943; first resistant strains of *Staphylococcus* – 1947; Methicillin – 1960; resistance by 1980; Vancomycin - 1972, resistance by 2002; equal to evolution of the horse

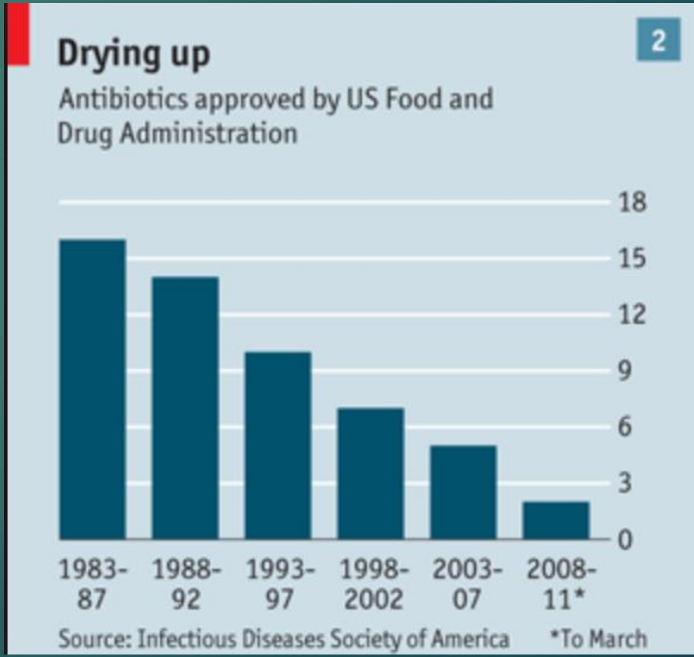
C. Lee Ventola, 2015

Resistance: each human body is an island,

- Take the common bacterium *Staphylococcus aureus,* which lurks in hospitals and causes serious infections, especially among surgery patients. Penicillin, becoming available in 1943, proved almost miraculously effective in fighting staphylococcus infections. Its deployment marked a new phase in the old war between humans and disease microbes, a phase in which humans invent new killer drugs and microbes find new ways to be unkillable. The supreme potency of penicillin didn't last long. The first resistant strains of *Staphylococcus aureus* were reported in 1947. A newer staph-killing drug, methicillin, came into use during the 1960s, but methicillin-resistant strains appeared soon, and by the 1980s those strains were widespread. Vancomycin became the next great weapon against staph, and the first vancomycin-resistant strain emerged in 2002. These antibiotic resistant strains represent an evolutionary series, not much different in principle from the fossil series tracing horse evolution from *Hyracotherium* to *Equus*
- Antibiotics exert a powerful evolutionary force, driving infectious bacteria to evolve powerful defenses against all but the most recently invented drugs. Insects and weeds acquire resistance to our insecticides and herbicides through the same process


A bunch of bacteria, including a resistant variety...
...get bathed in antibiotics. Most of the normal bacteria die.
The resistant bacteria multiply and become more common.
Eventually, the entire infection evolves into a resistant strain.
normal bacterium
dead bacterium
resistant bacterium


Antimicrobial Resistance for Selected Pathogens over Time
1 = Staphylococcus aureus resistant to methicillin
2 = Enterococci resistant to vancomycin
3 = Pseudomonas aeruginosa resistant to imipenem
4 = Acinetobacter spp resistant to imipenem
5 = Candida spp resistant to fluconazole
Percentage of isolates resistant
70
60
50
40
30
20
10
0
1970
1980
1990
2000
2010


Drying up
2
Antibiotics approved by US Food and Drug Administration
18
15
12
9
6
3
0
1983-87
1988-92
1993-97
1998-2002
2003-07
2008-11*
Source: Infectious Diseases Society of America
*To March

Bed Bugs, Pesticide Resistance, and Cancer

Modern bedbugs are increasingly resistant to pesticides. Some populations, in fact, can survive 1,000 times the amount of pesticide that would be needed to kill a traditional bug.

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%.

STOP!!

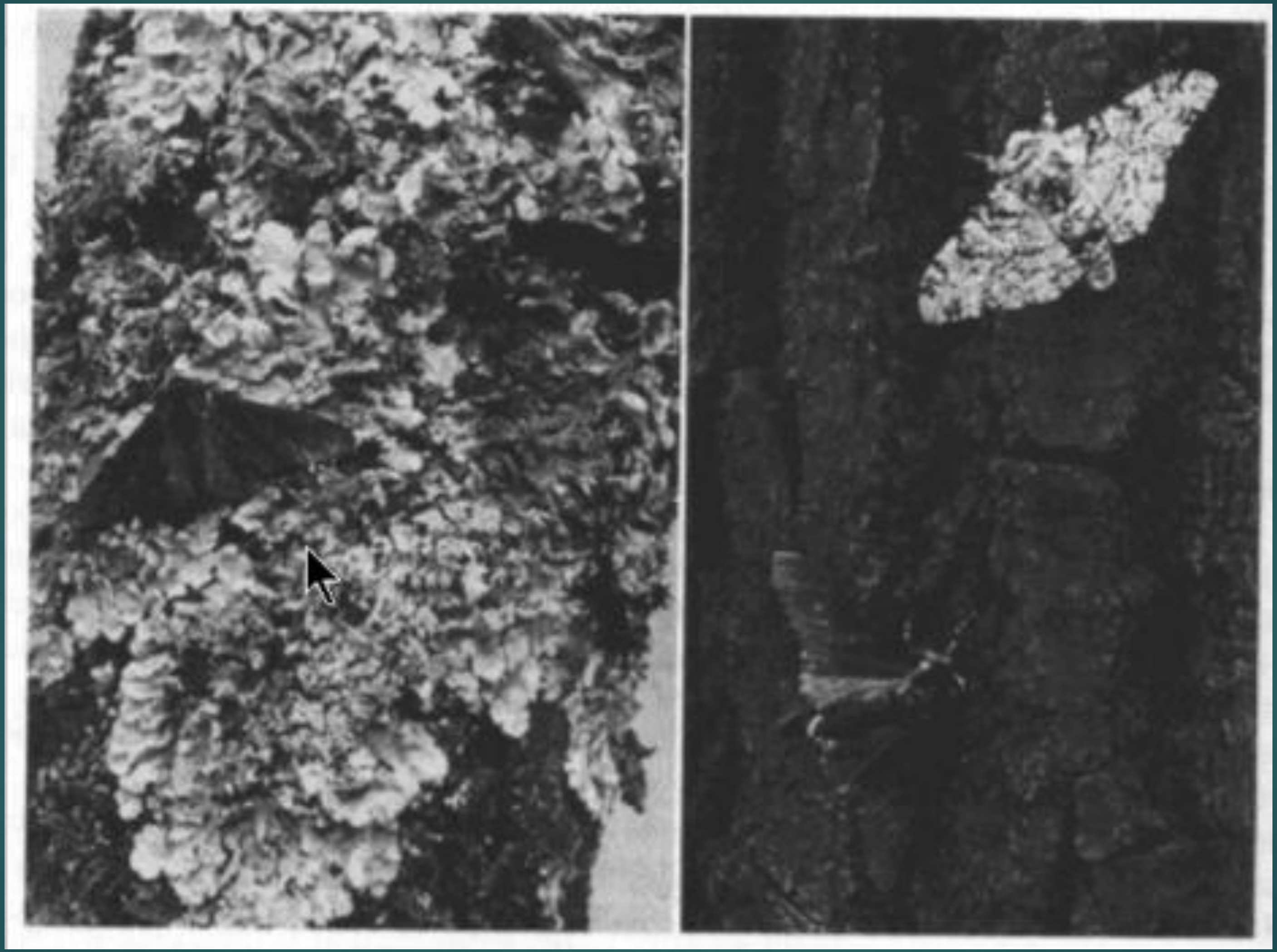
2000: 5%

2014: 11%

Antibiotic resistance

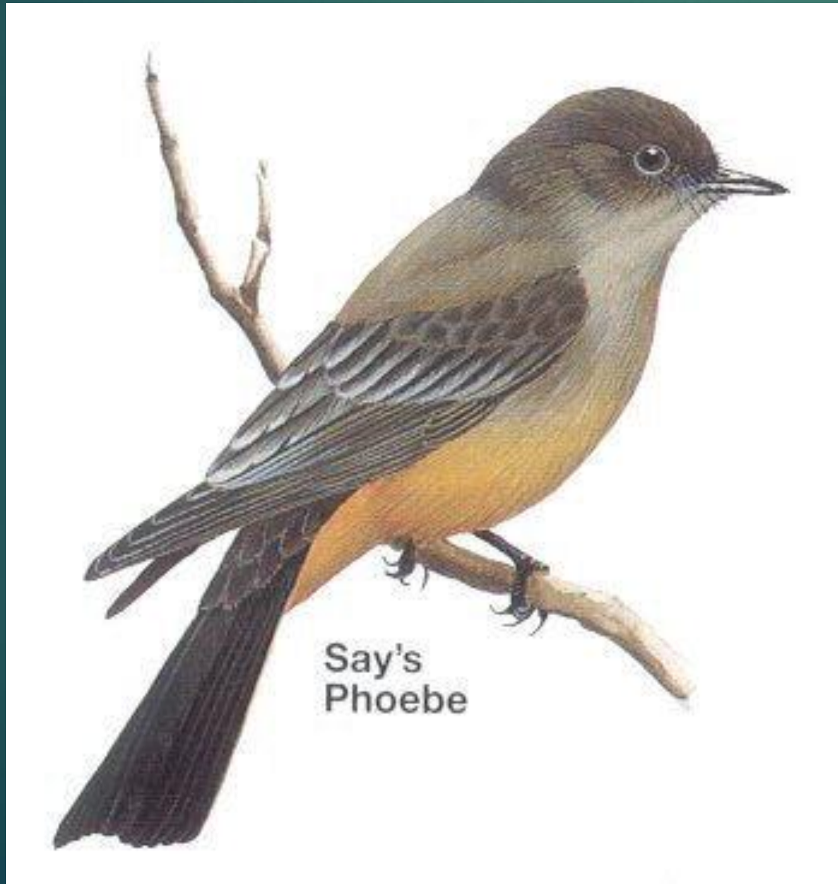
- Each year in the United States, at least 2 million people become infected with bacteria that are resistant to antibiotics and at least 23,000 people die each year as a direct result of these infections.
- There are drug resistant bacteria that kill 50% of infected; found in hospitals in 27 states in 2017
- These bacteria can spread to other patients, and spread their resistance genes to other bacteria
- 1 of 10 people tested were positive for the above bacteria; and could spread the bacteria
- Mostly in hospitals and nursing homes; wash your hands

Classic Example: Pepper Moths during Industrial Era in England



Peppered Moth

- Which moth will the bird catch?

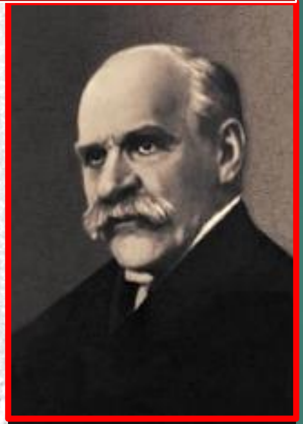


A

B

Peppered Moth

Haldane and the peppered moth



http://en.wikipedia.org/wiki/Image:Biston.betularia.7200.jpg
en.wikipedia.org/wiki/Image:Biston.betularia.f.carbonaria.7209.jpg
en.wikipedia.org/wiki/J._B._S._Haldane

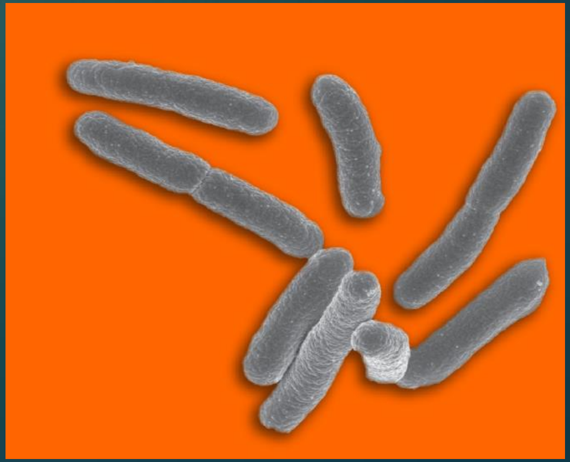
- The Peppered Moth is an example of Natural Selection in action discovered by Haldane
- During the Industrial Revolution the trees on which the moth rested became soot-covered.
- This selected against the allele for pale color in the population (which were poorly camouflaged from predators) and selected for the dark color allele.

3 studies of direct observation of evolution

- Harvard study of *E. coli* in 2 x 4 foot petri dish
- Peter and Rosemary Grant, two British-born researchers who have spent decades where Charles Darwin spent weeks, have captured a glimpse of evolution with their long-term studies of beak size among Galápagos finches & evidence of new speciation.
- William R. Rice and George W. Salt achieved fruit flies who refused to breed with flies from different environment in their lab, through an experiment involving 35 generations of the fruit fly *Drosophila melanogaster, a* speciation.

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,

Current evidence of evolution

- Misuse of pesticides on California cotton crops: most crop pests are now immune to most of our pesticides. Some feed on the pesticides. Natural selection has an amazing ability to change organisms to help them survival.
- Misuse of antibiotics in animals: increasing bacterial resistance to all of our antibiotics, i.e. staph (staphylococcus bacteria) resistance in hospitals

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/

Examples of fast Evolution: Invasive species

Cane toad in Australia is probably one of the world’s most famous invasive species; brought in to control cane beetle in 1935; it is highly destructive. No predators.

Darwin's Finches

Peter and Rosemary Grant: competition of two rival species. The medium ground finch was well established on the isle of Daphne, and had been studied in depth. Its beak was suited perfectly for cracking large nuts. In 1982, the large ground finch from a neighboring island arrived. These larger finches could drive away the native medium ground finches and would eat all the large nuts. The medium ground finches of Daphne island developed smaller beaks more suited to the smaller nuts, ignored by the invading larger finches.

Twenty years of dry and wet climates: percentages of bill size change based on food sources

Blunt beaks are associated with a new form of a gene called *ALX1*. That gene is also known to control facial development in people. Hybridization may be important for giving species genes that help them adapt to new environments or food sources.

Blue Moon Butterfly and its parasite

The Blue Moon Butterfly (Hypolimnas bolina) of the Samoan islands was being attacked by a parasite which destroyed male embryos. Males ended up making up only 1% of the butterfly population.
Within ten generations (~1 year) males had returned to 40% of the population.
Parasite is still present, but is no longer deadly to male embryos. This case shows how a mutation giving an advantage can rapidly spread throughout a population. Any male with the ability to survive infection would be able to mate with a great many females, due to the paucity of other males, and spread his immunity through the gene pool.

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

Four Forces and Populations

	Within	Between
Mutation	↑	↑
Genetic Drift	↓	↑
Natural Selection	= ↓	↑
Gene Flow	↑	↓

Populations

Name the four forces of evolution and how each affects variation within and between populations.
Mutation - increase, increase; natural selection - decrease/maintain, increase; genetic drift - decrease, increase; Gene flow – increase, decrease

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

Mutations

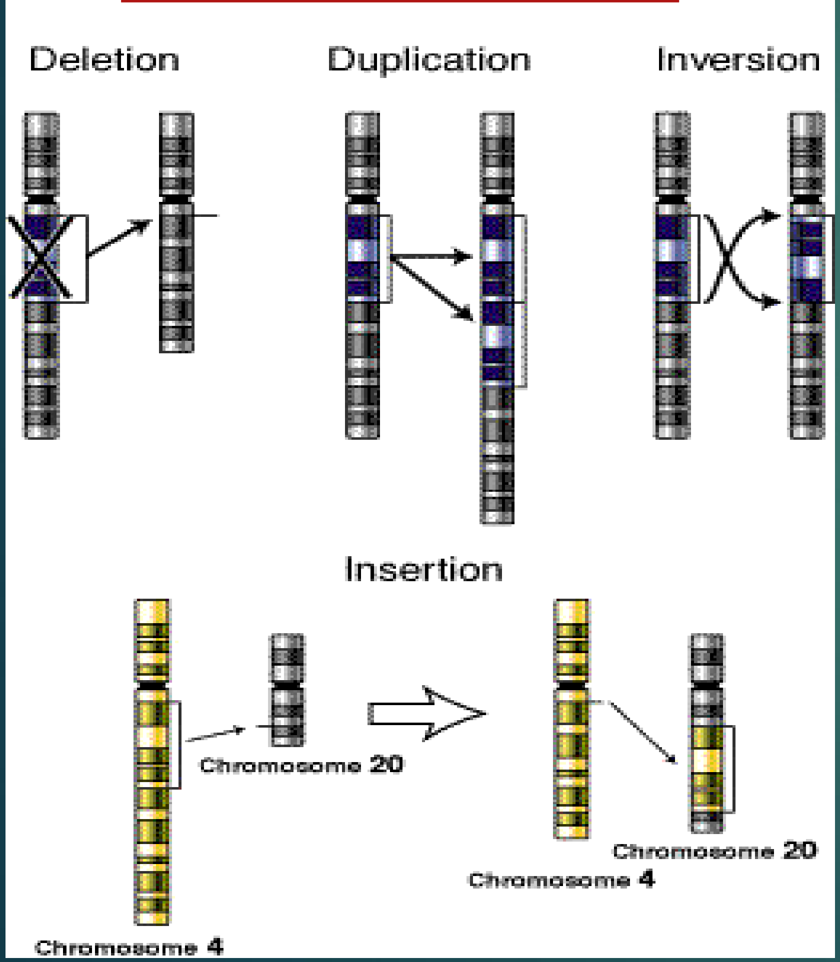
- Mutations that reduce an organism’s ability to survive and reproduce will be less likely to end up in offspring. Mutations that give an organism a survival and reproductive advantage will be more likely to show up in offspring.
- “Bad” - reduces the protein’s ability to function causing reduction in fitness
- Neutral - no change in protein form or function
- “Good” - increases protein’s ability to function, enhances fitness

Mutation

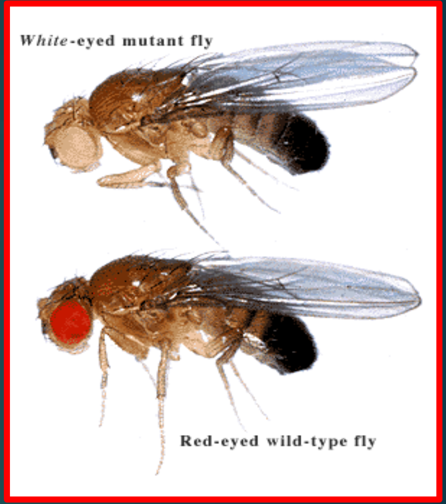
- Change in base sequence of DNA
  - • Occurs during replication stage of meiosis (or mitosis)
  - • MAY change the amino acid change and therefore the protein
- Mutation is the most basic and fundamental force of evolutionary change. Broadly speaking, mutation refers to the creation of new variation from one generation to the next.

Mutation

Types of mutation



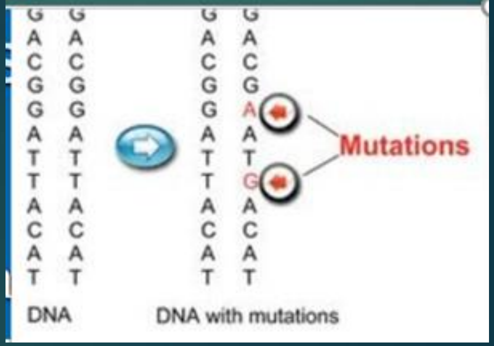
- DNA can fail to copy accurately when DNA is replicated.
- Mutations may be caused by radiation, viruses, or carcinogens.
- Mutations are rare and can have damaging effects.
-
- Organisms have special enzymes whose job it is to repair faulty DNA.



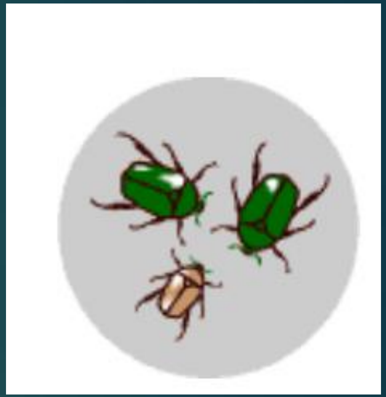
Mutant fruit fly = 1 mutation = red to white eye

upload.wikimedia.org/wikipedia/commons/7/79/Types-of-mutation.png humansystemstherapeutics.com/bb.htm

Mutation



- Creates new alleles
- Can be beneficial, neutral or lethal
- Passed on to new generations if they arise in gametes
- Can also reduce chances of survival and reproduction



- If it causes severe reductions, usually ends with death

- Neutral mutation changes base sequence but has no effect on survival or reproduction

- Beneficial mutation: example - corn plant has a mutation that makes it grow faster or larger giving it best access to sunlight and nutrients
- Neutral mutation might prove helpful if the environment changes

Mutation

- The mutation with the least possible impact on the phenotype is a replacement mutation. (vs. an insertion, deletion)
- Mutations often have little phenotypic effect because
  - they often occur in non-coding regions.
  - codon changes are often insignificant because of the redundancy of DNA
  - proteins can withstand minor amino acid variations

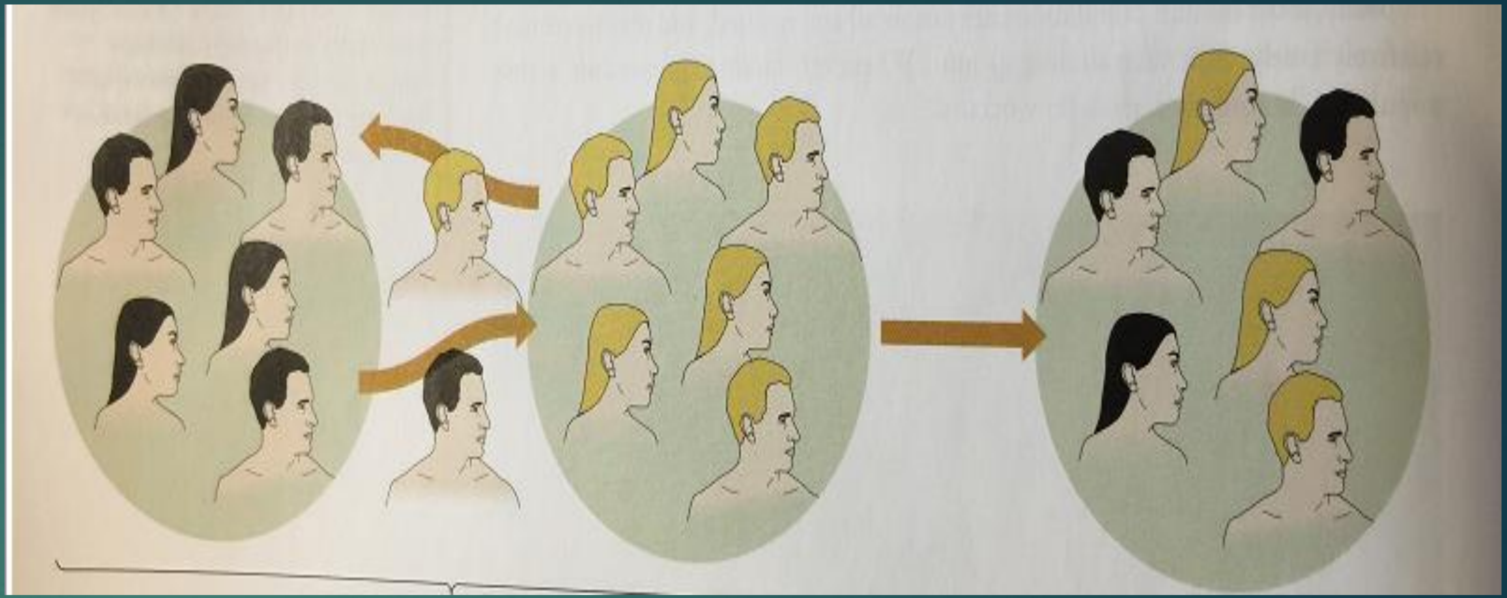
Mutations

- The only way to introduce new genetic variation
- • Very common
- • many are neutral
- • many deleterious enough to get removed quickly
- • some are incorporated
- Kinds:
  - Substitution - replace one base with another
  - Frame Shift
    - • Insertion- an extra base gets pulled in
    - • Deletion- a base gets omitted

How common is a mutation

- • happens all the time
- • assume a rate of one in a million per locus per gamete
- • assume approximately 50,000 loci
- • 5% of gametes have a mutation
- • an individual is combination of two gametes
- • assume a rate of one in 100 million bases
- • repair mechanisms fix 99% for effective mutation rate of 10^{-10}
- • gives a rate of 130 mutations per individual per generation

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 <u>increases the variability of the gene pool by adding new alleles</u>

- Tends to <u>reduce differences between populations</u>

- <u>Gene flow opposes the effects of mutation, natural selection, and genetic drift</u>

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.

Introgression or gene flow 2

- Like genetic drift (which by chance often gets eliminated); unless N contribution was being actively selected for because it was advantageous (adaptive introgression).

- So was it gene flow between two populations or introgression between two species? Need more data.
- Speciation is a process, not an event.

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: random, stronger in small populations

- Genetic drift is random fluctuations in allele frequencies in a small population from 1 generation to the next

- Unlike natural selection, genetic drift does not depend on an allele's beneficial or harmful effects.

- Drift changes allele frequencies purely by chance, as random subsets of individuals (and the gametes of those individuals) produce the next generation.

- Every population experiences genetic drift, but small populations feel its effects more strongly. The smaller the size of the population, the more likely there is to be a major shift in allele frequencies.

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: The random factor - opponent of variation

- Genetic drift opposes variation; causes less genetic variation
- A decrease in population size will increase effect of genetic drift. Drift is common in two population events:
  - genetic bottlenecks
  - founder events
- Most of the variation produced by mutation is lost, and it's lost through an evolutionary force that we refer to as genetic drift.

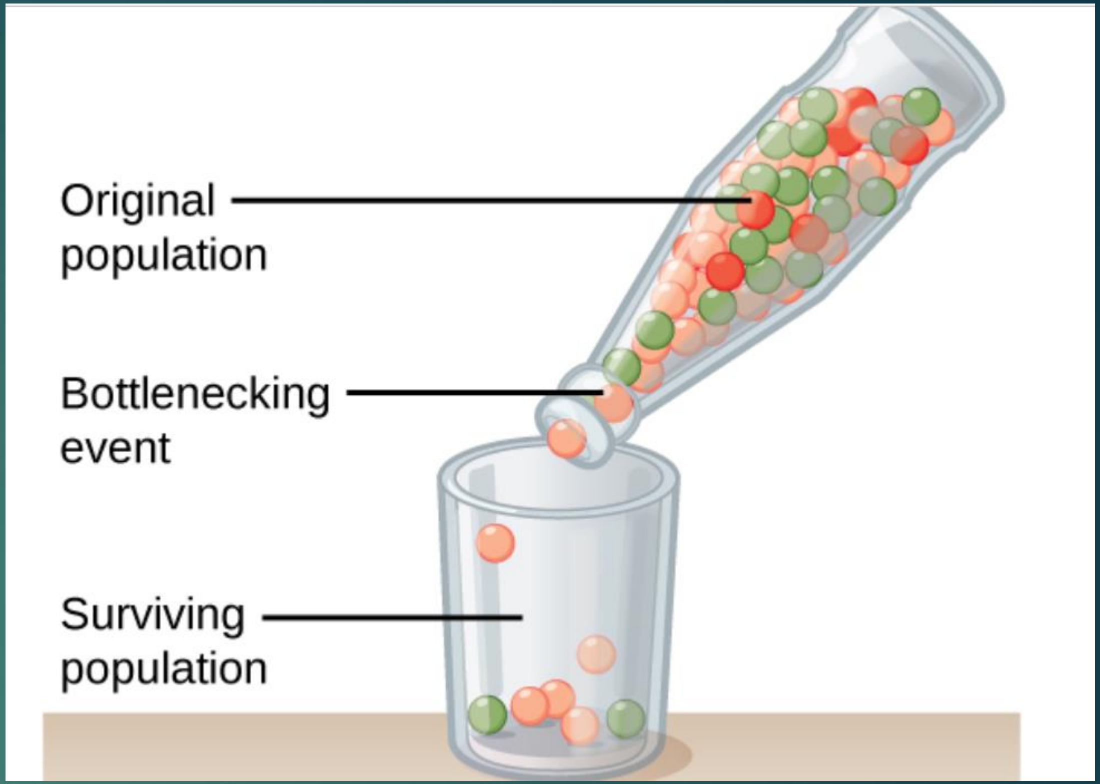
Almost extinct: These elephants have no tusks

- Addo, S. Africa: Up to 95% of the 300 female elephants have no tusks. A 100 year old evolution. Normally only 2% of cows lack tusks. They are among the least poached because poachers like tusks.
- The “great white hunter” Maj. P. J. Pretorius, had wiped out nearly all of them in the early 1900s; he left only 11.
- Due to genetic drift, not natural selection due to poaching

Genetic Drift

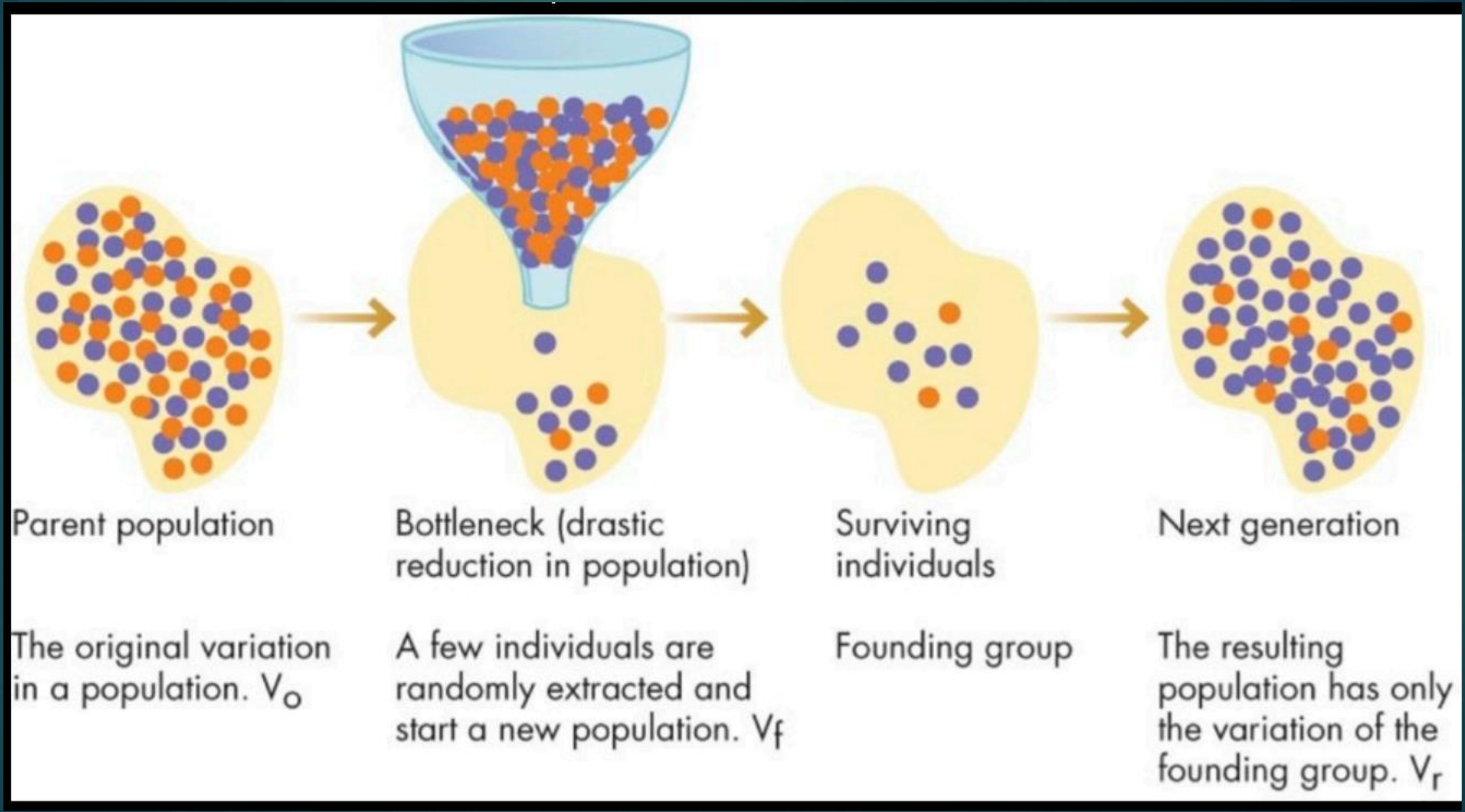
- Greatest effect in small populations: The smaller the population, or the fewer coins you toss in our analogy, the more likely you are to have a significant deviation from a 50/50 toss outcome.
- If population = 2, then possibility of total loss of 1 in next generation.
- Over time, genetic drift acts in just this manner to eliminate variation.
- The ultimate fate of any new mutation that arises, any new variant that arises, is either to be lost to genetic drift, or to become fixed in a population.
- Finite populations by probability error alone are unlikely to sample themselves perfectly from one generation to the next.

Genetic drift: Bottleneck effect



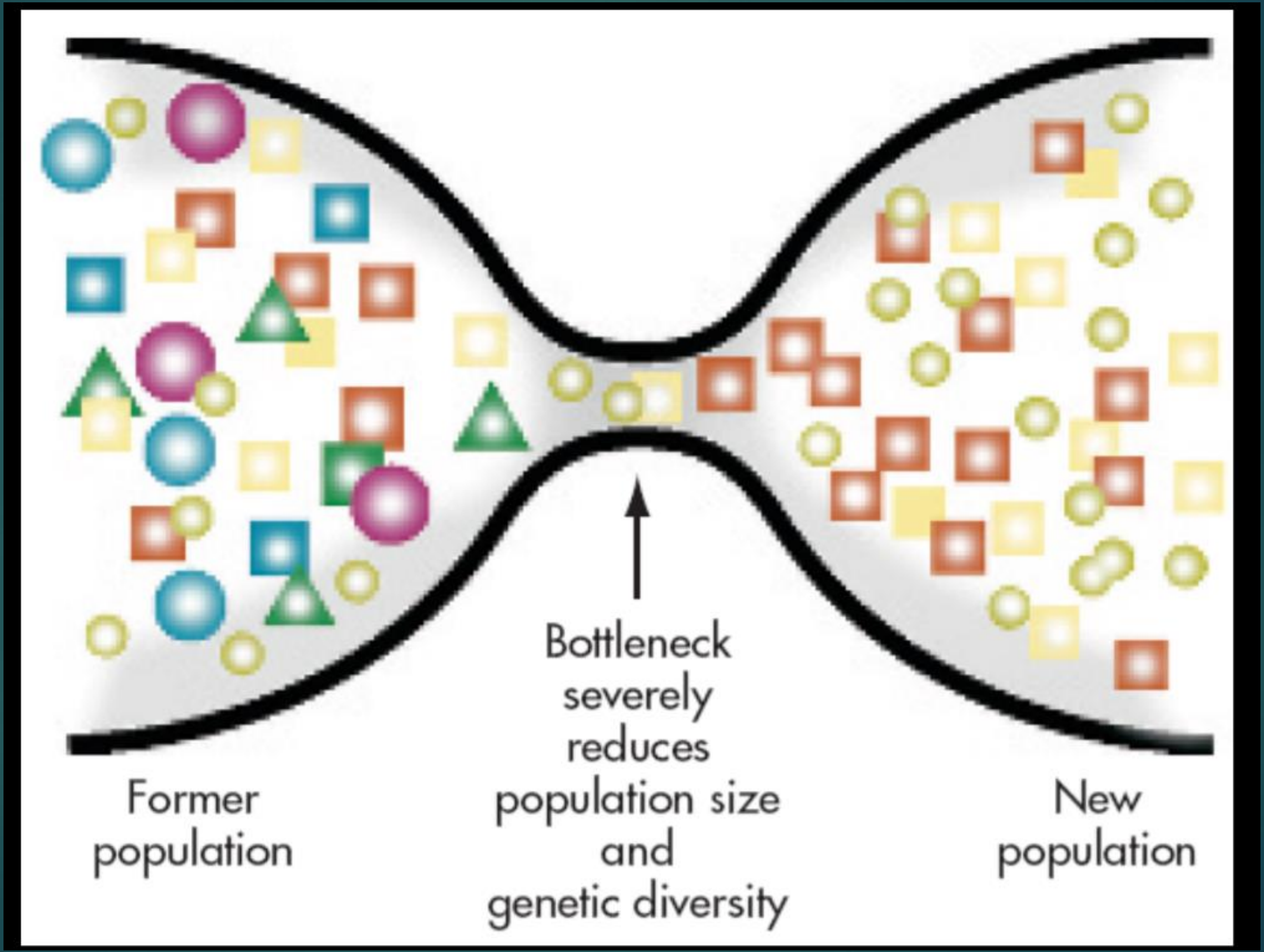
- Bottleneck effect = event which significantly reduces population size, i.e. habitat destruction, genocide:
- Original population contains larger genetic diversity, i.e. Africa
- If bottleneck occurs, surviving population has less genetic diversity (fewer alleles; higher level of genetic drift due to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

Genetic Drift - Bottleneck



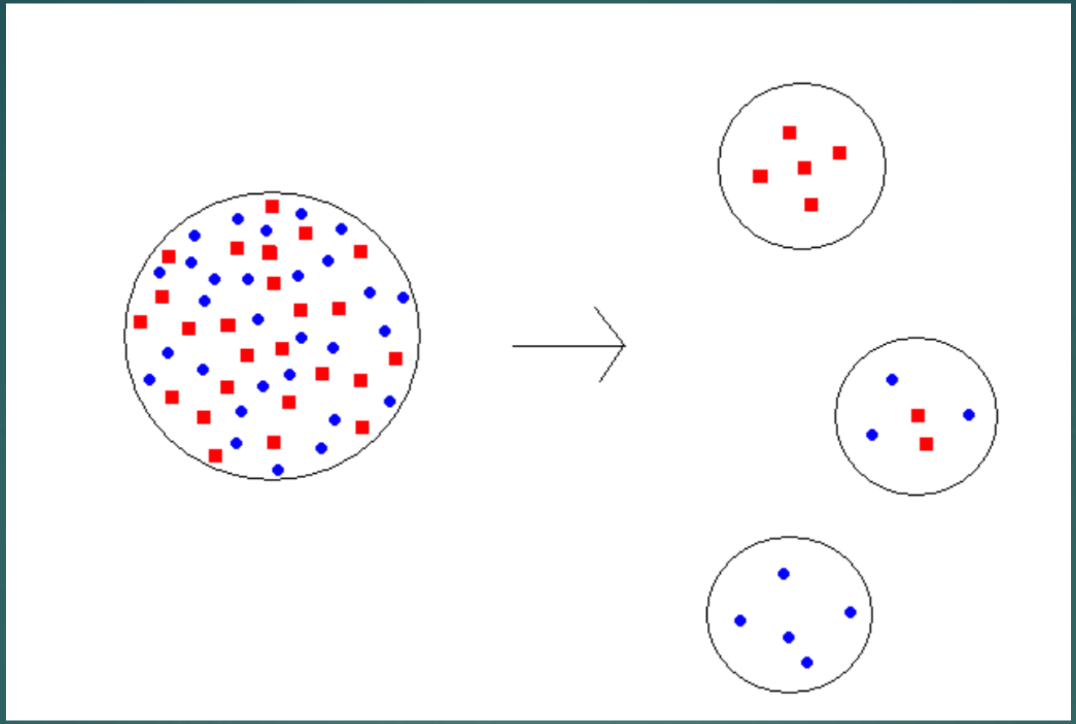
Genetic Drift - Bottleneck

6 types:
Blue
Purple
Orange
Dark Green
Light Green
Yellow



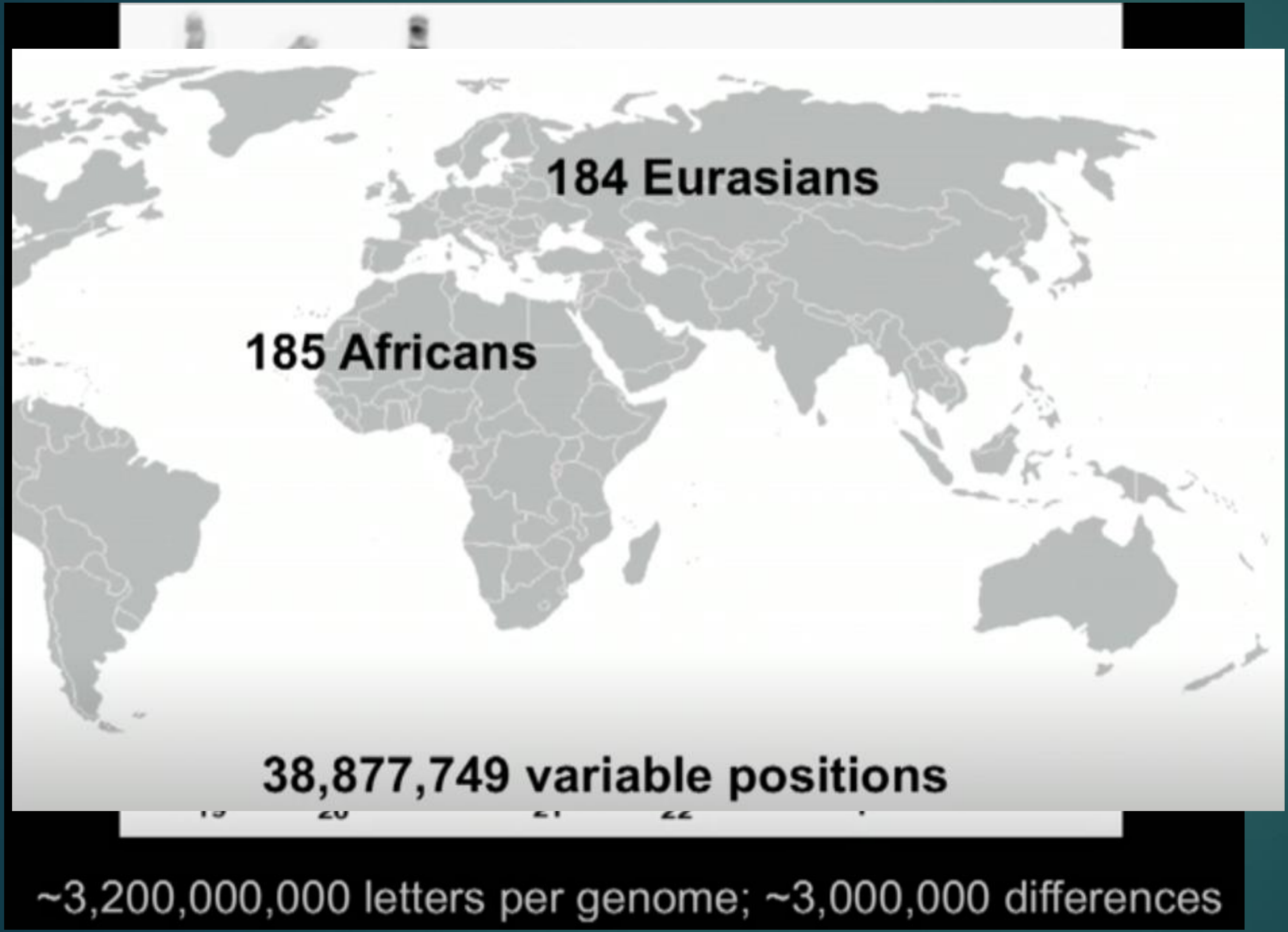
Only 3 types:
No:
Blue
Purple
Dark Green

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.

DNA: 3 M differences between 2 humans



- Africa has 6-8 fewer people than rest of world, but has significantly greater genetic diversity
- Genomes outside of Africa are more closely related to each other than in Africa; 20% of African genomes have no other genetic relationship
- We are Africans: Modern humans originated in Africa between 100-200 K ago
- 39 M letter differences between Africans & Eurasians
- No single difference that is 100% different between the two; only 12 at 95% differences

Random positive or negative new traits & survival

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

Natural selection

- So the <u>action of natural selection is specific to a given time and place</u>.
- As the properties of that time and place change, as the environment changes, as the phenotype of individuals within a given population change, or as the genotype of a population changes, we would expect natural selection to change in how it acts.

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.

Natural Selection

- Natural selection does not "choose" anything.
- Nor are evolutionary "winners" predetermined. Those traits that provide organisms with a fitness advantage at a given time, in a given environment, are more likely to be represented in subsequent generations.
- As a result, the action of selection is only something we can understand after the fact...it is not a forward looking process.

Natural Selection

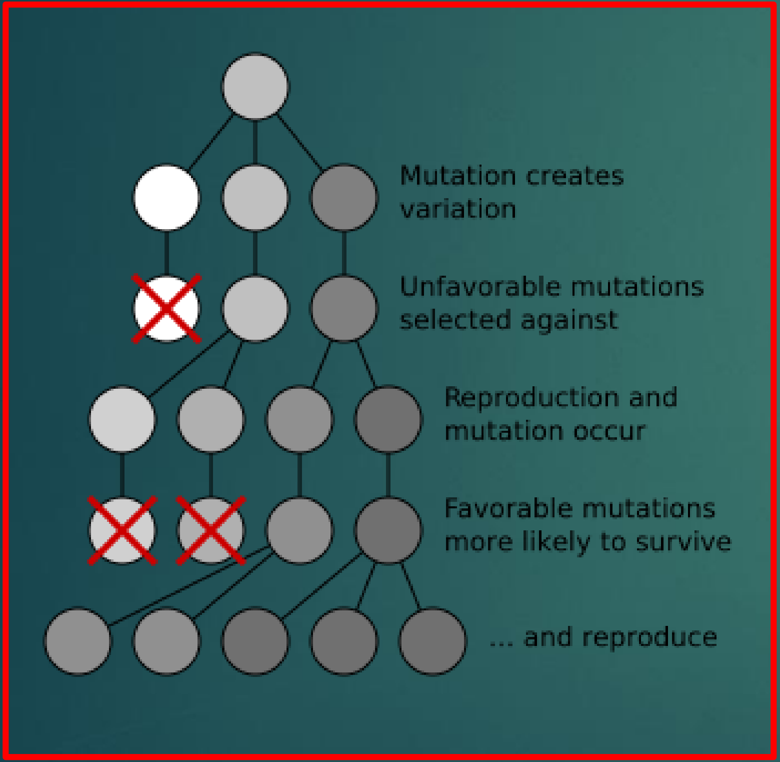
- Think of natural selection as a process rather than as a guiding hand.
- It is an after the fact explanation of the process that produced a result.
- Natural selection is the simple result of the processes of variation, differential reproduction, and heredity and their results— it is mindless and mechanistic.
- It has no goals; it's not striving to produce "progress" or a balanced ecosystem

Speciation

- Speciation is the process by which new species are formed.
- When a species gets split into two groups by a river, mountain range, island, lake, or ocean via earthquakes, floods, droughts, climate change, or continental drift, the two populations will begin to drift genetically.

Natural Selection

Selection of dark gene



- Mutant alleles spread through a population by sexual reproduction.
- If an allele exerts a harmful effect, it will <u>reduce the ability of the individual to reproduce and the allele will probably be removed from the population.</u>
- <u>In contrast, mutants with favorable effects are preferentially passed on</u>

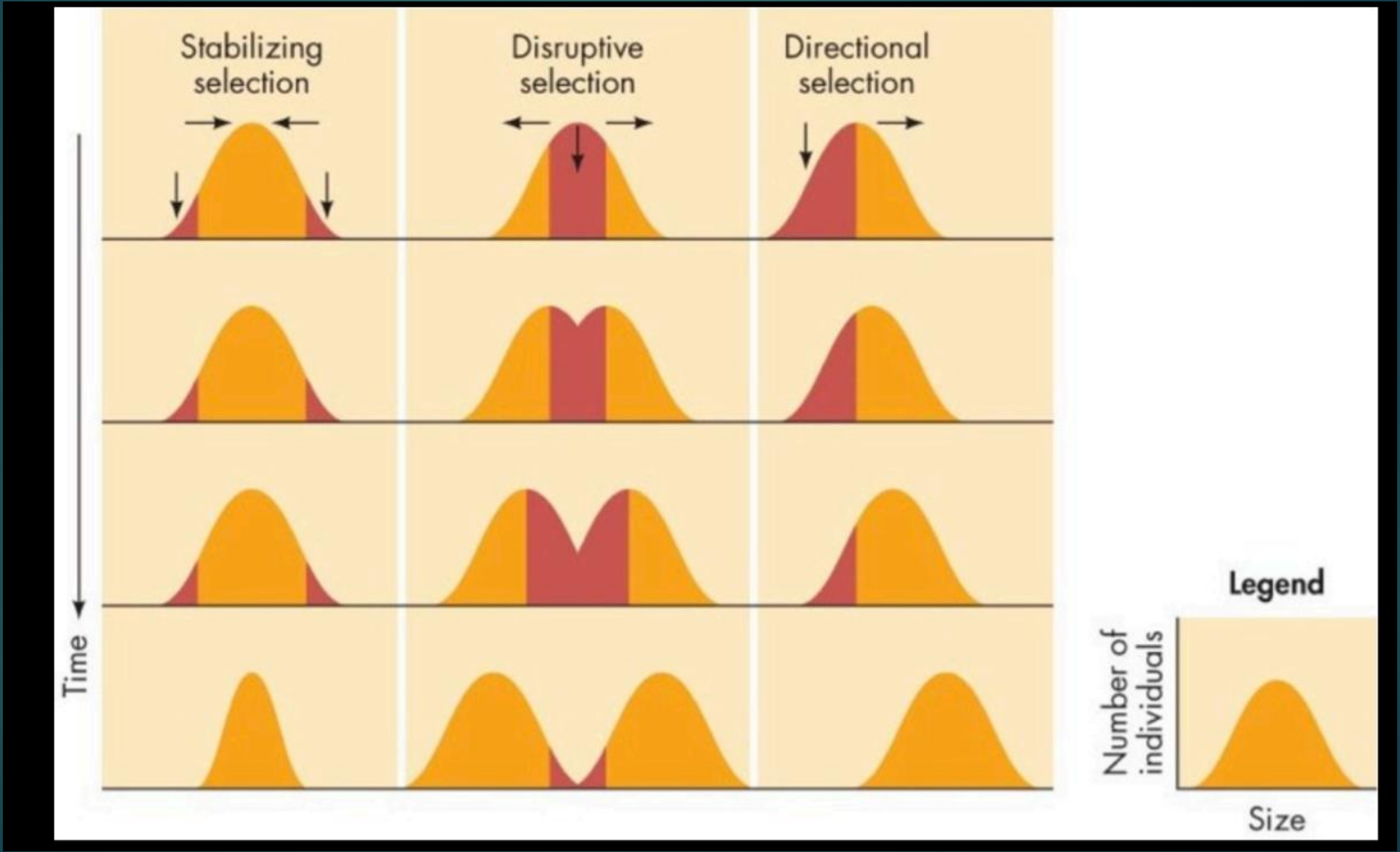
3 types of natural selection

- The directional selection theory says that an extreme phenotype (characteristics or traits) is favored over other phenotypes and this causes the allele frequency (how often the variant of a gene shows up in a population) to shift over time in favor of the extreme phenotype. In other words, if a particular trait is favorable, it will be expressed at the most beneficial frequency in the population. Antibiotic resistance; overfishing produces smaller fish
  - Decreases genetic variance in a population; i.e. giraffe neck lengths. Directional selection is common during environmental stress (predation) and pushes the population in one direction.
- Stabilizing (purifying) selection can be thought of as “middle-of-the-road” selection, meaning a non-extreme trait is favored instead of one of the two extreme traits. An example of this is plant height. In a population of plants, those that are short may not get enough sunlight, but those that are tall may be subjected to wind damage. This results in an increase in the number of medium-height plants and a decrease in very tall and very short plants. Because most traits do not change drastically over time, stabilizing selection is considered to be the most common mechanism for natural selection. i.e. birth weight of humans. Stabilizing selection acts against the extremes so that the average is favored.
  - Removes genetic diversity. NS as a conservative force. Wolves have remained the same, despite dogs; sharks the same

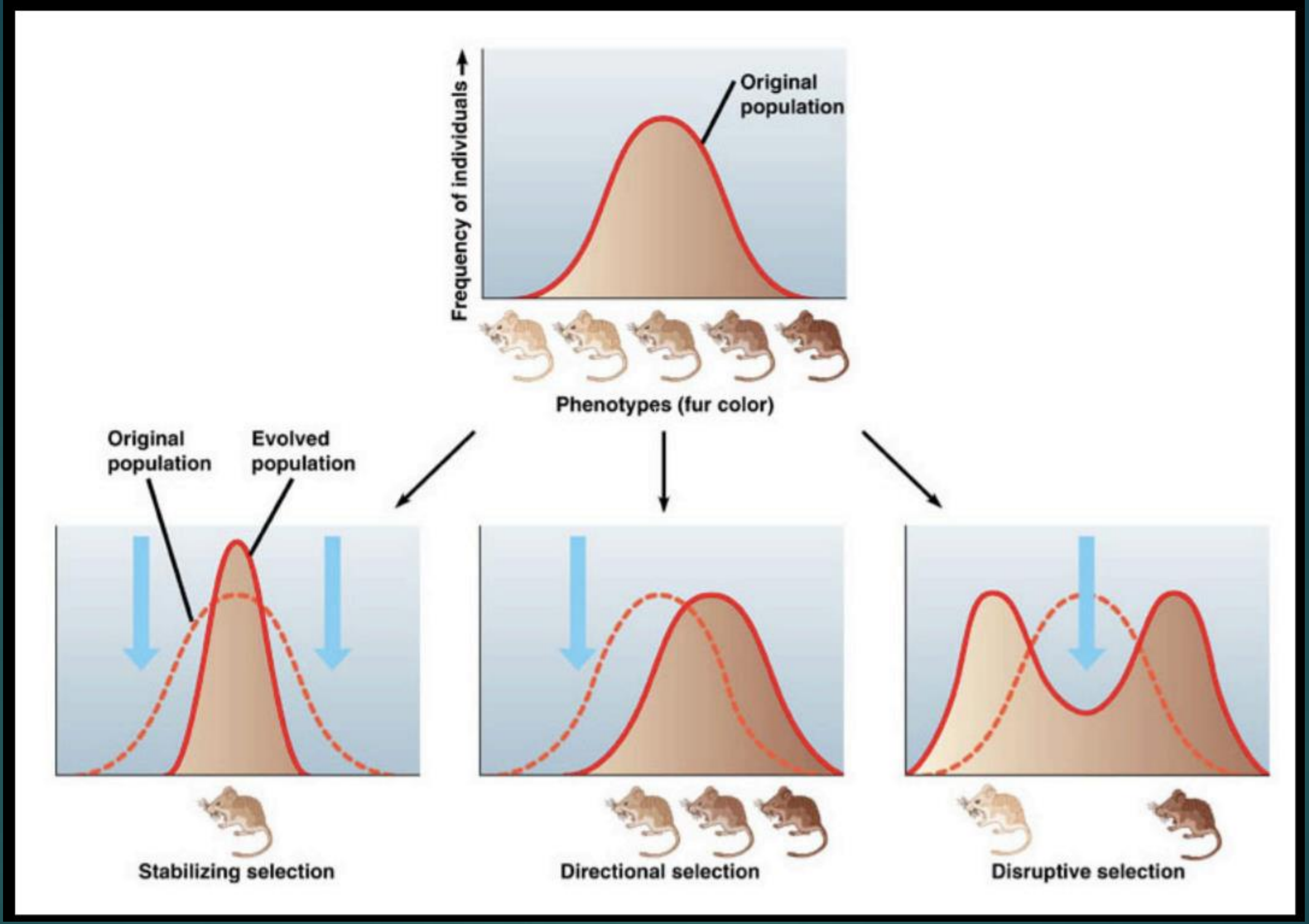
3 types of natural direction

- Disruptive Selection: This type of natural selection is bimodal and favors both extreme traits in a population, not the average. For example, in a population of plants, there are some pollinators that visit the tallest plants, a different species of pollinator visits medium-height plants and a third species of pollinator that prefers the shortest plants. If the pollinator that prefers medium-height plants is removed, natural selection would select against medium-height plants and the overall plant population would move toward having only tall and short plants, the two extreme phenotypes. Diversifying (disruptive) selection acts against the average and both extremes are favored
  - A more classic example of disruptive selection is the beak size of finches on the Galapagos Islands that was studied by Darwin. Because the majority of seeds found on some of the islands were either large or small, finches with large and small beaks (no medium-sized beaks) were favored on those islands.
  - Sympatric speciation: driving force behind birth of new species in same location

Natural Selection



Directional: Increases proportion of genotypes with aa more extreme value of the trait



Disruptive: unlikely to be symmetrical, & thus usually shifts the mean

Stabilizing: does not alter the mean, but may reduce variance (variation)

Fitness

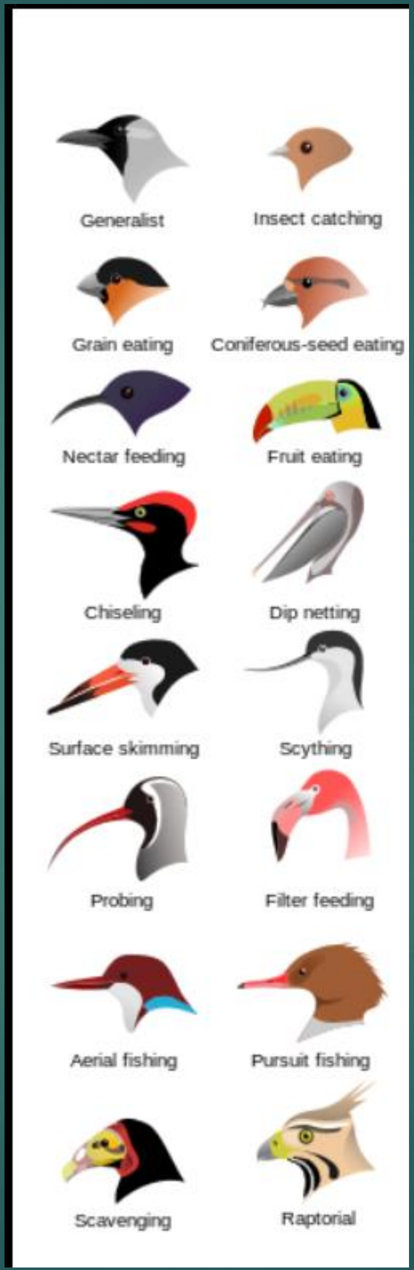
- Fitness describes how good a particular genotype is at leaving offspring in the next generation relative to how good other genotypes are at it.
- So if brown beetles consistently leave more offspring than green beetles because of their color, you'd say that the brown beetles had a higher fitness.
- 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.

Adaptation

- An adaptation is a feature that is common in a population because it provides some improved function. Adaptations are produced by natural selection.
- Adaptations can take many forms: a behavior that allows better evasion of predators, a protein that functions better at body temperature, or an anatomical feature that allows the organism to access a valuable new resource — all of these might be adaptations.
- Sewall Wright: Adaptive landscape: The basic idea is that any individual phenotype has a specific fitness associated with it, given a specific environment.
- Note, that fitness in this case refers to basically how likely an individual with that phenotype is to survive and reproduce into future generations or, basically, how fit they are for their environment, how likely they are to pass on their genes.
- No population or organism is perfectly adapted.

Adaptations

Succulents from Different Continents



Coastal Redwood

- Succulents
- Bird Beaks
- Tall Trees
- Light skin
- a single sickle-cell gene = anti-malaria
- Lactose persistence
- Bulbous penis = displaces rival semen

Adaptation 2

- So <u>an adaptation</u> is a <u>trait that's become highly frequent in a population because natural selection has made it more frequent within a population. It's a trait which confers high fitness.</u>

- Evolution doesn't necessarily optimize an organism's phenotype. Rather, it optimizes within a local context. Evolution can only operate on the variation that’s present within a population.

- Both mutation and gene flow can prevent adaptation.

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

Artificial Selection

- Dogs – Great Dane to chihuahuas
- Chickens, turkeys
- Horses
- Wild Silver Foxes into Puppies in 10 generations
- Corn

Natural selection

- Darwin noted that islands often produced unique species, similar to species on nearby continents (Galapagos tortoise different from African ones, but very similar to S American chaco tortoise); believed this explainable by idea of common descent – random variation from common ancestor over long time;
- Specially adapted to island life: Galapagos have 18 island; larger grassy islands have heavier, domelike shelled tortoises; smaller islands with tall cactuses have longer necked saddle like shelled tortoises
- Farmers have modified species vis selective breeding (wild boars into pigs, varieties of chickens/pigeons, colored vegetables); breed for a valued trait; only best allowed to reproduce; single weed produced cauliflower, broccoli, cabbage, kale, Brussel sprouts

Natural selection

- Natural selection occurs when individuals with certain genotypes are more likely than individuals with other genotypes to survive and reproduce, and thus to pass on their alleles to the next generation.
- As Charles Darwin (1859) argued in *On the Origin of Species*, if the following conditions are met, natural selection must occur:
  - There is variation among individuals within a population in some trait.
  - This variation is heritable (i.e., there is a genetic basis to the variation, such that offspring tend to resemble their parents in this trait).
  - Variation in this trait is associated with variation in fitness (the average net reproduction of individuals with a given genotype relative to that of individuals with other genotypes).

Natural Selection

- Nature itself is capable of selection
- Nature is extremely dangerous; nature simply by being difficult to survive in, acts as selector of which variation in traits succeed, i.e. peppered moth in smoky environment
- Creatures in specific environment become more fit to survive and reproduce there; this process is natural selection
- NS is an observable fact in nature and the lab
- <u>Natural selection</u>: the process by which random evolutionary changes are selected for by nature in a consistent, orderly, non-random way
- Through <u>descent with modification</u>, new traits are randomly produced; nature decides which traits to keep; positive changes add up over multiple generations; negative traits are discarded

Evolution is not just natural selection

- Evolution and natural selection are not equivalent terms.
  - Natural selection is one force that can drive and influence evolutionary change, but other mechanisms can be equally important.
  - Trait changes among the members of a population are not always a result of selective processes. For instance, the appearance and accumulation of a deleterious trait (e.g., a genetic disease) in a population should not be ascribed to direct selection for the trait in question.

- Similarly, alleles that have no effect on traits under selection may undergo mutations that do not influence the fitness of the organism carrying them.

- Proponents of the neutral theory of molecular evolution argue that many, if not most, of the genetic differences between species are selectively neutral.

Evolution

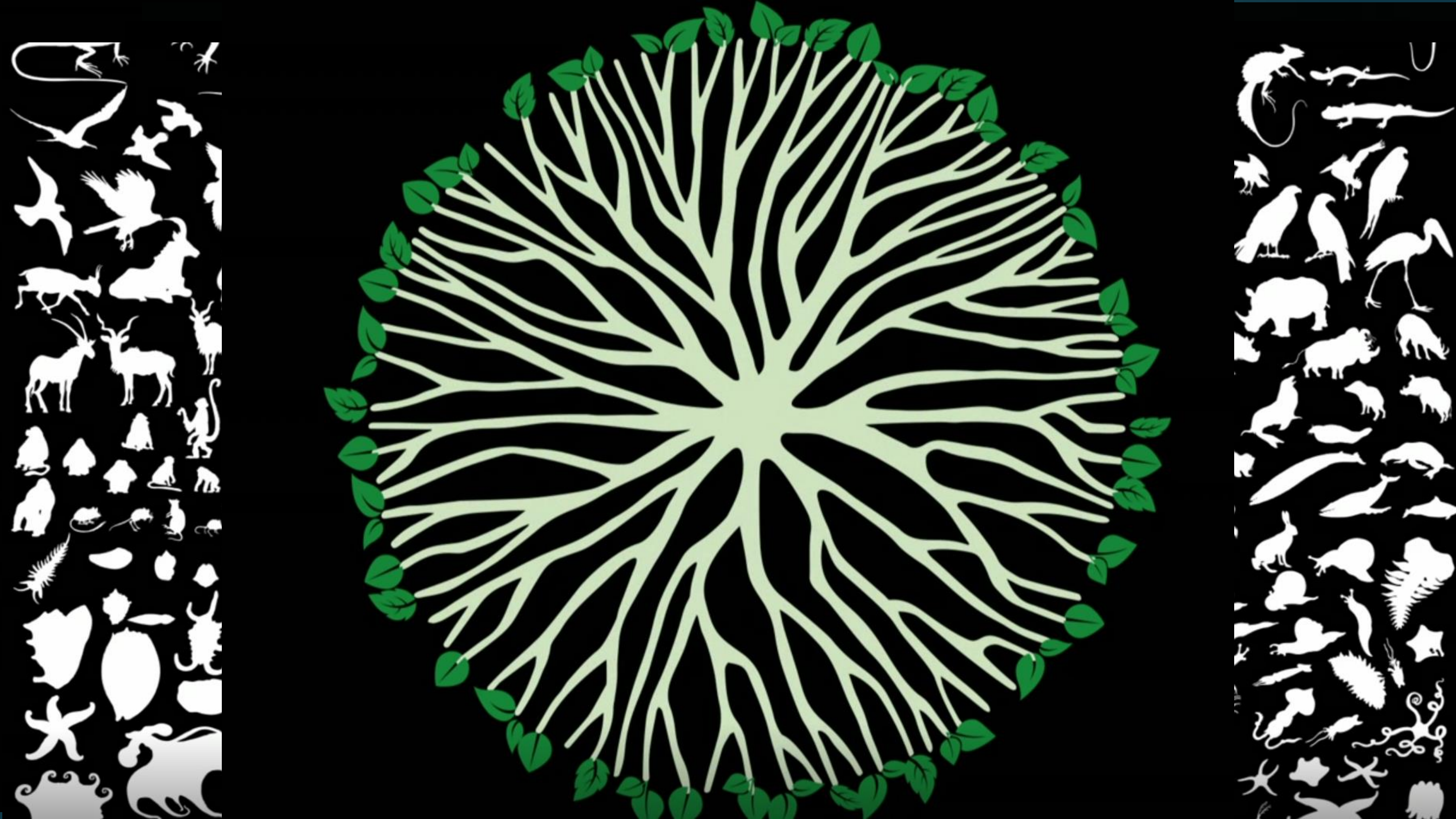
- NS keeps around traits that are furthering organism's survival and reproduction today, not traits that might come in handy a million years from now. Evolution is a kind of Zen. No striving, no trying. Just use what happens to be useful now.

- 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;

Not "survival of the fittest"

- Survival of the fittest usually makes one think of the biggest, strongest, or smartest individuals being the winners, but in a biological sense, evolutionary fitness refers to the ability to survive **and** reproduce in a particular environment.
- Survival of the fit enough is better; nature is not a constant life-or-death struggle against competitors. Many organisms are a perfect niche fit; many have no competitors.
- And many organisms are the "fittest" because they cooperate with other organisms, rather than competing with them.
- Popular interpretations of "survival of the fittest" typically ignore the importance of both reproduction and cooperation. To survive but not pass on one's genes to the next generation is to be biologically unfit.
- Natural selection is not *just* about survival. To pass on genes to next generation, organisms must both survive and reproduce.



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*.

Reproductive Isolating Mechanisms

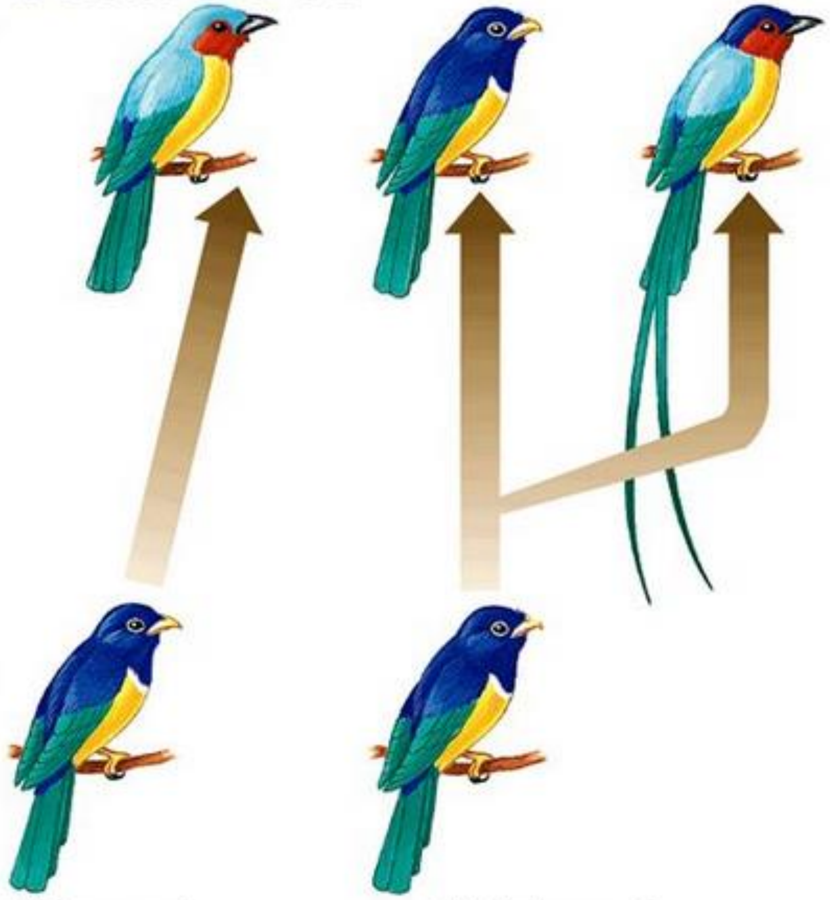
- Premating RIMs
  - Geographic/Habitat isolation – river, mountain range
  - Reduction of gene flow across a species range
  - Temporal isolation
  - Behavioral isolation: evolution of different mating location, mating time, or mating rituals
  - Mechanical incompatibility: Lack of "fit" between sexual organs

- Postmating RIMs
  - Sperm-egg incompatibility
  - Zygote unviability
  - Embryonic or fetal unviability

Patterns of speciation

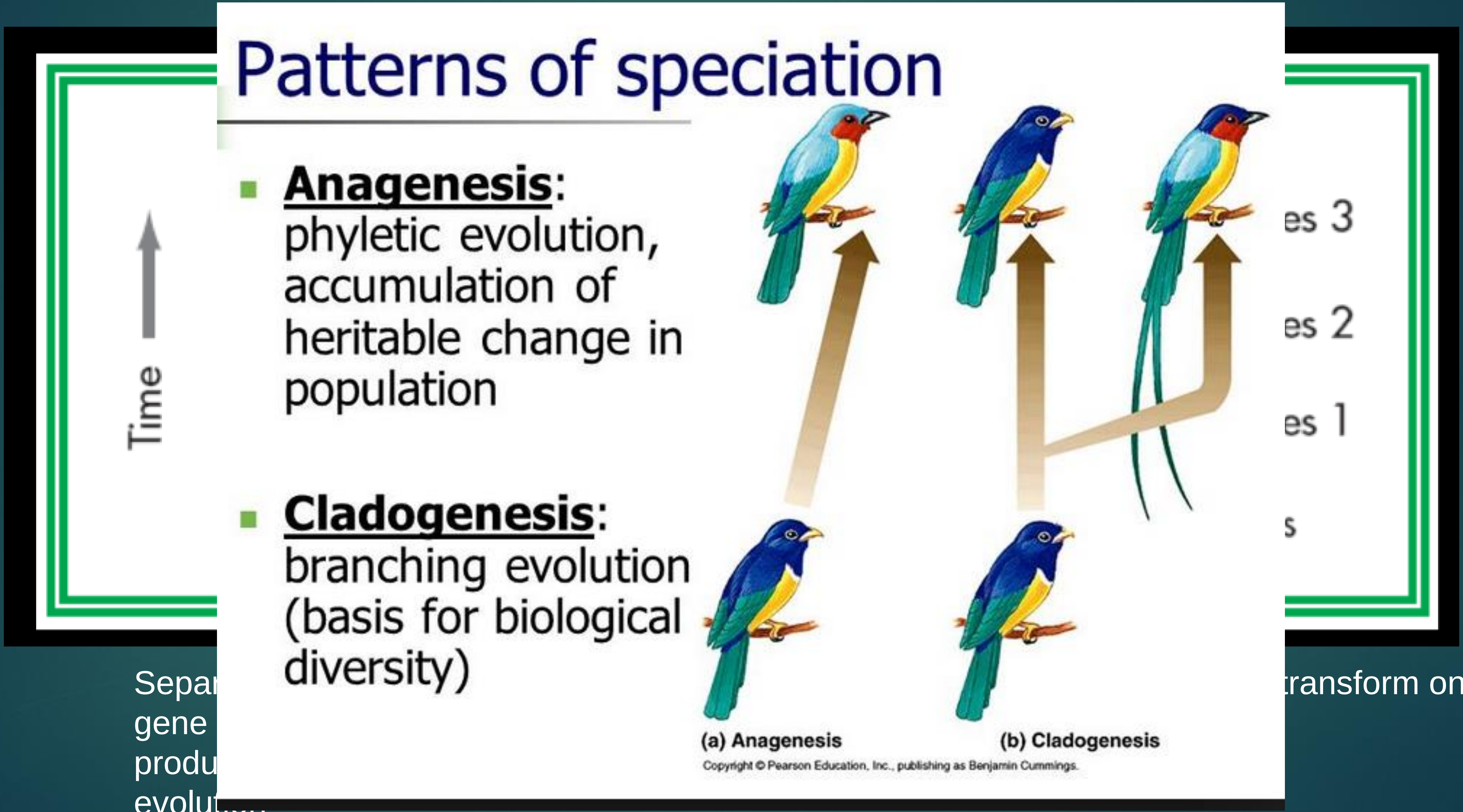
- **Anagenesis**: phyletic evolution, accumulation of heritable change in population

- **Cladogenesis**: branching evolution (basis for biological diversity)



(a) Anagenesis (b) Cladogenesis

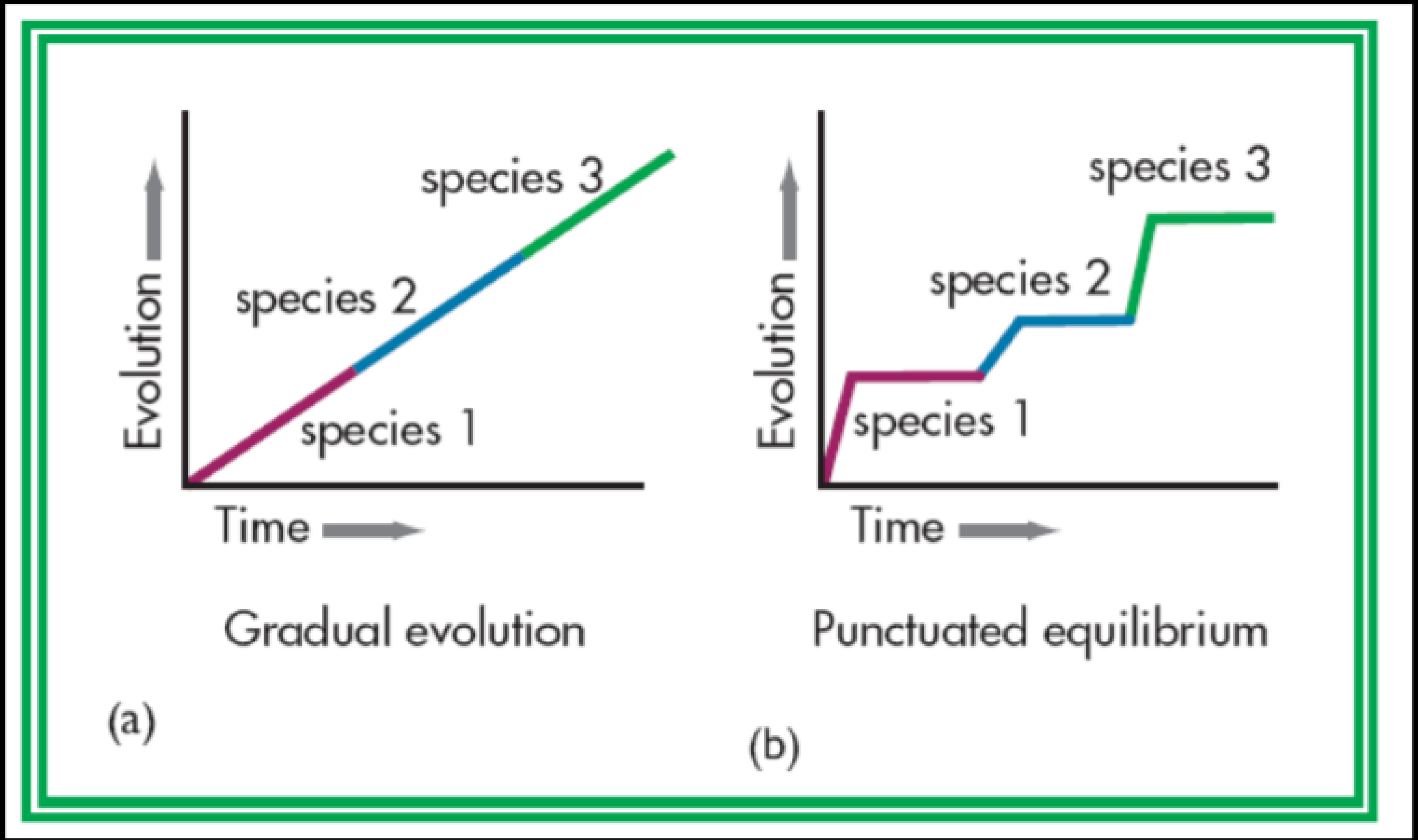
Modes of Evolutionary Change



Separ transform one
gene
produ
evolut

Tempo of Speciation?

- Gradualism?
- Punctuated Equilibrium?



Speciation

- Anagenesis: Gradual change within a species that transforms that species without need for speciation.

- Speciation: Genetic changes sometimes accumulate within an isolated segment of a species, but not throughout the whole, as that isolated population adapts to its local conditions. Gradually it goes its own way, seizing a new ecological niche. At a certain point it becomes irreversibly distinct—that is, so different that its members can't interbreed with the rest. Two species now exist where formerly there was one.
- Darwin called that splitting-and specializing phenomenon the "principle of divergence."

SPECIES CONCEPT	CHARACTERISTICS OF SPECIES
Biological species concept (Mayr)	Groups of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups
Specific mate recognition concept (Paterson)	Members sharing a specific mate recognition system to ensure effective syngamy within a population of organisms
Cohesion species concept (Templeton)	The most inclusive population of individuals having the potential for phenotypic cohesion through intrinsic cohesion mechanisms
Evolutionary species concept (Simpson)	A lineage evolving separately from others and with its own unitary evolutionary role and tendencies (and historical fate)
Ecological species concept (Van Valen)	A lineage which occupies an adaptive zone minimally different from that of any other lineage in its range and which evolves separately from all lineages outside that range
Phylogenetic species concept (Cracraft)	The smallest diagnosable cluster of individual organisms within which there is a parental pattern of ancestry and descent

defined as reproductively isolated groups

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.

Micro vs Macro Evolution

- Microevolution = the small scale changes: changes in gene frequencies in a population from generation to generation;

- Microevolution looks at changes within species over time—changes that may be preludes to speciation, the origin of new species. i.e. Grants' studies of evolving beak shapes among Galapagos finches; observable

- Macroevolution = the cumulative effect of these small changes over a long period of time - may lead to Speciation

Microevolution (below level of species)

- Microevolution
  - Changes in allele frequencies over relatively short time periods/small geographic ranges/small genomic ranges
  - Evolution over short time periods
  - Happens on a small scale (within a single population)
  - Occurs in our lifetime, i.e. is observable to all of us

- Examples: explosion of house sparrow; peppered moth; smaller size of elephant tusks; smaller fish due to overfishing

Microevolution

- Examples: Evolution of resistance — of pests to pesticides, weeds to herbicides, and pathogens to medicines — all of which are cases of microevolution by natural selection:
  - mosquitoes evolving resistance to DDT
  - whiteflies evolving resistance to pesticides
  - gonorrheal bacteria strains evolving resistance to penicillin
  - HIV strains evolving resistance to antiviral medicines

Macroevolution

- Macroevolution studies how taxonomic groups above the level of species change. Evolutionary modifications can be large scale – the descent of different species from an ancestor over long periods of time

- Its evidence draws frequently from the fossil record and DNA comparisons. rather than direct observation

- Human evolution example: Evolution implies that between the earliest known ancestors of humans (roughly five million years old) and the appearance of anatomically modern humans (about 200,000 years ago), one should find a succession of hominin creatures with features progressively less apelike and more modern, which is indeed what the fossil record shows. But one should not—and does not—find modern human fossils embedded in strata from the Jurassic period (65 million years ago).

Microevolution: no new species

Dogs are wolves

- The dog is another example of how selection can change the frequency of alleles in a population.

- Dogs have been artificially selected for certain characteristics for many years, and different breeds have different alleles.

- All breeds of dog belong to the same species, *Canis lupus* (the wolf) so this is an example of microevolution as no new species has resulted.

www.puppy-training-solutions.com/image-files/dog-breed-information.jpg

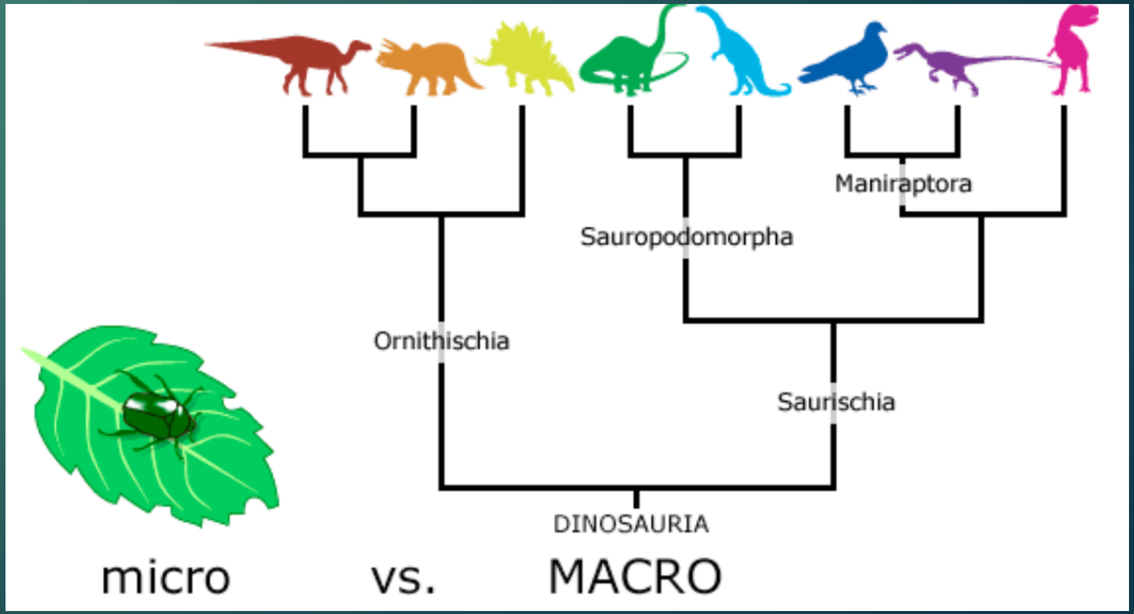
Macroevolution (above level of species)

- Changes in allele frequencies over relatively long time periods/large geographic ranges/large genomic ranges; Large-scale history of life.

- Evolution over long time periods
  - Creationists have problem with macroevolution because they say we can't directly observe macroevolution
  - We can't do million year experiments, but we can make testable predictions, like in geology or astronomy
  - Speciation
  - Studies of macroevolution tend to rely

on inferences from fossil evidence,

phylogenetic reconstruction,



Macroevolution

- Isolation: If two populations of a species become isolated from one another for tens of thousands of years, genetic difference may become marked.

- If the two populations can no-longer interbreed, new species are born. This is called Macroevolution.

- Darwin's Galapagos finches are an example of this process in action.

Galapagos finches

www.ingala.gov.ec/galapagosislands/images/stories/ingala_images/galapagos_take_a_tour/small_pics/galapagos_map_2.jpg

Microevolution and Macroevolution

- How does Microevolution add up to macroevolution?
- • What are species?
- • How are species created?
- • What are anagenesis and cladogenesis?
- Evolutionary changes in a lineage over time resulting in the change from one species to the next is called anagenesis.
- (Cladogenesis / anagenesis) is the process of a lineage changing significantly over time from one form to another, perhaps from one species to another.

Science

- Science is a system for acquiring knowledge based on a specific method –
- the method includes forming a hypothesis based on what is already known
- the hypothesis must best testable
- those tests must be repeatable and verifiable
- the results of such tests, both positive and negative are organized into a theory to explain observed phenomena or to make predictions

Science Is…

- Empirical
- Systematic and explicit
- Theoretical, explanatory, predictive
- Self-critical, based on testing and evidence
- Subject to falsifiability
- Public

Scientific Theory

a. A guess about how the world works

b. A really good guess about how the world works

c. A hypothesis (limited explanation of a phenomena) in need of testing

d. A hypothesis that has been tested a couple of times and might hold true

e. An idea that has been tested and retested and stood up to all tests (scientific theory; in depth explanation) – is as close to fact as scientists get

f. At any point in the future, if contradictory evidence emerges, the original theory is discarded; It can be falsified if they are found in contradiction with new data. (i.e. geocentric universe; stress theory of ulcers; immovable continents)

Scientific Theories

- Gravity
- E=MC2
- Evolution
- Earth orbits around the sun rather than vice versa (by Copernicus)
- Roundness of the earth
- Continental drift
- The existence, structure, and dynamics of atoms.
- Electricity
- Each of these theories is an explanation that has been confirmed to such a degree, by observation and experiment, that knowledgeable experts accept it as fact. That's what scientists mean when they talk about a theory: not a dreamy and unreliable speculation, but an explanatory statement that fits the evidence. It is the best available view of reality, at least until some severely conflicting data or some better explanation might come along.

The scientific method begins with observations, forms hypotheses to try to explain what has been observed, tests these hypotheses and then accepts, modifies, and most often discards them on the basis of the results. A hypothesis that has been sufficiently tested and refined, and then verified by other scientists, eventually becomes a theory, meaning that it is currently the best acceptable explanation of the data observed. Even after that, it is still subject to correction,

Scientific Methodology

<u>Scientific methodology</u> includes the following:

- Objective observation: Measurement and data (possibly although not necessarily using mathematics as a tool)
- Evidence
- Experiment and/or observation as benchmarks for testing hypotheses
- Induction: reasoning to establish general rules or conclusions drawn from facts or examples
- Repetition
- Critical analysis
- Verification and testing: critical exposure to scrutiny, peer review and assessment

Some basic definitions

- Fact: an observation that has been repeatedly confirmed
- Law: a descriptive generalization about how the physical world behaves, i.e. gravity; an explanation about the fact
- Hypothesis: a testable statement that can be used to build inferences and explanations

Some basic definitions

- Theory: a well-substantiated explanation that incorporates facts, laws, inferences and tested hypotheses.
- A scientific theory stands until proven wrong -- it is never proven correct.

In science, you don't get any better than a theory.

Scientific theory

- According to the National Academy of Sciences (NAS), a scientific theory is "a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses." No amount of validation changes a theory into a law, which is a descriptive generalization about nature.
- So when scientists talk about the theory of evolution—or the atomic theory or the theory of relativity, for that matter—they are not expressing reservations about its truth.
- In addition to the *theory* of evolution, meaning the idea of descent with modification, one may also speak of the *fact* of evolution. The NAS defines a fact as "an observation that has been repeatedly confirmed and for all practical purposes is accepted as 'true.'" The fossil record and abundant other evidence testify that organisms have evolved through time. Although no one observed those transformations, the indirect evidence is clear, unambiguous and compelling.

Theory vs hypothesis

- A *theory* in science is not a hunch; it is a broad, natural explanation for a wide range of phenomena.
- Theories are concise, coherent, systematic, predictive & broadly applicable, often integrating and generalizing many hypotheses.
- Theories accepted in science are generally strongly supported by many different lines of evidence; but theories may be modified or overturned if warranted by new evidence. Think of gravity, cell theory, evolution.
- In everyday language, word *hypothesis* usually refers to an educated guess. In science, they are explanations for a fairly narrow set of phenomena and are usually based on prior experience, observations & logic, and often supported by many different lines of evidence.

Evolution is both a fact and a theory

- Confusion sometimes arises as to whether Evolution is a theory or a fact.
  - Actually it is both!

- The theory of Evolution deals with how evolution happens. Our understanding of this process is always changing.

- Evolution is also a fact as there is a huge amount of indisputable evidence for its occurrence.

Why is evolution considered a scientific “fact?”

- A scientific fact may be defined as a theory that has been repeatedly confirmed and never refuted.
- Evolution fits this description, but that does not mean that new evidence couldn’t refine or disprove the theory.
- Science is a progression, not a destination.

Don’t a lot of scientists disagree with the concepts of evolution?

- One of the wonders of science is that it is self-correcting.
- Scientists may disagree on the precise mechanism, often violently, (i.e., punctuated equilibrium “evolution by creeps and jerks”), but the underlying premise is not in question.
- 99.9% agree that evolution is a fact

Choosing our words carefully

- In talking about evolution:
  - Talk about function, not purpose
    - Structures of living things have functions. Purpose implies design or intent.
  - Adaptation, not design
    - Use terms like structure & adaptation when referring to organisms
    - Not “how is aardvark designed to eat ants?” but “What adaptations do aardvarks have that allow them to eat ants?”

Choosing our words carefully 2

- Evolution, not development
  - Development occurs as a living thing grows up. Evolution occurs as genetic makeup of a population changes over time.

- Accept, not believe
  - Not “do you believe in evolution?”
  - Science is not about belief; it is about making inferences based on evidence.
  - A scientific idea is accepted (it is the most accurate current hypothesis available based on critical evaluation of evidence); “I accept the fact that the Earth is ancient & life has evolved over billions of years because of the evidence supporting that idea.”
  - Belief implies faith, and science is not about faith. It’s about evidence. I agree with evolutionary theory because of the strong evidence supporting it.

Choosing words carefully 3

- Evidence, not proof
  - Scientific ideas are not proven. Proof is not used in science because it implies certainty. Science gathers evidence which may help support or refute a hypothesis or theory; but they can never be absolutely proven

- Adapt
  - Evolution does not consist of individuals adapting to changing environments in their lifetimes.
  - Evolutionary adaptations occur through action of natural selection working on populations of genetically varying individuals (phenotypic plasticity).
  - Some of those genetic variations may have advantages over others in that environment and will increase in frequency over many generations (evolutionary adaptations).

Choosing words 4

- Randomness
  - Erroneous thinking that evolution is random because some elements of its process are random.
  - Mutations (and variation generated by them) are “random” in that the sort of mutation that occurs can’t be predicted. While some aspects of mutation are random, natural selection is not. It favors mutations that confer a fitness benefit to the individuals that carry them.
  - Evolution that occurs through natural selection is not random at all, even though the genetic variation, upon which natural selection acts, is generated by random mutations.
- Ancestor vs. relative
  - Humans and chimps are relatives, descending from common ancestor. We did not evolve from apes; they are not our ancestors.
- Neither primitive nor advanced
  - Describing any organism as primitive or advanced is a value judgment that is not scientific. The terms ancestral and derived can only be used to refer to traits not organisms.

“Missing Link” = nonscientific term

- The term "missing link" refers back to the originally static pre-evolutionary concept of the great chain of being, a deist idea that all existence is linked, from the lowest dirt, through the living kingdoms to angels and finally to God.
- It is, however, avoided in the scientific press, as it relates to the concept of the great chain of being and to the notion of simple organisms being primitive versions of complex ones, both of which have been discarded in biology.

Choosing words 5

- Transitional features, not missing links
  - Most organisms are not preserved as fossils, and of those that are, the majority have not been found.
  - Biologists expect that most intervening steps in evolutionary transition (ancient arthropod to modern butterfly) will be recorded as fossils. Therefore “missing links” are not missing, and having gaps in fossil record is to be expected & perfectly consistent with evolutionary theory.
  - Preferable to discuss organisms with specific transitional features, not whole missing links.
  - A **transitional fossil** is any fossilized remains of a life form that exhibits traits common to both an ancestral group and its derived descendant group

No goal or direction

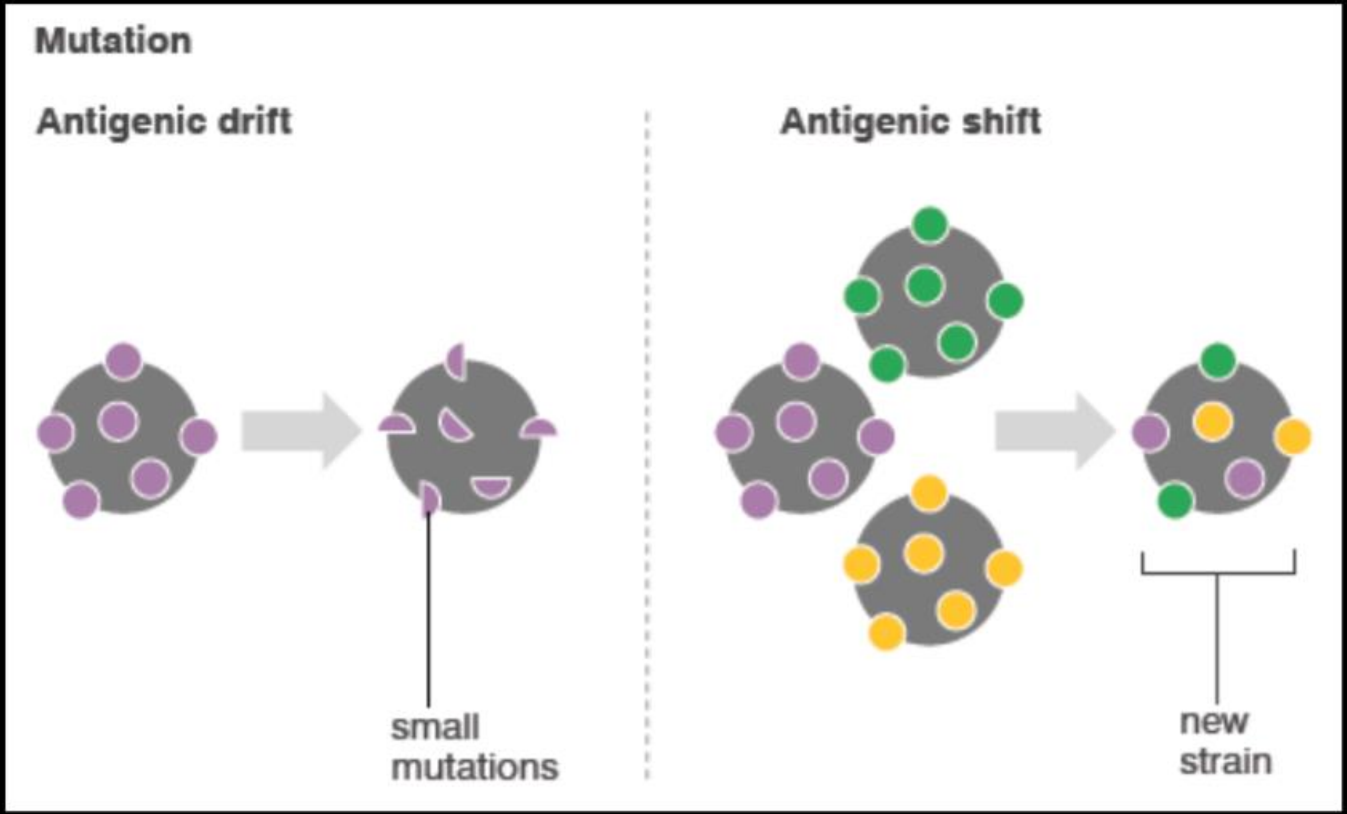
- For instance, that single-celled organisms eventually gave rise to multicellular organisms might appear to exemplify directed movement towards so-called "higher" life-forms. But as Gould (1996) and others point out, there is a left-hand wall to complexity; by definition, the simplest possible organism can only become more complex or stay the same. In this sense, evolution is a "drunkards walk", wherein certain lineages inevitably attain unexplored novelty in form and function.

So what does evolution mean?

- Evolution is a change in the number of times specific genes that code for specific characteristics occur within an interbreeding population
- Individuals don’t evolve, only populations do
- In the 1970s, Stephen Jay Gould pushed his readers to appreciate human evolution as a bush, rather than a simplistic march of progress.
- There is no implied “improvement” in evolution: no goal, no direction, no director.

Dog breeds

The flu



Mutation
Antigenic drift
Antigenic shift
small
mutations
new
strain

Positive selection

- Positive natural selection, or the tendency of beneficial traits to increase in prevalence (frequency) in a population, is the driving force behind adaptive evolution.
- For a trait to undergo positive selection, it must have two characteristics.
- First, the trait must be beneficial; in other words, it must increase the organism's probability of surviving and reproducing.
- Second, the trait must be heritable so that it can be passed to an organism's offspring.
- Beneficial traits are extremely varied and may include anything from protective coloration, to the ability to utilize a new food source, to a change in size or shape that might be useful in a particular environment.
- If a trait results in more offspring who share the trait, then that trait is more likely to become common in the population than a trait that arises randomly.
- At the molecular level, selection occurs when a particular DNA variant becomes more common because of its effect on the organisms that carry it.

Neutral Selection, Negative Selection & Selective sweeps

- In humans, at least, the great majority of mutations are thought to be selectively neutral, conferring neither benefit nor cost on their bearers.
- The frequency of some of these neutral genetic variants (alleles) increases simply by chance, and the resulting "genetic drift" is thought to be the most common process in human evolution.
- Moreover, when selection does occur, it is most often in the form of negative, or purifying, selection, which removes new deleterious mutations as they arise, rather than promoting the spread of new traits
- As advantageous alleles that are under positive selection increase in prevalence, these alleles leave distinctive signatures, or patterns of genetic variation, in the DNA sequence. Consider a population of individuals for which, before selection, there are hundreds of thousands of varied chromosomes in the population, all with different combinations of genetic variants. Now, say that an advantageous allele arises as a mutation on one copy of a chromosome. Through succeeding generations, the descendants of this copy, including the selected allele and nearby "hitchhiking" alleles, become more common through a process called a "selective sweep"

Example of Selective Sweep

- **Lactose Tolerance**: those who could best digest new foods in an environment get a selective advantage.
- The best understood of these adaptations is lactose tolerance; ability to digest lactose, a sugar found in milk, usually disappears before adulthood in mammals. for some people, including a large fraction of individuals of European descent, the ability to break down lactose persists because of a mutation in the lactase gene (*LCT*).
- This suggests that the allele became common in Europe because of increased nutrition from cow's milk, which became available after the domestication of cattle. Nearly 80% of people of European descent carry this allele, and it has evidence of a selective sweep spanning roughly 1 million base pairs. Indeed, lactose tolerance is one of the strongest signals of selection seen anywhere in the genome.
- A distinct LCT mutation also confers lactose tolerance, in this case in African pastoralist populations, suggesting the action of convergent evolution

Positive Sweep: Malaria resistance

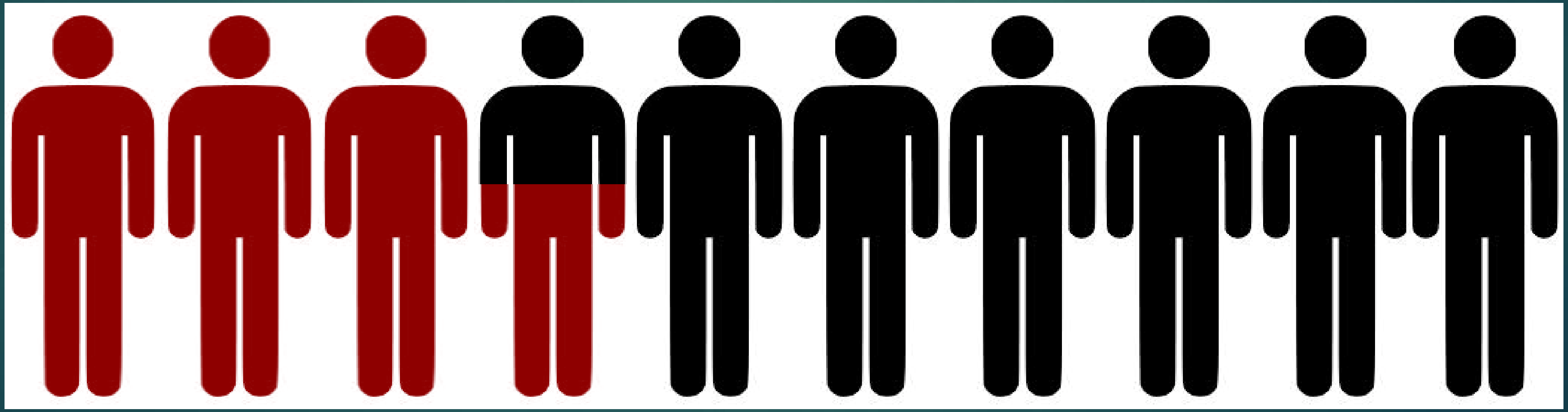
- Increased population density made the transmission of infectious diseases easier, and it probably expanded the already substantial role of pathogens as agents of natural selection
- Malaria infects hundreds of millions of people and kills 1 to 2 million children in Africa each year. In fact, malaria was responsible for the first case of positive selection demonstrated genetically in humans in the 1940s and 1950s, by J. B. S. Haldane and A. C. Allison; sickle-cell mutation (Glu6Val) in the beta hemoglobin gene (*HBB*) was limited to Africa and correlated with malaria endemicity, and that individuals who carry the sickle-cell trait are resistant to malaria
- Malaria also drove one of the most striking genetic differences between populations. This difference involves the Duffy antigen gene (*FY*), which encodes a membrane protein used by the *Plasmodium vivax* malaria parasite to enter red blood cells, a critical first step in its life cycle. A mutation in *FY* that disrupts the protein, thus conferring protection against *P. vivax* malaria, is at a frequency of 100% throughout most of sub-Saharan Africa and virtually absent elsewhere; such an extreme difference in allele frequency is very rare for humans.

Positive Sweep: Pigmentation

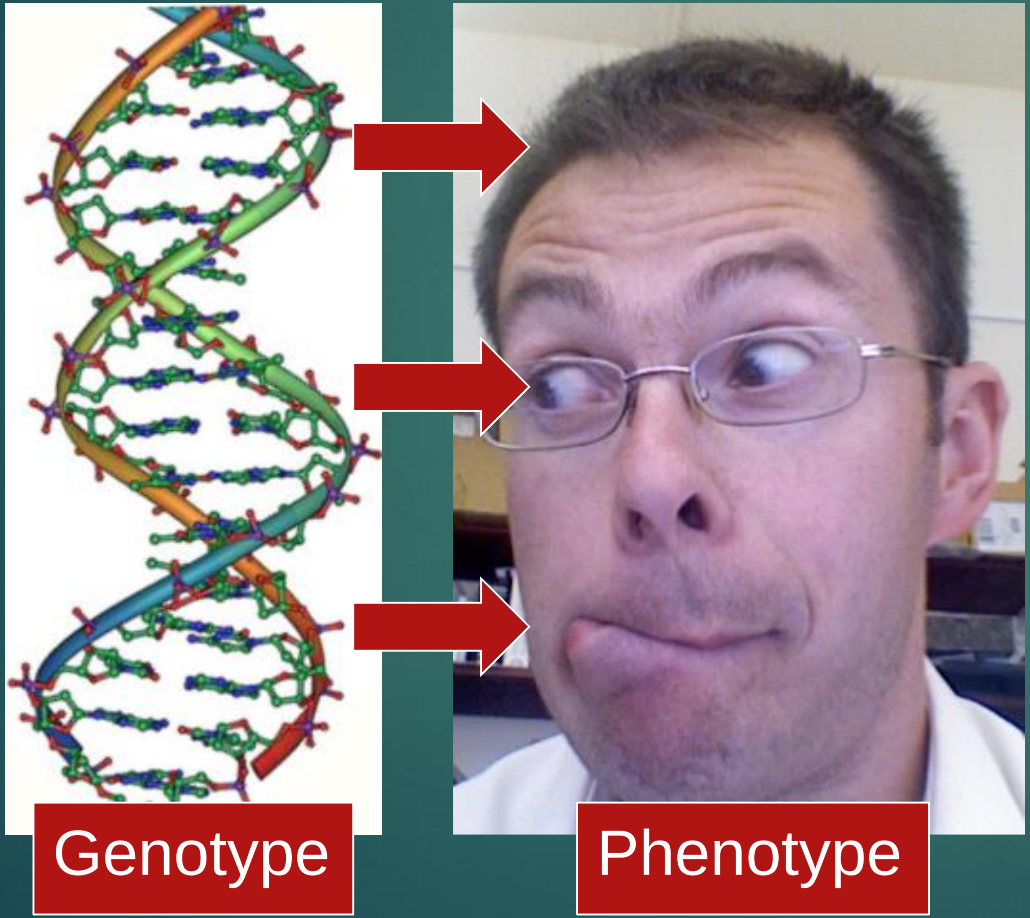
- As proto-Europeans and Asians moved northward out of Africa, they experienced less sunlight and colder temperature, new environmental forces that exerted selective pressure on the migrants. Exactly why reduced sunlight should be a potent selective force is still debated, but it has become clear that humans have experienced positive selection at numerous genes to finely tune the amount of skin pigment they produce, depending on the amount of sunlight exposure.
- Evidence for purifying selection has also been found to maintain dark skin color in Africa, where sunlight exposure is great.
- A good example of selection for lighter pigmentation is the gene *SLC24A5*, which was one of the first to be characterized. A human variant in the gene explains roughly one-third of the variation in pigmentation between Europeans and West Africans, and that the European variant was a target of selection
- For the great majority of selective sweeps, the pressure that drove selection, the trait selected for, and even the specific gene involved are unknown.

Lactase Persistence

HOWEVER… **35% of humans do produce lactase after weaning**, and are therefore able to continue to consume milk and other dairy products into adulthood.



Genes



commons.wikimedia.org/wiki/Image:DNA_double_helix_vertikal.PNG

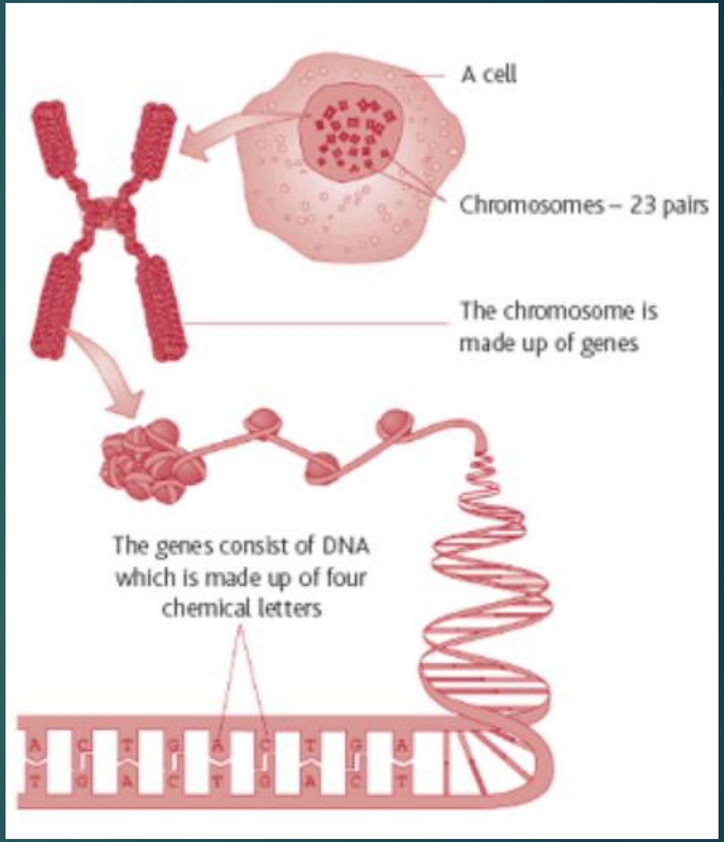
- The genetic make-up of an organism is known as its genotype.
- An organism's genotype and the environment in which it lives determines its total characteristic traits i.e. its phenotype.

Gene

- 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 code for something, like a unique recipe
- Gene can create 20 amino acids which can create millions of specifically shaped proteins – cells – tissues – organ - organism
- ~20K human genes
- small genes (300 Ns) vs large (> 1M Ns);
- size determines function of gene (hemoglobin captures and releases Ox; Pepsin breaks down food; keratin, a structural protein, creates hair & fingernails, claws, beaks

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: the different versions of a trait in a gene (1 from Mom, 1 from Dad)
  - Example: purple vs white flower



DNA replication

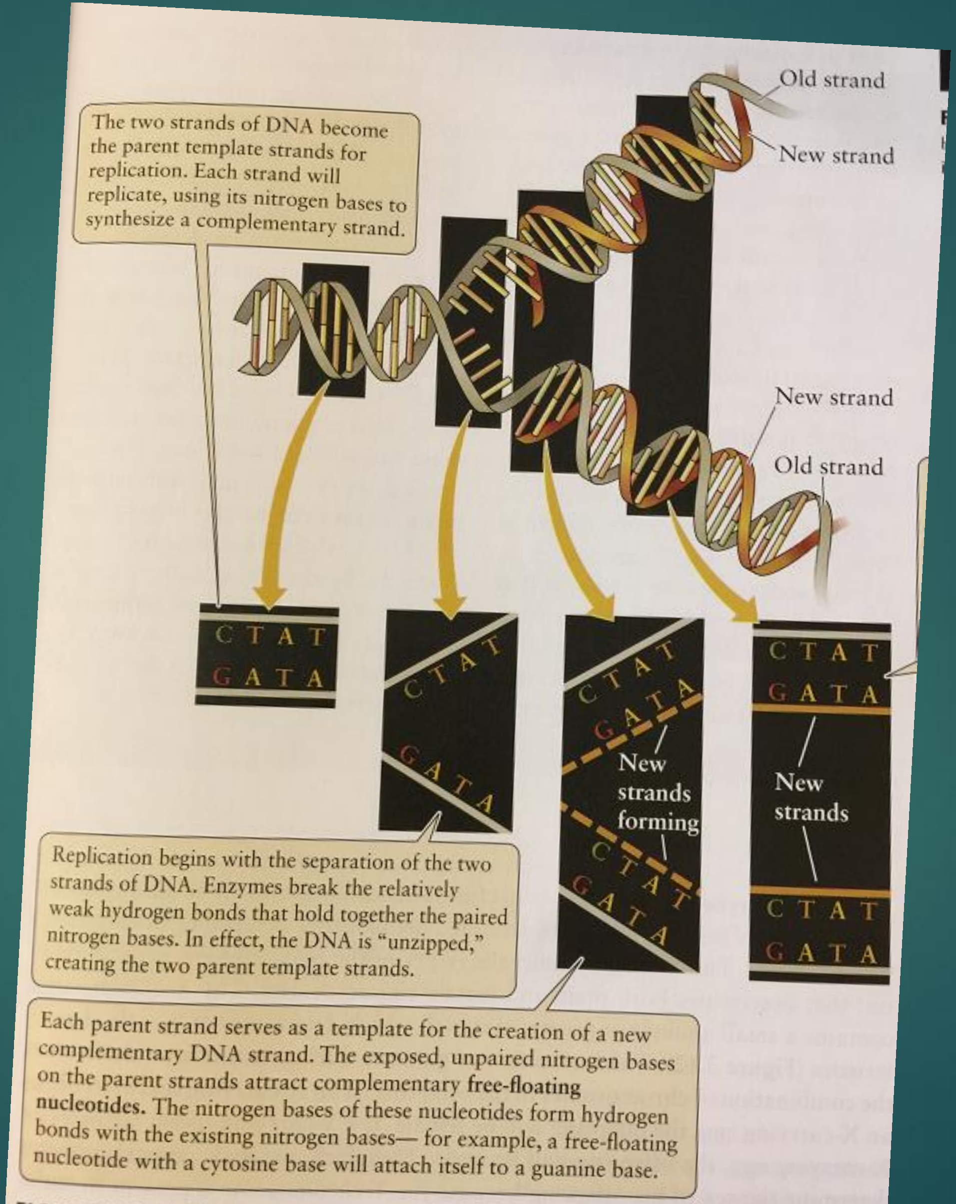


FIGURE 3.10 ■ The Steps of DNA Replication

Human Genome: DNA

- The **human genome** is the complete set of nucleic acid sequences for humans, encoded as DNA within the 23 chromosome pairs in cell nuclei and in a small DNA molecule found within individual mitochondria.
- Genome size: 3,234.83 Mb (Mega-basepairs) per haploid genome 6,469.66 Mb total (diploid).
- ~20,000 protein coding genes = sequences that can be transcribed into mRNA and translated into proteins
- 0.1% difference between 2 people; 99.9% identical

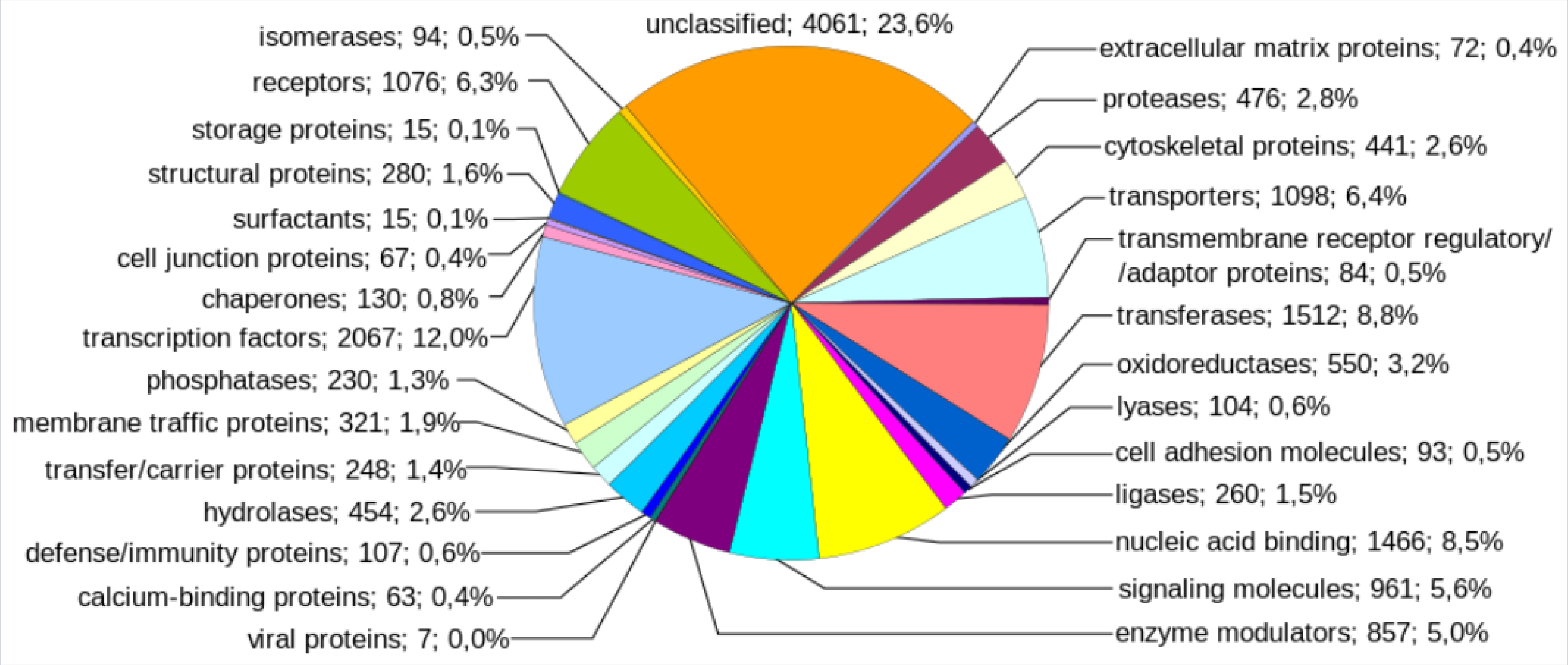
Non-coding DNA

- Noncoding genes = 98% of genome; some of this junk DNA is highly conserved, implying positive selection
- A large portion of eukaryotic organisms' total DNA does not produce amino acids. In humans, more than 98% of the genome is noncoding. Much of this DNA is vestigial–it expressed in our ancestors but not longer serves a purpose. DNA that does not serve a purpose can mutate without having any affect on the organism.
- Has some with important biological functions (i.e. switches of turning on coding gene expression)
- Stickleback fish: ocean variety have spikey fins (hard to swallow); lake variety have lost spikes on belly (gene not turned on because of mutation)

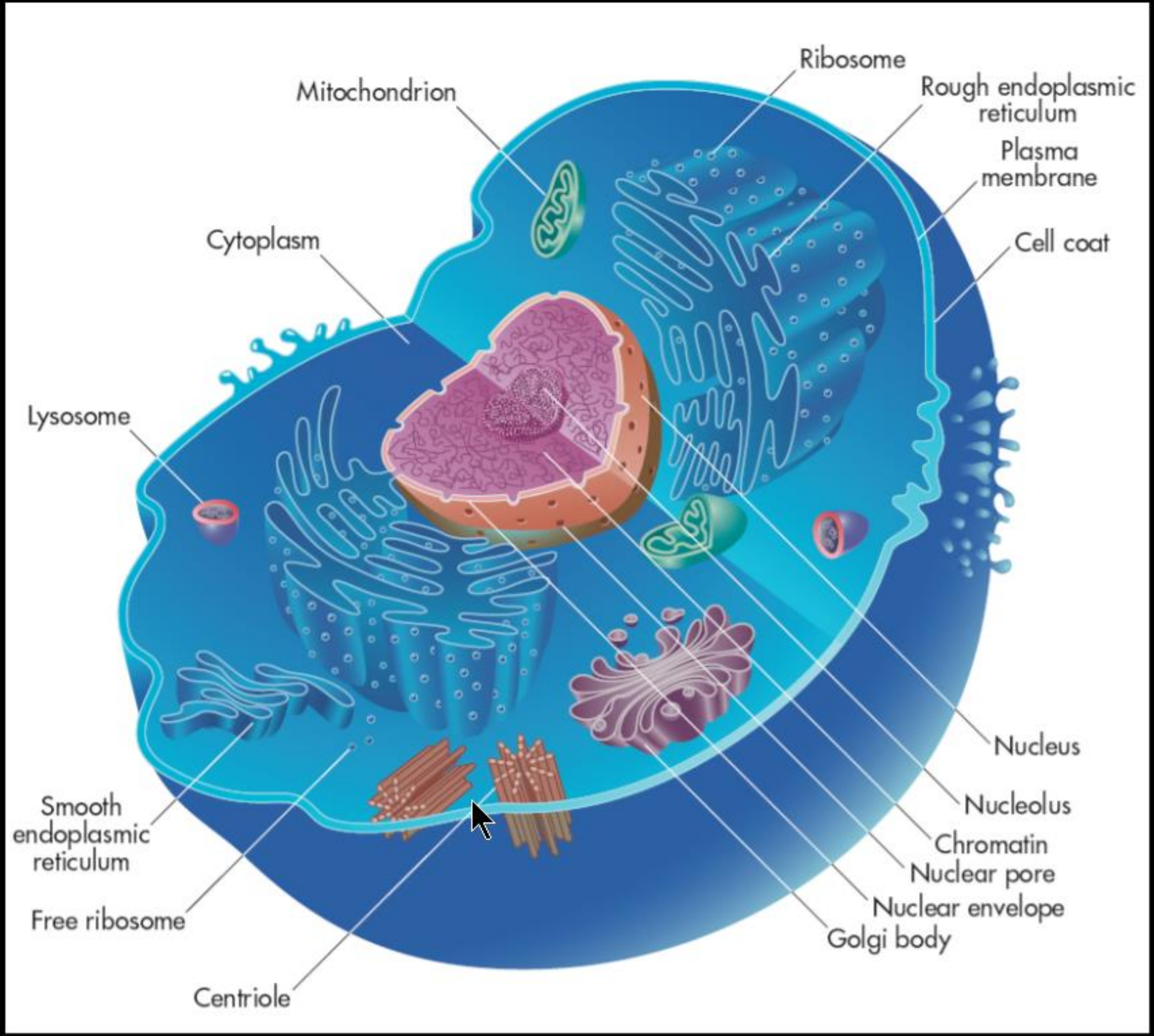
Non-coding DNA

- Hind limb loss: species that lose hind legs (snakes, whales, manatee); flag is pelvic bone that is bigger on left and smaller on right
- Same body plan gene that removed spikes are in control of hind legs
- What triggers those genes? Genes that boss other genes around: Darwin’s finches are born with beaks fully formed (depended on 24 hour timing difference of expression of gene

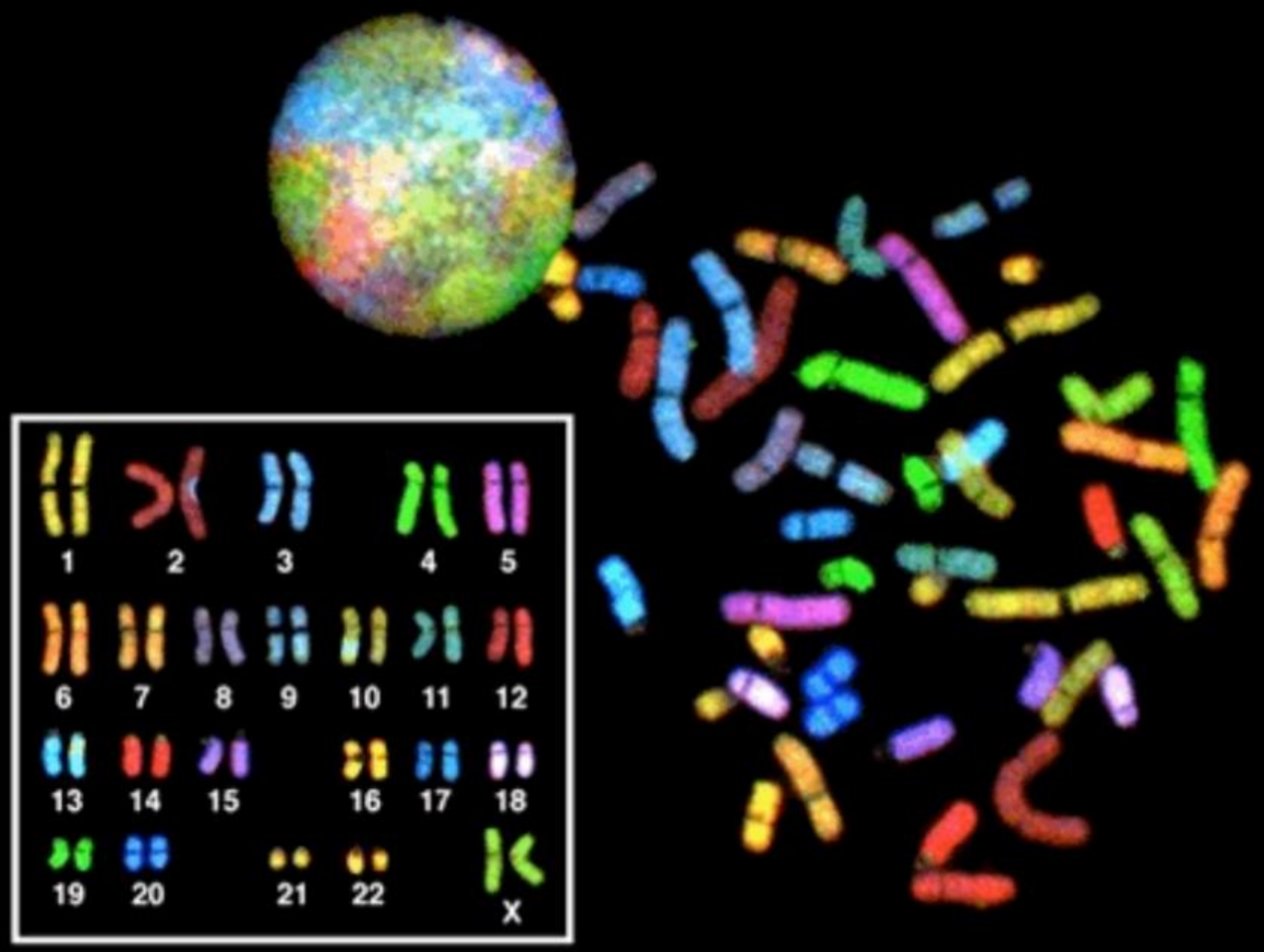
Gene functions

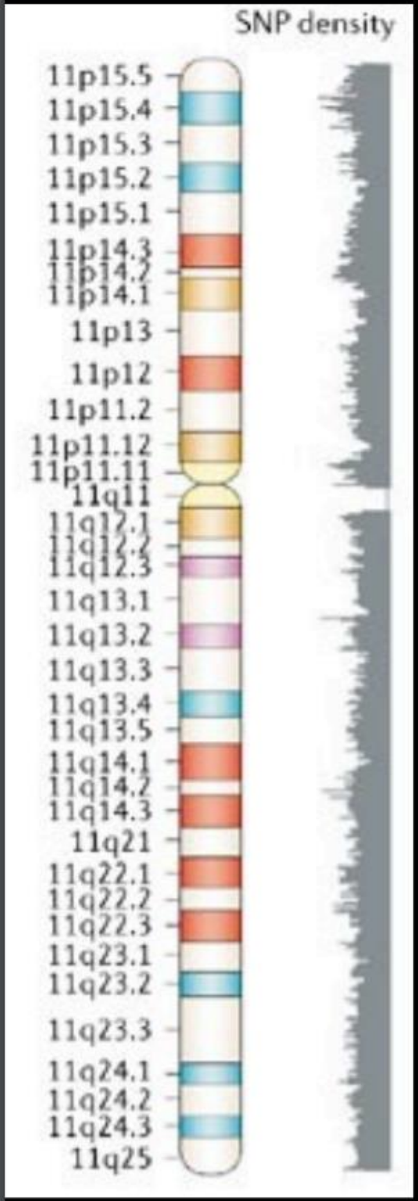


Human genes categorized by function of the transcribed proteins, given both as number of encoding genes and percentage of all genes.[15]


Ribosome
Mitochondrion
Rough endoplasmic reticulum
Plasma membrane
Cytoplasm
Cell coat
Lysosome
Nucleus
Nucleolus
Chromatin
Nuclear pore
Nuclear envelope
Golgi body
Smooth endoplasmic reticulum
Free ribosome
Centriole

Human DNA in Chromosomes

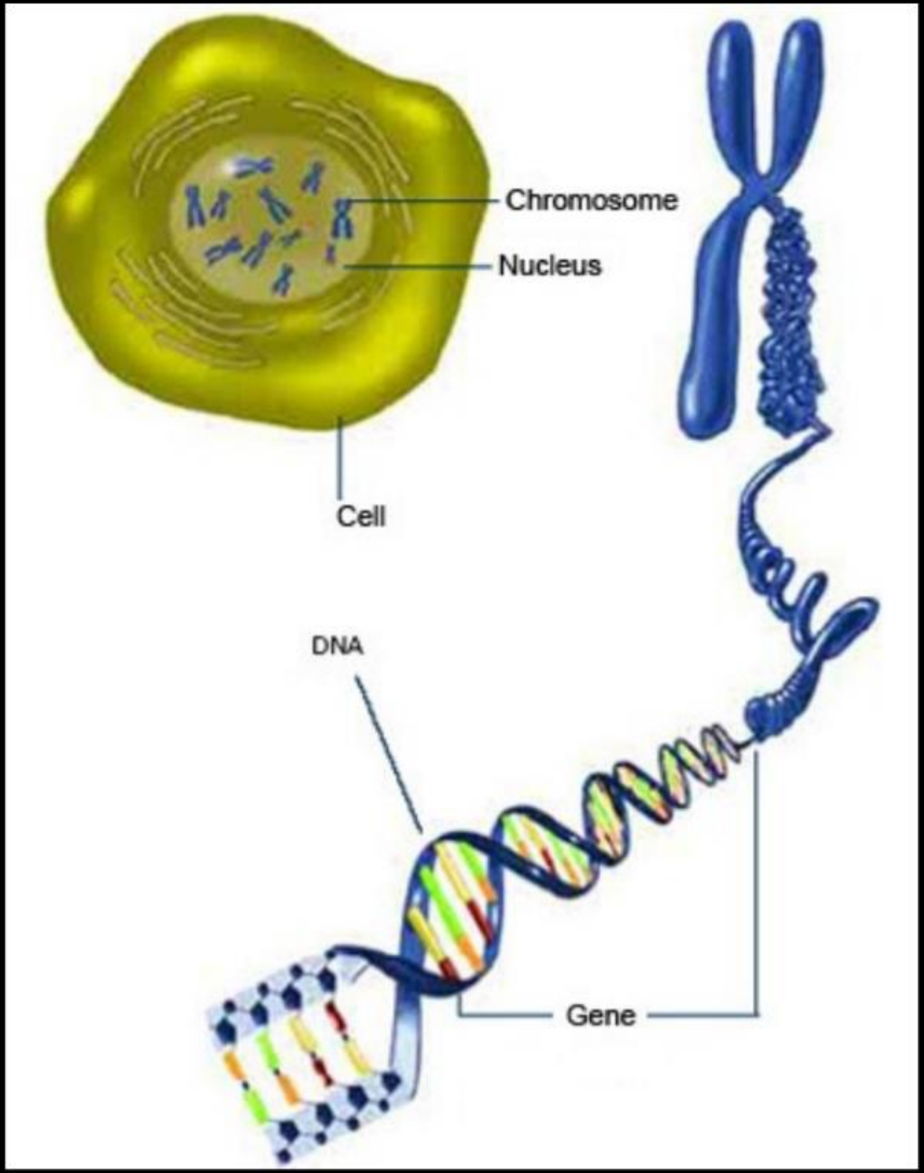




Example: Sickle Cell Anemia

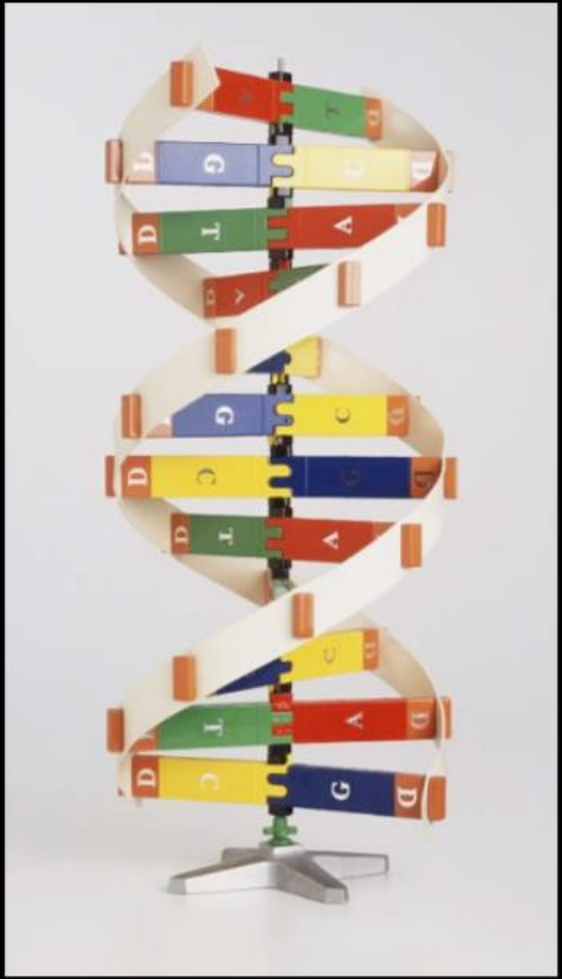
- result of recessive allele at 11p15.5

Chromosomes are DNA



DNA made of 4 bases

- Adenine
- Guanine
- Cytosine
- Thymine



A--T
G--C

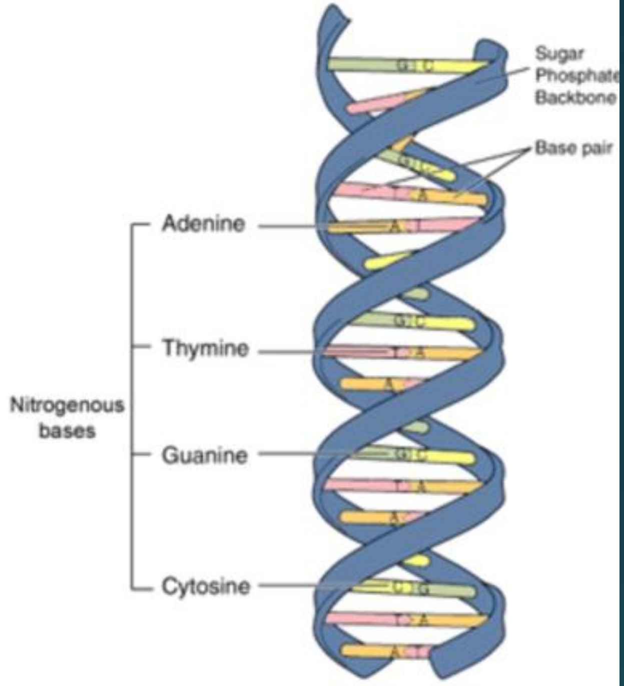
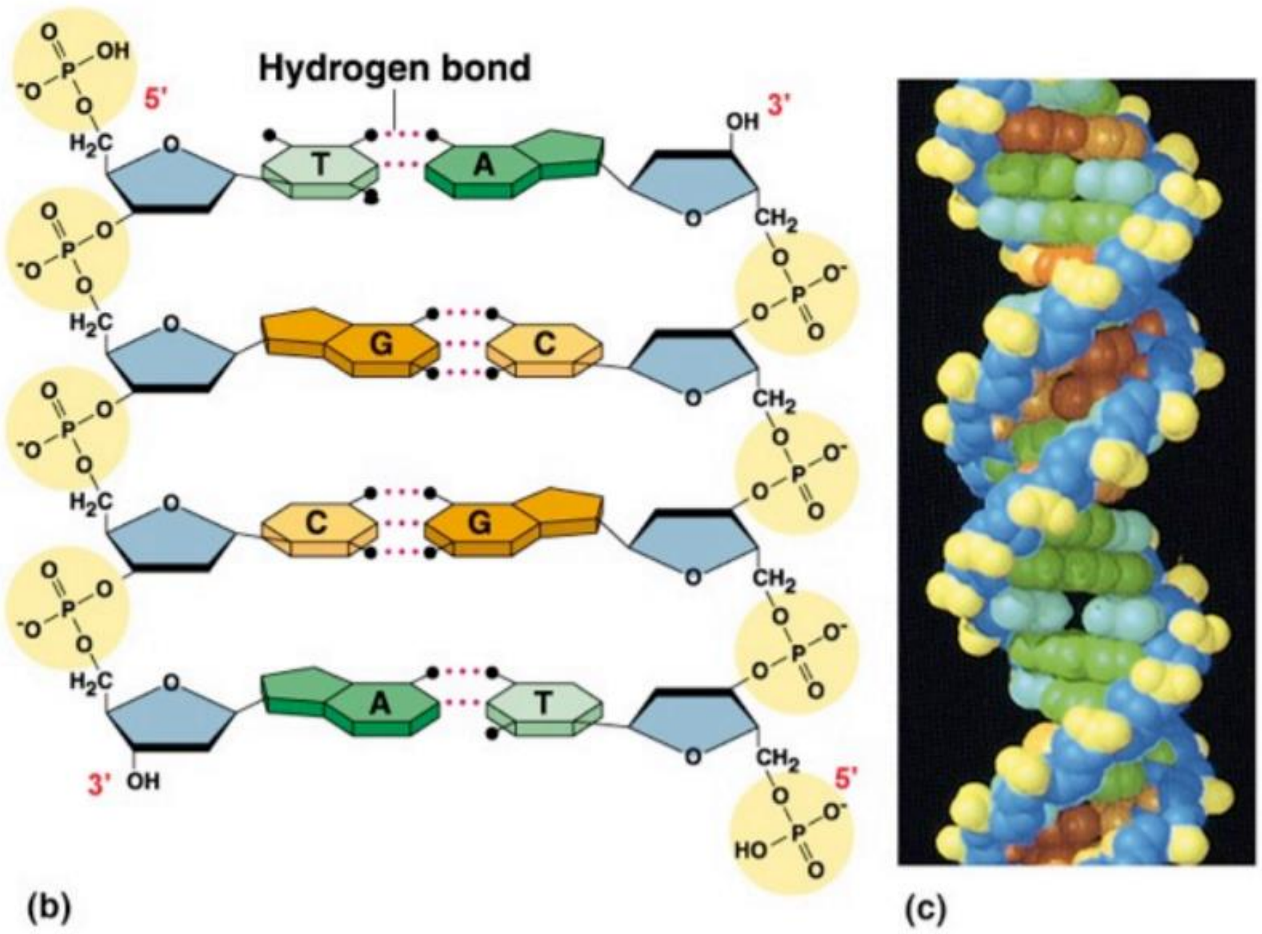


Image adapted from: National Human Genome Research Institute.

The DNA double helix showing base pairs

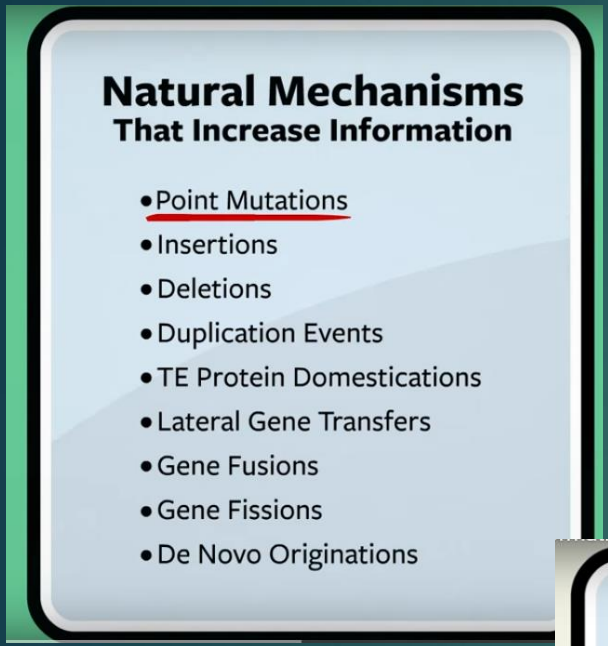
DNA structure

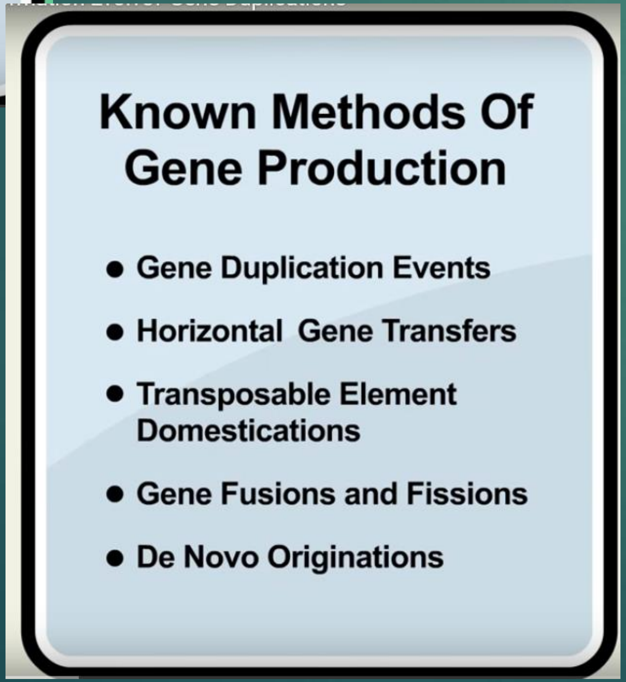


Genes

- Tree of life depends on shared DNA & genes;
- Chimp and human, 98% identical; fruit fly and human, 50%
- DNA in nucleus; amino acids in cytoplasm
- DNA make segments =
  - RNA (single side); RNA exits nucleus and ribosomes, read RNA & creates proteins from amino acids
- DNA is molecular blueprint for life

Ways genes change





- In point mutation, only 1 change in a nucleotide pair, when cell reproduces, is mostly random, and are common.

- Every child born has 36 point mutations: can be +, -, neutral. Positive point mutations can result in a different creature. In E.coli, change of A to T, created an E.coli that dominated. In dogs, 1 point mutation caused long hair

- Duplications: method to create new genes
- Stretch of DNA is duplicated & reinserted into DNA; including an entire gene stretch; with mutations in new gene, new function
- Examples: Dachshunds legs (FGF4 gene dup), *snake venom* (from saliva – factor X seals wounds in blood; venom is preactivated factor X which causes massive clotting in victim; arose from duplication of gene

Terms

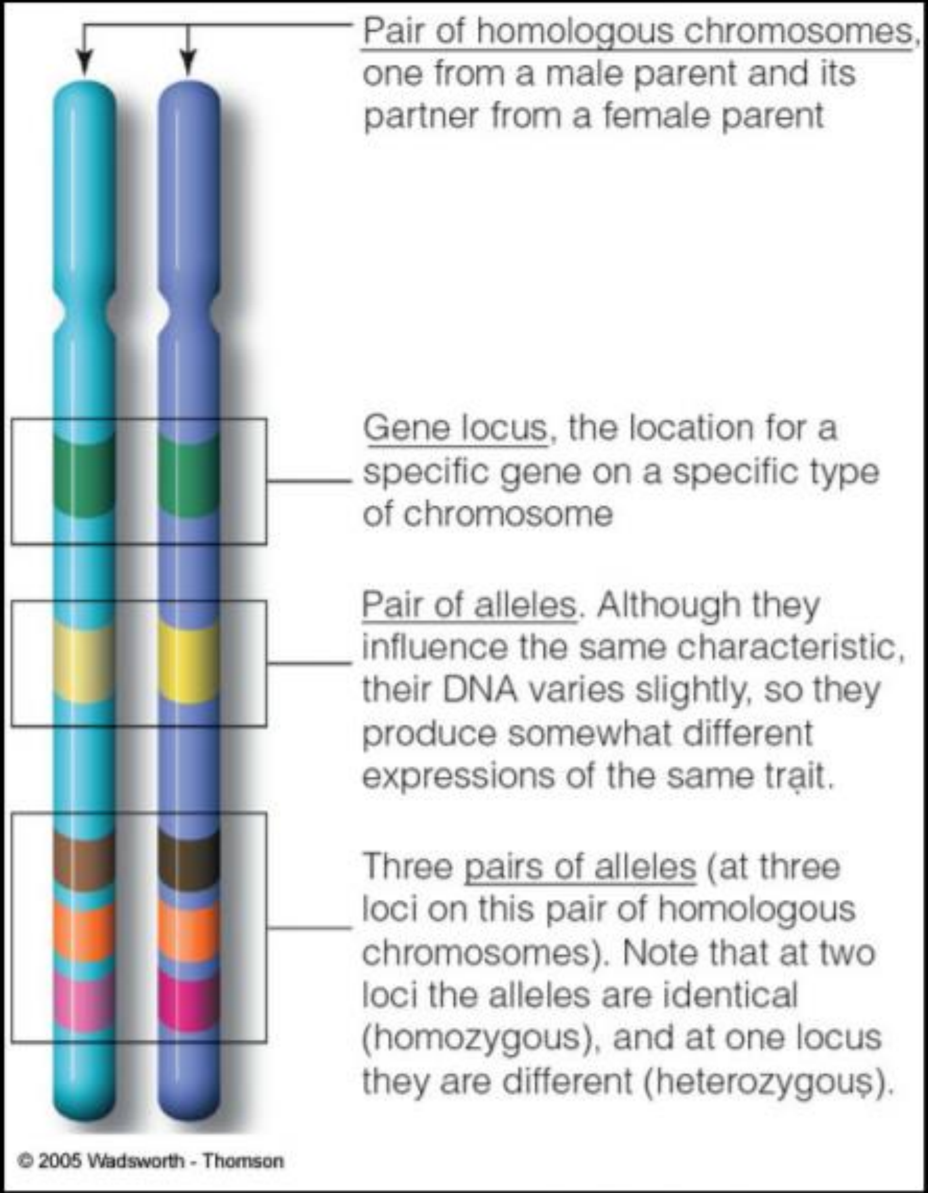
- Dominant trait: when a single allele is present it is expressed; it overrides the other allele, i.e. brown eyes
- Recessive: only expressed when both alleles are the recessive trait, i.e. blue eyes, cystic fibrosis, sickle cell disease
- Incomplete dominance: when both alleles affect a trait, i.e. blended color, i.e. hazel eyes
- Homozygous: if both alleles that cause a trait are the same
- Heterozygous: if alleles that cause a trait are not the same

locus= the location of a gene on a chromosome

Allele= alternative form of a locus

homozygous= having the same allele at the locus on both chromosomes

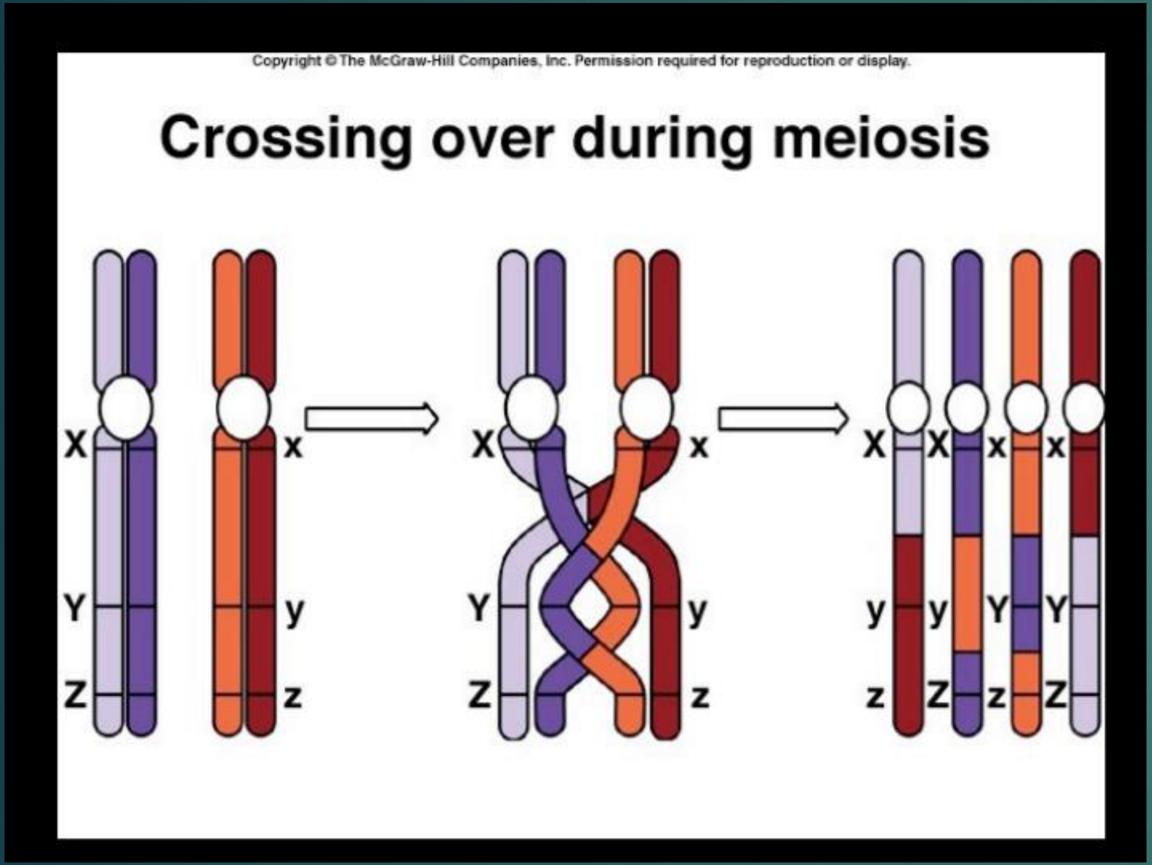
heterozygous= having different alleles at the locus on both chromosomes

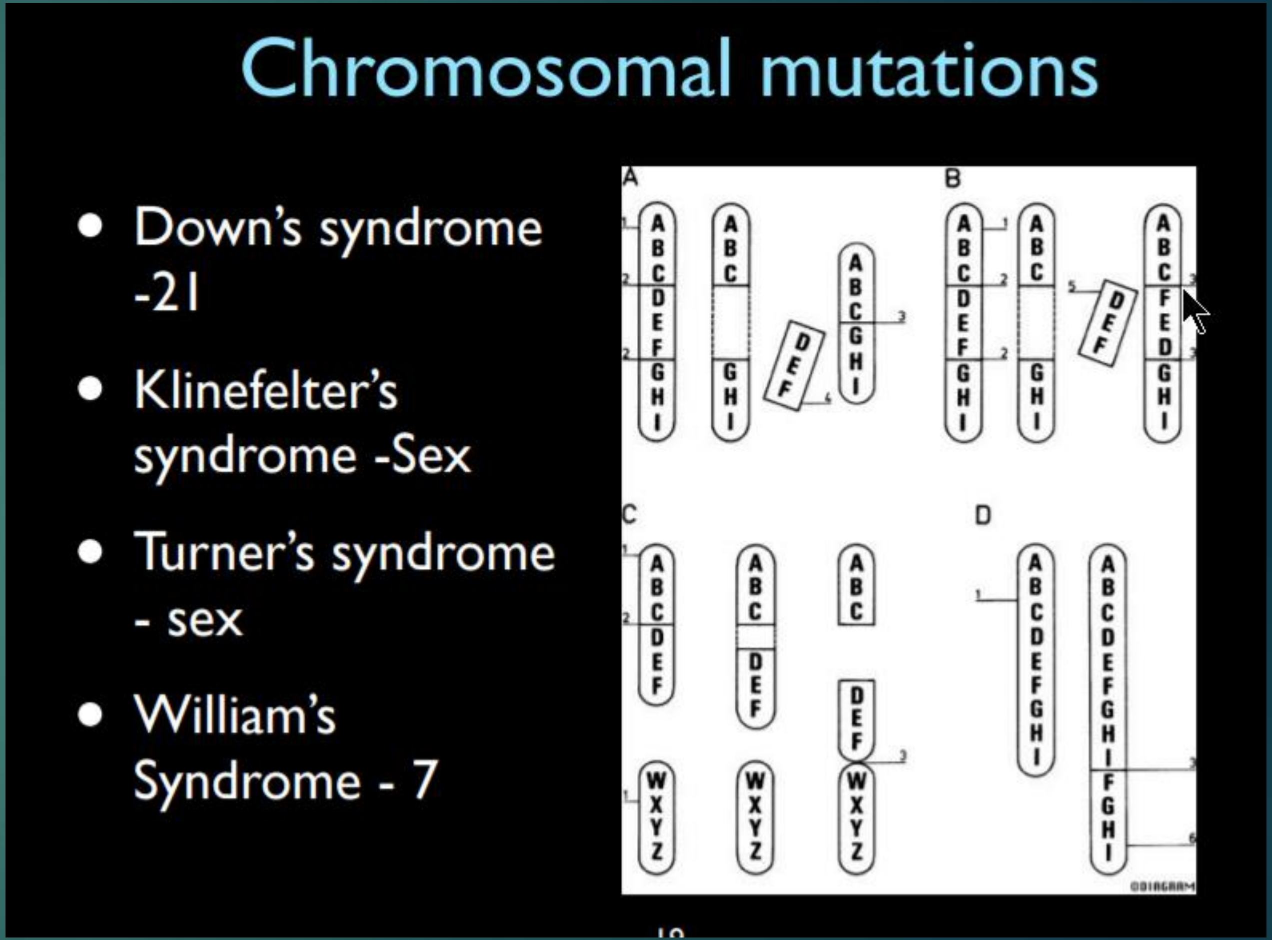


Eye Color

- Actually created by pigment genes at least 3 locales
- Blue eyes are due to the lack of other pigmentation; blue is structural effect, not due to pigmentation
- One allele makes nothing, others make pigmentation.

Crossing Over

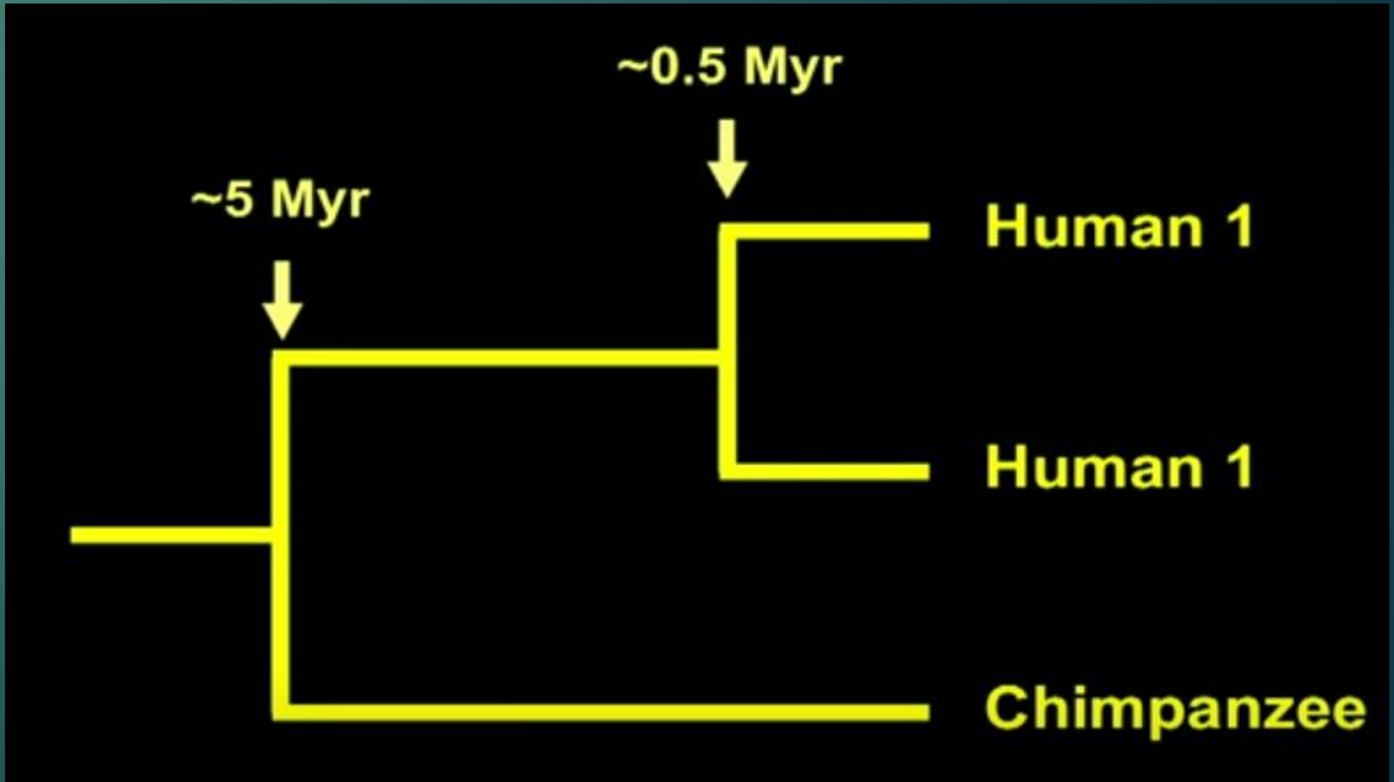




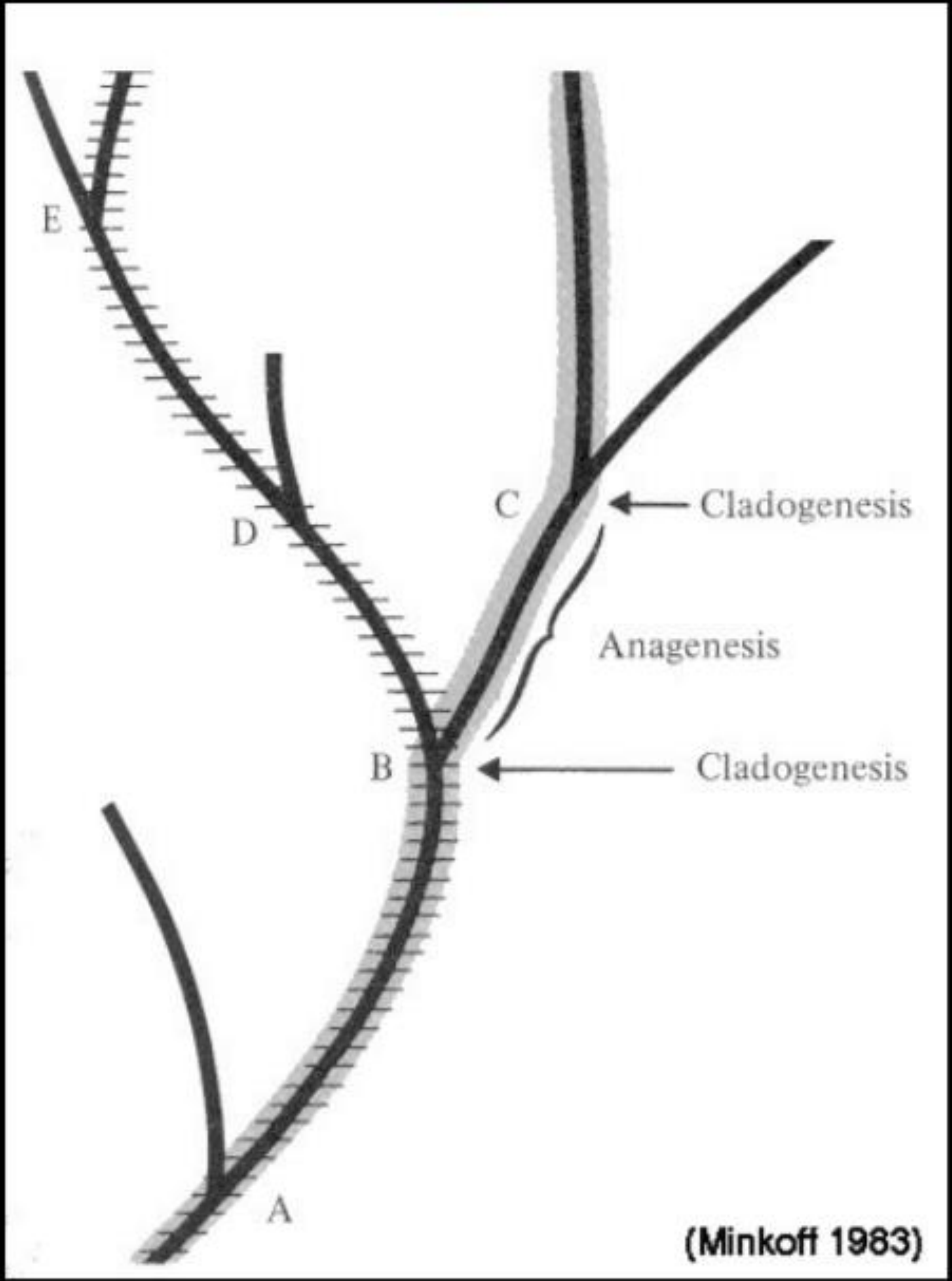
The process by which the chromosome pairs exchange information in meiosis, exchange parts of themselves is called CROSSING OVER.

Human DNA differences

- 3 billion base pairs
- Mutations: 2 people have a base difference every 1200 to 1400 bases
- Mutations accumulate as a function of time
- Between chimps & us, difference in every 100 places
- Track mutations in time

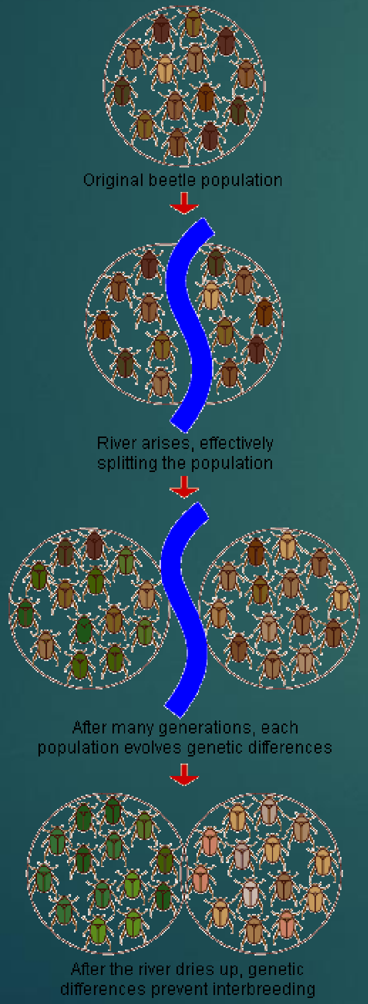


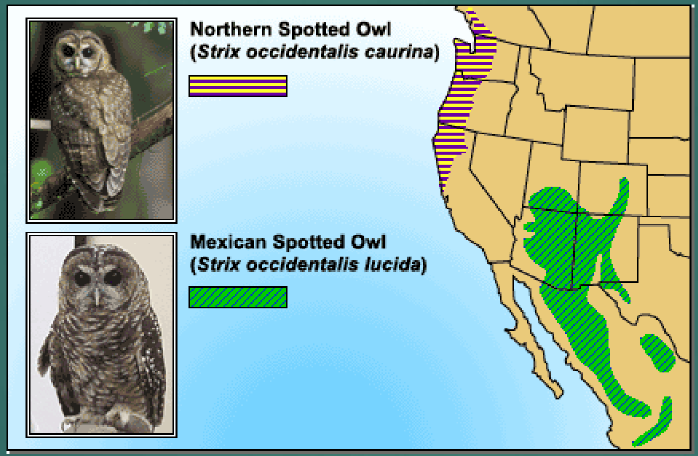
Cladogenesis

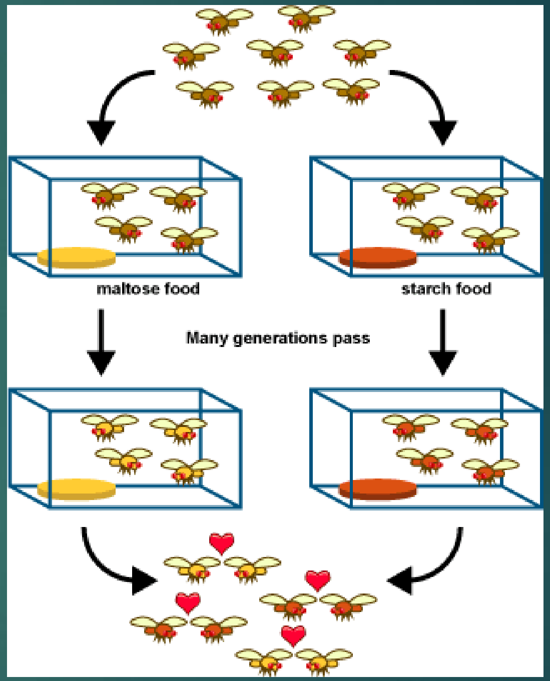


WHAT IS SPECIATION?

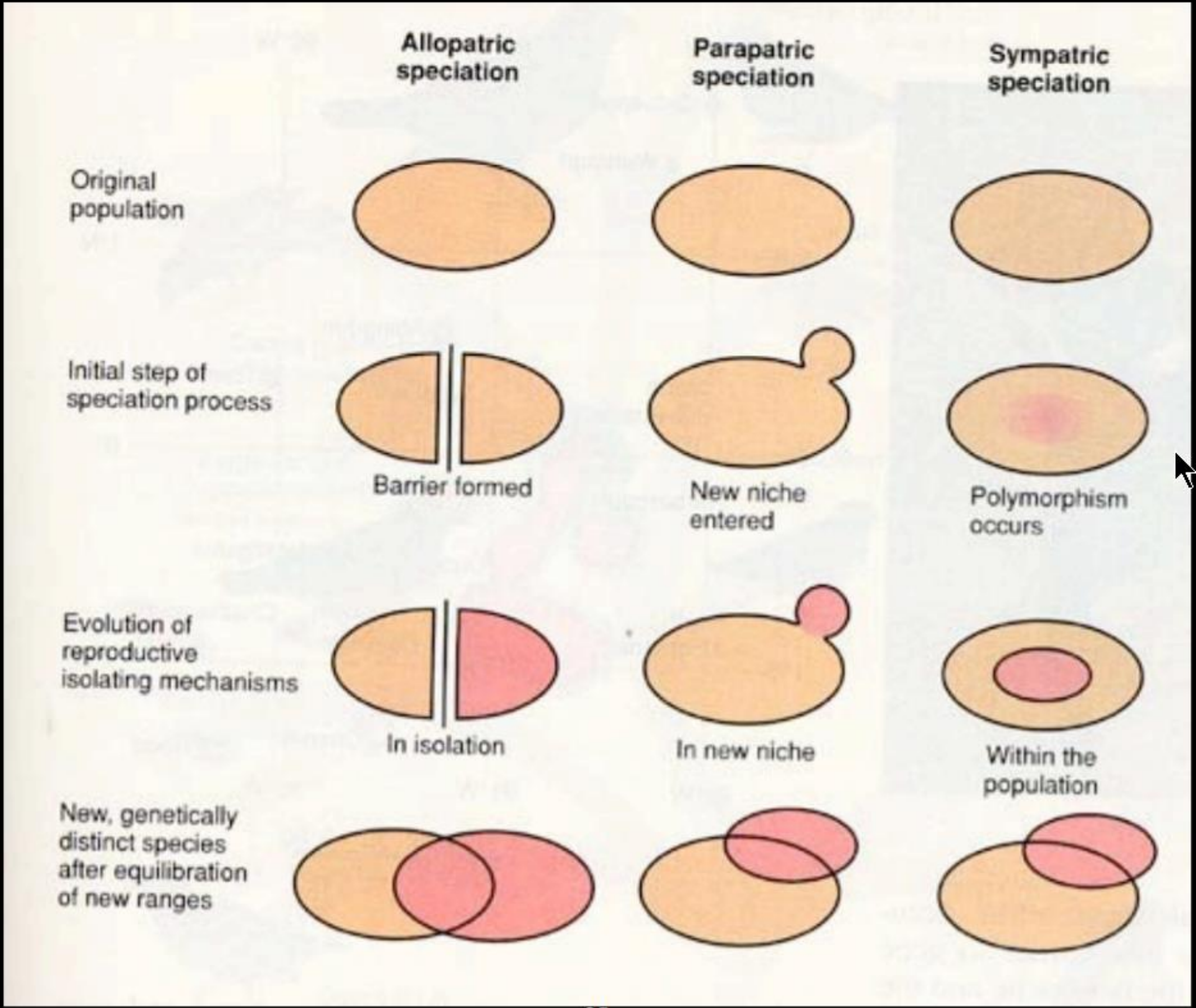
- GEOGRAPHIC ISOLATION
- REPRODUCTIVE ISOLATION

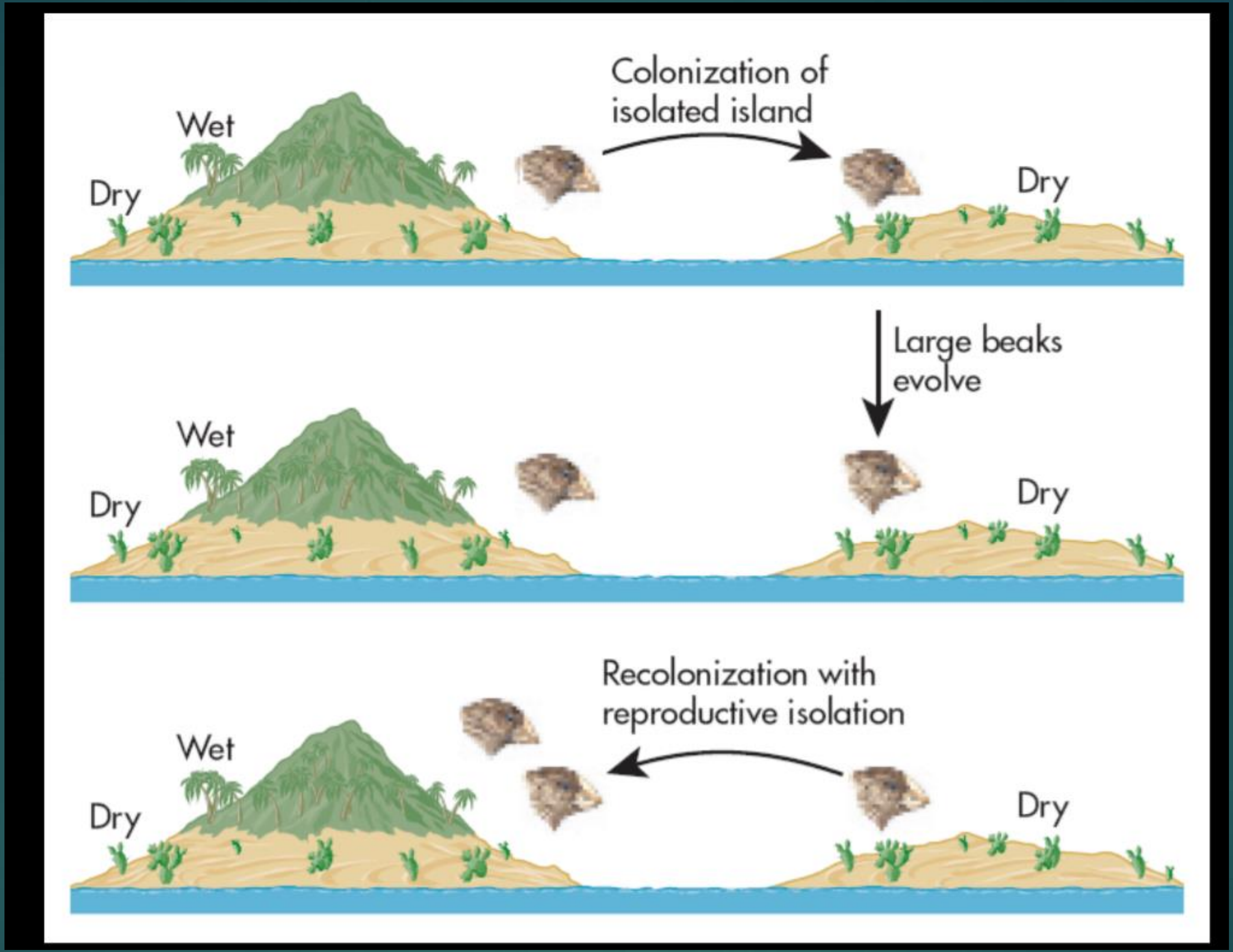






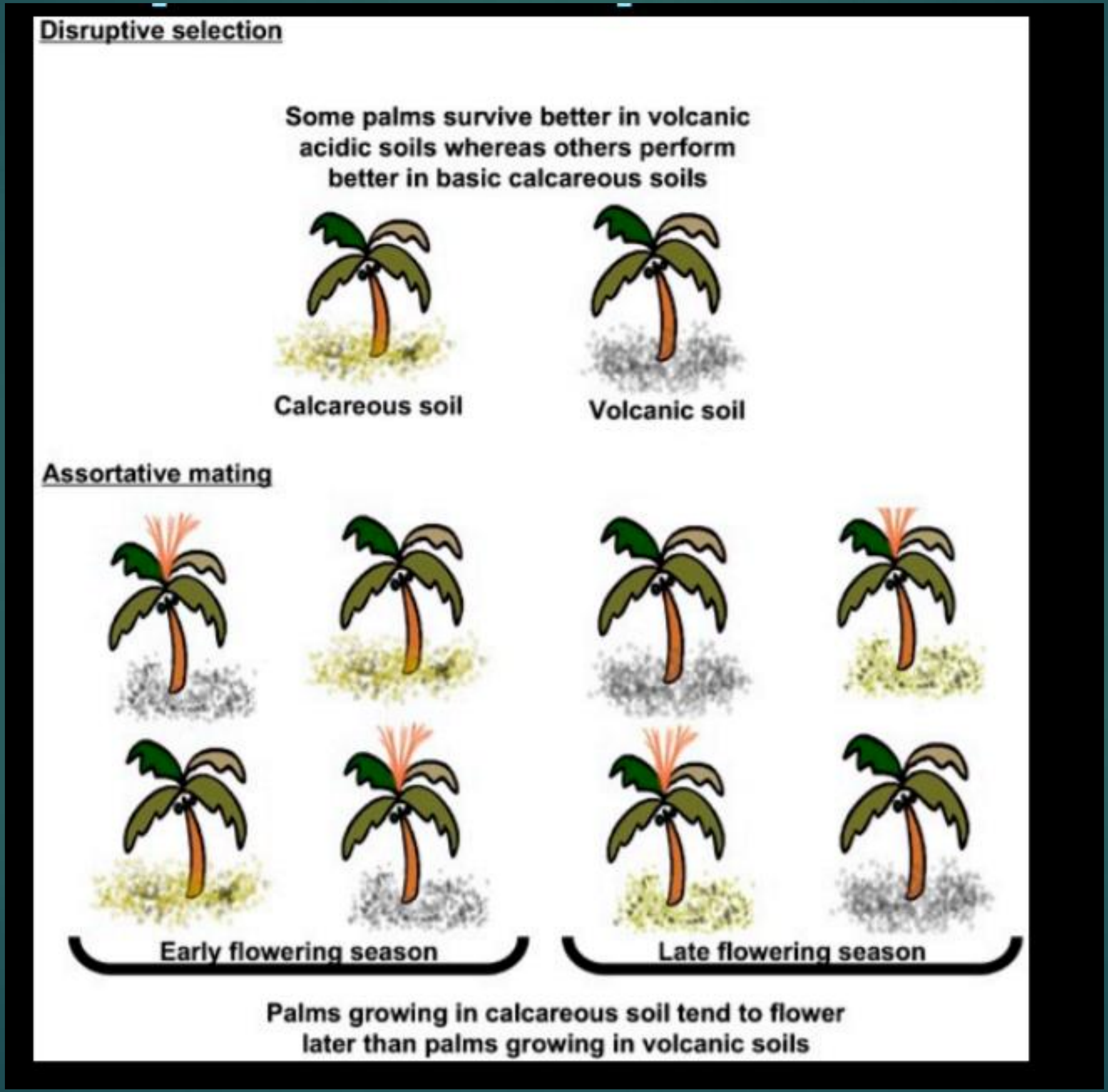
http://evolution.berkeley.edu/evolibrary/home.php


Allopatric speciation
Parapatric speciation
Sympatric speciation
Original population
Initial step of speciation process
Barrier formed
New niche entered
Polymorphism occurs
Evolution of reproductive isolating mechanisms
In isolation
In new niche
Within the population
New, genetically distinct species after equilibration of new ranges



Speciation due to geographic separation of two populations is called (allopatric / sympatric) speciation.

Sympatric speciation



4 types of speciation

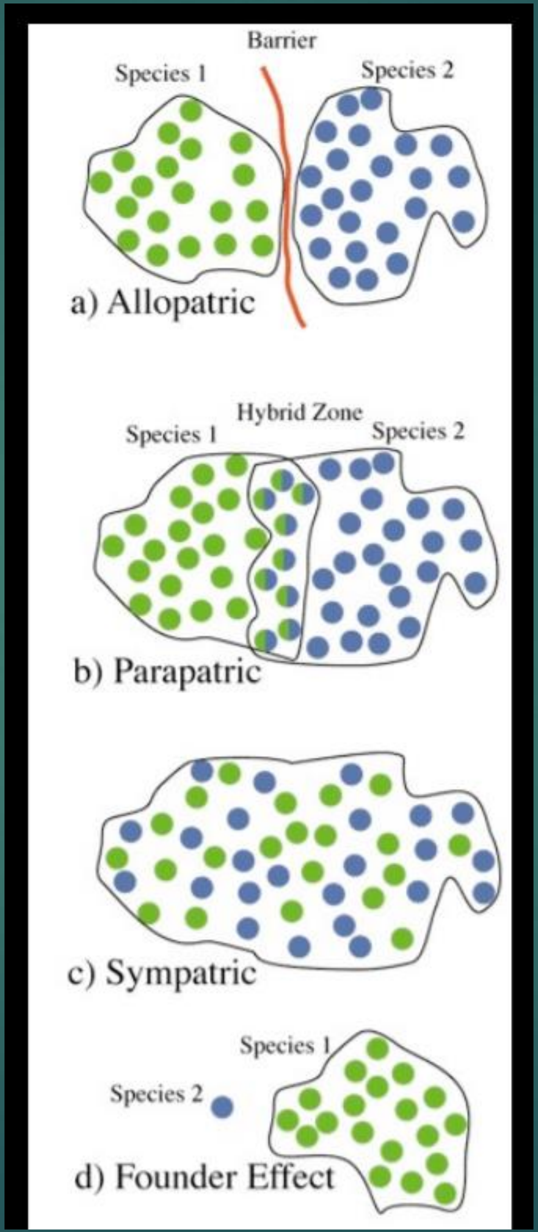
- 4 types: Allopatric, peripatric, parapatric, and sympatric and artificial.
- 1 - Allopatric speciation: occurs when a species separates into two separate groups which are isolated from one another. A physical barrier, such as a mountain range or a waterway, makes it impossible for them to breed with one another. Each species develops differently based on the demands of their unique habitat
- 2 – Peripatric speciation: When small groups of individuals break off from the larger group and form a new species. The main difference between allopatric speciation and peripatric speciation is that in peripatric speciation, one group is much smaller than the other.

4 types of speciation

- 3 - Parapatric speciation: a species is spread out over a large geographic area. Although it is possible for any member of the species to mate with another member, individuals only mate with those in their own geographic region. Like allopatric and peripatric speciation, different habitats influence the development of different species in parapatric speciation. Instead of being separated by a physical barrier, the species are separated by differences in the same environment.
- 4 - Sympatric speciation: controversial. Occurs when there are no physical barriers preventing any members of a species from mating with another, and all members are in close proximity to one another. A new species, perhaps based on a different food source or characteristic, seems to develop spontaneously. The theory is that some individuals become dependent on certain aspects of an environment—such as shelter or food sources—while others do not.

Cultural speciation

- Nongenetically based changes of mate recognition systems can lead to genetic polymorphism (discontinuous genetic variation – sex, blood types) and eventually to speciation
- Bird songs can be considered purely cultural, nongenetic. Combined with - equally culturally determined - differential preferences of females for male bird songs; cultural preferences of females with respect to male songs may differ strongly and diverge within a species. Nongenetically encoded phenotypic behavior may cause actual isolation of subpopulations, leading to increased genetic polymorphism in the population and eventually to speciation.
- Bird song differences
- Whales: good evidence for cultural transmission in song, migrations, foraging behavior, social conventions, cooperative associations with humans, and play. Culture seems to have driven killer whales into distinct ecotypes (food type (salmon, seal, shark), low mtDNA diversity), which may be incipient species
- Isolation (enhanced by cultural differences) between hominin groups
- Human tribes: practice of kidnapping females from other tribes (legends of Sabine virgins, Helen of Troy)


Barrier
Species 1
Species 2
a) Allopatric
Hybrid Zone
Species 1
Species 2
b) Parapatric
c) Sympatric
Species 1
Species 2
d) Founder Effect

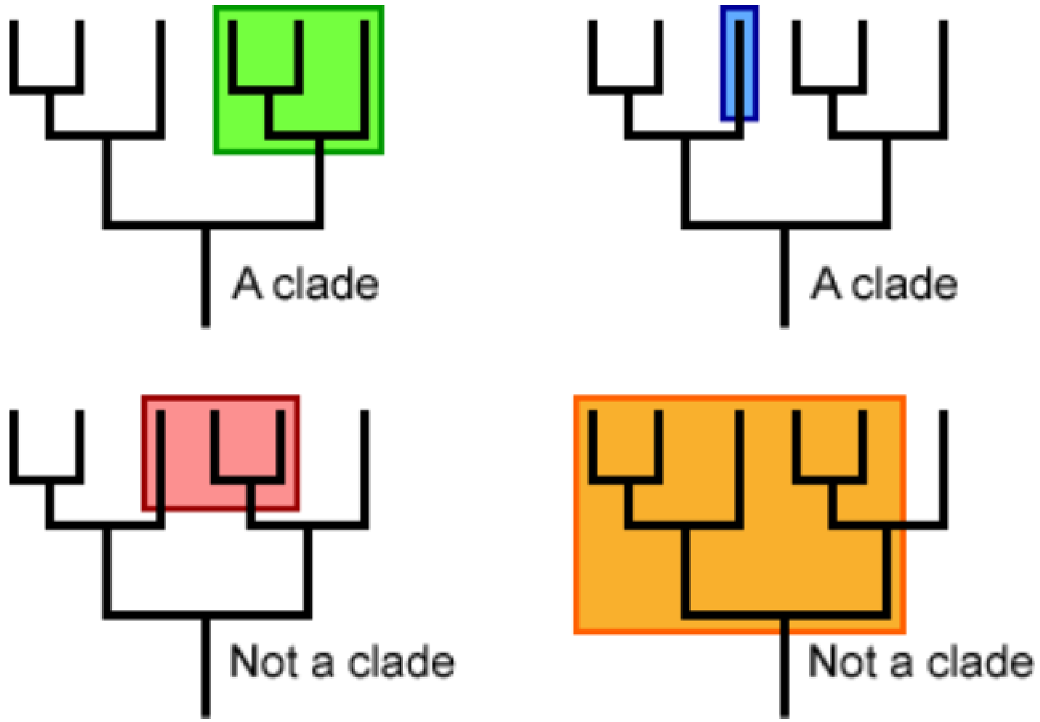
Speciation creates clades

- Clades are evolutionarily related groups

- Classification is the naming of these groups

- Started with Linnaeus
  - • tried to group organisms together based on relationship
  - • based on similarity

A clade is a grouping that includes a common ancestor and all the descendants (living and extinct) of t
ancestor. Using a phylogeny, it is easy to tell if a group of lineages forms a clade. Imagine clipping a si
branch off the phylogeny — all of the organisms on that pruned branch make up a clade.



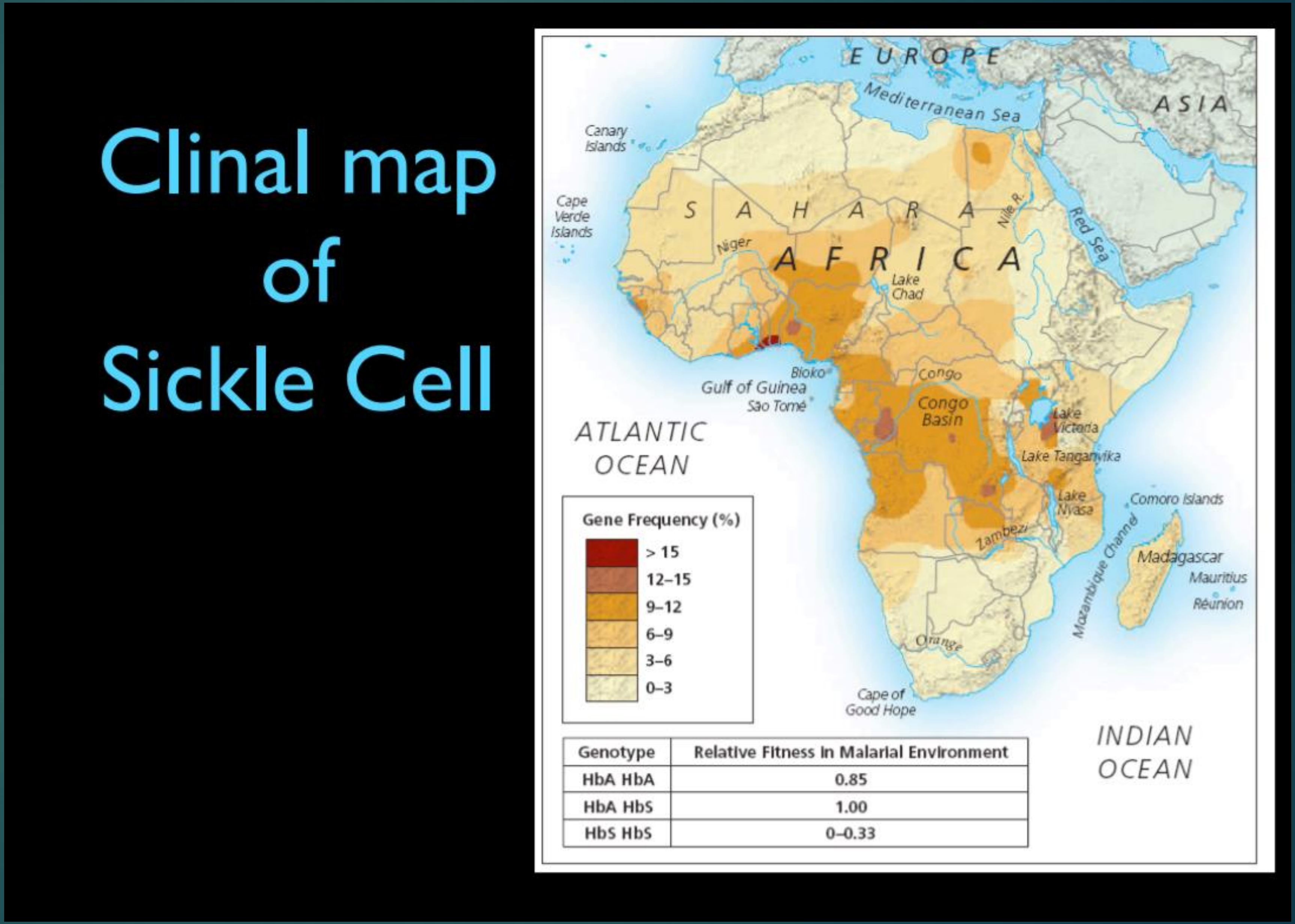
Clades are nested within one another — they form a nested hierarchy. A clade may include many thousands of species or just a few. Some examples of clades at different levels are marked on the phylogenies below. Notice how clades are nested within larger clades.

Altitude

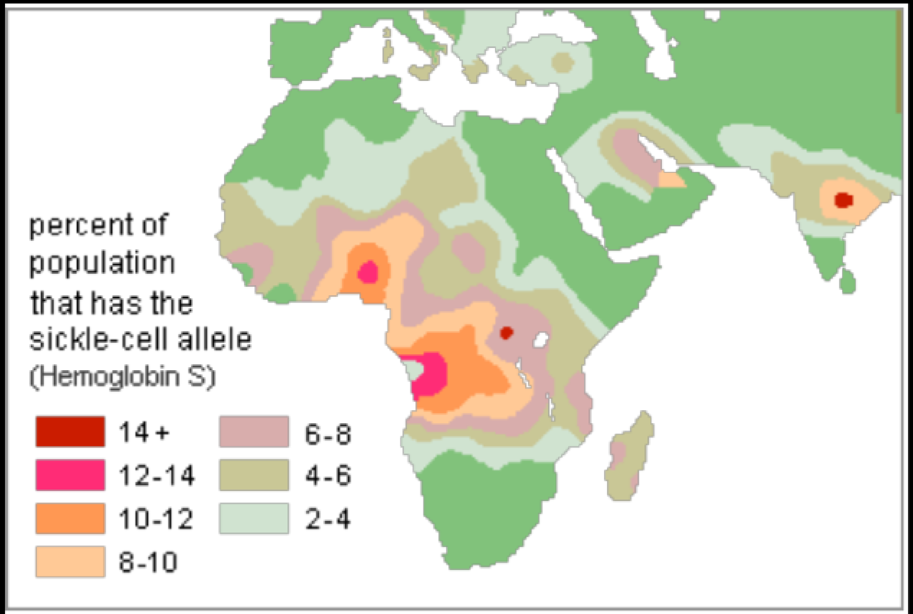
Andes

Himalayas

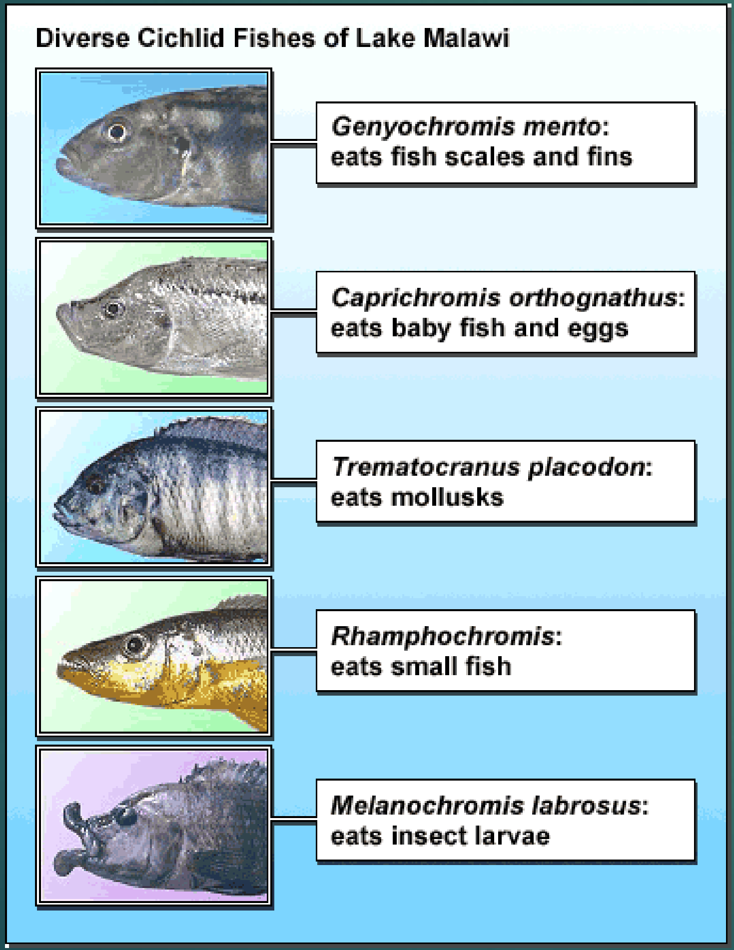
The continuous geographic variation of a trait is called a CLINE.



Sickle Cell and Malaria



Speciation: Adaptive Radiation – An example of Divergent Evolution



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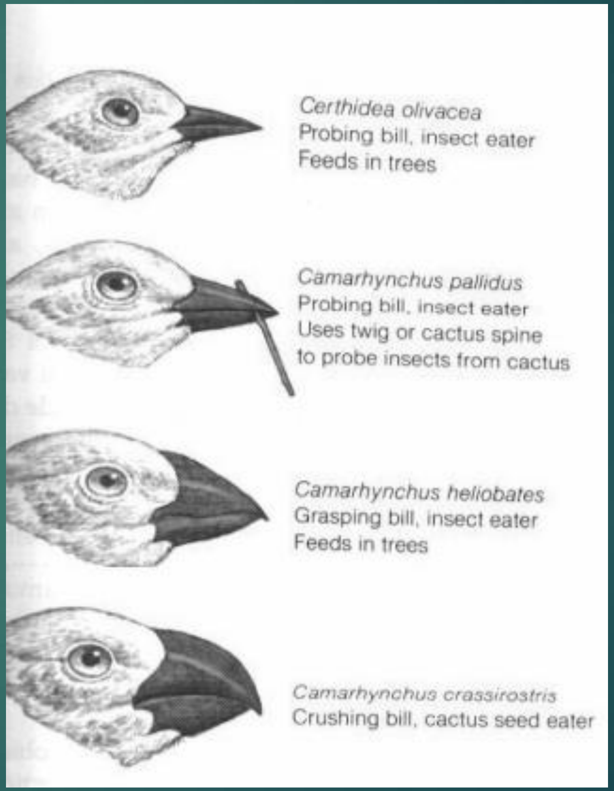


http://www.vanderbilt.edu/AnS/english/Clayton/Galapago_finches.gif

Evolution: life through better chemistry

- Evolution: change through time
- Biological evolution: reproduction (living things make copies of themselves) & adaptive change (better adaptation & survival in their environments) via natural selection based on variation
  - Reproduction: holly=smooth vs spiked leaves - if harder to eat, reproduce better; venom, hands; origin of biological reproduction from chemical evolution via repetitive production (carbon monoxide + hydrogen + minerals + heat= fatty acids – which can create nonliving hollow spheres like cell membranes)
  - Variation
  - Selection

http://statedclearly.com

Evolution

- Evolution explains how life diversified into the many variants that exist today and in fossils
- Explains how modern creatures continue to adapt to natural conditions (pesticide resistance)
- Evolution: any change in heritable traits within a population across generations
- All living things can make copies of themselves; DNA is the method; errors/mutations during copies causing difference in form or function; i.e. taller, darker skin, longer arms; unique recombination of parental traits
- Examples: grey wolves to dogs, taming of silver foxes in 20 generations
- Reproduction with variation over millions of years

Evolution: no breeder needed

- Natural selection is method for descent with modification and common descent
- Descent with modification: observable fact that your sibs are different from you; descend from parents with differences; due to random genetic mutations
- Common descent: descent from common ancestor; conclusion from massive amount of data (genetics, fossil, comparative anatomy, biochemistry, species distribution)
- Rejected because of idea that you cannot get order and complexity from random chaos alone; bodies of living things show order & complexity; descent with modification produces random variation

Co-evolution

- Predator-prey: selective pressure on the prey to avoid capture and thus, the predator must evolve to become more effective hunters; evolutionary arms race going back to Pre-Cambrian
- Herbivores and plants: lodgepole pine seeds – in red squirrel (gnaw thru) areas, cones are denser, contain fewer seeds, and have thinner scales; in crossbill (specialized mandibles) areas, cones are lighter and contain thick scales
- Acacia ants and Acacias: symbiotic relationship - ants provide the plant with protection against other damaging insects; the plant provides the ants with shelter and essential nutrients
- Flowering Plants and Pollinators: co-adaptations (visual cues, scent, mimicry of female insects) that allow flowers to attract pollinators, and insects and birds have developed specialized adaptations for extracting nectar and pollen; shape and length of the flower's corolla tubes, which have adapted to the shape and length of the hummingbird bill that pollenates that plant





Neuro-parasitology: parasites that can control the nervous system of the host. It offers the possibility of discovering how one species (the parasite) modifies a particular neural network, and thus particular behaviors, of another species

Cricket: suicide by drowning

Wasp manipulates caterpillar into serving as a bodyguard to its cocoons

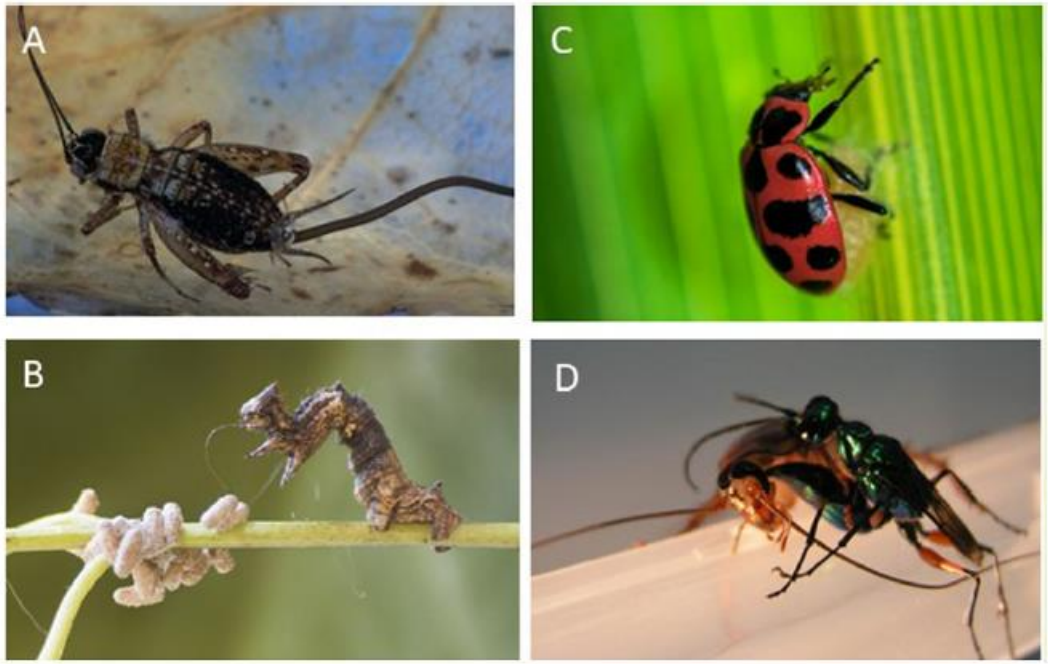


FIGURE 1 | (A) A parasitic worm emerging from its drowning cricket host (Credit: Pascal Goetgheluck). (B) Ladybug guarding a wasp cocoon (Credit: Mathieu B. Morin). (C) Wasp manipulates caterpillar into serving as a bodyguard to it cocoons (Credit: Jose Lino-Neto). (D) Wasp injects venom into the brain of a cockroach to use it as a fresh food supply for its offspring (from the authors' lab).

Ladybug guards wasp nest

Wasp injects venom into cockroach brain to use it as food supply for its offspring

Coevolution: Fungus control an ant

Ant infected with Cordyceps – a parasitic fungus that causes the ant to climb a tree. After emerging from the ant's body, the fungus releases spore-filled capsules. Image: Shutterstock

An ant falling victim to parasitic fungus of the genus *Cordyceps.*
It is manipulated to produce a behavior (climb a tree) that facilitates dispersal of the fungus, thereby optimizing the parasite's chances of reproduction

Frederic Libersat, et al., 2018

Other parasites

- Liver fluke: a strategy to facilitate the transmission from the intermediate host (the ant) to the final host (a grazing animal). The Lancet liver fluke (*Dicrocoelium dendriticum*) takes over the ant's (*Formica fusca*) navigational skills to coerce it into climbing to the tip of a blade of grass; to be eaten by a grazing animal.
- It's cycle starts with the mature Lancet fluke housing in the liver of the grazing animal and producing eggs which are expelled in the digestive system of the grazer to end up in its feces.
- Snails get infected by feeding on such droppings. The fluke larvae settle in the snail to be in turn expelled in slime balls
- Ants are fond of these slime balls and after a brief sojourn in the ant's gut, the parasites infest the ant's hemolymph and drift inside its body. Remarkably, only one of those parasites migrates alone to the ant's head and settles next to one of the cerebral ganglia, the sub-esophageal ganglion.
- Crickets: Crickets and other terrestrial insects can fall victim to hairworms, which develop inside their bodies and lead them to commit suicide in water, enabling the exit of the parasite into an aquatic environment favorable to its reproduction

Infected Caterpillar

Human Microbiome:
You are a hybrid organism

- 10 times as many bacteria as human cells in human body. (approximately 10^{14} versus 10^{13})
- It is estimated that 500 to 1,000 species of bacteria live in the human gut.
- Bacterial cells are much smaller than human cells. The mass of microorganisms are estimated to account for 1-3% total body mass.
- Though members of the flora are found on all surfaces exposed to the environment (on the skin and eyes, in the mouth, nose, small intestine), the vast majority of bacteria live in the large intestine.

Phylogeny

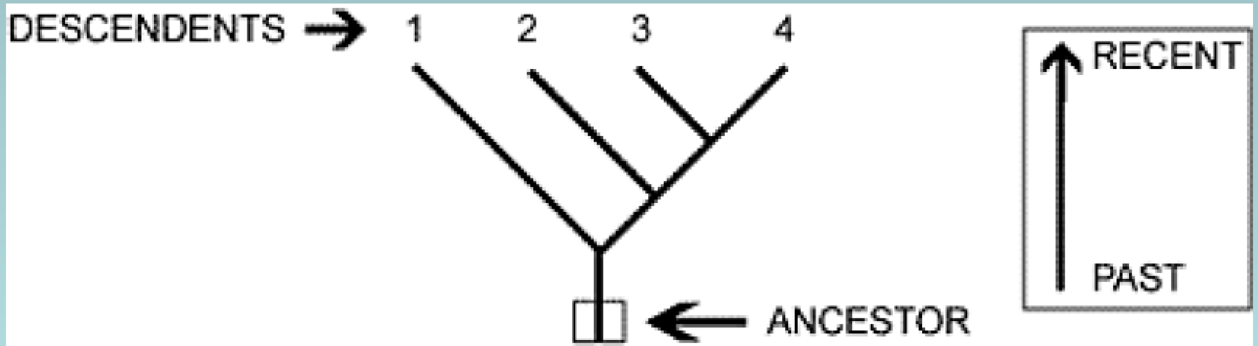
Phylogenies

- Biologists use phylogenetic trees for many purposes, including:
  - Testing hypotheses about evolution
  - Learning about the characteristics of extinct species and ancestral lineages
  - Classifying organisms
- Using phylogenies as a basis for classification is a relatively new development in biology.

Family Trees = Phylogenies

Understanding Phylogenies

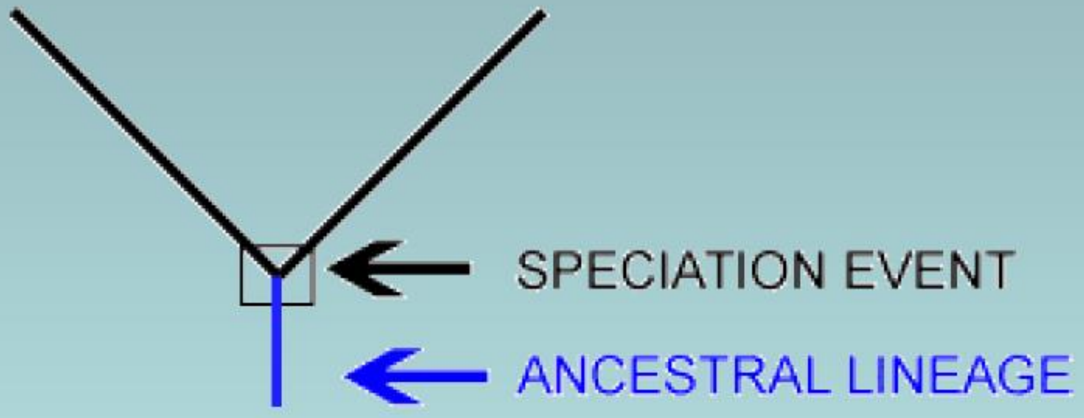
Understanding a phylogeny is like reading a family tree. The root of the tree represents the ancestral lineage, and the tips of the branches represent the descendents of that ancestor. As you move from the root to the tips, you are moving forward in time.



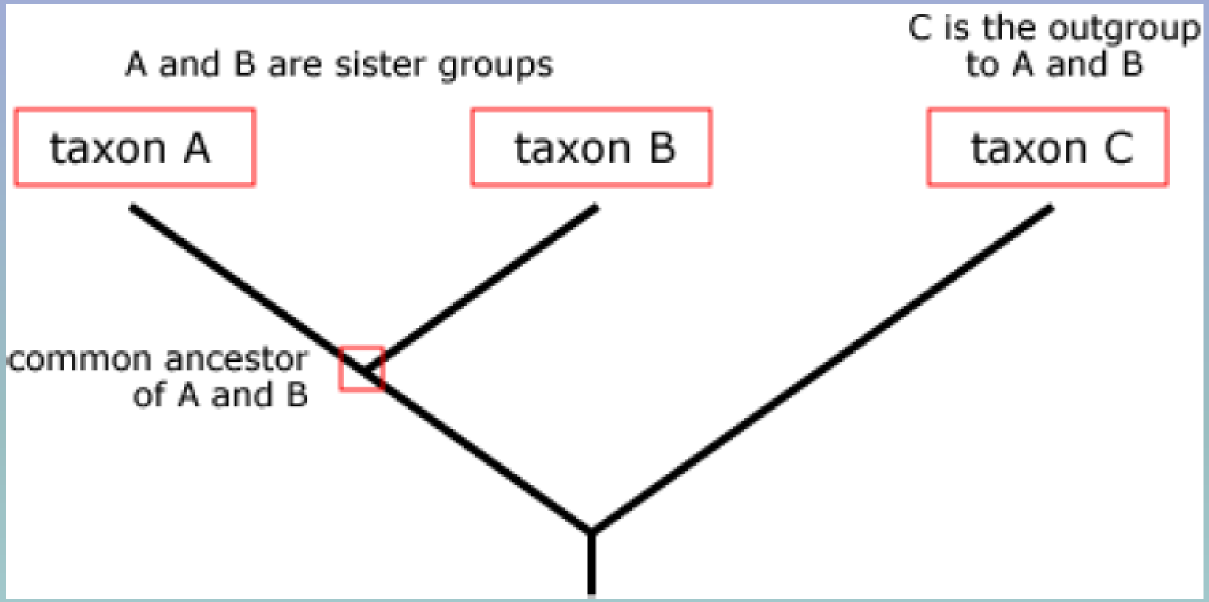
Time

Speciation on a phylogeny

When a lineage splits (speciation), it is represented as branching on a phylogeny. When a speciation event occurs, a single ancestral lineage gives rise to two or more daughter lineages.



Review - How To Read A Phylogenetic Tree



The “tree” represents evolutionary relationships

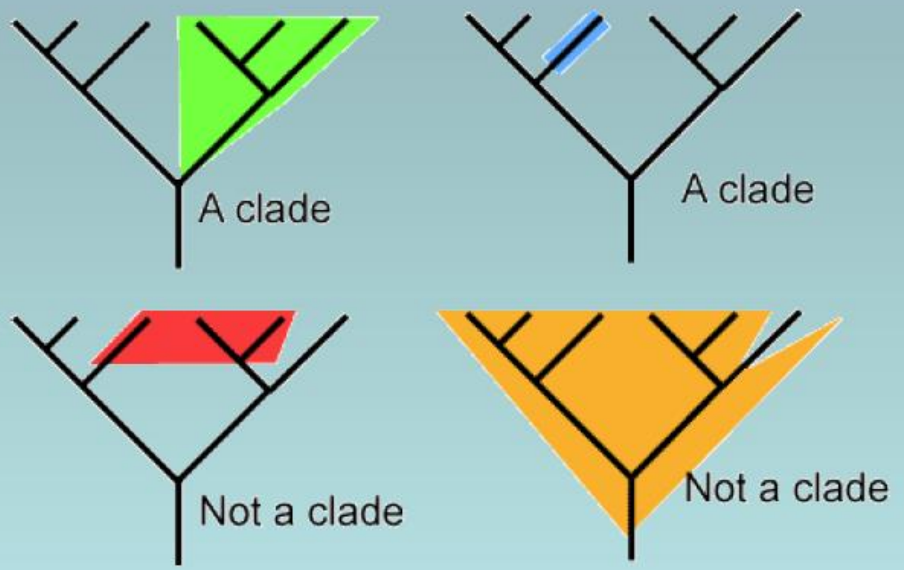
-the tips of the tree represent taxa (often species)

-the nodes represent a common ancestor

- the “outgroup” is a closely related taxon – used for comparison

Evolutionary Trees Depict “Clades”

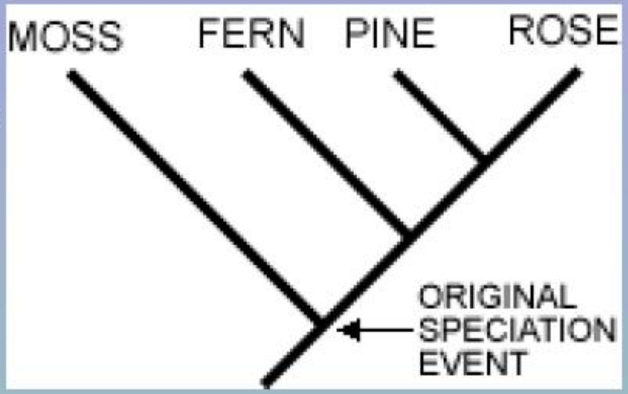
A clade is a group that includes a common ancestor and all of the descendents (both living and extinct) of that ancestor. We use a phylogeny to determine if a group of lineages form a clade.



This phylogenetic classification system names only clades — groups of organisms that are all descended from a common ancestor.

Higher is not more advanced; equally evolved

It's easy to misinterpret phylogenies as implying that some organisms are more "advanced" than others; however, phylogenies don't imply this at all.



To the right is a simplified phylogeny for plants

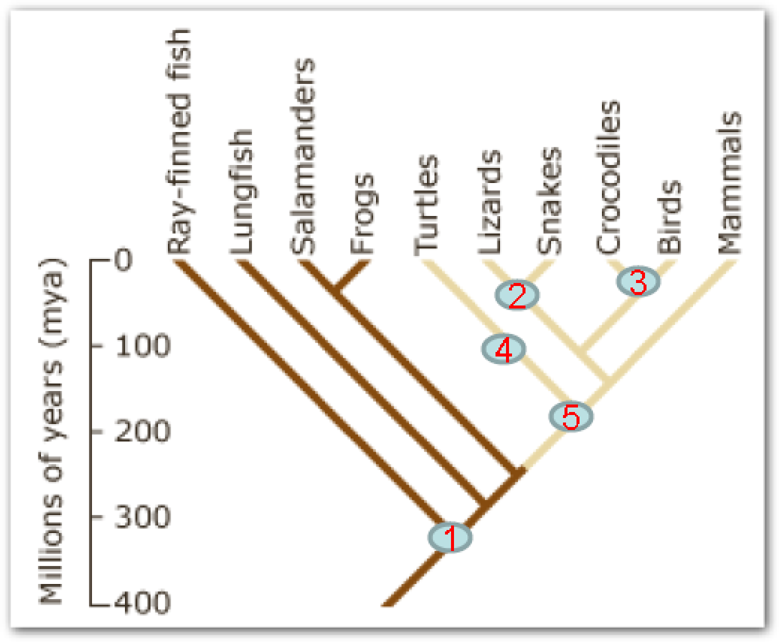
-A speciation event resulted in 2 lineages

-One led modern mosses; the other led to ferns, pines & roses

-Since the original event, both lineages have had equal time to evolve

-Although living mosses share many features with the ancestor of modern plants, they are not ancestral to modern land plants

-Mosses are also NOT more primitive – they are cousins



What does this tree say?

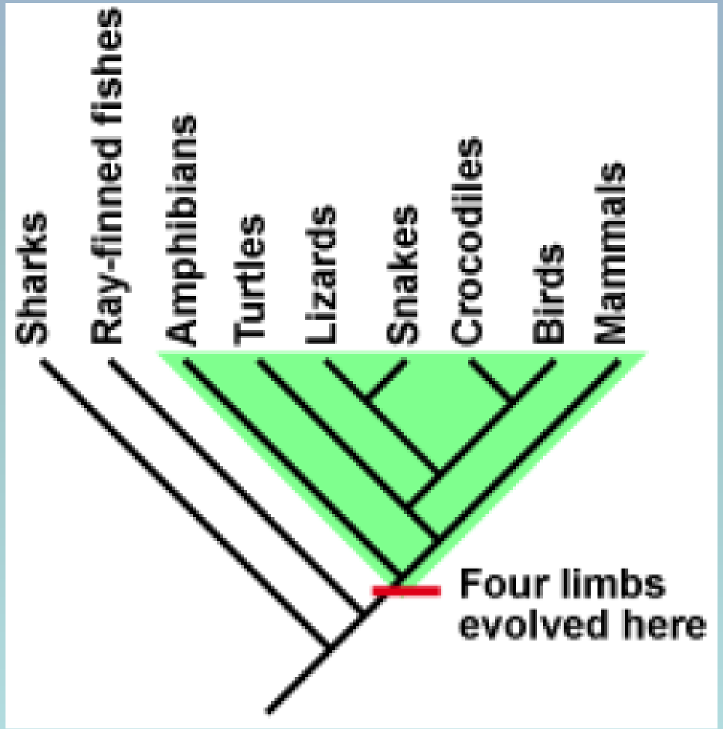
This is a phylogenetic tree of the 10 major groups of vertebrates.

Notice the time scale on the right.

1) All vertebrates share a common ancestor
2) Lizards and snakes are more closely related to each other than to turtles
3) Crocodiles and birds are more closely related to each other than crocs are to other herps
4) Turtles are not closely related to the other reptiles
5) Mammals and reptiles have a common ancestor

How Do You Build a Phylogeny Anyway?

What scientists are looking for is something called a "shared derived character"



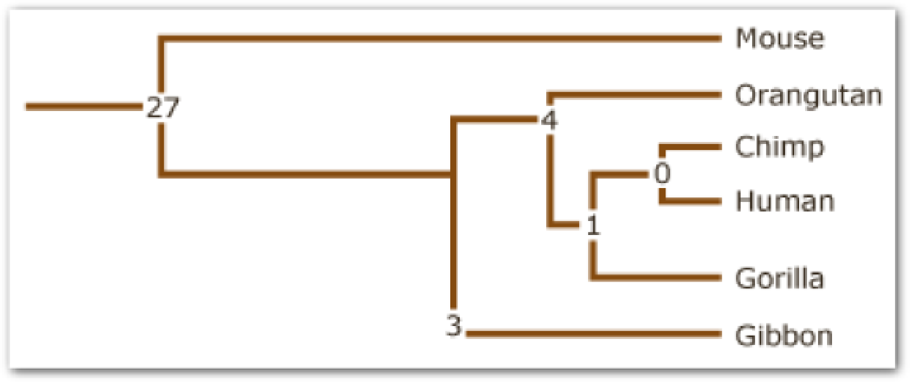
The shared derived character – "four limbs" is useful for finding the common ancestor of all land animals.

It is not useful for looking at relationships between land animals

Reading This Tree

- This tree was constructed using molecular data.
- Protein molecules are made up of amino acids – of which there are 20 kinds
- Hemoglobin is a protein found in blood – carries oxygen
- Each species has a specific number & kind of amino acids in a specific sequence
- Differences in amino acid sequences can tell us how closely or distantly related species are

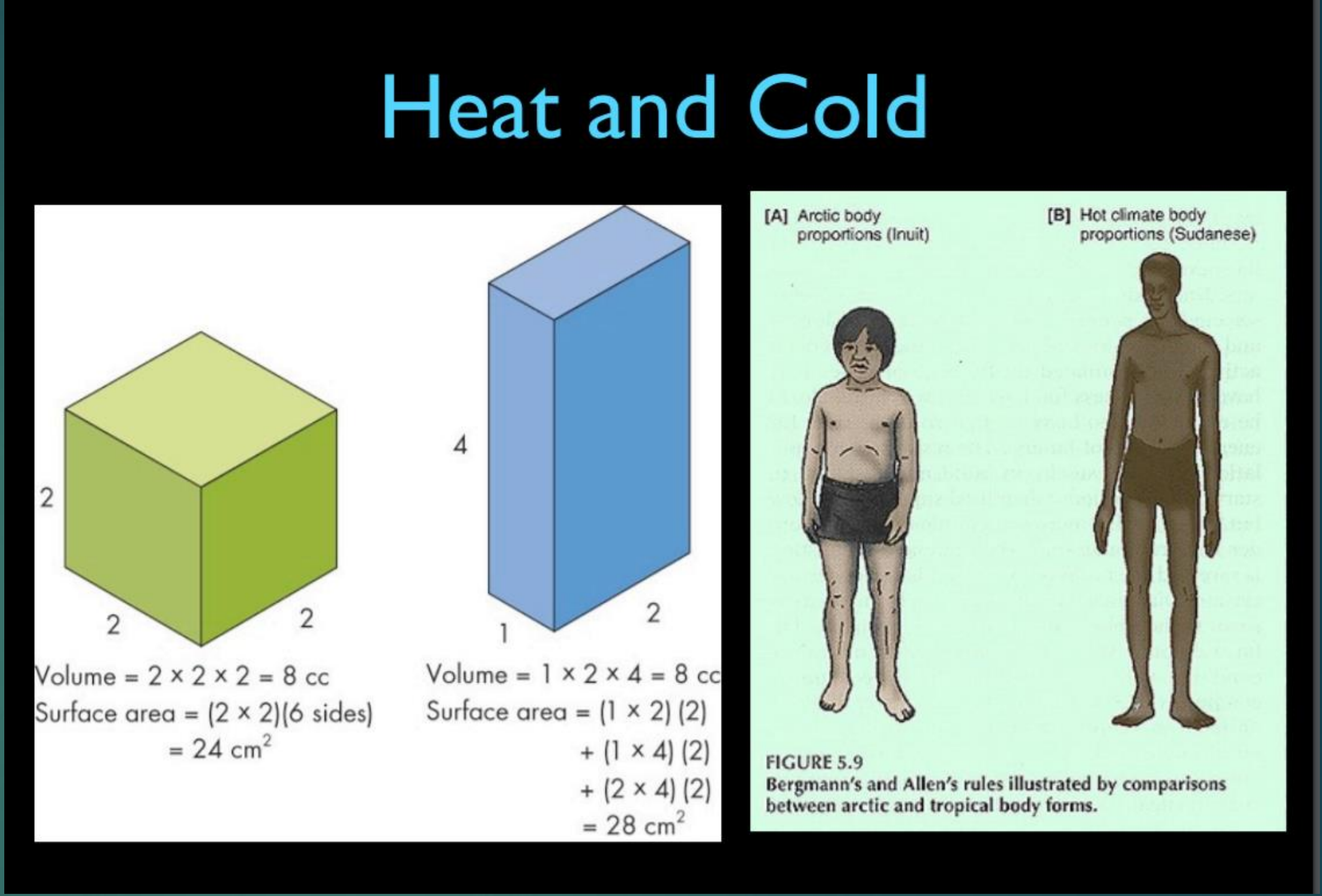
1) There are no differences in the sequence of amino acids in chimps & humans
2) There is one difference between the branch leading to chimps/humans and the one leading to gorillas



3) There are 27 differences between mice and primates

4) There are a total of 35 differences between mice and humans OR chimps

Bergman and Allen

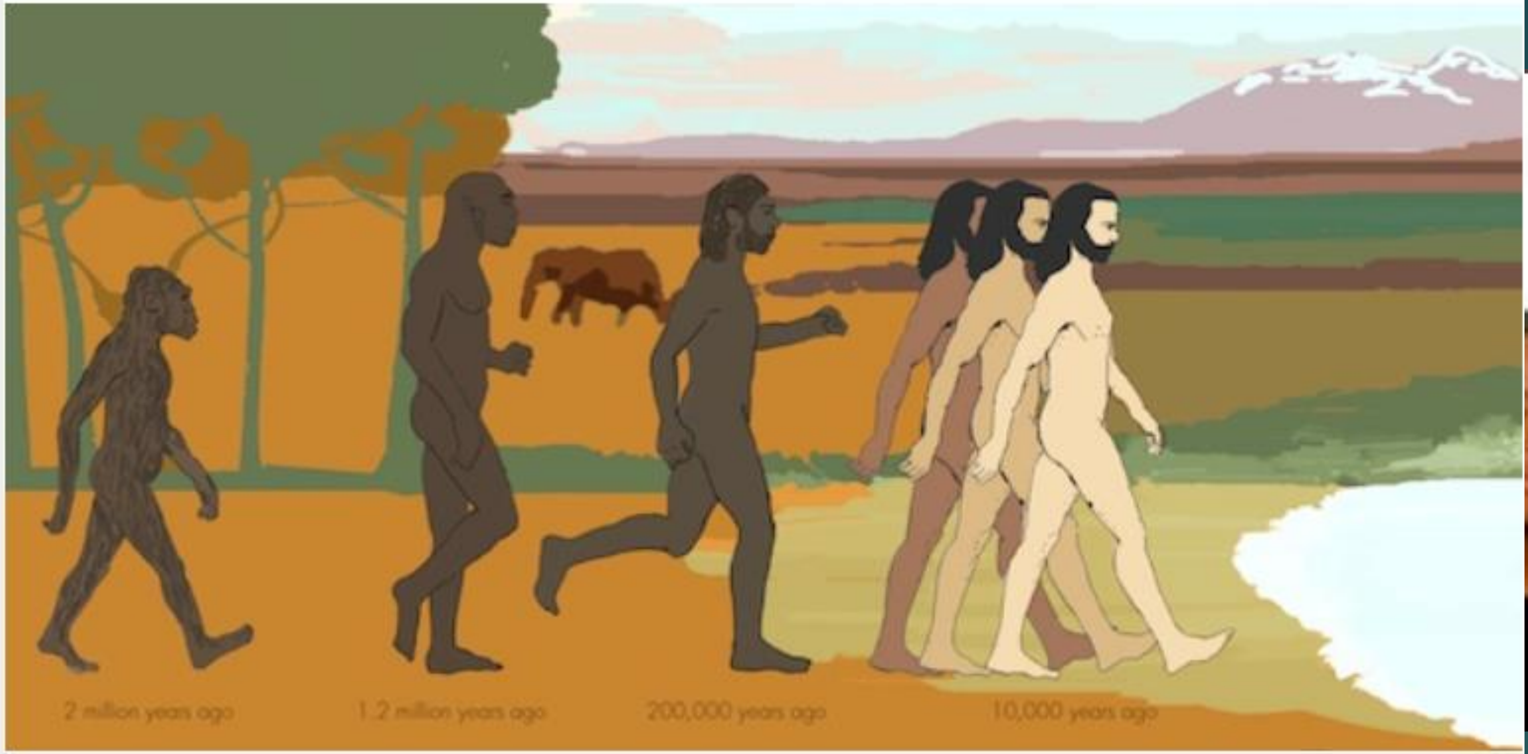


Each human population in general has all the same alleles as other human populations, just at different frequencies

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

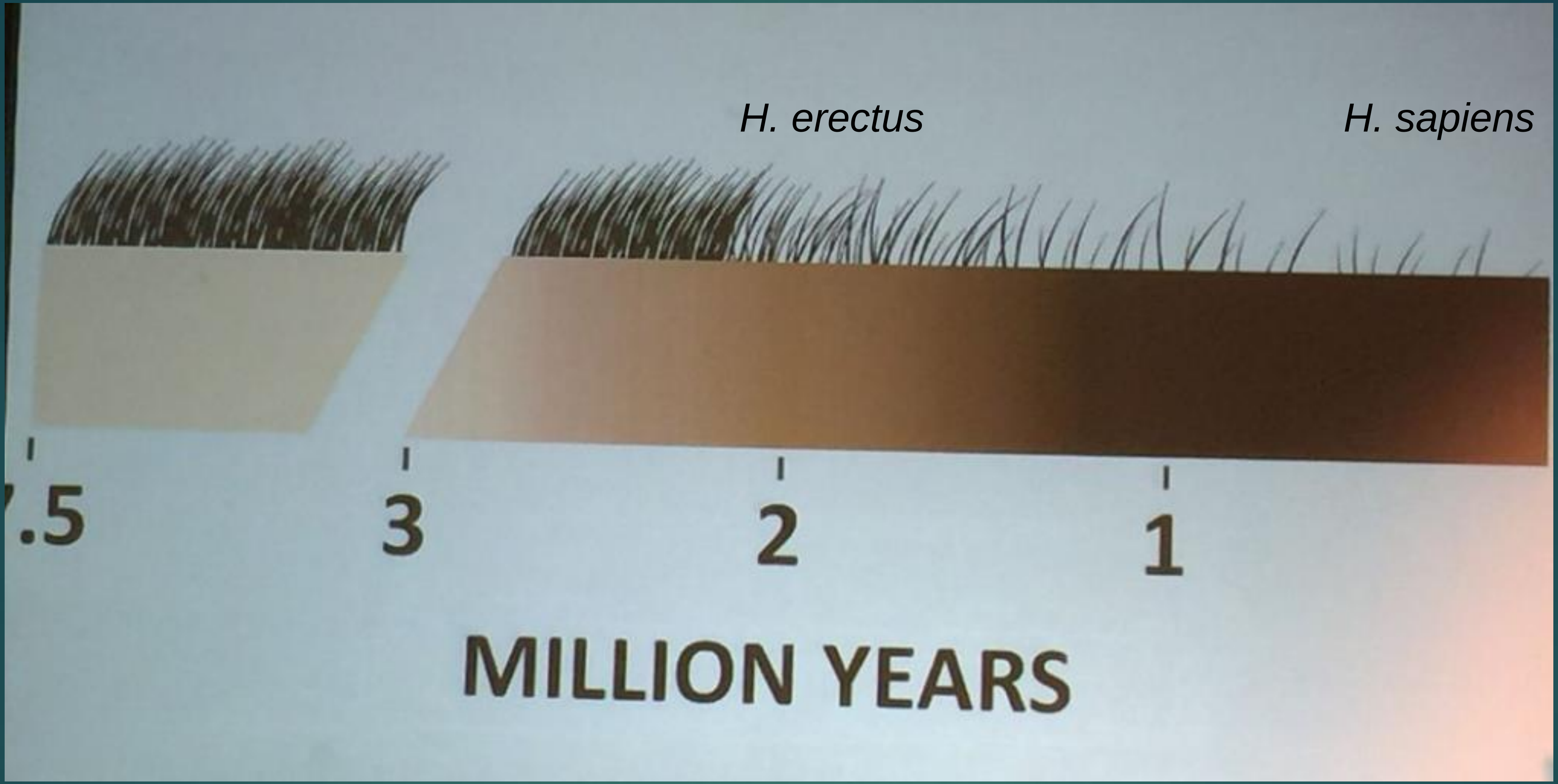


Human evolution from the equatorial African forests to the temperate zone.
Illustration by Jessica C. Kraft

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

Biogeography of Lactase Persistence

Pastoralism

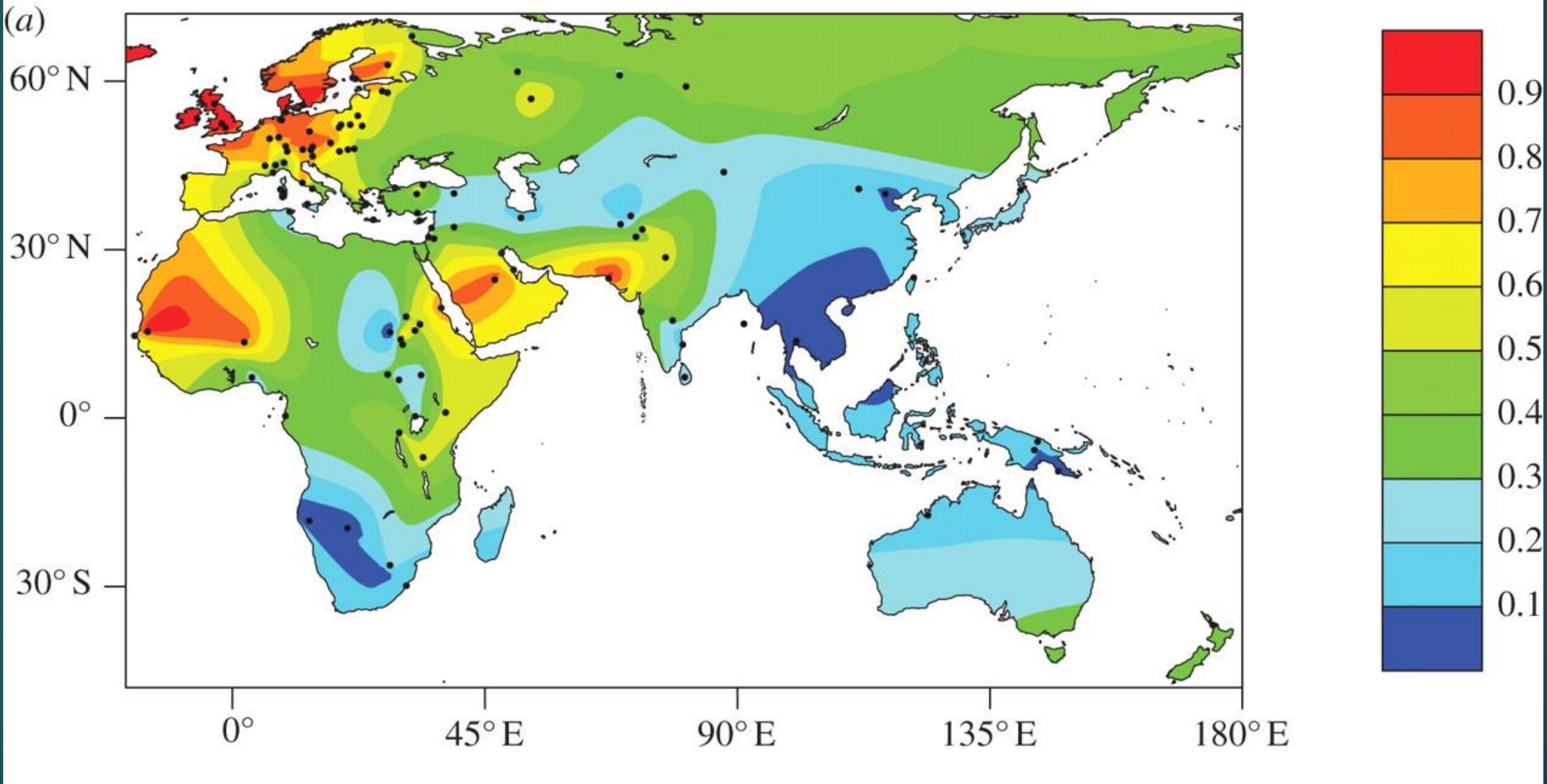
Pastoralism, **the cultural practice of milking livestock** (such as goats, sheep, cows, and camels), was another innovation of the Neolithic Revolution. It was adopted in various cultures between 12,000 and 7,000 years ago.

Milking Livestock and Drinking that Milk

The Biocultural Coevolution theory proposes that pastoralism and lactase persistence coevolved.

This means that they arose around the same time*, and both changes were reinforced by each other.

Current Distribution of Lactase Persistence



LP trait

Two Different Histories

Lactase persistence and pastoralism arose and spread through Europe and Africa independently, an example of **convergent evolution**.

Convergent Evolution is the independent evolution of similar features in separate lineages.

This leads to two different “stories” of how Pastoralism and Lactase Persistence arose.

The Story of LP in Europe

The earliest evidence of pastoralism was discovered in the Middle East: bones of young cattle, slaughtered before their first birthdays, indicate that humans in the area had begun domesticating and milking cattle.

The cattle bones found in the Middle East were about

rs old.

Migration

The earliest domesticated cattle in Greece and the Balkan States (8,000 years old) were more closely related to the domesticated cattle from the Middle East than the wild cattle found in Europe at the time. This indicates that **migrants** from the Middle East brought their cattle with them.

Migration

Because Middle Eastern cattle herders had more advanced food technology, they easily out-competed the local hunter-gatherers they encountered in Central and Northern Europe.

An Apparent Paradox?

Anthropological evidence places the advent of pastoralism at 10,500 to 6,500 years ago.

However, genetic research says the lactase persistence trait did not become widespread in Europe until 7,000 to 5,000 years ago.

This suggests that for several thousand years some humans were milking sheep, goats, cows, or camels *despite* being unable to digest milk.

What was going on?

Cheese

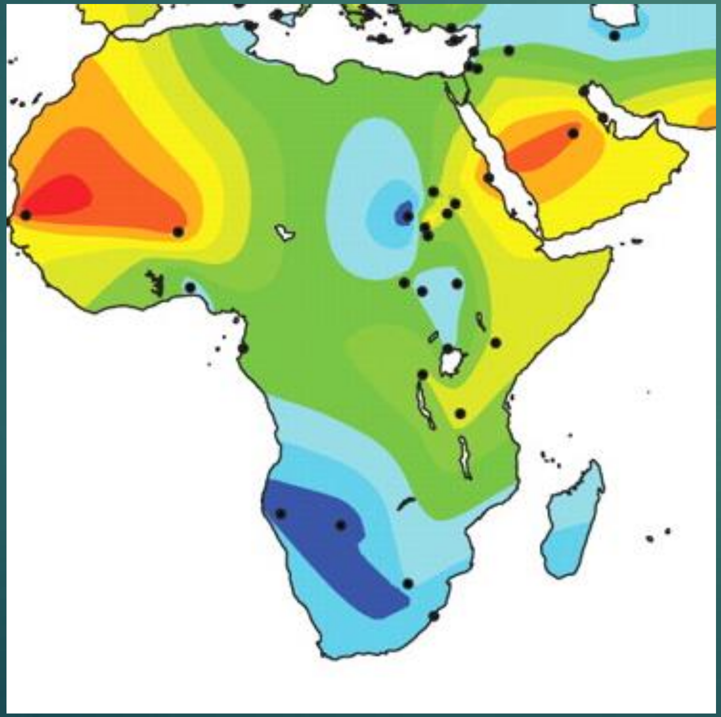
It is likely that Neolithic humans fermented milk into cheese, which **greatly reduced the lactose content** of the dairy product, making it more accessible.

Ancient pottery remnants like this, found in Northern Europe, were likely sieves used to strain and ferment milk into cheese

The Story of LP in Africa

In Africa, lactase persistence evolved independently from the European lineage. The mutations responsible for lactase persistence are different.

Prevalence of Lactase Persistence



Prevalence of T-13910 SNP

The Story of LP in Africa

Neolithic humans in Africa experienced similar selective pressures to adopt pastoralism and evolve lactase persistence.

Through slightly different mutations, G-13915 and G-13907, different peoples in Kenya and Sudan evolved lactase persistence via the same Oct1 transcription factor enhancer site.

The Story of LP in Africa

Notice how close the mutation (SNP) sites for Kenya and Sudan are to the European SNP, T-13910. All of these mutations affect the enhancer site of Oct1, the activator that increases promoter activity at the Lactase gene.

```
Wild Type:  ...AAGATAATGTAGCCCCTG...
Europe:     ...AAGATAATGTAGTCCCTG...  (T-13910)
Kenya:      ...AAGATAAGGTAGCCCCTG...  (G-13915)
Sudan:      ...AAGATAATGTAGCCCGTG...  (G-13907)
```

How Did Lactase Persistence Spread?

Negative Selection

(disadvantages of Lactose Intolerance)

- Individually: Non-LP individuals missed out on a potentially important source of nutrition and hydration
- Experiencing painful, dehydrating symptoms upon consuming milk (see slide 15), which could be deadly.
- Culturally: Without pastoralism, herders must slaughter their livestock to gain dietary protein from their meat.

Positive Selection

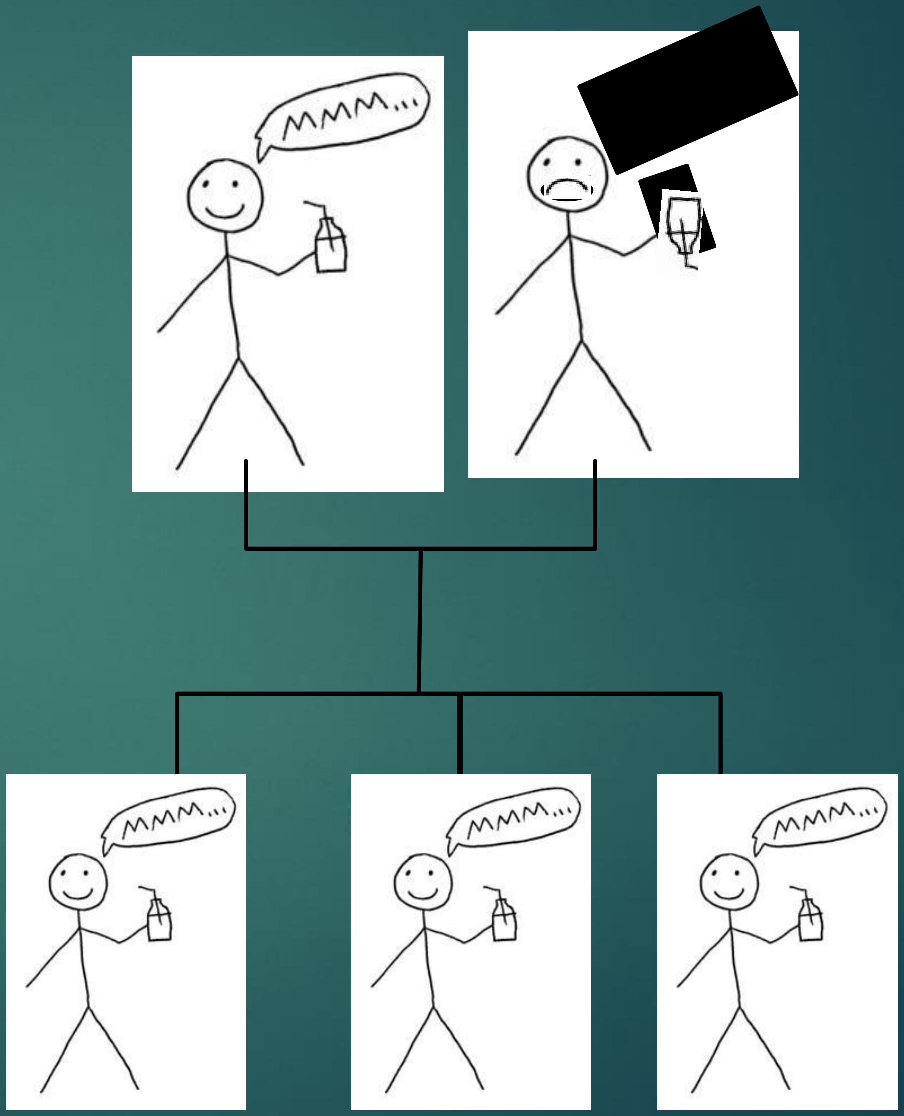
(advantages of Lactase Persistence)

- Individually: Milk supplies protein, fat, sugar, and vitamins, and is dependable despite cold weather and/or bad crops
- Neolithic women who could digest milk were estimated to produce 32% more offspring.
- Culturally: Milk is a more efficient protein source: it does not require killing livestock, yet the milk from one cow nearly equals the caloric value of the meat from a whole cow.

How Did Lactase Persistence Spread?

Lactase Persistence is a dominant trait. This is also an important aspect of how LP spread throughout the population over time.

“Dominant trait” means that if one parent is homozygous for lactase persistent, all the children will be lactase persistent.

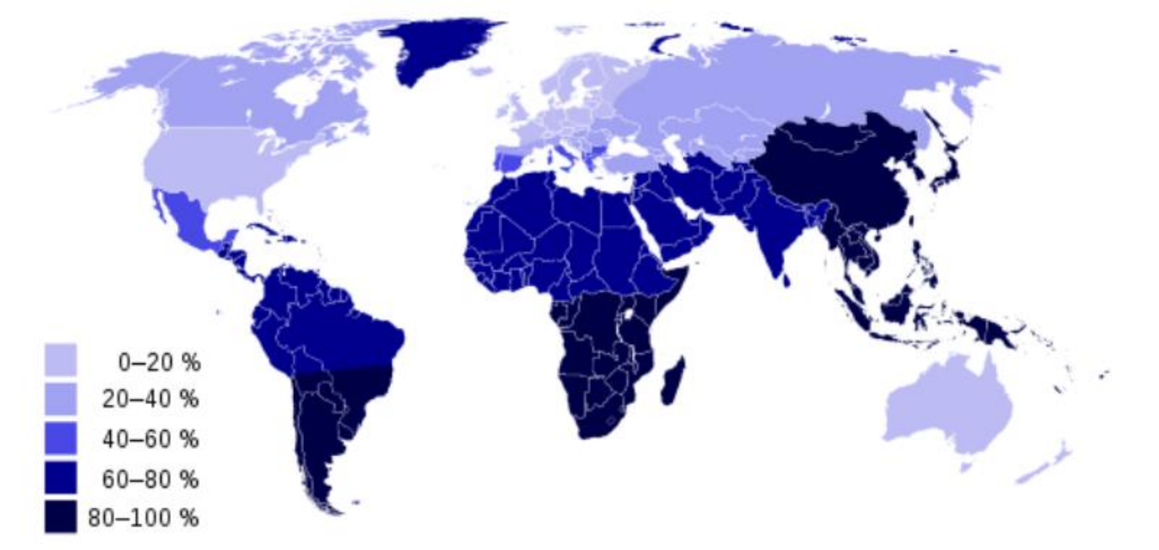


Lactase Regulation

Almost all known mammals – including 65% of humans **–** experience a **decrease in lactase biosynthesis** in the years **after weaning**.

The regulation of lactase biosynthesis after weaning is the main factor that separates Lactase Persistent from Lactase Non-Persistent individuals.

Got Milk!: Example of evolution in last 10,000 years - Evolution of lactose tolerance



Lactase is an enzyme needed for the metabolism of the lactose sugar found in milk. 75% of the global population is lactose intolerant. Ability to drink milk as an adult is due to some individuals living around 4,000 BC in Sweden or the Middle East who acquired a particular mutation on chromosome 2. This gave an evolutionary advantage following the first domestication of cattle and rise of dairy farming since milk then became a valuable source of nutriment. Most of Western Europeans have inherited this mutation and can safely consume milk. Native Americans are 100% lactose intolerant.

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