

Evidence for Evolution

Rafael Navajas-Pérez

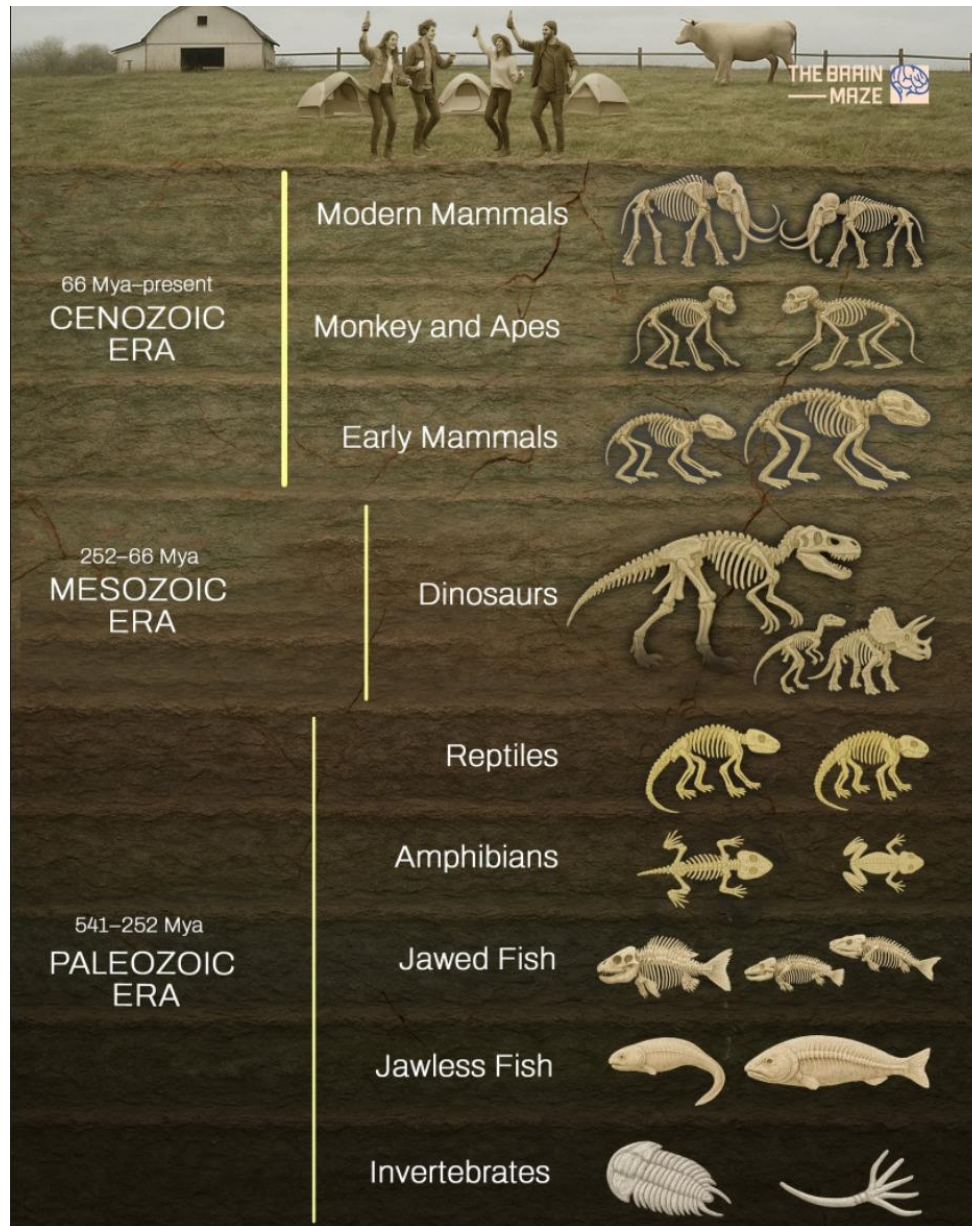
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The Fossil Record

Fossils document the existence of now-extinct past species that are related to present-day species.

The Fossil Record



Chronological Succession:
The simplest fossils are found in the oldest strata, and the most complex organisms in the most recent ones.

The Fossil Record

Transitional Forms: Fossils that show intermediate states between an ancestral group and its descendants.



Source: shutterstock

RETURN OF TETRAPODS TO SEA (*Ambulocetus*): “The walking whale” will eventually become cetaceans.



Source: reddit.com

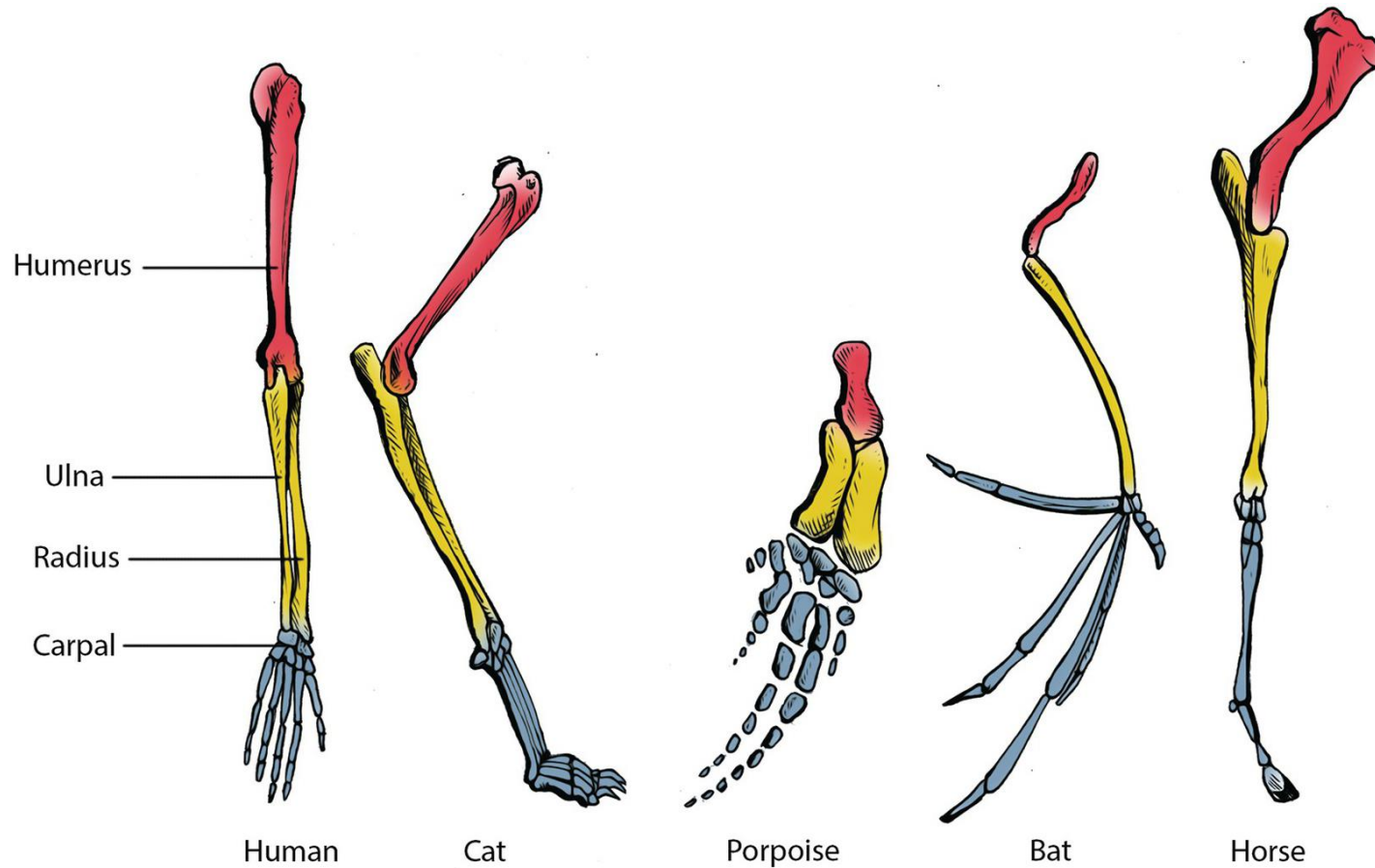
TRANSITION FROM REPTILES TO BIRDS (*Archaeopteryx*): Displays characteristics of both dinosaurs (teeth, long tail) and birds (feathers).

Comparative Anatomy

Species share similar physical features because the feature was present in a common ancestor.

Comparative Anatomy

The Pentadactyl Limb:

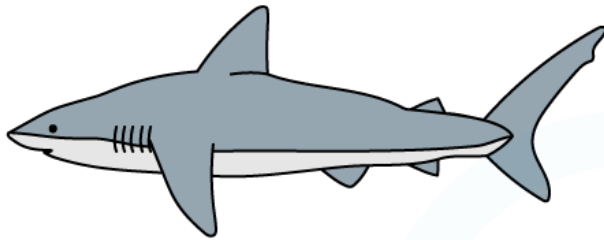


Homologous Structures: Physical features shared due to evolutionary history (a common ancestor) are said to be **homologous**. This can be caused by This process is called **divergent evolution**.

*"Different function,
same origin"*

Comparative Anatomy

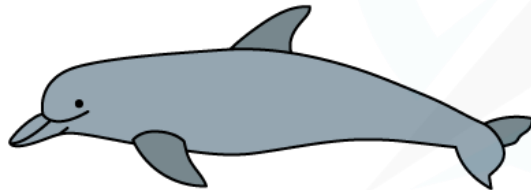
SHARK



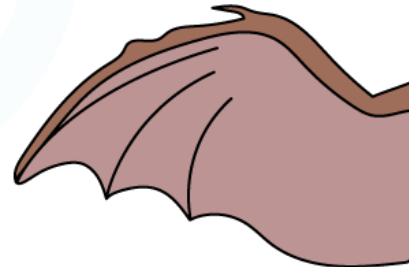
BUTTERFLY



DOLPHIN



BAT

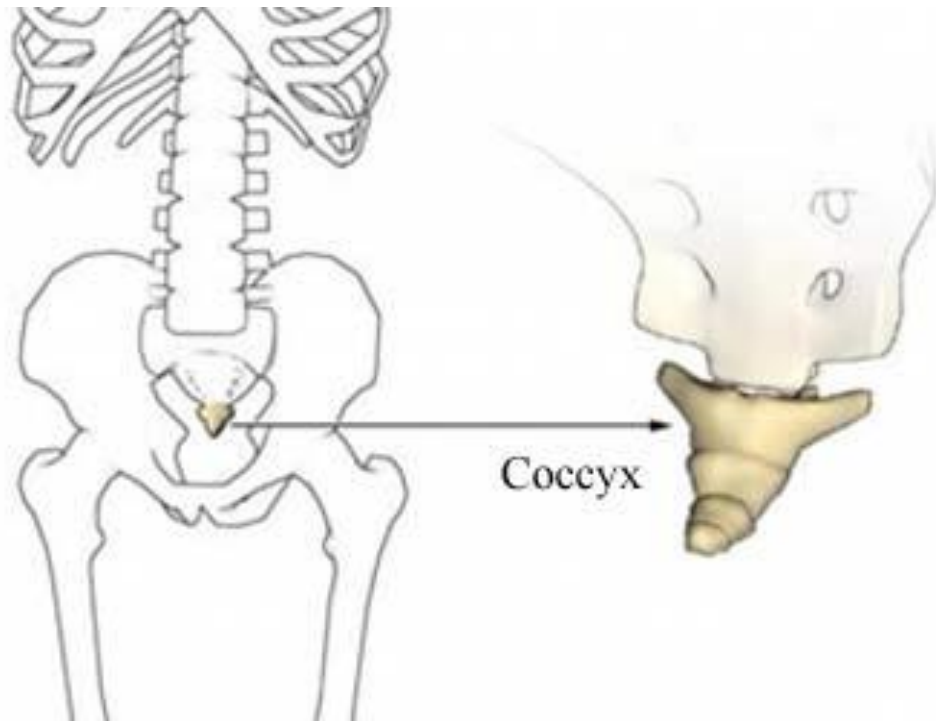


STREAMLINED BODY
SHAPE AND FINS

WINGS ADAPTED
FOR FLIGHT

Be aware of **Analogous Structures**: They evolved independently in different organisms because the organisms lived in similar environments or experienced similar selective pressures. This process is called **convergent evolution**.

Comparative Anatomy



Coccyx

Source: X.com

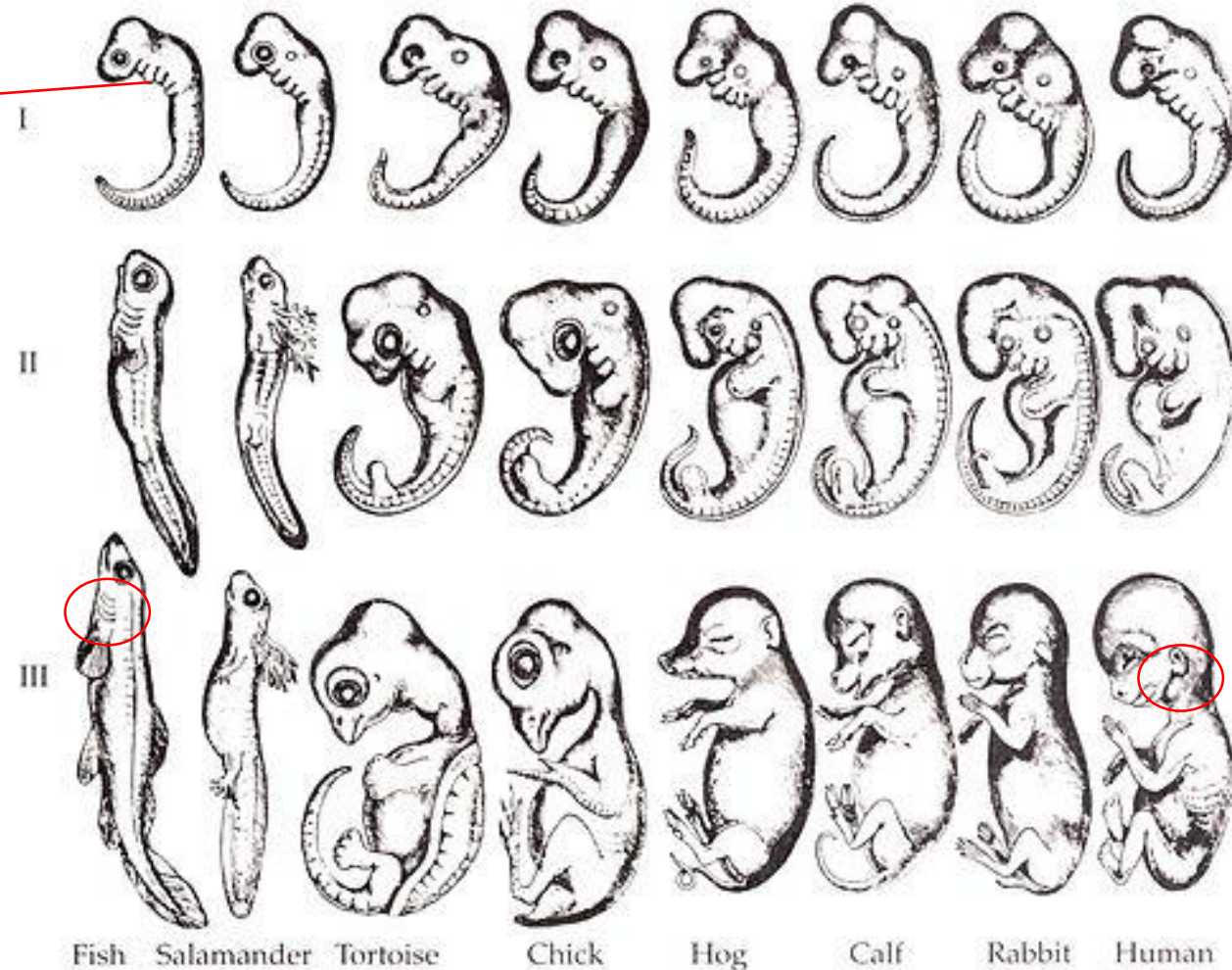
Vestigial Organs:
These are remnants of organs that were functional in ancestors but are no longer used (or have minimal function).

Comparative Anatomy

Embriology

Pharyngeal arches

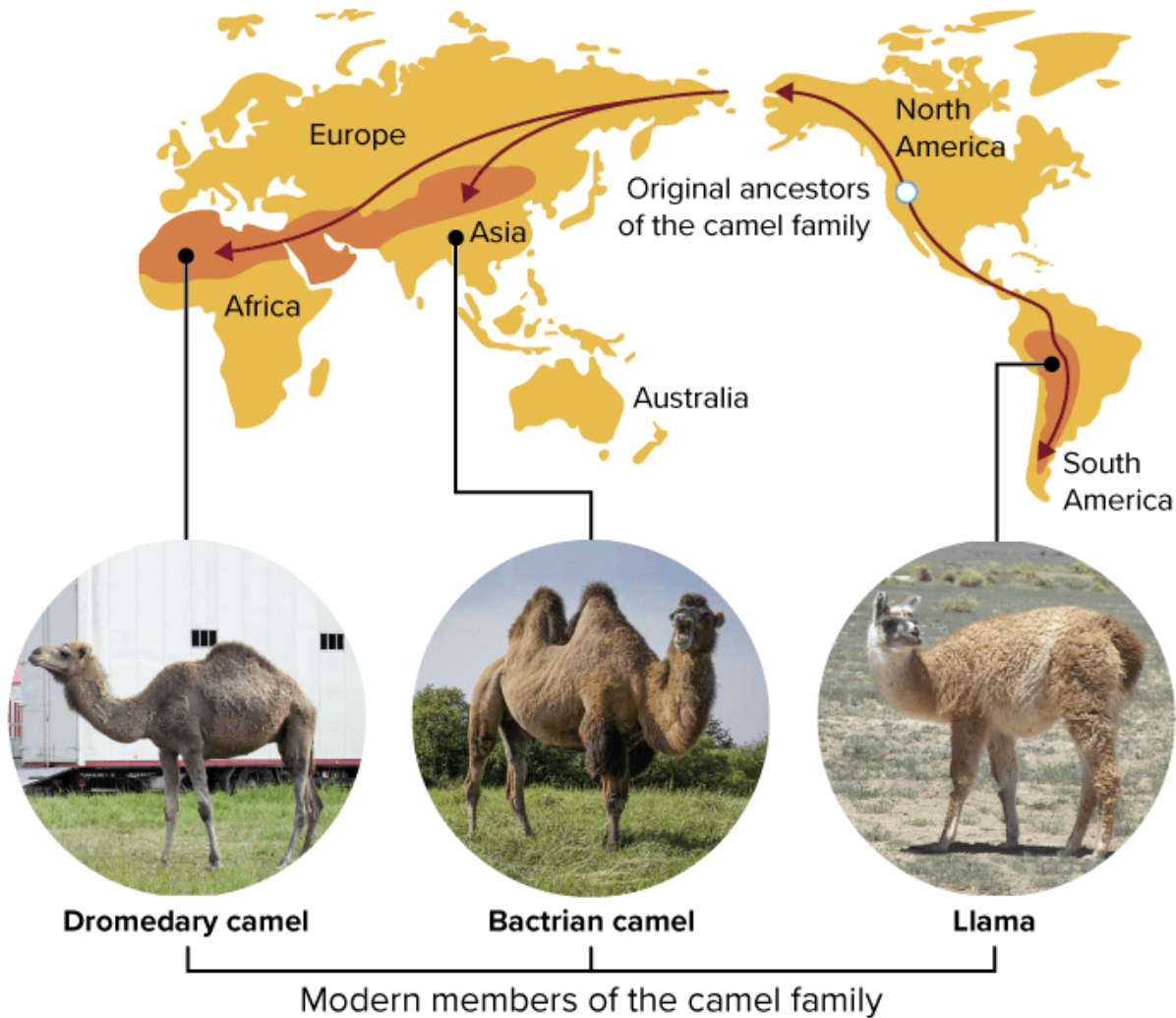
Recapitulation
Theory:
"ontogeny
recapitulates
phylogeny"



Biogeography

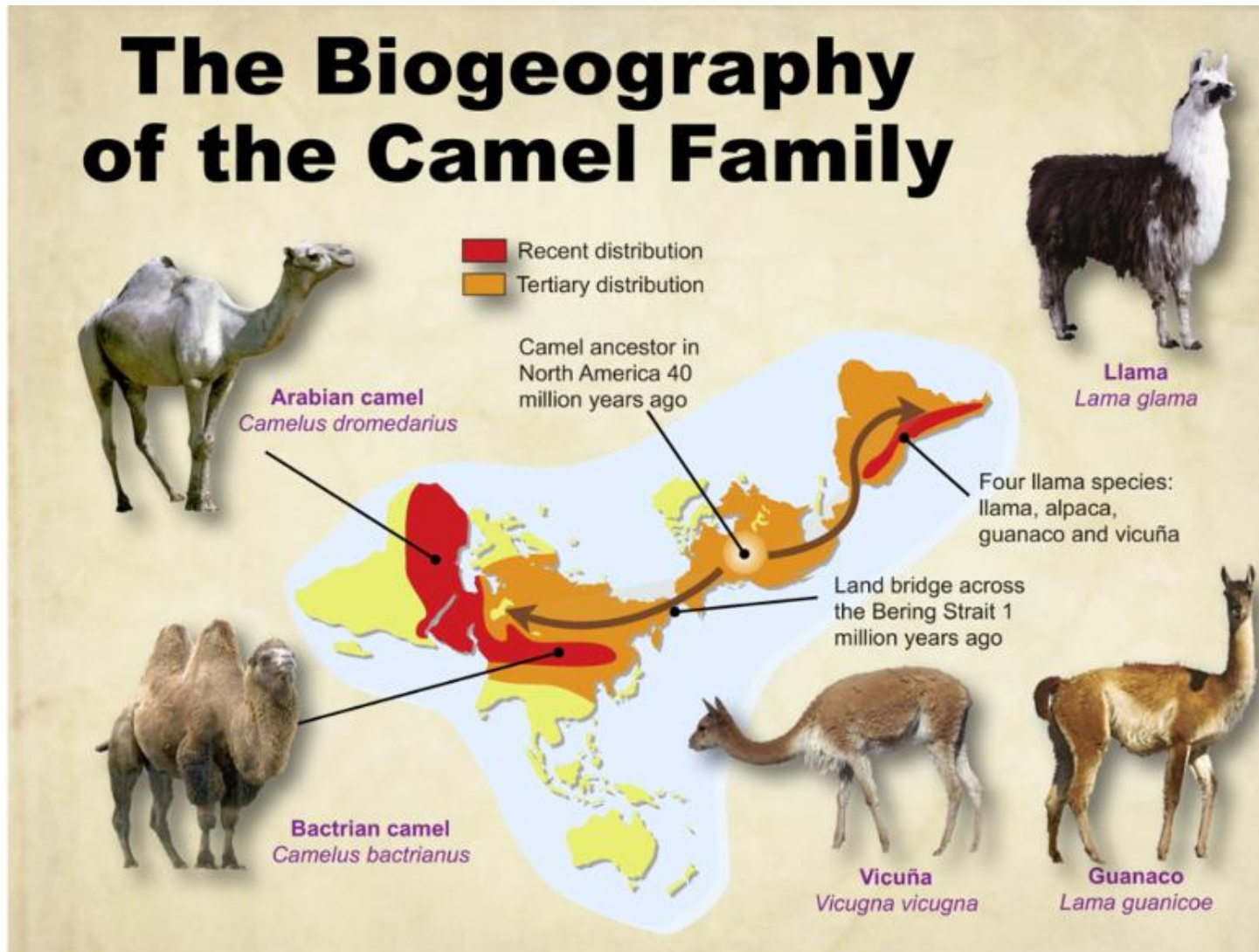
The distribution of species on the planet is not random; it is explained by evolutionary history and the movement of tectonics plates.

Biogeography



The geographic distribution of organisms on Earth follows patterns that are best explained by **evolution**, in combination with the **movement of tectonic plates** over geological time.

Biogeography



All of today's camels are descended from the same camel ancestors. These ancestors lived in North America about a million years ago.

Biogeography

Marsupials



Isolation + Divergence: Places that have been isolated for a long time possess unique flora and fauna.

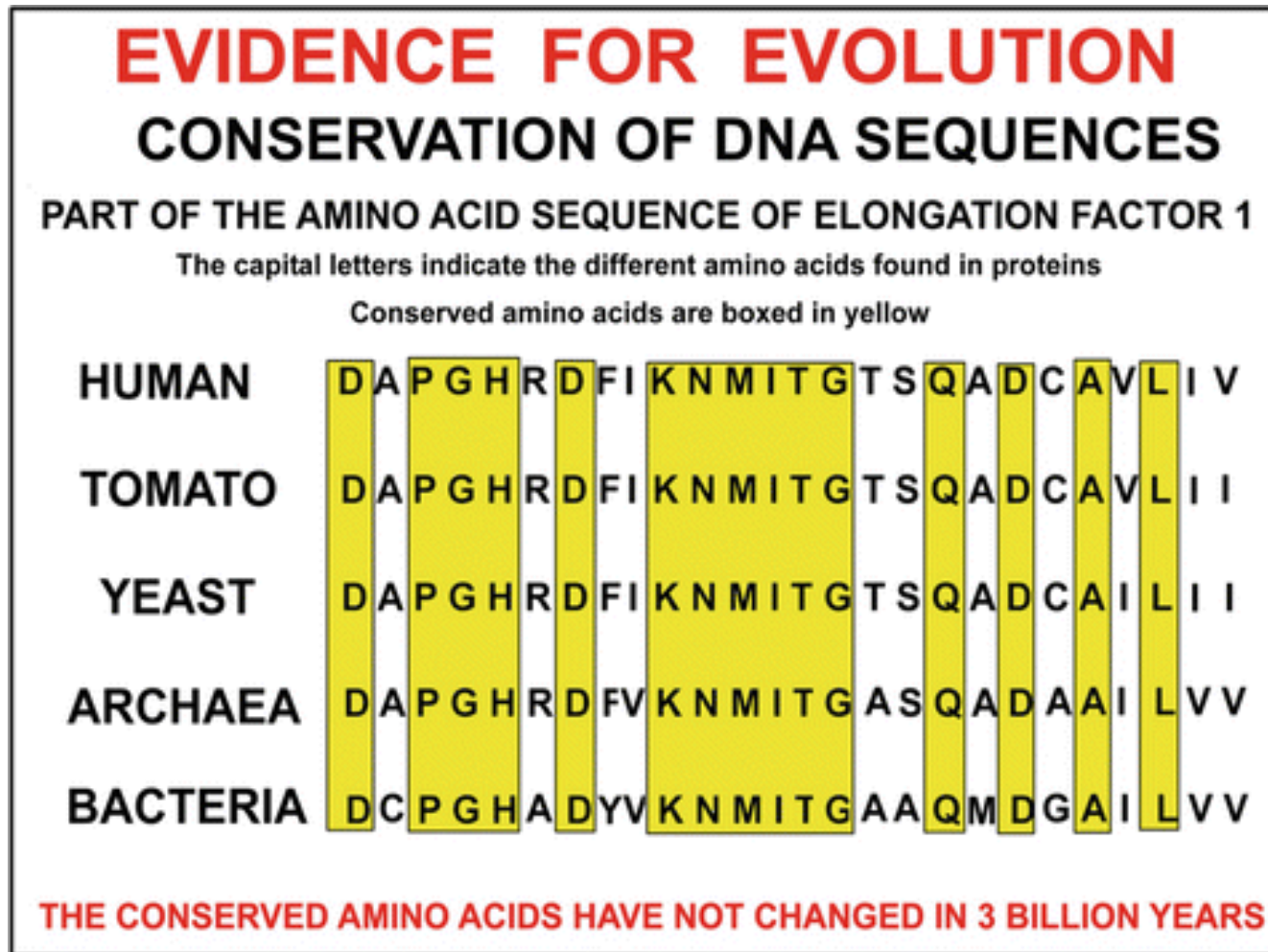
There are unique groups of plants and animals on northern and southern continents that can be traced to the split of Pangaea into two supercontinents (Laurasia in the north, Gondwana in the south).

Molecular Biology

All living beings share the same genetic code, indicating a single origin of life.

- The same genetic material (DNA)
- The same, or highly similar, genetic codes
- The same basic process of gene expression (transcription and translation)
- The same molecular building blocks, such as amino acids

Molecular Biology

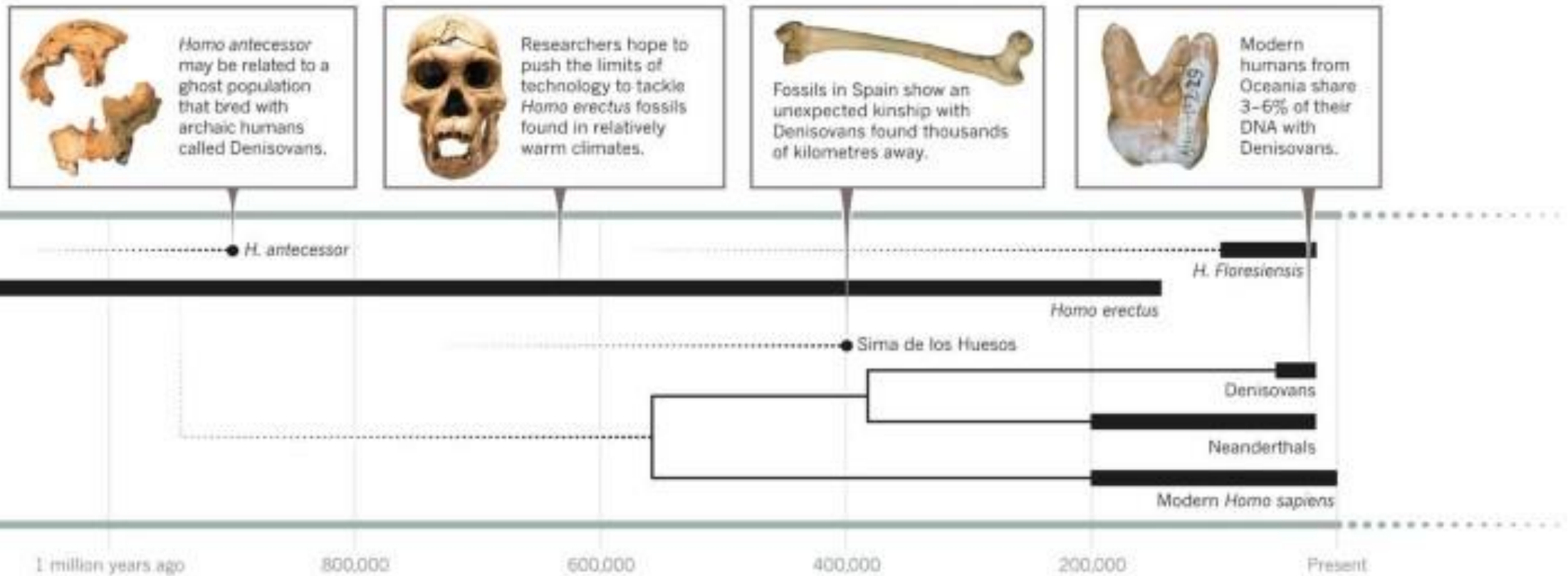


DNA Similarity: The more closely related two organisms are, the more their DNA resembles each other.

Our DNA contains remnants from ancient ancestors from millions of years ago.

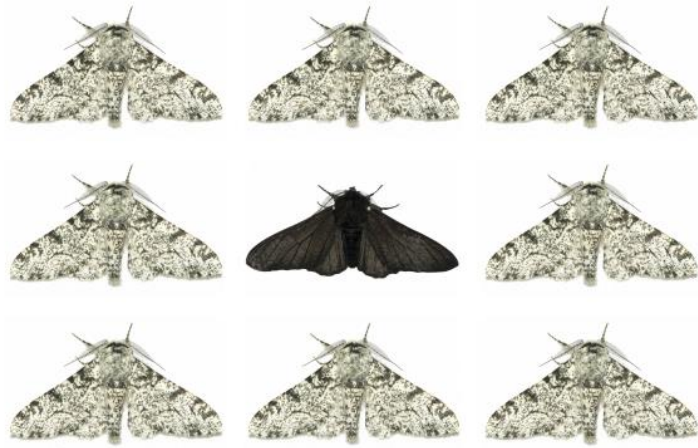
Molecular Biology

HIDDEN HERITAGE *The study of ancient DNA is revealing connections between archaic humans – and the traces they left behind in modern genomes.*



Direct Observation (Microevolution)

Sometimes evolution happens fast enough to see it in “real-time”



Source: news.liverpool.ac.uk

Peppered moth: genetic mutation that gave rise to the black form, which spread rapidly during Britain’s Industrial Revolution.



Source: sciencephoto.com

Evolution on Trial: The Case of the Giraffe's Neck



From Classical Antiquity through to
the mid-19th century (1860, Pasteur)



1. The Spontaneous Generation Advocate (Aristotle / Van Helmont style)

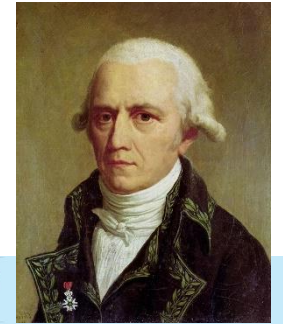
"Ladies and gentlemen, you are looking for ancestors where there are none. Life is not a chain; it is a **sudden event**. Just as maggots arise from rotting meat, or mice from wheat, the giraffe arose from the **vital force** of the African earth itself. The sun warmed the mud, and matter organized itself into life. Evolution? No. It is **creation by spontaneous emergence**."



Source: x.com y posterazzi.com

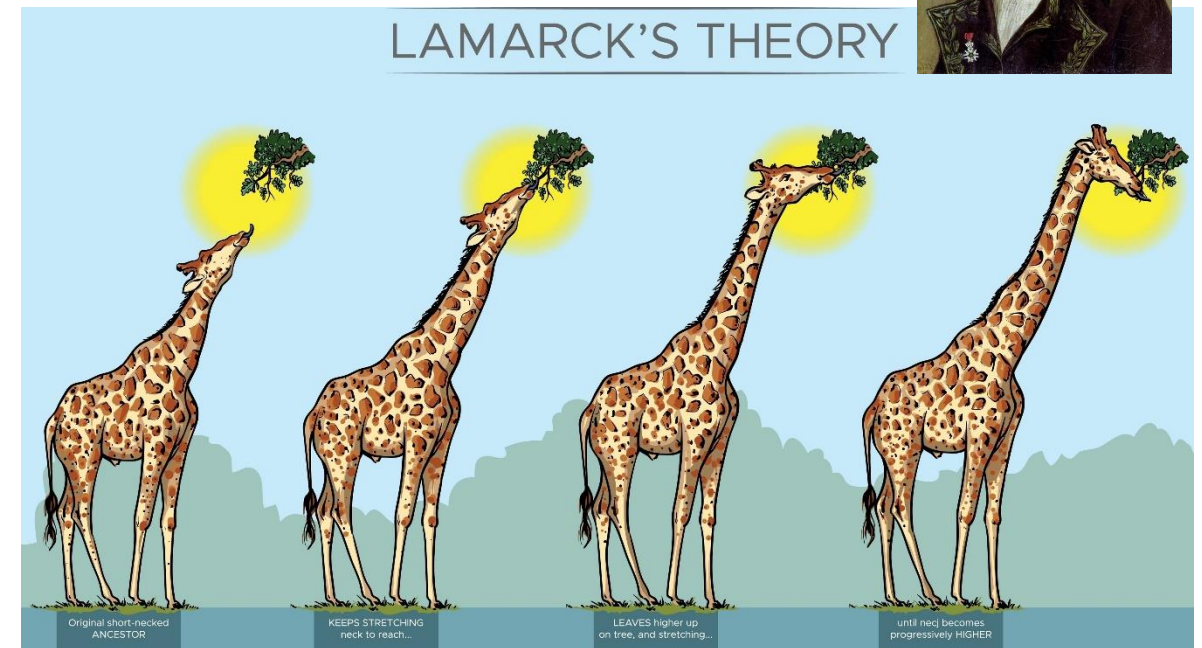
Keywords: *Spontaneous Generation, Vital force, Creationism, Emergence.*

1809-1880



2. The Lamarckian Advocate (Jean-Baptiste Lamarck style)

"Objection! Life is driven by an **inner need**. The ancestors of the giraffe were short, but they were hungry. They **strived** to reach the higher leaves. This constant effort physically stretched their necks during their lifetime. This **acquired characteristic** was then passed down to their offspring. Evolution is progress fueled by **willpower and use**."



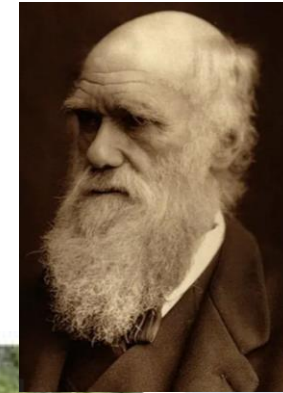
Source: Shutterstock y Wikipedia

Keywords: Use, Disuse, Acquired traits, Lamarckism

1859 to date

3. The Darwinian Advocate (Charles Darwin style)

"My colleagues are mistaken. There is no 'willpower.' In the ancestral population, **variation already existed** by chance: some necks were slightly longer, some shorter. When food became scarce, the short-necked ones died. The long-necked ones **survived and reproduced**. Nature acts as a **filter**, not a sculptor. Over millions of years, this gradual selection shifted the average."



Source: netxplica.com y getty images

Keywords: *Variation, Differential Survival, Natural Selection, Darwinism.*

1900 to date



4. The Saltationist Advocate

(Hugo de Vries / Richard Goldschmidt "The Hopeful Monster" style)

"Darwin is too slow! Nature does not make small steps; nature makes **leaps**. A slightly longer neck offers no advantage. We believe in **macromutation**. One day, a genetic accident occurred, and a 'monster' was born with a significantly longer neck in a single generation. It was a **sudden, drastic change**. Evolution is not a slope; it is a staircase."



Source: news.ucsb.edu y 1000kitap

Keywords: *Macromutation, Sudden change, Hopeful Monster, Saltationism.*

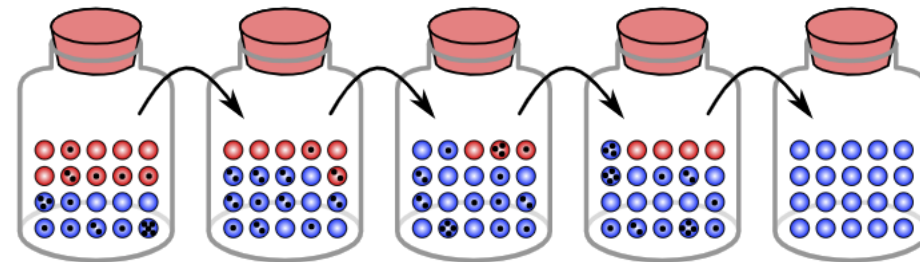
1968 to date



5. The Neutralist Advocate

(Motoo Kimura / Modern Population Genetics style)

"You all assume the long neck is 'better.' But what about **luck**? Consider a small population where a flood killed most individuals by accident. The survivors happened to have long necks, not because it helped them, but because they were on high ground. This is **Genetic Drift**. Evolution is often just a statistical accident, survival of the **luckiest**, not the fittest."



Source: nursinghero.com y Wikipedia

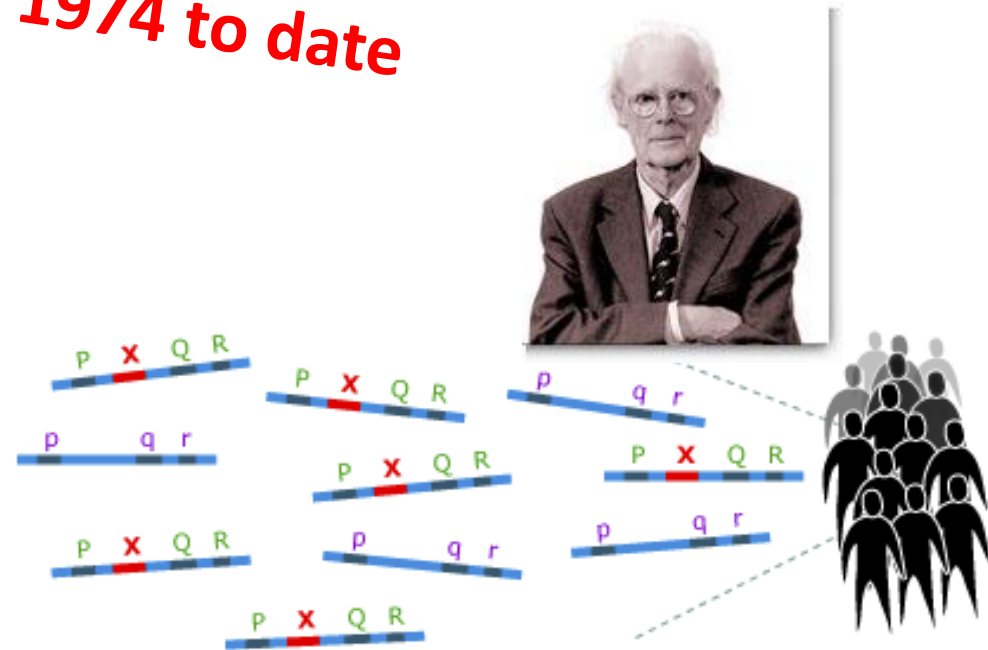
Keywords: *Neutralism, Randomness, Genetic Drift.*

1974 to date

6. The Surprise Guest

(John Maynard Smith / John Bryan Hitchhiker style)

“The notion that the giraffe's neck is solely a trophy won in an arduous battle for leaves is ridiculous. The theory I present asserts that the giraffe's elongated neck was not the star of the show, but a **passenger on a genetic highway**. Evolution is messy and opportunistic; genes do not always travel alone. We argue that the genes coding for neck growth were physically located in **linkage disequilibrium**—tightly linked—to a different set of genes that were **under strong positive selection**.”



Source: evolution.berkeley.edu y edge.org

Keywords: Genetic Hitchhiking, Pleiotropy, Linkage Disequilibrium, Indirect Selection.

Macroevolution and Speciation

Rafael Navajas-Pérez

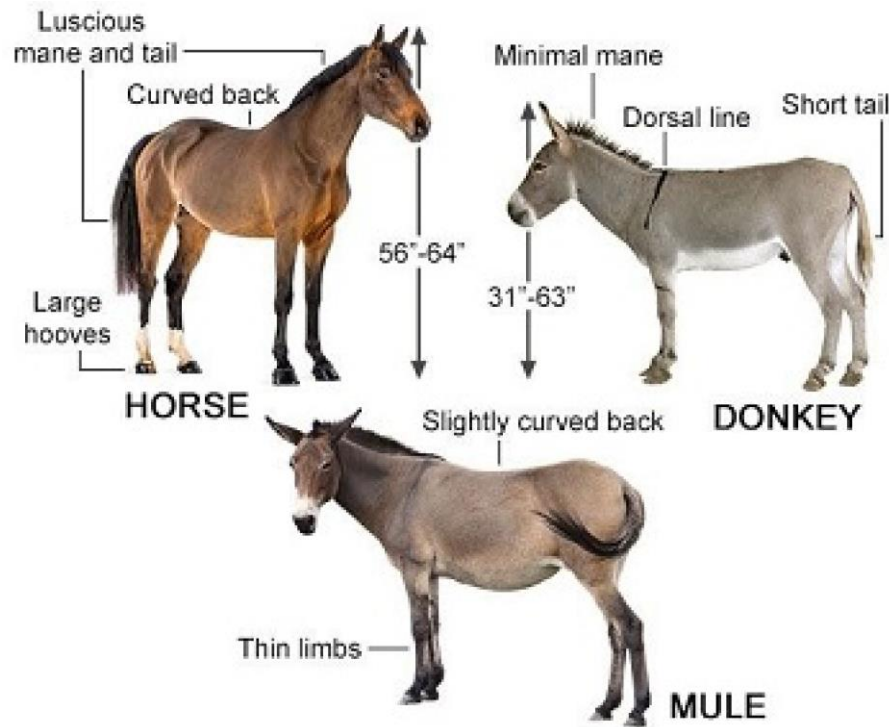
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The Classical Definition (Morphological Species Concept): based solely on observable physical characteristics (**anatomy, external traits and type specimens -the holotype**) , a species is defined as a group of organisms that look distinctive and share unique structural features. If two organisms look sufficiently similar to one another—and distinct from others—they are considered the same species.

Limitations: it could not account for several biological realities such as **Sexual Dimorphism**, **Cryptic Species** (species looking identical to the human eye that cannot interbreed), **Phenotypic Plasticity**.



Source: greensboroughvets.com.au

Classic Example: The Mule

- A **Horse** and a **Donkey** can mate.
- They produce offspring: a **Mule**.
- However, the mule is **sterile** (it cannot reproduce).
- Conclusion:** Because the genetic line stops at the mule, the Horse and the Donkey remain **separate species**. They are reproductively isolated.

The **Biological Species Concept** (Ernst Mayr, 1942): a species is a group of individuals with the potential to **interbreed in nature** (organisms must be able to mate naturally) and produce **viable, fertile offspring** (the offspring must be able to have offspring of their own), but do not produce viable, fertile offspring with members of other such groups.

Reproductive Isolation

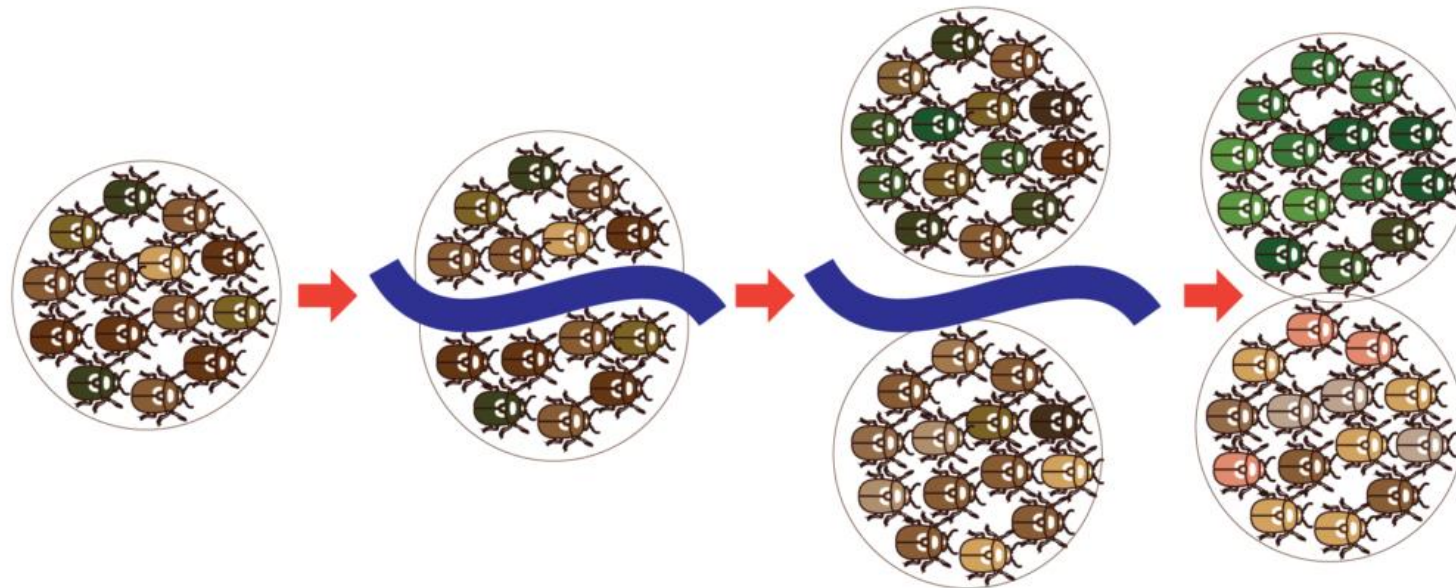
Species are maintained by **Reproductive Barriers**, which prevent **Gene Flow** between species.

- Prezygotic Barriers:** Prevent mating or fertilization (e.g., different mating songs, breeding at different times of year, incompatible reproductive anatomy).

- Postzygotic Barriers:** Mating occurs, but the offspring is weak or sterile (e.g., the mule).

Allopatric Speciation

Allopatric speciation (from Ancient Greek *allos*, meaning "other", and *patra*, meaning "fatherland") is the most common and widely accepted form of speciation. It occurs when biological populations of the same species become **geographically isolated** from each other to an extent that prevents or interferes with gene flow



Allopatric Speciation

Geographic Isolation (Vicariance, a physical barrier separates a single population into two or more groups).

Divergence (once separated, the populations evolve independently).

***Different Selective Pressures** (natural selection favors different traits in each group).*

***Genetic Drift** (random fluctuations in allele frequencies, especially if the populations are small).*

***Mutation** (random mutations arise in different groups and cannot spread to the other because there is no gene flow).*

Reproductive Isolation (genetic differences become so great that species cannot longer interbreed).

Allopatric Speciation



Figure 3. An example of geomorphically induced reproductive isolation: the distinctive Abert's (A) and Kaibab (B) squirrel. *Photo courtesy of the author*

Source: Vincent L. Santucci

Visitors to Grand Canyon National Park may learn about the story of the tassel-eared squirrels. The **Abert's** squirrel and **Kaibab** squirrel are believed to be descendents of a common ancestor. With the development of the Grand Canyon, two populations of the squirrel were geographically isolated. **Eventually the isolated populations evolved into distinct taxa.**

Peripatric Speciation

Peripatric speciation is a specific and accelerated version of allopatric speciation. The term comes from the Greek *peri* (around, near, or edge) and *patra* (fatherland). It occurs when a **very small sub-population** becomes isolated at the **periphery** (edge) of the main population's range.

Peripatric Speciation

Main Population (a large species lives in a continuous area) + **Dispersal** (a small group of individuals migrates to a new isolated niche).

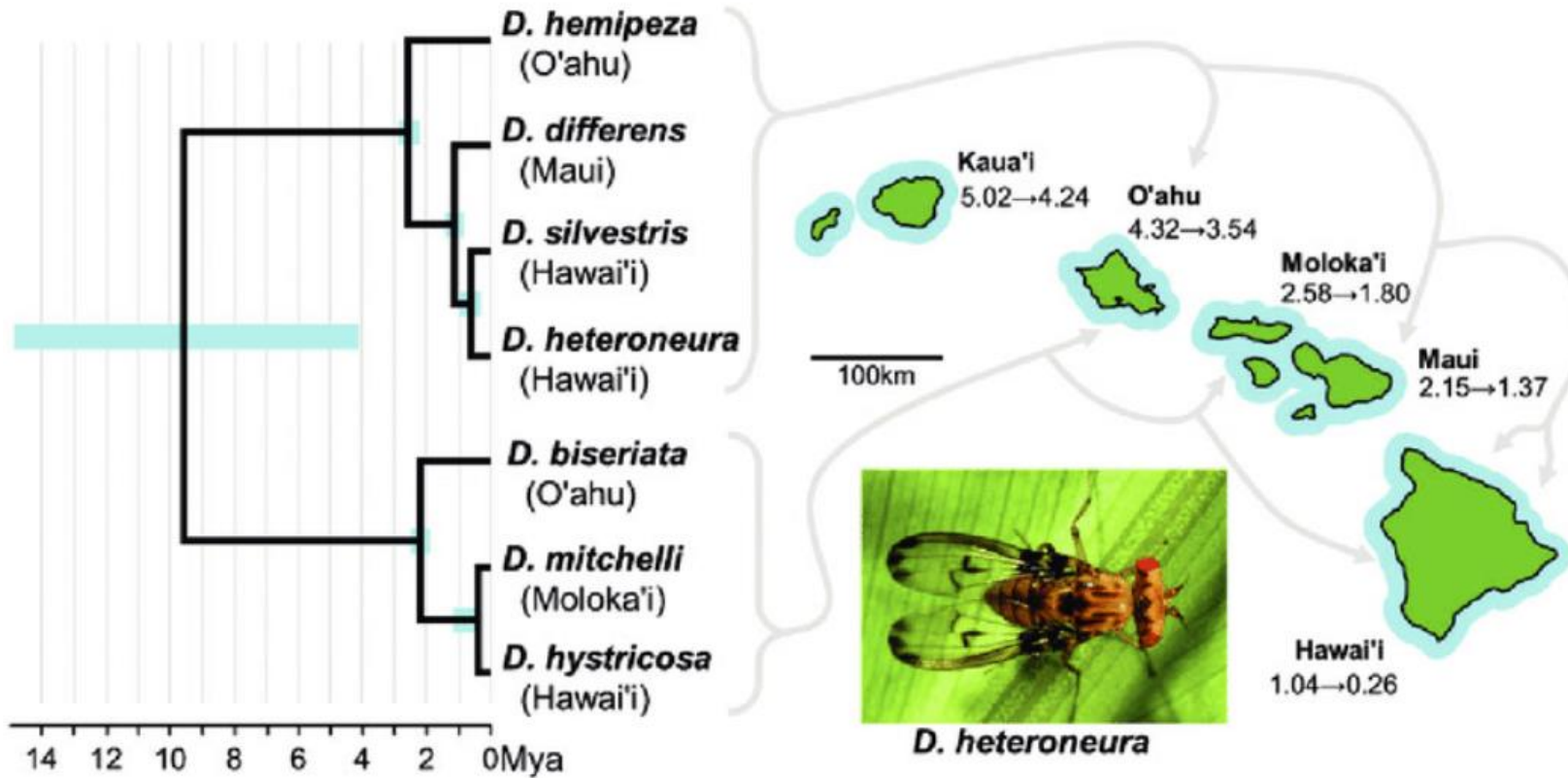
Isolation & Drift: This small colony is cut off. Their genetic makeup shifts rapidly, distinct from the ancestor due to:

***The Founder Effect** (the splinter group is so small so it does not carry all the genetic diversity of the main group).*

***Genetic Drift** (rare genes from the original population might become common in the new group simply by chance. With a small gene pool, new traits can become fixed in the population quickly).*

Reproductive Isolation (genetic differences become so great that species cannot longer interbreed).

Peripatric Speciation



Drosophila speciation on the Hawaiian Islands. As new Hawaiian islands are formed to the east, species from the nearest extant island are able to colonize the new island and become reproductively isolated (gray arrows).

Parapatric Speciation

Parapatric speciation (from Greek *para*, meaning "beside", and *patra*, meaning "fatherland") represents the "middle ground" between Allopatric (total separation) and Sympatric (total overlap) speciation.

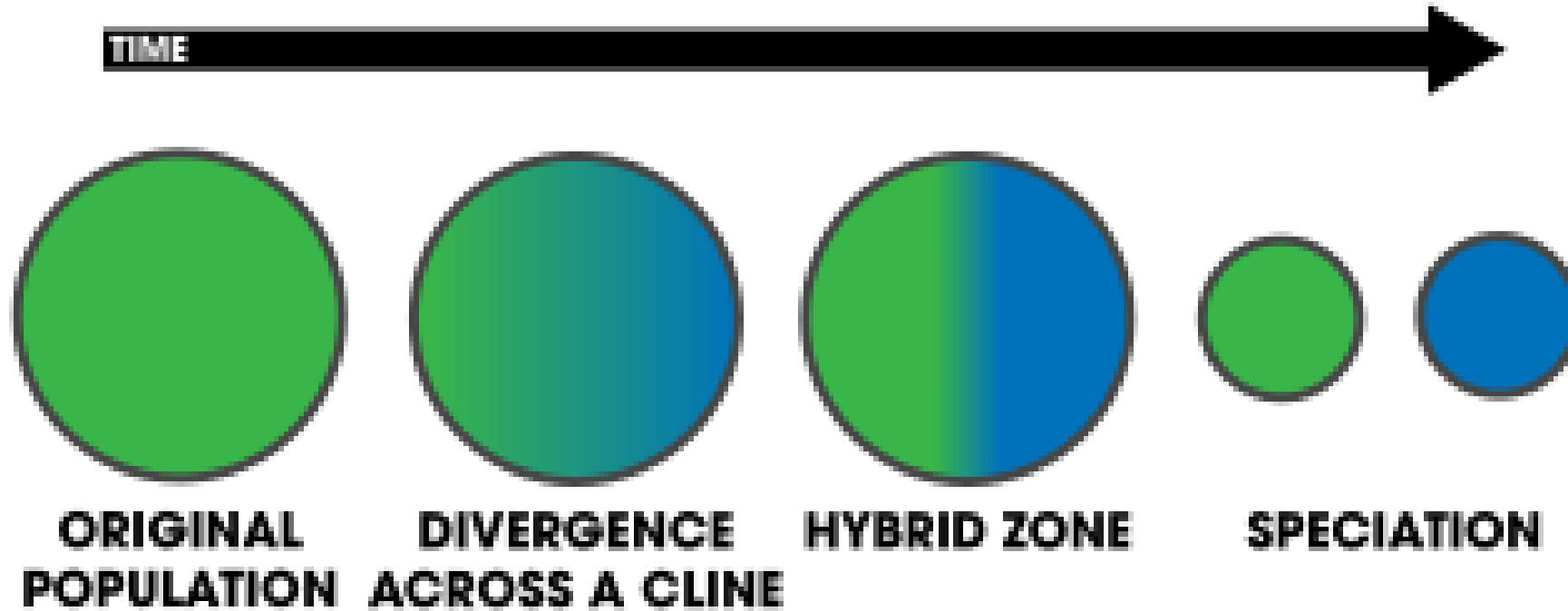
In this model, there is **no specific physical barrier** to gene flow. The population is continuous, but it does not mate randomly. Individuals are more likely to mate with their geographic neighbors than with individuals in a different part of the population's range.

Parapatric Speciation

- **Continuous Range:** The individuals can technically move anywhere, but in reality, they mate with their neighbors.
- **Environmental Gradient:** The environment changes gradually. Conditions in the more distant areas can be very different.
- **Divergent Selection:** Due to environmental conditions individuals belonging to different areas can exhibit different phenotypes.
- **Limited Gene Flow:** Because individuals only mate with neighbors, the gene flow is limited.

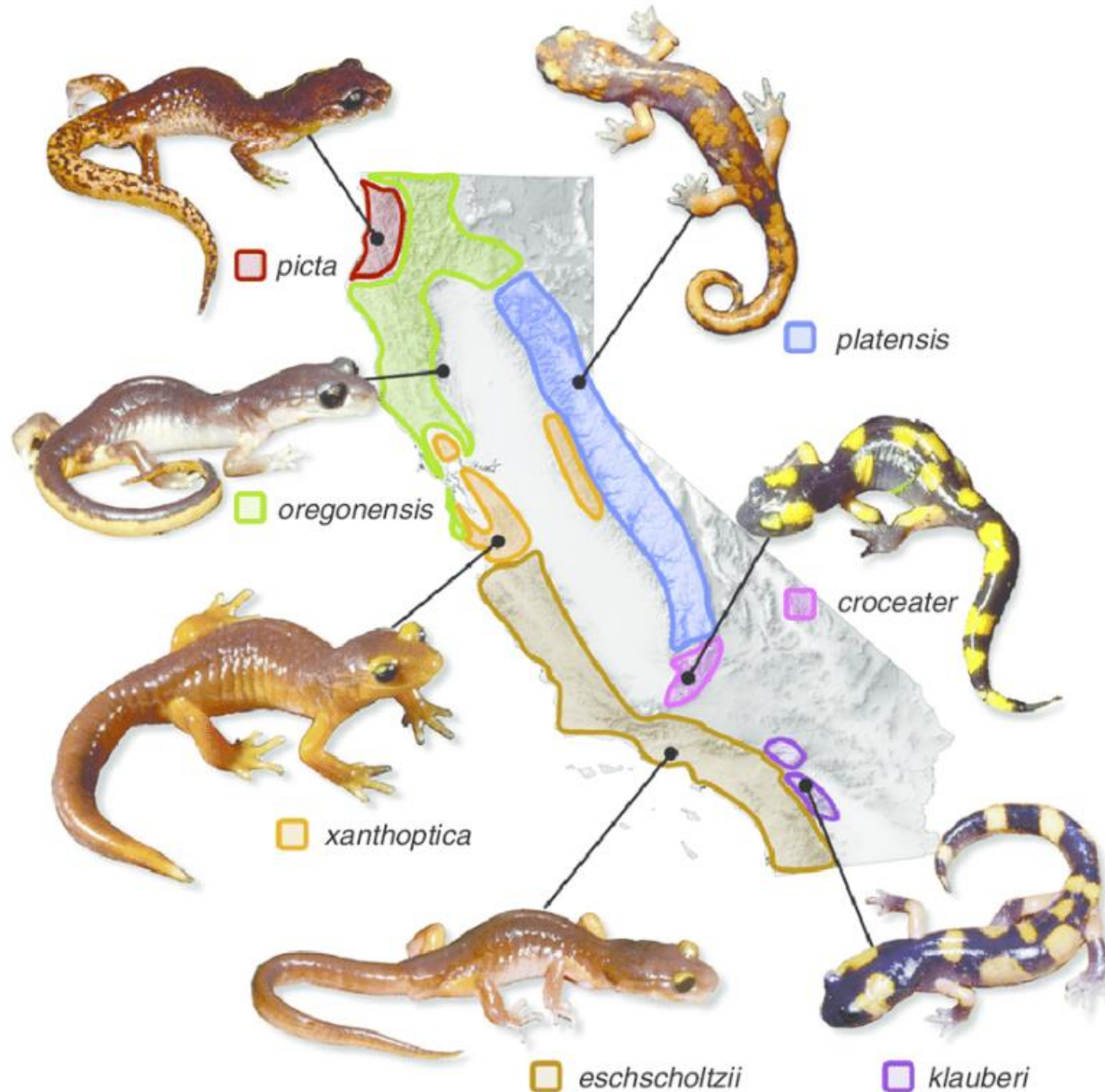
If the hybrids are weak/sterile: Natural selection will favor individuals who only mate with their own kind (reinforcement). The hybrid zone narrows, and the two groups eventually become distinct species.

Parapatric Speciation



Source: Wikipedia

Parapatric Speciation

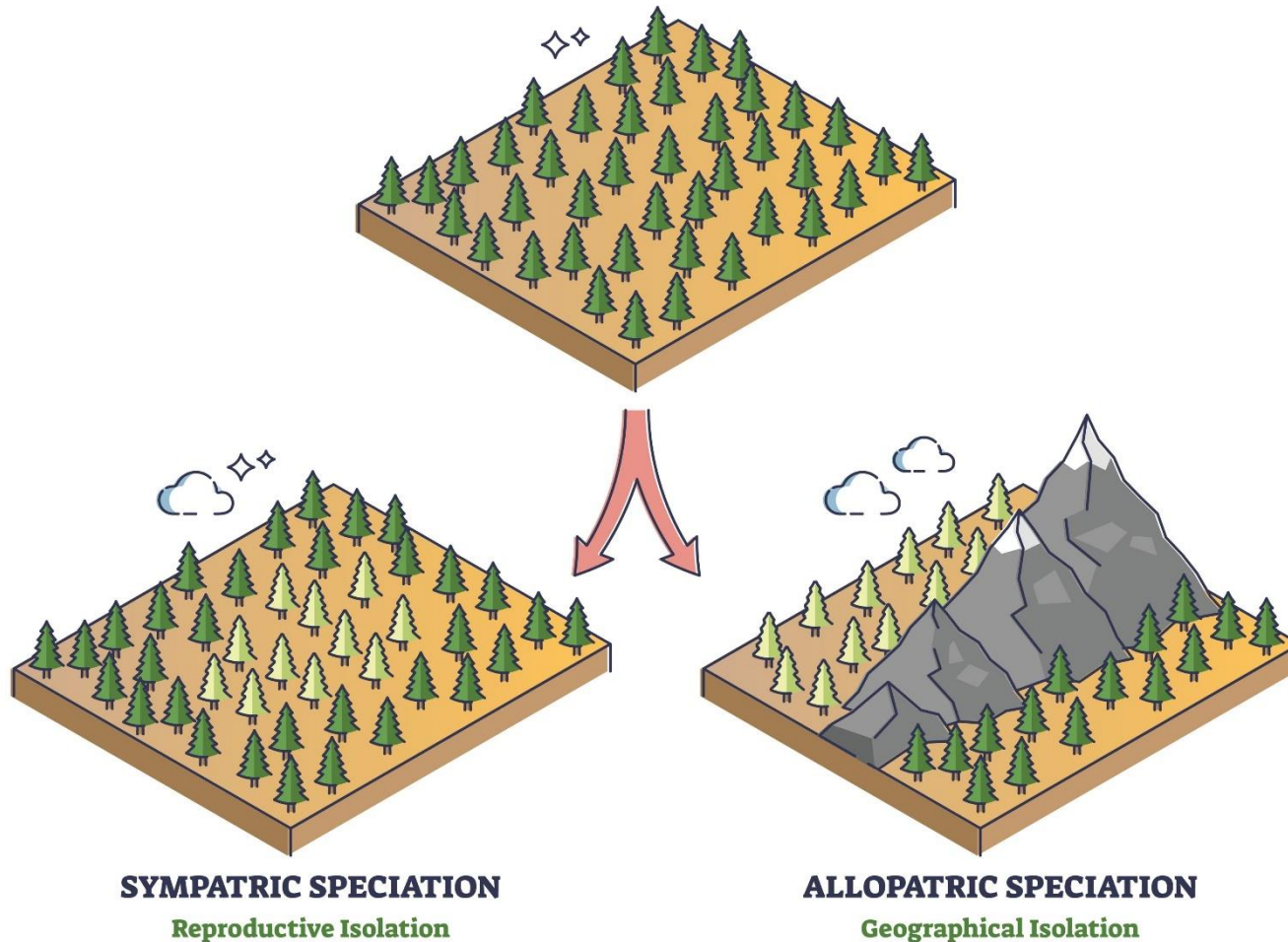


Geographic variation among races in the *Ensatina eschscholtzii* ring species in California.

Reproductive isolation is stronger between the southern forms *klauberi* and *eschscholtzii* than elsewhere around the ring.

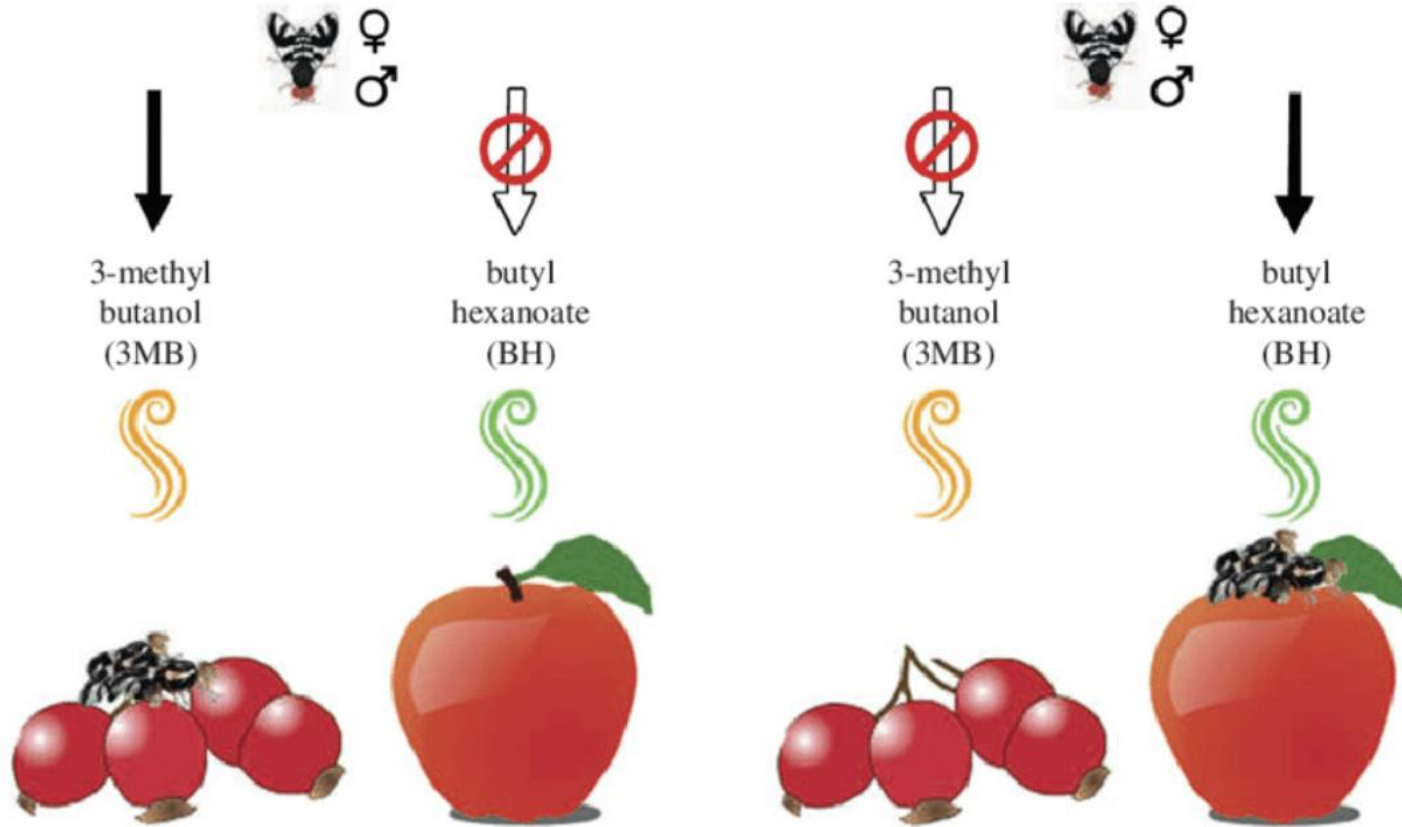
Source: Pereira, R.J., Monahan, W.B., Wake, D.B., 2011).

Sympatric Speciation



Sympatric speciation (from Greek *sym*, meaning "together", and *patra*, meaning "fatherland") is the evolution of a new species from a surviving ancestral species while both continue to inhabit the **same geographic region**.

Hawthorn/Apple Maggot Fly Attraction

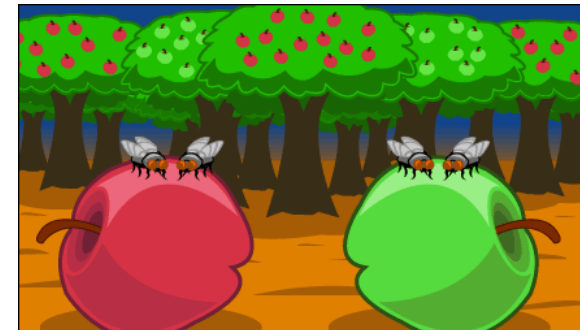


Rhagoletis pomonella host fidelity. Both sexes of the ancestral hawthorn race are attracted to volatiles from hawthorn fruit. BH, a key apple volatile, is an antagonist (Source: Tait et al., 2021. 10.1098/rspb.2021.0192).

Sympatric Speciation

Habitat Differentiation (Ecological Isolation)

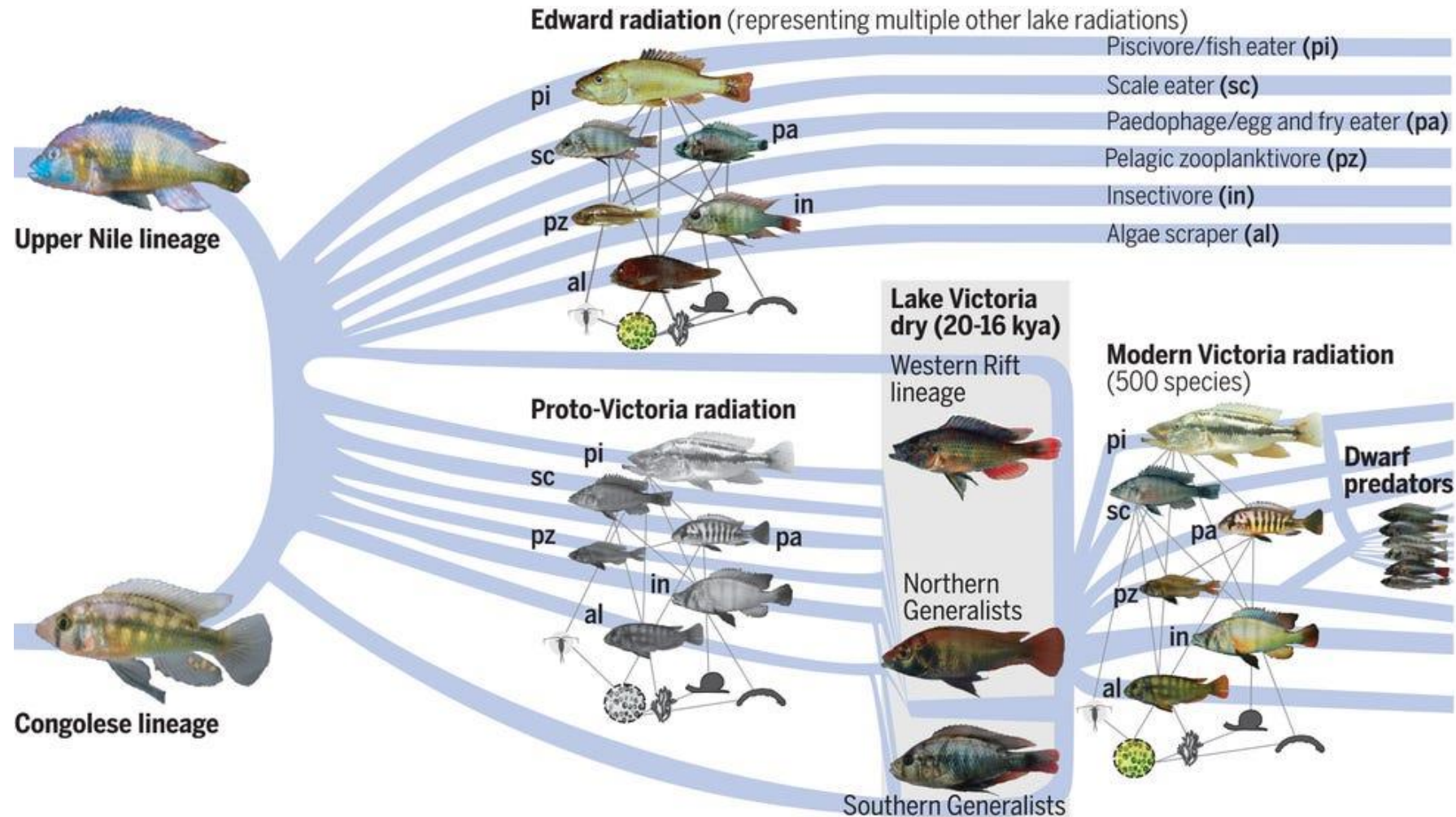
A sub-population starts exploiting a **new resource** or habitat within the same range. They eventually mate *on* that source, they become isolated over time.

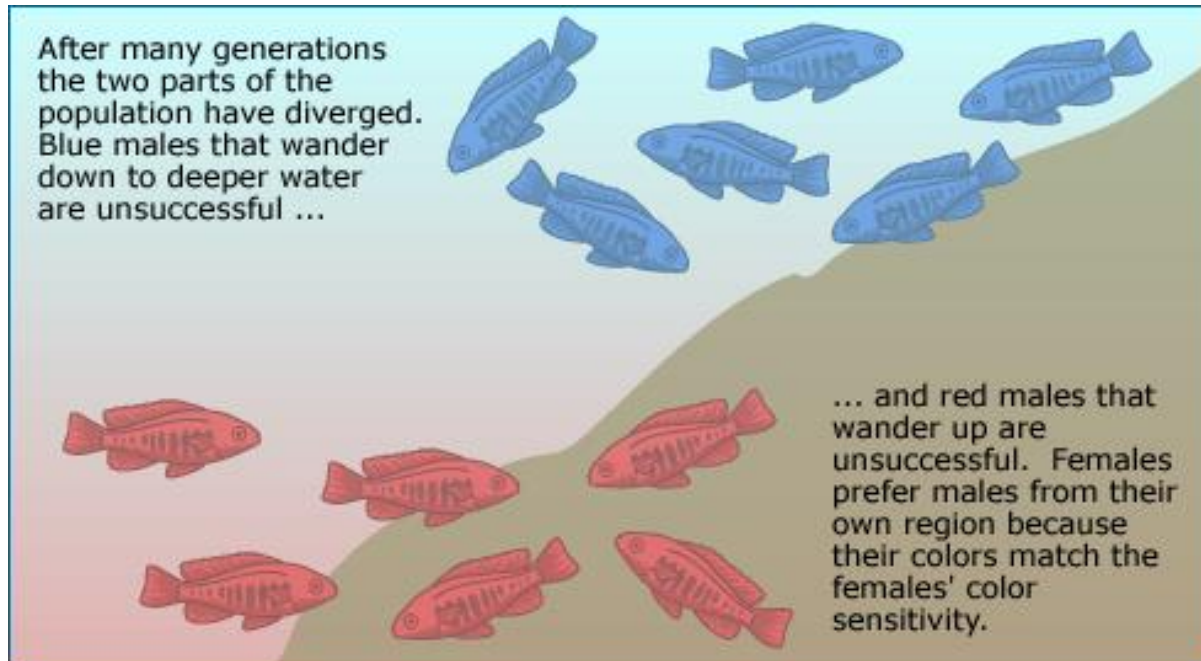
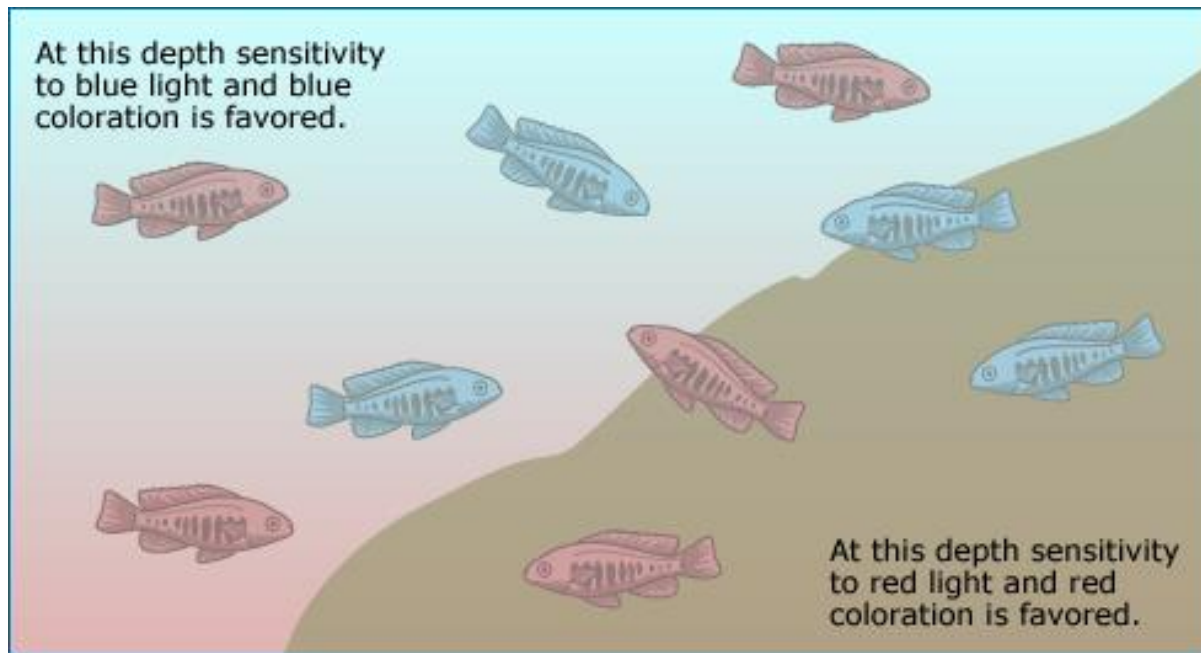


Cichlid Fish in Lake Victoria

“The most rapid radiation event among vertebrates” ever discovered.

Sympatric Speciation





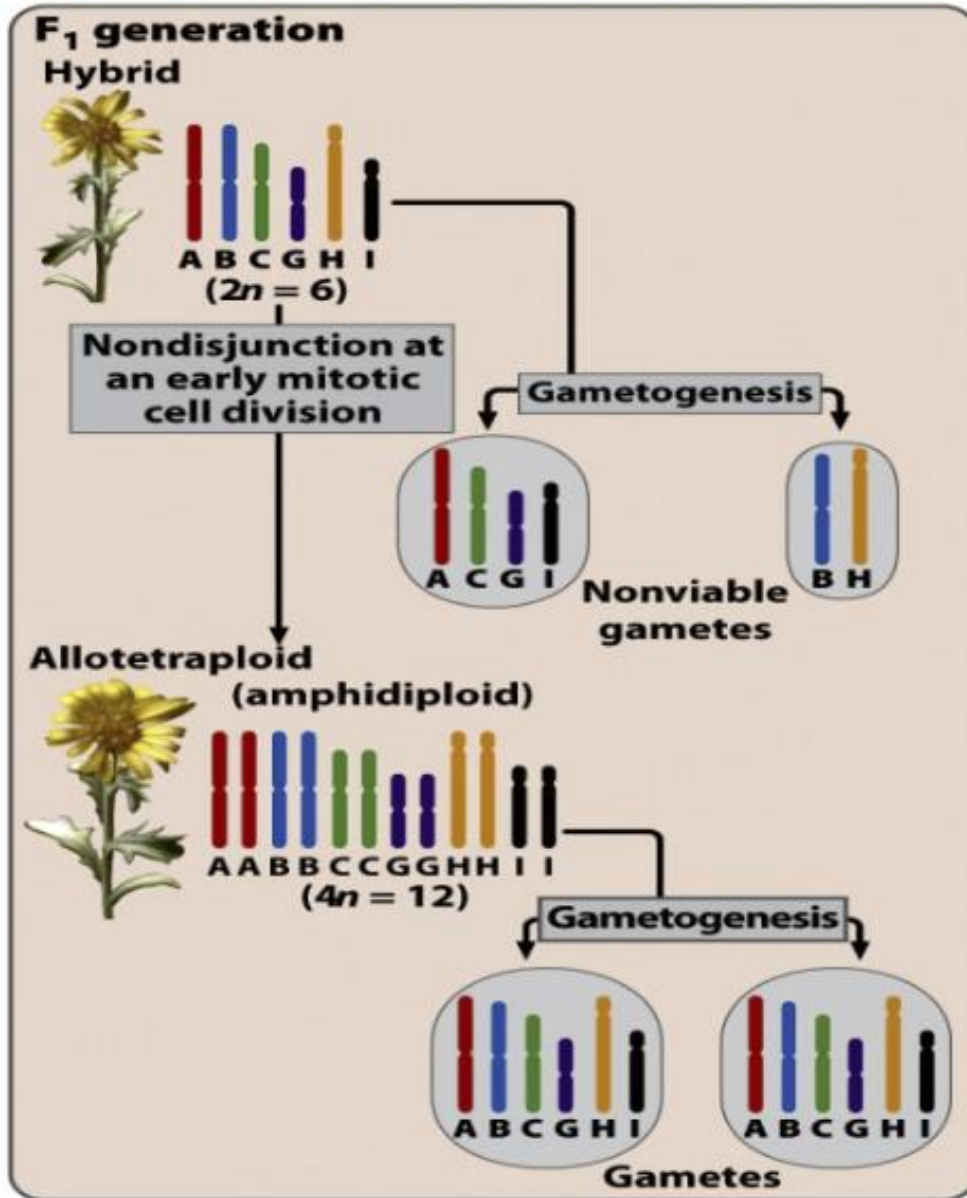
Sympatric Speciation

Sexual Selection

Females of a species may start selecting males based on extremely specific traits.

In clear waters, females of closely related species choose males based on specific coloring (e.g., *Pundamilia pundamilia* females like blue males; *P. nyererei* females like red males).

The gene pool will eventually split, even if they swim in the same pond.



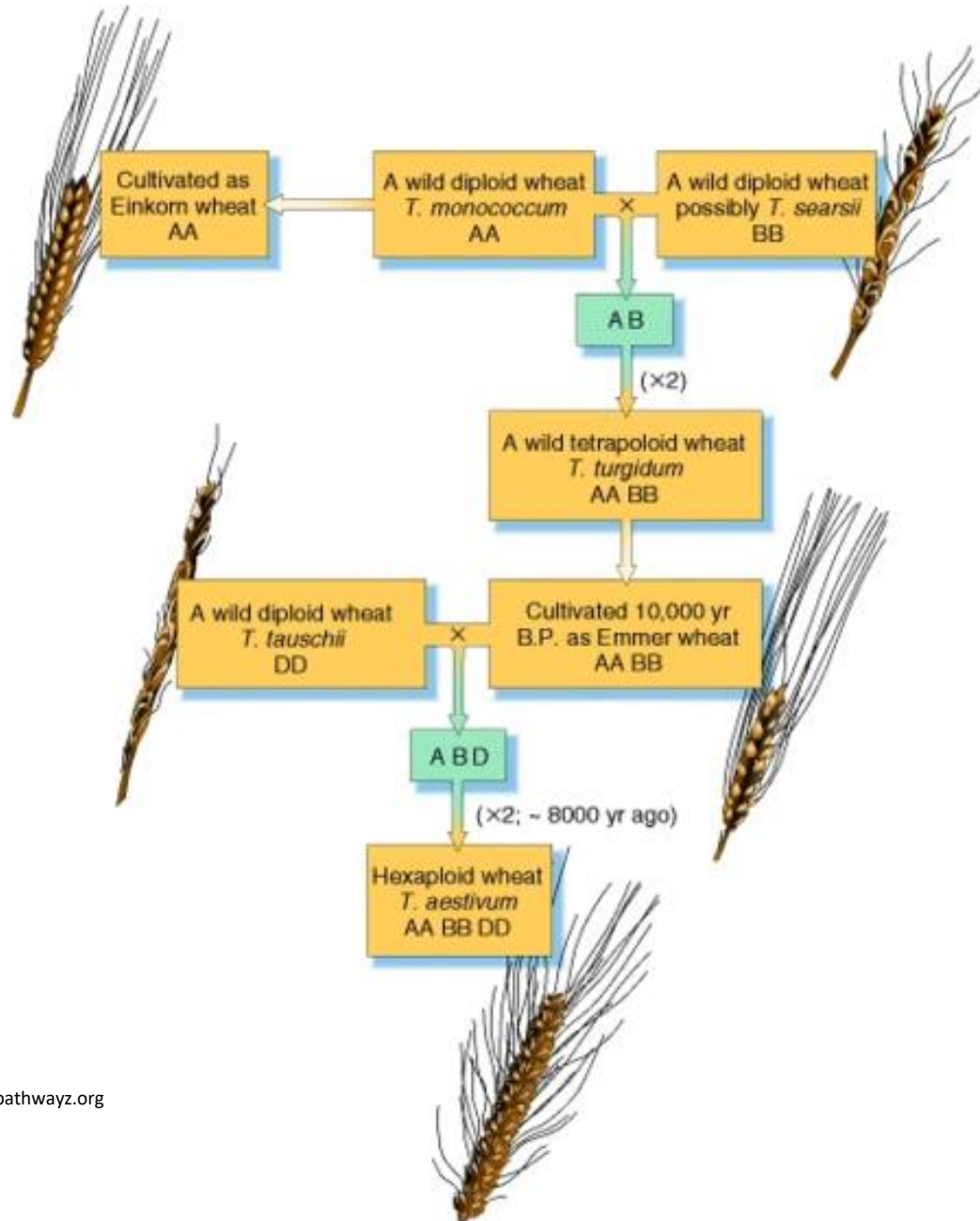
Sympatric Speciation

Polyploidy: Widely considered the **fastest mechanism of speciation** known in nature. Polyploidy can create a new, reproductively isolated species in a **single generation**.

Figure 9-28 part 2
Genetics: A Conceptual Approach, Third Edition
 © 2009 W. H. Freeman and Company

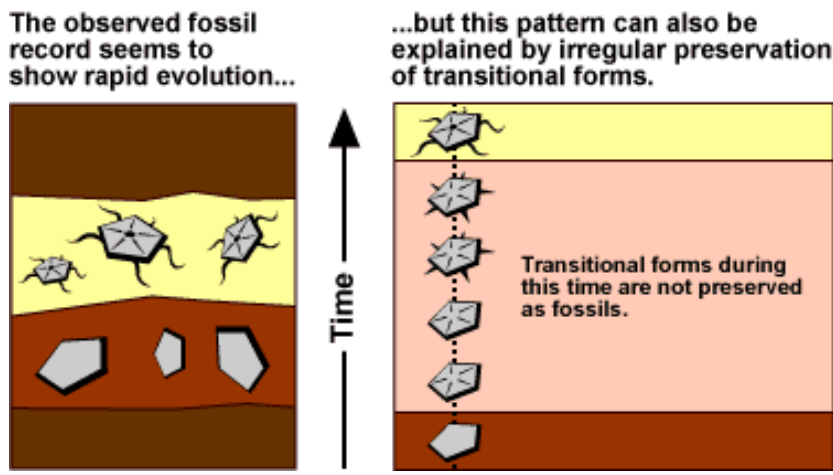
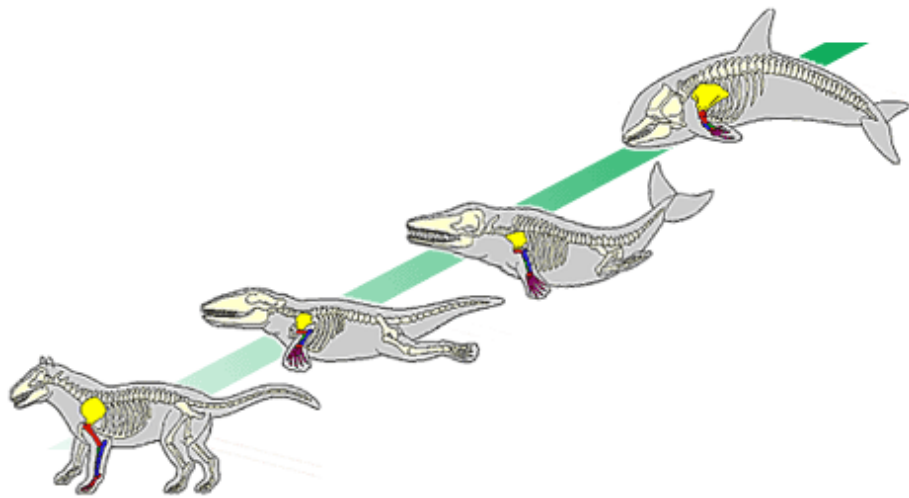
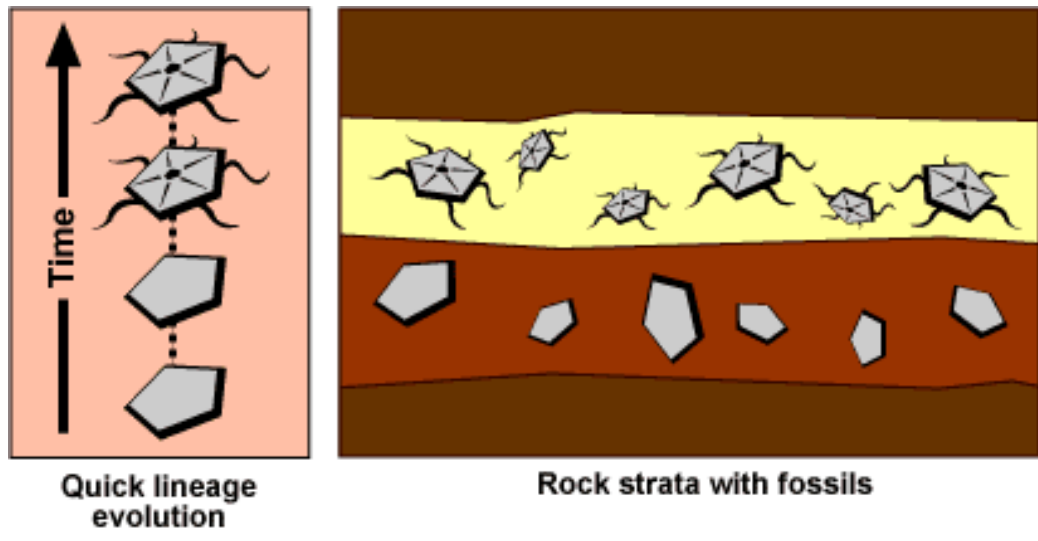
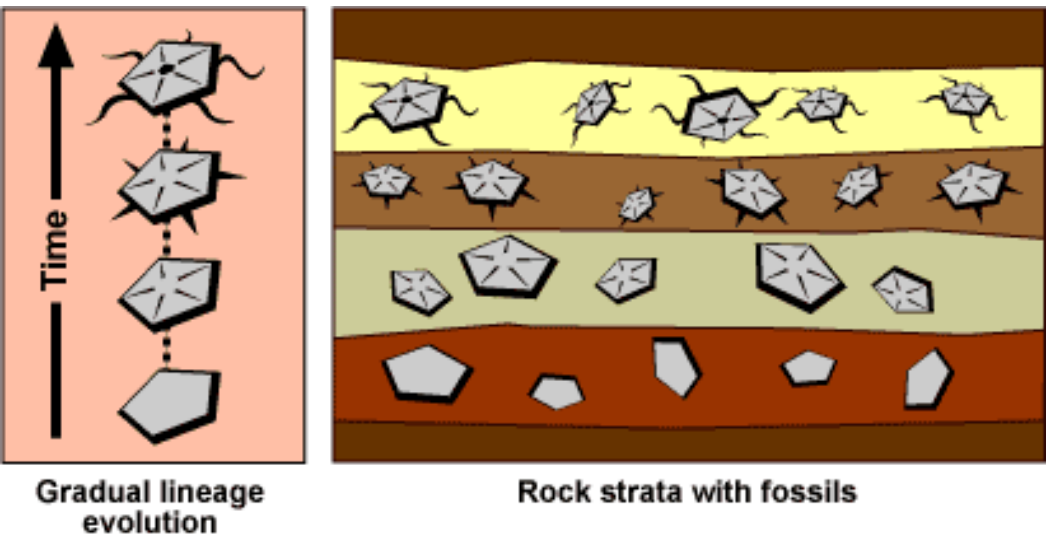
Sympatric Speciation

Common wheat has developed as a result of several polyploid events after the formation of hybrids between different grass species.

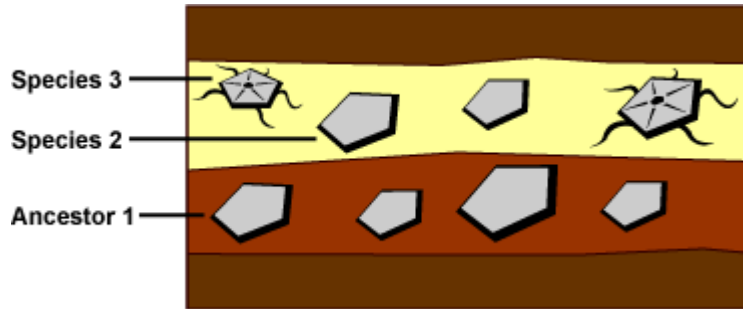


The Pace of Evolution

The Pace of Evolution

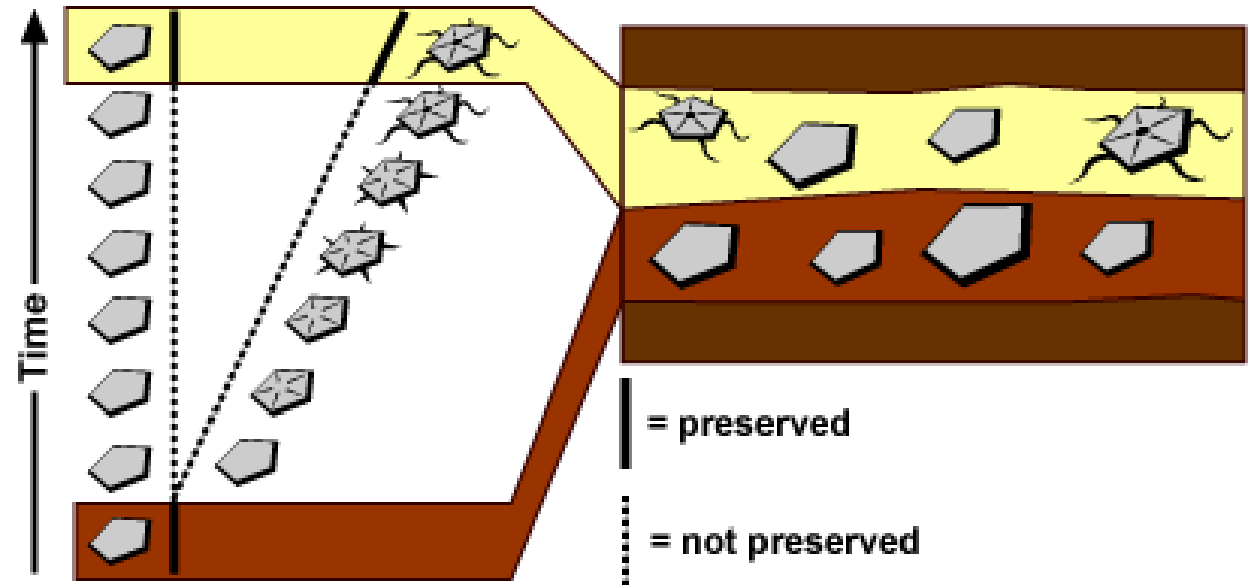


Competing Hypothesis

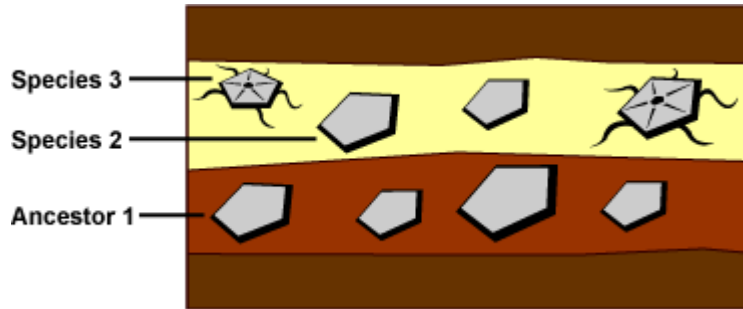


Phyletic gradualism — slow steady divergence of lineages

The “burst” of evolution is a geological illusion. It only looks like a burst because a lot of time — say, 5 million years — passed between the times when the two rock layers were laid down. In this period of time, species 3 gradually diverged from ancestor 1 through a series of transitional forms, but these transitional forms were not preserved.

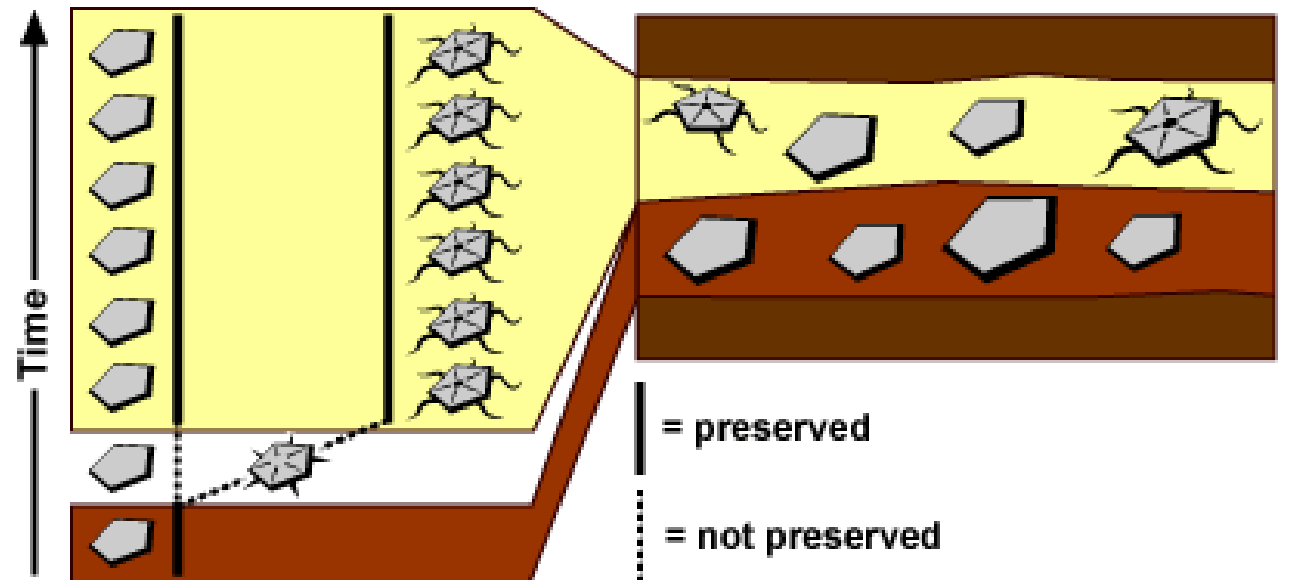


Competing Hypothesis

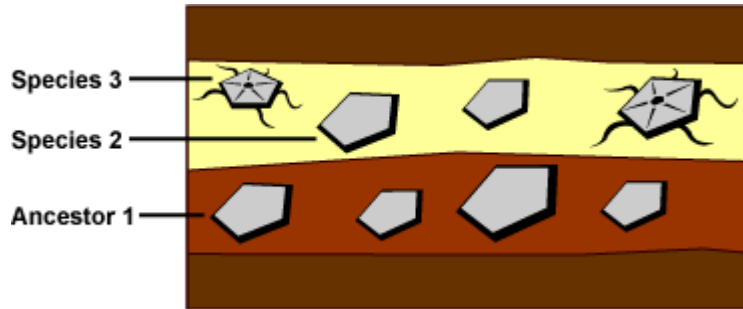


Punctuated equilibrium — a large amount of change in a short time tied to a speciation event

Species 2 and 3 are only 100,000 years younger than ancestor 1, and all the evolutionary change connecting them took place in this short time. The “burst” of evolution is really a burst. Transitional forms between ancestor 1 and species 3 did exist, but for such a short amount of time that they were not preserved in the fossil record.

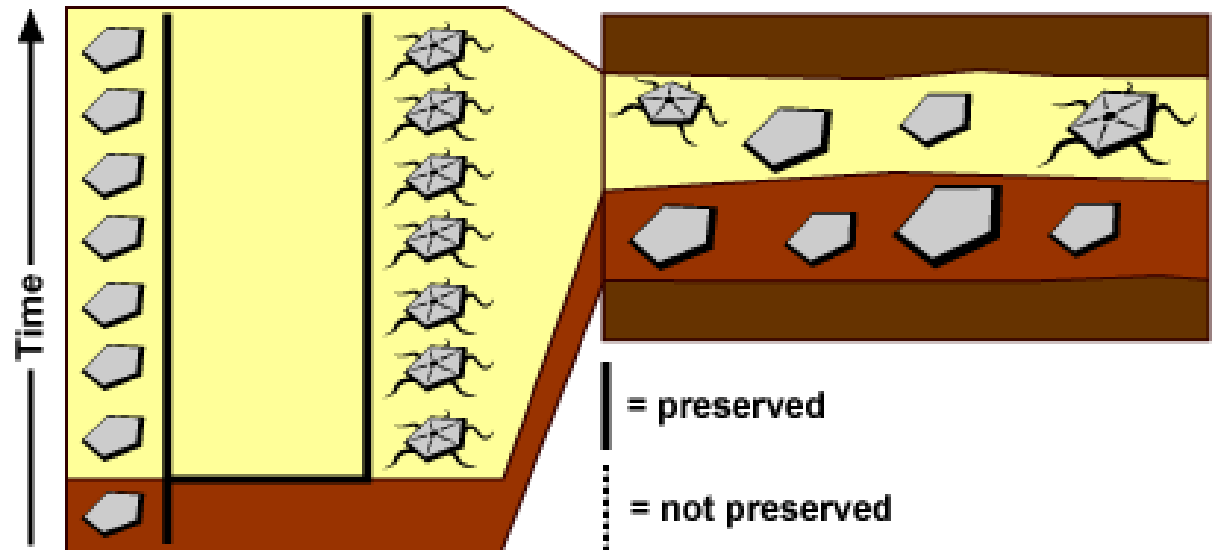


Competing Hypothesis



Macromutation — a big mutation produces sudden evolutionary change skipping over transitional forms

The “burst” of evolution is really a burst — there was a lot of evolutionary change in a very short amount of time. Species 3 was produced by a mutation that radically changed the offspring of ancestor 1 in many ways. Such extreme mutants are sometimes called “hopeful monsters.” This hypothesis is consistent with the fossils; however, based on other observations, we do not have clear evidence that such extreme yet adaptive mutations generally occur. Nevertheless, it is possible that mutations affecting development have far-reaching phenotypic effects and have played an important role in the evolution of life.



The Molecular Clock

The molecular clock is a tool used to calculate the timing of evolutionary events.

The concept of a molecular clock was first put forward in 1962 by chemist **Linus Pauling** and biologist **Emile Zuckerkandl**, and is based on the observation that genetic mutations, although random, occur at a relatively constant rate. Thus, the theory goes, the number of differences between any two gene sequences increases over time. This thinking led to the idea that the number of **mutations in a given stretch of DNA could be used as a measure of time.**

In brief:

- The Watch:** Is the DNA (or protein) sequence.
 - The "Tick-Tock":** Are mutations (changes in the DNA letters).
 - The Premise:** We assume these mutations accumulate at a relatively constant rate over long periods.
- When a species splits into two different lineages, both lineages begin to accumulate mutations independently.**

The Molecular Clock

CONSTRUCTING MOLECULAR PHYLOGENIES

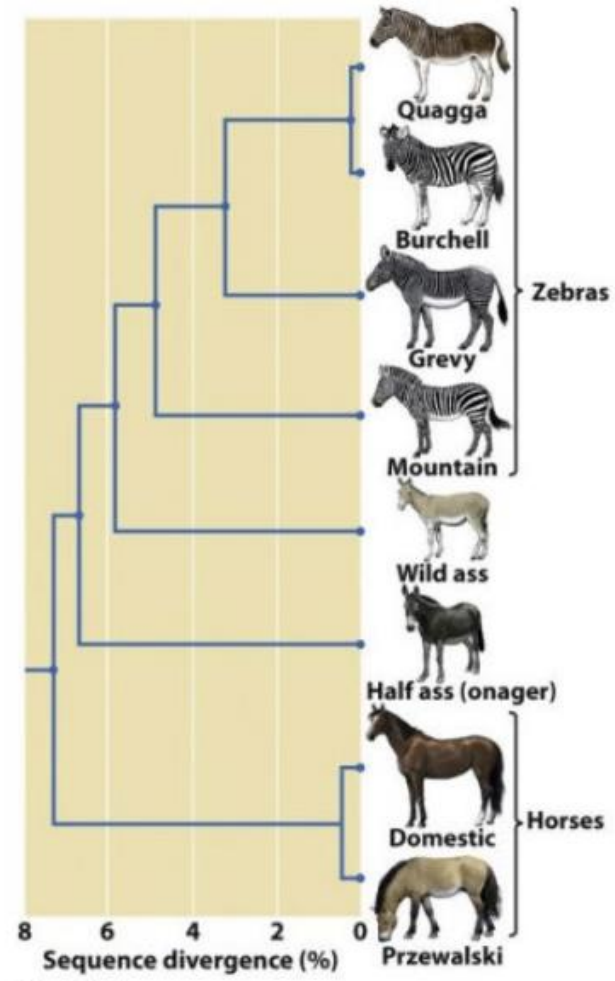
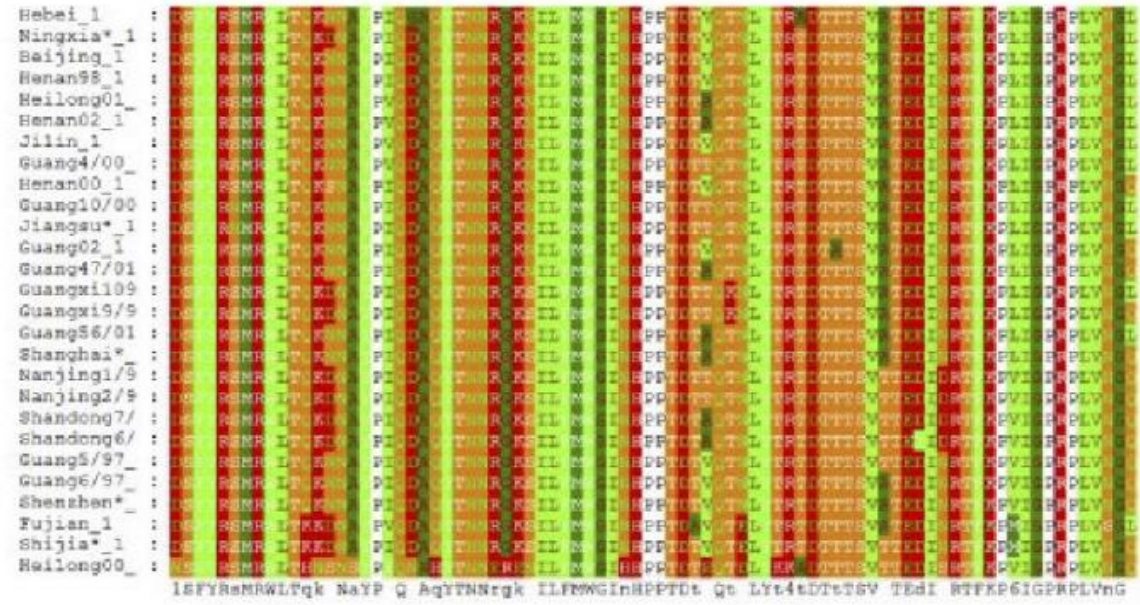


Figure 26-13
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The Molecular Clock

To calculate the time (T), we use the basic formula:

$$T = \frac{D}{2 \times R}$$

Where:

- D = Number of differences (mutations) between two species.
- R = Mutation Rate (the speed at which changes occur).
- Note: We divide by 2 because **both** species have been mutating independently since they separated.

The Molecular Clock

Species

Human (Reference)

Chimpanzee

Mammal Unk.

DNA Sequence (15 base pairs)

ATG - CCG - TTA - GCA - TTG

ATG - CCG - TTA - GCA - TTA

ATG - CTG - ATA - GCA - TTC

Human vs. Chimpanzee:

Total Differences $D = 1$

Human vs. Mammal:

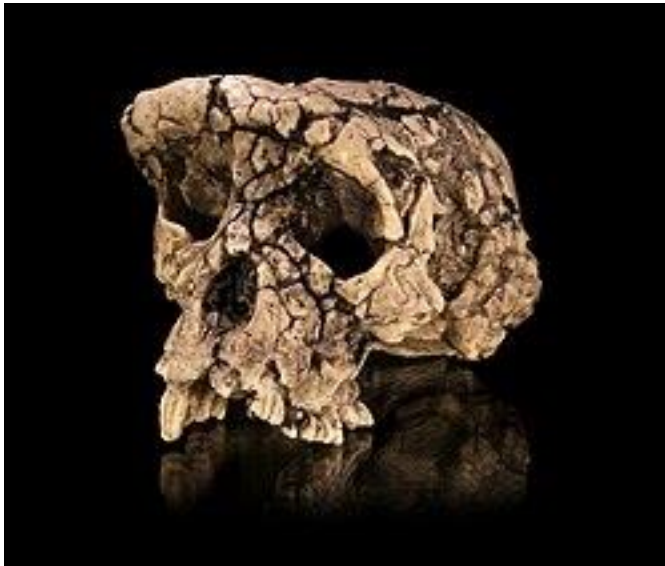
Total Differences $D = 3$

$$T = \frac{D}{2 \times R}$$

Calibration of the Molecular Clock

The ideal situation is to calibrate the clock using a **known event** (usually from the fossil record).

Fossil Fact: The fossil record suggests the common ancestor of **Humans and Chimpanzees** lived approximately **6 million years ago (Ma)**.



Sahelanthropus tchadensis

Source: Wikipedia

$$R = \frac{1 \text{ mutation}}{2 \times 6 \text{ million years}} = \frac{1}{12} \approx 0.083 \text{ mutations per million years}$$

In this specific fragment of DNA, roughly 1 mutation occurs every 12 million years per lineage.

The Molecular Clock

Assuming we don't have a record fossil for the ancestor of this Unk. Mammal, we can use the mutation rate we just calculated to **estimate the time of divergence from human.**

Human vs. Mammal:
Total Differences $D = 3$

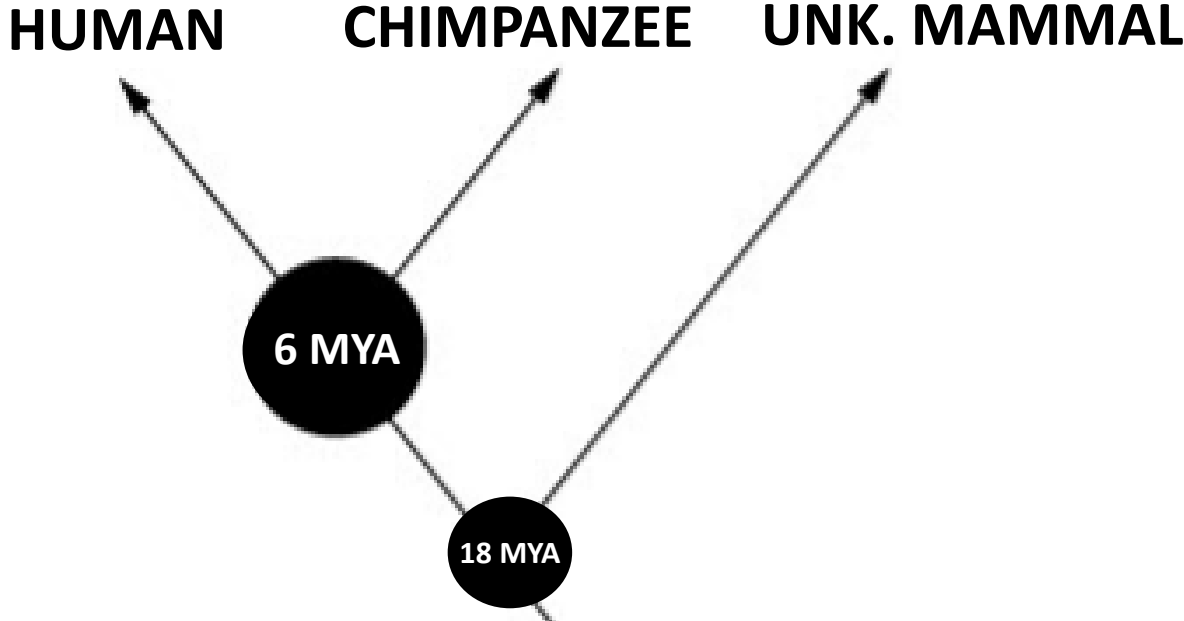
$$T = \frac{3}{2 \times 0.083}$$

Estimated Mutation Rate:

$$R = \frac{1 \text{ mutation}}{2 \times 6 \text{ million years}} = \frac{1}{12} \approx 0.083 \text{ mutations per million years}$$

$$T = \frac{3}{0.166} \approx 18 \text{ million years}$$

The Molecular Clock



The Molecular Clock

CRITICISMS/LIMITATIONS

Saturation: Over very long periods, a nucleotide might change from A to T, and then randomly mutate back to A. The clock "loses count" of the changes.

Different Clocks: Not all genes tick at the same speed.

1. *Essential Proteins (like Housekeeping genes):* Mutate very slowly (useful for ancient events/distant species).
2. *Non-coding DNA / Mitochondrial DNA:* Mutates fast (useful for recent events/closely related species).

Generation Time: Animals that reproduce quickly (like mice) accumulate mutations faster than those with long lives (like elephants or whales).