# *The Theory of Evolution*

**CBGS Marine & Environmental Science**

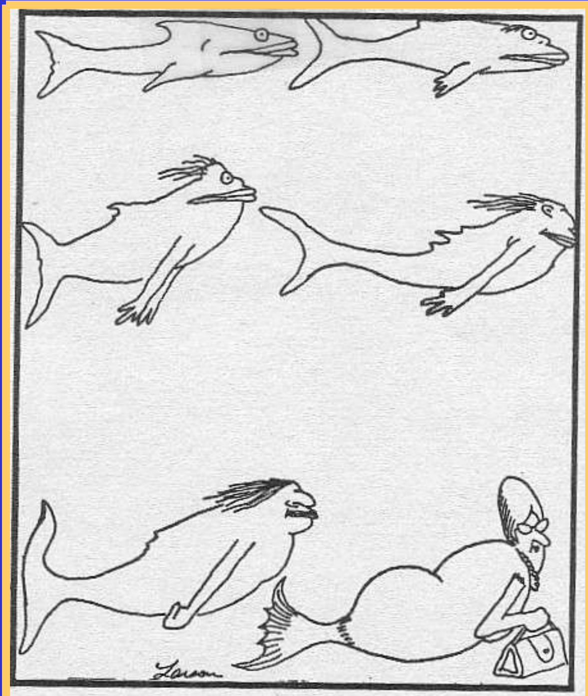
- **<u>Unity of Life</u>**
  - **Life arises only from pre-existing life (spontaneous generation is disproved)**
  - **All living organisms are composed of one or more cells**
  - **All organisms share a single DNA code (A, T, G, C)**
- **<u>Diversity of Life</u>**
  - **Earth has been host (now and in the past) to a staggering variety of life forms …penguins to petunias, dandelions to dinosaurs, ostriches to octopi, lobsters to lions, banana trees to bacteria, mushrooms to monkeys**

***How can life be so diverse yet still unified???***

# *Answer: Life Changes over Time*

**Evolution = A gradual change in a population's genes and traits over time, with increasing adaptation to the prevailing environment**

***Evolution of Complex Life Forms from Simpler Ones***



Mermaid evolution

***An Historically Controversial Theory***

# “Lamarckism”
## (Jean Lamarck, 1809)

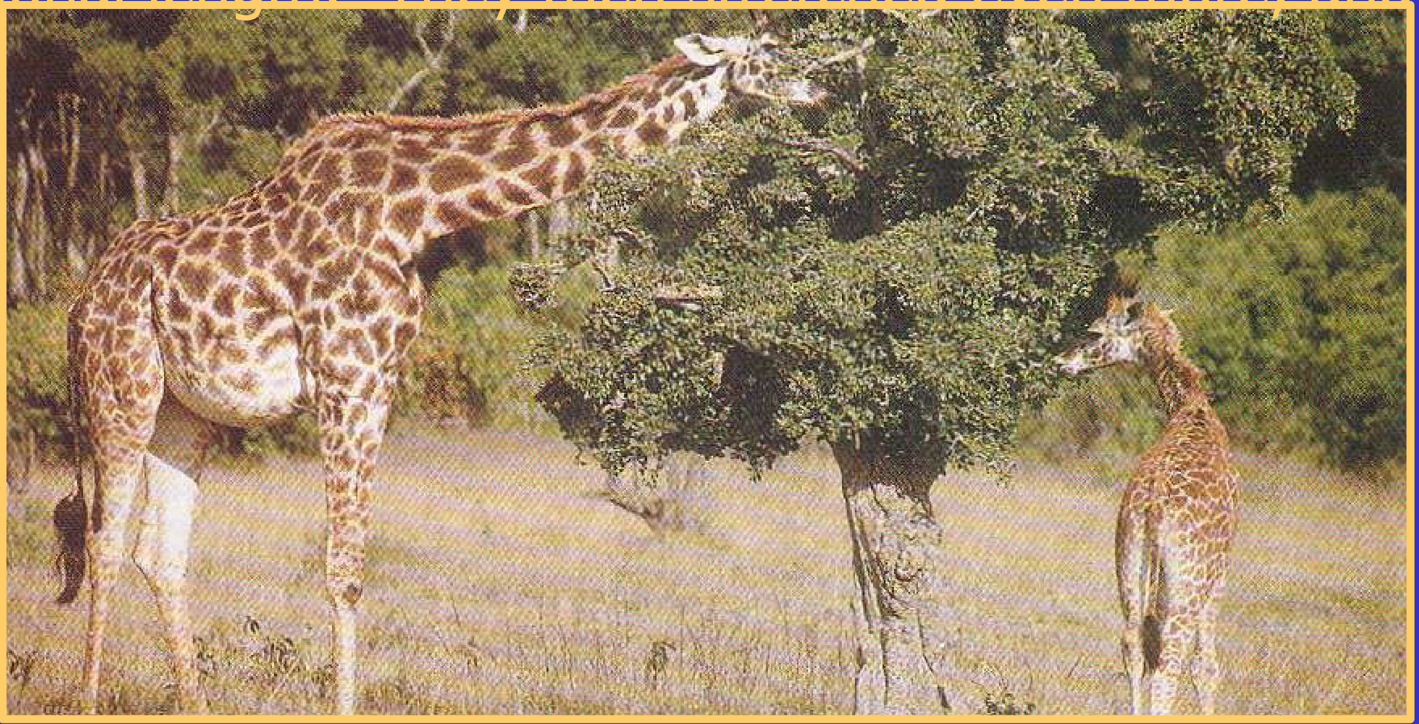
***The first hypothesis of evolution (now <u>rejected</u>!):***

1) Individual organisms can acquire new traits during their own lifetimes ...they can change their own bodies through effort, behavior, use (or disuse) of parts, etc.

2) Their offspring will inherit these acquired traits.

***WRONG!!!*** *Even if an organism does change its body during its lifetime, its offspring will <u>not</u> inherit those changes. Organisms cannot alter their genes or DNA through their behavior!*

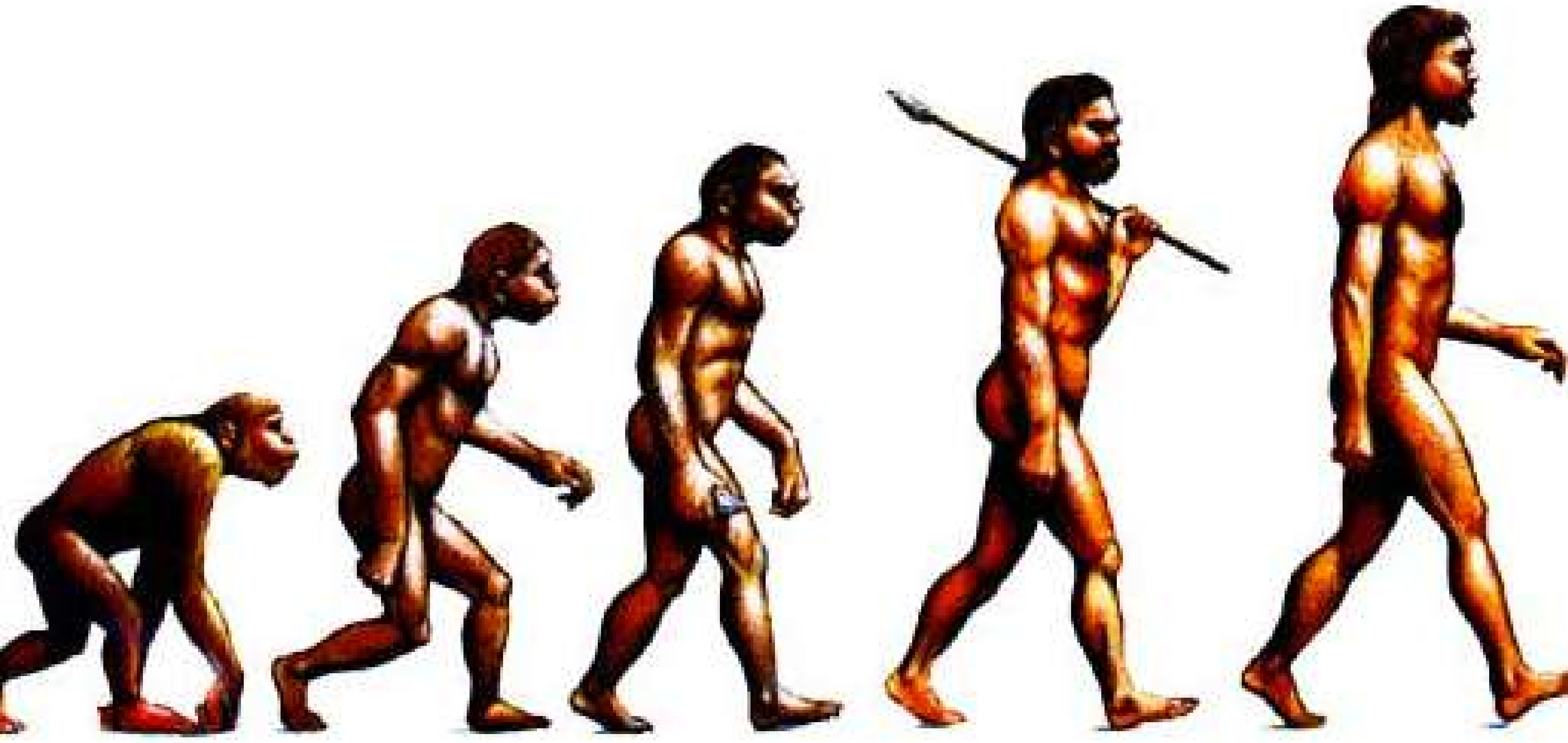
*The classic Lamarckian example:* Giraffe evolution. Lamarck suggested that early giraffes acquired longer necks by stretching for the most distant leaves. Their offspring inherited the additional length. They then stretched even more, and so on…



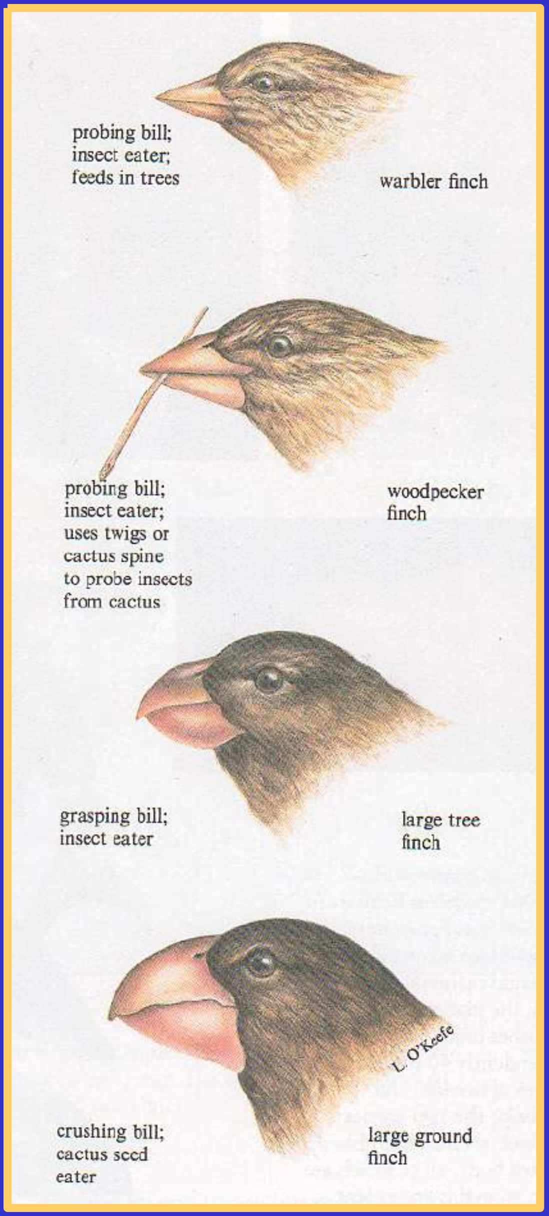
***NO!***

***Baby giraffes can't inherit the results of parental***

# Darwin's Theory of Evolution



# *Charles Darwin, mid-1800's*




**During his famous voyage around South America on the HMS Beagle, Darwin visited the Galapagos archipelago, a collection of young volcanic islands off the coast of Ecuador. Here he collected finches from different islands. Each island had its own peculiar variety of finch. What's more, each finch was well adapted for feeding on that particular island.**

**Darwin proposed that these finches shared a common ancestry, but had "evolved" to become adapted for the particular habitat on each island.**

***But how???***

**Darwin observed that no two members of the same species are perfectly identical. Each organism is born slightly different from its parents, from its brothers and sisters, and from other members of that species.**

**(We now know that this stems from random reshuffling of genes during sexual reproduction, plus the occasional mutation ...things Darwin knew nothing about!).**

**He reasoned that over many generations,**

**a lot of little differences can add up to**

**some really enormous changes!**

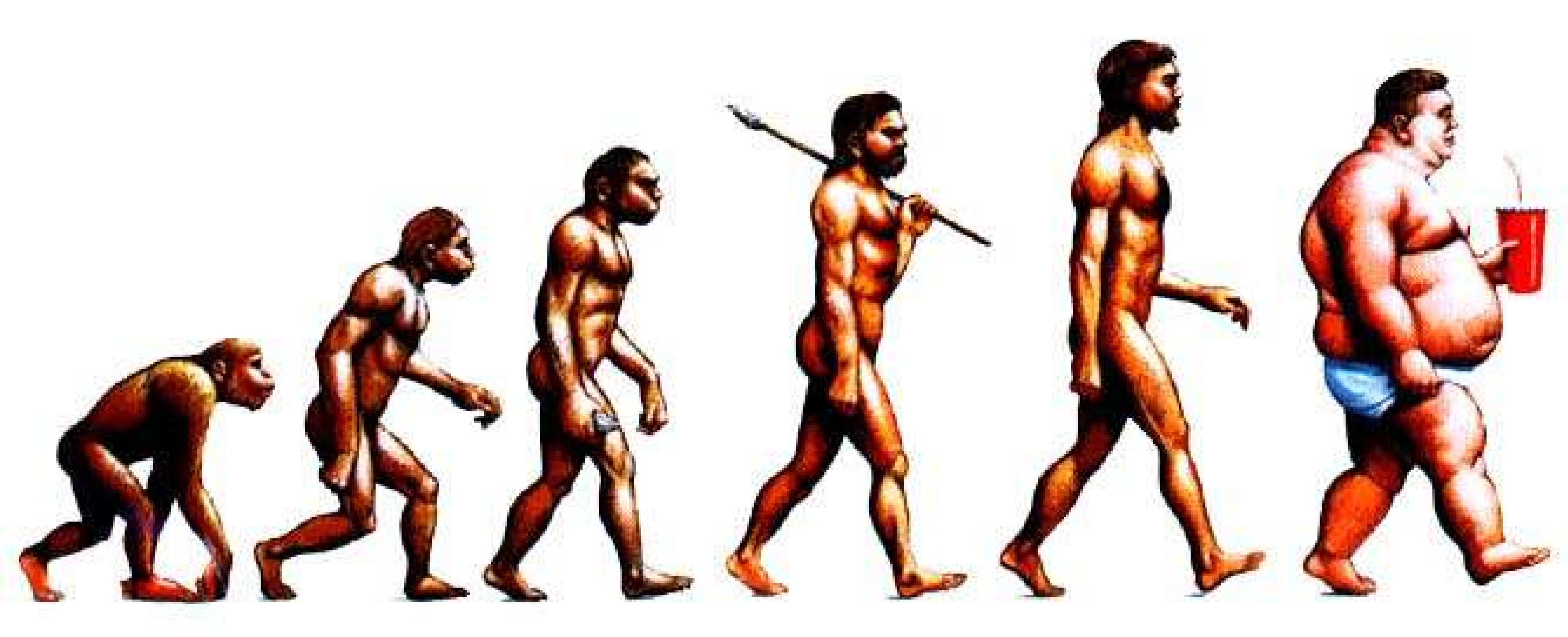

***But why does this lead to better and better adaptations???***

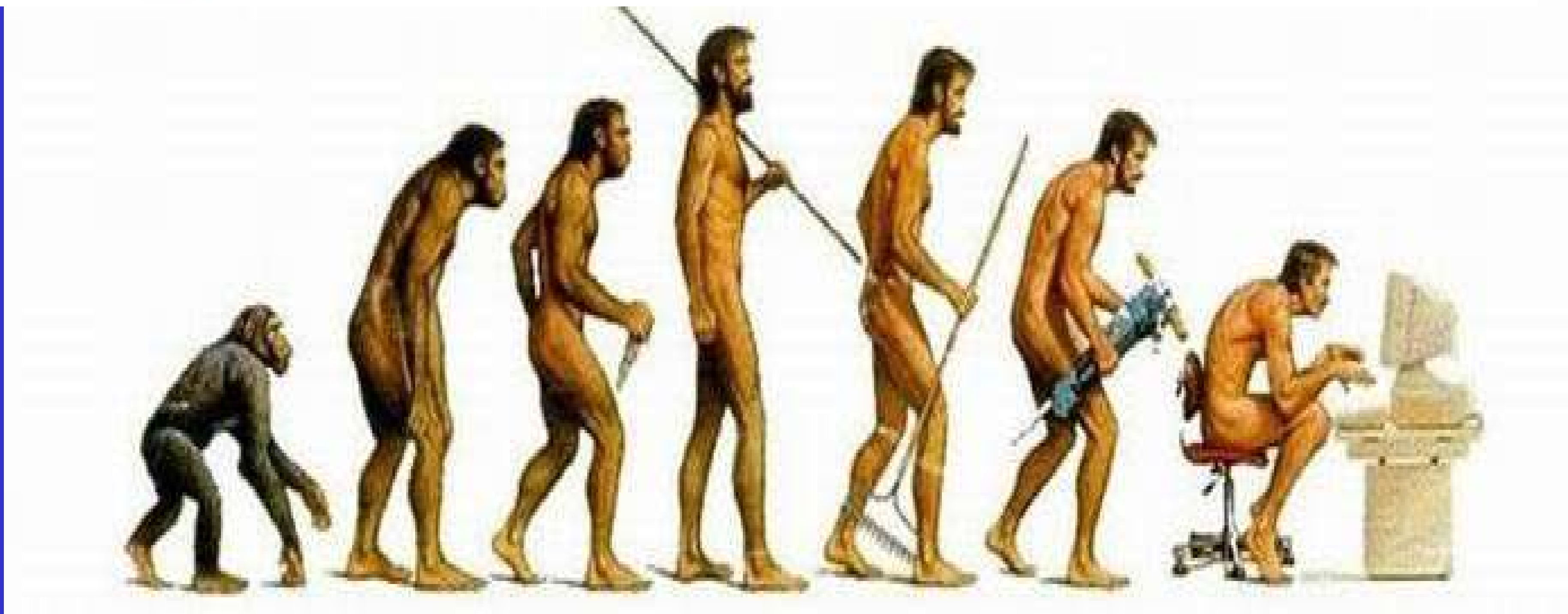
# Evolution by "Natural Selection"
## (Charles Darwin, 1859)

1) In any population, more offspring will be produced than will survive (environment has a fixed & finite "carrying capacity")
2) Those offspring will <u>compete</u> with one another for survival and limited resources (escaping predators, finding food and shelter, etc.)
3) A random <u>variety</u> of traits will appear among those offspring
4) Some traits are more favorable (or "<u>adaptive</u>") than others for competing and surviving in a particular <u>environment</u> ("Survival of the Fittest")
5) Those offspring which happen to be born with more adaptive traits will have a better chance of surviving long enough to <u>reproduce</u>, thereby passing on their adaptive traits
6) In the next generation there will be a higher <u>frequency</u> of adaptive traits (= Evolution)

- **Darwin understood that the key to evolution was the passing of selected TRAITS that enhances the organisms ability to survive and/or reproduce from one generation to the next**

- Darwin used evidence from Fossil records, comparative anatomy, and embryology
- What Darwin did not have was the ability to study DNA sequencing and genes (a fundamental component of the modern Theory of Evolution!)





**Modern day flying fish have broad, wing-like pectoral fins that enable them to glide just above the surface of the water. Like many small pelagic fish, when a predator strikes from below, a flying fish leaps out of the water. Unlike most fish, however, it then spreads its fins (or "wings") and glides in the air for as far as 100 yards away, thus escaping its attacker! Suppose that modern day flying fish evolved from ancient ancestors that had "normal" pectoral fins.**

- **Explain how a flying fish's wings might have <u>gradually</u> evolved through Lamarckism?… …."Natural Selection."??**

**Is this Micro- or Macro-evolution??**

# Empirical Evidence for Microevolution & Macroevolution

# *Two different scales of evolution…*


*As generations of polar bears have expanded their range into the Arctic, they've evolved thicker coats, a 4" layer of blubber, and white fur (cryptic coloration)*

## (1) Microevolution

Gradual, short-term *adaptation* of a species to its environment; evolution of traits *within* a single population of interbreeding individuals

*(ex)* goldfish tails becoming broader (or narrower), flying fish fins becoming wider and more wing-like, deepening of finch bills, etc.

Sometimes possible to quantify & study through *direct observation* of living populations (e.g., Darwin's finches)

# (2) Macroevolution

Long-term evolution *across* entire taxonomic groups ("taxa" …kingdom, phylum, class, order, family, genus, species…), including the evolution of one taxon into one or more NEW taxa

*(ex) land mammals evolving into whales, lungfish evolving walking limbs and becoming tetrapods, feathers evolving from reptile scales, etc.*

Studied indirectly via fossil record, comparative anatomy/embryology, & DNA sequencing

*Of course, where Microevolution ends and Macroevolution begins can be a hazy boundary (Is the evolution of flying fish micro or macro???). The bridge between Micro- and Macroevolution is the process of Speciation: the evolution of a single species (= an interbreeding population) into one or more new species*

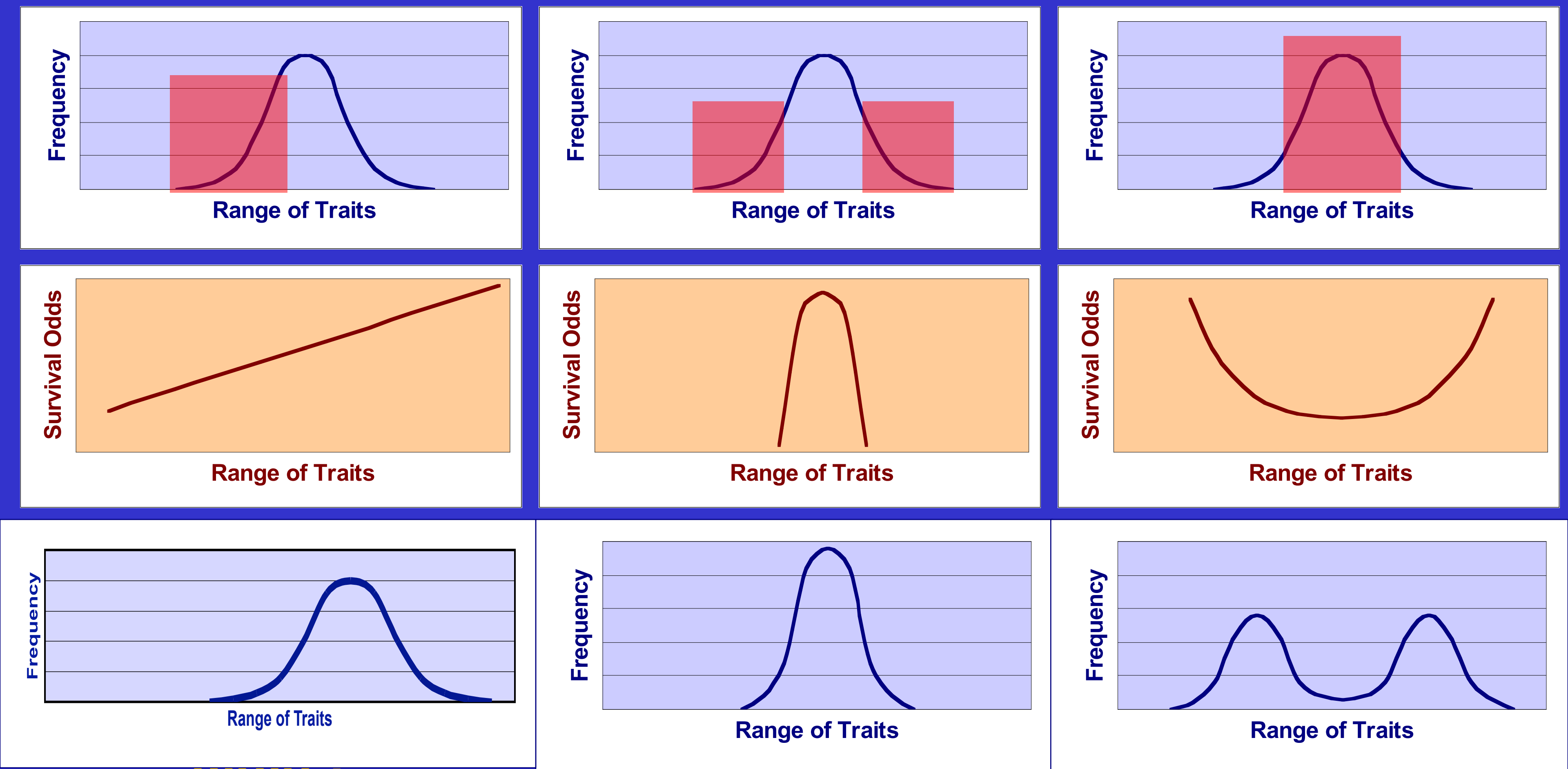
******Bottom Line: Over the long haul of time, a series of small Microevolutionary changes can add up to great Macroevolutionary revolutions******

# *Three Patterns of Natural Selection*

## Directional
One extreme favored, the other extreme weeded out

## Stabilizing
Both extremes weeded out

## Disruptive
Both extremes favored



# *Microevolutionary Consequences…*

- **<u>Directional Selection</u>**: traits gradually evolve in one particular "direction" …thicker, darker, longer, etc.

  (ex) flying fish wings, giraffe necks, & pelican bills

- **<u>Disruptive Selection</u>**: leads to a "divergence" of traits, eventually yielding *two different body forms* (or "morphs") within the species

  (ex) <u>Dimorphism</u> in peppered moths (light vs. dark)

  (ex) many plants & animals exhibit <u>Sexual Dimorphism</u>: males & females bearing different body forms

- **<u>Stabilizing Selection</u>**: occurs when a trait is already "optimal" …so in effect, even though natural selection IS occurring, evolution itself does NOT!

  (ex) hummingbird bills …not too short, not too long

# *Evidence for Macroevolution*

Roughly speaking, Macroevolution is what Darwin called "Descent with Modification": descendants from a common ancestor gradually change and branch off into new groups. Darwin himself recognized this process in the following:

1) **Fossil Record** – extinctions, with a sequential succession of forms, including transitional forms

2) **Biogeography** – geographical distributions that correspond to kinship among taxa

3) **Homology** – anatomical, developmental, and molecular similarities between organisms that trace back to a common ancestor

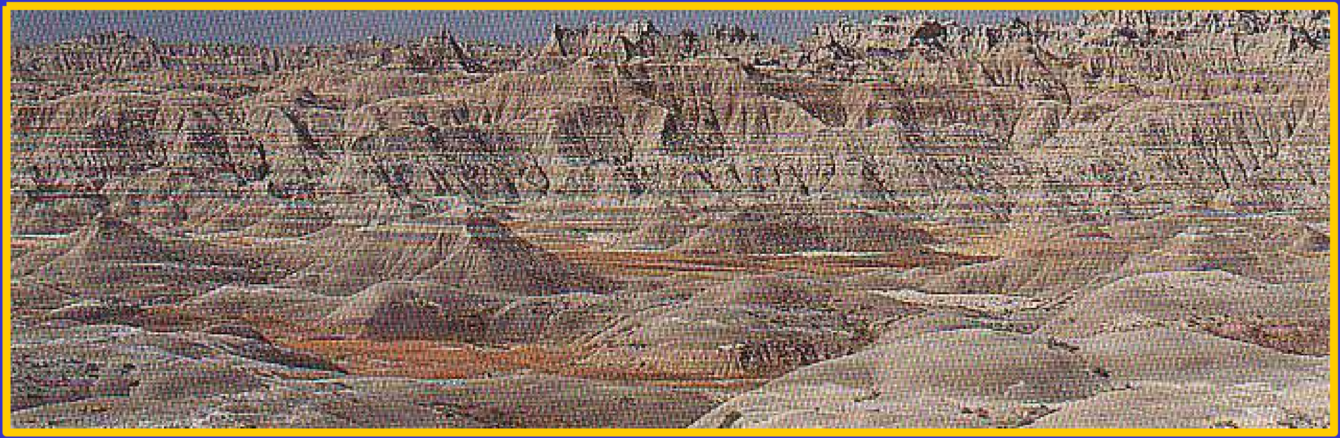
"Homologous" refers to body structures in different species that have *different forms & functions*, yet share a *common ancestry*

("Analogous" refers to structures that bear a similar form & function, but have entirely different evolutionary histories, such as snail shells & turtle shells or bee stingers & stingray stingers)

# *Fossil Record: Extinction & Succession of Forms*

Older (deeper) rocks contain simpler forms of life than younger rocks. That is, they show a sequence or "Succession" of <u>increasing complexity</u>. Moreover, *living* organisms in a geographic area resemble *extinct* fossilized forms from that same area.

*The Badlands of South Dakota, with strata (layers) of different ages exposed by the Missouri River.*

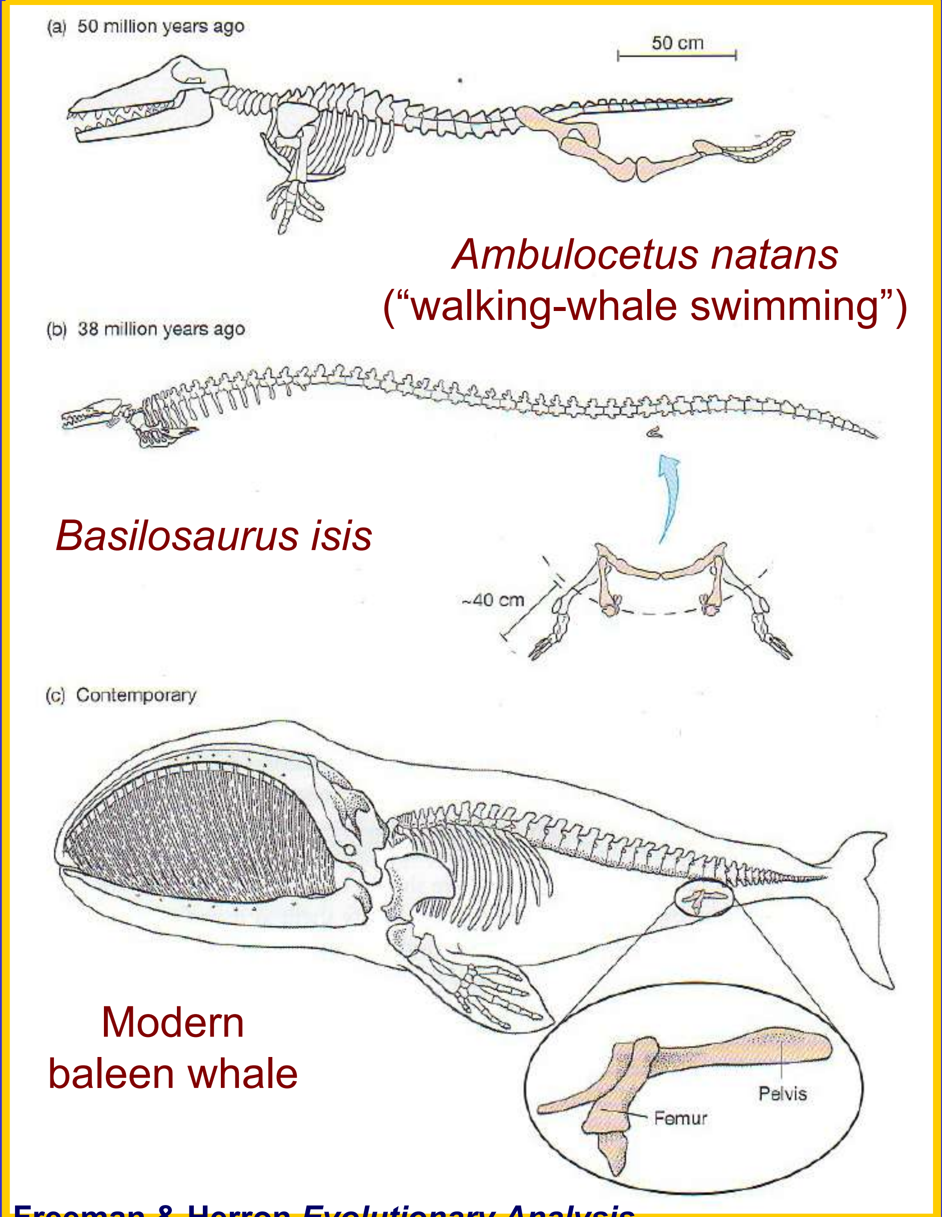


# *Transitional Forms*

represent "stages in between" major taxa. They exhibit characteristics both of ancient ancestral species and more recent descendants.


U Cal Berkeley Museum of Paleontology

*Archaeopteryx, an early species of bird with wings & feathers, yet with reptilian traits such as teeth, long tail, and claws on the wings*

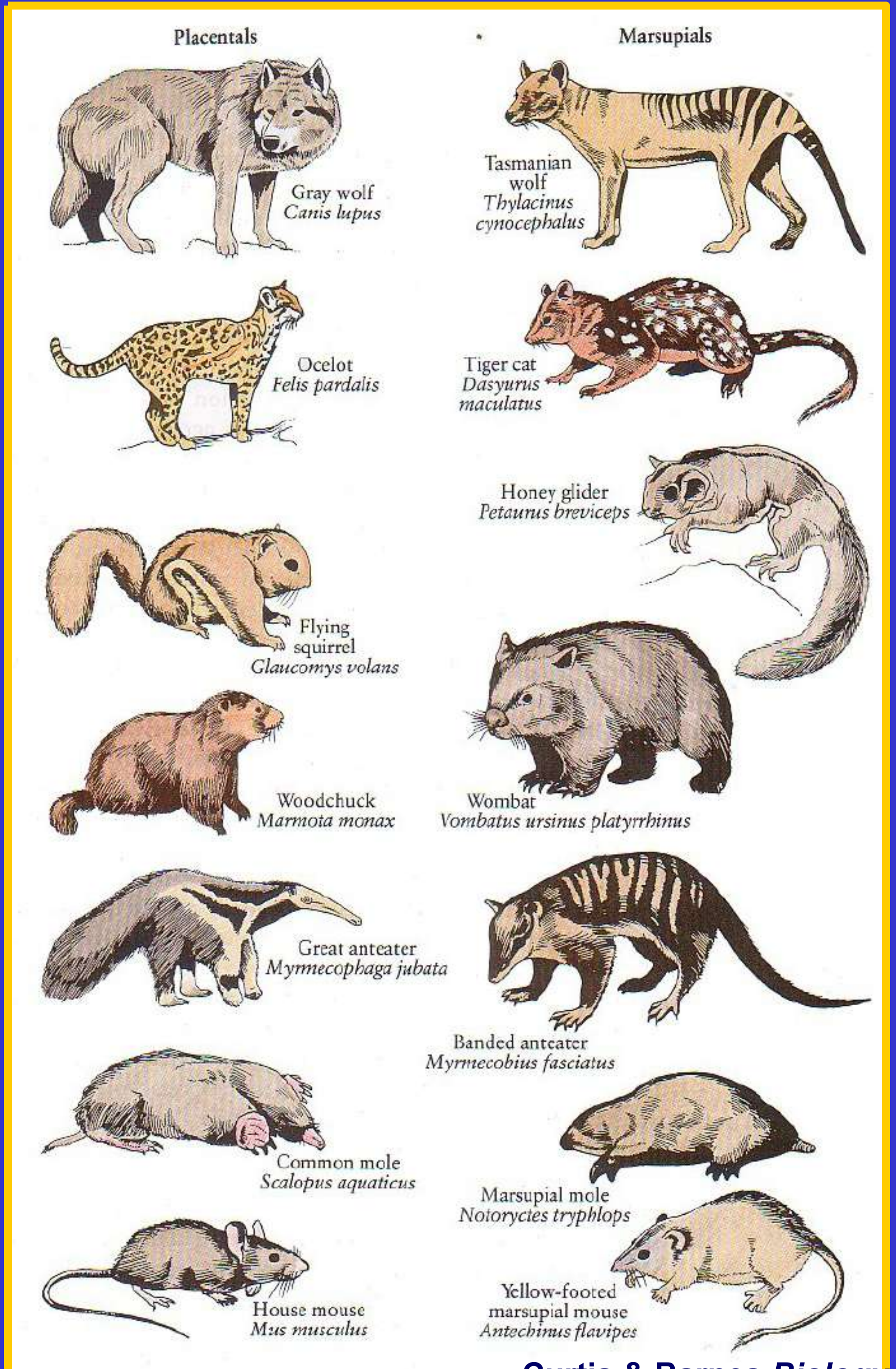



Freeman & Herron *Evolutionary Analysis*

*Whale ancestry, with vestigial pelvis & legs*

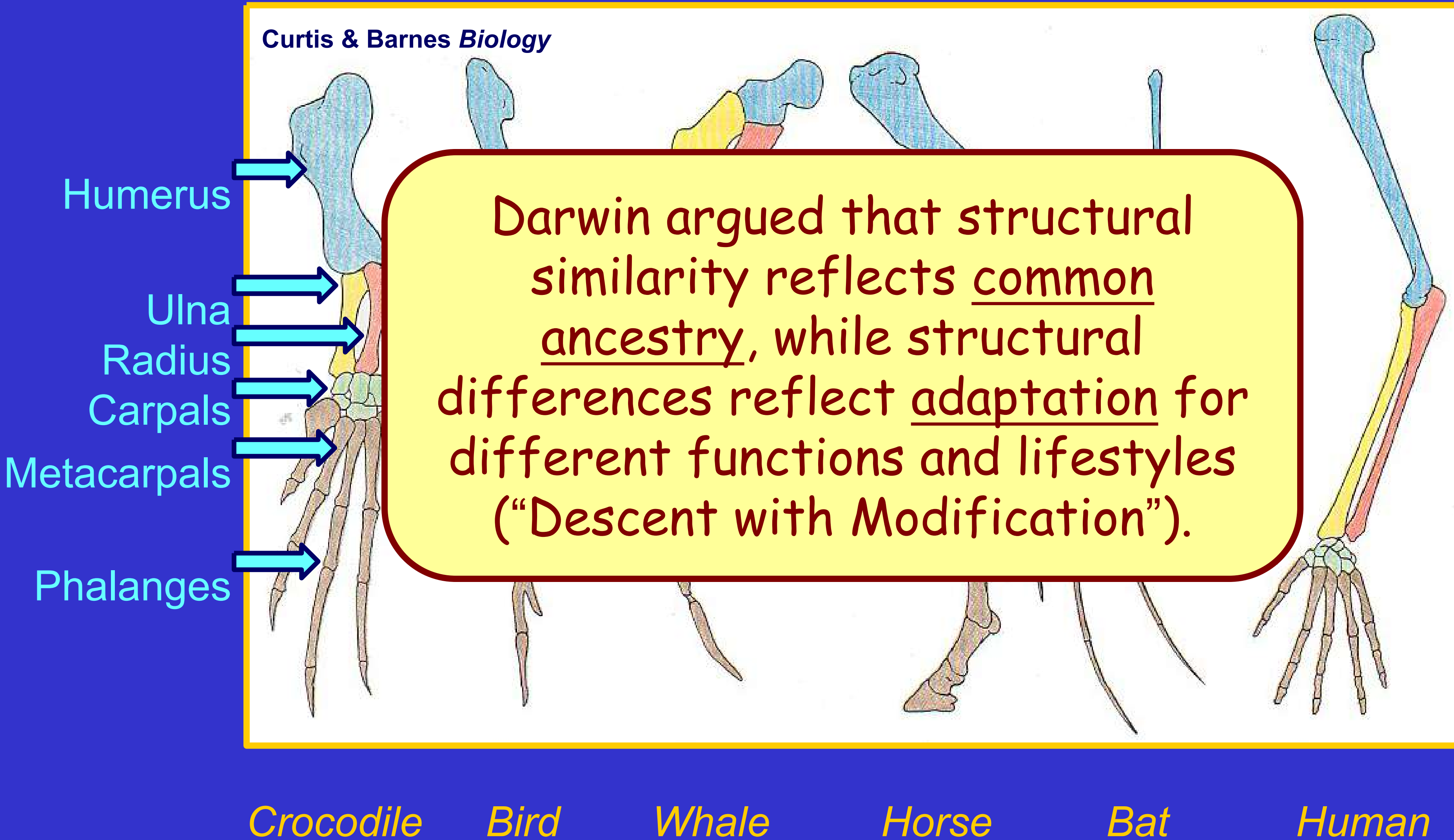
# *Biogeography*

Geographic regions with similar habitat, climate, and topography are often NOT inhabited by the same species, nor even by close relatives. Taxa show distinct geographic distributions, and this often corresponds to the kinship among them. A striking example are the parallels between the marsupials of Australia and placental mammals from other continents …similar adaptations for similar habitats & lifestyles, yet the marsupials are more closely related *to each other* than they are to their placental look-alikes!!!




Curtis & Barnes *Biology*

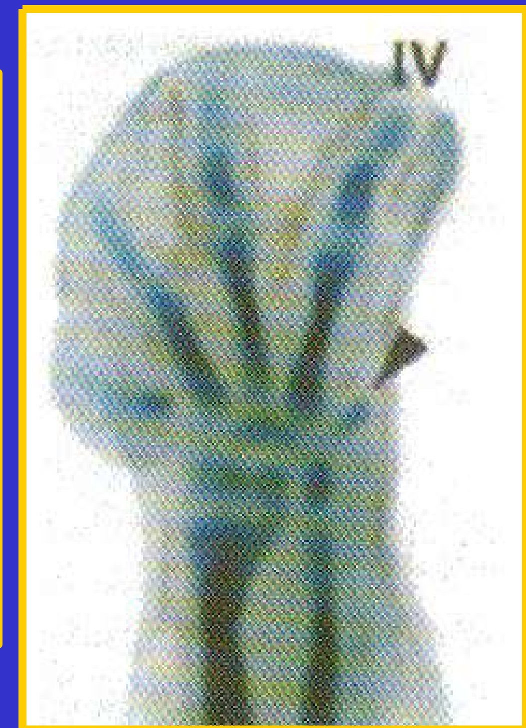
# *Anatomical Homologies*




Darwin argued that structural similarity reflects common ancestry, while structural differences reflect adaptation for different functions and lifestyles (“Descent with Modification”).

## *Interpretation???*

All Figures from Freeman & Herron *Evolutionary Analysis*

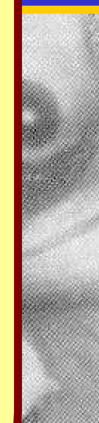



Vestigial Structures (now functionless): Human tailbone (coccyx), cave salamander with tissue bulbs in place of eyes, extra digit in wings and feet of chick embryos (absent in adults). Also, pelvic bones in whales.

# *Embryological Homologies (incl. vestiges)*

Again, Darwin argued that common ancestry was the most reasonable explanation for developmental similarity. Only later in development do the structures "diverge" into their various adult forms & functions, just as traits diverged during the course of evolution.

An old maxim of biology is "Ontogeny Recapitulates Phylogeny," which means that developmental sequences retrace evolutionary history. Although not strictly valid, there is some truth in this: we can often see in embryos and larvae certain traces of their ancient ancestry *…tails & gill slits in us humans, for example!*



***Interpretation???***

Photos from Curtis & Barnes *Biology*

# ***Molecular (Genetic) Homologies***

Just as anatomical similarities stem from shared developmental sequences, developmental sequences in turn stem from a shared genetic program.

Recall that our genetic code is rooted in molecules of DNA. DNA is itself a long chain of component molecules called nucleotides, whose initials are A, T, G, & C.  As with Morse code and the alphabet, the secret to the genetic code lies in the SEQUENCE of its components  …the sequential order of those A's, T's, G's, & C's.

The sequence of nucleotides in DNA "spells out" the directions for assembling *Proteins* in the cell.  And each protein itself comprises a sequence of *amino acids*.  So the sequence of nucleotides "translates" into a sequence of amino acids.  Dig?!

*Modern Biotechnology enables us to "read" the sequence of both DNA & Proteins …shedding much light on Macroevolution.*

*Cytochrome-c is a protein found in the mitochondria of cells. It aids in the process of Cellular Respiration, helping to harness energy from food molecules. All plants and animals have cytochrome-c, but there ... cids. Th ... n cyt ... ??*

Once again, it's "Descent with Modification." The more distantly related the organism, the more differences in their molecular makeup. And since the amino acid sequence is a direct reflection of the DNA sequence, these differences really represent genetic mutations. In short, the longer it's been since the common ancestor, the more changes that have occurred in the genetic code.

| | |
|---|---|
| Rattlesnake | **12** |
| Rhesus monkey | **1** |

*This principle can be used to piece together evolutionary histories where the fossil record and comparative anatomy/embryology fail. For example, where do Whales fit in among the Mammals???*

*Since all mammals produce milk, and milk is rich in various proteins, this might be a good place to look. The table below actually gives the DNA sequence for a section of the gene for beta-casein, a protein in the milk of dairy cows and other mammals.*

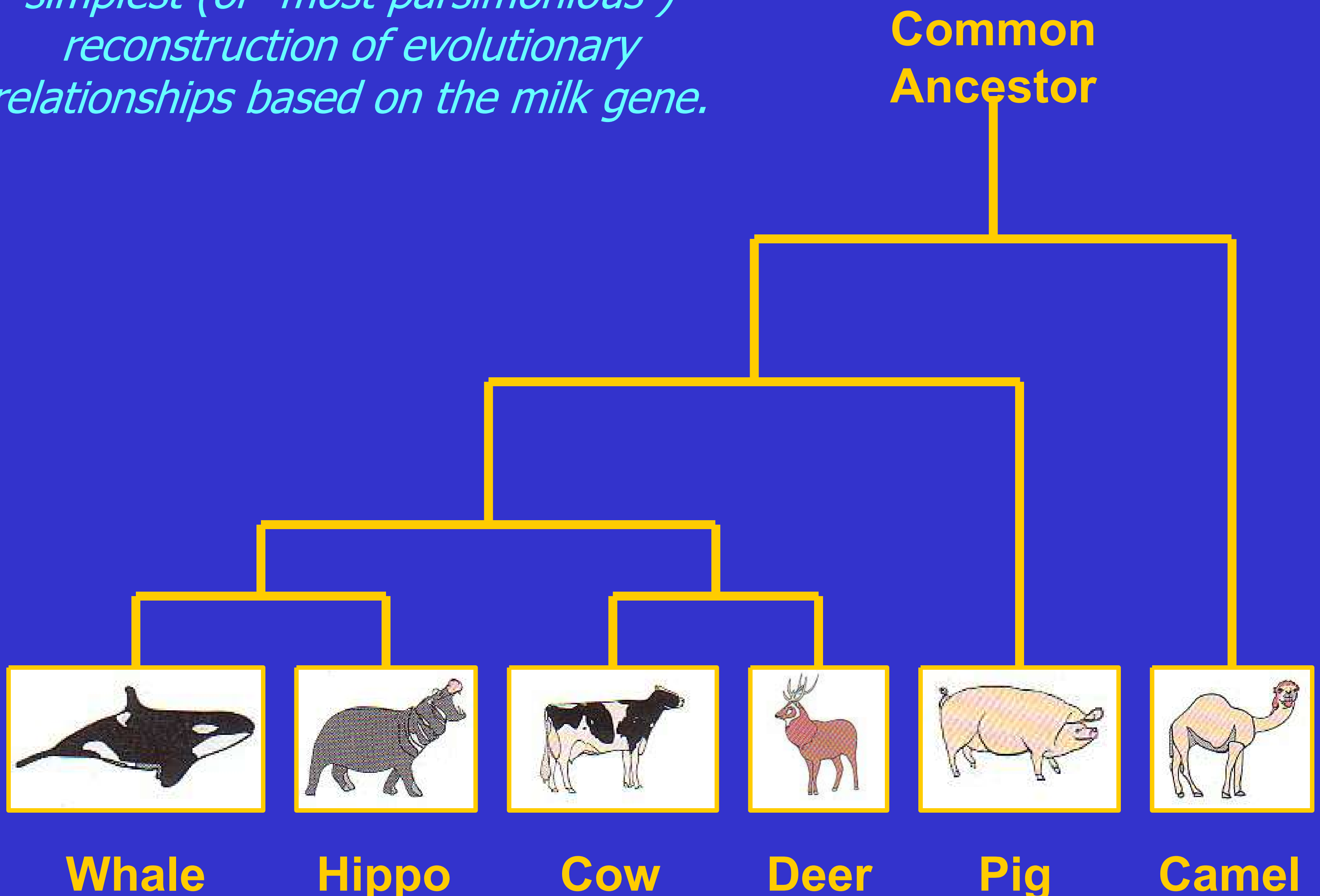
| | |
|---|---|
| Whale | AGT CCC CAA AGC TAA GGA GAC TAT CCT TCC TAA GCA TAA AGA AAT GCG CTT CCC TAA ATC |
| Cow | AGT CCC CAA AGT GAA GGA GAC TAT GGT TCC TAA GCA CAA GGA AAT GCC CTT CCC TAA ATA |
| Deer | AGT CTC CGA AGT GAA GGA GAC TAT GGT TCC TAA GCA CGA AGA AAT GCC CTT CCC TAA ATA |
| Pig | AGA TTC CAA AGC TAA GGA GAC CAT TGT TCC CAA GCG TAA AGG AAT GCC CTT CCC TAA ATC |
| Camel | TGT CCC CAA AAC TAA GGA GAC CAT CAT TCC TAA GCG CAA AGA AAT GCC CTT GCT TCA GTC |
| Hippo | AGT CCC CAA AGC AAA GGA GAC TAT CCT TCC TAA GCA TAA AGA AAT GCC CTT CTC TAA ATC |

**Data from Freeman & Herron *Evolutionary Analysis***

| # of Nucleotide Differences on Beta-casein Gene | | | | | | |
|---|---|---|---|---|---|---|
| | Whale | Hippo | Cow | Deer | Pig | Camel |
| Whale | --- | | | | | |
| Hippo | **3** | --- | | | | |
| Cow | **8** | **8** | --- | | | |
| Deer | **11** | **10** | **4** | --- | | |
| Pig | **10** | **11** | **11** | **13** | --- | |
| Camel | **10** | **11** | **14** | **15** | **13** | --- |

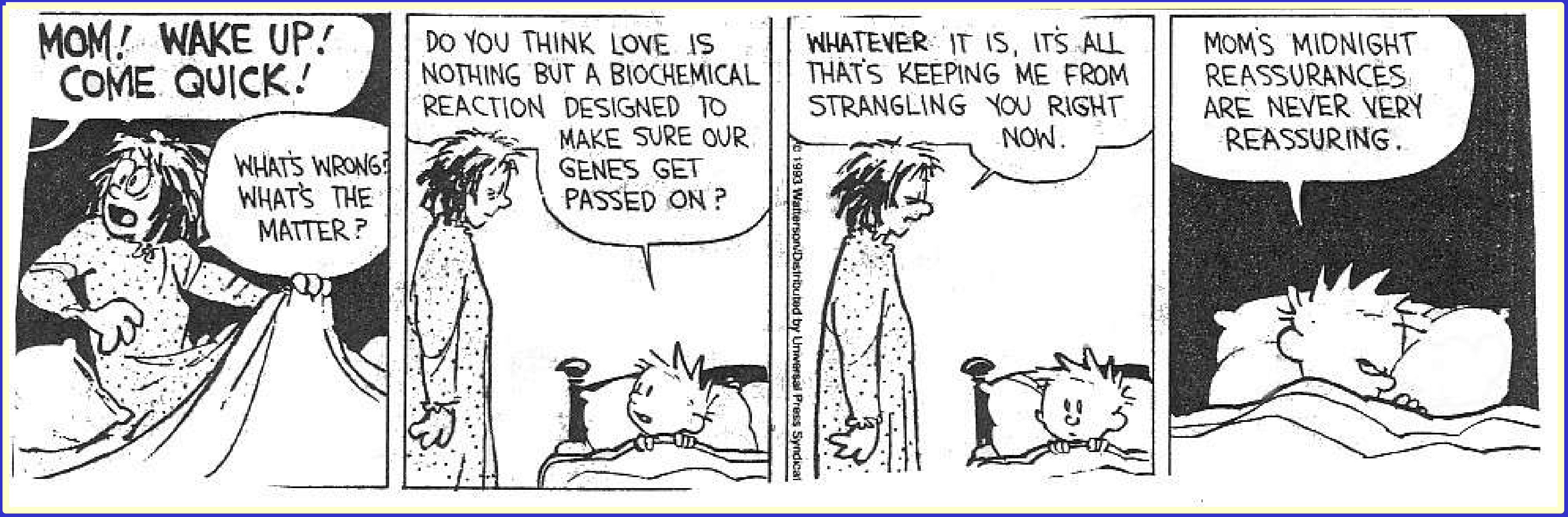
*The data indicates that Whales are most closely related to Hippos! It also suggests a close kinship between Cows and Deer. Camels and pigs are more distant cousins.*

*This Phylogenetic Tree shows the simplest (or "most parsimonious") reconstruction of evolutionary relationships based on the milk gene.*



- The theory of evolution is a genetic theory.
- Evolution is the changing over time of the frequency of genes within a wild population.
- For Natural Selection to occur, there must exist a variety of traits among members of that population.
- And within any population, as we shall see, the potential for such Genetic Variation is vast…

# The Genetic Basis for Evolution: Genetic Variation



# Evolution & Genetic Variation

A population cannot evolve unless there is genetic variation among the members of that population.  (A population of genetic clones, for example, would not be able to evolve …at least until some mutations had occurred.)

For Natural Selection to occur, there must be a variety of traits for “nature” to “select” from.

***How does Genetic Variety arise within a population???***

As it turns out, there are a handful of basic genetic mechanisms that generate an endless variety of traits among the members of a population…

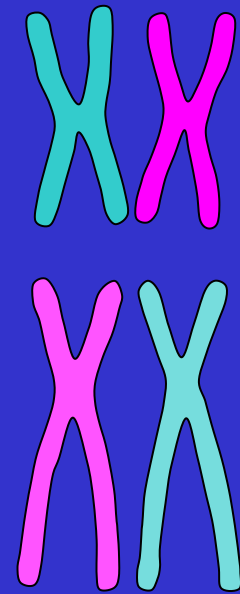
# Five Sources of Genetic Variety

## 1) Independent Assortment of chromosomes during meiosis:

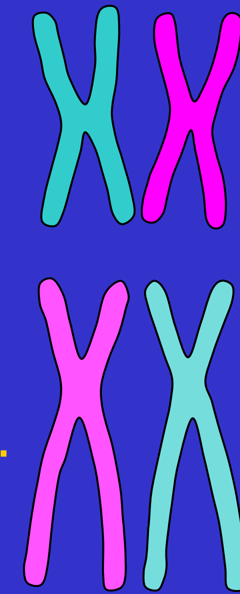
- Through meiosis, each sperm or egg receives only half (23) the original number of chromosomes (46), one from each homologous pair. During metaphase I, homologous chromosomes pair up along the equatorial plane, one on the left and one on the right. However, it's random as to which one lines up on the left and which one lines up on the right. The left/right arrangement of one pair of homologues has nothing to do with the left/right arrangement of the next pair. In short, homologous pairs "assort" themselves "independently" of one another. Therefore when the pairs later separate, it is completely random as to which 23 chromosomes each sperm (or egg) receives. Thus it is very unlikely for any two sperm or any two eggs to receive the same 23 chromosomes.

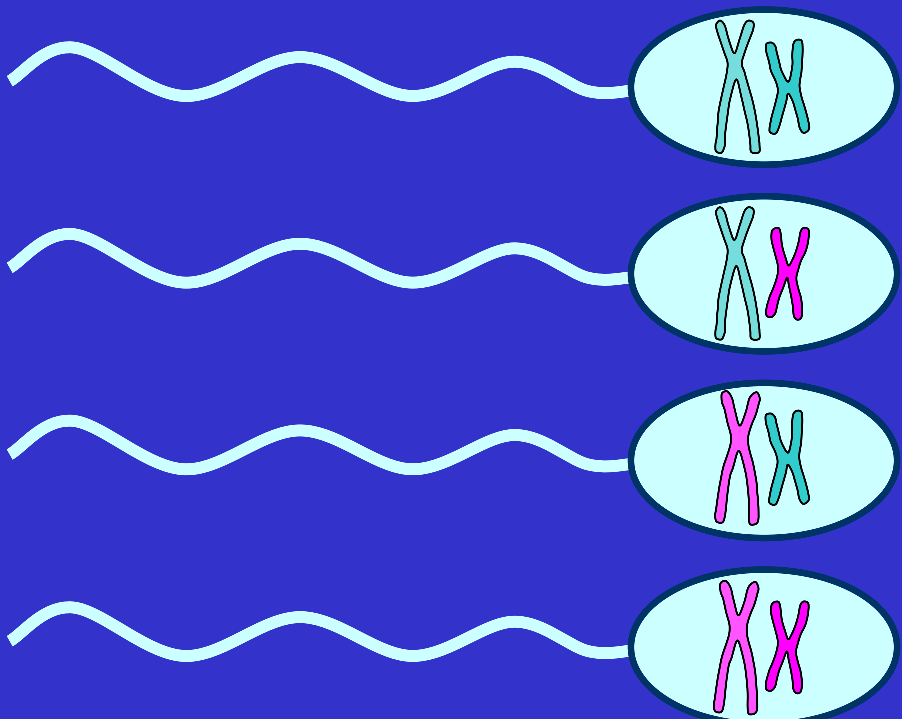
During Metaphase I, if the first two homologues pair up like this…

…then the second two homologues may pair up like this…



…OR like this…





With 2 pairs of chromosomes, then, each sperm (or egg) can get $2^2$ (= 4) possible combinations of chromosomes.

With 23 pairs of chromosomes, there are $2^{23}$ possible combinations.

That's 8,400,000 possible different sperm per human male!!!

## 2) Sexual Reproduction (= two parents):

| Father | | Mother | | |
|---|---|---|---|---|
| **8,400,000** possible sperm | × | **8,400,000** possible eggs | = | **70,000,000,000,000** possible zygotes |

*In short, a single married couple can, in theory, give birth to 70 trillion chromosomally different young'uns. That's a really HUGE number!!!*

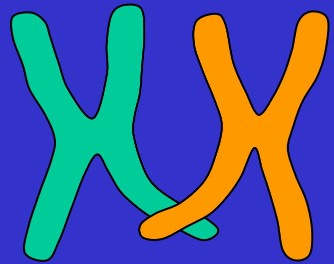
## 3) Random Mating within a population:

Since any male can breed with any female, the number of possible zygotes further depends on the size of the adult population. For example, take even a tiny population of, say, 100 CBGS students (50 male and 50 female), and suppose that every student's future spouse will be another CGBS student. That's $50^2$ or 2500 possible marriages, each of which can produce 70 trillion different offspring, which multiplies out to 175,000,000,000,000,000 possible CBGS babies.

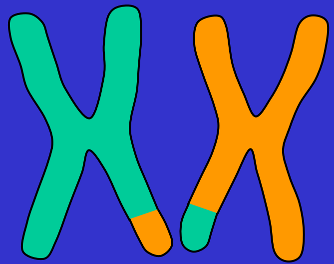
# 4) “Crossing Over” of chromosomes:

During meiosis, homologous chromosomes often exchange long sections of DNA with one another. In effect, they are trading genes, thereby creating new chromosomes!!!

Step 1 - Homologues paired up during metaphase I of meiosis.



Step 2 - Now “crossing over” and trading DNA from the cross-over point down…

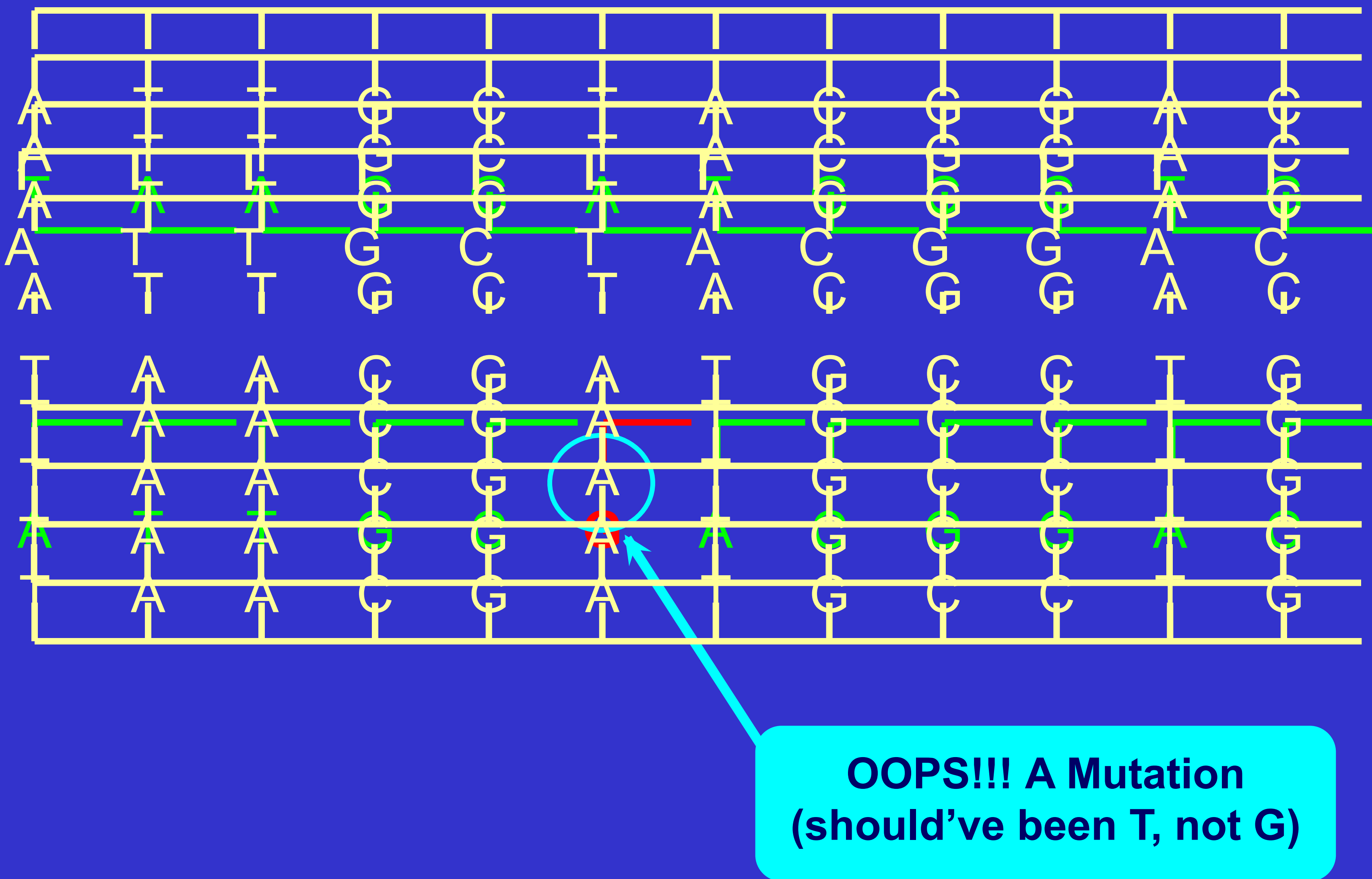


Step 3 - Chromosomes are different now! This process increases the number of possible sperm or eggs from 70 trillion to near infinite…

***Not just reshuffling chromosomes here, but shuffling individual genes!***

# 5) Mutations:

When replicating (copying itself), DNA sometimes makes a mistake …this alters the <u>gene</u> and so can generate a **new trait**!!!



# Types of Mutations

(Background Info: in cells, DNA is "read" or "translated" in groups of <u>three</u> nitrogen bases, called <u>codons</u>. Each codon in turn is the code for a single amino acid in the protein to be synthesized.)

<u>Original Sentence</u> (all three letter words, like codons):

**THE OLD DOG RAN AND THE FOX DID TOO**

<u>Substitution</u> (or "Point" mutation) – A single letter is miscopied:

**THE OLD <u>H</u>OG RAN AND THE FOX DID TOO**

## <u>Frameshift Mutations</u>

<u>Deletion</u> of a single letter (the "R" in "RAN"):

**THE OLD DOG <u>A</u>NA NDT HEF OXD IDT OO**

<u>Insertion</u> of an extra letter (copied "H" in "THE" twice):

**THE OLD DOG RAN AND TH<u>H</u> EFO XDI DTO O**

# Rates & Effects of Mutation

Mutations create new alleles of genes.  Many (probably most) of these new alleles do not have any noticeable effect on the organism's phenotype.  Of those that do cause a change in the organism's phenotype, most are likely to be harmful.  But occasionally a mutation might be beneficial or useful!

How often do mutations occur?  The mutation rate is low on a "per gene" basis.  But since there are so many genes (60,000 in humans), overall rates can be quite high.  Perhaps 10% of all gametes carry a phenotypically detectable mutation.  Most offspring probably carry at least one or two new alleles somewhere in their chromosomes.

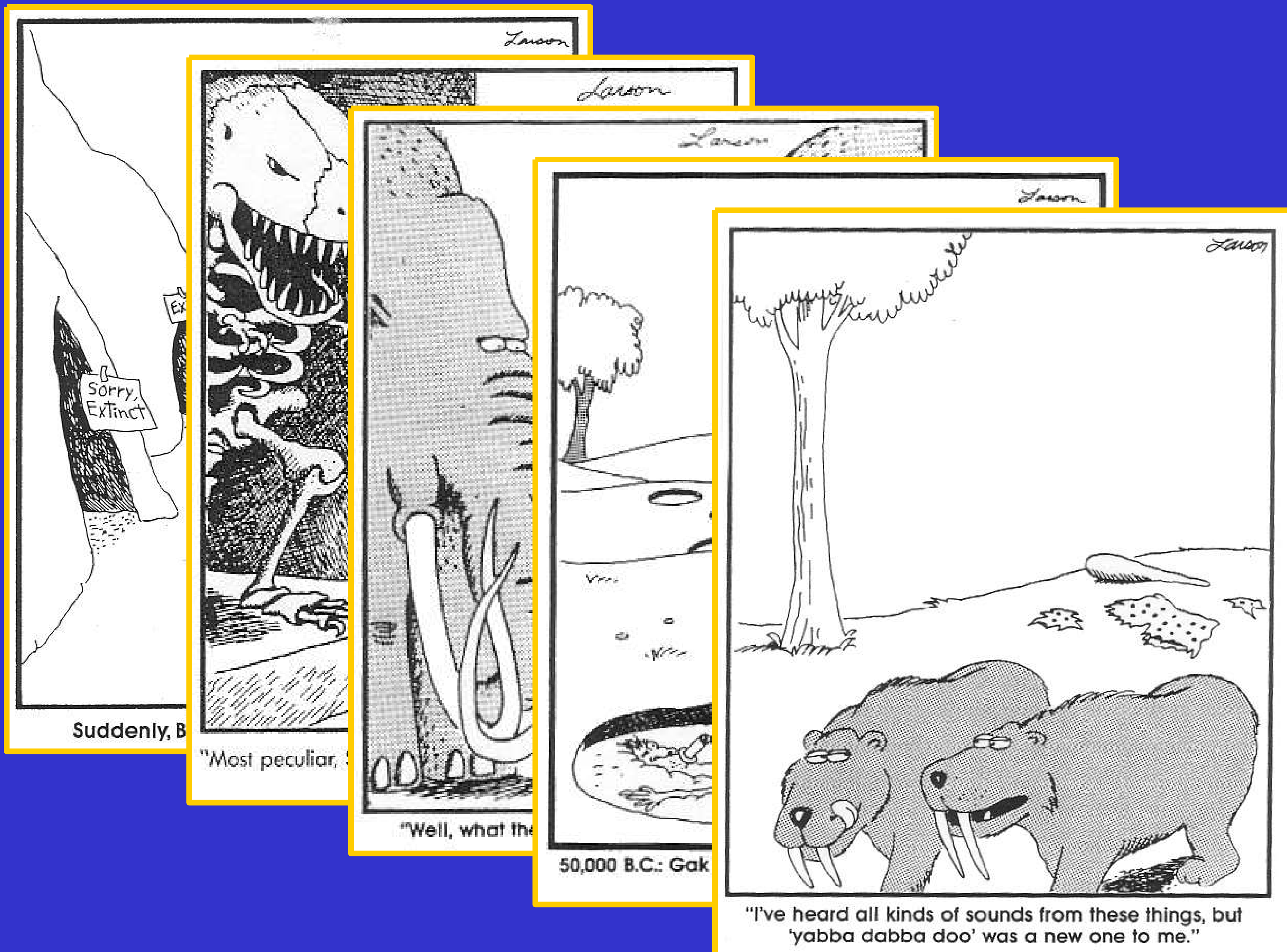
*Add that up across the total population, and across thousands of generations, and you can appreciate that the accumulation of mutations can lead to revolutionary changes!!!*

# Summary of Sources of Genetic Variation
## (deck of cards analogy)

1) Sexual Reproduction and Meiosis <u>reshuffle</u> already existing genes, alleles, and traits: a) independent assortment, b) crossing over, c) fertilization of eggs by sperm, and d) random mating. This is known as <u>genetic recombination</u>.

2) Mutations <u>deal in new</u> genes and alleles, and therefore entirely <u>new</u> traits.

***Meiosis and mutations provide the genetic variety necessary to drive the process of evolution. Genetic reshuffling (recombination) can fuel short-term "microevolution," but long-term "macroevolution" requires the accumulation of mutations in the gene pool.***


Sorry, Extinct
Suddenly, B
"Most peculiar,
"Well, what the
50,000 B.C.: Gak
"I've heard all kinds of sounds from these things, but 'yabba dabba doo' was a new one to me."