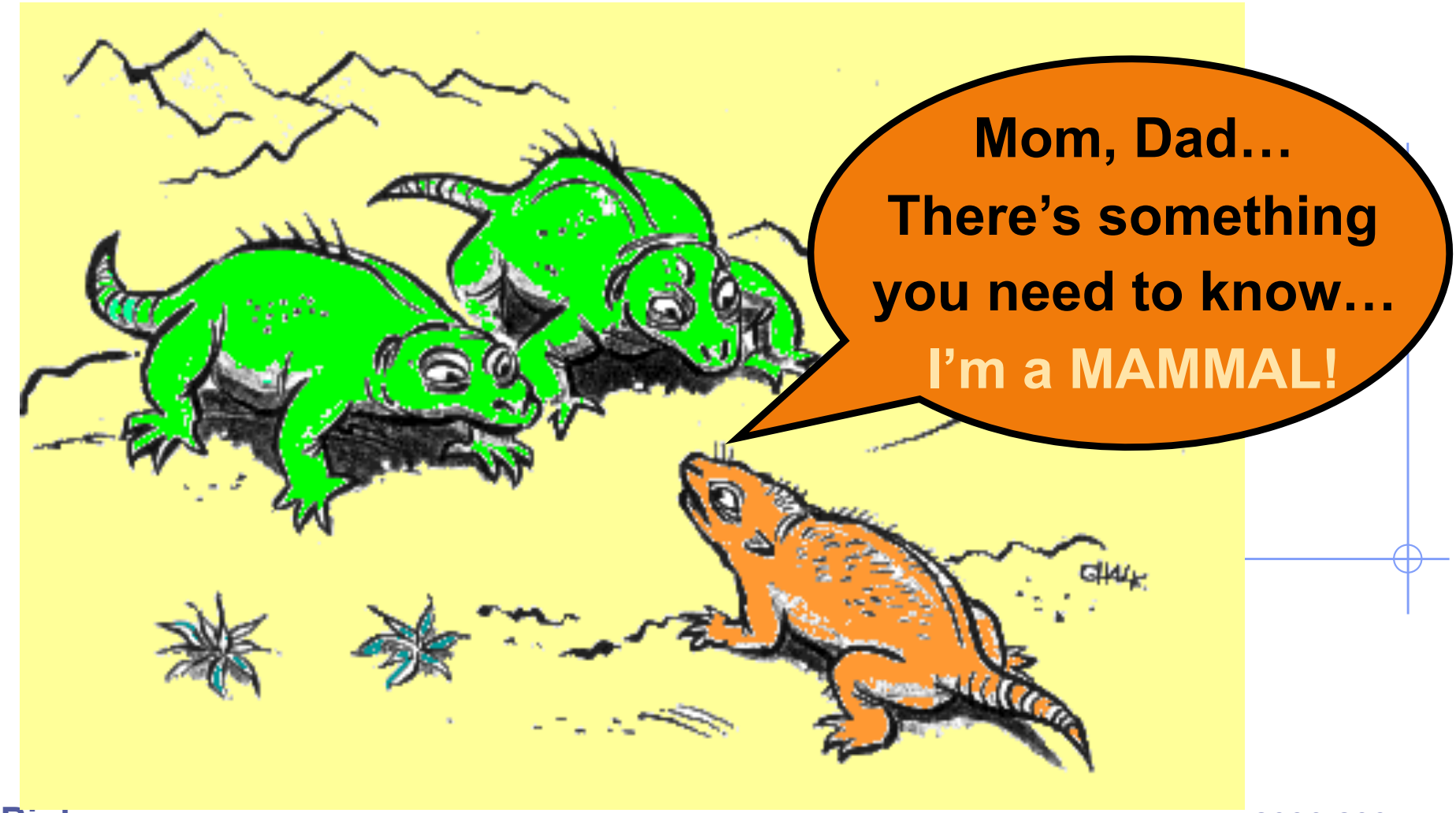
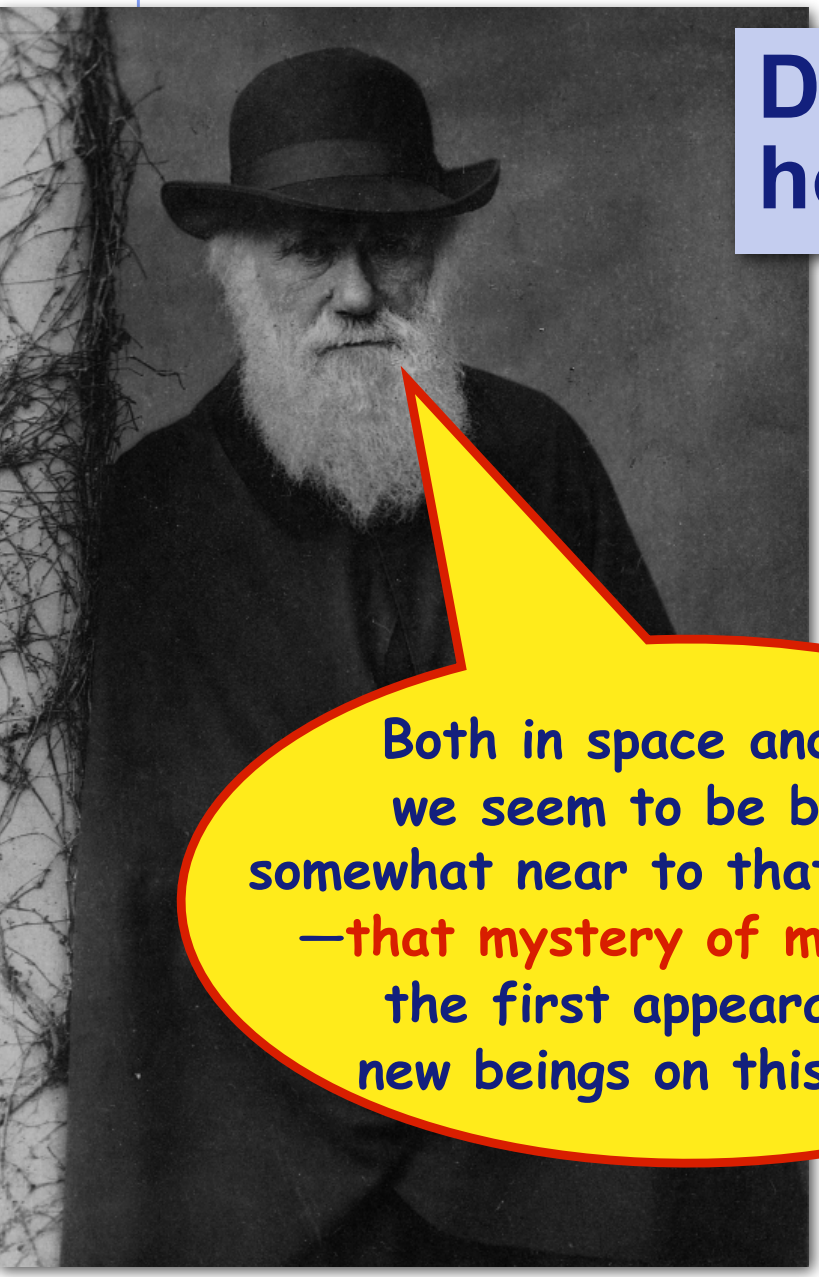
The Origin of Species

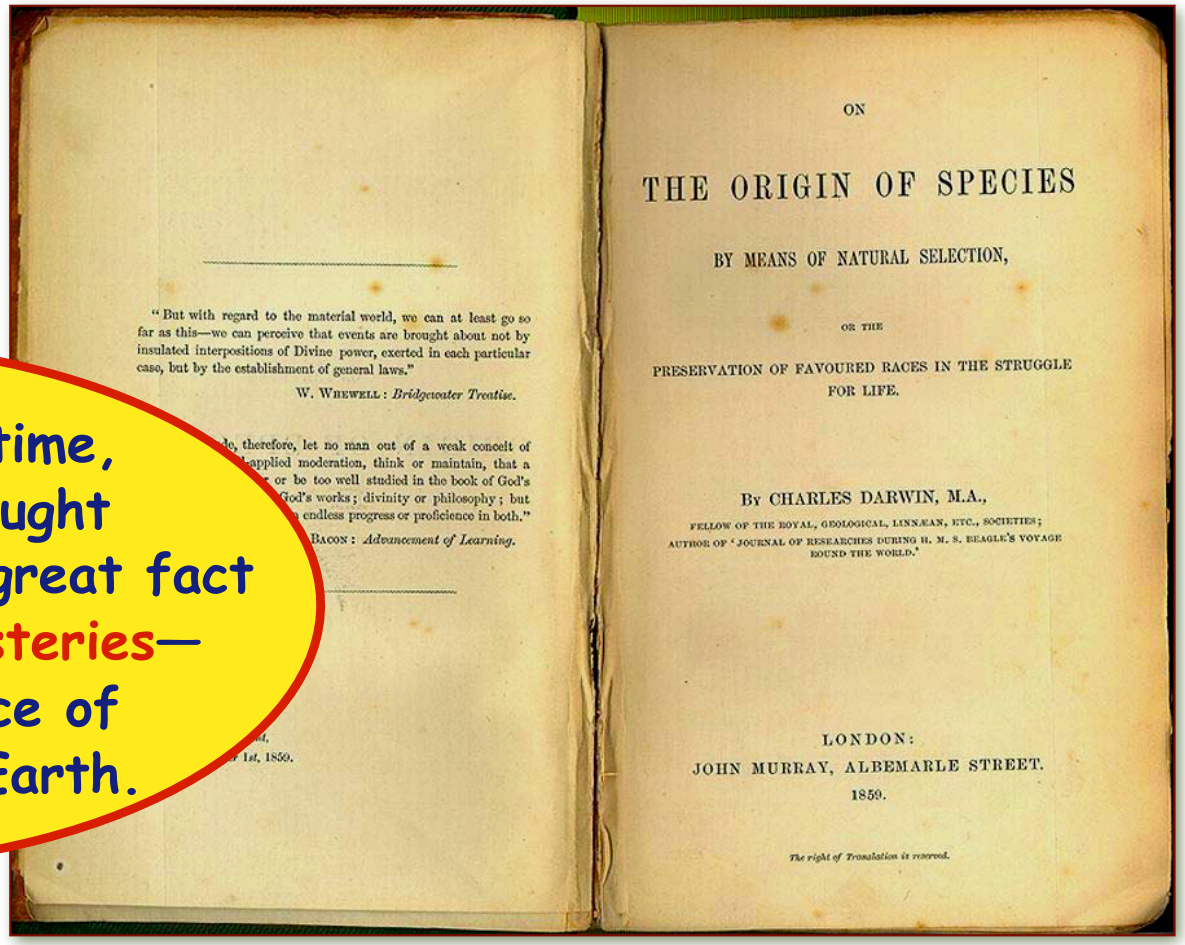


"That mystery of mysteries…"



Darwin never actually tackled how new species arose…

Both in space and time,
we seem to be brought
somewhat near to that great fact
—that mystery of mysteries—
the first appearance of
new beings on this Earth.



"But with regard to the material world, we can at least go so far as this—we can perceive that events are brought about not by insulated interpositions of Divine power, exerted in each particular case, but by the establishment of general laws."

W. Whewell: *Bridgewater Treatise.*

…do, therefore, let no man out of a weak conceit of sobriety, or…applied moderation, think or maintain, that a man can search too far or be too well studied in the book of God's word, or in the book of God's works; divinity or philosophy; but rather let men endeavour an endless progress or proficience in both."

Bacon: *Advancement of Learning.*

…1st, 1859.

ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

By CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES; AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

The right of Translation is reserved.

So…what is a species?

- "Species" = Latin for 'kind' 'appearance'

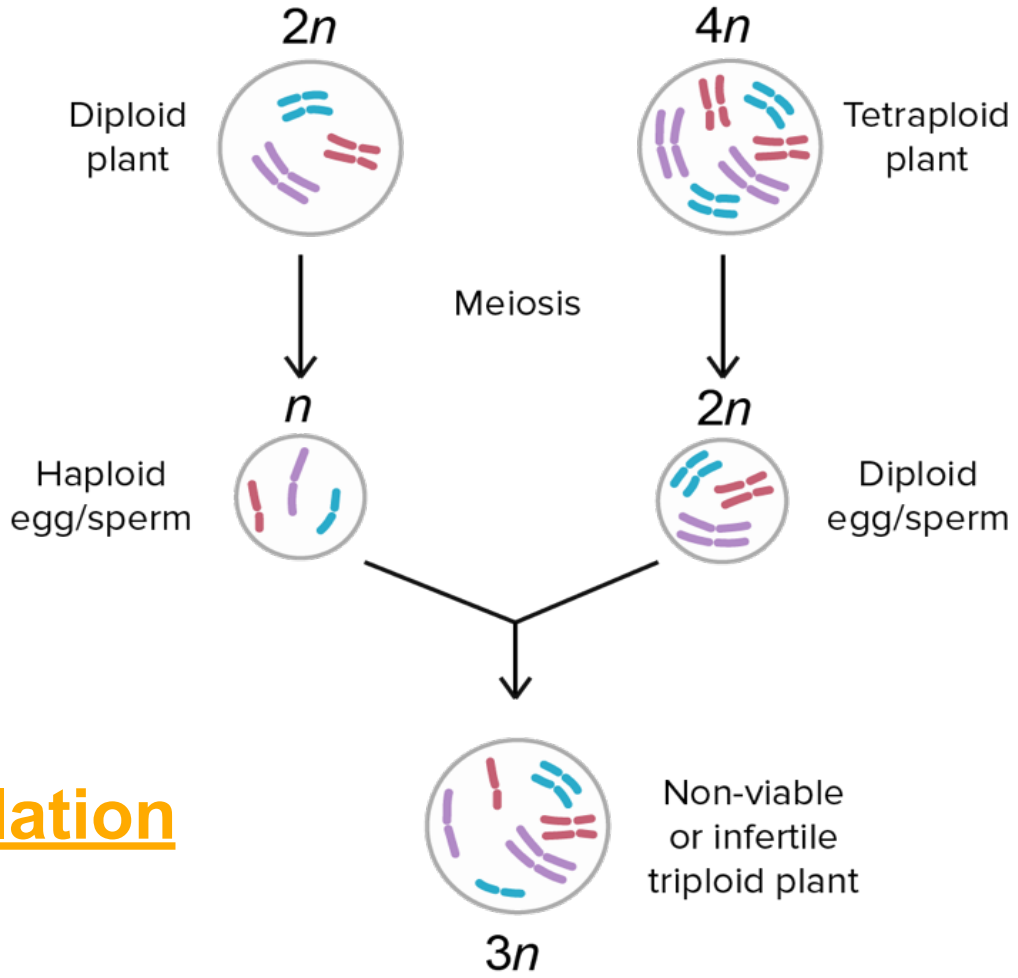
- **Biological species concept**
  - defined by Ernst Mayr
    - population whose members can interbreed & produce viable, fertile offspring
      - reproductively compatible

Distinct species:
songs & behaviors are different enough to prevent interbreeding

Humans are so diverse but considered one species, whereas these Meadowlarks look so similar but are considered different species.

Biological Species Concept

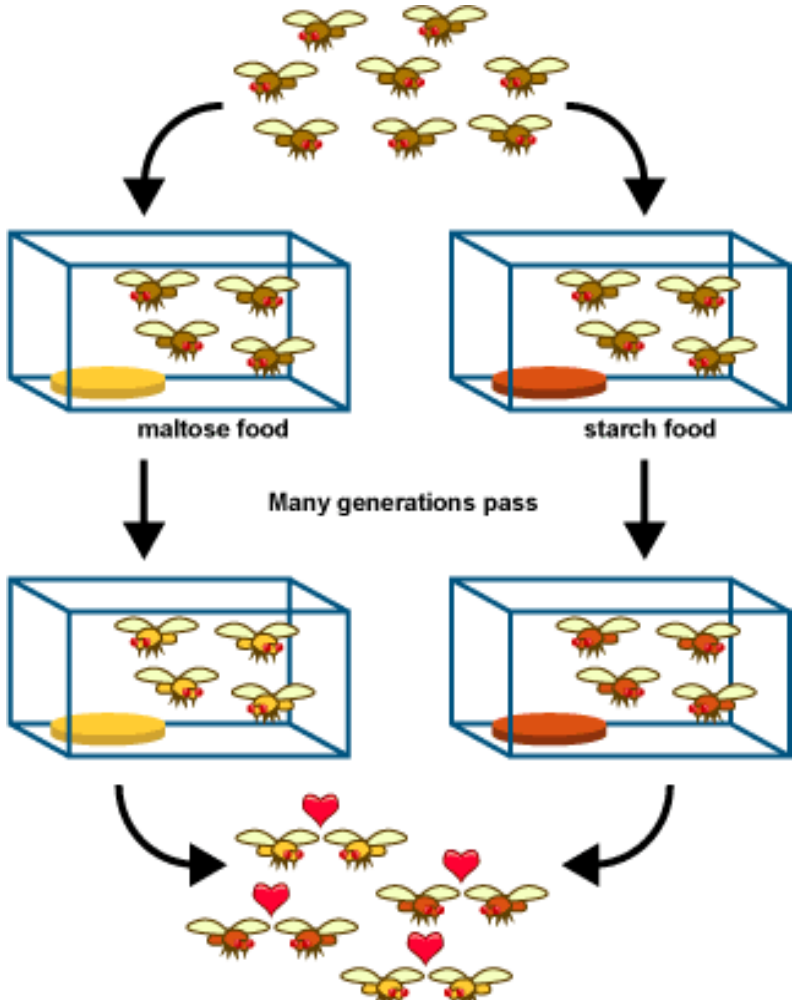
- If two organisms cannot make a fertile offspring, then the two organisms are considered part of two separate species according to the biological species concept



  - Reproductive isolation defines a species
    - There may be many reasons why two organisms cannot successfully mate.
    - *For Ex: When chromosomes duplicate tetrads cannot form for all chromosomes. The cell may not continue past metaphase checkpoint so no gametes get made.*

How and why do new species originate?

- **Members of a species resemble each other because their populations are connected by gene flow.**
  - Species are created by a series of evolutionary processes:
    - Speciation involves populations becoming reproductively isolated
      - Isolated populations evolve independently *because they experience an end to gene flow* (allowing gene pools to diverge)
    - Over many generations, the genetic differences that accumulate decrease the likelihood that members of the two groups will successfully mate and produce viable offspring.



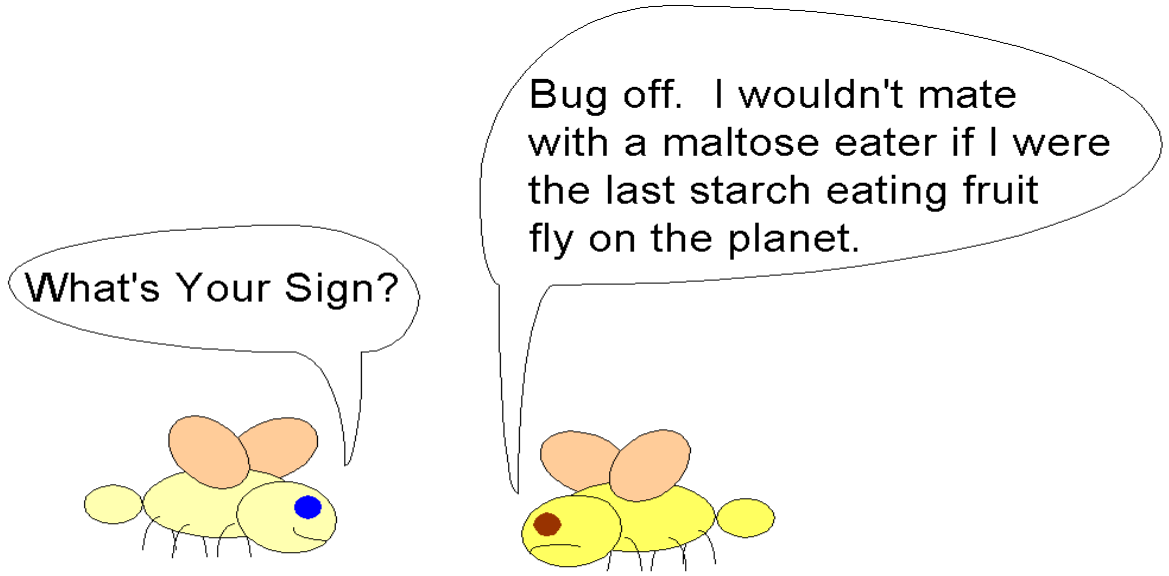
How and why do new species originate?

- When no genetic exchange occurs any longer between a population of a current species and its ancestral species, we say that **speciation** has occurred.
  - *Speciation is the process of forming a new species*

Various Types of Speciation models have been proposed:

1. Sympatric
2. Allopatric
3. Peripatric
4. Parapatric

and more....

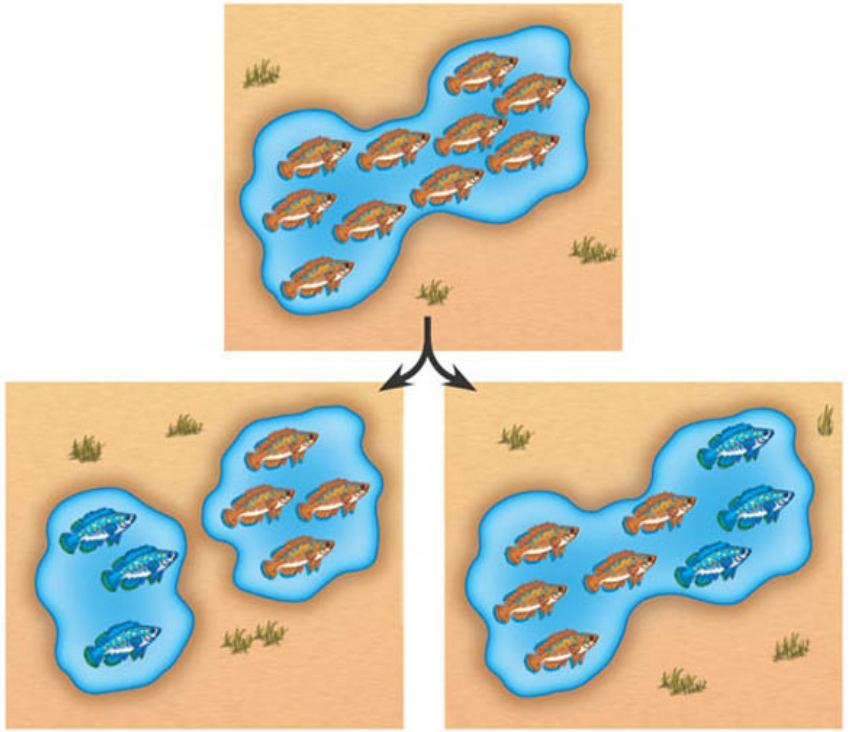


Speciation in the Lab

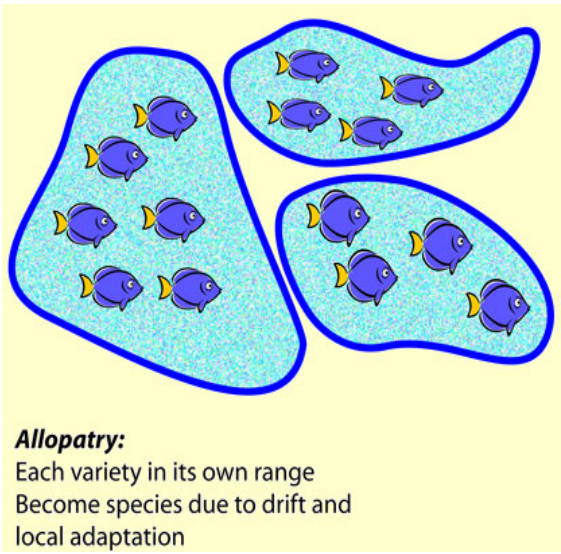
How and why do new species originate?

- **Two main types of speciation exist in which gene flow is interrupted:**

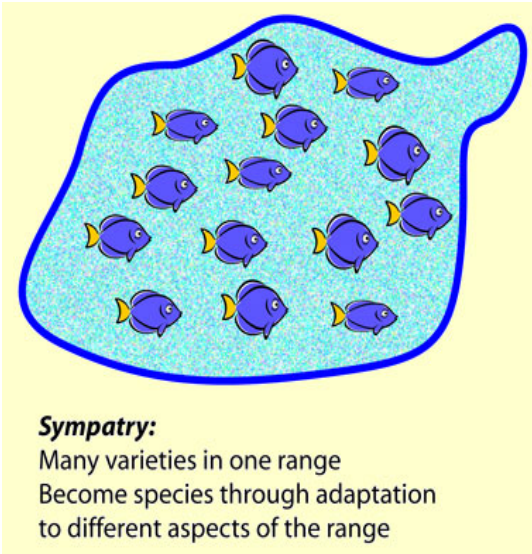
1. **Allopatric Speciation**
   - Greek "allos" for other, "patra" for homeland.
   - **Gene flow is interrupted when a population is divided into geographically isolated subpopulations**
2. **Sympatric Speciation**
   - Greek "syn" for together, "patra" for homeland.
   - **Gene flow is interrupted in populations that live in the same geographical area**
     - **Less common than allopatric speciation**
     - **Occurs from polyploidy, habitat differentiation, sexual selection**



(a) Allopatric speciation. (b) Sympatric speciation.



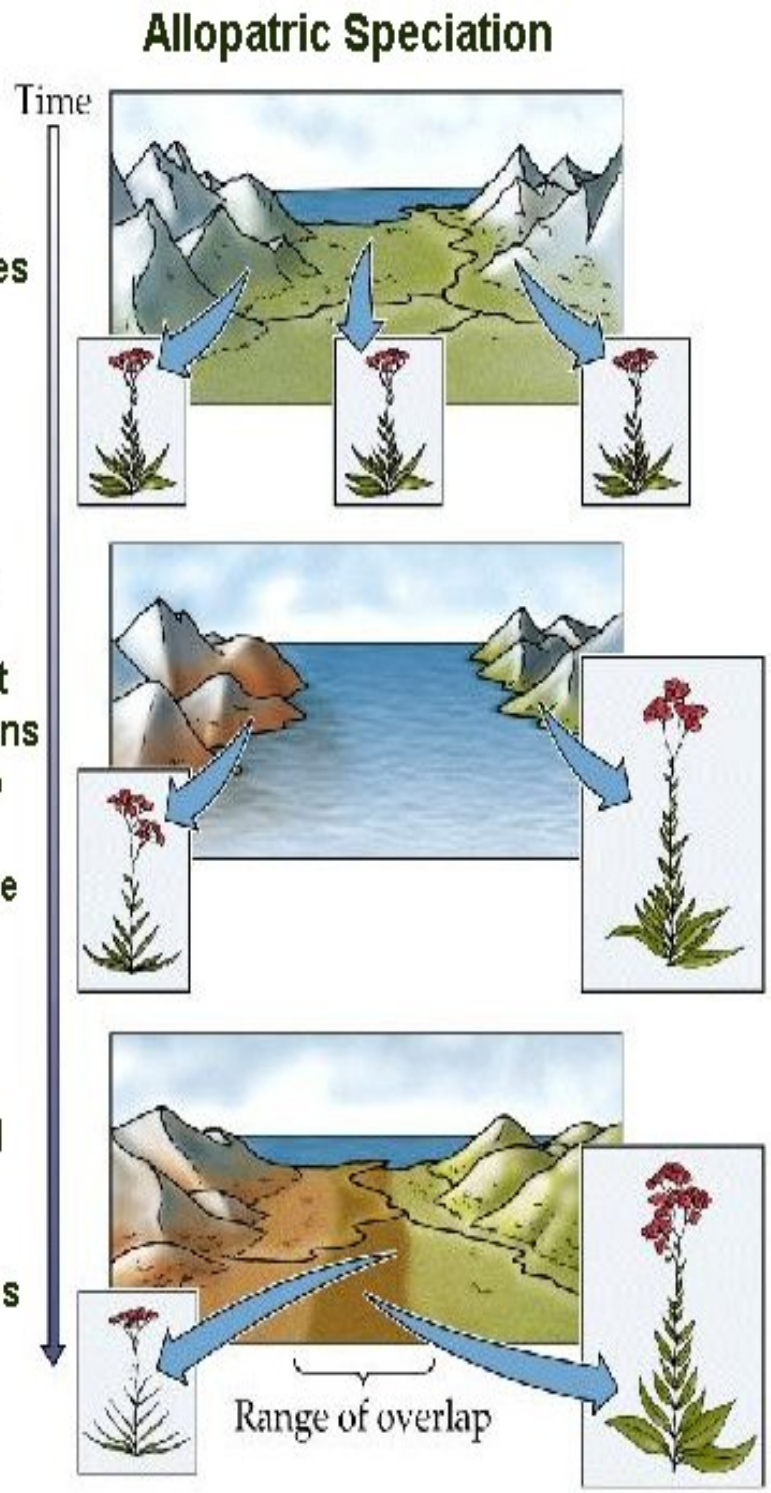
Allopatry:
Each variety in its own range
Become species due to drift and local adaptation



Sympatry:
Many varieties in one range
Become species through adaptation to different aspects of the range

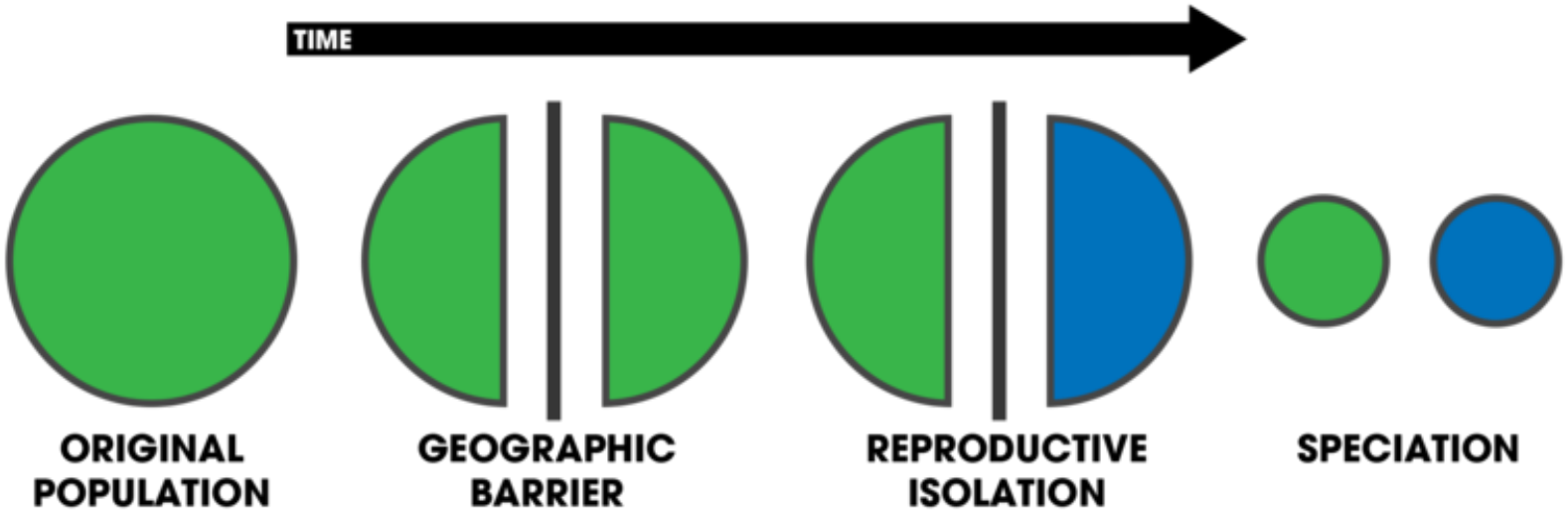
How and why do new species originate?

- Different types of speciation exist in which gene flow is interrupted:
  - ✓ **Allopatric Speciation**
    - Greek "allos" for other, "patra" for homeland.
    - Gene flow is interrupted when a population is divided into geographically isolated subpopulations
    - Ex: Geographic barriers can be barriers to gene flow and aid speciation along

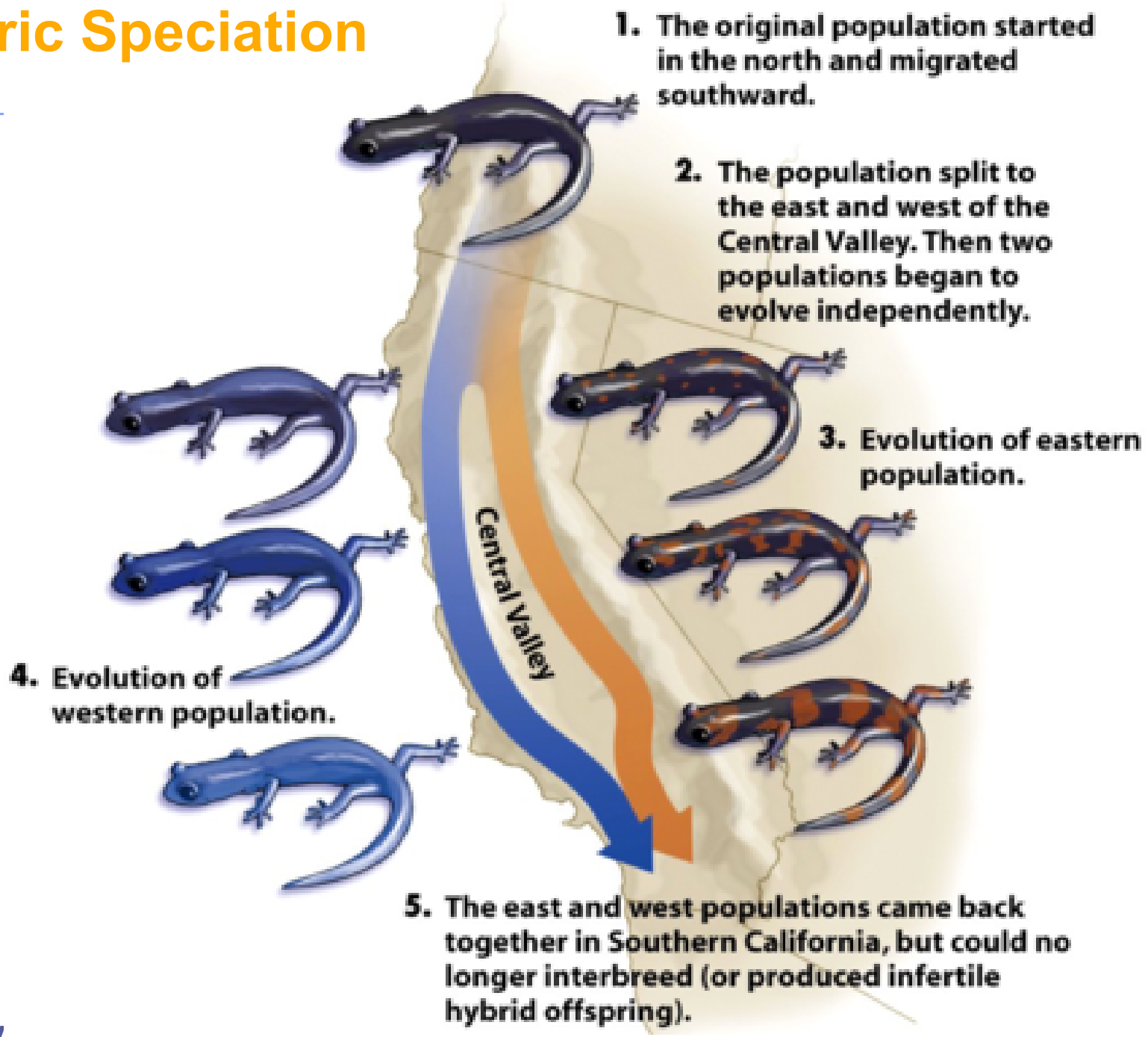


Allopatric Speciation

- Emergence of a new species when a population is geographically isolated from its ancestor due to changes in land topography due to earthquakes, desert formation, mountain formation, swamp formation, ice field formation
  - Allopatric speciation is the most common type of speciation.
  - Gene flow ceases between the two population and each population becomes genetically different over time.
    - After separation, small populations may contain different allele frequencies since they undergo founder effect
    - Genetic drift may occur differently in the two population - *allele frequencies may change differently in each population by chance over time*
    - Different environmental variables will influence what type of natural selection occurs between the two populations - each population experiences different selective pressures



Allopatric Speciation

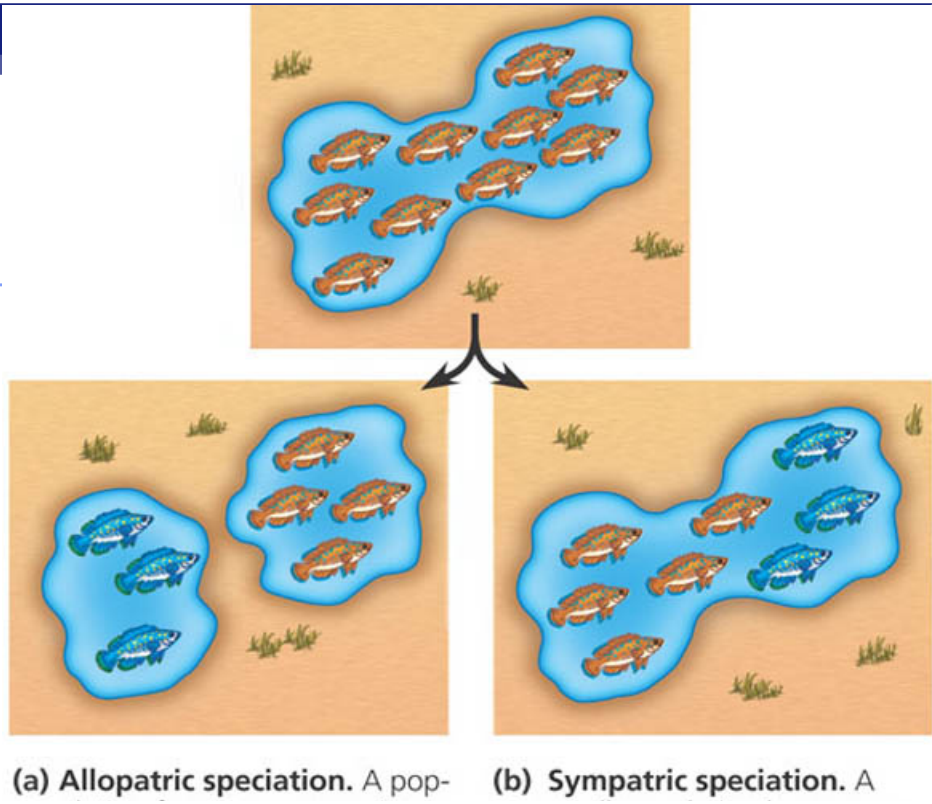


How and why do new species originate?

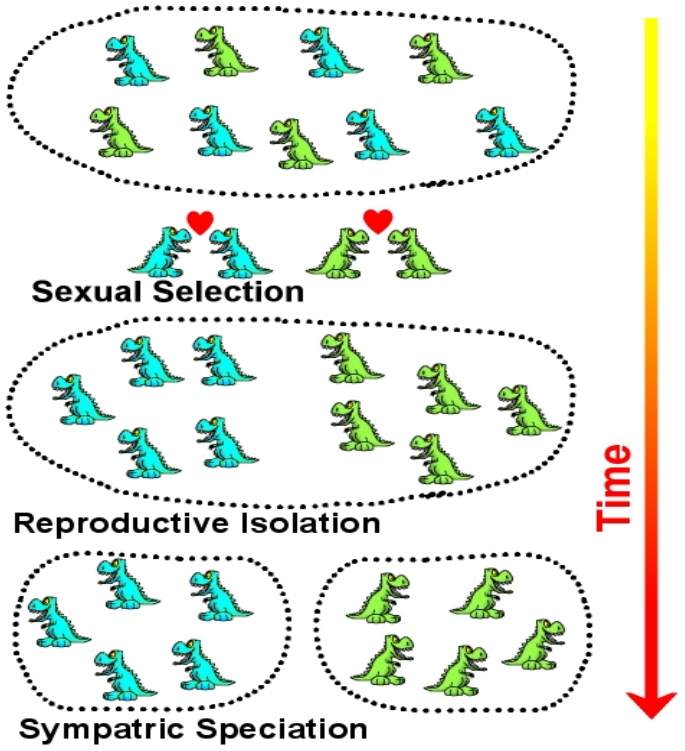
✓ Sympatric Speciation

- Greek "syn" for together, "patra" for homeland.

- **Gene flow is interrupted in populations that live in the same geographical area**
  - **Less common than allopatric speciation**
  - **Caused from:**
    1. **Polyploidy**
    2. **Habitat differentiation**
    3. **Sexual selection**

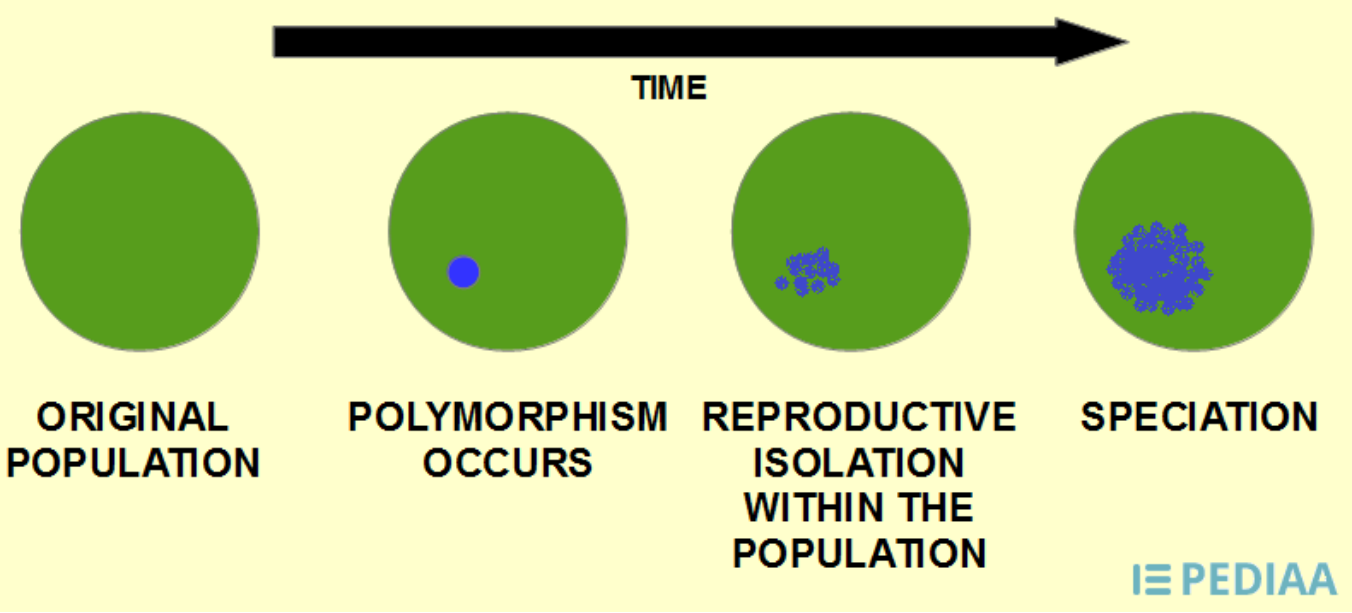


(a) Allopatric speciation. A pop- (b) Sympatric speciation. A



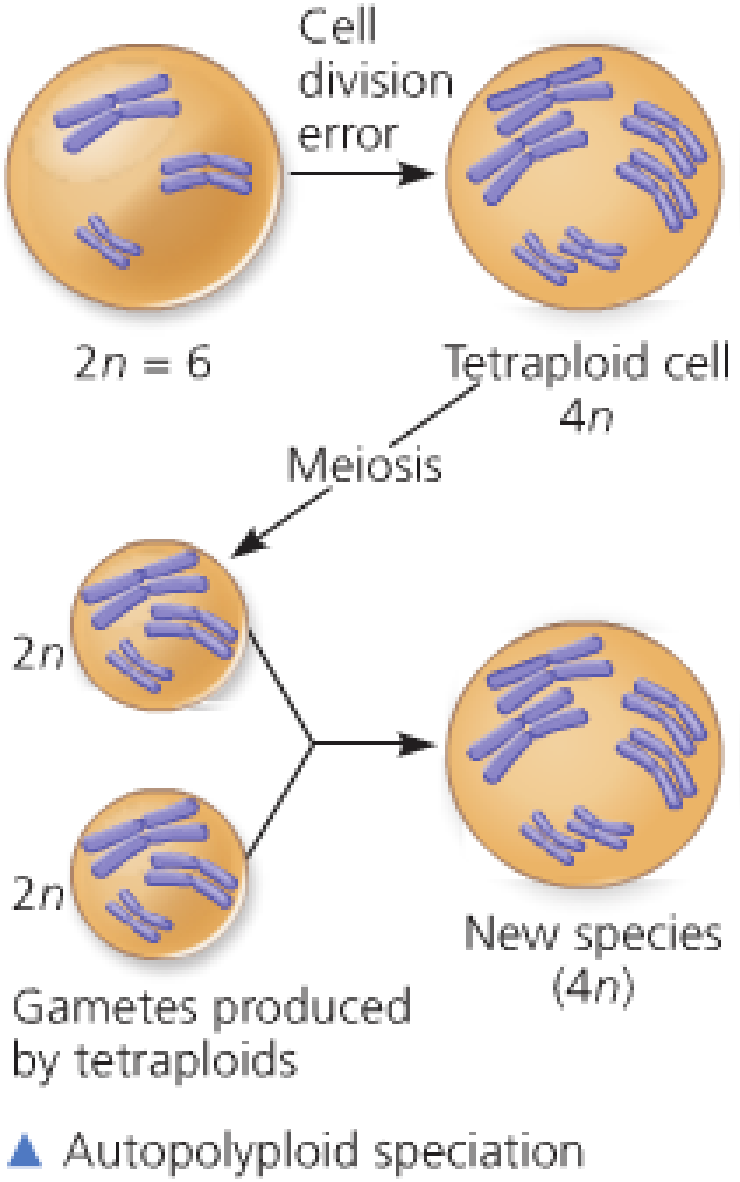
Sympatric Speciation

- **The speciation which occurs when the individuals in the same habitat become reproductively isolated from each other**
  - **Because polyploidy is a major cause of sympatric speciation, it is more common in plants and is rare in animals.**
    - **Since plants are capable of self-reproducing, the polyploid offspring can produce a new, distinct generation by themselves.**
  - ***The two types of sympatric speciation are allopolyploid speciation and autopolyploid speciation.***



Sympatric Speciation by AutoPolyploidy

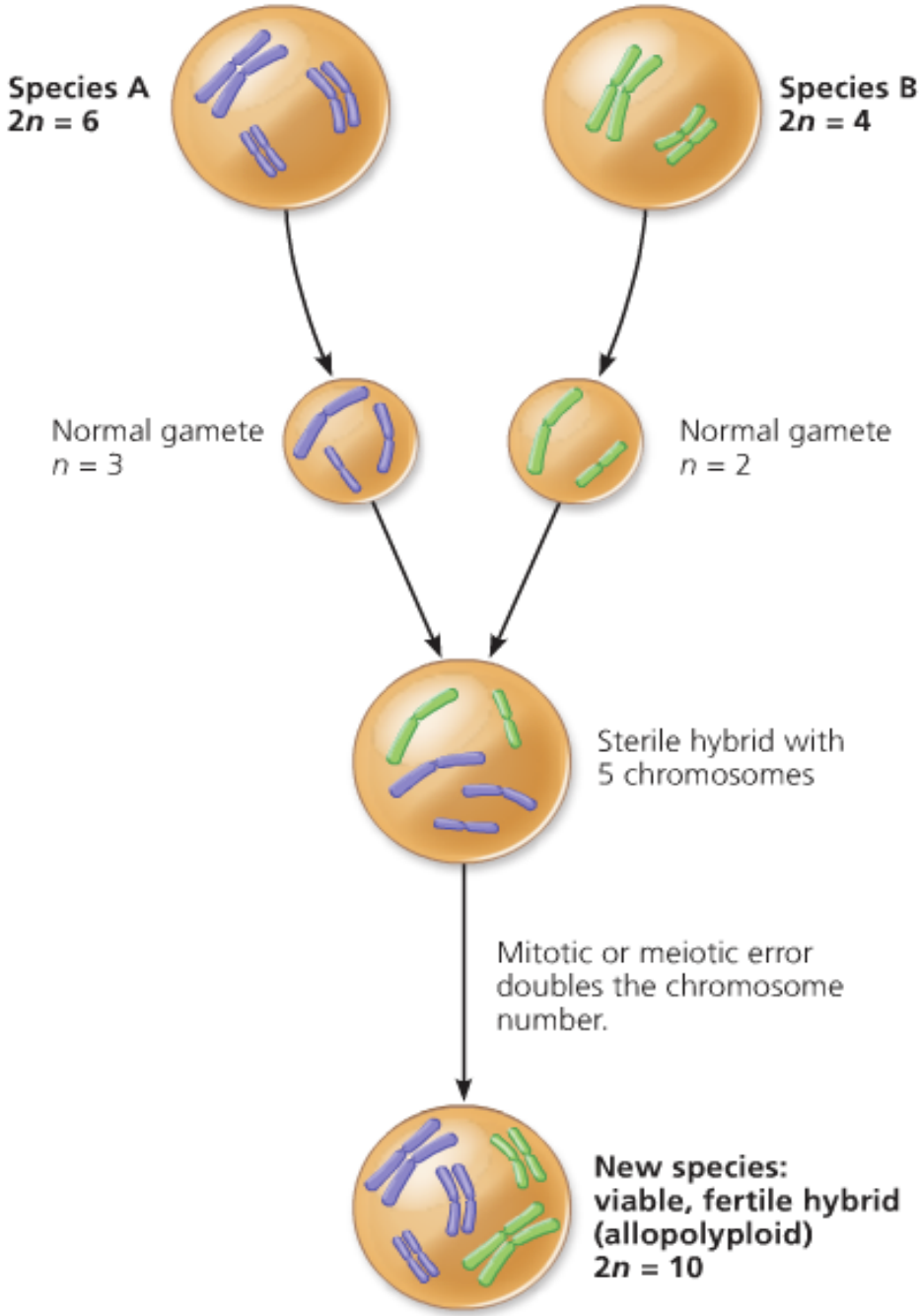
- A new species can result from a mistake during meiotic cell division resulting in extra sets of chromosomes in gamete cells and therefore fertilized cells **(aneuploidy).**
  - **Ex: Grey Tree Frog & 80% of plant species**
  - **Failure of disjunction of all duplicated chromosomes in a cell can lead to a 4n daughter cell instead of 2n cells.**
    - **Tetraploids can produce fertile tetraploid offspring by self-pollinating or mating with other tetraploids that now all make diploid gametes.**
    - **These tetraploids are reproductively isolated from the original diploid 2n plant since the new diploid gamete and an old haploid gamete make a 3n triploid offspring with has reduced fertility.**



▲ Autopolyploid speciation

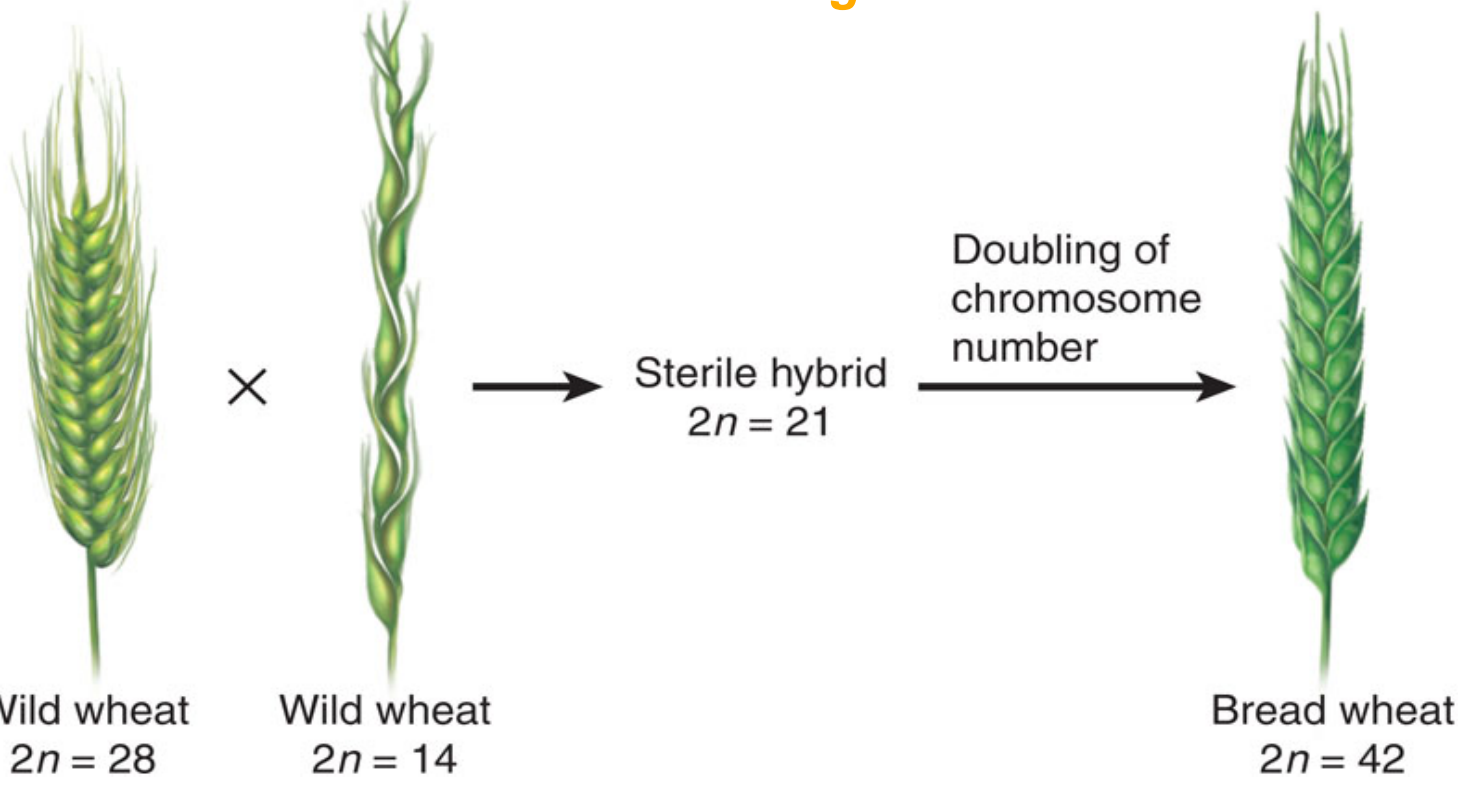
Sympatric Speciation by AlloPolyploidy

- A new species can result from two species interbreeding and producing hybrid offspring, which are sterile because the set of chromosomes from one species cannot pair (form tetrads) during meiosis with the set of chromosomes from the other species properly halting M phase at the M phase checkpoint
  - These hybrids might be able to reproduce asexually (especially plants - through mitosis).
    - Later, non-disjunction can change the sterile hybrid into a fertile polyploid called an allopolyploid.
      - These are fertile when mating with each other only.



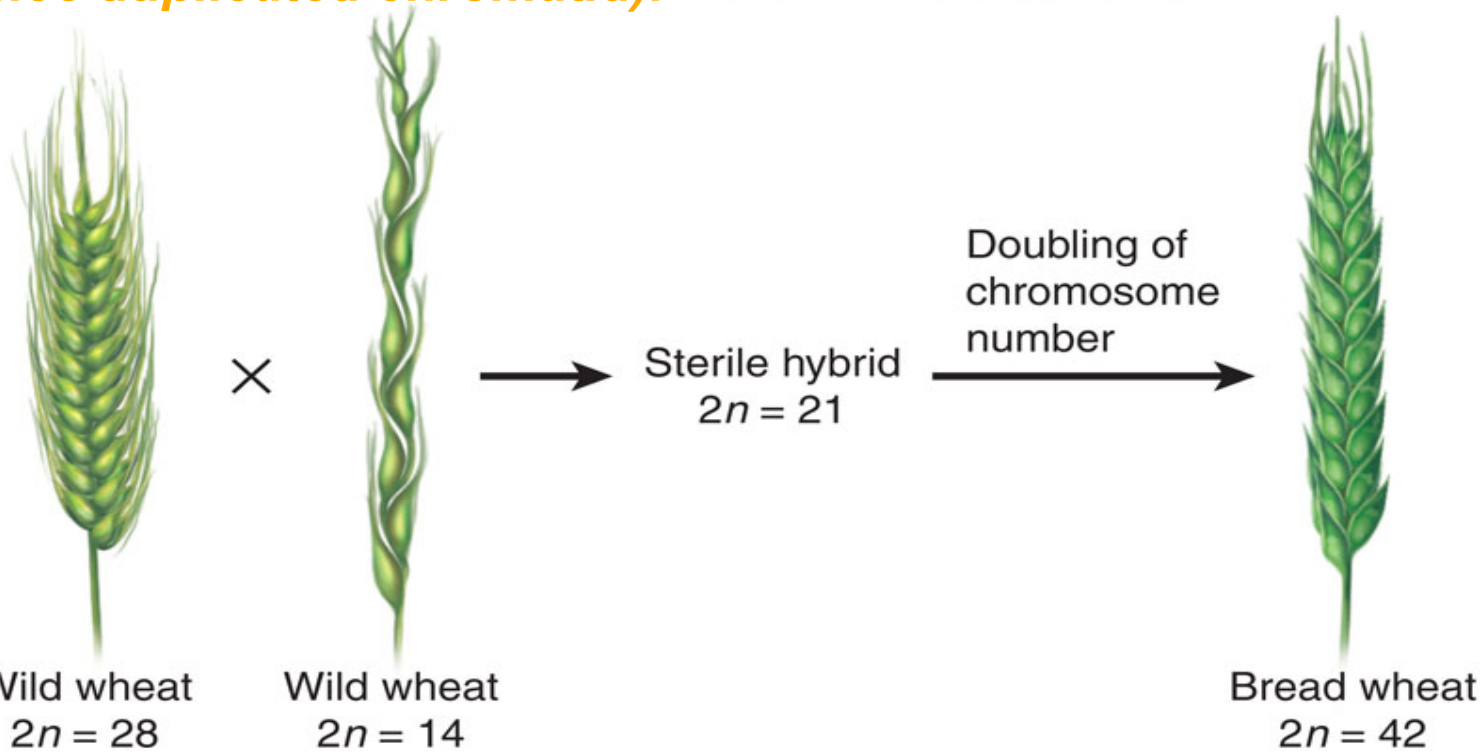
Sympatric Speciation by AlloPolyploidy

- **Two species different species of wheat produce gametes (n = 14 & n = 7) which can fuse, the zygote will have 2n = 21.**
  - **7 chromosomes of one parent can pair with 7of the other parent during tetrad formation**
  - **7 chromosomes are left unpaired so M phase is not completed due to cell division stopping at the metaphase checkpoint.**
    - ***Sexual reproduction isn't possible but asexual reproduction may still work because 2n = 21 can undergo mitosis to make 2n = 21 cells***



Sympatric Speciation by AlloPolyploidy

- Two species different species of wheat produce gametes (n = 14 & n = 7) which can fuse, the zygote will have 2n = 21.
  - If in the 2n = 21 hybrid plant one day a nondisjunction error happens and all chromatids for all 21 duplicated chromosomes do not separate during M phase, separating only in G1 when cohesions are broken down, then the cell that had 2n = 21 becomes 2n = 42
    - Now each type of chromosome has a homologous partner *(the once duplicated chromatid).*

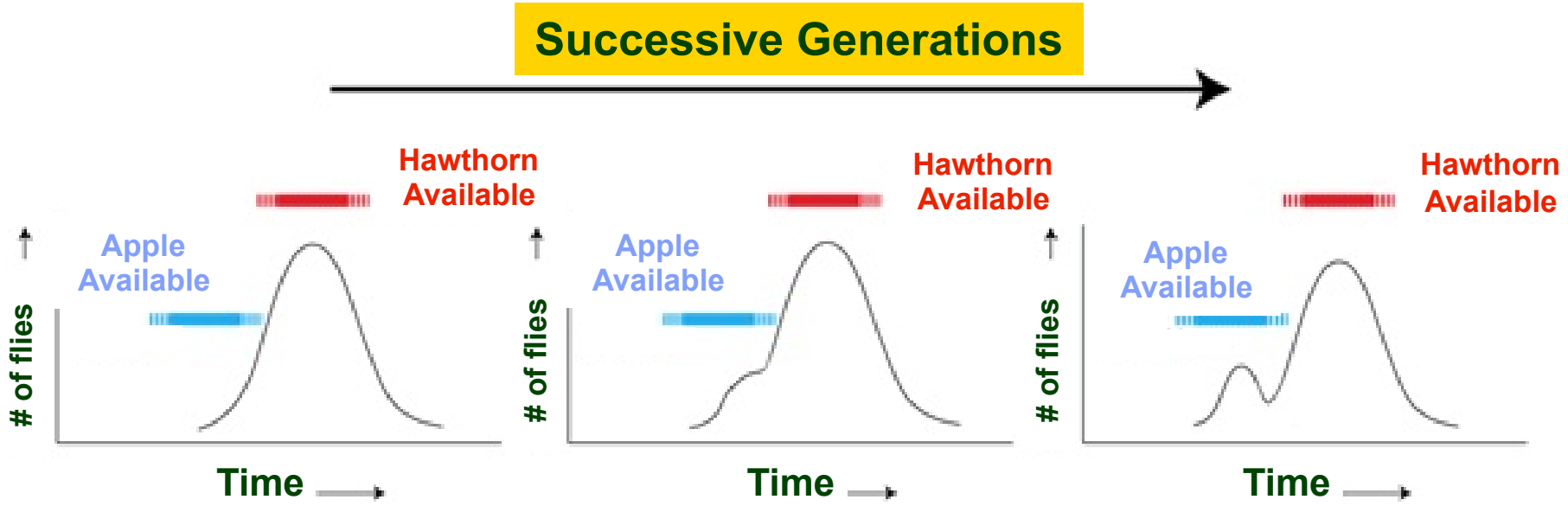


Sympatric Speciation by Habitat Differentiation

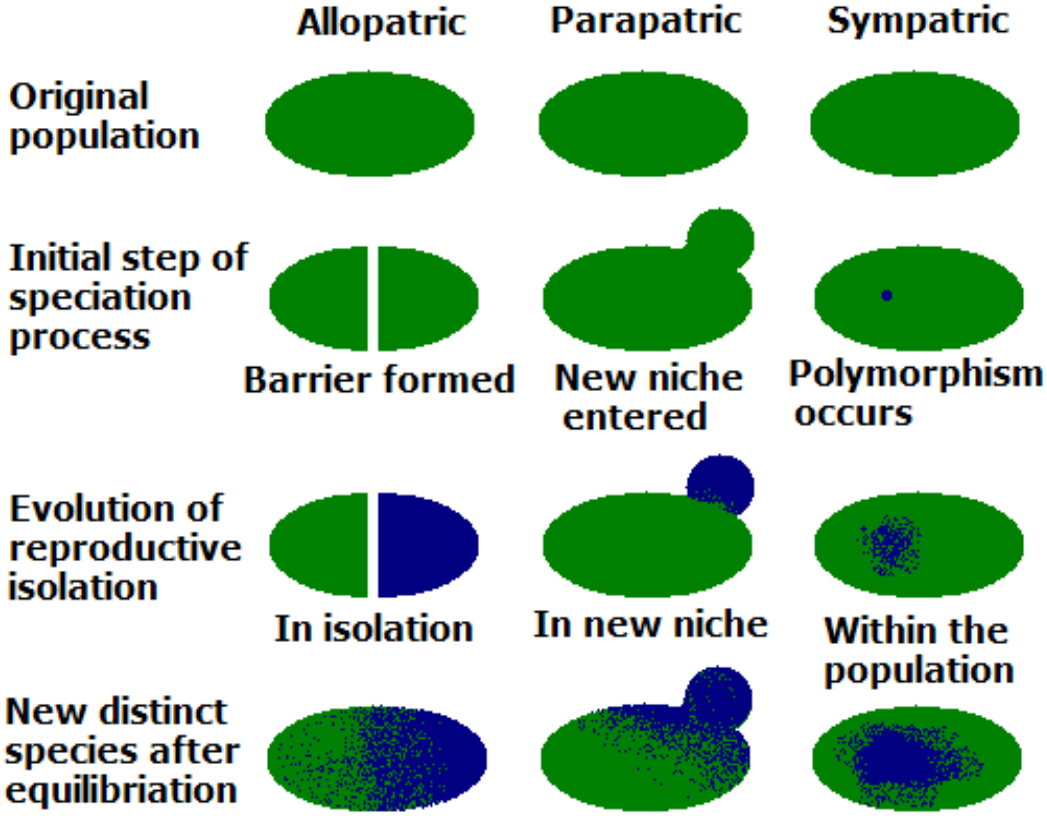
- A subpopulation may exploit a habitat or resource not used by the parent population.
  - Over time these may start evolving into distinct species.
  - Ex: Apple Maggot Fly
    - Habitat Differentiation: The North American apple maggot fly originally lived on the native hawthorn tree.
    - 200 years ago, some colonized apple trees introduced by European settlers.
    - The flies usually mate on or near their host tree so there was not much interaction between the flies on these two different trees.
      - Thus a pre-zygotic barrier known as Habitat Isolation took place.

Sympatric Speciation by Habitat Differentiation

- Evolutionary mechanisms like differential Natural Selection can then cause additional changes in the genetic make-up of populations.
  - Apples mature faster than hawthorn fruit.
    - Flies with slightly faster development had higher biological fitness when living on the apple trees and were selected for.
    - The genetic make up between the two populations started to differ and gene flow halted now due also to Temporal Isolation.
  - Also, alleles have been found that benefit the flies that use one host plant and harm the other host plant.
    - Natural Selection selected certain versions of alleles as a post-



How and why do new species originate?

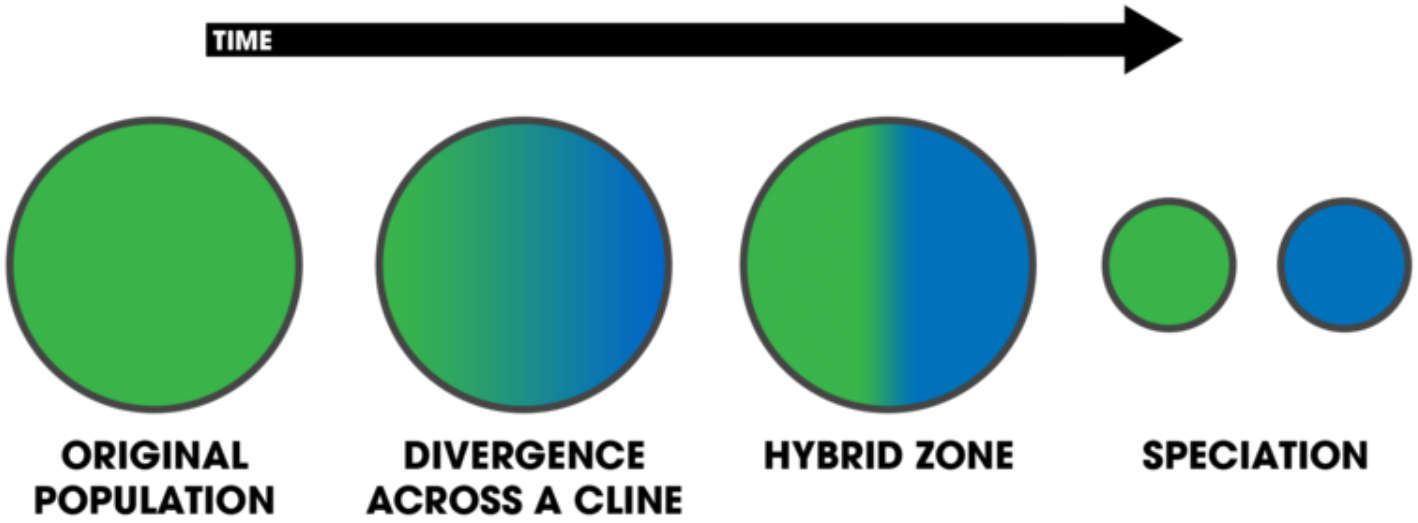


- **Parapatric Speciation** - Subtype of Sympatric Speciation
  - Greek "para" for besides
- Gene flow is interrupted between individuals at the outer edge of a population's range though gene flow physically possible
  - no specific extrinsic barrier to gene flow exists
  - The population is continuous, but nonetheless, the population 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.

How and why do new species originate?

Parapatric Speciation - Subtypes of Sympatric Speciation

- In parapatric speciation, two subpopulations of a species evolve reproductive isolation from one another while they were still initially able to exchange genes.
- **This mode of speciation has three distinguishing characteristics:**
  - 1) mating occurs non-randomly
  - 2) gene flow occurs unequally
  - 3) populations exist in either continuous or discontinuous geographic ranges as a result of unequal dispersal, incomplete geographical barriers, or divergent expressions of behavior, among other things.
- *Parapatric speciation predicts that hybrid zones will often exist at the junction between the two populations as speciation takes place.*

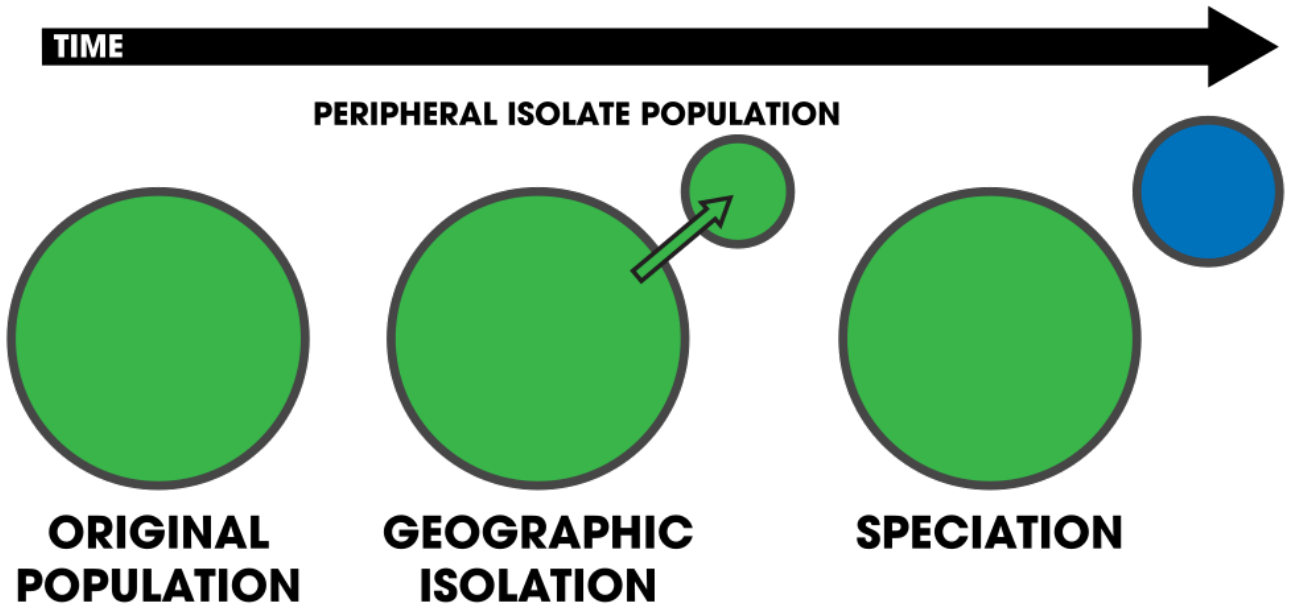


How and why do new species originate?

Peripatric Speciation - Subtypes of Allopatric Speciation

- Greek "peri" for around and "para" for besides

- **Gene flow is interrupted between individuals at the edge of a population's range because gene flow becomes physically difficult**
  - **A mode of speciation in which a new species is formed from an isolated peripheral population.**
    - **As populations enter new niches, populations become isolated which prevents the exchanging genes.**
  - ***What makes peripatric somewhat different from allopatric speciation is that one of the populations - the one that evolves reproductive isolation - is much smaller than the main population***



How and why do new species originate?

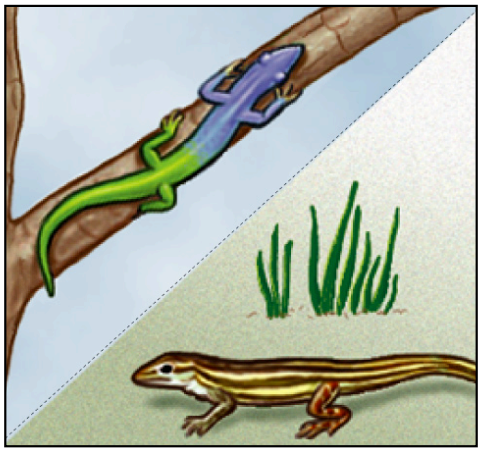
- **Reproductive Barriers come in two forms:**
  - **Prezygotic Barriers = prevent mating or fertilization if mating happens**
    - Habitat Isolation
      - Geographical Isolation
      - Ecological Isolation
    - Temporal Isolation
    - Behavioral Isolation
    - Mechanical Isolation
    - Gametic Isolation

  - **Postzygotic Barriers = prevent a hybrid zygote from developing into a viable, fertile adult**
    - Reduced Hybrid Viability
    - Reduced Hybrid Fertility
    - Hybrid Breakdown

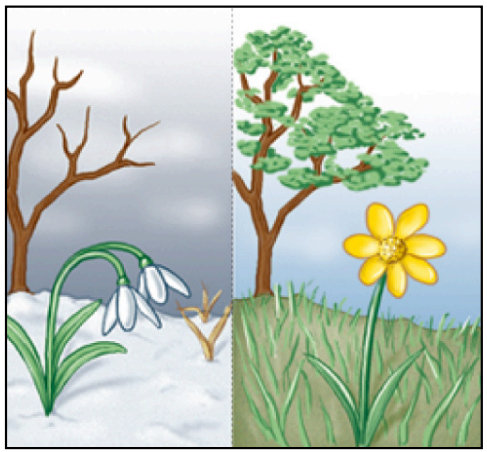
PRE-reproduction barriers

- Obstacle to mating or to fertilization if mating occurs

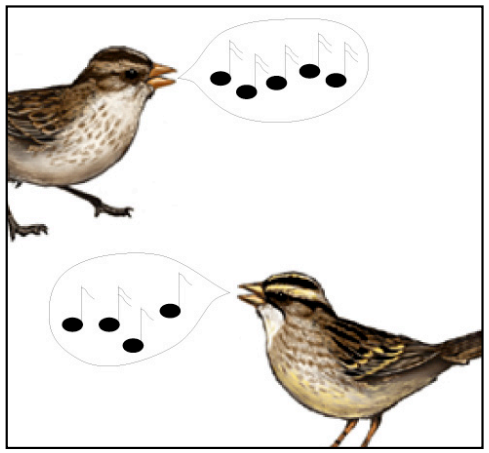
geographic isolation



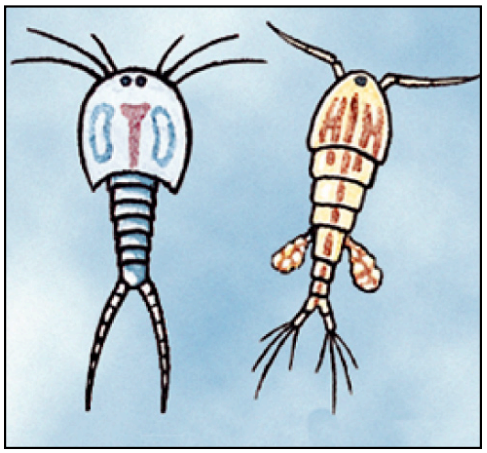
ecological isolation



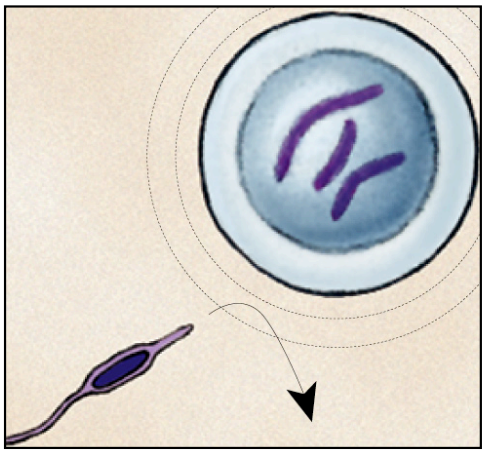
temporal isolation



behavioral isolation



mechanical isolation



gametic isolation

1. Geographic isolation

Ammospermophilus spp

- Species in different areas do not interact
  - physical barrier prevent gene flow
  - **Example of allopatric speciation**

Harris's antelope squirrel inhabits the canyon's south rim (L). Just a few miles away on the north rim (R) lives the closely related white-tailed antelope squirrel

2. Ecological isolation

- Species occur in same region, but occupy different habitats so rarely encounter each other, if at all
  - No offspring form = reproductively isolated

2 species of garter snake, occur in same area, but one lives in water & other is terrestrial

lions & tigers could hybridize, but they live in different habitats:
- lions in grasslands
- tigers in rainforest

3. Temporal isolation

- **Species that breed during different times of day, different seasons, or different years cannot mix gametes**
  - **No offspring form = *reproductive isolation***
    - **Example of sympatric speciation**
      - ***"same country"***

Eastern spotted skunk (L) & western spotted skunk (R) overlap in range but eastern mates in late winter & western mates in late summer

4. Behavioral isolation

Could a change in behaviors within a population lead to sympatric speciation?

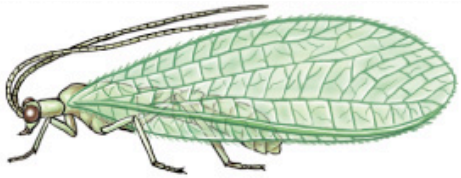
- **Having unique or different behavioral patterns & courtship rituals can isolate species**
  - Used to identify members of species
  - Used to attract potential mates of same species
    - Ex: courtship displays & mating calls
- **Leads to reproductive isolation**

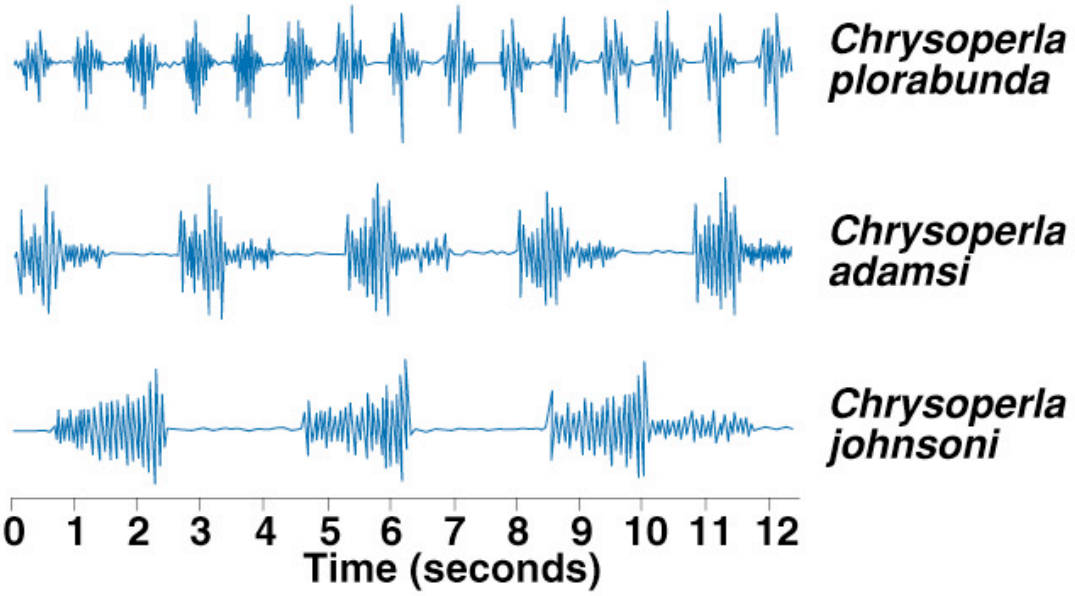
Blue footed boobies mate only after a courtship display unique to their species

courtship display of Gray-Crowned Cranes, Kenya

Recognizing your own species

courtship songs of sympatric species of lacewings





firefly courtship displays

5. Mechanical isolation

Could also lead to sympatric speciation.

- Morphological differences can prevent successful mating
  - Ex: Mating is attempted but cannot be completed successfully
  - Ex: Difference in flower shape alters the type of pollinator attracted
- Also results in reproductive isolation

✓ Even in closely related species of plants, the flowers often have distinct appearances that attract different pollinators.

✓ These 2 species of monkey flower differ greatly in shape & color, therefore cross-pollination does not happen.

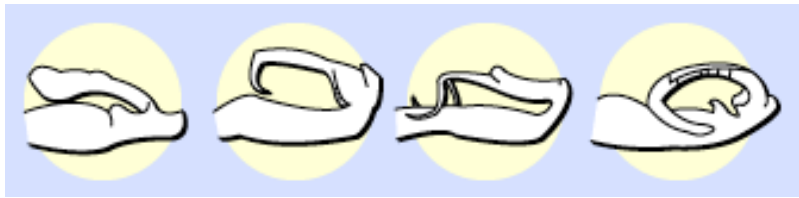
Plants

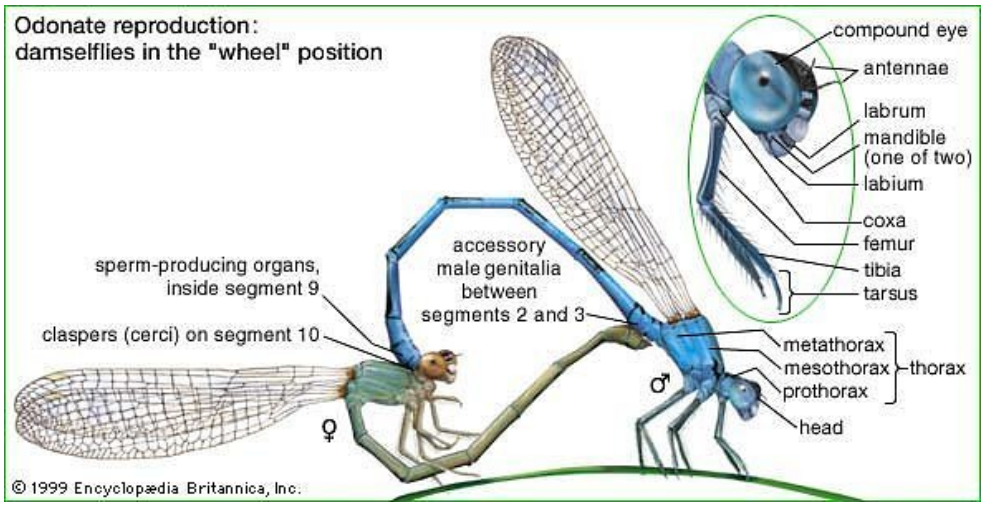
Mechanical isolation

Animals

- For many insects, male & female sex organs of closely related species do not fit together, preventing sperm transfer
  - lack of "fit" between sexual organs:
    - hard to imagine for us…
    - but a big issue for insects with different shaped genitals!

Damsel fly penises





6. Gametic isolation

Again, causes sympatric speciation

- **Sperm of one species may not be able to fertilize eggs of another species**
  - mechanisms
    - biochemical barrier
      - sperm cannot penetrate egg
        - receptor recognition: **lock & key between egg & sperm surface proteins**
    - chemical incompatibility
      - sperm cannot survive in female reproductive tract

- **Sea urchins release sperm & eggs into surrounding waters where they fuse & form zygotes.**
  - **Gametes of different species— red & purple —are unable to fuse.**

AP

POST-reproduction barriers

- **Hybrid zygote that DOES form from fertilization is prevented from developing into a viable, fertile adult**

Reduced hybrid fertility

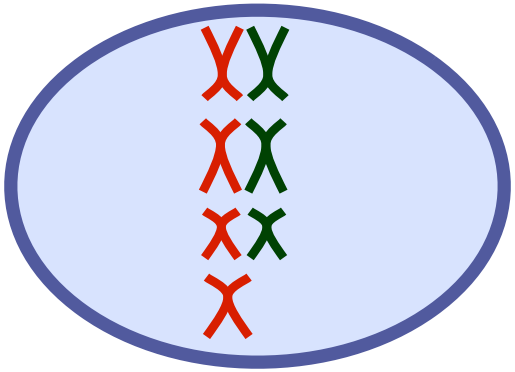
Reduced hybrid viability

Hybrid breakdown

1. Reduced hybrid fertility

Contributes to sympatric speciation

- Even if hybrids are vigorous they may be sterile
  - chromosomes of parents may differ in number or structure & meiosis in hybrids may fail to produce normal gametes



Mules are vigorous, but sterile

Horses have 64 chromosomes (32 pairs)

Mules have 63 chromosomes!

Donkeys have 62 chromosomes (31 pairs)

2. Reduced hybrid viability

Contributes to sympatric speciation

- **Genes of different parent species may interact & impair the hybrid's development**
  - **Hybrids do not survive or are weak**

Species of salamander genus, *Ensatina,* may interbreed, but most hybrids do not complete development & those that do are frail.

3. Hybrid breakdown

May also leads to sympatric speciation

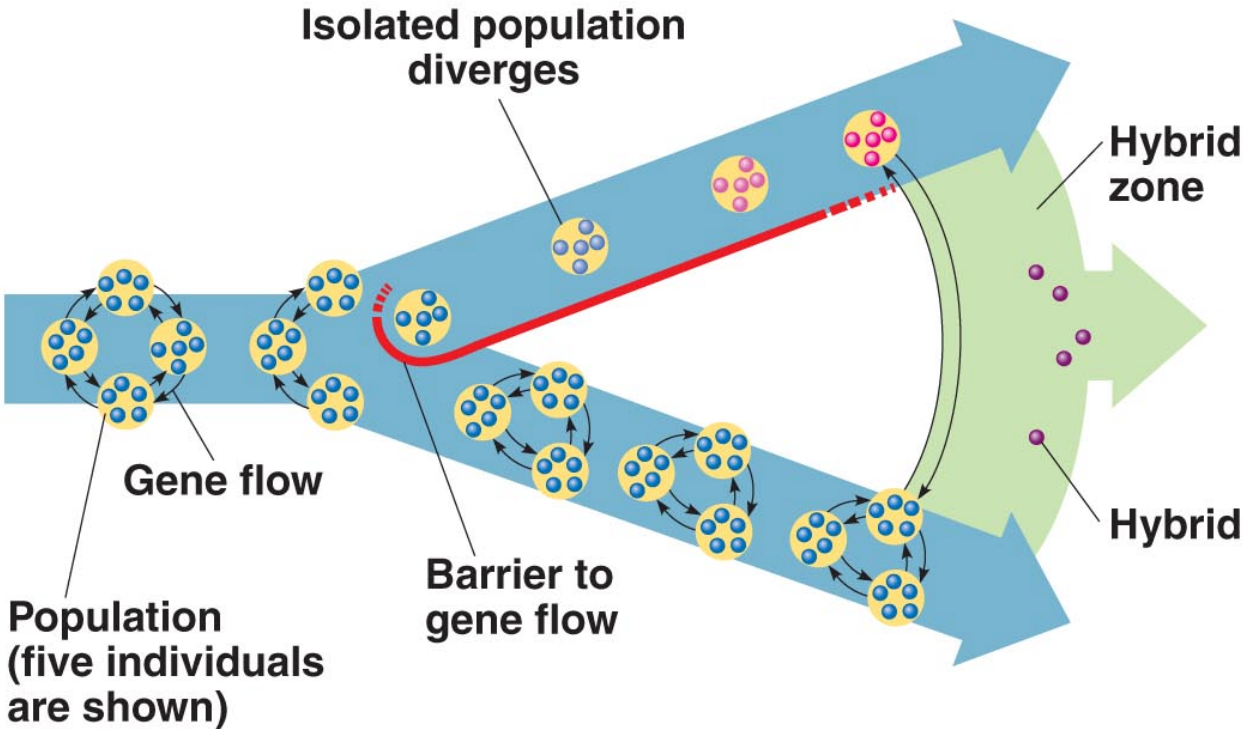
- **Hybrids may be fertile & viable in first generation, but when they mate hybrid's offspring are feeble or sterile**

In strains of cultivated rice, hybrids are vigorous but plants in next generation are small & sterile.

The two parents are on path to separate species.

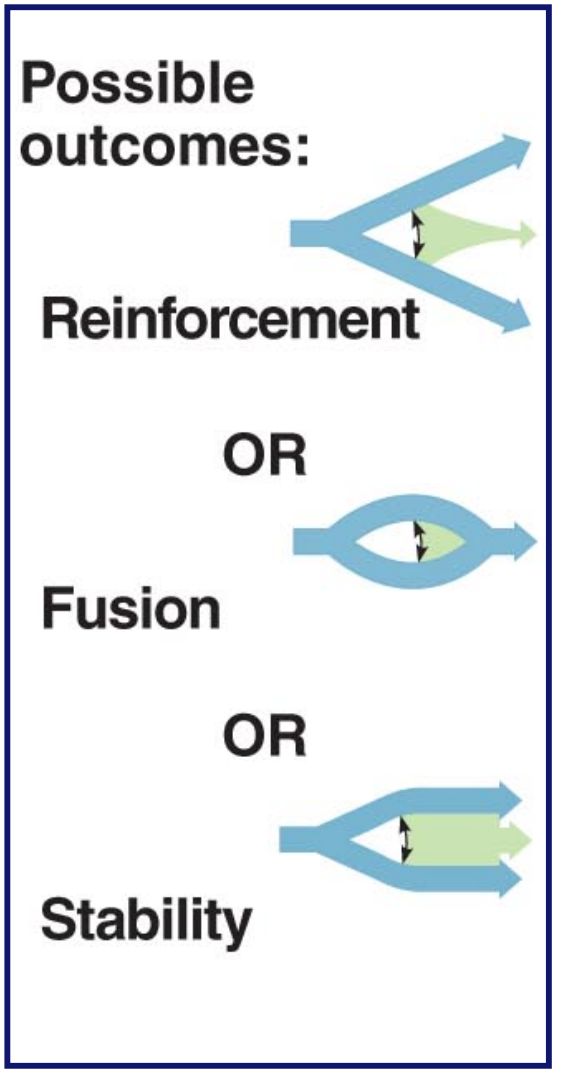
Hybrid Zones

- **Closely related species may experience incomplete reproductive barriers.**
  - **When these species mate they form hybrid zones = regions in which members of different species meet and mate, producing mixed offspring (hybrids).**
  - **Hybrid zones can still cause decreased or increased gene flow**
    - **They are located typically where habitats of interbreeding species meet.**



Three outcomes of Hybrid Zones

1. **Reinforcement: Strengthening of Reproductive Barriers**
   - If hybrids are less fit than members of each parent species then natural selection with strengthen prezygotic barriers to reproduction, reducing the formation of such hybrids.
2. **Fusion: Weakening of Reproductive Barriers**
   - If hybrids are viable and fertile, gene flow may occur readily and the two species may become increasingly alike, reversing the speciation process.
   - The two species may fuse back into one.
3. **Stability: Continued formation of Hybrids**
   - Hybrid zones may continue to exist if hybrids continue to survive and reproduce, sometimes better than either parent species.



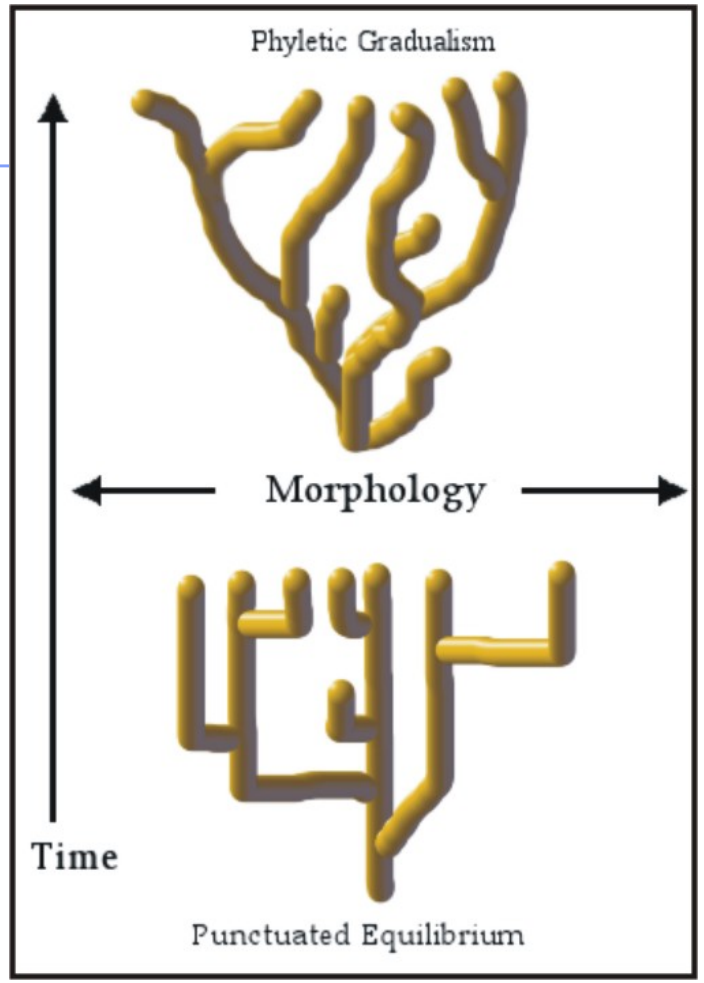
Rate of Speciation

- **Current debate**:

  Does speciation happen gradually or rapidly?

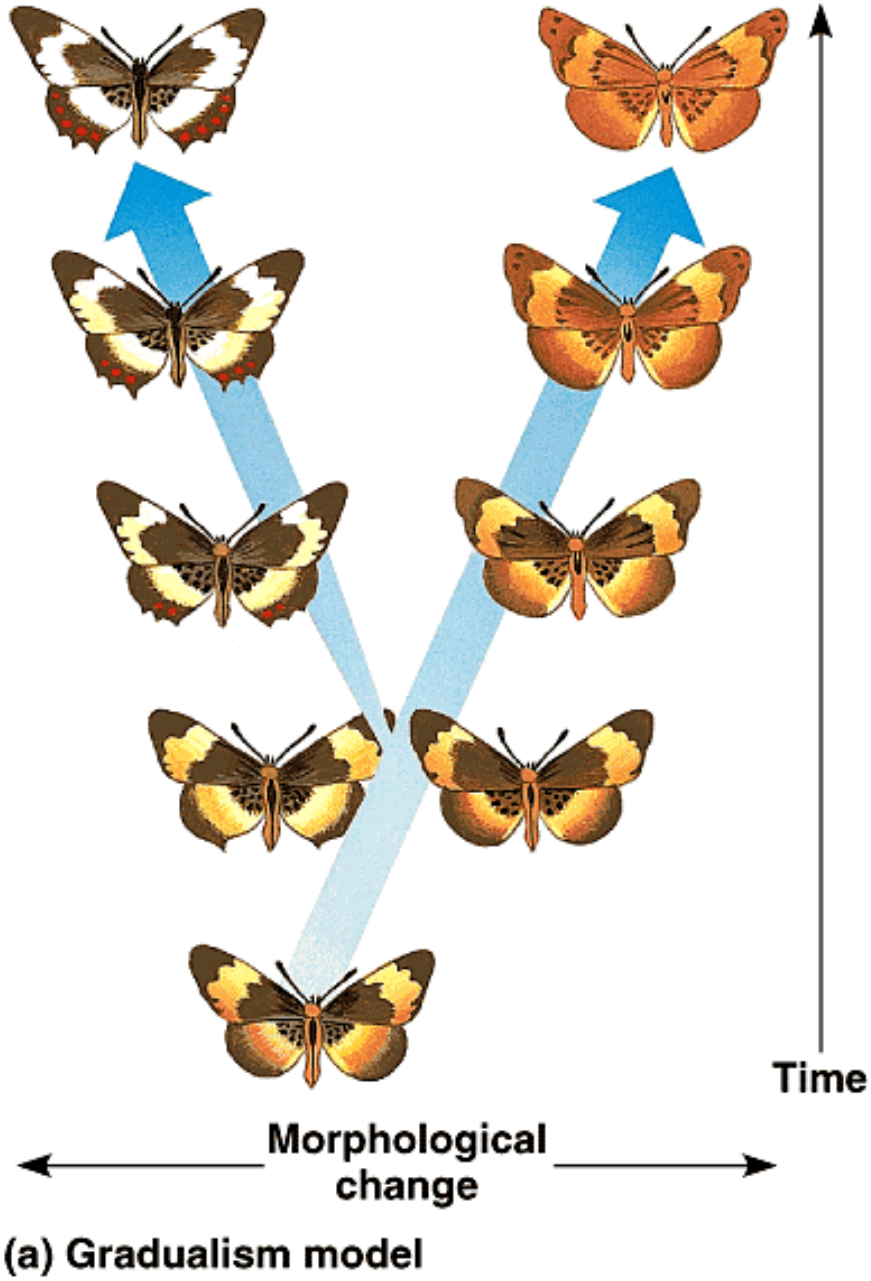
  We see both in different species:

  - **Gradualism**
    - Species change gradually, slowly, over long periods of time
      - Charles Darwin
      - Charles Lyell
  - **Punctuated equilibrium**
    - Describes rapid periods of stasis (no change) punctuated by sudden change.
      - Stephen Jay Gould
      - Niles Eldredge



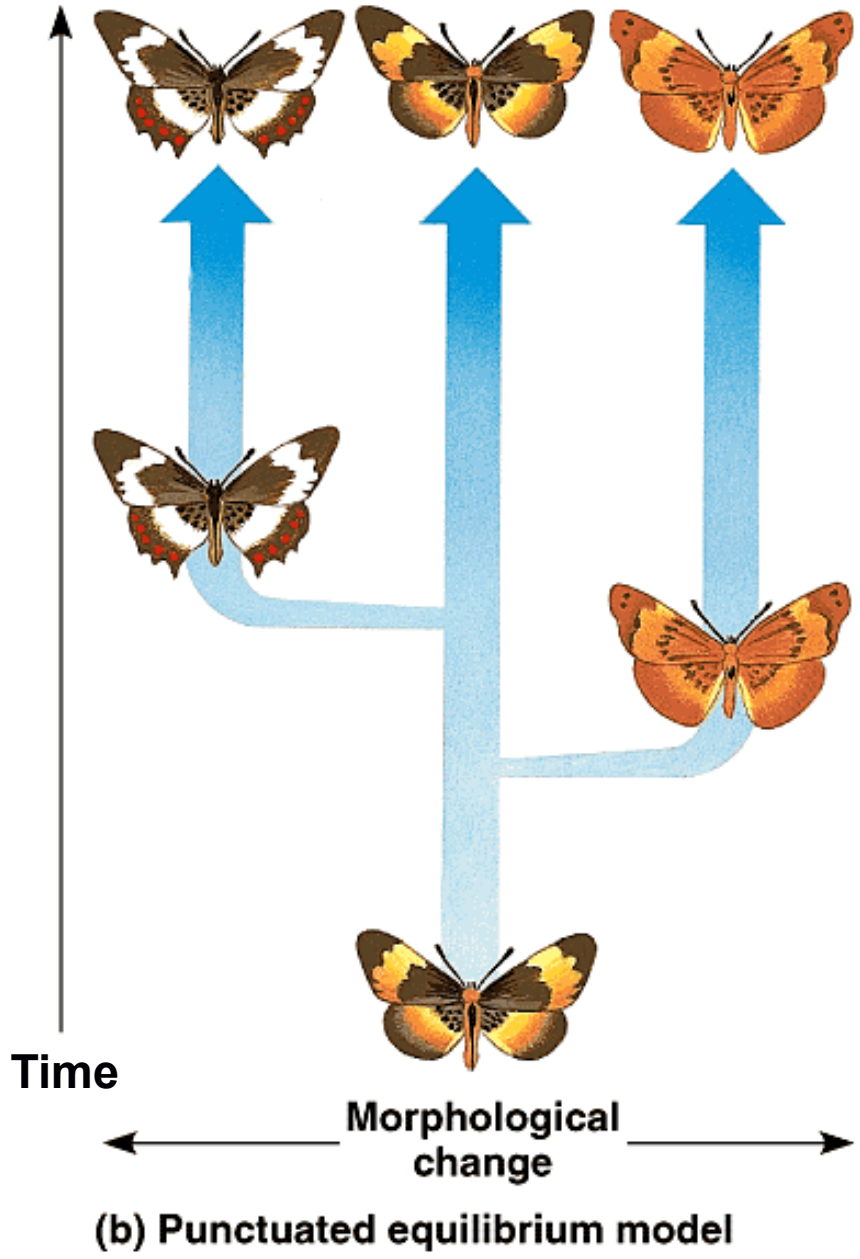
Gradualism or Gradual Evolution

- **Gradual divergence over long spans of time**
  - **assumes that big changes occur as the accumulation of many small ones**



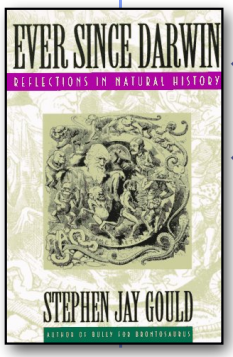
Punctuated Equilibrium

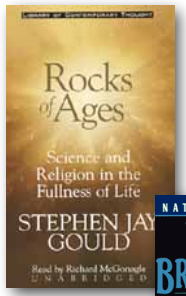
- **Rate of speciation is not constant**
  - rapid bursts of change
  - long periods of little or no change
    - Species undergo rapid change when they 1st bud from parent population

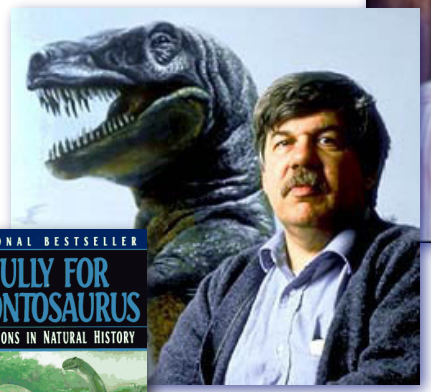


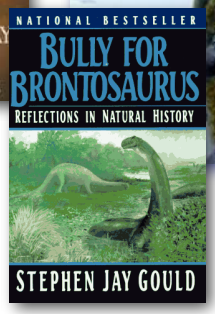
Stephen Jay Gould (1941-2002)

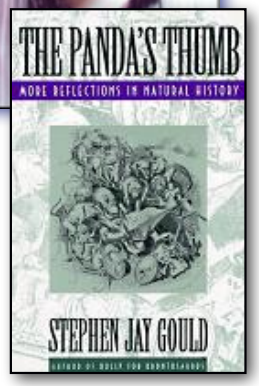
- Harvard paleontologist & evolutionary biologist
  - punctuated equilibrium
  - prolific author
    - popularized evolutionary thought



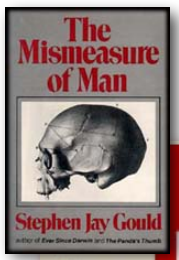


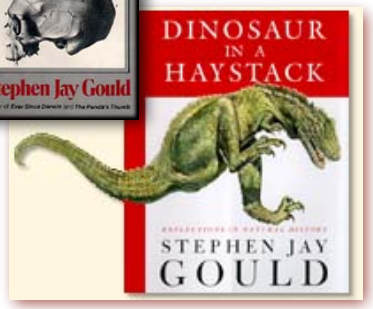


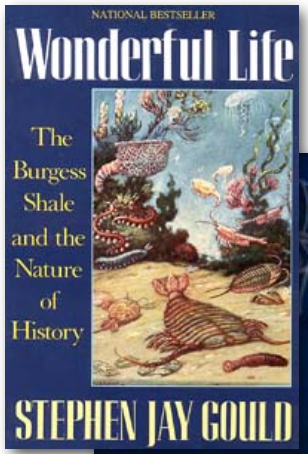




- He served as a member of the faculty at Harvard University beginning in 1967.
  - He helped Niles Eldredge develop Eldredge's theory of punctuated equilibrium 1972, wherein evolutionary change occurs relatively rapidly in comparatively brief periods of environmental stress, separated by longer periods of evolutionary stability.

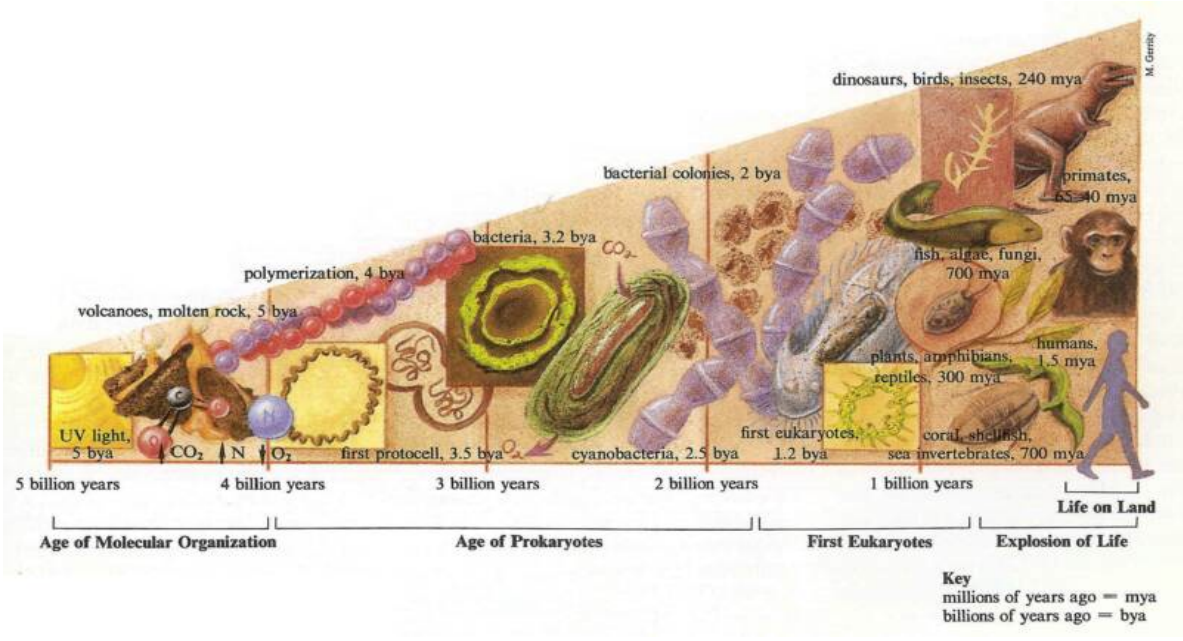






Evolution does NOT produce perfect organisms

- ✓ Selection only acts on existing variation. It cannot create wished for variation.
- ✓ Evolution is limited by the constraints of history. Evolution does not start building a new structure or behavior from scratch but modifies structures or behaviors that already exist based on the history of that species.
- ✓ Adaptations are often compromises. Organisms must perform many tasks like escape predators and find a mate and so must compromise in their behaviors, structures, or functions between ideals for each individual task.
- ✓ Random chance and the changing environment are involved as well.
- ✓ Remember that for humans as well!



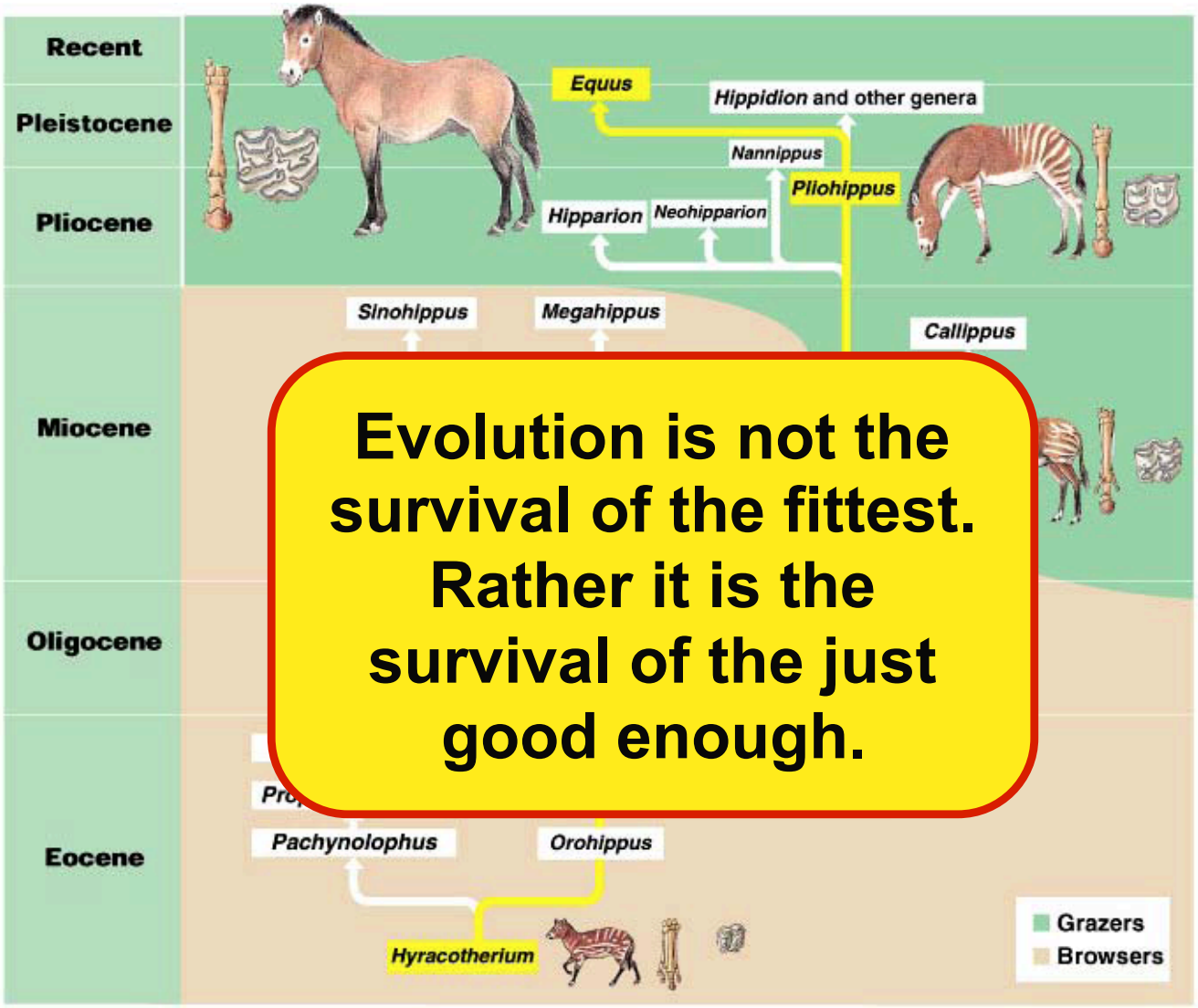
Evolution is NOT goal-oriented

An evolutionary trend does not mean that evolution is goal-oriented.

Surviving species do not represent the peak of perfection.

There is compromise & random chance involved as well

Remember that for humans as well!!!



Evolution is not the survival of the fittest. Rather it is the survival of the just good enough.

Can't find out the facts if you don't ask the questions!