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THE DIVERSITY OF LIFE

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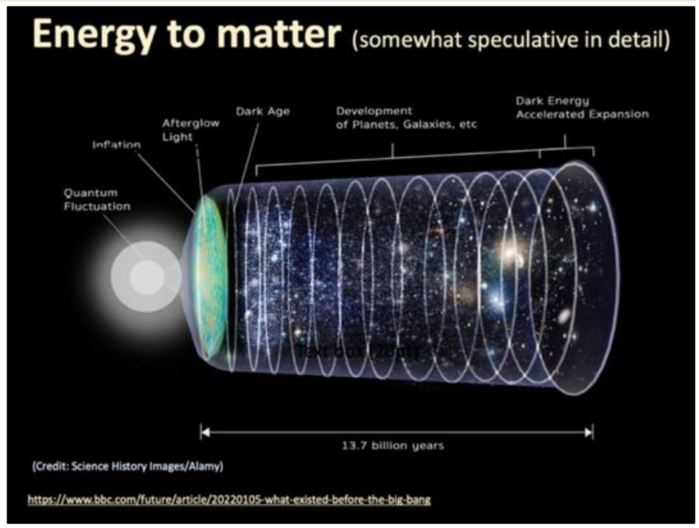
1. The Diversity of Life

History

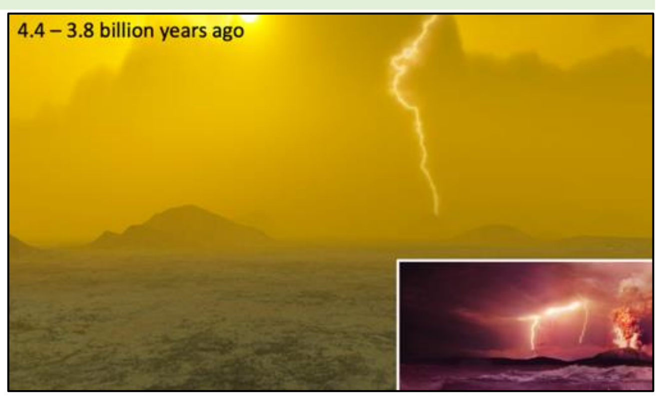
Big Bang Singularity

- Big bang – a singularity that exploded an enormous amount of energy into space
    - Singularity event we think was an enormous explosion hat ejected energy which cooled to be able to form matter, which congealed into planets, suns, solar systems, galaxies, etc
- Periods of inflation and then after glow after big bang, then dark age, then development of planets etc then Earth 4.6 billion years ago



Pre-Biotic Earth

- Rocky planet with a molten core at this point with no life
- Evidence inferred from chemistry of relics available form this time tells us there was water on the planet
- Clean slate right now – no life on it but water and other compounds, molecules, and complex amino acids in a few billion years



2. How Did Life Start on Earth?

Conditions Favourable for Life

Fundamental Properties for Living Things

Living things all share fundamental properties:

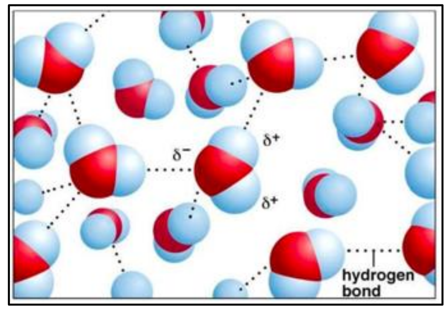
Metabolism	• *They need a source of energy* • Something that allows cells to grow and divide
Homeostasis	• *They control their internal conditions* • Because the conditions on the insides of cells are different to those in the external environment • Homeostasis = keeping things at particular levels of pH, temperature, molecules etc.
Replication	• *They make copies of themselves (with DNA*)
Evolution	• *Their DNA can change over time*

Conditions Needed for Life

Complex atoms	• Formed during supernova explosions • Things other than just hydrogen and helium – carbon iron, phosphorus, sulphur, etc and you can't get them until they are generated in supernovas
An energy source	• Being the right distance from the sun • Not so far away that you get no light energy, and not so close that you get burned up
A medium in which molecules can interact	• A liquid medium stable over a range of temperatures • This needs to be liquid • Molecules can't move around and interact in a solid – not many dynamic processes happening • Molecules too far to interact in a gas • The liquid also needs to be stable over a range of temperatures ○ This is water

Water

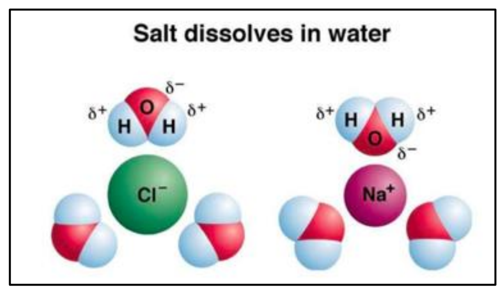
- **The most abundant molecule in living things**.
- The properties of water are essential for life as we know it.
- Water molecules form hydrogen bonds between each other. This makes water 'sticky', gives it cohesiveness and allows it to dissolve many other molecules.
- 2 hydrogen atoms attached to a red oxygen
  - Hydrogen atoms have slight positive charge, and oxygen has a slight negative charge
  - So different water molecules are attracted to each other by a process called hydrogen bonding
  - Don't stick molecules together in a permanent way, but makes them sticky
  - This gives them cohesiveness and allows them to dissolve lots of other molecules – essential for life to form



Weird Properties of Water

Polarity and hydrogen bonding give water unique properties:

- H-bonding keeps water liquid between 0 and 100°C (most low molecular weight compounds are gases in this range)
- Water is a universal solvent for charged molecules, and helps chemical reactions occur
- Polarity = slightly charged on either end
- Polarity gives it hydrogen bonding, and this in turn gives water unique properties



Cohesion

- H-bonding gives water cohesion and makes it an ideal means of transporting other molecules around organisms
- Water streams, surface tension and dewdrops: all examples of cohesion
- Droplets of rain, etc – hydrogen bonding occurring at the atomic level allows droplets to sit in this way and form these droplets
- Makes it a really good means of transporting molecules around organisms e.g., in our bloodstream

Stability

- H-bonding means that large amounts of energy must be gained or lost for water temperature to change significantly. This stabilizes the temperature of organisms (and oceans).
- Good in the long term in terms of origin and maintenance for life on the planet, but also in the short term because it takes a lot of energy to warm oceans up, and oceans take up 75% of the planet

6. Mechanisms of Evolution

Evolution

Evolution defined as:

- A **change in population gene frequencies over time**. Can be adaptive or non-adaptive:
- **Adaptive evolution** involves Natural Selection (from Charles Darwin and Alfred Russel Wallace)
- **Non-adaptive evolution** involves “neutral mechanisms” e.g., Genetic drift

Natural Selection

3 Necessary & Sufficient Conditions for Natural Selection to Occur

If these 3 conditions exist, natural selection will occur:

1. Variation
    a. The whole suite of traits that make up the phenotype of an organism — Genetic variation
    b. We need some variation among the phenotypes in the population
2. Mechanism of heredity
    a. We now know this is supplied by the different genetic makeup of individuals
3. Competition among heritable variants
    a. = differential survival/reproduction
    b. Ability to replicate themselves

Genetic Variation

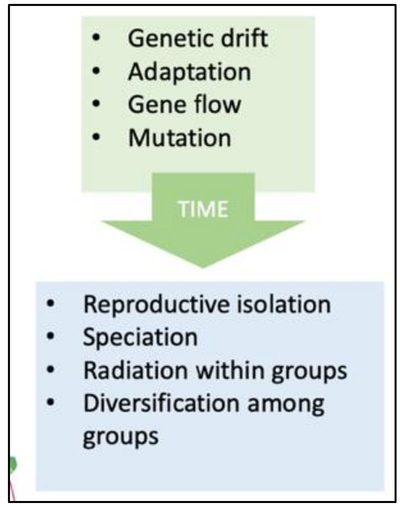
- Variation in sequence code of an organism
    - Sequence code – heap of different base pairs along the double helix of DNA that is housed across al the chromosomes an individual possesses
    - Genome – the sum total of sequence variation across the chromosomes (the entire karyotypes) an individual possesses
- Sequences code for genes
- Genes code for phenotypic characters
    - Any trait that lies in a discrete region of the genome = gene
- Gene pool: The total aggregate of genes in a population at any given time;
    - We need a robust gene pool for evolution and natural selection
    - Conservation of biodiversity – talking about genetic variation that underlines phenotypic variation

Mechanisms that Produce Genetic Variation Overview

7. The Species Concept and Speciation

Key Points

- Latin: Species ~ "kind" (meaning like – individuals that are morphologically similar)
- Evolutionary Biology explains the diversification of life on Earth in terms of the **origin of species**;
- Speciation provides the conceptual link between **microevolution** and **macroevolution** (2 levels of evolutionary analysis)**;**
- Variation and link at both micro- and macro-evolutionary scales constitutes what we know as **biodiversity**.
- Distinction between microevolution and macroevolution is given by the level at which variation exists
- Microevolution processes are the drivers or processes that engender the macro evolutionary changes



Microevolution	Genetic (and phenotypic) changes that occur within populations;	• Can be studied in contemporary timeframes (years or decades) • In green on picture
Macroevolution	Changes that occur over longer time-frames at broader levels of biological organisation.	• Beyond the level of species – looking at divergence of species and things that have brought upon the broader scale of the diversity of life on our planet • Cannot really be studied in contemporary timeframes

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The Species Concept

Species – members of populations that are able to **interbreed in nature.**

- The barrier that defines two species – the inability to fuse gametes and produce a viable offspring
- Pertains to contemporary timescales.
  - We don't know what happened in the past
- Emphasises **reproductive isolation**.

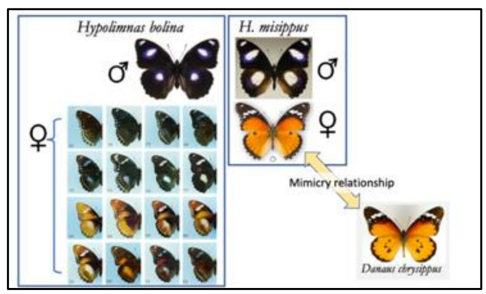
- We have two individuals that are seemingly the same species and can mate under natural conditions but cannot produce offspring under those conditions – this is reproductive isolation and is the barrier that defines two separate species

Classifying Species

Different Classifications

1. Biological species concept (reproductive isolation)
    a. Current concept – however cannot be applied to what has been the case in the past
2. Morphological species concept
3. Paleontological species concept (fossils)
    a. Morphological differences among fossils which in some way is the next best proxy of information for what may have constituted different species in the long distant past
4. Ecological species concept (niche)
    a. Ecological niche that different species might inhabit under natural circumstances
5. Phylogenetic species concept

Morphological Species Concept

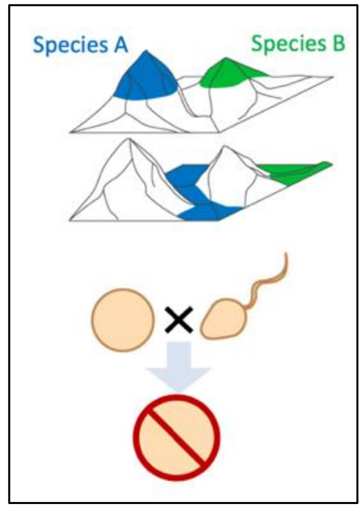


- This was used a lot in the past
- However, similarity of appearance is only useful in the most general sense
- E.g., butterflies
- The males look the same but the females can take on a number of different phenotypic appearances
- And then we have two different butterfly species that look almost the same – the misippus is a mimic of another butterfly species – the chrysippus
- Note that this is a dictionary example
- So the definition of species has to come from the ability to two individuals to interbreed together

Biological Species Concept

Reproductive Isolation in Nature

Arises from barriers that either occur before individuals mate and before gametes can reach each other vs barriers that occur following fertilisation and two gametes fusing.



Arises due to either:

1. **Pre-zygotic barriers**: factors preventing mating or fertilization;
2. **Post-zygotic barriers**: factors that determine inviability of fertilized gametes;

Pre-Zygotic Barriers

Often geographic/physical distances between two species. Any factor that prevents gametes from encountering each other:

Spatial Segregation	**Geography**	• E.g., lizards separated on the Galapagos Islands by water and therefore bound to their particular island
	Habitat preferences	• Individuals that prefer to be in the forest vs out in the open • Creates a barrier between individuals meeting and having a fertilisation of gametes
Temporal Segregation	**Temporal activity regimes**	• E.g., flies that do certain particular activities at different times of the days • Temporal segregation of activities throughout the day can create barriers between species stopping them from meeting up
Other	**Morphology**	• Some morphological differences make it difficult for mismatched individuals to mate together • E.g., successful pairing in snails depends upon a similar coiling direction • E.g., rapid evolution in genital morphological in damselflies

	Mate recognition/preference	• Determine preferences of mating and can sometimes be strengthened by selection resulting in a species diverging into a subspecies and then so forth • E.g., rapid evolution of colour-based mating preference in butterflies

Post-Zygotic Barriers

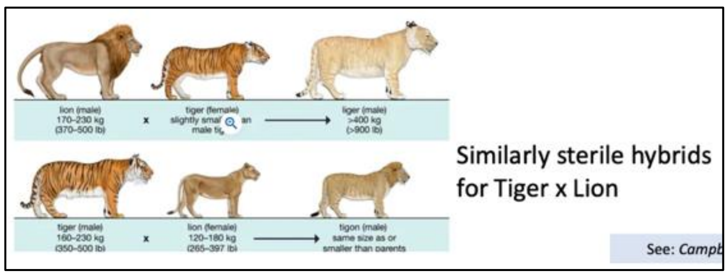
- Occur between diverging species or closely-relating and hybridising species
- Primarily expressed via reduced hybrid viability (or sterility) due to genetic incompatibility.

Mules

- E.g., Hybrids between horses and donkeys (mules) are robust yet sterile due to chromosome numbers
- Horse 64: haploid gamete = 32
- Donkey 62: haploid gamete = 31
- Hybrid: haploid gamete = 31.5
- Mix of incompatible gametes is not compatible for the hybrid resulting in it being sterile

Lions and Tigers

- Lions and tiges can produce viable offspring but they are sterile



Limitations to the Biological Species Concept

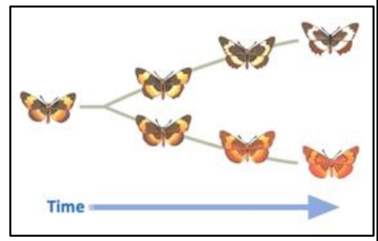
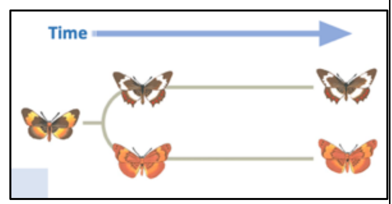
- It only really applies for extant organisms (i.e., the contemporary timeframe);
    - We can only apply the metric of reproductive isolation and ability to interbred for species that exist now
    - We cannot extrapolate this back through time
    - So reconstruction of evolutionary events need to rely on metrics other than this
- Difficult to apply for asexual species;
    - Those such as many prokaryotes that reproduce through binary fission
- Breaks down in the case of hybridising species
    - Species that are presently hybridised
    - We know there are various species and populations that are currently diverging and moving to separate species and are occasionally hybridised

Speciation

Models of Speciation

- We can infer that the basis of evolutionary biology stems from the idea that Earth began sterile with no life

Inference from the **fossil record** implies two complimentary modes of speciation:

Anagenesis (gradual change)	• One species that through the fossil record, appears to gradually change • There is an existence of intermediance along a continuum from one species to a divergence into two • There are examples in the fossil record where we see this change from one phenotype to two discreet phenotypes	
Cladogenesis (punctuated change)	• Quick change of two distinct phenotypic species from one parent species • A quick diversification • This has been explored by palaeontologists who have an evolutionary interest in the concept of evolutionary equilibrium on the sense that there is an equilibrium for a period of time, and then we see a rapid occurrence of these events – e.g., the Cambrian explosion	

We see examples of both of these processes in the fossil record

How Long Does Speciation Take?

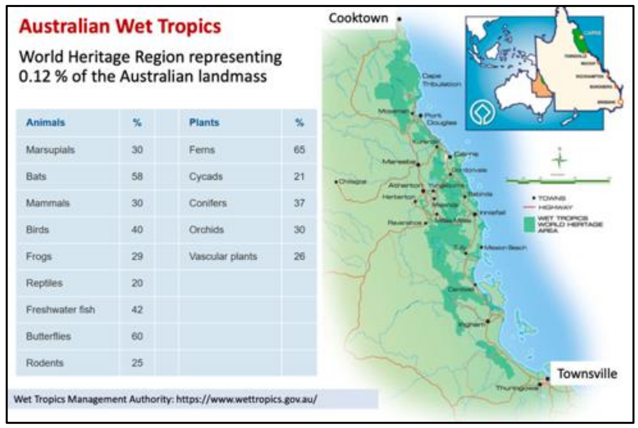
- Survey of data from 84 groups of plants and animals:
- Speciation intervals ranged from **4,000** years (fast – in cichlids of Lake Nabugabo, Uganda) to **40 million years** (in some beetles).
- Overall, the time between speciation events **averaged 6.5 million years** and was rarely less than 500,000 years.
- It has proven impossible to generate two different reproducing species in a lab in contemporary timeframes
- So takes an enormous number of generations for two distinct species to form from one

How Does Speciation Occur?

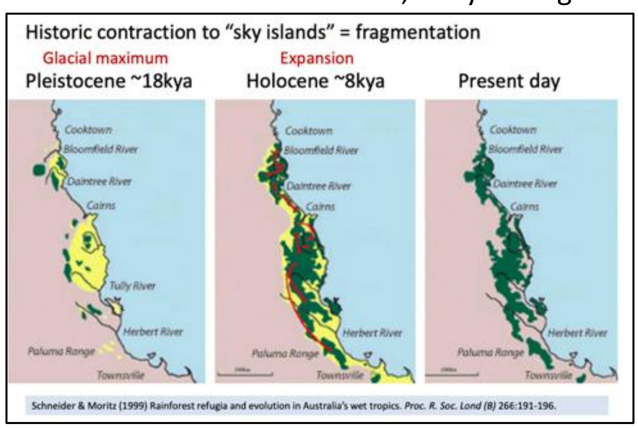
Allopatric Speciation

- A new species arises when a sub-population is geographically isolated from its parent population.
- Populations which are geographically isolated for along period of time and they subsequently evolve reproductive isolation
- No gene flow is happening between these populations
- Allo Gr. ~ 'different' Patros Gr. ~ 'homeland'

Australia Example



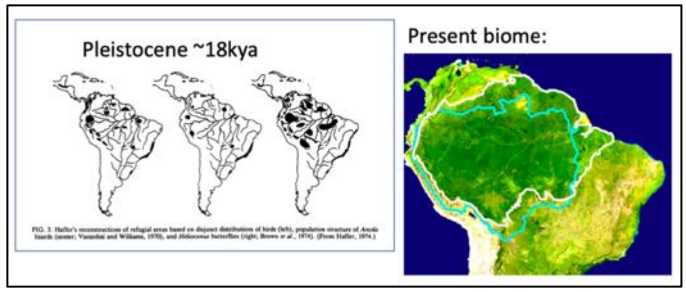
- Coast between Cook Town and Townsville
- Geography coupled with seasonal weather flow has generated this intensely rainforest-ed area
- Very large biodiversity area
- Numbers come from Wet Tropics Management Authority
- A large slab of Australia's biodiversity occurs in this small pocket of 0.12% of the landmass
- Particularly studied since the last glacial maximum – the Pleistocene = 18,000 years ago



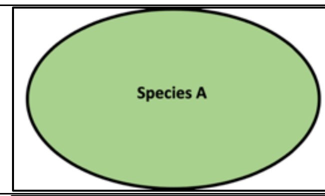
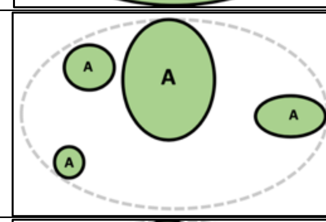
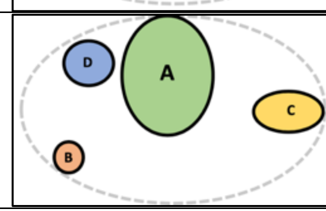
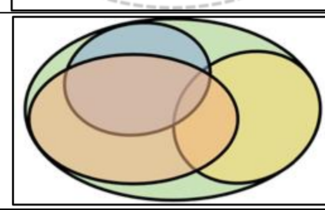
- The rainforest contracted in the ice age but there was also a fragmentation
- It then expanded by the Holocene and slightly contracted a bit in the present day
- So if we go from a situation with continuous rainforest situations that housed an above average number of species into a fragmented situation where those species are forced into refugia, slices of each population are fragmented and unable to change genes, and you have the perfect situation for speciation to occur

Amazon Example

- Similar history of contraction then expansion in the Amazon.
- Refugial maps for different species of birds (left), lizards (middle), butterflies (right)
- Same situation of habitat fragmentation
- So species potentially isolated and they evolved into completely different species

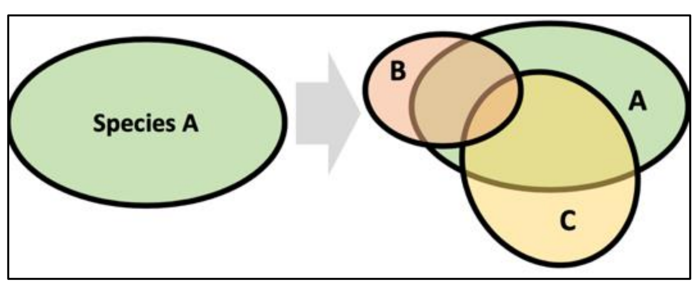


Process of Allopatric Speciation

1. Original widespread distribution of species A	
2. Habitat constriction = fragmented populations	
3. Over time, fragmented populations diverge and become separate species (A, B, C, D)	
4. Subsequent habitat expansion = species then evidently sympatric *And then no longer able to interbreed under natural conditions*	

Sympatric Speciation

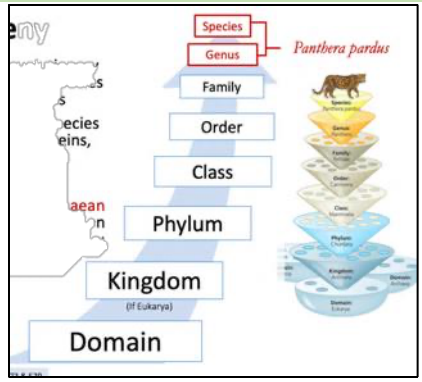
- A new species arises from a subset of the population without geographic separation.
- Different species arise from within the common range of an existing population.
- A single species can give rise to multiple species but without any process of geographic isolation or fragmentation



8. Phylogenies

Phylogeny

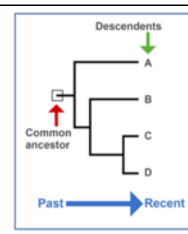
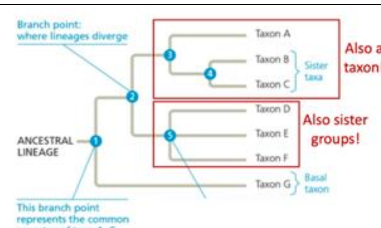
- Phylogeny – The historical evolutionary relationship among species or **higher-level** groups
    - (or sometimes sub-species phenomena like proteins, nucleic acids or genes)
- First, recall the Linnaean hierarchical classification scale:

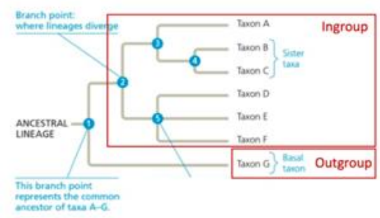
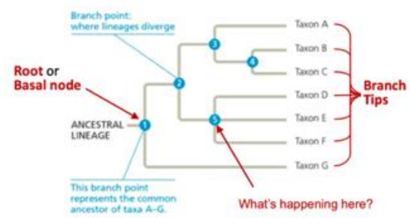
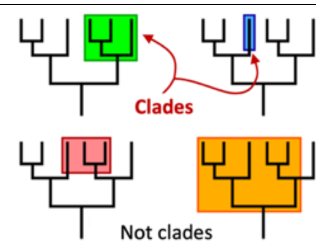


Phylogenetic Trees

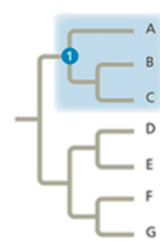
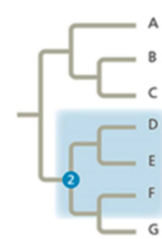
- Used to illustrate the connection between **classification** and **phylogeny**
- Visual representation of the evolutionary relationships among species and broad groups of organisms
- Each lineage has ancestors that are unique to that lineage as well as ancestors they share with other lineage.

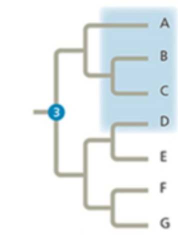
Reading Phylogenetic Trees

Stem	Represents the ancestor	
Branches	Represent descendants (or lineages)	
Tree left to right or down to up	Represents passage of time	
Taxon/taxa	Group of organisms (species, genus, phylum)	
Sister groups	Two (or more) taxa that split from the same node Share the most recent common ancestor	
Ingroup	Taxa of interest	

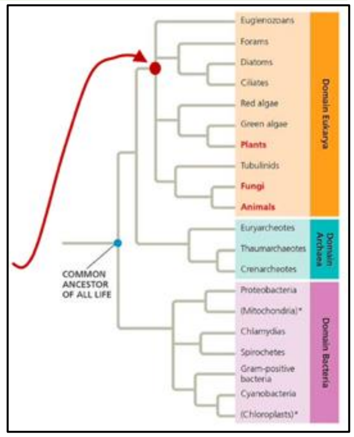
	The group of taxa at any hierarchical level (family, genera, species, etc) at the end point of the phylogeny in which we are making comparisons among individuals/node sin the group	
Outgroup	Taxon outside the group of interest The control or distantly related group of members	
Tips of trees	Descendants	
Root of tree/basal node	Ancestor – the most fundamental branch point	
Fork	Node where two or three individuals evolve and diverge from a taxonomic node	
Clade	A monophyletic group; that is, a group consisting of an ancestor and all descendants. A self-contained unit within a phylogeny including all the descendants of interest and all their ancestors and the basal common ancestor for that group	

Phylogenetic Classifications

Monophyletic group	• Indicated as the shaded region including the 3 descendant species (A,B,C) plus their common ancestor. • A group tracing to a single node	
Paraphyletic group	• Includes three descendant species (D,E,F) plus their common ancestor, but omits all descendants (i.e., species G left out). • We have a series of descendants from a common ancestor but not all of them	

Polyphyletic group	• Including four descendant species (A,B,C,D) but excludes their common ancestor • Excluding the common ancestor of the descendants	

Unresolved Phylogeny and Polytomy

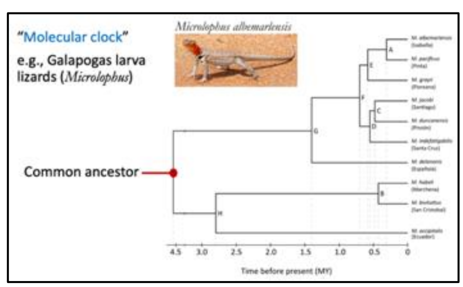


- Where the precise relationships cannot be determined, the phylogeny is referred to as unresolved.
- Such points are represented by polytomy
- Speciation or group segregation is likely to happen overtime
- A scenario where a single species generates multiple new divergent branches instantaneously is highly unlikely
- We cannot necessarily infer the order in which groups diverged, so we leave them as diverging simultaneously and refer to them as an unresolved node of the phylogeny called the **polytomy**
- Polytomy – the divergence from a particular node that involves more than a binary split

Molecular Clock – Branch Lengths Can Represent Evolutionary Time

- If we assume that the rate of change in a common genome in the common ancestor happens constant over time, then we would expect changes/divergence from that common sequence to accumulate at a steady rate throughout evolutionary history
- We can make these inferences on the differences in contemporary species that we can find the genotype of
- So we can make inferences based on this idea of molecular clock in terms of amount of absolute deviation in the genome across the group of species
    - The differences in the genome
- Idea of calibrating the x-axis and variation of branch lengths is often informed by the knowledge we have of molecular differences between species across the phylogenies and referred to as a concept of the molecular clock
- Requires a bit more information (not always present) to put into the phylogeny

Galapagos Larva Lizards Example



- Galapagos larva lizards
- Phylogeny based on DNA and molecular knowledge, and knowledge of where the species exist across the Galapagos in relation to when the islands first appeared