Marine Science Lesson Enhancements
based on **Grade 11 & 12 curriculum** in
Physics, Chemistry & Biology

Evolution in Action

Ocean Explorer

Module 11

Bayworld Centre for Research & Education

Overview

1 - The Theory of Evolution

Evolution is the process by which populations and species change over time and the principles of evolution explain why life on Earth is so diverse and why organisms are the way they are.

Info +

Evolution rates

Changes within a population happen when new generations are born. Children are always a little different from their parents, and this is how a population is evolving, thanks to these changes. This is why evolution is calculated in generations, and bacterias evolve much faster than elephants !

Descent with modification

Biological evolution, simply put, is descent with modification. This definition encompasses small-scale evolution (changes in gene frequency in a population from one generation to the next) and large-scale evolution (the descent of different species from a common ancestor over many generations).

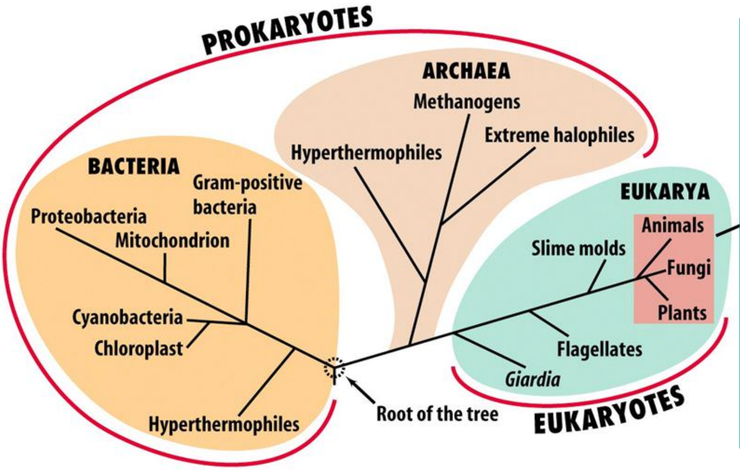
The central idea of biological evolution is that all life on Earth shares a common ancestor, just as you and your cousins share a common grandmother.

Through the process of descent with modification, the common ancestor of life on Earth gave rise to the fantastic diversity that we see documented in the fossil record and around us today. Evolution means that we're all distant cousins: humans and oak trees, hummingbirds and whales.

A huge family tree

The process of evolution produces a pattern of relationships between species. As lineages evolve and split and modifications are inherited, their evolutionary paths diverge. This produces a branching pattern of evolutionary relationships.

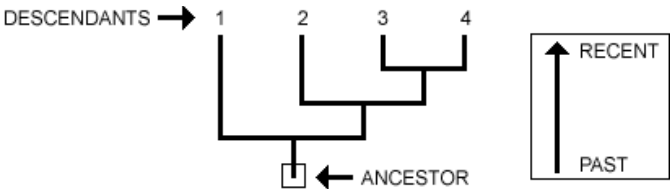
By studying inherited species' characteristics and other historical evidence, we can reconstruct evolutionary relationships and represent them on a "family tree" called a **phylogeny**.



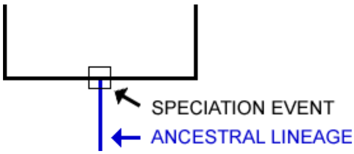
This diagram represents the 3 domains of life in which all life on Earth is classified.
Plants and animals are only a small part of one of these domains, the vast majority of life is made out of other small organisms such as bacterias !

Understanding Phylogeny

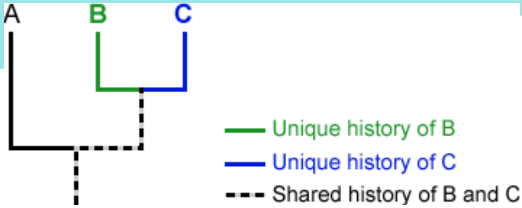
It is like reading a family tree. The root of the tree represents the ancestral lineage, and the tips of the branches represent the descendants of that ancestor. As you move from the root to the tips, you are moving forward in time.



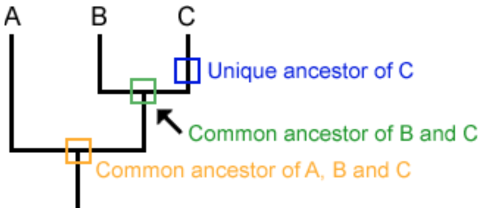
When a lineage splits (speciation), it is represented as branching on a phylogeny. When a speciation event occurs, a single ancestral lineage gives rise to two or more daughter lineages.



Phylogenies trace patterns of shared ancestry between lineages. Each lineage has a part of its history that is unique to it alone and parts that are shared with other lineages.

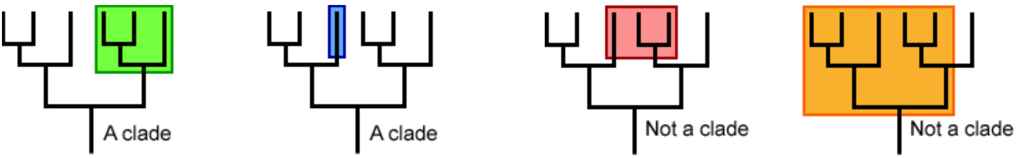


Similarly, each lineage has ancestors that are unique to that lineage and ancestors that are shared with other lineages. These are named **common ancestors**.

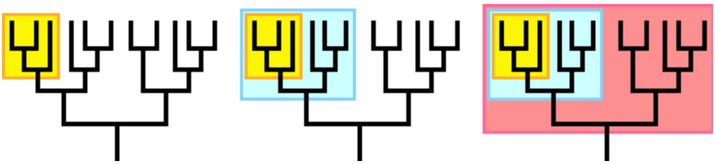


What is a "clade"?

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



Clades are nested within one another. A clade may include many thousands of species or just a few.

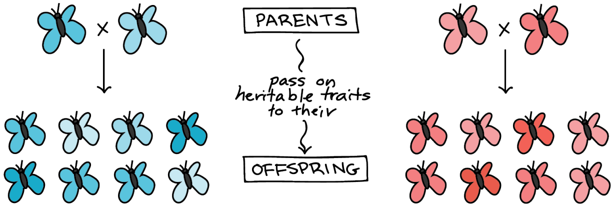


2 - What is Natural Selection ?

Natural selection is one of the basic mechanisms of evolution, along with mutation, migration, and genetic drift.

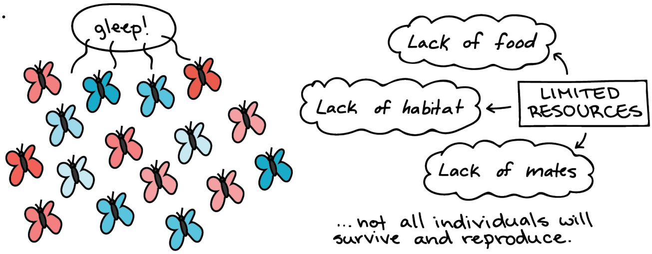
Natural Selection is based on 3 observations :

- **Traits are often heritable.** In living organisms, many characteristics are inherited, or passed from parent to offspring.

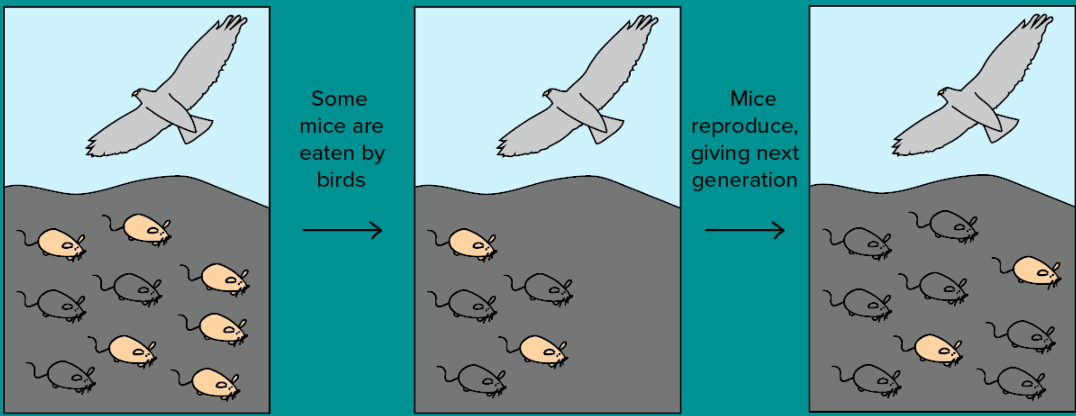


- **Offspring vary in their heritable traits.** The offspring in any generation will be slightly different from one another in their traits (color, size, shape, etc.), and many of these features will be heritable.

- **More offspring are produced than can survive.** Organisms are capable of producing more offspring than their environments can support. Thus, there is competition for limited resources in each generation.



An example of Natural Selection : Predation onto a mice population



A population of mice has moved into a new area where the rocks are very dark. Due to natural genetic variation, some mice are black, while others are tan.

Tan mice are more visible to predatory birds than black mice. Thus, tan mice are eaten at higher frequency than black mice. Only the surviving mice reach reproductive age and leave offspring.

Because black mice had a higher chance of leaving offspring than tan mice, the next generation contains a higher fraction of black mice than the previous generation.

3 - Evolution in ecosystems and the Red Queen hypothesis

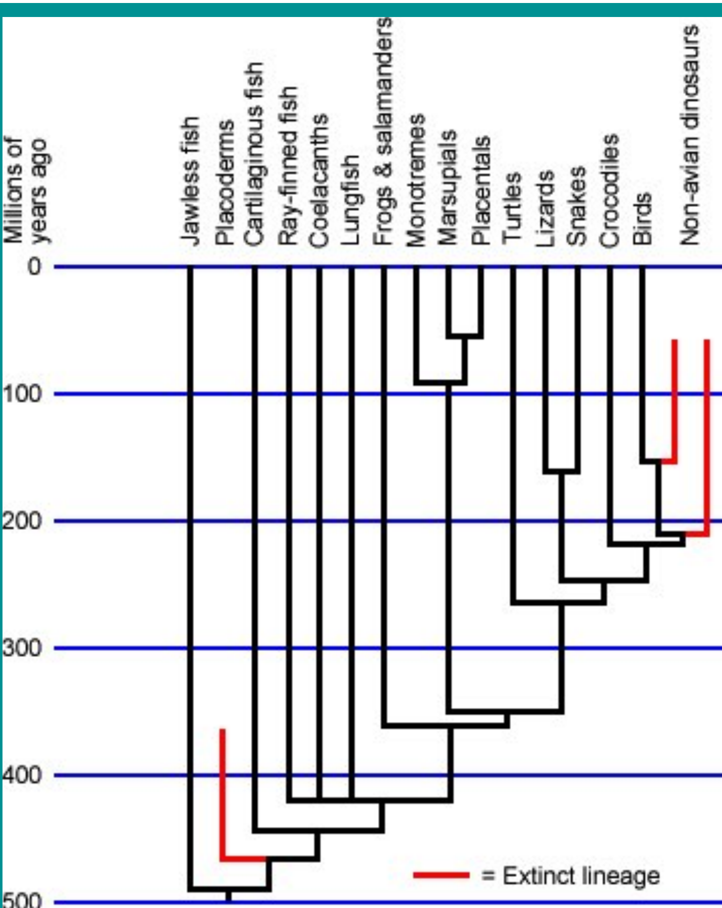
The Red Queen hypothesis is named after Lewis Carroll's character who, in the book "Through the Looking Glass," described her country as a place where "it takes all the running you can do, to keep in the same place."

In biology, this means that animals and plants don't just disappear because of bad luck in a static and unchanging environment, like a gambler losing it all to a run of bad luck at the slot machines. Instead, they face constant change, such as a deteriorating environment and more successful competitors and predators, that requires them to continually adapt and evolve new species in order to survive.
In short, if a species doesn't carry on evolving, it will disappear.

Time and Trees

In order to represent the time spent by organisms on Earth, one can make a phylogenetic tree with different branch lengths. These branches will start when the species appeared on Earth (usually known by fossils that we can date back to certain time), and stop when it goes extinct.

As it is difficult to squeeze the 3.5 billion years of the history of life on Earth into a single tree, scientists do not talk about evolution in years but in million years.



Vertebrate evolution

This tree represent only a small clade on the tree of life. The lengths of the branches have been adjusted to show when lineages split and went extinct.

All lineages alive today reach the top of the graph while others stop at different height depending when they went extinct.

4 - Phylogenetic trees and classification

Biologists use phylogenetic trees for many purposes, including :

- Testing hypotheses about evolution
- Learning about the characteristics of extinct species and ancestral lineages
- Classifying organisms

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Linnaean system of classification

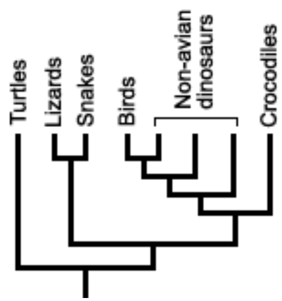
This is the oldest classification system in biology. It assigns every organism a kingdom, phylum, class, order, family, genus, and species, hence the scientific name of species such as "Homo sapiens" made of a genus ("Homo") and a species ("sapiens"). Careful : scientific names are always written in italic and with a capital letter for the genus only !

Using phylogenies as a basis for classification is a relatively new development in biology.

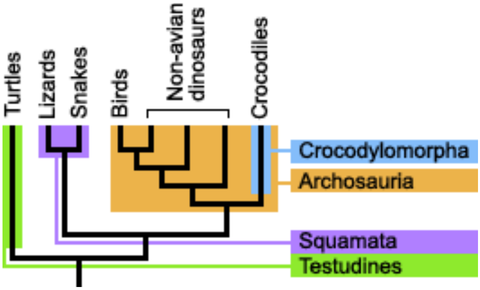
Most of us are accustomed to the Linnaean system of classification. This system was created long before scientists understood that organisms evolved. Because the Linnaean system is not based on evolution, most biologists are switching to a classification system that reflects the organisms' evolutionary history.

The phylogenetic classification system

The phylogenetic classification system names only clades, groups of organisms that are all descended from a common ancestor. As an example, we can look more closely at reptiles and birds.

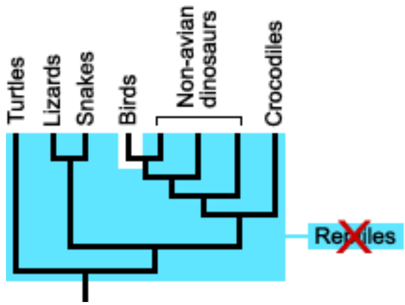


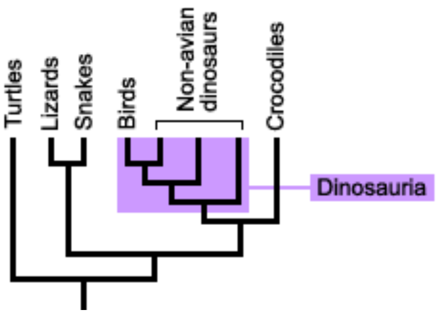
Reptiles and birds phylogenetic tree



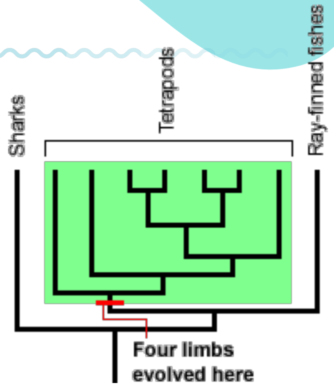
Under a system of phylogenetic classification, we could name any clade on this tree. For example, the Testudines, Squamata, Archosauria, and Crocodylomorpha all form clades.

However, the reptiles do not form a clade, as shown in the tree. That means that either "reptile" is not a valid phylogenetic grouping or we have to start thinking of birds as reptiles.





Another cool thing about phylogenetic classification is that it means that dinosaurs are not entirely extinct. Birds are, in fact, dinosaurs (part of the clade Dinosauria). It's pretty neat to think that you could learn something about *T. rex* by studying birds !



Since a phylogenetic tree is a hypothesis about evolutionary relationships, we want to use characters that are reliable indicators of common ancestry to build that tree. We use **homologous characters**. An example of homologous characters is the four limbs of tetrapods. Birds, bats, mice, and crocodiles all have four limbs. Sharks and bony fish do not. The ancestor of tetrapods evolved four limbs, and its descendants have inherited that feature so the presence of four limbs is a homology.

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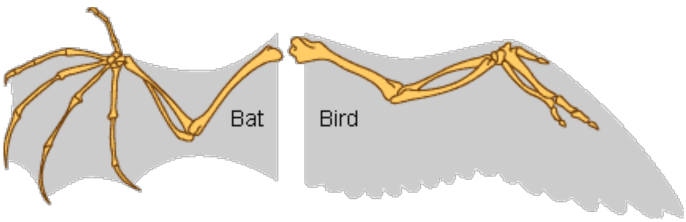
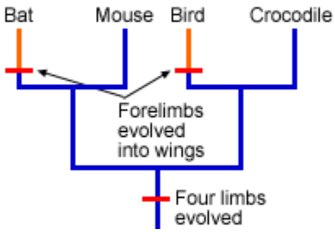
Homologous characters : *characters in different organisms that are similar because they were inherited from a common ancestor that also had that character.*

Not all characters are homologies. For example, birds and bats both have wings, while mice and crocodiles do not. Does that mean that birds and bats are more closely related to one another than to mice and crocodiles ? No. When we examine bird wings and bat wings closely, we see that there are some major differences.





Bat wings consist of flaps of skin stretched between the bones of the fingers and arm. Bird wings consist of feathers extending all along the arm. These structural dissimilarities suggest that bird wings and bat wings were not inherited from a common ancestor with wings.

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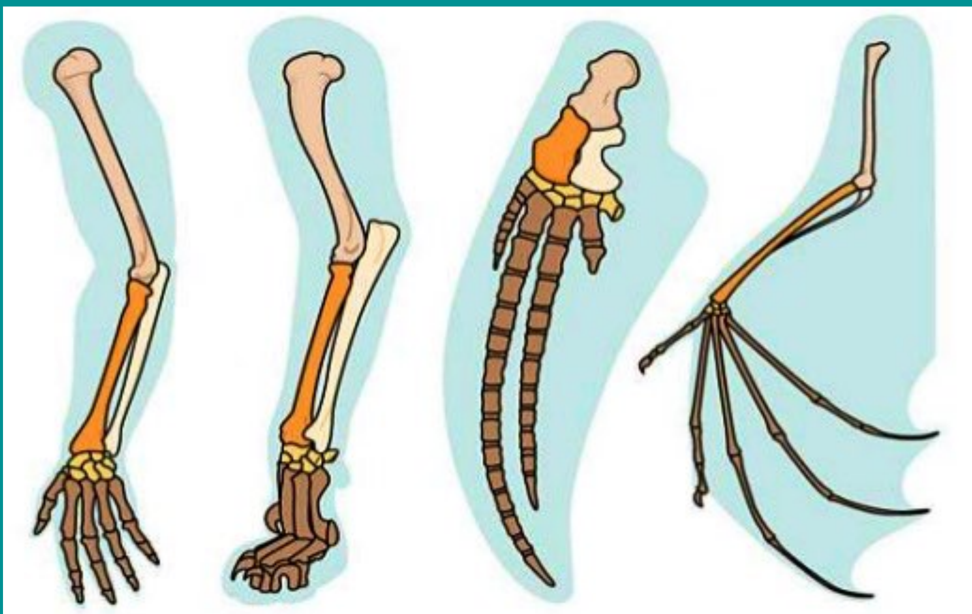
Analogous characters :
characters that have separate evolutionary origins, but are superficially similar because they have both experienced natural selection that shaped them to play the same key role.

Bird and bat wings are **analogous**, they are both shaped for flight. Analogies are the result of convergent evolution.

Interestingly, though bird and bat wings are analogous as wings, as forelimbs they are homologous. Birds and bats did not inherit wings from a common ancestor with wings, but they did inherit forelimbs from a common ancestor with forelimbs.

Homology of the forelimb in 4 different species

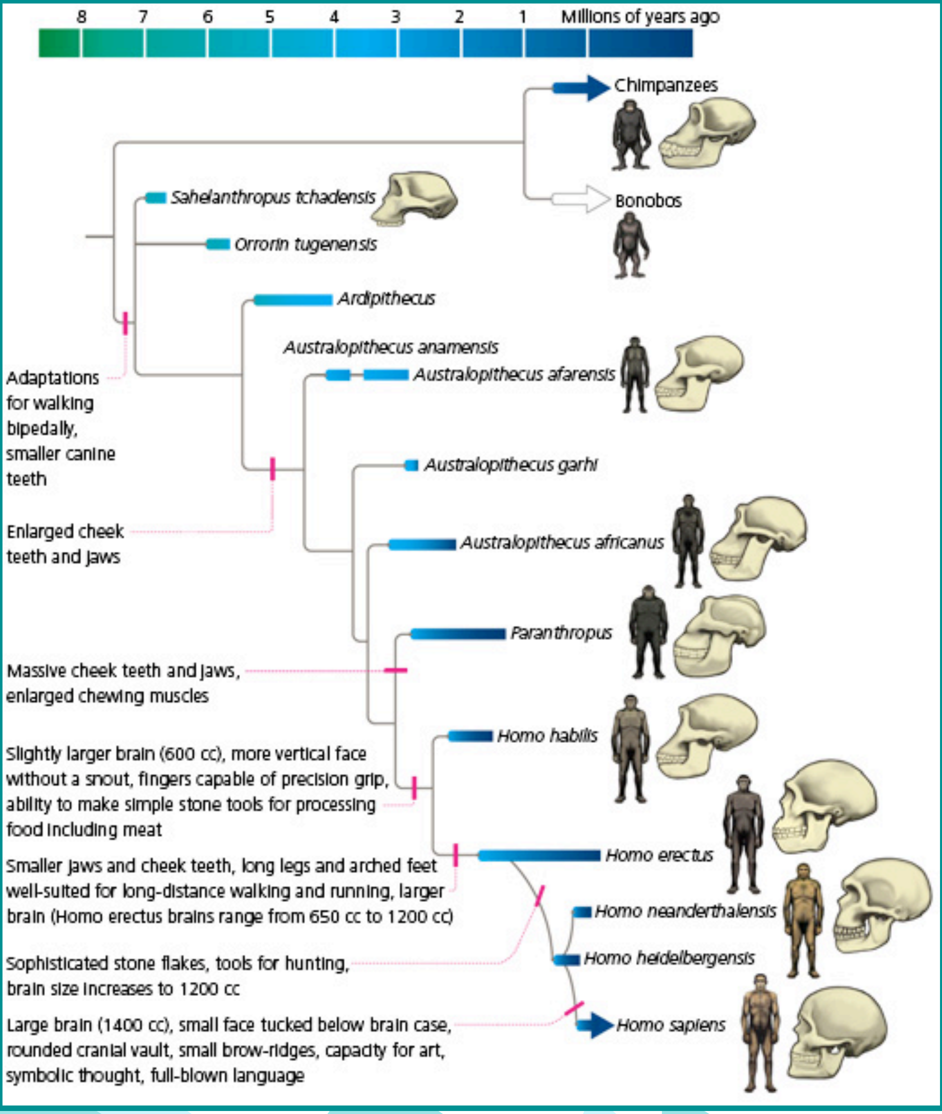
The bony structure of the forelimb has been inherited from a common ancestor to all tetrapods (4 legged animals). This is the reason why even though the bones do not have exactly the same morphology depending on the walking/running/flying/swimming adaptation of the animal, it is still possible to find the same number of bones and their organization within the limb for each tetrapod animal.



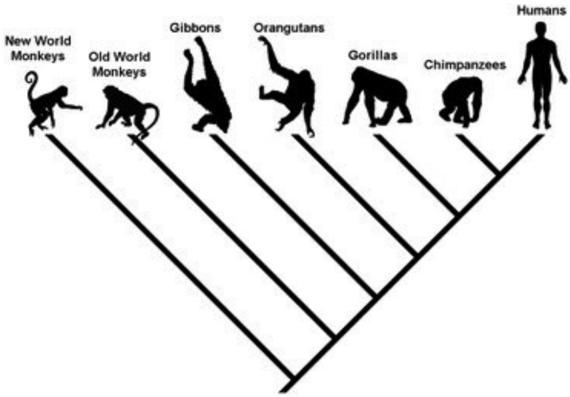
Human *Cat* *Whale* *Bat*

Humans are part of the tree of life, like any other species on Earth.

The human phylogenetic tree, including our extinct cousins
There used to be a wide diversity of species within the Ape family. Humans were not the only hominids to ever live on Earth.



Although scientists do not always agree on the relationships between the different hominid species, there is a consensus on the fact that Humans have evolved from a common ancestor of the Ape family. Humans are Apes.



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Hominids :

Primates of the family Hominidae, whose only living members are modern humans. Hominids are characterized by an upright gait, increased brain size and intelligence, a flattened face, and reduction in the size of the teeth and jaw. Besides the modern species Homo sapiens, hominids also include extinct species of Homo (such as H. erectus) and the extinct genus Australopithecus.

Bipedal stance

Much discussion in human palaeontology surrounds the evolution of a bipedal, upright stance. When and why did this occur ? One thing to keep in mind is that "bipedal" and "upright" are not equivalent terms. An animal can be bipedal without having a vertical backbone (think *T. rex*). From the fossil record of hominids, habitual bipedality preceded the evolution of a recurved spine and upright stance.

***Homo* evolution**

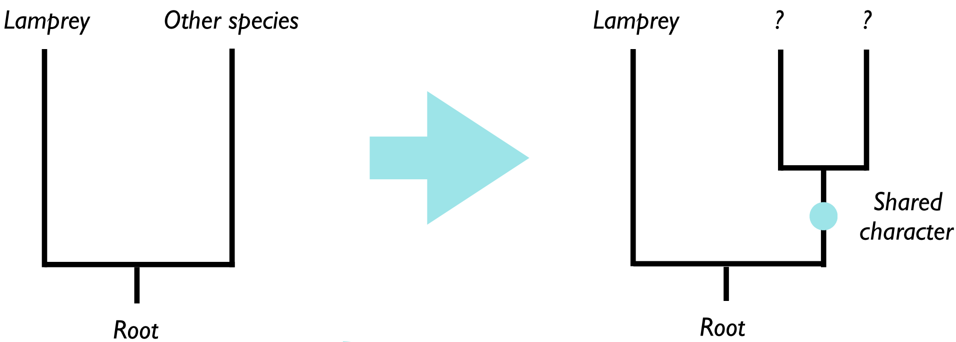
By the time the animals known as *Homo* evolved, they could make tools, and their hands were well suited for complex manipulations. These features were accompanied by the reduction of the lower face (jaws and teeth), the recession of the brow, the enlargement of the brain, the evolution of a more erect posture, and the evolution of a limb more adapted for extended walking and running (along with the loss of arboreally oriented features). Yet each of the *Homo* species was unique in its own way, so human evolution should not be seen as a simple linear progression of improvement toward our own present-day form.

Questions

1 - Look at the table below. It indicates character states for each animal. This is called a matrix and it is used by scientists to build phylogenetic trees. According to the characteristics of each animal shown in the matrix, which ones are closest together ?

Characters	Fur/hair	Lungs	4 legs	Jaws	Gizzard	Feathers
African penguin	No	Yes	Yes	Yes	Yes	Yes
Dolphin	Yes	Yes	Yes	Yes	No	No
Antelope	Yes	Yes	Yes	Yes	No	No
Sea bass	No	No	No	Yes	No	No
Lamprey	No	No	No	No	No	No
Alligator	No	Yes	Yes	Yes	Yes	No

2 - Which animal has none of these characteristics ? Start drawing your tree, starting with this animal. You can look at the explanation on the next page for help.



3 - Then look at your matrix : which character is shared by most animals ? Add it to your tree, on the "other species" side.

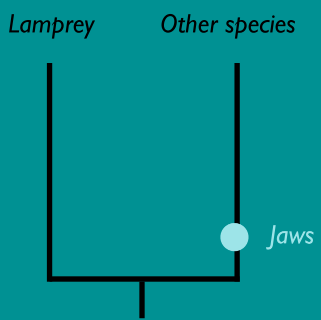
4 - Build your tree by grouping the species together depending on their characteristics. You must finish without having to place one character twice on the tree.

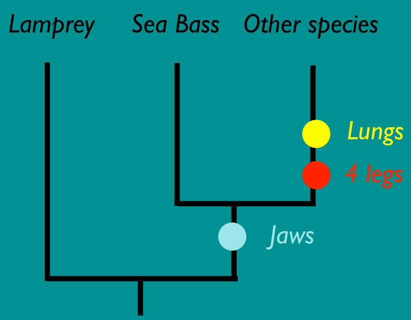
5 - Where is the dolphin on your tree ? According to its position, do you think it is a fish or a mammal ?

6 - Is there a characteristic that is a particularity of one animal only ? If yes, which one ? Do you think they help to build a tree ? Explain.

How to build a tree

Start building our tree by grouping organisms according to their shared derived features. A good place to start is by looking for the derived trait that is shared between the largest number of organisms. In this case, that's the presence of jaws : all the organisms except the lamprey have jaws. So, we can start our tree by drawing the lamprey lineage branching off from the rest of the species, and we can place the appearance of jaws on the branch carrying the non-lamprey species.





Next, we can look for the derived trait shared by the next-largest group of organisms. This would be lungs and 4 legs, shared by the antelope, penguin, dolphin, and alligator, but not by the sea bass. Based on this pattern, we can draw the lineage of the sea bass branching off, and we can place the appearance of lungs and 4 legs on the lineage leading to the other species.

And carry on with the remaining characters !