Vertebrate Diversity study pack

The following web-book contains a series of information chapters broadly outlining the diversity of living vertebrates, with a few notes on their fossil relatives. Below is a collage of specimens from UCL's Grant Museum of Zoology illustrating the wide diversity covered in this web-book – from jawless vertebrates, sharks, and ray-finned fishes, to amphibians, reptiles, and mammals.

To **download** this resource as a single file, see the collection page: <https://open-education-repository.ucl.ac.uk/id/eprint/204>

Also see the related resource **Vertebrate Palaeontology and Evolution** study pack here: <https://open-education-repository.ucl.ac.uk/id/eprint/195>









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# Introduction

The first chapter considers the lampreys - a [clade](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_clade) of jawless vertebrates that are thought, based on analysis of their morphology, to be the group that first diverged from the remaining vertebrate [clades](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_clade).

Subsequent chapters follow a structure that roughly reflects the evolutionary relationships (or [phylogeny](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_phylogeny)) between the higher level vertebrate groups - for example, the turtles, lizards, tuatara, crocodiles, and birds are all reptiles and, as such, their chapters are clustered together. This structure need not imply any increase in complexity or morphological "progress" as one descends through the chapters - indeed, every [taxon](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_taxon) discussed in this web-book is [extant](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_extant), meaning that it has some members that are still living, and are therefore also evolving under the selection pressures of their current environment. Rather, the structure reflects the greater focus of this web-book on those four-limbed vertebrates (tetrapods) whose ancestors colonised the terrestrial world in the Devonian swamps of nearly 400 million years ago - in particular the hair-covered, milk-producing mammals.

While the structure of the web-book may not always act as an accurate representation of the evolutionary history of vertebrates, the phylogenetic tree below illustrates how all the major vertebrate [clades](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_clade) are thought to be related.



Adapted from Meyer & Zardoya (2003), this is a conservative estimate of vertebrate [phylogeny](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_phylogeny), reflecting the prevailing consensus between morphological and molecular data. Conflict between morphology and molecules is manifest at the unresolved nodes, or polytomies - those nodes that are formed when greater than two branches coalesce.

For example, the most popular view of morphologists is that lampreys represent the closest living relatives of the jawed vertebrates (Gnathostomata), together forming the Vertebrata. This hypothesis excludes hagfishes from the vertebrates on the basis that they do not possess some of the derived morphological features shared by lampreys and gnathostomes - in particular, they lack a vertebral column. Instead, hagfishes are placed as the sister group to the vertebrates, together forming the Craniata (or craniates) - animals possessing a skull, or cranium. This view of craniate evolution makes the living jawless vertebrates, or agnathans, a [paraphyletic](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#paraphyletic) group. This means that the jawless vertebrates do not form a natural (or [monophyletic](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_monophyletic)) grouping, as their most recent common ancestor is not unique to them - it is shared with the jawed vertebrates as well.

In contrast, molecular data tend to group the lampreys and hagfishes to the exclusion of the gnathostomes, making the living agnathans a [monophyletic](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_monophyletic) group termed Cyclostomi. Under the cyclostome hypothesis, it is presumed that the common ancestor of the cyclostomes and gnathostomes possessed a vertebral column, which was subsequently lost in the evolution of the hagfishes.

Despite the disparities between morphological and molecular data evident from the [cladogram](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossar_cladogram) above, the evolutionary history of the vertebrates is fairly well resolved, with many major traditionally identified groupings persisting through recent advances in methods for phylogenetic inference and the advent of molecular systematics. Consequently, this tree should be used as a working guide while exploring the [taxa](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_taxon) described within the web-book, providing an evolutionary context that highlights the shared ancestry of the different vertebrate lineages, as well as helping to trace some of the evolutionary innovations that gave rise to the many different forms - including the origin of jaws, ossification of the endochondral skeleton, evolution of terrestrially adapted limbs, and the amniotic egg.

# Chondrichthyes

**Chondrichthyes - cartilaginous fishes**

|  |
| --- |
| Vertebrata; Gnathostomata; **Chondrichthyes** |

|  |  |  |  |
| --- | --- | --- | --- |
| Show Torpedo ray - dorsal view ImageTorpedo ray - dorsal view  | Show Torpedo ray - ventral view showing toothplate ImageTorpedo ray - ventral view showing toothplate  | Show Torpedo ray - ventral close-up showing pelvic claspers ImageTorpedo ray - ventral close-up showing pelvic claspers  |  |

## Diversity and Lower Taxonomy

The class Chondrichthyes comprises almost 1050 [extant](#_extant) species ofcartilaginous fishes, encompassing skates, sharks, rays, andchimaeras. The class contains 12 orders which are divided between 2 [monophyletic](#_monophyletic) subclasses, the Elasmobranchii(sharks, rays and skates) and Holocephali(chimaeras). With the Holocephali now represented by only ~40 living species of chimaera in the single order Chimaeriformes, the vast majority of [extant](#_extant) chondrichthians are elasmobranchs, and are divided between 11 orders. Although traditional classifications separated the elasmobranchs into two groups, the sharks and the batoids (rays and skates), Campagno (1973, 1977) recognised four distinct groupings on the basis of phenetics (overall similarity), and identified these as the four elasmobranch superorders as follows:

* Subclass **Elasmobranchii** (sharks, rays and skates)
	+ Superorder **Batoidea** (over 500 species of rays and skates):
		- Order **Rajiformes** (common rays and skates)
		- Order **Pristiformes** (Sawfish)
		- Order **Torpediniformes** (electric rays)
	+ Superorder **Squalomorphii:**
		- Order **Hexanchiformes**: containing 5 [extant](#_extant) species within 2 families, the **Hexanchidae**(cow shark) and **Chlamydoselachidae** (frilled shark), distinguished by their additional gill slits (either six or seven).
		- Order **Squaliformes**: containing 80 species divided into 3 families: **Echinorhinidae**(Bramble Sharks), **Squalidae** (Dogfish sharks) and **Oxynotidae** (Roughsharks).
		- Order **Pristiophoriformes**: containing 5 species within a single family,**Pristiophoridae**(sawsharks).
	+ Superorder **Squatinomorphii:**
		- Order **Squatiniformes**: containing 13 species in 1 family, **Squatinidae** (Angel sharks).
	+ Superorder **Galeomorphii:**
		- Order **Heterodontiformes**: 8 species in 1 family, **Heterodontidae** (bullsharks).
		- Order **Orectolobiformes**: 7 families are found within this order: **Brachaeluridae** (blind catsharks and blind sharks), **Ginglymostomatidae** (nurse sharks), **Hemiscylliidae**(bamboo sharks and longtailed carpetsharks), **Orectolobidae** (wobbegongs),**Parascyllidae** (collared carpetsharks), **Rhincodontidae** and **Stegostomatidae**(zebra sharks).
		- Order **Carcharhiniformes**: this is the largest order containing approximately 200 species within 8 families: **Carcharhinidae** (requiem sharks), **Hemigaleidae** (weasel sharks),**Leptochariidae**(barbeled houndsharks), **Proscylliidae** (finback catsharks), **Pseudotriakidae**(false cat sharks),**Scyliorhinidae** (cat sharks), **Sphyrnidae** (bonnethead sharks, hammerhead sharks, and scoophead sharks), **Triakidae** (houndsharks, smooth-hounds, topes, and whiskery sharks).
		- Order **Lamniformes**: known as mackerel sharks, this order contains 7 families and 16 species:**Alopiidae** (thresher sharks), **Cetorhinidae** (basking sharks), **Lamnidae** (mackerel sharks, porbeagles, and white sharks), **Megachasmidae** (megamouth sharks),**Mitsukurinidae** (goblin sharks), **Odontaspididae** (goblin sharks, sand sharks, and sand tiger sharks) and **Pseudocarchariidae** (crocodile sharks)
* Subclass **Holocephali** (chimaeras)
	+ Order **Chimaeriformes**: 40 species in 6 genera and three families, **Callorhinchidae**,**Chimaeridae** and **Rhinochimaeridae.**

Following this view of chondrichthian classification, Maisey (1980) adopted a more phylogenetic approach, identifying a potential shared derived morphological charcater between the squalomorph and squatinomorph sharks - an [orbit](#_Orbit)al process in the eye socket protruding from the upper-jaw [c](http://www.ucl.ac.uk/museums-static/obl4he/vertebratediversity/glossary.html#zoomoodle_glossary_cartilage)artilage. This [synapomorphy](#_synapomorphy) was used to unite these two superorders in a group termed the "[orbit](#_Orbit)ostylic" sharks, to the exclusion of the galeomorphs and batoids. Further, the galeomporphs were proposed as the sister group to the [orbit](#_Orbit)ostylic sharks, resulting in a return to the traditional view that sharks and batoids represent separate natural groupings (see [cladogram](#_cladogram) below).



This view was strongly contested in the following decade, with many morphological phylogenetic studies (Shirai, 1992, 1996; de Carvalho, 1996) gathering support for the **hypnosqualean hypothesis**, which states that batoids (rays and skates) are in fact derived sharks, grouped with the Pristiophoriformes and Squatinomorphii in the [clade](#_Clade) "Hypnosqualea" (see [cladogram](#_cladogram) below). The remaining squalomorph orders (Squaliformes and Hexanchiformes) then grouped (whether as a clade or grade) nearest to the Hypnosqualea, to form the "Squalea", which formed the sister group to the remaining elasmobranchs - the [monophyletic](#_monophyletic) Galeomorphii. In addition to the controversial proposal that sharks are in fact [paraphyletic](#_Paraphyletic) with respect to rays and skates, these studies were significant in that they began to identify the fragility of the superorder Squalomorphii as a natural grouping, in these instances containing both the batoids and the squatinomorphs. This, over time, has led to the breakdown of the Squatinomorphii as a distinct elasmobranch superorder, with its single order (Squatiniformes) being redefined as an order within a newly defined Squalomorphii (containing its original three orders plus Squatiniformes).



Since the turn of the millenium, a wealth of molecular studies starting with Douady et al (2003) have brought about a new view of elasmobranch [phylogeny](#_phylogeny) that strongly and consistently rejects the hypnosqualean hypothesis, and returns to the classically held view that sharks form a [monophyletic](#_monophyletic) group, the Selachimorpha, which is sister to the rays and skates (Batoidea). Within Selachimorphi, there has been repeated support for the [monophyly](#_monophyletic) of the new Squalomorphii containing squatiniform sharks (Douady et al, 2003; Winchell et al, 2004; Naylor et al, 2005; Mallatt et al, 2007; Heinicke et al, 2009; Vélez-Zuazo & Agnarsson, 2011). Note that this newly defined Squalomorphii is equivalent in terms of membership to the [orbit](#_Orbit)ostylic sharks. The phylogenetic positions of the remaining four orders (galeomorph sharks) have, in contrast, been less consistent. While some studies have recovered amonophyletic Galeomorphii (Heinicke et al, 2009; Vélez-Zuazo & Agnarsson, 2011), others have placed the Heterodontiformes as the closest living relative to the Squalomorphii (Winchell et al, 2004; Mallatt et al, 2007). Most molecular studies have, nonetheless, recovered the remaining galeomorph orders (Orectolobiformes, Carcharhiniformes, and Lamniformes) as a monophyletic grouping (see Douady et al, 2003 for exception), although the interelationships between these groups is still a matter of debate. The two cladograms below show recent conflicting views on the phylogeny of Selachimorpha based on DNA sequence data.



## Distribution and Habitat

Most chondrichthyans are **marine** species. Only 5% (approximately 45 species) are restricted to **freshwater**, such as the giant freshwater stingray, *Himantura chaophraya* (Fowler et al., 2005; Helfman et al., 2009). Others enter estuaries and freshwater sporadically, often to breed.

Members of the Chondrichthyes can be found in nearly all aquatic ecosystems and depths, except the most extreme conditions. But most species are restricted to and specialised for a particular oceanic zone. For example, the skates (members of Rajidae) and angel sharks (Squatinidae) are **benthic** species. The Lamnidae (white sharks) are **pelagic**, but in the upper depths only (Fowler et al., 2005). Approximately 50% of species inhabit the **continental slopes**, up to 200m, and 35% occupy depths between **200 - 2000m** (Helfman, 2009). Only 5% of species, mainly the large pelagic ones, inhabit the open ocean. For example, the mantarays (Myliobatiformes) make annual migrations, while the great white shark (*Carcharodon carcharias*) has been known to travel between South Africa and Australia (Fowler et al., 2005).

The **elasmobranchs** occcupy the widest range of habitats - even the icy waters of the Arctic and Antarctic Ocean. But their physiology cannot withstand the most extreme conditions such as high salinity or the oxygen deficient depths that some teleosts have become specialised to endure. Therefore most sharks do not inhabit very deep water, although some species have been sighted at depths up to 4000m (Helfman et al., 2009). The **Holocephali** are found only in temperate waters up to 2000m, and prefer the cooler depths below 80m (Fowler et al, 2005; Helfman et al., 2009).

Conservation Status (IUCN)

The 2008 IUCN Red List categorised **17% of chondrichthyan species (181/1044)** as **threatened with extinction**. The majority of these are in the lowest risk category (*Vulnerable*), but 42 species are *Endangered*, and 25 are placed within the highest risk category (*Critically Endangered*). The Squatiniformes (angelsharks) are the chondrichthyan order at greatest risk, with over half (12/22) of its species considered threatened with extinction (3x *Critically Endangered*, 5x *Endangered*, and 4x *Vulnerable*). Seven of the remaining ten species are *Data Deficient*, and so may themselves also be under threat.

Chondrichthyes are an ancient and successful [clade](#_Clade), having survived 400 million years of changing environments. Yet human presence and intervention has put them at risk. The life history of Chondrichthyes marks them as vulnerable to extinction. As a **K-selection** species, they give birth to only a few young after a long gestation, which grow slowly and reach sexual maturity late (Fowler et al., 2005). Although their rate of survival is usually high, if populations become rapidly depleted, recovery can be difficult and lengthy.

The primary threat to sharks, rays, and chimaeras is **fishing** (Fowler et al. 2005). Commercial demand for shark meat and fins is high and fisheries are unmanaged, pushing population levels to dangerously low numbers. Many species are also often killed as **by-catch** from bottom trawlers.

Loss of habitat is also a significant threat, and those species which inhabit regions closest to human activity are at most risk from habitat degradation and pollution. Estuaries, whose shallow waters provide invaluable nurseries for chondrichthyans are being destroyed or polluted. Similarly, certain freshwater systems are becoming increasingly degraded by pollution, making them inhospitable to indigenous species.

## Features

* Skeletons formed of calcified cartilage - no bone.
* Covered in placoid scales - a structure like teeth, with a dentine crown coated in an enamel-like material, a vascularised pulp cavity, and a bony base. They are sometimes referred to as denticles.
* True teeth, which are shed and replaced regularly in modern species.
* The males of all but the oldest fossil species have a pelvic clasper, used in courtship and mating. It is formed of the pelvic meta-pterygium - the basal cartilage of the pelvic fin.

# References

[**Chondrichthyes**](#_Chondrichthyes)

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# [Glossary](http://www.ucl.ac.uk/museums-static/obl4he/vertebratepalaeo/glossary.html)

## A

### akinetic

In anatomy, this refers to a low level of flexibility in a structure due to a lack of moveable joints.

### amniote

Those vertebrates with an amniotic egg. The [extant](#_extant) [clades](#_Clade) are Testudines (turtles), [Diapsida](#_diapsid) (lepidosaurians, crocodilians, and birds), and [Synapsida](#_synapsid) (mammals).

### anapsid

Skull possessing **no** **temporal fenestrae** (NB. an- = without).

[Amniotes](#_amniote) with this skull condition form a [paraphyletic](#_Paraphyletic) group including the Parareptilia (turtles and their extinct relatives), the extinct common ancestor of all [amniotes](#_amniote), and [basal](#_Basal)eureptiles (the extinct precursors of [diapsids](#_diapsid)).

Note that the Testudines (turtles and relatives) have modified the anapsid condition through a reduction (emargination) of the posterior region of the skull.

### Apatite

Calcium phosphate: the crystalline component of bone.

### apomorphy

A derived or specialised character.

### Appendicular skeleton

The endoskeletal element of the fins or limbs of a vertebrate, and their associated girdles (pectoral or pelvic).

### Axial skeleton

All parts of the vertebrate endoskeleton except the limbs or fins and their associated girdles. That is, the cranium, visceral skeleton, notochord, [vertebrae](#_vertebrae), and ribs.

## B

### Basal

Of, relating to, located at, or forming a base.

### Bicuspid

A tooth bearing two [cusps](#_Cusp).

## C

### Calcified cartilage

[Cartilage](#_Cartilage) strengthened with a scattering of [apatite](#_Apatite) crystals (calcium phosphate), as seen in Chondrichthians.

### Cartilage

A tough, elastic, fibrous connective tissue composed of collagen fibres. Used as skeletal tissue in vertebrates, it is non-mineralised and is often the developmental precursor of bone.

### Clade

A phylogenetic lineage comprising a common ancestor and all its descendant species.

Note that the difference between a [taxon](#_taxon) and a clade is that a clade must include all descendant species from a common ancestor, whereas a [taxon](#_taxon) need not.

### cladistic

Relating to the branching sequences of [phylogeny](#_phylogeny).

### cladogram

A branching tree-like diagram representing the phylogenetic relationships (evolutionary history) of a lineage.

### cloaca

The common opening for the reproductive, urinary, and digestive tracts, seen in all vertebrates except therian mammals (marsupials and placental mammals).

The term comes from the Latin for sewer.

### Cursorial

Adapted for running.

### Cusp

The biting point of a tooth.

## D

### Dentary

The anterior bone of the lower jaw which bears the teeth. It forms the whole of the lower jaw in mammals.

### Dentine

A bone-like substance, lacking cell bodies and consisting mainly of calcium phosphate ([apatite](#_Apatite)) in a fibrous matrix.

### Dermal bone

A type of bone forming within the dermis - the deep layer of vertebrate skin cells below the surface layer, the epidermis.

### diapsid

Skull possessing both an **upper and a lower** **temporal fenestra** (NB. di- = two).

[Amniotes](#_amniote) with this skull condition form the [monophyletic](#_monophyletic) [clade](#_Clade) **Diapsida**, which includes the lepidosaurs (lizards, snakes, and tuatara), archosaurs (crocodilians, dinosaurs, and birds), and their other extinct relatives.

Note that some diapsids, such as lizards, have lost the temporal bar separating the fenestrae to form one large window. Others, such as the Aves (birds), have merged both fenestrae with the [orbit](#_Orbit).

## E

### Enamel

The crystalline material covering the crown of a tooth, or certain scales.

### Endopterygota

A [clade](#_Clade) of insects charachterised by their undergoing complete metamorphosis (i.e. [holometabolous](#_Holometabolous)).

See Insect Diversity WebBook for the [clades](#_Clade) within (from Neuroptera down).

### Epidermal

Pertaining to, or originating from, the epidermis - the surface layer of skin cells in vertebrates

### euryapsid

Skull possessing an **upper** [**temporal fenestra**](#_temporal_fenestra) **only**.

However, animals with this skull condition do not represent an important [amniote](#_amniote) lineage, as they are likely to be a [polyphyletic](#_polyphyletic) group, originating a least twice within the [Diapsida](#_diapsid). [Euryapsids](#_euryapsid) include the plesiosaurs and ichthyosaurs - Mesozoic marine reptiles.

### extant

Not extinct.

## F

### fossorial

Specialised for burrowing.

### furcula

The fused clavicle bones of a bird, also known as the wishbone.

## H

### Hemimetabolous

Refers to a type of insect development that is categorised by three distinct, progressive life stages: egg, nymph, imago (adult). Changes are gradual, with no pupal stage.

Some hemimetabolous insects include grasshoppers, cicadas, cockroaches, termites, earwigs, and dragonflies.

Also termed incomplete metamorphosis.

### Holometabolous

Refers to a type of insect development that is categorised by four distinct, progressive life stages: embryo, larva, pupa, imago (adult).

Seen exlusively in the [Endopterygota](#_Endopterygota), which includes beetles, butterflies, wasps, bees, ants, and others.

Also termed complete metamorphosis.

### Horny

Consisting of horn - a tough material composed mainly of keratin.

## I

### ilium

In tetrapods, the dorsal section of the pelvis, which articulates with one or more sacral [vertebrae](#_vertebrae).

## K

### Kinetic

In anatomy, referring to a high level of flexibility afforded by numerous moveable joints.

## L

### Lymph heart

Muscular dilation in a lymph vessel, which pumps lymph (fluid containing white blood cells called lymphocytes important in immune response) around the body of some lungfishes, amphibians and reptiles.

## M

### Metacone

In mammals, the metacone is the distobuccal (rear-most and cheek side) cusp of an upper molar tooth.

### monophyletic

Having a single evolutionary origin. A [taxon](#_taxon) is monophyletic if it contains all the descendants of a common ancestor.

For example, mammals are a monophyletic group, as all species descended from the first known mammal are considered mammals.

See [paraphyletic](#_Paraphyletic) and [polyphyletic](#_polyphyletic) for alternative terms.

### Myrmecophagy

Feeding behaviour categorised by an exclusive (or near exclusive) diet of ants ant termites.

## O

### Orbit

The bony socket of the eye.

### Osteosclerosis

An increase in the density of bone.

## P

### Pachyostosis

A thickening of the bone, often associated with a reduction in the volume of marrow tissue contained within.

### Paracone

In mammals, the paracone is the mesiobuccal (front-most and cheek side) [cusp](#_Cusp) of an upper molar tooth.

### Paraphyletic

A [taxon](#_taxon) including a common ancestor and some but not all of its descendants.

For example, the class Reptilia is paraphyletic, as it does not include birds, who are considered a separate class: Aves. However, birds evolved from theropod dinosaurs, and are therefore reptiles themselves. Similarly, all tetrapods are, evolutionarily speaking, lobe-finned fish.

Importantly, reptiles can be made [monophyletic](#_monophyletic) through the addition of birds to the [taxon](#_taxon).

See [monophyletic](#_monophyletic) and [polyphyletic](#_polyphyletic) for alternative terms.

### Pectoral girdle

In vertebrates, the skeletal structure that provides support for the fore limbs or fins.

### Pelvic girdle

In vertebrates, the skeletal structure that provides support for the hind limbs or fins, which also fuses with the sacral [vertebrae](#_vertebrae).

### phylogeny

The evolutionary history of organismal lineages as they develop through time.

### plesiomorphy

An ancestral character.

### polyphyletic

Referring to a group that does not contain the common ancestor of all the [taxa](#_taxon) within. Therefore, this is not a true taxonomic group, but is often a term used to categorise organisms with a similar ecology, such as insectivorious mammals, or marine mammals.

It is also used when the evolutionary origin of a group, such as snakes, is unsure, and characteristic species within may have originated separately.

### Protocone

In mammals, the protocone is the mesiolingual [cusp](#_Cusp) of an upper molar tooth.

### Pulp cavity

The space within a tooth, or a [dentine](#_Dentine) scale, occupied by blood vessels and nerves.

## S

### symplesiomorphy

A character that is shared between groups but was inherited from an ancestor prior to the last common ancestor.

These are characters that - at the level at which they are referred to as sym[plesiomorphies](#_plesiomorphy) - are not used to form [cladistic](#_cladistic) groupings, or [clades](#_Clade).

### synapomorphy

A derived or specialised character that is shared between two or more groups, and was inherited from the common ancestor in which it originated.

These are the characters that morphological systematists use to support the existence of particular [clades](#_Clade), forming the basis of the field of [**cladistic**](#_cladistic)**s**.

### synapsid

Skull possessing a **lower** [**temporal fenestra**](#_temporal_fenestra) **only**.

[Amniotes](#_amniote) with this skull condition form the [monophyletic](#_monophyletic) [clade](#_Clade) **Synapsida**, which includes the mammals and their extinct ancestors, the non-mammalian reptile-like synapsids.

Note that in the Mammalia, the lower temporal fenestra has merged with the [orbit](#_Orbit).

## T

### taxon

A group of organisms sharing a common ancestry.

Note that the difference between a taxon and a [clade](#_Clade) is that a [clade](#_Clade) must include all descendant species from a common ancestor, whereas a taxon need not.

Pl. taxa.

### temporal fenestra

An opening in the temporal region of the skull seen in [amniotes](#_amniote), providing a flat edge for the attachment of strong lower jaw closing muscles to the skull.

[Amniotes](#_amniote) show **four skull types**, based on the position and number of these temporal fenestrae, two of which define two major lineages of the [amniotes](#_amniote). The skull types and associated groups are as follows:

1) [**Synapsid**](#_synapsid) - Skull possessing a **lower temporal fenestra only**. [Amniotes](#_amniote) with this skull condition form the [monophyletic](#_monophyletic) [clade](#_Clade) [**Synapsida**](#_synapsid), which includes the mammals and their extinct ancestors, the mammal-like reptiles. Note that in the Mammalia, the lower temporal fenestra has merged with the [orbit](#_Orbit).

2) [**Diapsid**](#_diapsid) - Skull possessing both an **upper and a lower** **temporal fenestra** (NB. di- = two). [Amniotes](#_amniote) with this skull condition form the [monophyletic](#_monophyletic) [clade](#_Clade) [**Diapsida**](#_diapsid), which includes the lepidosaurs (lizards, snakes, and tuatara), archosaurs (crocodilians, dinosaurs, and birds), and their other extinct relatives. Note that some groups within the [Diapsida](#_diapsid), such as lizards, have lost the temporal bar separating the fenestrae to form one large window. Others, such as the Aves (birds), have merged both fenestrae with the [orbit](#_Orbit).

3) [**Anapsid**](#_anapsid) - Skull possessing **no** **temporal fenestrae** (NB. an- = without). [Amniotes](#_amniote) with this skull condition form a [paraphyletic](#_Paraphyletic) group including the Parareptilia (turtles and their extinct relatives), the extinct common ancestor of all [amniotes](#_amniote), and [basal](#_Basal) eureptiles (the extinct precursors of [diapsids](#_diapsid)). Note that the Testudines (turtles and relatives) have modified the [anapsid](#_anapsid) condition through a reduction (emargination) of the posteriorregion of the skull.

4) [**Euryapsid**](#_euryapsid) - Skull possessing an **upper temporal fenestra only**. However, animals with this skull condition do not represent an important[amniote](#_amniote) lineage, as they are likely to be a [polyphyletic](#_polyphyletic) group, originating a least twice within the [Diapsida](#_diapsid). [Euryapsids](#_euryapsid) include the plesiosaurs and ichthyosaurs - Mesozoic marine reptiles.

## V

### vertebrae

From anterior to posterior:

Cervical vertebrae: Facilitate the mobility of the head. The first two, the **atlas** and the **axis** are highly specialised, the former articulating with the occipital region of the skull.

Thoracic vertebrae: Articulate with the ribs that fuse with the sternum.

Lumbar vertebrae: Generally larger, with small ribs not attached to the sternum, which support the posterior musculature.

Sacral vertebrae: Fused to the [pelvic girdle](#_Pelvic_girdle), allowing the transfer of force from the [appendicular skeleton](#_Appendicular_skeleton) (limbs) during locomotion.

Caudal vertebrae: Small and less specialised, forming the tail.

### Vertebrate anatomical directions and axes

The image below illustrates the terms used for anatomical directions and axes in vertebrates.



### Vestigial

Occurring as a structure that, once functional (whether during development or in earlier evolutionary forms), is **now reduced** or **degenerate**. An example is the vestigial [pelvic girdle](#_Pelvic_girdle) seen in many snakes, including the boas and pythons, which bears no function.

## Z

### Zygapophysis

Articular process of a vertebra that articulates with the corresponding process of an adjacent vertebra.

Plural = zygapophyses