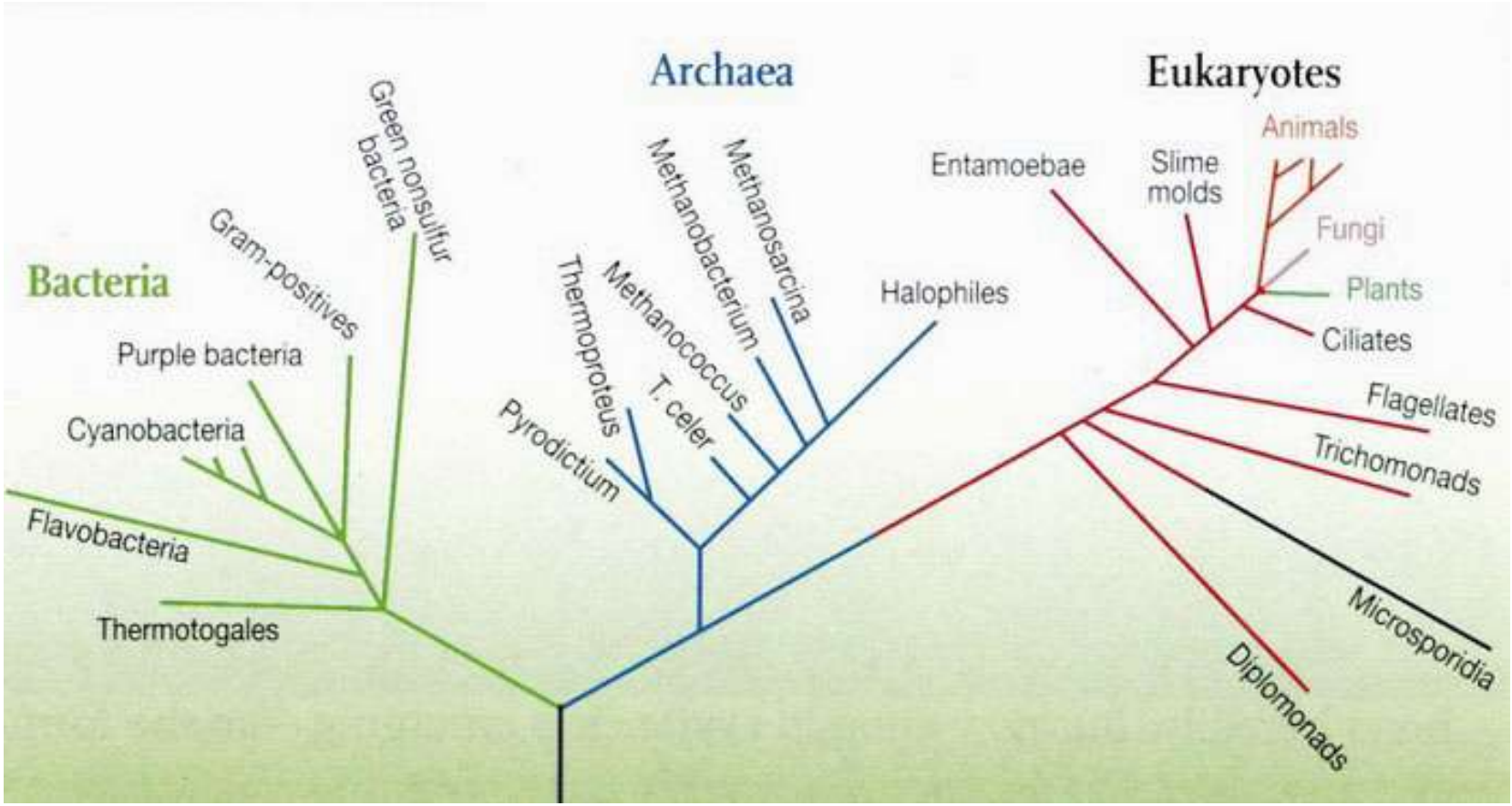
Reconstructing Phylogeny

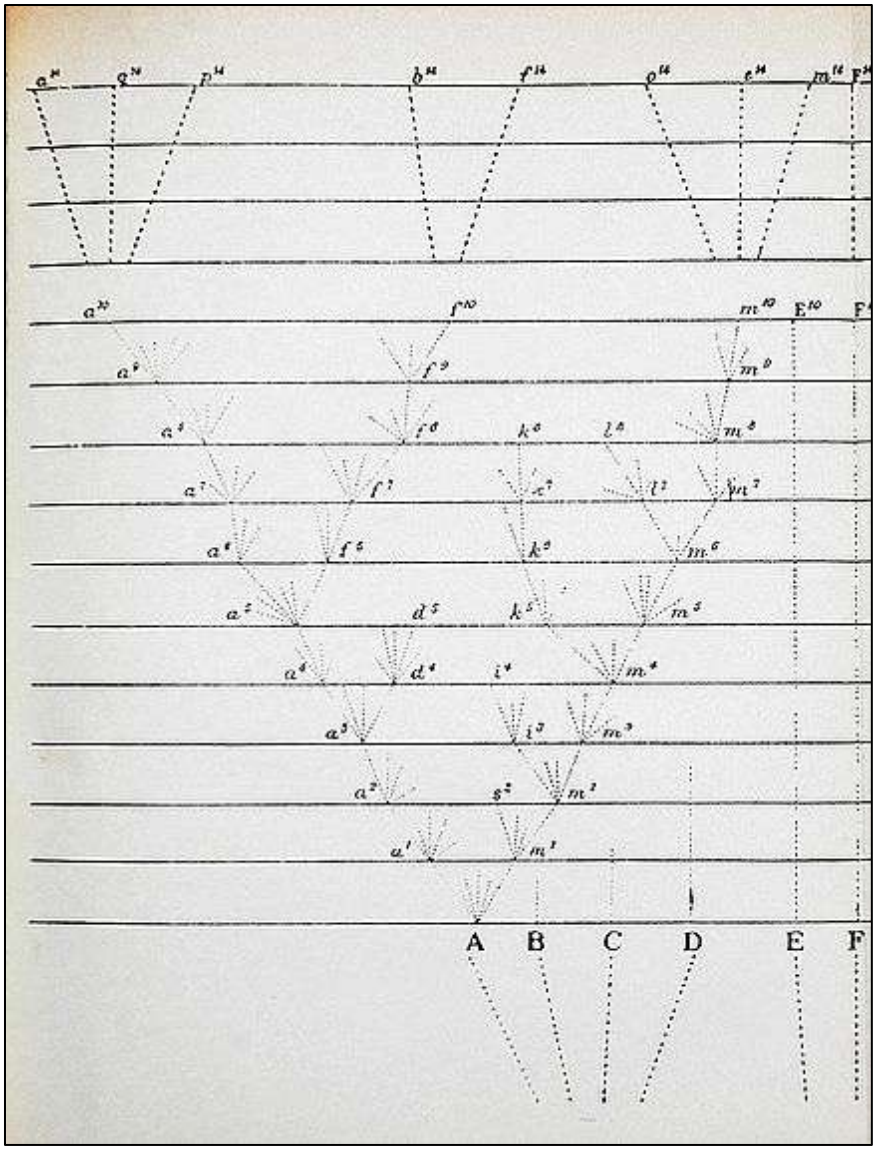
Classification
Phylogeny
Systematics

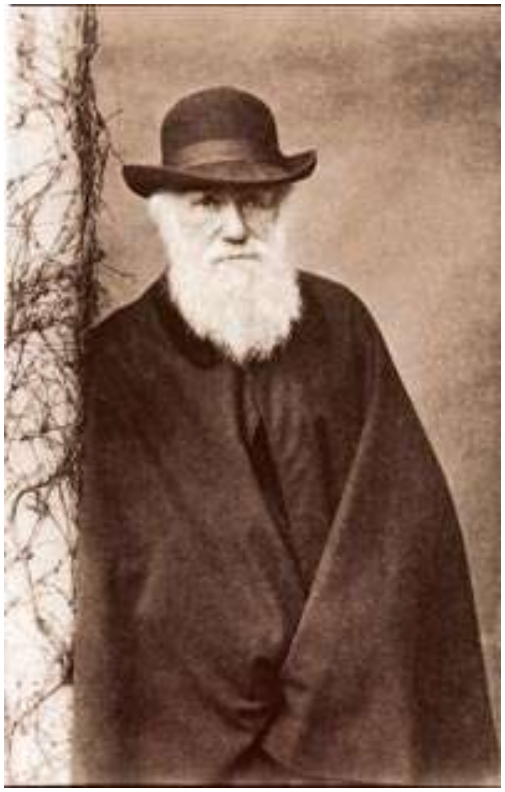


In *the Origin of Species*, Darwin included just one illustration — a "tree" depicting branching and extinction through time.

With this he crystallized the idea that species share common ancestors at various points back in time.

He referred to the genealogical relationships among all living things as **"the great Tree of Life."**





"The affinities of all the beings of the same class have sometimes been represented by a great tree... As buds give rise by growth to fresh buds, and these if vigorous, branch out and overtop on all sides many a feebler branch, so by generation I believe it has been with **the great Tree of Life**, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever branching and beautiful ramifications."

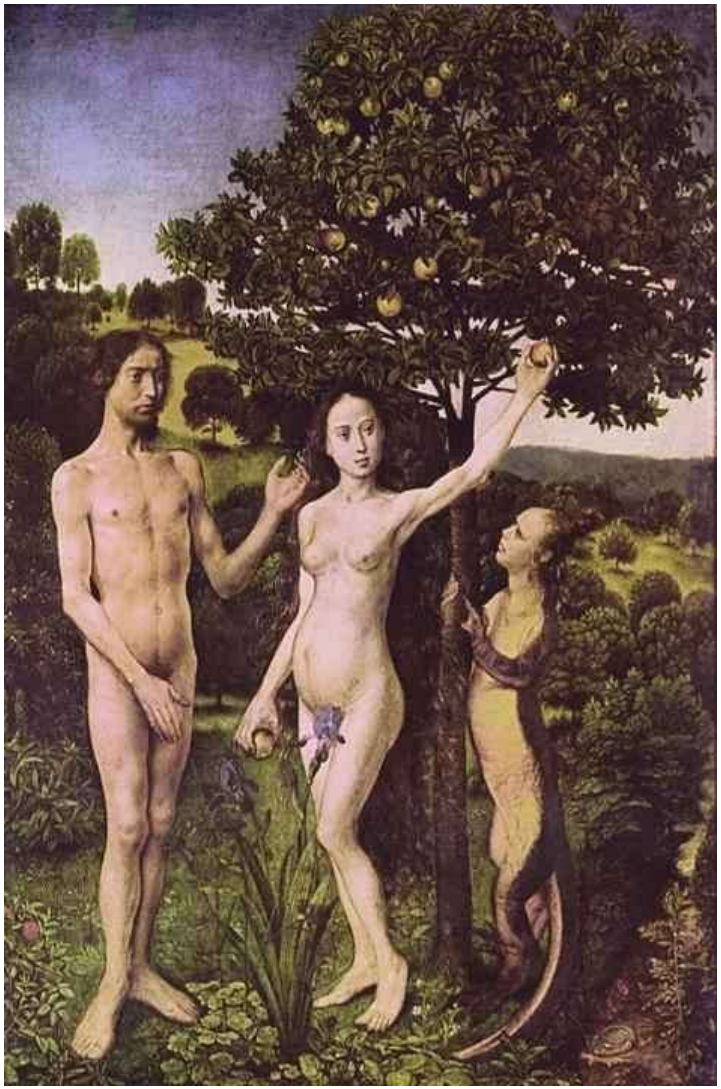
Charles Darwin, 1859

“Tree of Life” in Antiquity

Babylon

Egypt

Tree of Life in Antiquity



Adam and Eve,
Tree of Knowledge

Yggdrasil, the world-tree of
Norse mythology

Phylogenetic Tree of Life

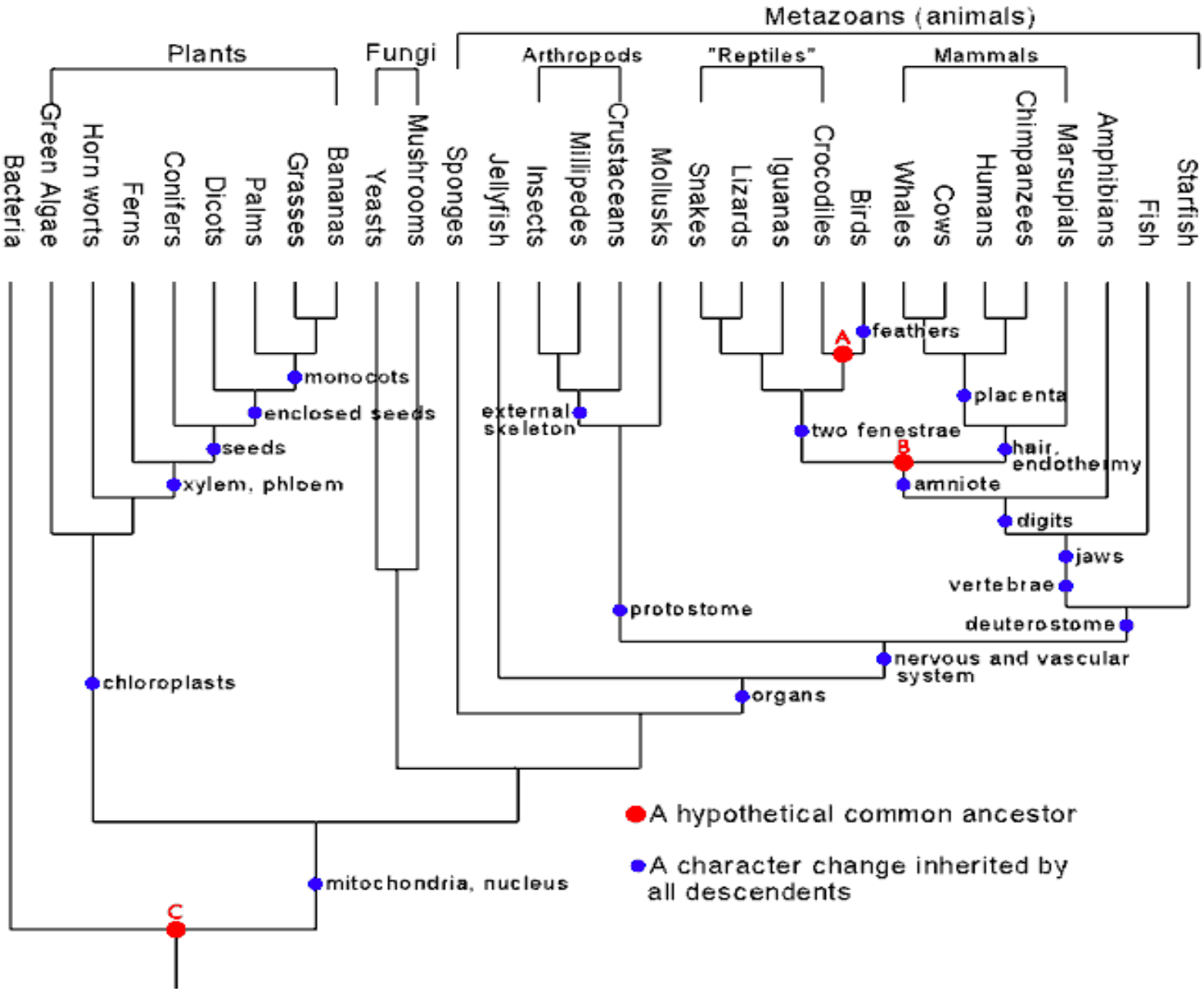
Why is phylogeny important?

Understanding and classifying the diversity of life on Earth

Testing evolutionary hypotheses:
- trait evolution
- coevolution
- mode and pattern of speciation
- correlated trait evolution
- biogeography
- geographic origins
- age of different taxa
- nature of molecular evolution
- disease epidemiology

…and many more applications!

Simplified Tree of Life – branches supported by characters



Some definitions…..

Classification - arrangement of objects and organisms into groups.

Taxonomy - the science of identifying classifying them and naming objects (nomenclature).

Systematics - the scientific study of the diversity and relationship of organisms and how they are related in an evolutionary context.

Phylogeny is the evolutionary relationships among organisms.

Cladistics – study of relationships of groups of organisms depicted by evolutionary trees parsimony, maximum likelihood, bayesian

Three Kinds of Classification Systems

- **Artificial** - based on similarities that might put unrelated plants in the same category. - Linnaeus.

- **Natural** - categories reflect relationships as they really are in nature. - e.g. B. de Jussieu.

- **Phylogenetic** - categories based on evolutionary relationships. Current emphasis on monophyletic groups. – e.g. Angiosperm Phylogeny Group (APG).

Carolus Linnaeus

1707 - 1778

Tried to name and classify all organism

Binomial nomenclature

Species Plantarum - 1753

System of Classification

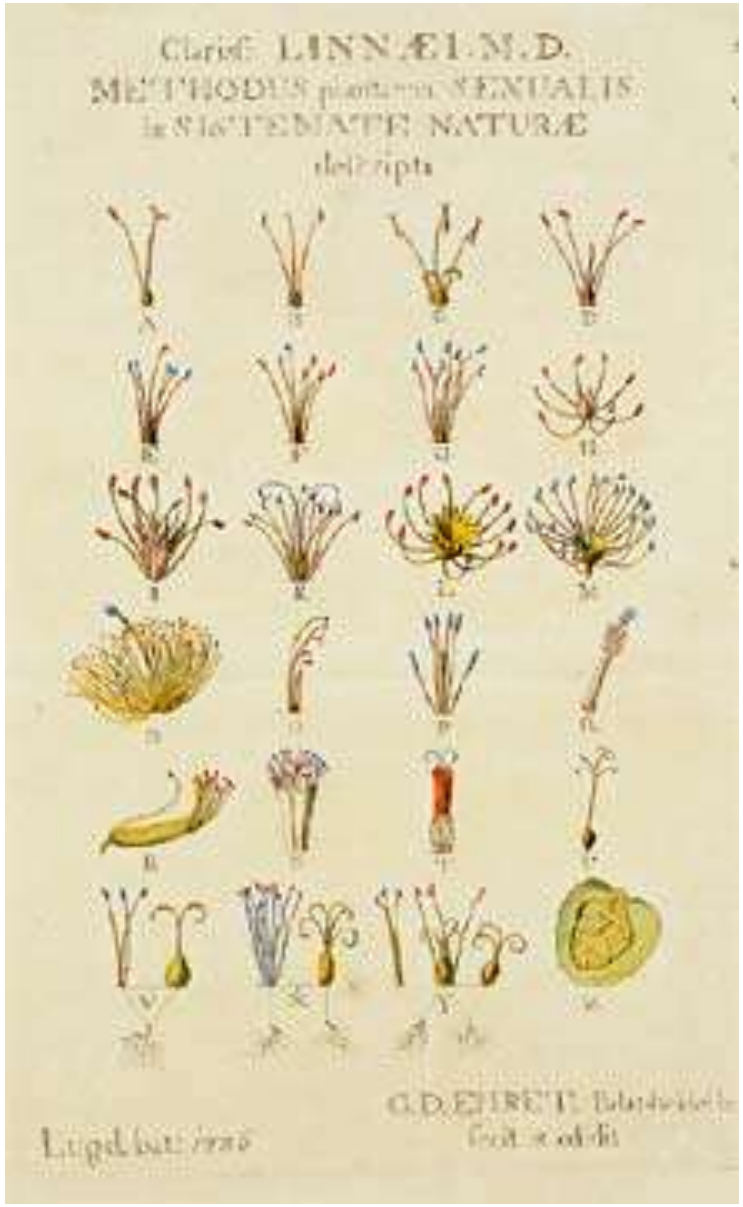
"Sexual System"

Classes - number of stamens

Orders - number of pistils

He was incredibly prolific (or his students were who sent specimens for naming). Named 12,000 species (7,700 plants, 4,300 animals). 1,105 genera named by him.

Artificial Classification System – Linnaeus' sexual system, a practical method for identification, count stamens and pistils



A View of the Twenty-four Classes of the SEXUAL SYSTEM *of* LINNÆUS, *with their Names and Characters; also the Number and Explanation of Orders contained in each.*

Number of the Classes.	Their Names and Characters.	Number of Orders in each.	Their Names, expressive of the Number of Female Parts or Styles.	Names.
1.	MONANDRIA. One fertile ſtamen, i. e. having the *Anthera*.	2	1. Monogynia,	1
			2. Digynia,	2
2.	DIANDRIA. Two fruitful *Stamina* or male parts.	3	1. Monogynia,	1
			2. Digynia,	2
			3. Trigynia,	3
3.	TRIANDRIA. Three ditto.	3	1. Monogynia,	1
			2. Digynia,	2
			3. Trigynia,	3
4.	TETRANDRIA. Four ditto, all of equal length, by which it is diſtinguiſhed from the fourteenth claſs.	3	1. Monogynia,	1
			2. Digynia,	2
			3. Tetragynia,	4
5.	PENTANDRIA. Five ditto.	3	1. Monogynia,	1
			2. Digynia,	2
			3. Triginia,	3
			4. Tetragynia,	4
			5. Pentagynia,	5
			6. Polygynia,	many
6.	HEXANDRIA. Six ditto, all of equal length, by which this is diſtinguiſhed from the ſixteenth claſs.	5	1. Monogynia,	1
			2. Digynia,	2
			3. Trigynia,	3
			4. Tetragynia,	4
			5. Polygynia,	many
7.	HEPTANDRIA. Seven ditto.	4	1. Monogynia,	1
			2. Digynia,	2
			3. Tetragynia,	4
			4. Heptagynia,	7
8.	OCTANDRIA. Eight ditto.	4	1. Monogynia,	1
			2. Digynia,	2
			3. Trigynia,	3
			4. Tetragynia,	4
9.	ENNEANDRIA. Nine ditto.	3	1. Monogynia,	1
			2. Trigynia,	3
			3. Hexagynia,	6

10. DECAN-

6. Aloë foliis ovato-lanceolatis carnoſis apice triquetris: angulis inerme dentatis. *Hort. cliff.* 131. *Hort. upſ.* 86. *Roy. lugdb.* 24.
Aloë africana minima atroviridis, ſpinis herbaceis numeroſis ornata. *Boerh. lugdb.* 2. *p.* 131. *t.* 131.
Habitat in Æthiopiæ *campeſtribus.* ♄
Flores *in hoc genere ſpecierum certiſſimi indices conjungunt Margaritiferam & Arachnoideam.*

9. ALOE floribus ſeſſilibus reflexis imbricatis priſmaticis. *Uvaria.*
Aloë foliis linearibus radicalibus membranaceis. *Hort. cliff.* 133. *Roy. lugdb.* 23.
Aloë africana folio triangulari longiſſimo & anguſtiſſimo, floribus luteis fœtidis. *Comm. hort.* 2, *p.* 29. *t.* 15. *Seb. theſ.* 1. *p.* 29. *t.* 19. *f.* 3.
Habitat ad Cap. b. Spei. ♄

AGAVE.

1. AGAVE foliis dentato-ſpinoſis, ſcapo ramoſo. *Gen. nov.* 1102. *americana.*
Agave foliis ſpinoſo-dentatis mucronatisque. *Hort. upſ.* 81.
Aloë foliis lanceolatis dentatis ſpina terminatis radicalibus. *Hort. cliff.* 130. *Roy. lugdb.* 22.
Aloë folio in oblongum mucronem abeunte. *Bauh. pin.* 286.
Habitat in America *calidiore.* ♄

2. AGAVE foliis dentatis, ſtaminibus corollam æquantibus. *vivipara.*
Aloë americana polygona. *Comm. rar.* 65. *t.* 65.
Habitat in America.
Confer. Aloe americana ſoboliferà. *Herm. lugdb.* 16. *t.* 17.

3. AGAVE foliis dentato-ſpinoſis, ſcapo ſimpliciſſimo. *Gen. nov.* 1102. *virginica.*
Aloe foliis lanceolatis ſpina cartilaginea terminatis, floribus alternis ſeſſilibus. *Gron. virg.* 152.
Habitat in Virginia. ♄

4. AGAVE foliis integerrimis. *Gen. nov.* 1102. *fœtida.*
Aloe foliis integerrimis patentiuſculis aculeo-terminatis, radice cauleſcente. *Hort. cliff.* 132.
Aloe americana, viridi rigidiſſimo & fœtido folio, Piet dicta indigenis. *Comm. hort.* 2. *p.* 35. *t.* 18.

Natural System – group taxa by a variety of shared similarities (use more characters)

Genera Plantarum - A. L. de Jussieu, 1789

Class III - Plantae Monocotyledones, Stamina Perigyna

Orders (similar to Families we use today):

- Palmae - *Calumus, Phoenix* etc.
- Asparagi - *Dracaena, Asparagus, Trillium, Convallaria, Dioscorea* etc.
- Junci - *Juncus, Xyris, Commelina, Melanthium, Colchicum,* etc.
- Lilia - *Lilium, Uvularia, Yucca* etc.
- Bromeliae - *Puya, Bromelia, Agave* etc.
- Asphodeli - *Aletris, Aloe, Asphodelus, Allium* etc.
- Narcissi - *Crinum, Hemerocallis, Narcissus, Polianthes, Tacca,* etc.
- Irides - *Tigridia, Iris, Crocus, Gladiolus* etc.

Herbarium – a museum of plant specimens arranged by family

Adolf Engler
(1844-1930)

Catkin or Ament Inflorescence

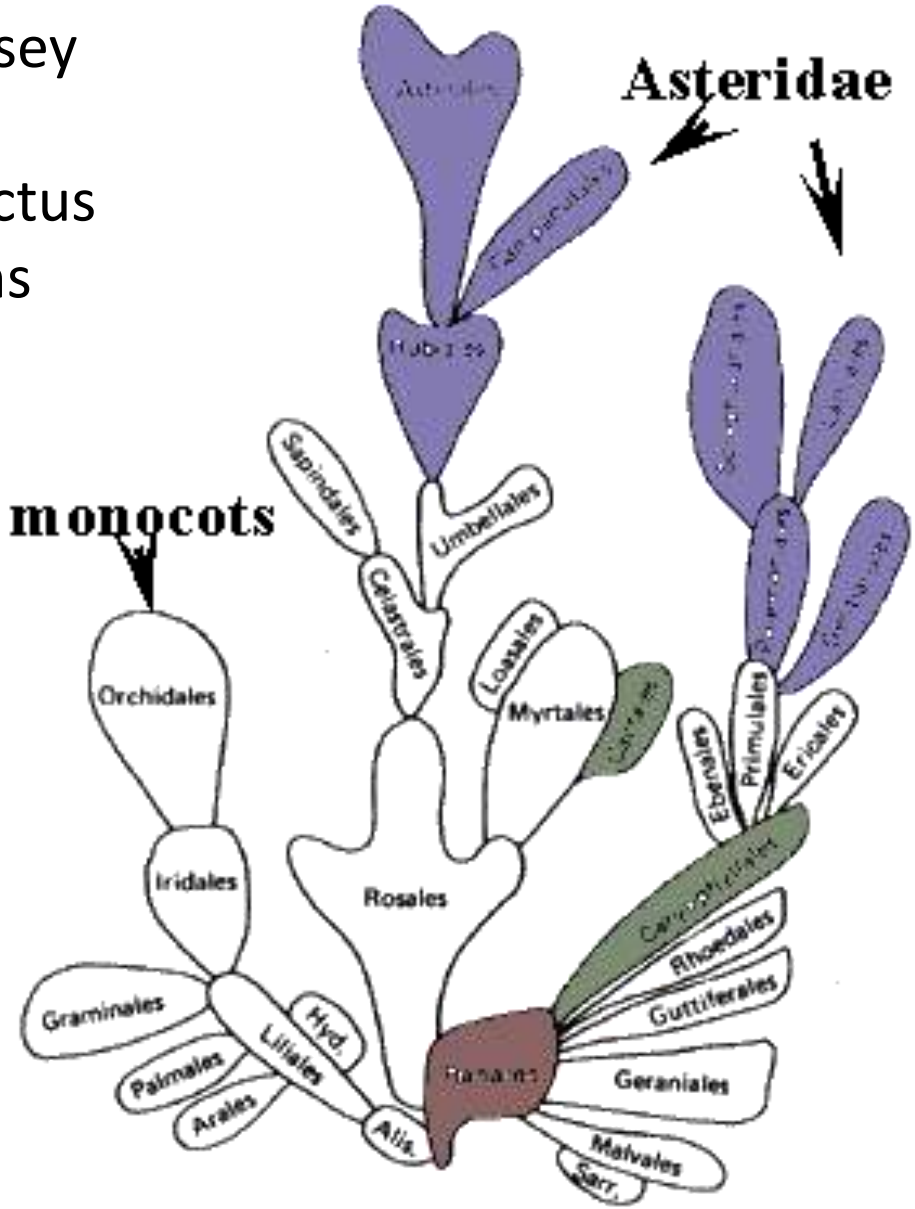
Die naturlichen Pflanzenfamilien
Das Pflanzenreich

Treatment of all known plants
Families with simple or reduced flowers are placed first (primitive?)
Widely used system (still used at MBG)

Monocots - 10 Reihen (Orders)
Pandanales - Typhaceae, Pandanaceae
Helobiae - Alismaceae etc.
Glumiflorae - grasses and sedges
Principes - palms
Syanthae - Cyclanthaceae
Spathiflorae - Araceae
Farinosae - Bromeliaceae, Commlinaceae etc.
Liliiflorae - Liliaceae, Amaryllidaceae etc
Scitamineae - Musaceae, Zingiberaceae
Microspermae - orchids

CHARLES EDWIN BESSEY
(1845–1915, American)

Charles Bessey
Early 1900s
Bessey's Cactus
Angiosperms



He developed a set of "dicta" (rules) stating which characters were primitive and which were advanced in flowering plants.

Not all considered correct today but many are (as Cronquist said, "we are all Besseyans").

Magnolias primitive

Nomenclature – system of naming species and higher taxa.

International Codes of Nomenclature - separate codes for plants, animals, fungi, bacteria

Binomial nomenclature – scientific name, usually Latinized

Each species has only **one scientific name**, eliminate confusion.

Priority - the correct name will be the **one that was published the earliest**, providing it is acceptable in terms of the rest of the code.

Causes discontent when it turns out that the name with priority is not the one in common usage, often because it was published in some obscure place. Invalid names = synonyms.

Starts with Linnaeus publications:

Plants - Species Plantarum (1753)

Animals - Systema Naturae (1758)

Type Concept - material on which an original description is based, fixes the meaning of a specific name. Type Specimen

Linnaean Hierarchy – "God's Creation Revealed"

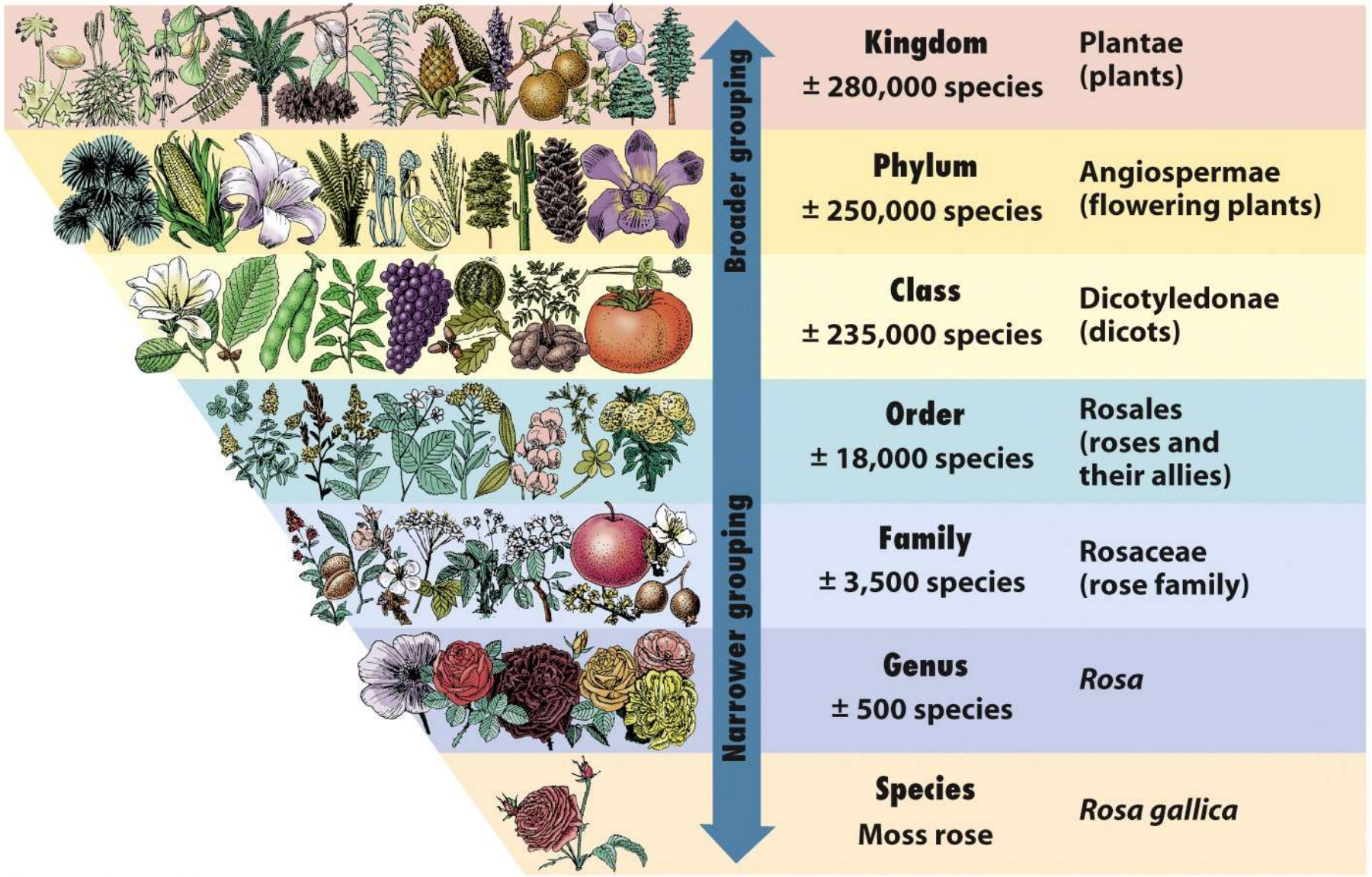
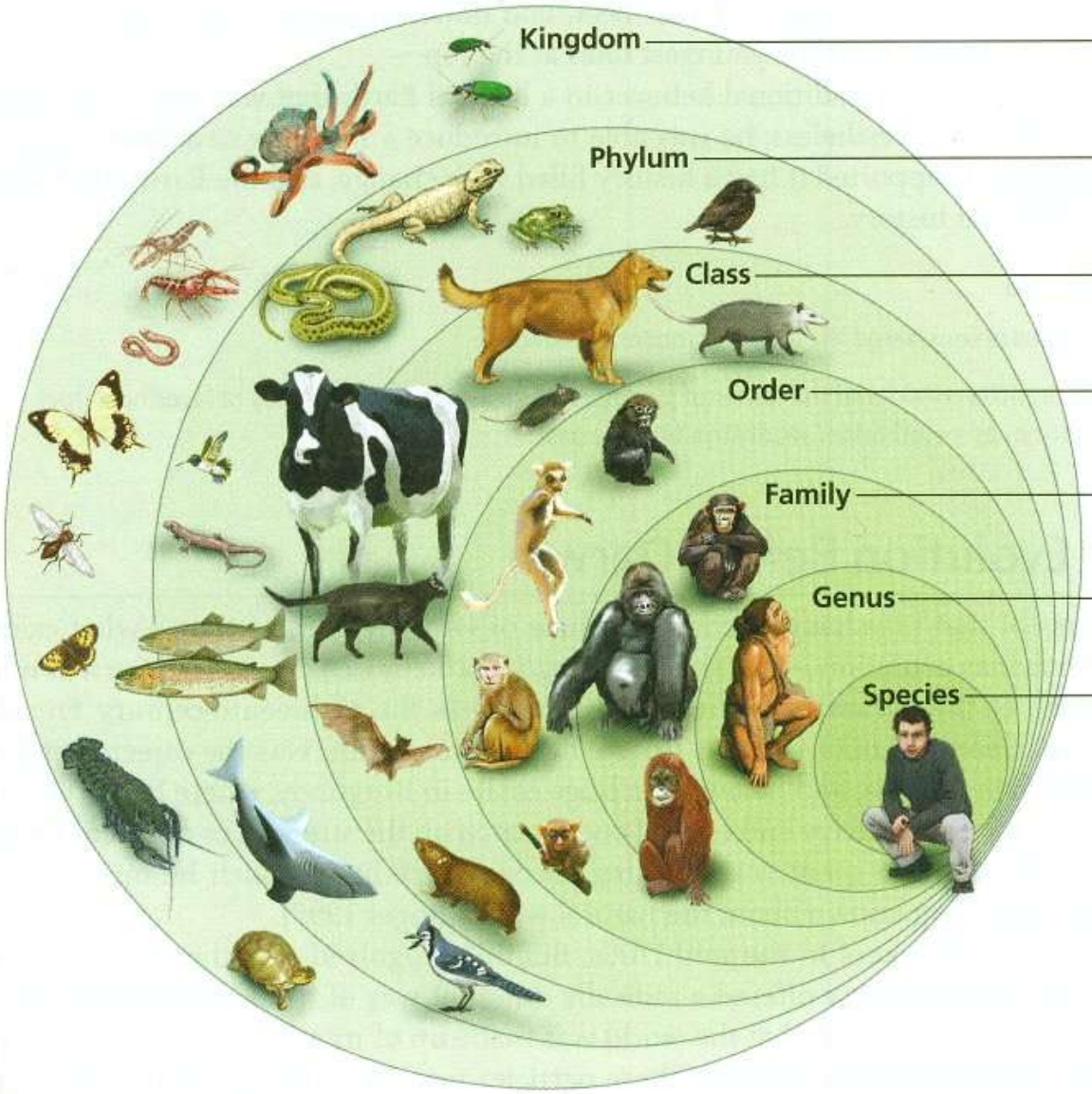


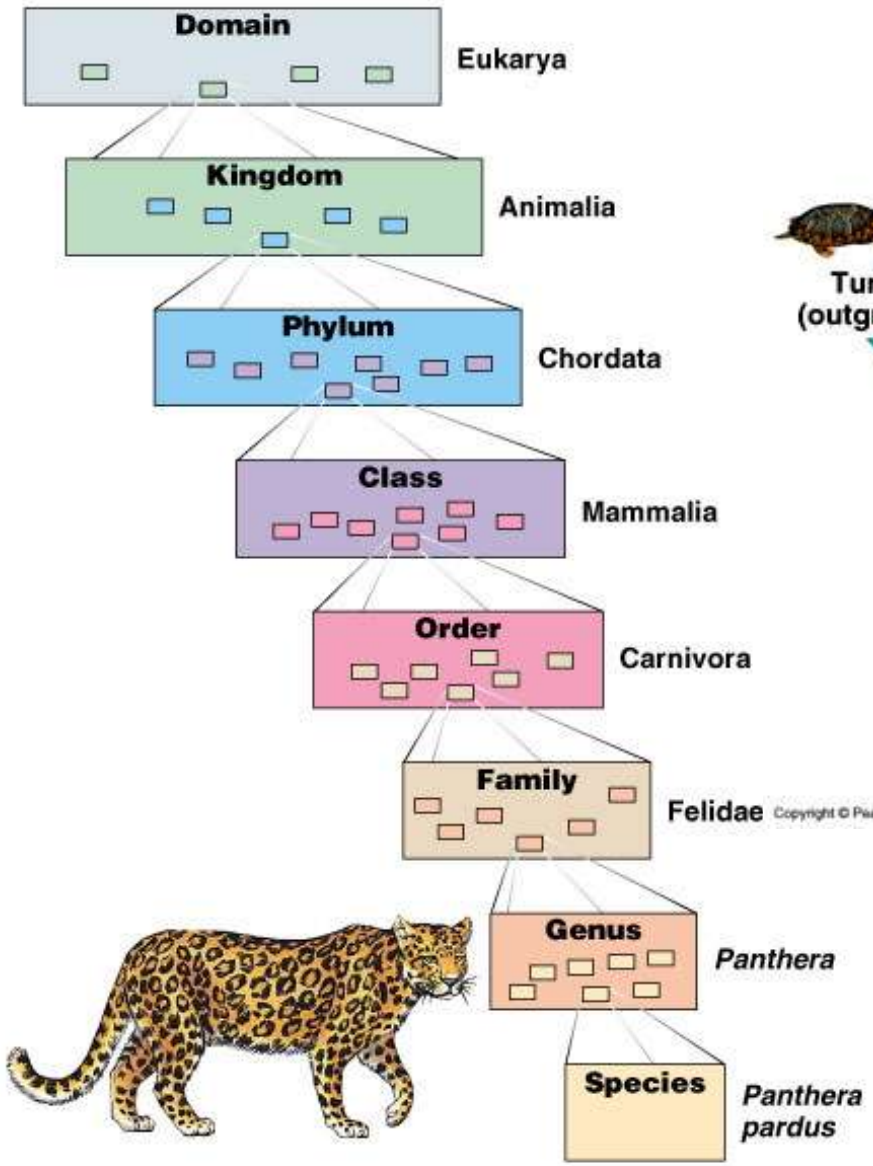
Figure 2-6 Discover Biology 3/e

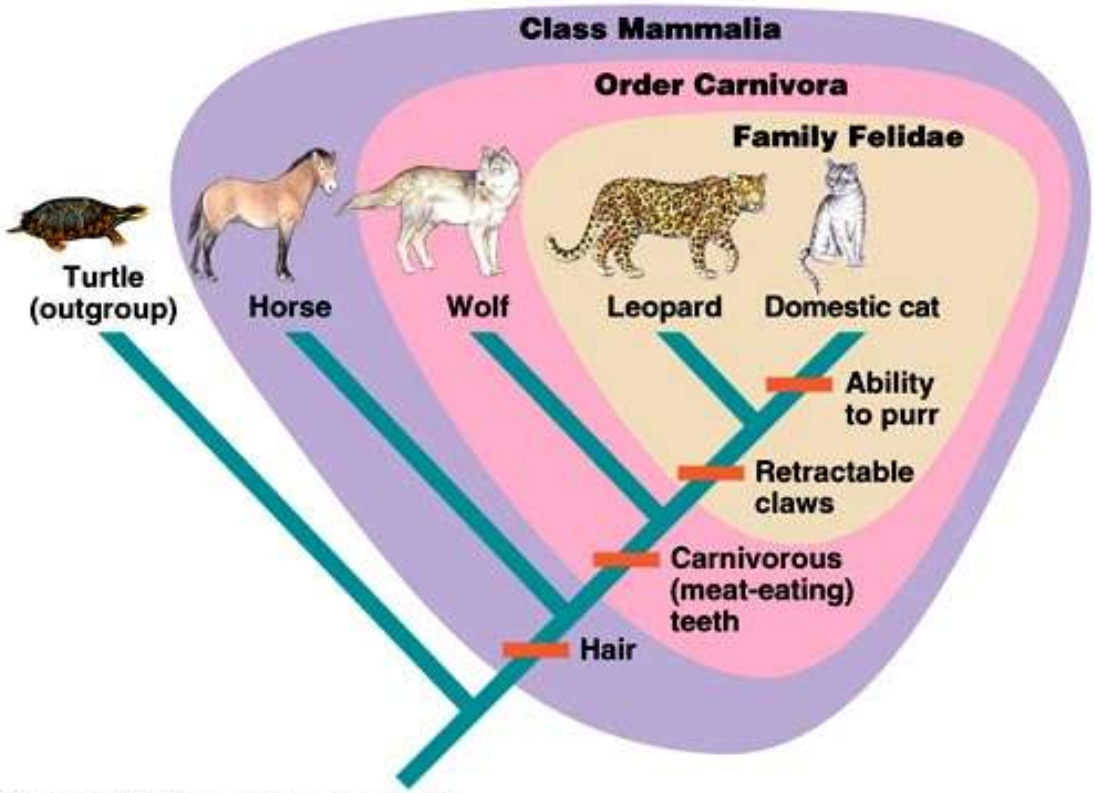


- **Animalia**
- **Chordata**
  (subphylum Vertebrata)
  Fish, amphibians, reptiles, birds, mammals
- **Mammalia**
- **Primates**
  Includes all prosimians (such as lemurs, tarsiers) and simians (monkeys, apes, humans)
- **Hominidae**
  Humans and great apes
- ***Homo***
  Modern and archaic humans
- ***Homo sapiens***
  Modern humans

Figure 2.3 The nested nature of biological classification.

Nested box-within-box hierarchy is consistent with descent from a common ancestor, used as evidence by Darwin.



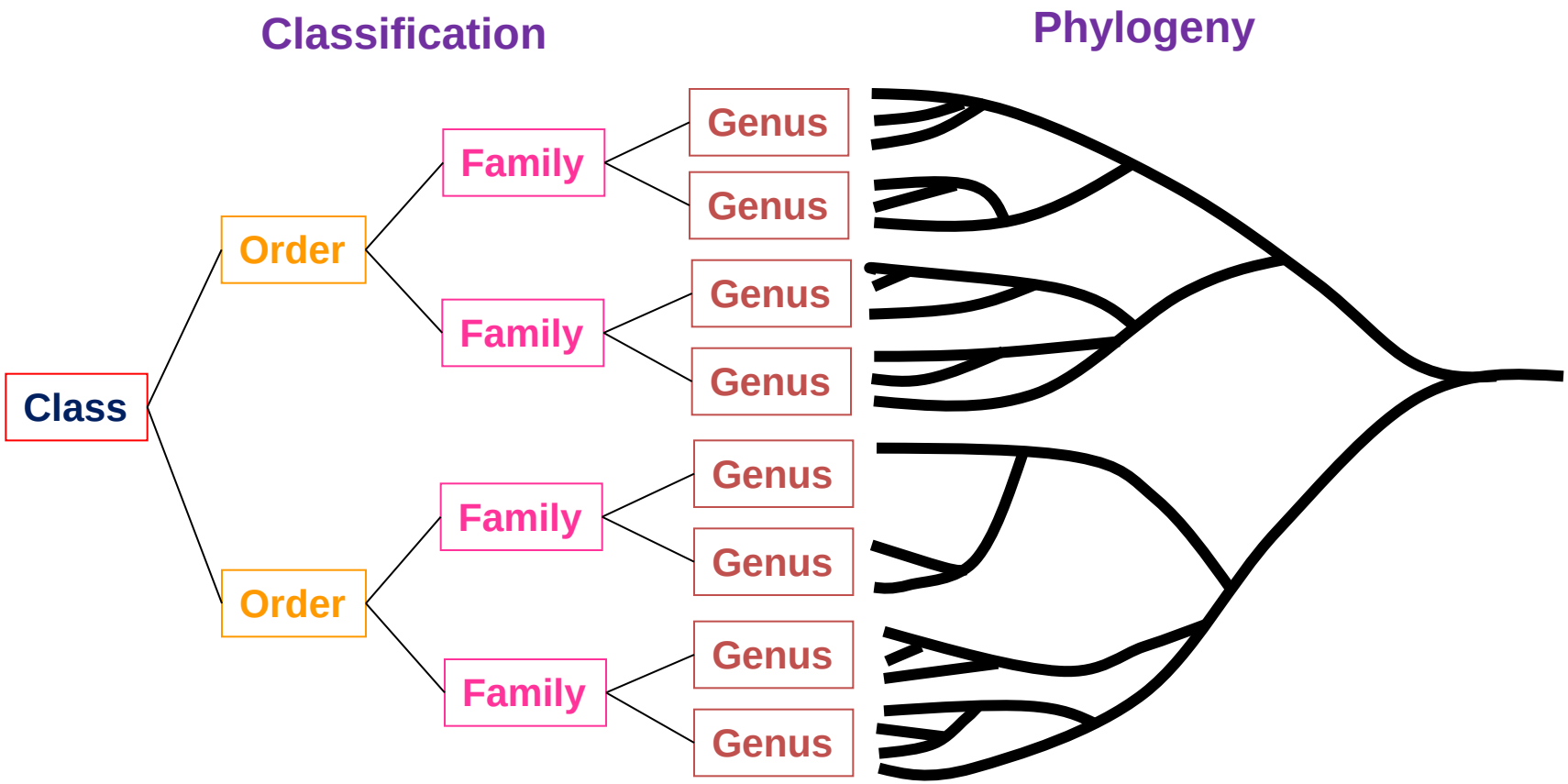


Phylogeny and classification

Hierarchy

Phylogenetic (cladistic) classification reflects evolutionary history

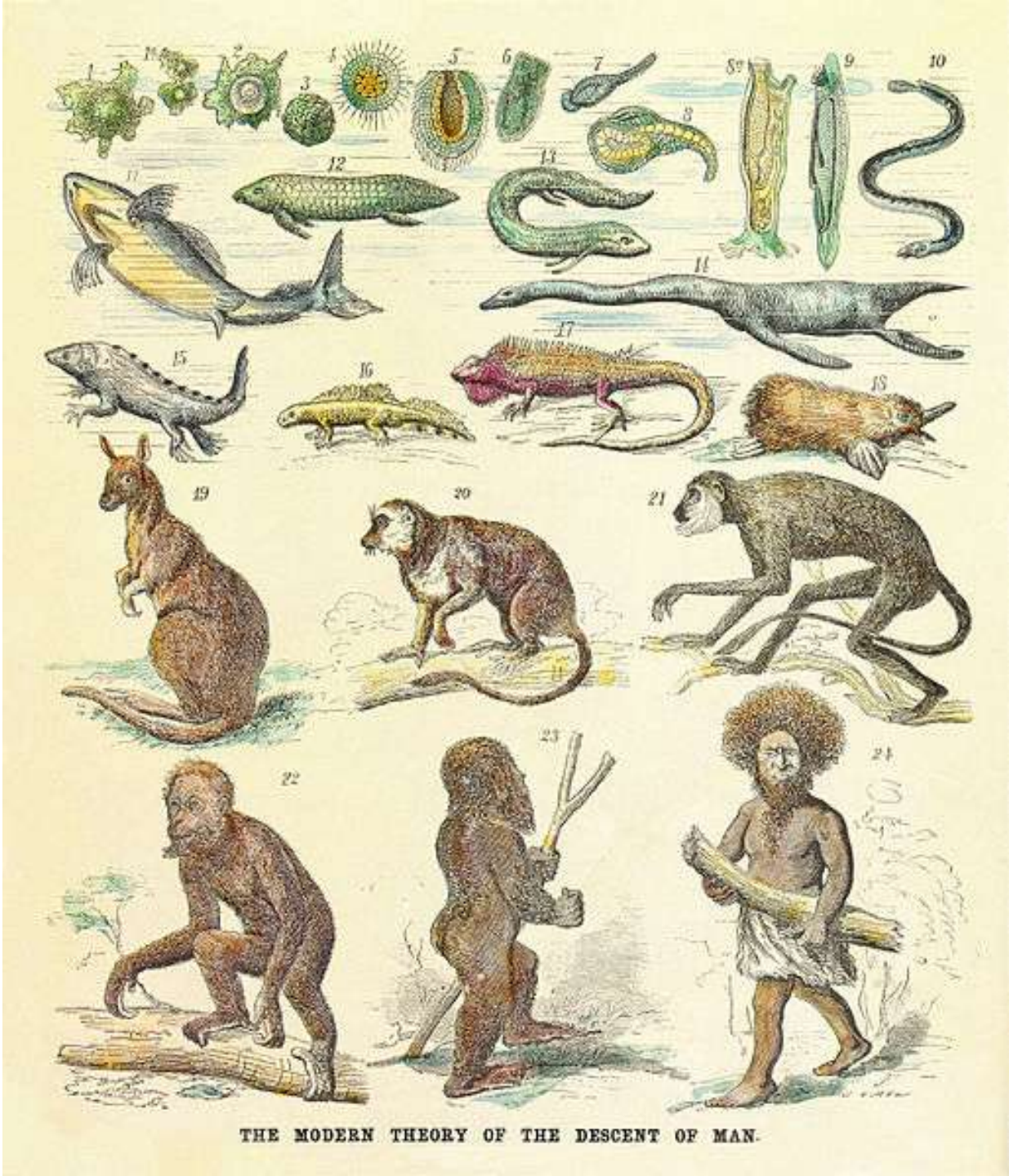
The only objective form of classification – organisms share a true evolutionary history regardless of our arbitrary decisions of how to classify them



Ernst Haeckel - 1860s

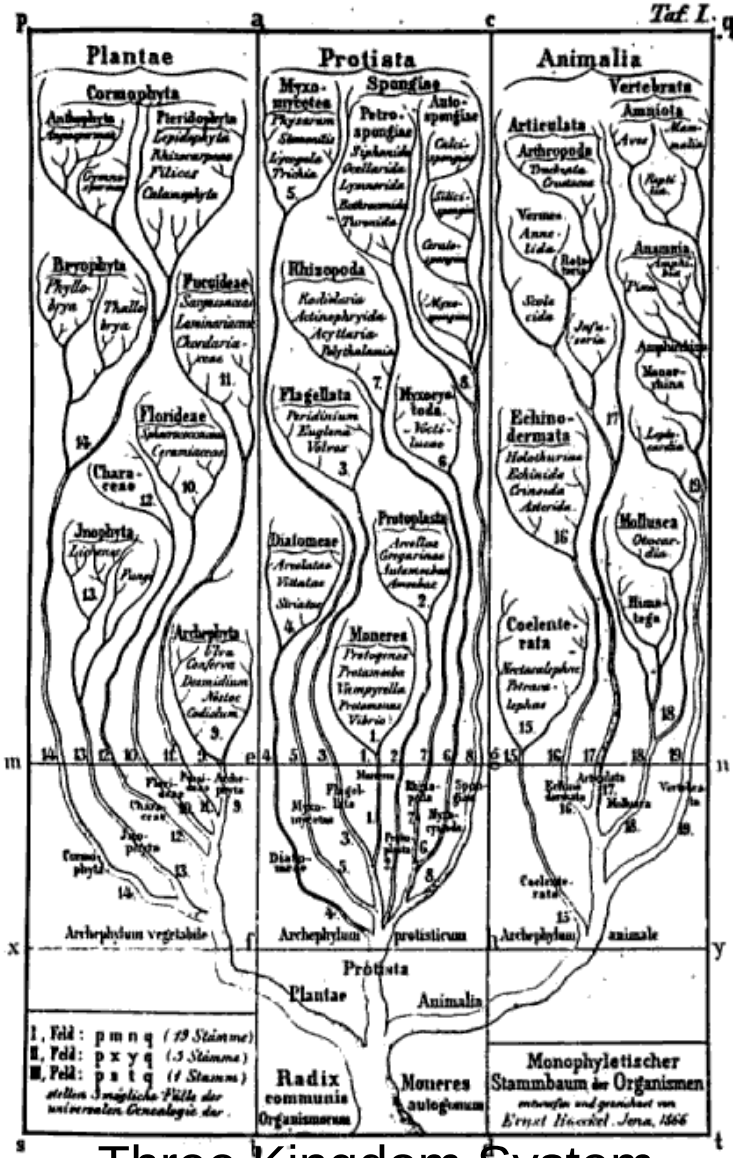
Phylum
Phylogeny
Ecology

Biogenetic Law - ontogeny recapitulates phylogeny (not really)

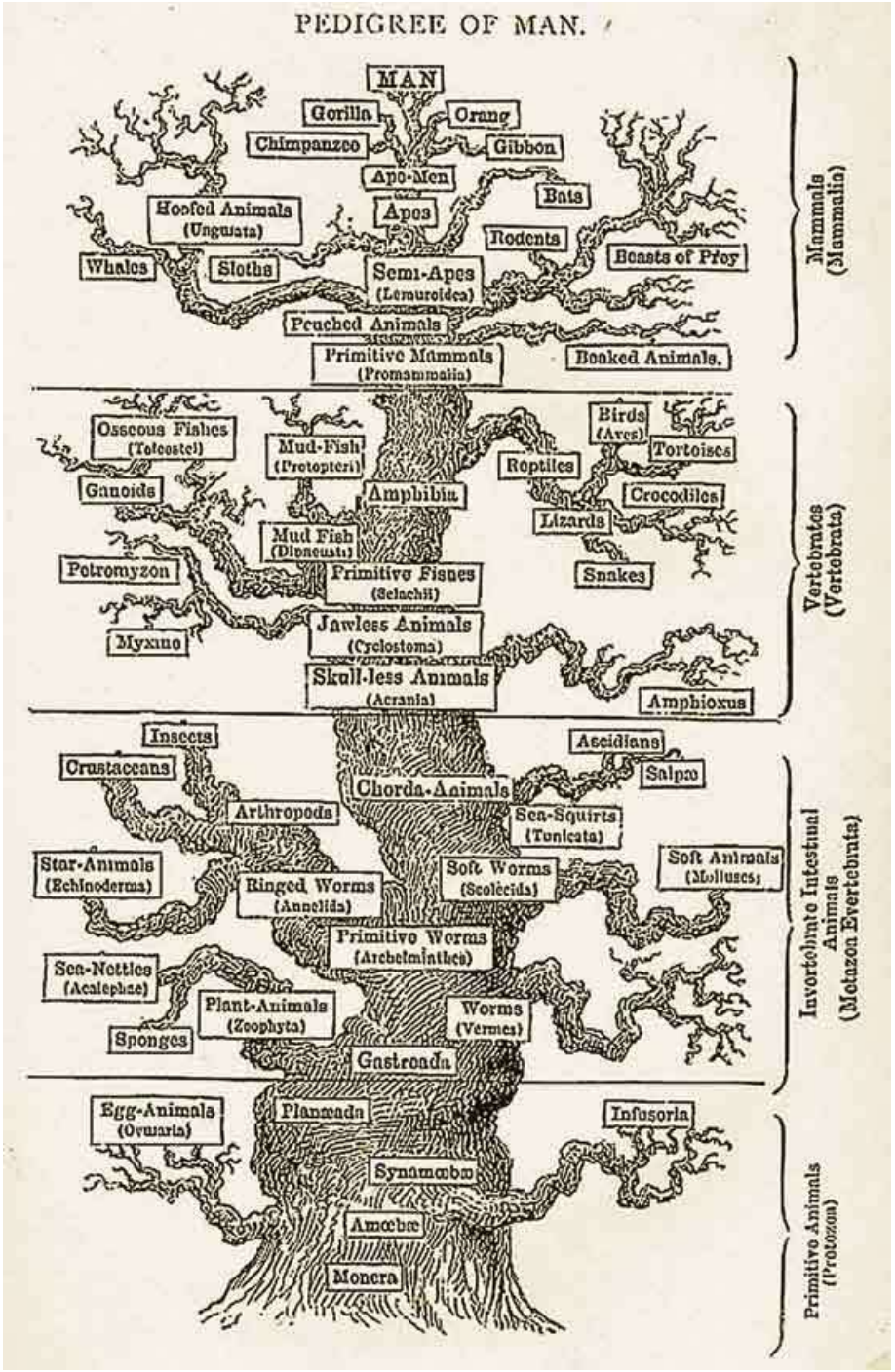


Ernst Haeckel Trees 1860s

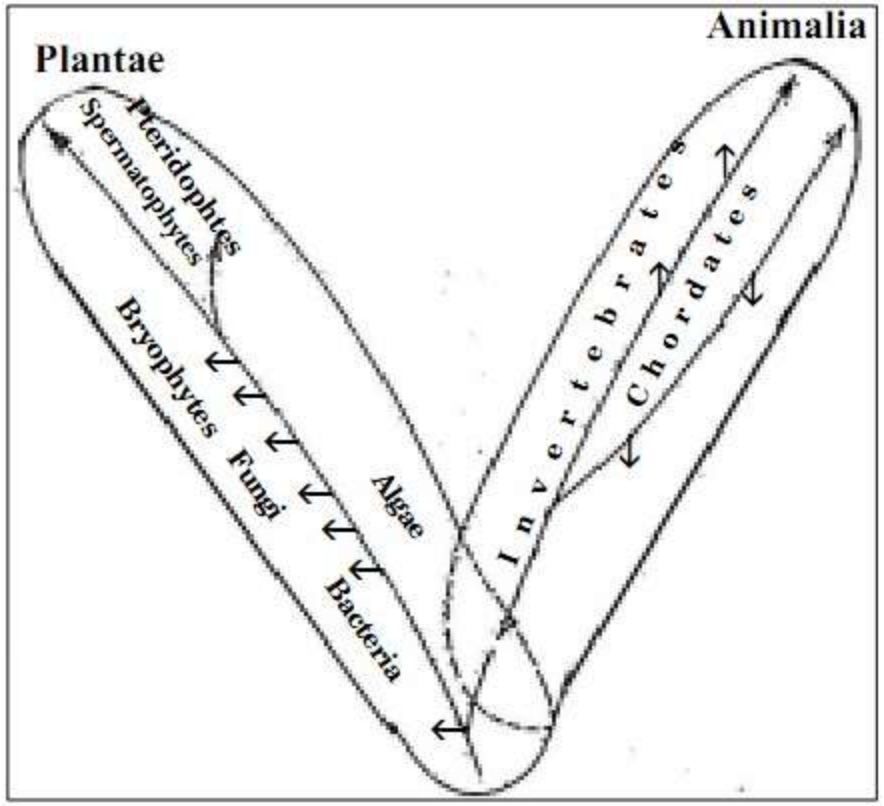
Drew complete Tree of Life



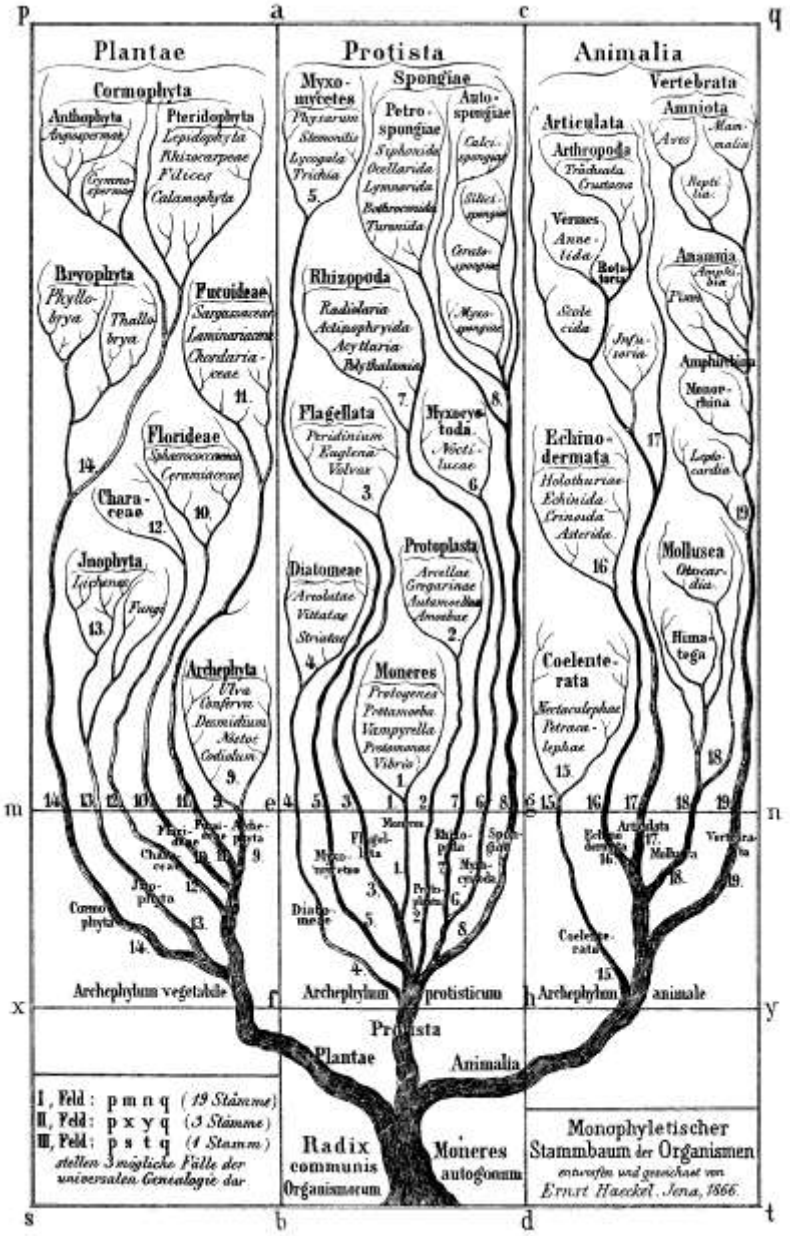
Three Kingdom System



Kingdom Classification Schemes



Linnaeus 2-Kingdoms



Haeckel 3-Kingdoms

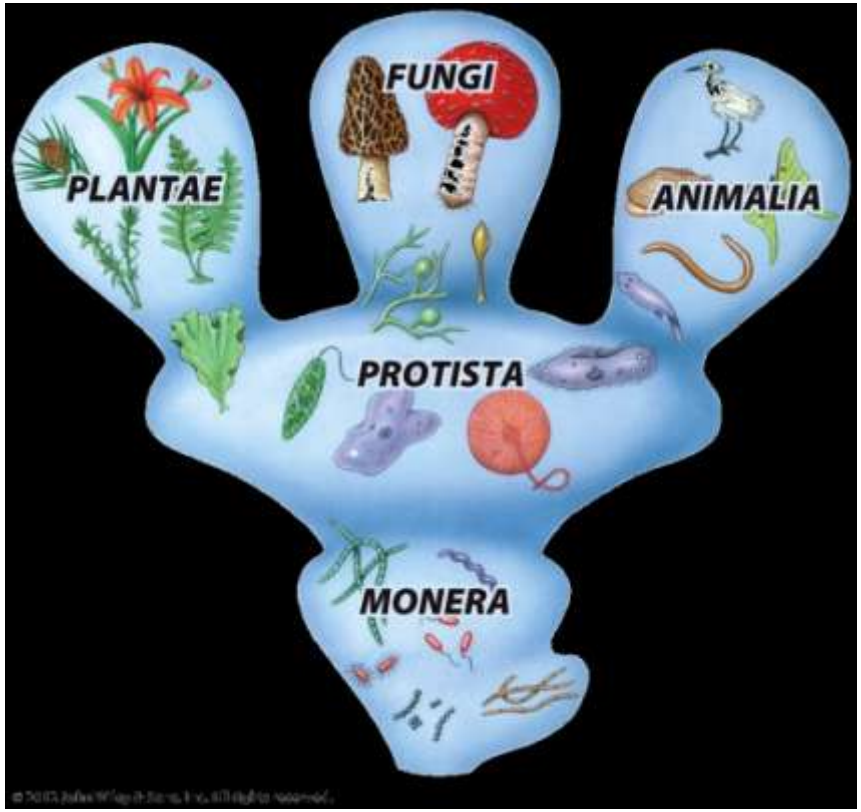
Four Kingdom Sysytem - 1950s

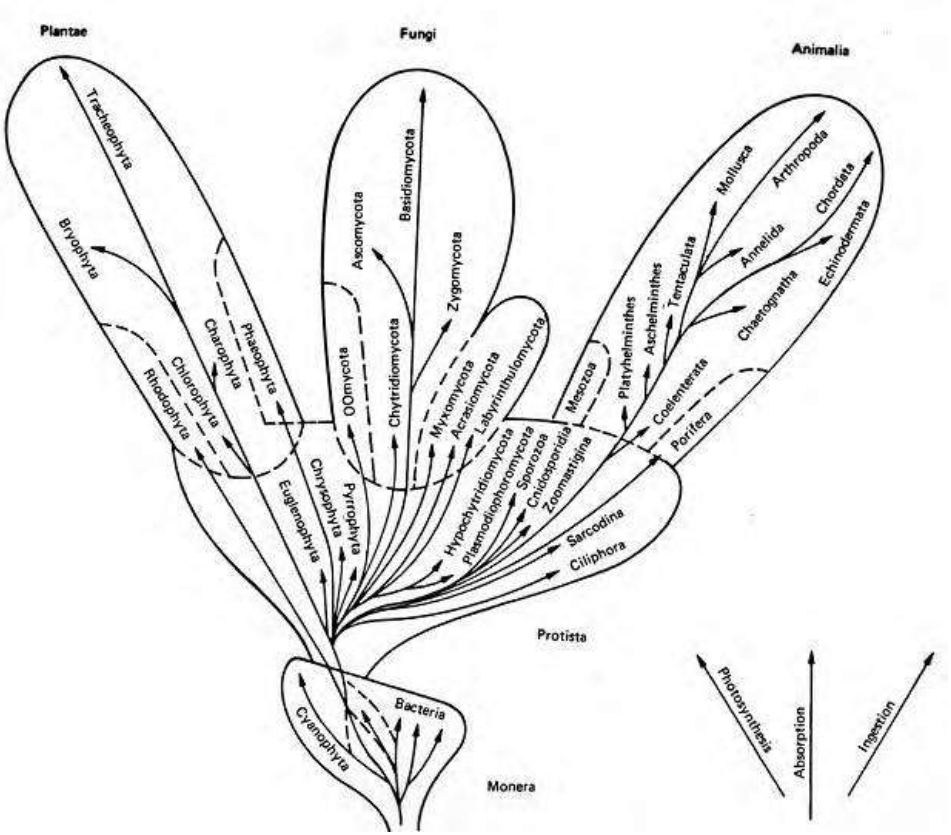
Protista lacking nuclei placed in separate kingdom, the Monera (bacteria)

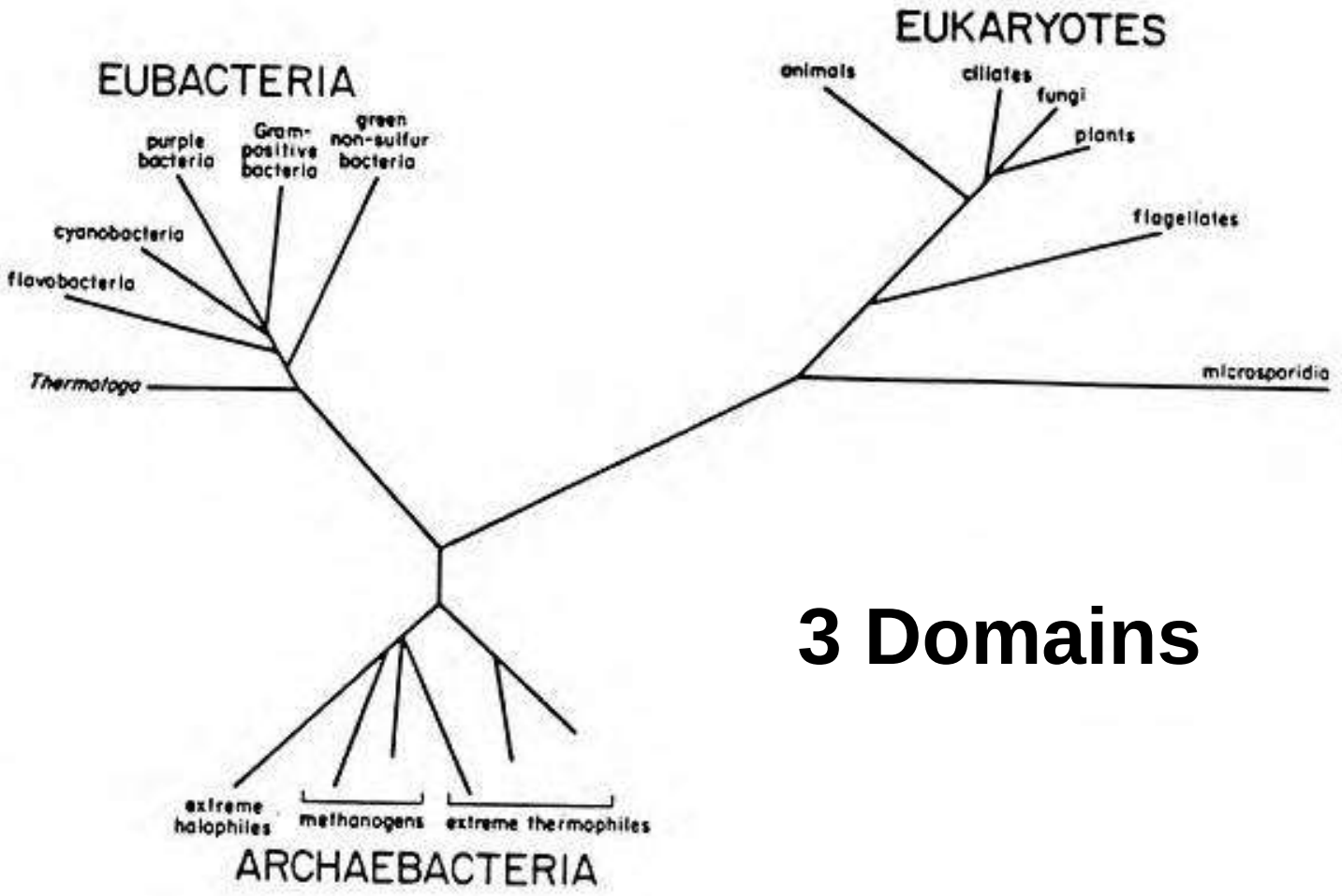
Five Kingdom System - Whittaker's Tree of Life, 1967

Stresses mode of nutrition (

Fungi recognized as separate kingdom, separate from plants

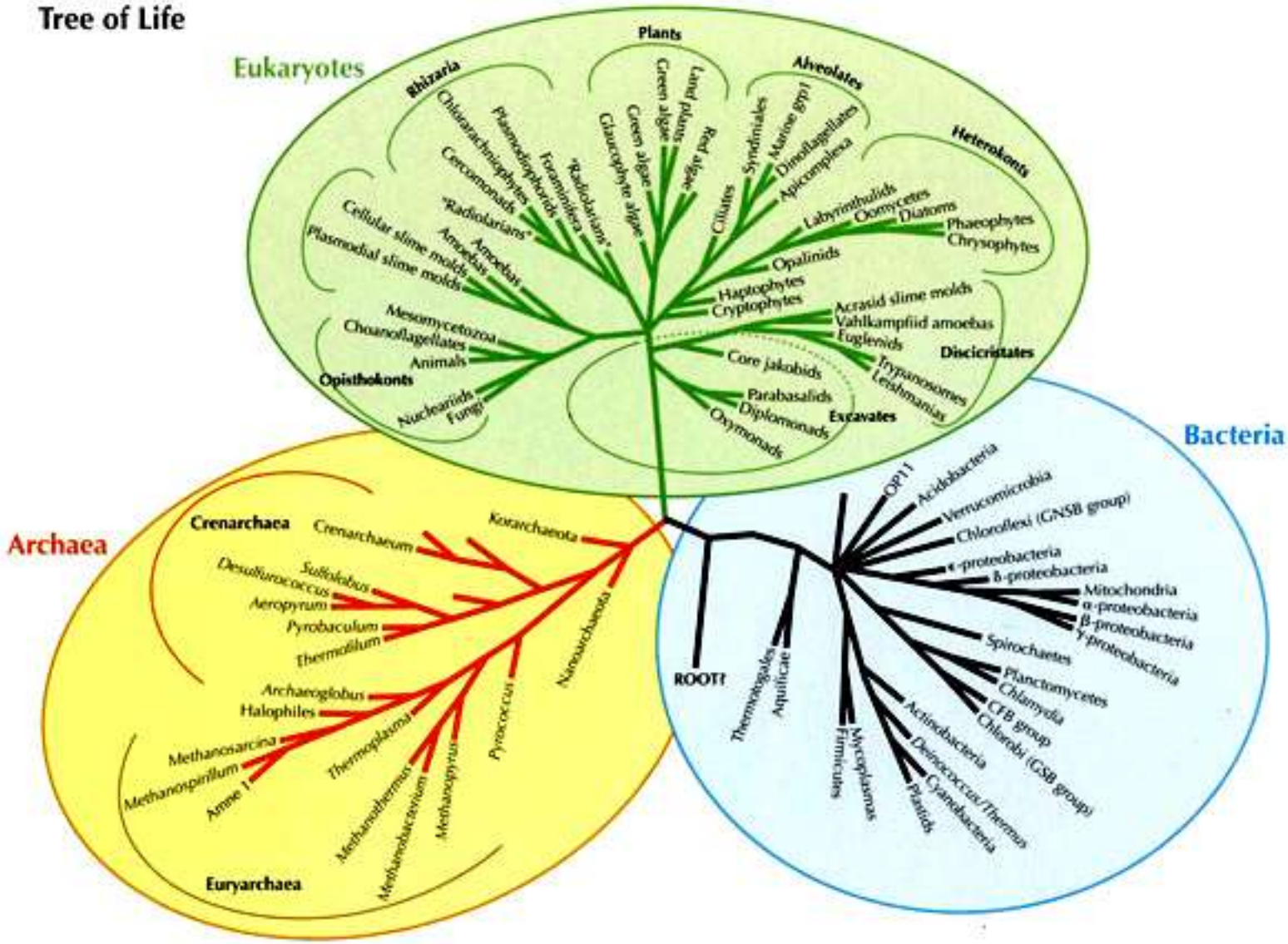




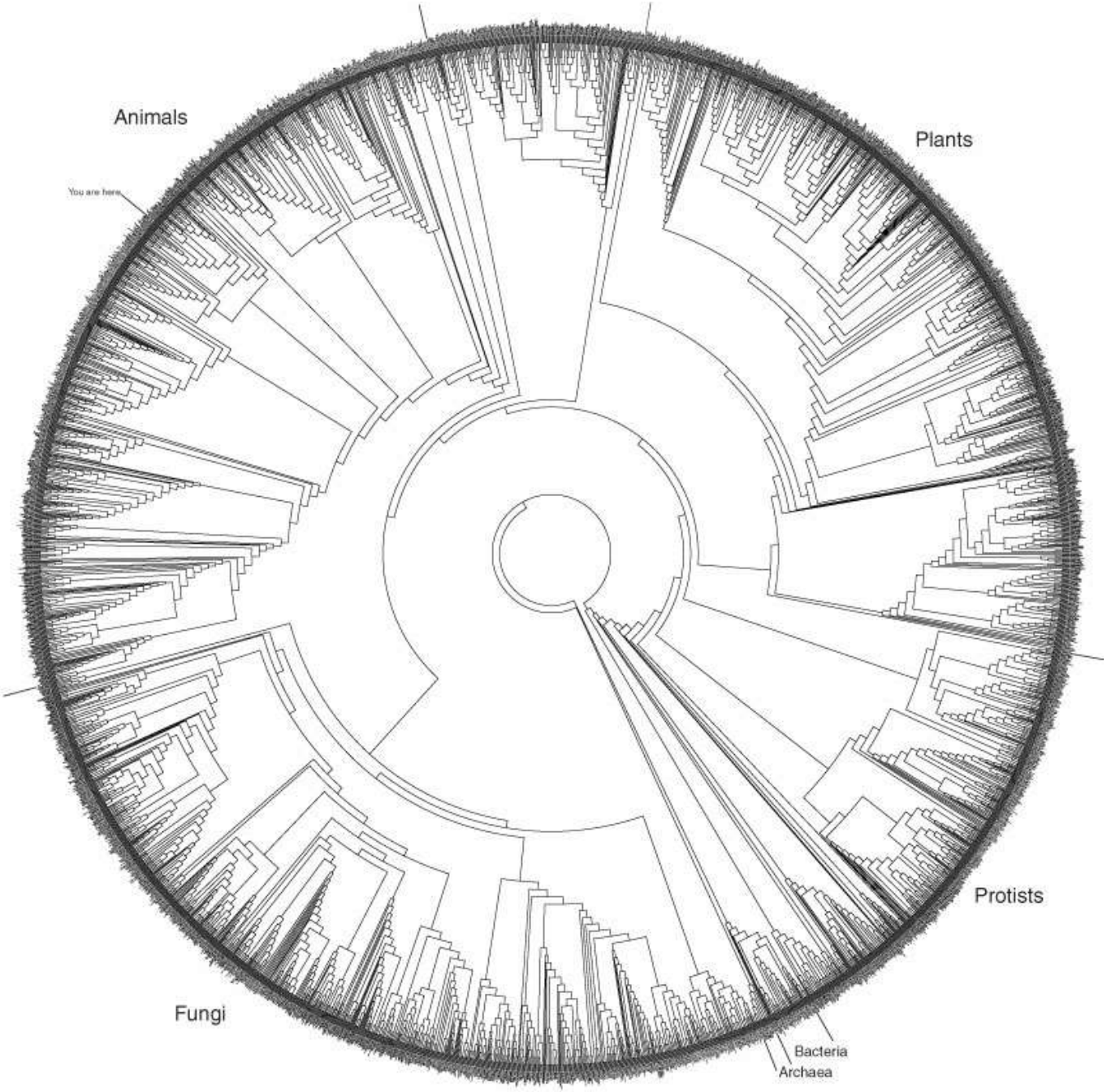


3 Domains

Carl Woese
1980s
ssRNA Sequences


Tree of Life
Eukaryotes
Plants
Rhizaria
Alveolates
Heterokonts
Chlorarachniophytes
Plasmodiophorids
Foraminifera
"Radiolarians"
Cercomonads
Glaucophyte algae
Green algae
Green algae
Land plants
Red algae
Ciliates
Syndiniales
Marine grp I
Dinoflagellates
Apicomplexa
Labyrinthulids
Oomycetes
Diatoms
Phaeophytes
Chrysophytes
"Radiolarians"
Amoebas
Amoebas
Cellular slime molds
Plasmodial slime molds
Opalinids
Haptophytes
Cryptophytes
Acrasid slime molds
Vahlkampfiid amoebas
Euglenids
Discicristates
Trypanosomes
Leishmanias
Core jakobids
Mesomycetozoa
Choanoflagellates
Animals
Opisthokonts
Nucleariids
Fungi
Parabasalids
Diplomonads
Oxymonads
Excavates
Bacteria
Archaea
Crenarchaea
Crenarchaeum
Korarchaeota
Desulfurococcus
Sulfolobus
Aeropyrum
Pyrobaculum
Thermofilum
Nanoarchaeota
Archaeoglobus
Halophiles
Methanosarcina
Methanospirillum
Arme 1
Thermoplasma
Methanothermus
Methanobacterium
Methanopyrus
Pyrococcus
Euryarchaea
ROOT?
Thermotogales
Aquificae
OP11
Acidobacteria
Verrucomicrobia
Chloroflexi (GNSB group)
ε-proteobacteria
δ-proteobacteria
Mitochondria
α-proteobacteria
β-proteobacteria
γ-proteobacteria
Spirochaetes
Planctomycetes
Chlamydia
CFB group
Chlorobi (GSB group)
Actinobacteria
Deinococcus/Thermus
Cyanobacteria
Plastids
Firmicutes
Mycoplasmas

ssRNA
3,000+ species



Historical Note

Until mid 1950's phylogenies were constructed by experts based on their opinion (subjective criteria)

Since then, there has been more focus on **objective** criteria for constructing phylogenetic trees

- Thousands of articles in the last decades

Important for many aspects of biology

- Classification
- Understanding biological mechanisms

Evolution of Horses – summary of data tree

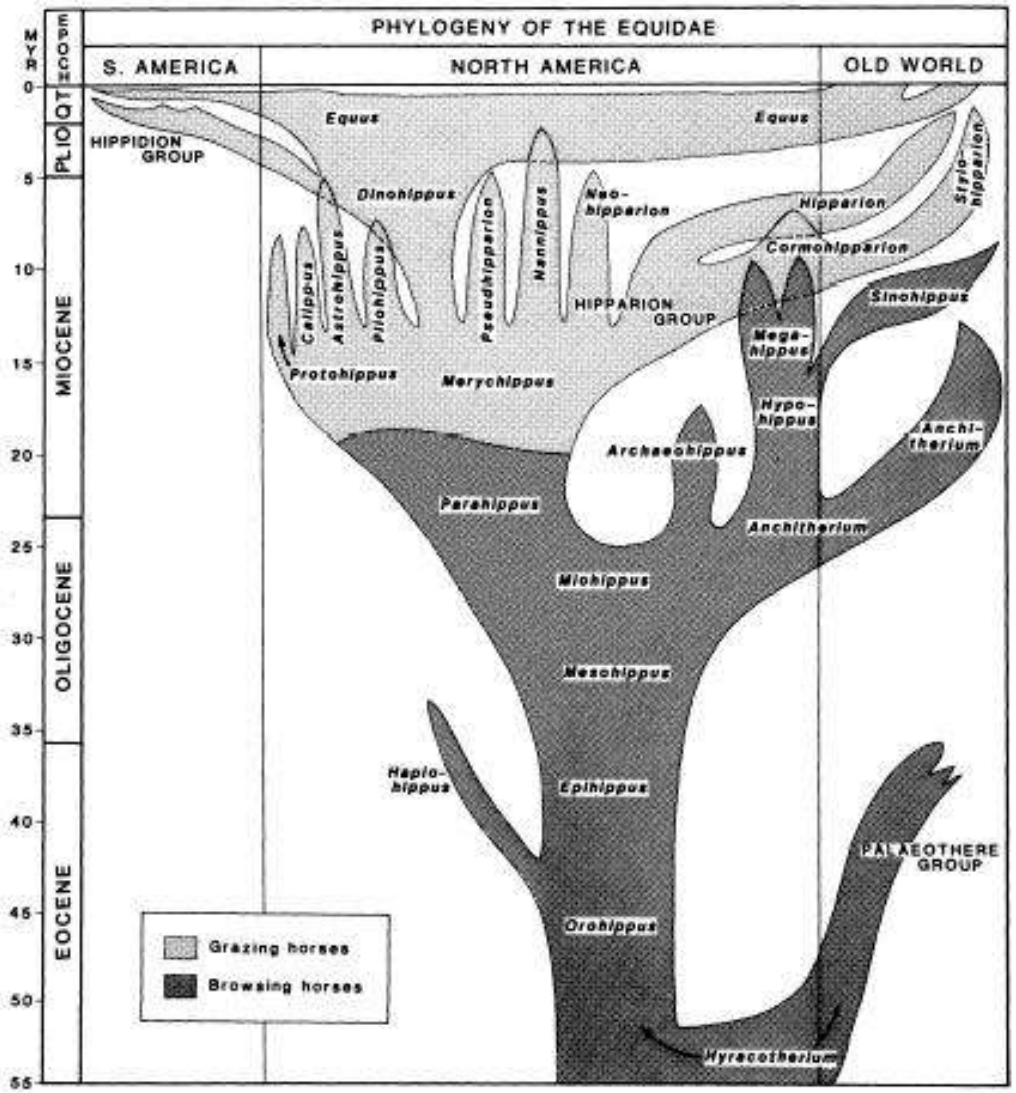
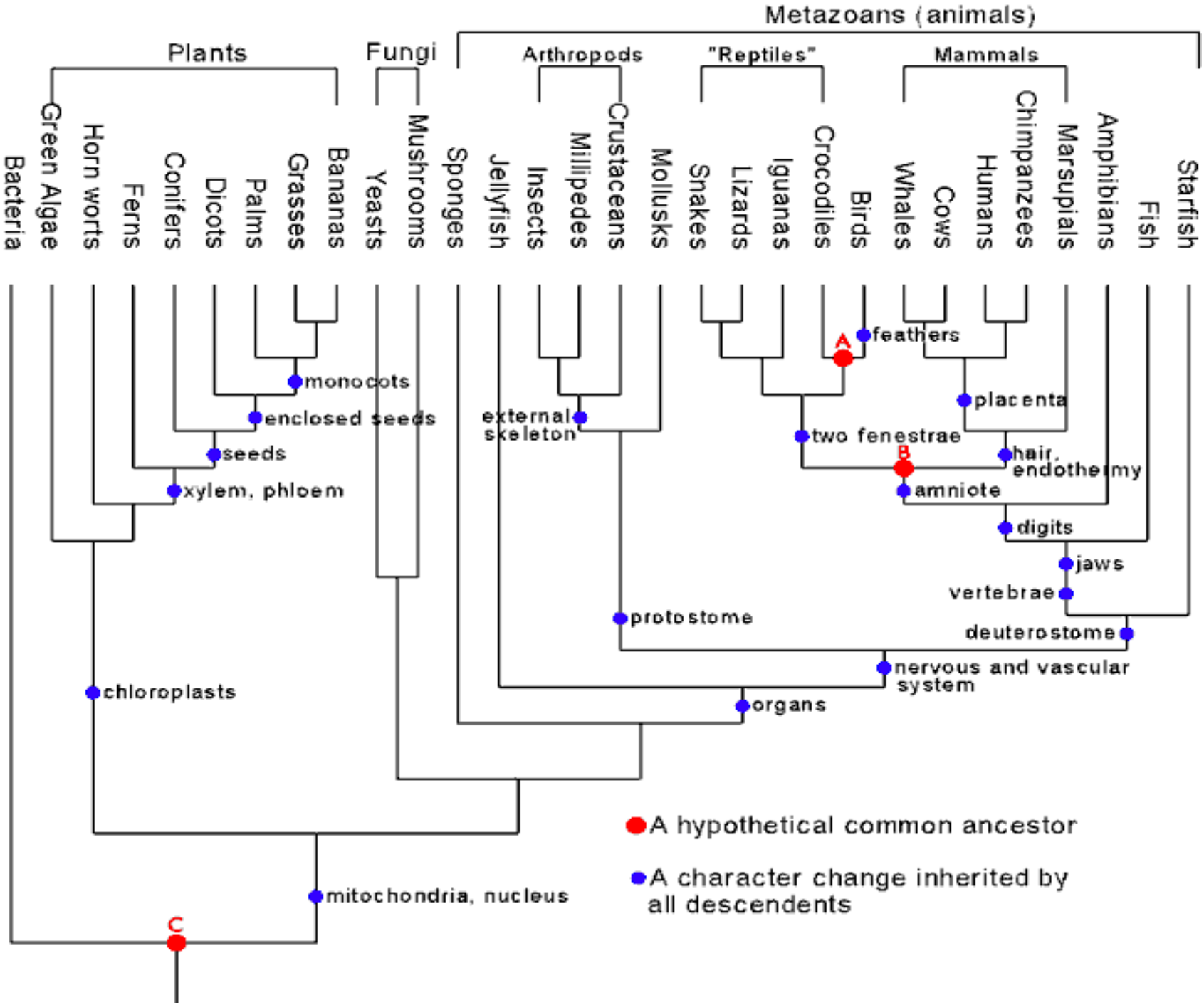


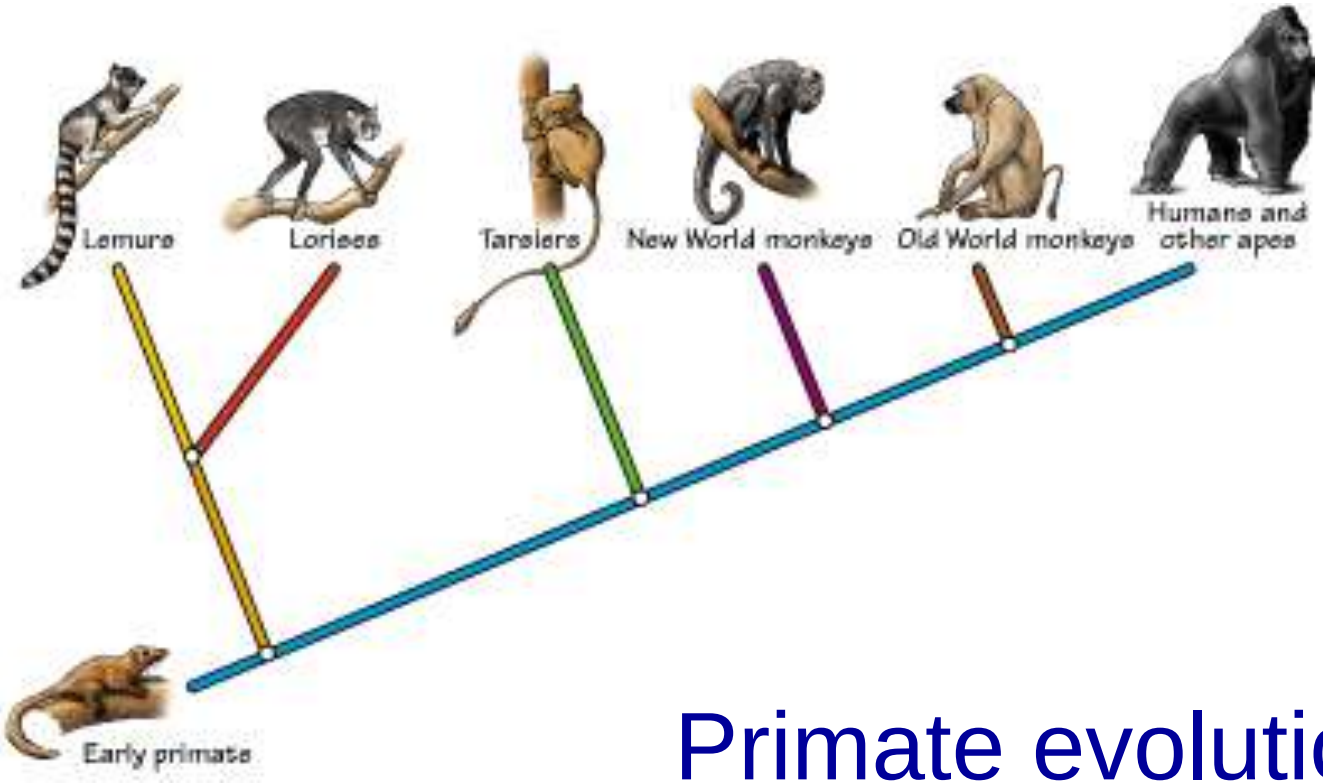
FIGURE 1. Current phylogeny of the Equidae, with particular emphasis on the North American taxa.


Metazoans (animals)
Plants
Fungi
Arthropods
"Reptiles"
Mammals
Bacteria
Green Algae
Horn worts
Ferns
Conifers
Dicots
Palms
Grasses
Bananas
Yeasts
Mushrooms
Sponges
Jellyfish
Insects
Millipedes
Crustaceans
Mollusks
Snakes
Lizards
Iguanas
Crocodiles
Birds
Whales
Cows
Humans
Chimpanzees
Marsupials
Amphibians
Fish
Starfish
A
feathers
monocots
enclosed seeds
seeds
xylem, phloem
external skeleton
placenta
two fenestrae
B
hair, endothermy
amniote
digits
jaws
vertebrae
protostome
deuterostome
nervous and vascular system
chloroplasts
organs
mitochondria, nucleus
C
A hypothetical common ancestor
A character change inherited by all descendents

Phylogenetic trees

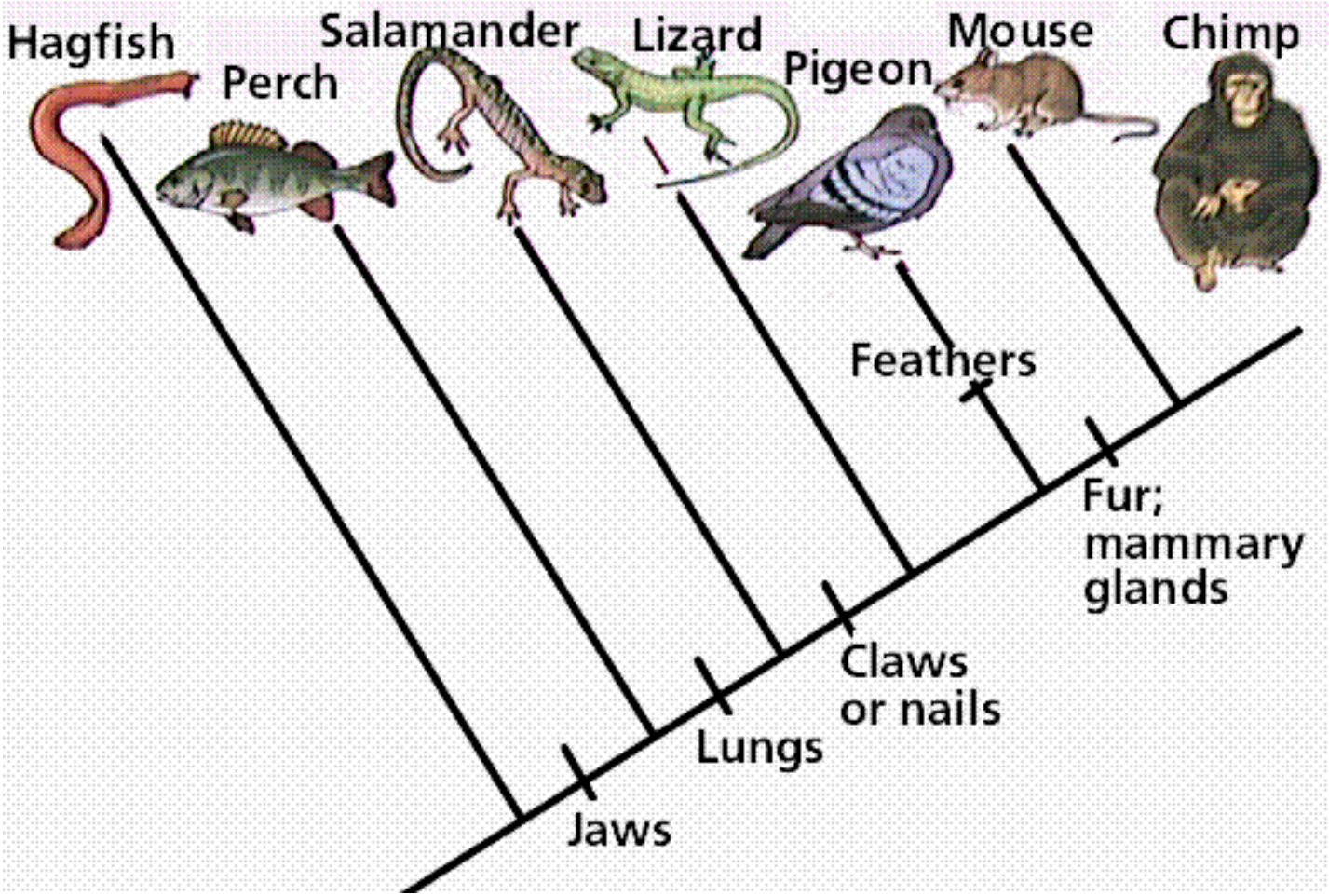
- The **phylogeny** of a group of taxa (species, etc.) is its evolutionary history.
- A **phylogenetic tree** is a graphical summary of this history — indicating the sequence in which lineages appeared and how the lineages are related to one another
- Because we do not have direct knowledge of evolutionary history, **every phylogenetic tree is an hypothesis** about relationships
- Of course, some hypotheses are well supported by data, others are not

A phylogenetic tree is a tree that describes the sequence of speciation events that lead to the forming of a set of current day species.



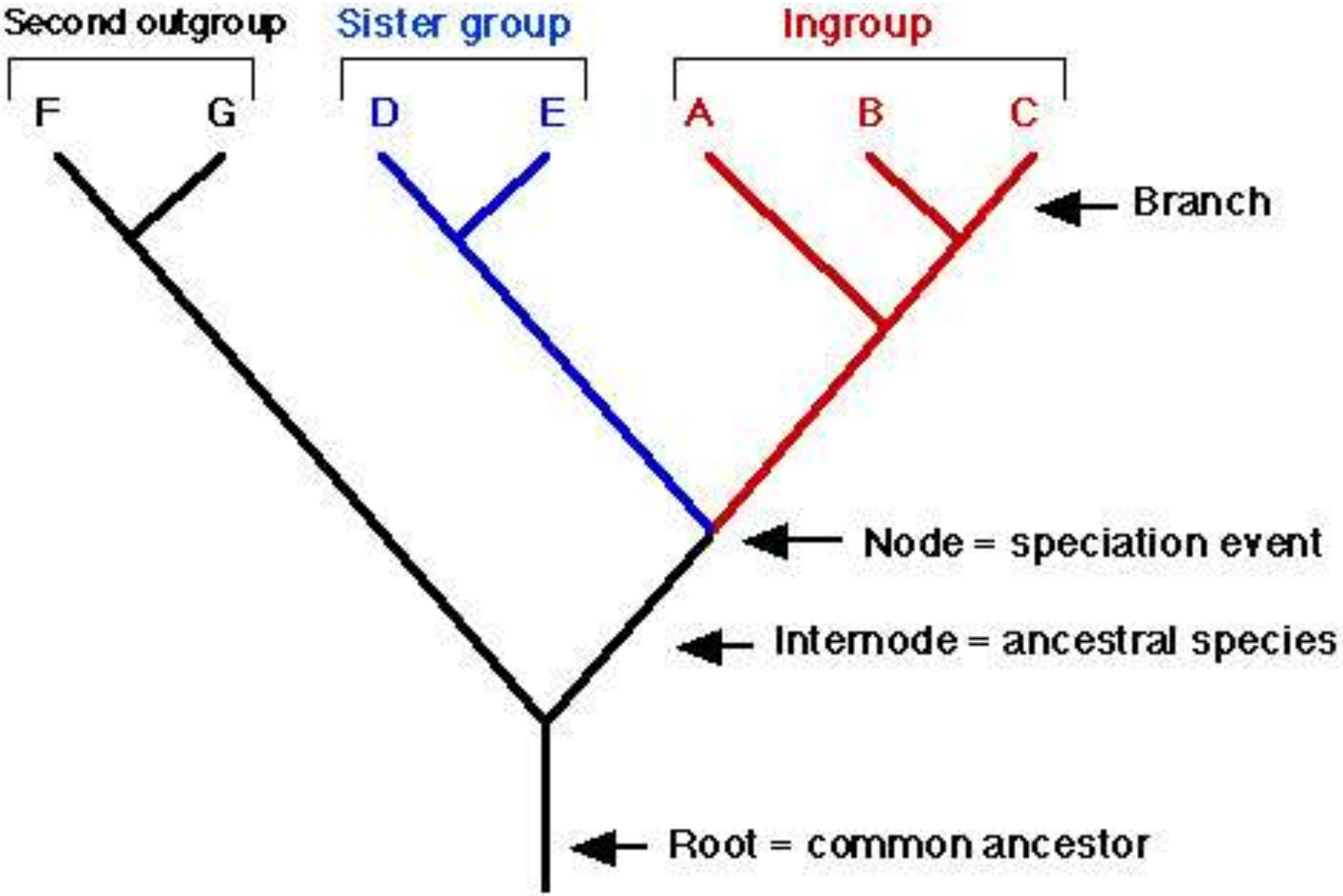
Primate evolution

Phylogenetic Trees are Based on Character Data

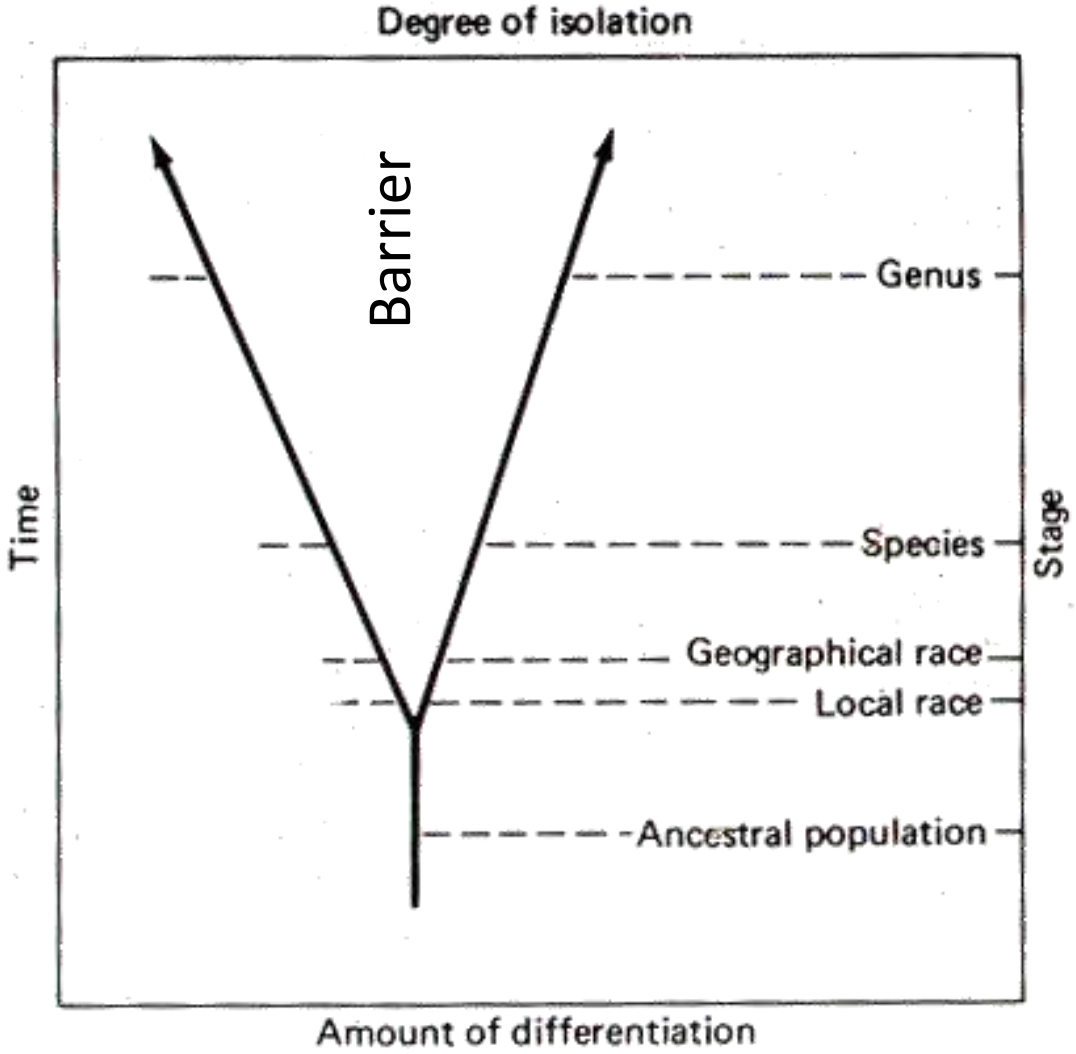


Cladogram of Vertebrates

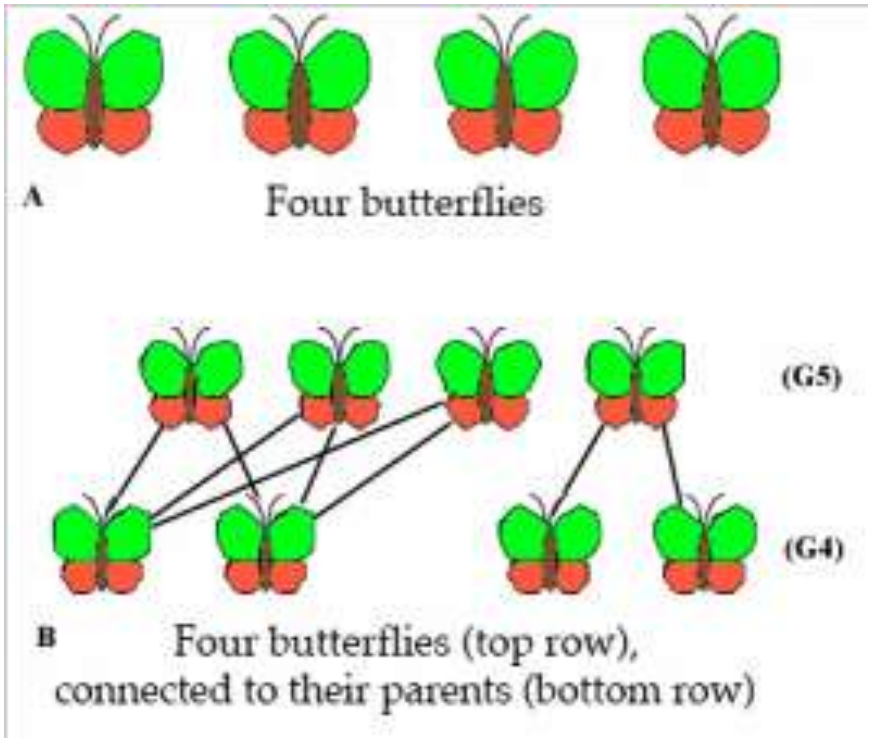
Tree Terminology

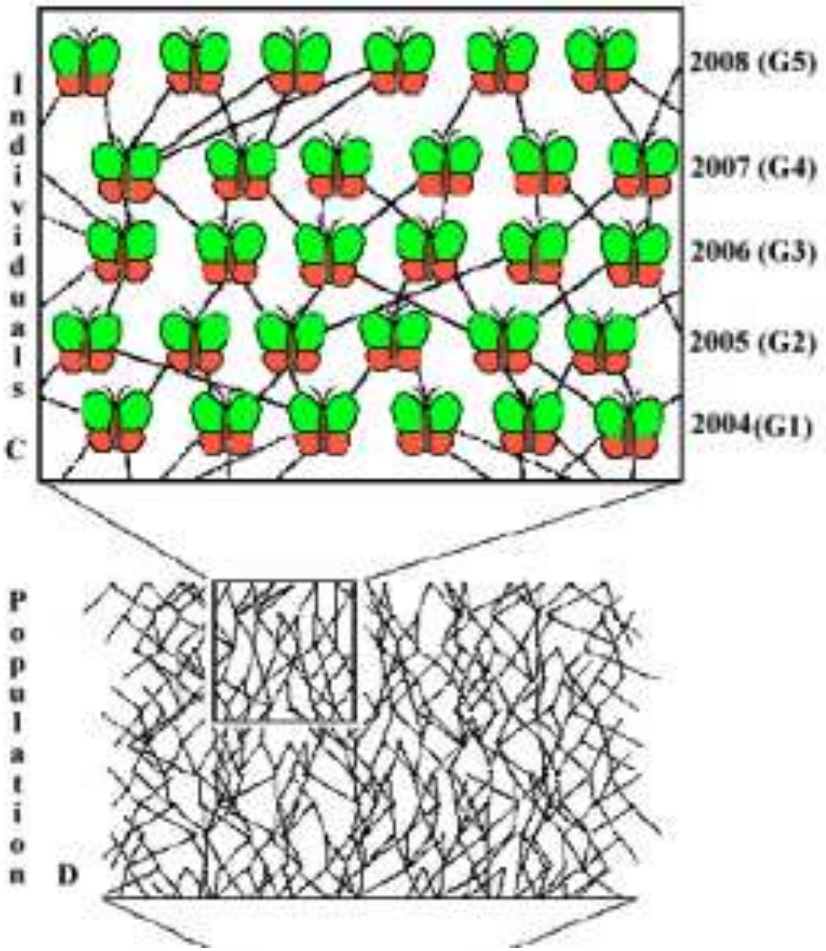


Node – Speciation Event

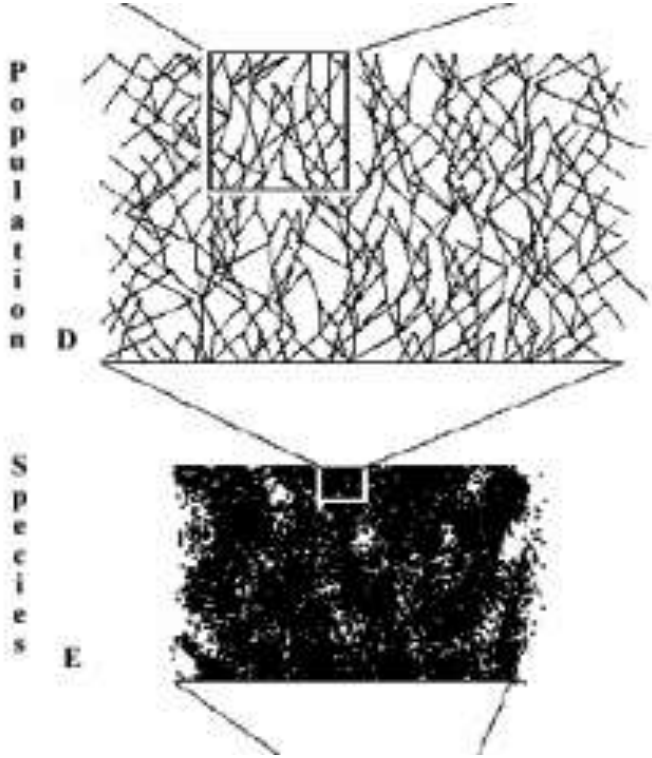


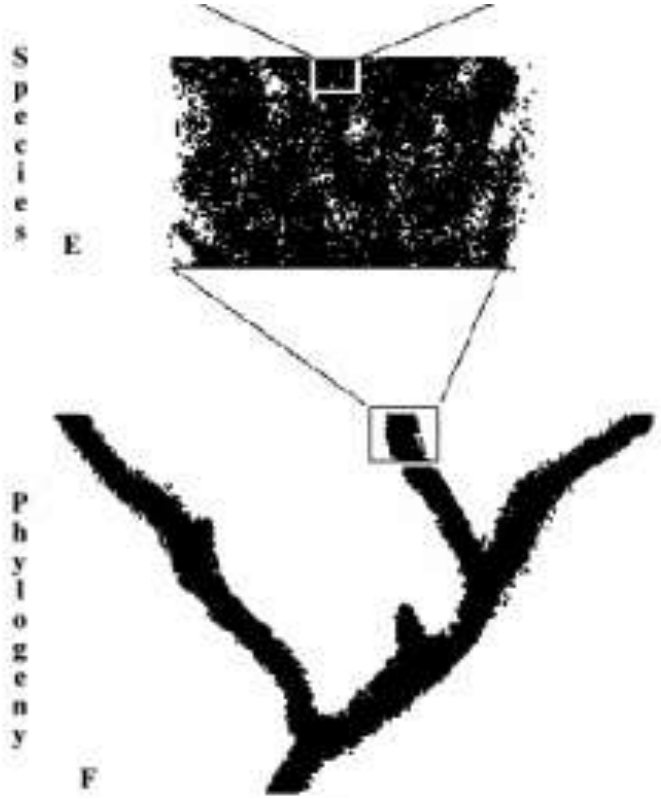
What an Evolutionary Tree Represents



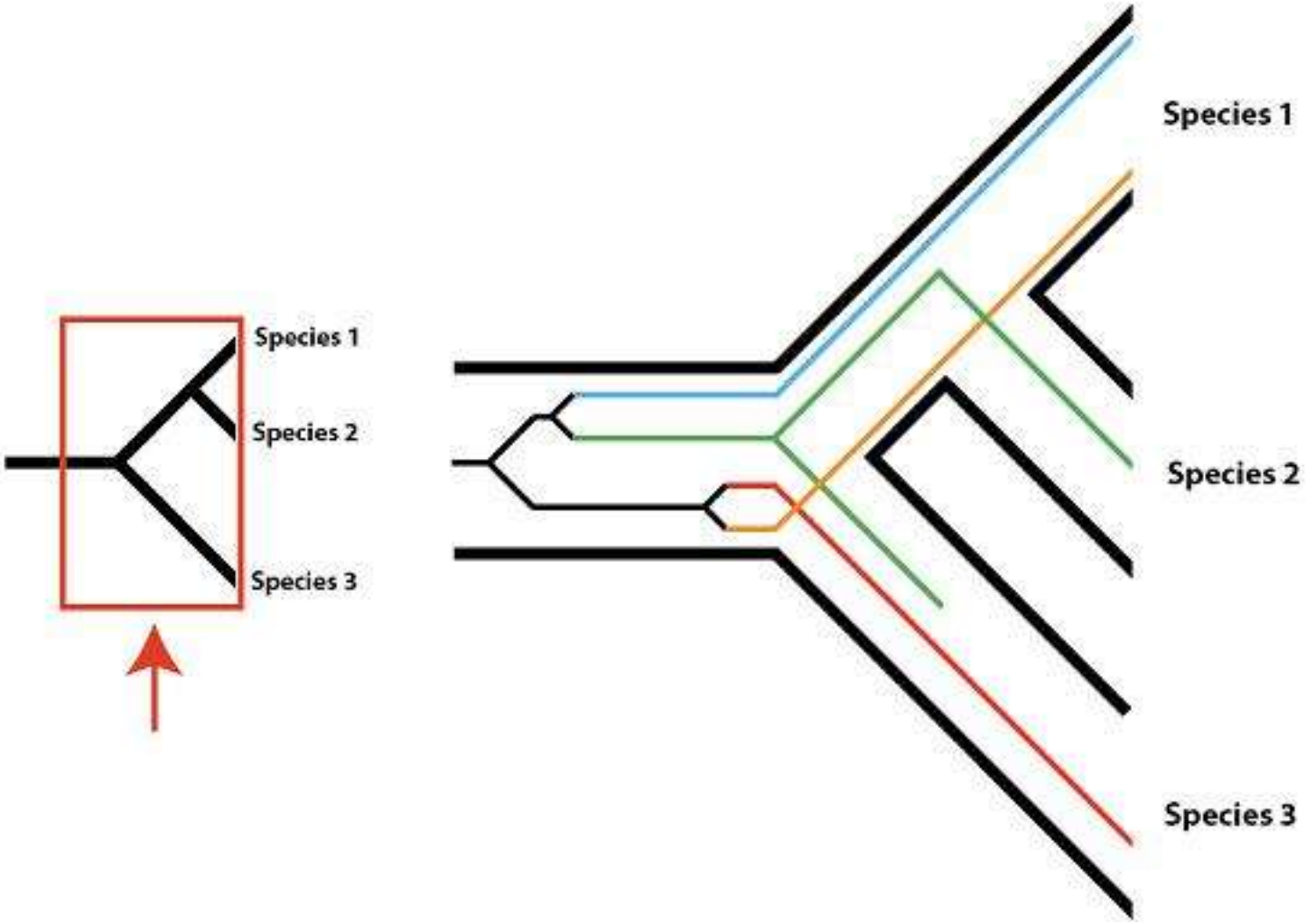


Zoooooming out…

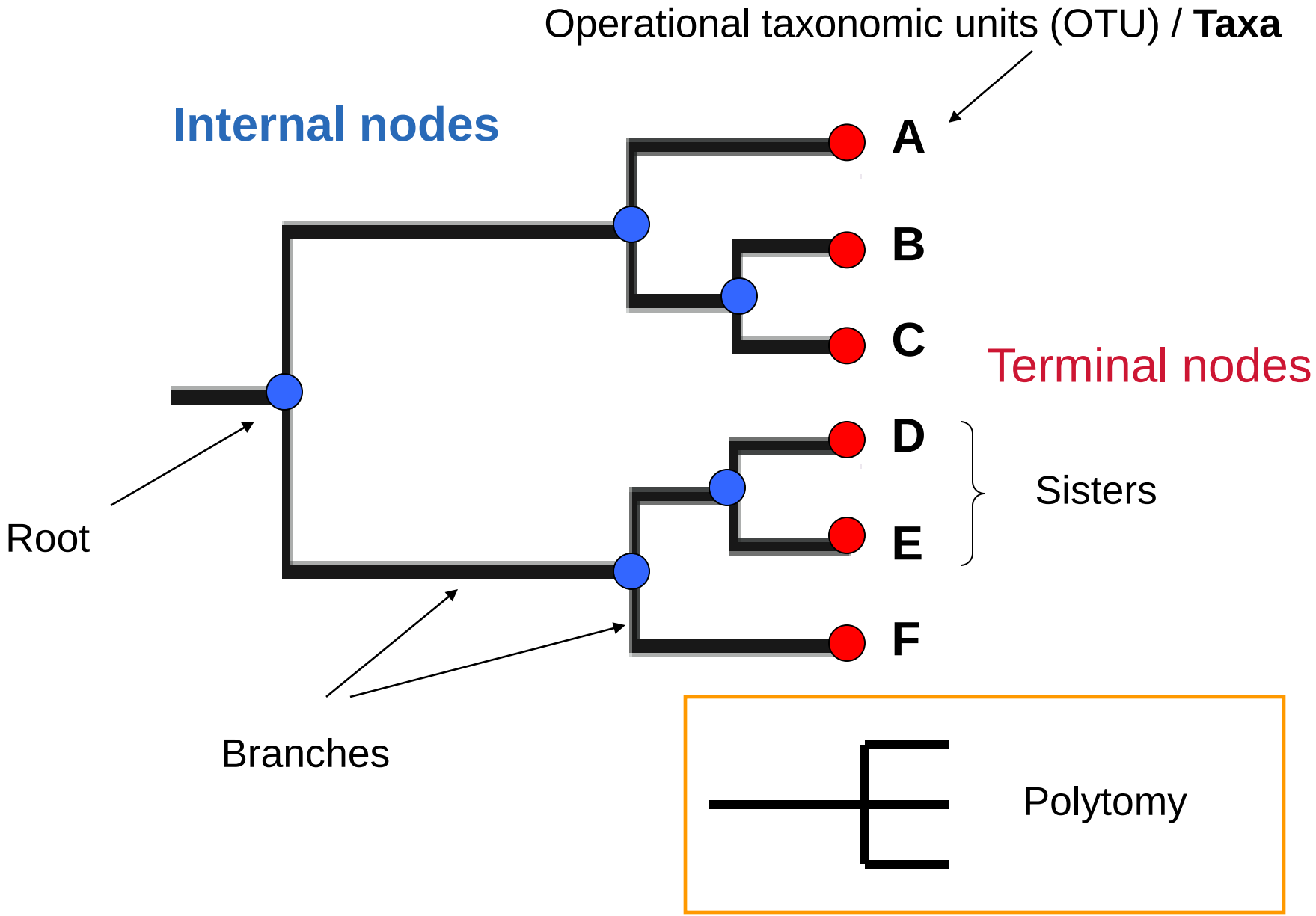




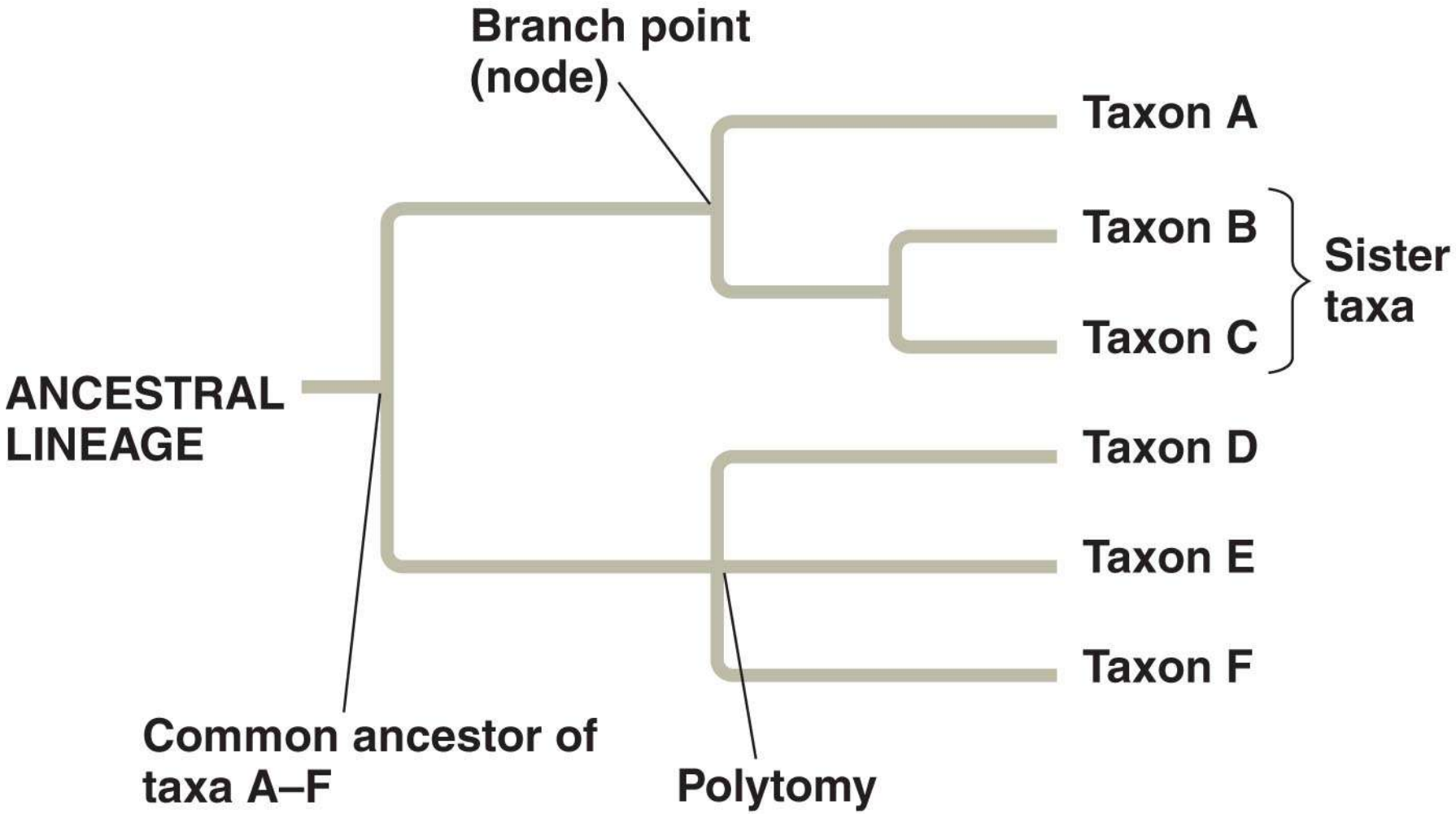
Lineage Sorting



Tree Terminology

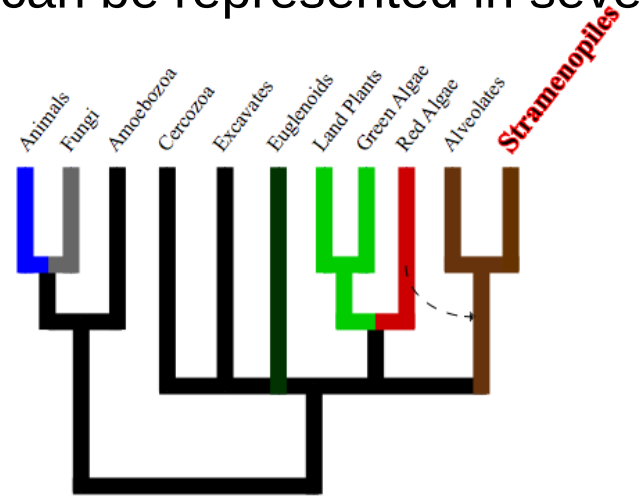


Tree Terminology

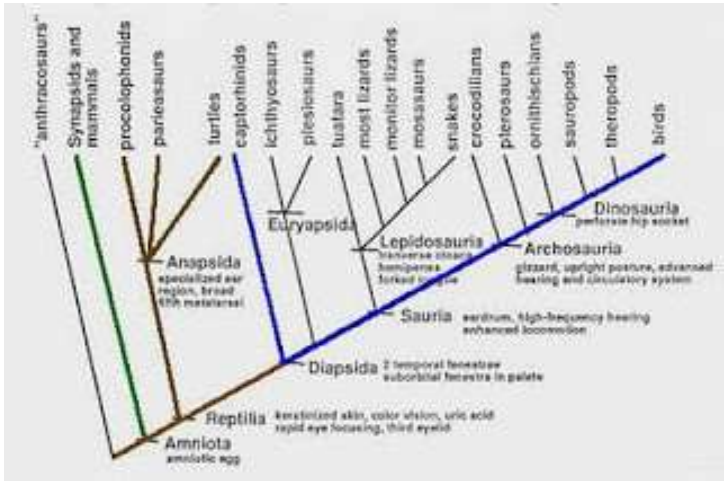


Tree Terminology

- Relationships are illustrated by a **phylogenetic tree / dendrogram**
- The branching pattern is called the tree's **topology**
- Trees can be represented in several forms:

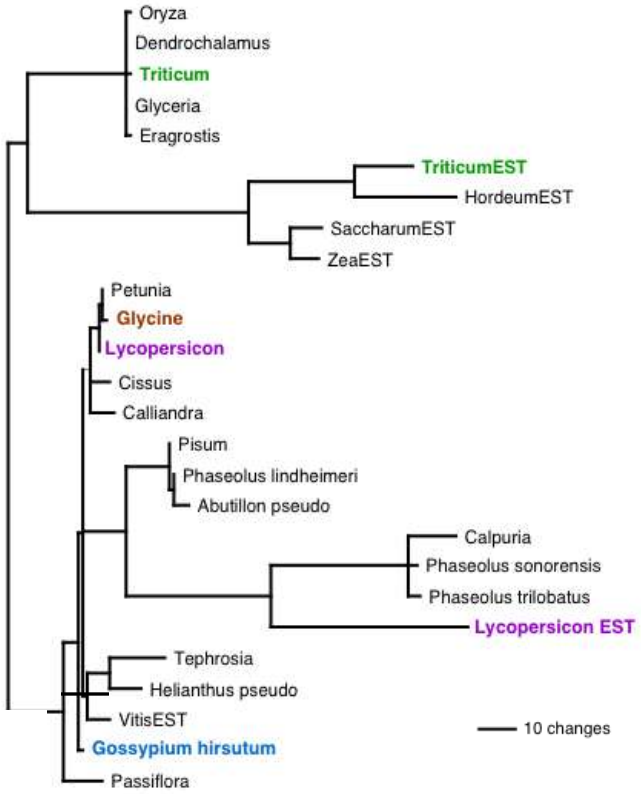


Rectangular cladogram



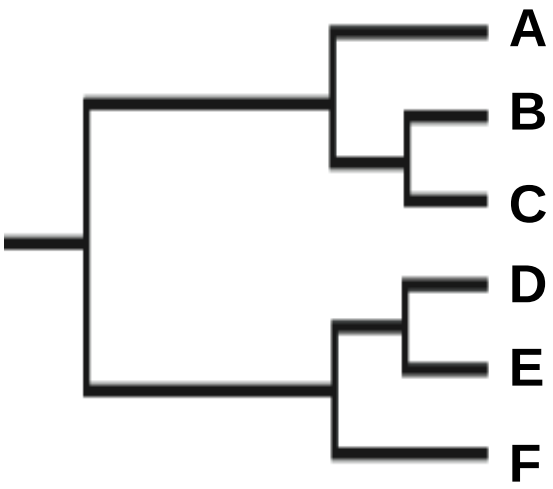
Slanted cladogram

Tree Terminology



Scaled trees: Branch lengths are proportional to the number of nucleotide/amino acid changes that occurred on that branch (usually a scale is included).

ɲscaled trees



Unscaled trees: Branch lengths are not proportional to the number of nucleotide/amino acid changes (usually used to illustrate evolutionary relationships only).

These trees depict equivalent relationships despite different styles

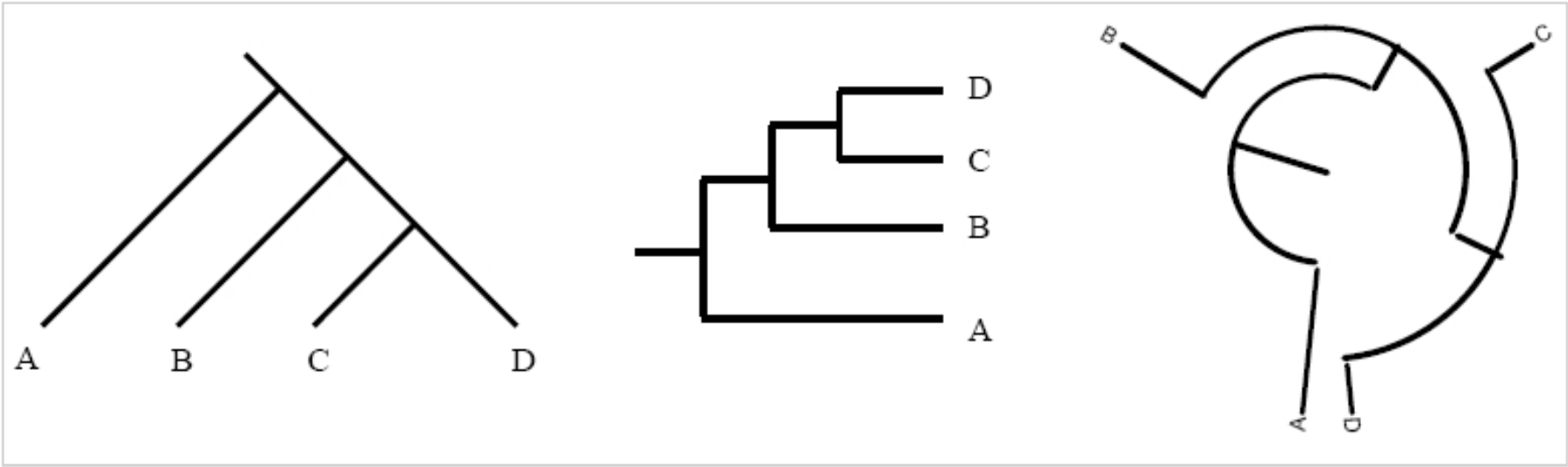
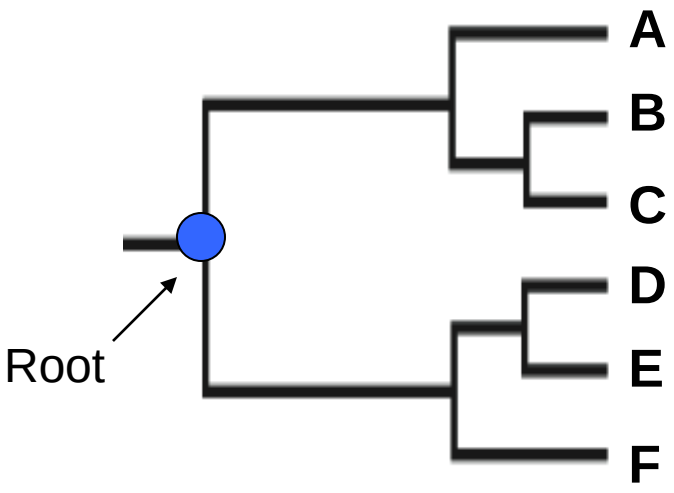
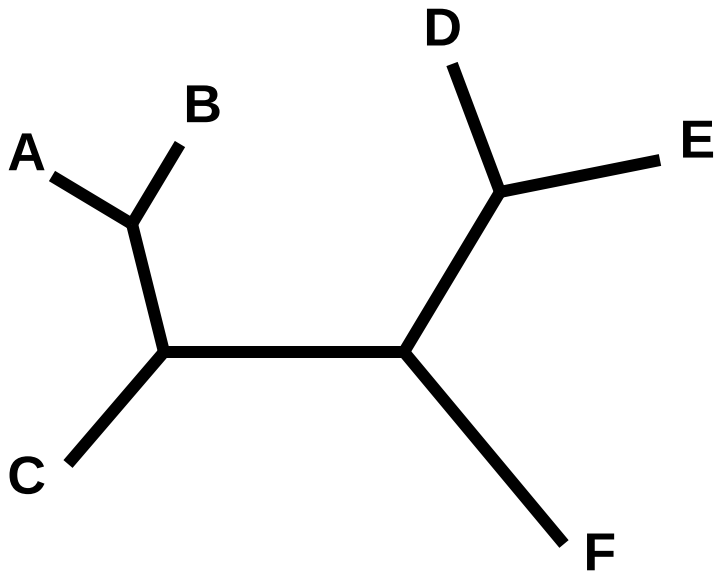


Figure 6 : These trees depict equivalent relationships despite being different in style.

Tree Terminology

Rooted vs. Unrooted trees

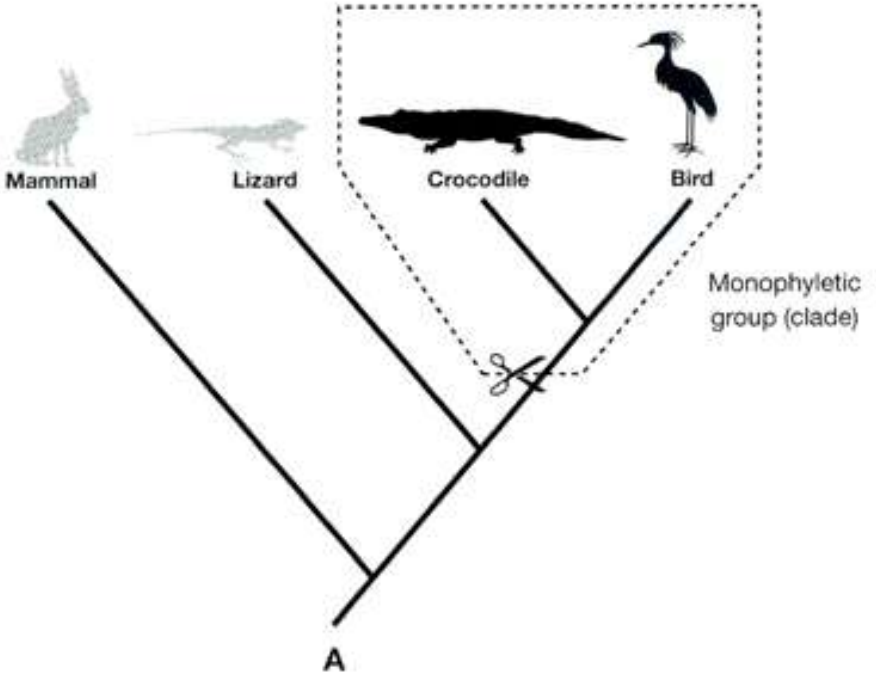




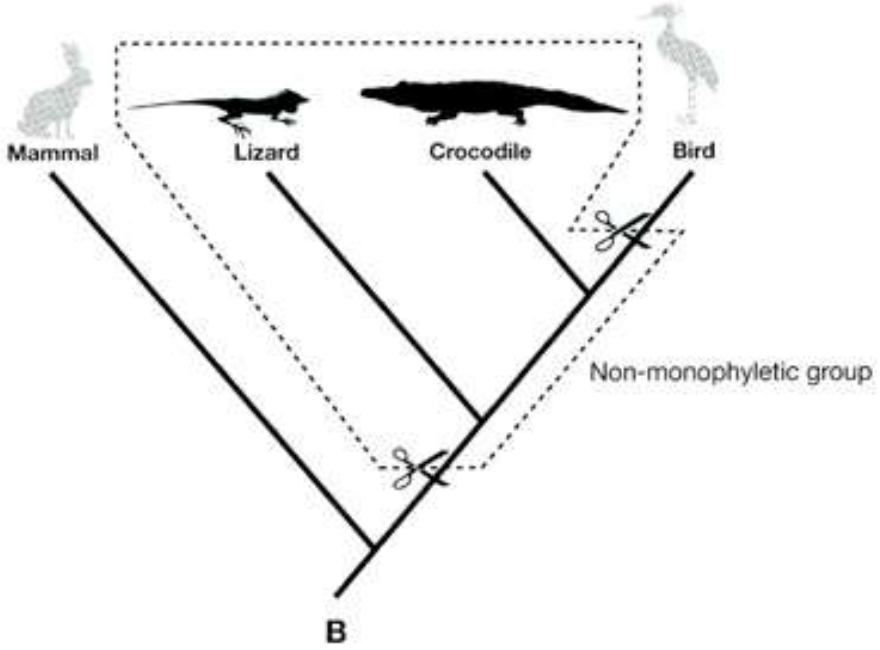
Rooted trees: Has a root that denotes common ancestry

Unrooted trees: Only specifies the degree of kinship among taxa but not the evolutionary path

Tree Terminology



A **clade** includes *all* and *only* the descendants of a particular ancestor



A monophyletic group = CLADE

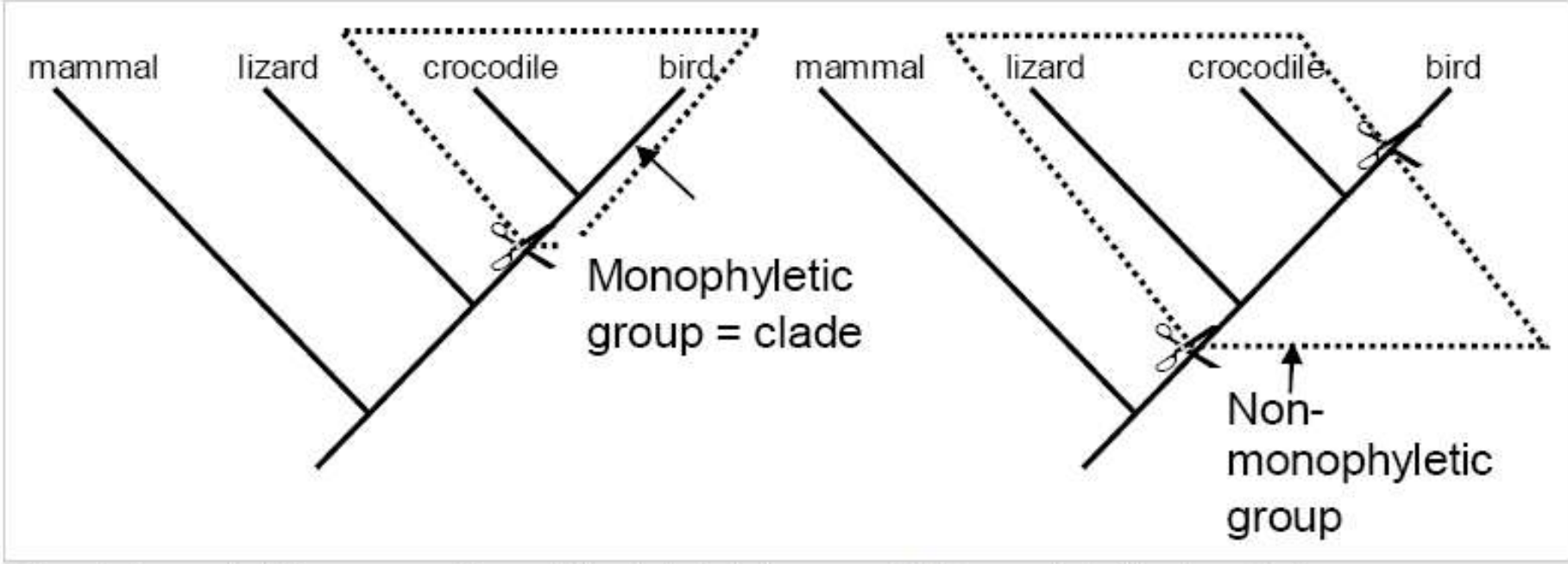
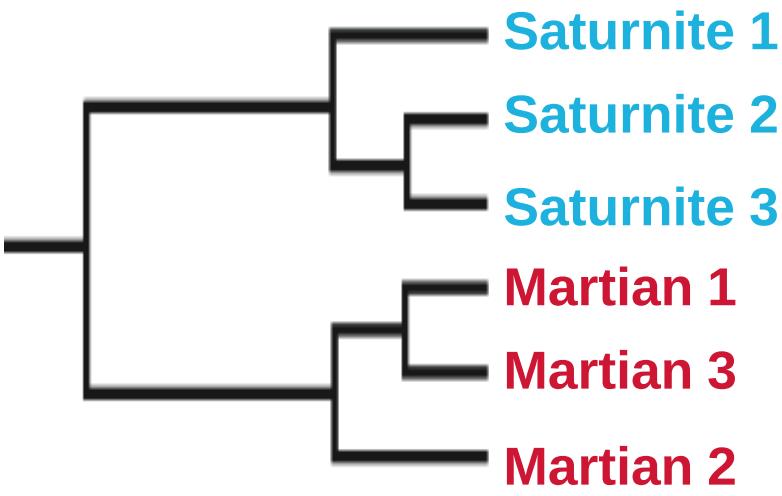


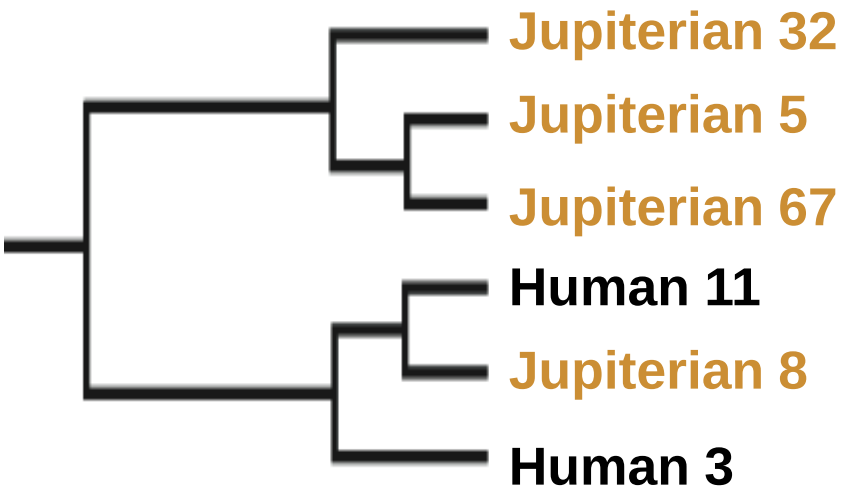
Figure 4 : A monophyletic group, sometimes called a clade, includes an ancestral taxon and all of its descendants.

A monophyletic group can be separated from the root with a single cut, whereas a non-monophyletic group needs two or more cuts.

Tree Terminology

Monophyletic vs. paraphyletic





Monophyletic groups:

All taxa within the group are derived from a single common ancestor and members form a natural clade.

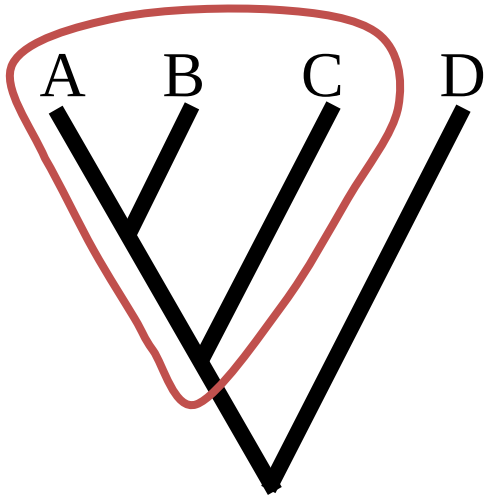
Paraphyletic groups:

The common ancestor is shared by other taxon in the group and members do not form a natural clade.

Phylogeny and classification

Monophyletic group

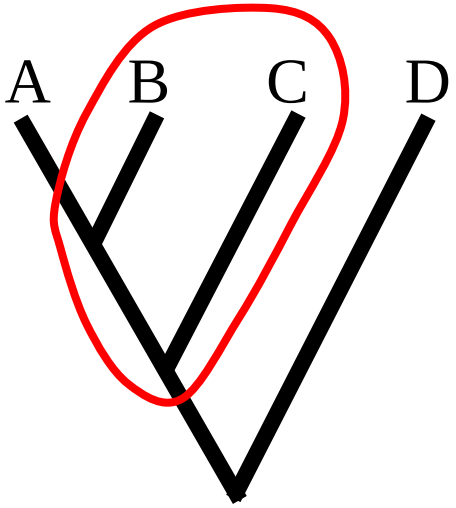
Includes an ancestor and all of its descendants



How could this happen?

Paraphyletic group

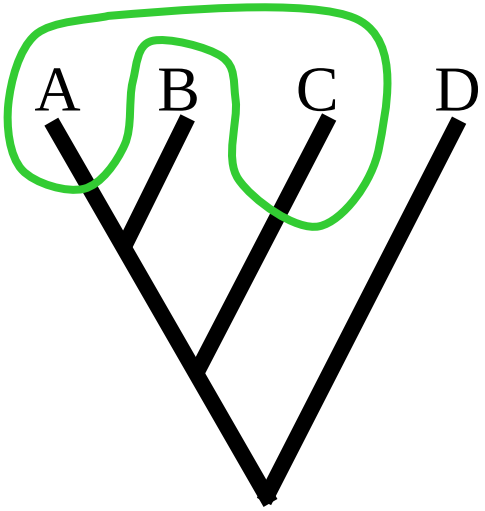
Includes ancestor and some, but not all of its descendants



Taxon A is highly derived and looks very different from B, C, and ancestor

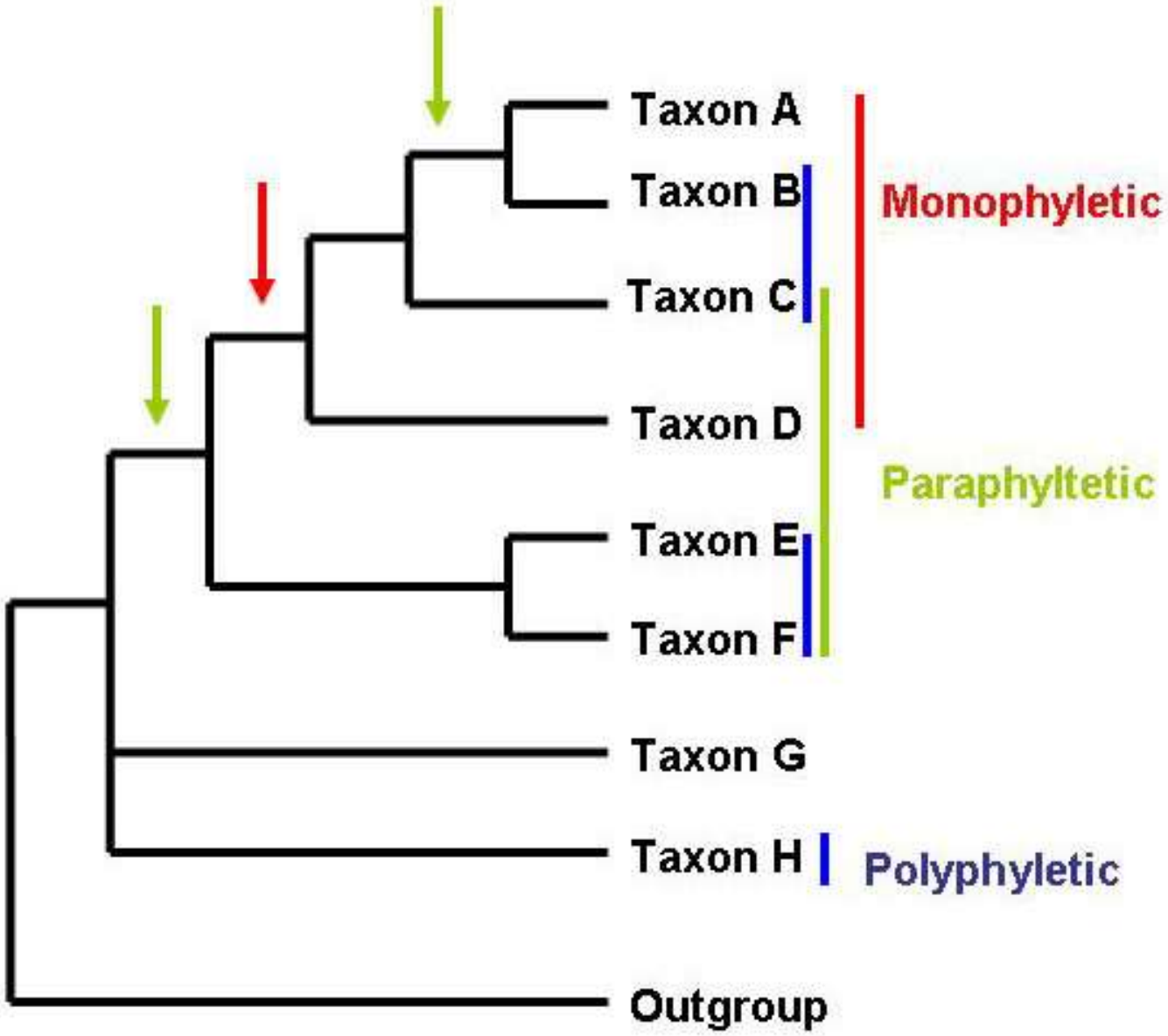
Polyphyletic group

Includes two convergent descendants but not their common ancestor



Taxon A and C share similar traits through convergent evolution

Only monophyletic groups (**clades**) are recognized in cladistic classification


Taxon A
Taxon B
Taxon C
Taxon D
Taxon E
Taxon F
Taxon G
Taxon H
Outgroup
Monophyletic
Paraphyltetic
Polyphyletic

Phylogeny and classification

Monophyly

Each of the colored lineages in this echinoderm phylogeny is a good monophyletic group

Asteroidea

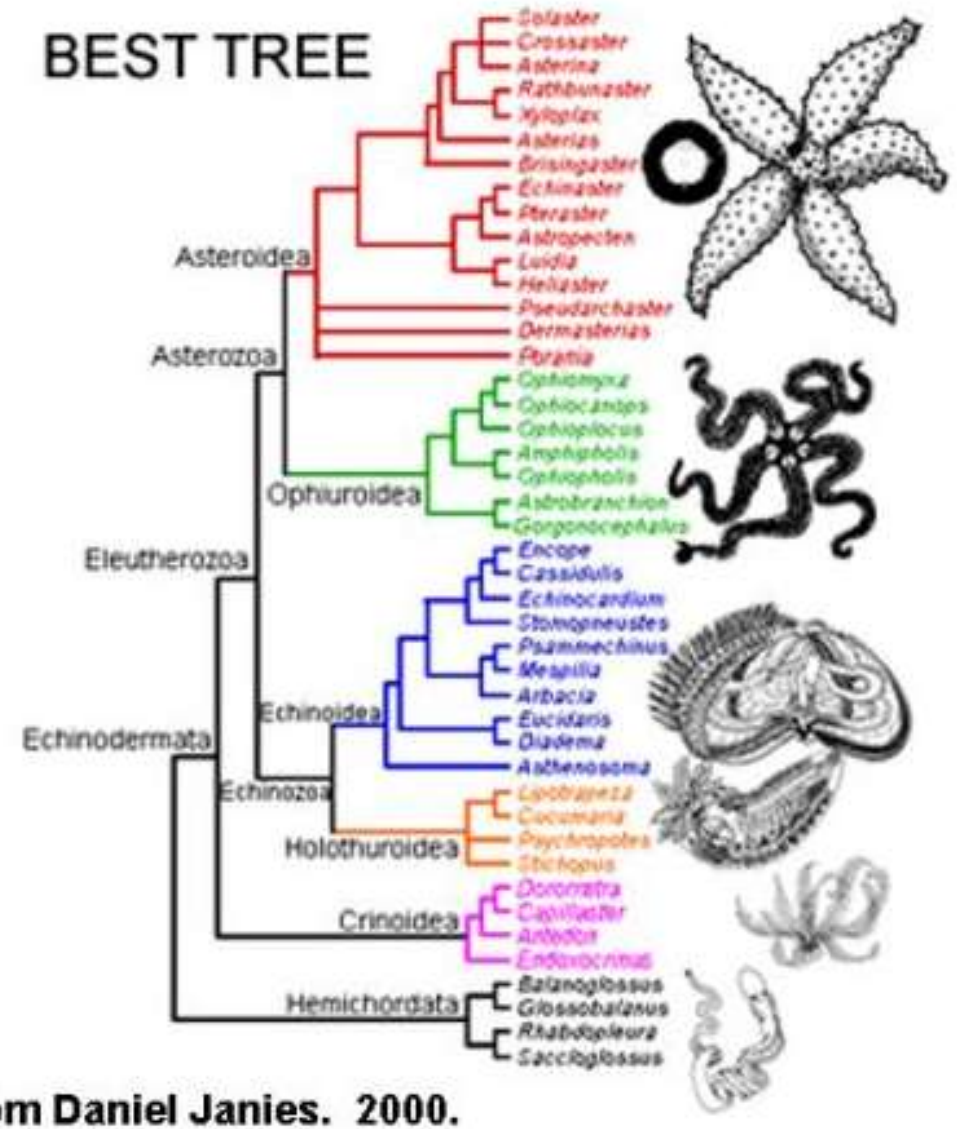
Ophiuroidea

Echinoidea

Holothuroidea

Crinoidea

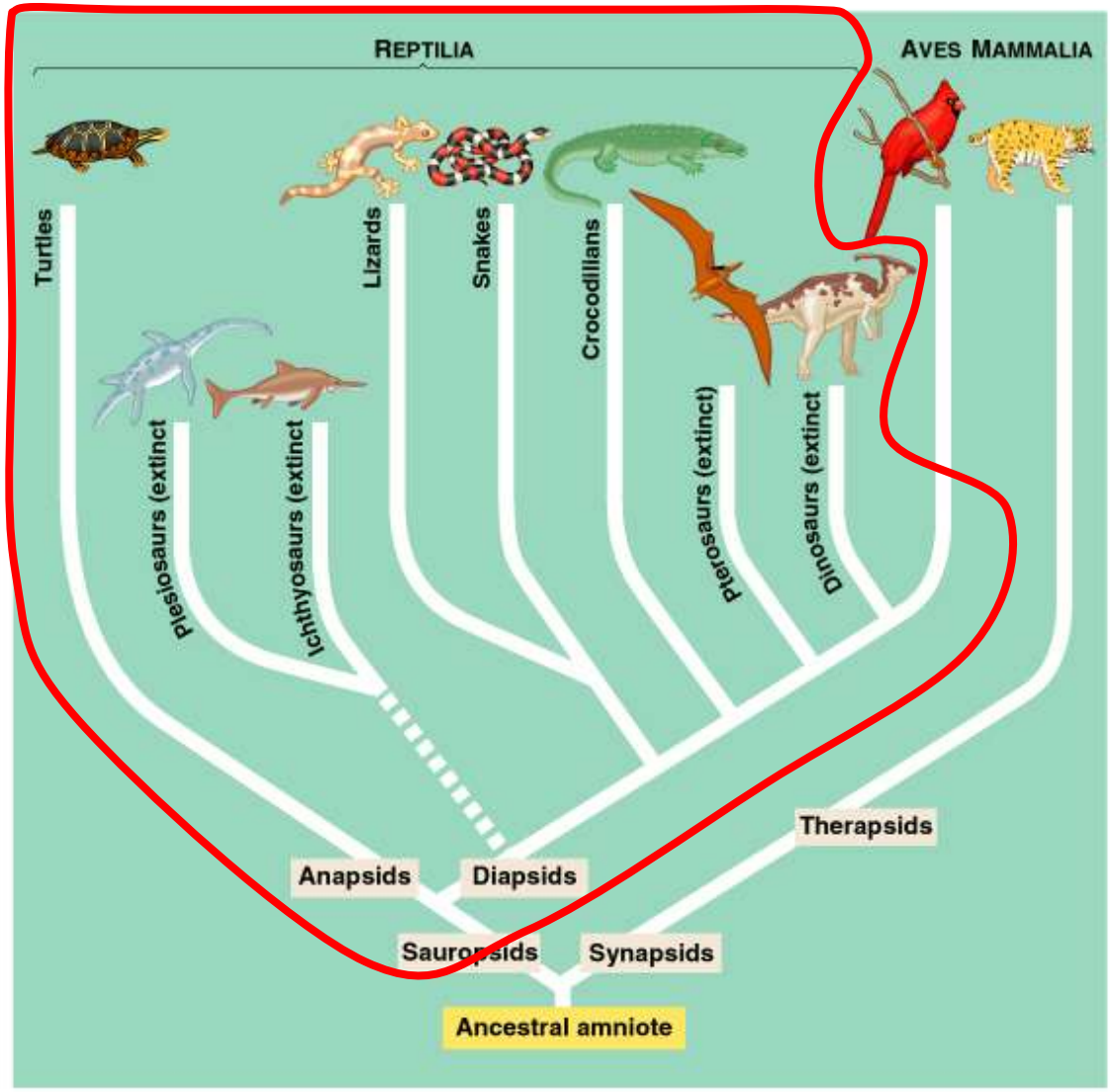
Each group shares a common ancestor that is not shared by any members of another group



From Daniel Janies. 2000.

Paraphyletic groups

Reptilia



Paraphyly

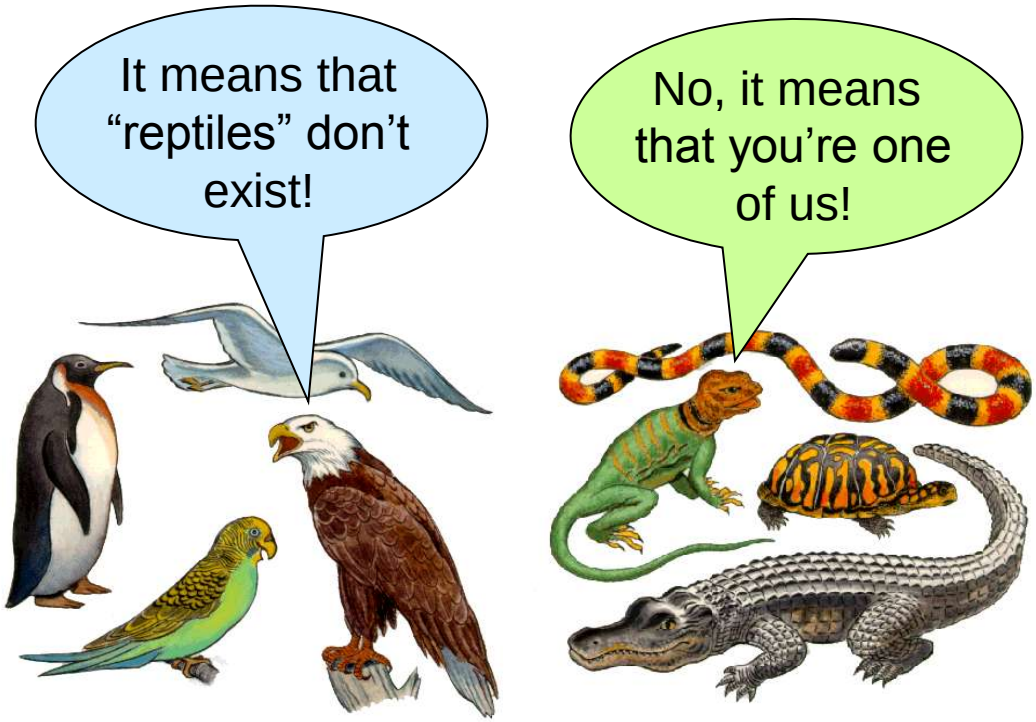
Birds are more closely related to crocodilians than to other extant vertebrates

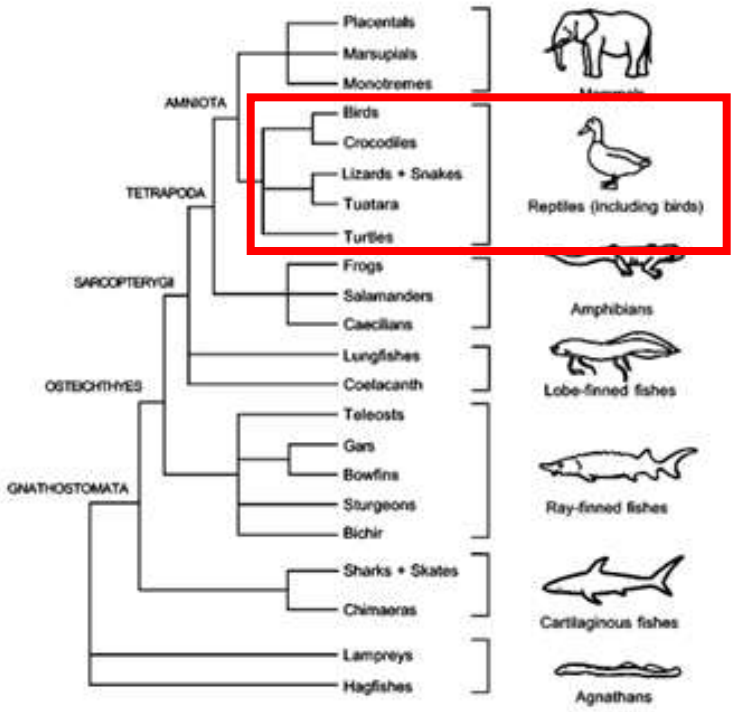
Archosauria = Birds + Crocs

We think of reptiles as turtles, lizards, snakes, and crocodiles

But Reptilia is a paraphyletic group unless it includes Aves

What does this mean?





What it means is that “reptile” is only a valid clade if it *includes* birds

Birds are still birds, but Aves cannot be considered a “Class” equivalent to Class Reptilia because it is evolutionarily nested *within* Reptilia

Reptilia

- **Aves (birds)**
- **Turtles**
- **Crocodiles**
- **Lizards and snakes**
- **Tuataras**

Questions

- How do we make phylogenetic trees?
  - Cladistic methodology
  - Similarity (phenetics)
- What kinds of data do we use?
  - Morphology
  - Physiology
  - Behavior
  - Molecules
- How do we decide among competing alternative trees?