What's in a name?

"Bears"

North America

Australia

Biological Classification

- **Taxonomy**: naming & classifying organisms
- **Systematics**: studying relationships among taxonomic groups

Systems of Systematics

I. **Anthrocentric**

II. **Ecological**

III. **Hierarchical**

IV. **Phylogenetic**

I. Anthrocentric Systems

- "human-centered" — Classified based on their relevance or usefulness to humans
  - Edible / inedible / medicinal
  - Wild vs. domestic
  - Crops vs. weeds
- Still basis for political policies
  - "Biological resources"
  - Commercially harvested vs. recreationally harvested vs. non-targeted (trash, by-catch) species

I. Anthrocentric Systems

Aristotle, 384–322 BCE

- *Scalae Naturae* ("ladder of nature")

- "advanced" = more human-like
- "primitive" = less human-like

* Archaic, prejudicial expressions: Any organism successfully surviving is <u>not</u> "primitive"!
* Better terms: "generalized" vs. "specialized" or "derived"

II. Ecological Systems

- Classified based on their habitat, niche or behavior
  - "Plant" (<u>plant</u>ed in place / sessile) vs. "Animal" (<u>anim</u>ated / motile)
  - "beasts of the field" / "beasts of the air" / "beasts of the sea" (fish)
- Useful for studying ecological relationships and effects of environment on body forms
  - Vegetation types: herb / shrub / tree
  - Aquatic life: plankton / nekton / benthos
  - Assemblages of organisms in a specific community
    - Oak woodland biota; coral reef biota; etc.

III. Hierarchical Systems

- Classified based on their relative similarities of body form

Carolus Linnaeus (Carl von Linné), 1707–1778
—*"Father of modern taxonomy & systematics"*

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Carl von Linné, 1775

- Swedish botanist, zoologist, physician, linguist, poet, & educator. Degree in Medicine; professor of medicine & botany - Uppsala University.
- Also one of the fathers of modern ecology. One of the most influential intellectuals of the 18th century.
- Students from all over Europe (esp. England) came to study under him. Then went out to join numerous exploratory expeditions around the world (e.g., with James Cook) and join faculties of major universities.
- Linnaeus also corresponded with collectors and naturalists around the world who sent him exotic specimens.

III. Hierarchical Systems

- Classified based on their relative similarities of body form

Carolus Linnaeus (Carl von Linné), 1707–1778
—*"Father of modern taxonomy & systematics"*

i. Recognize "patterns in creation"
   - Develop a standard hierarchy of similarities

ii. "…finish the work of Adam."
   - Identify, name, and categorize all forms of life on earth.
   - Develop a standard "universal" naming practice ("scientific name")

Taxonomy & Linnaean Hierarchy

- Levels called ***taxa*** (sing., ***taxon***: "classification")
  - The more similar two organisms are, the more levels they have in common

a) **Kingdom**
b) **Phylum (Division)***
c) **Class**
d) **Order**
e) **Family***
f) **Genus**
g) **Species**

*not in the original Linnaean hierarchy

Taxonomy & Linnaean Hierarchy

- For taxa with high diversity and large number of species, (esp., arthropods) additional levels may be added by using prefixes super-, sub-, or infra-
- E.g.,
  d) Order
  e) Family
- may be expanded to
  d) Order
  d') Suborder
  d") Infraorder
  d"') Superfamily
  e) Family

Biological Kingdoms

Classification of Life on Earth

- Classical two-kingdom model
  - Plants
  - Animals

  Worked well for macroscopic terrestrial life. But became inadequate once microbial and oceanic ecosystems were explored
- Expanded five-kingdom model (Whittaker 1960s)

  Cells are the basic unit of life, so define types of life by the types of their cells
  - Monera
  - Protista
  - Fungi
  - Plantae
  - Animalia

Linnaean Taxonomy

Some rules:

Since all scientific and academic work in Linnaeus' time was conducted in Latin or Greek,

- all taxonomic names are written in Latin or Greek …
  - *rosa*: "rose"
  - *homo*: "human"
  - *canis*: "dog"
  - *porifera*: "pore bearing"
  - *brevispinus*: "short-spined"
- … or in Latinized/Hellenized derivations of proper names
  - *ricketsia*: [in honor of Ed] Rickets
  - *californicus*: [discovered in] California

Linnaean Taxonomy

Some rules:

- Names of **families** always end in "*-idae*" [animals] or "-aceae" [plants & fungi]
  - Hominidae
  - Canidae
  - Rosacea
- Names of **genera** must be unique
  I.e., not given to any other genus
  - *Homo*
  - *Canis*
  - *Rosa*
- A **species** is a group of organisms similar enough to interbreed

Linnaean Taxonomy

The universal "scientific name" for a species:

- **Binomial nomenclature** ("two-name naming")
  The universal name for a species is its generic name with a specific epithet,
  i.e., its **genus + species** names
  - *Homo sapiens*
  - *Canis familiaris*
- The two names must be unique to one species.
- The genus name must be capitalized; the species name all lower case — even if it's in a title.
- The scientific name is always printed (type-set; word processed) ***in italics***. If handwritten, it must be underlined.
- The species name must include the genus.
  - *Homo sapiens* or *H. sapiens*, but never just *sapiens*

Classification of some edible shellfish

	American Lobster	Market Squid	Blue Mussel	Virginia Oyster	European Oyster
Kingdom	Animalia	Animalia	Animalia	Animalia	Animalia
Phylum	Arthropoda	Mollusca	Mollusca	Mollusca	Mollusca
Class	Malacostraca	Cephalopoda	Bivalvia	Bivalvia	Bivalvia
Order	Decapoda	Decapoda	Mytiloida	Pterioida	Pterioida
Family	Nephropidae	Loliginidae	Mytilidae	Ostreidae	Ostreidae
Genus	*Homarus*	*Loligo*	*Mytilus*	*Crassostrea*	*Ostrea*
Species	*americanus*	*opalescens*	*edulis*	*virginica*	*edulis*

Note: some names are duplicated for taxa other than genus!

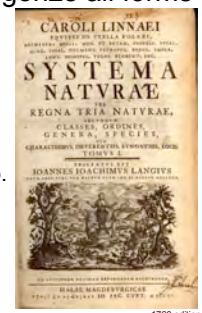
Linnaean Taxonomy

The **Law of Priority**:

- If more than one name has been assigned to organisms later decided to be all one species, the first published name becomes the name for the combined group.
- The specimen originally used to the describe the newly named species is the **type specimen**.
  - The type specimen is carefully archived in a certified museum collection available for subsequent studies.
- If a group of organisms originally classified as a single species becomes divided into multiple species, the original scientific name belongs to the new group that includes the type species.

"The Linnaean Enterprise"

- Identify, name, and categorize all forms of life on earth.
- ***Systema Naturae***
  - 1735 (first edition)
  - By 1758 (tenth ed.)
    - Included 4400 animal spp. & 7700 plant spp.
    - First consistent use of binomial nomenclature



1760 edition

"The Linnaean Enterprise"

- Still lots to do!
- Present — ~1.8 million species named (~70% of them are insects)

Only ~ 1% studied significantly

Estimated ~10 million spp. yet to be named

IV. Phylogenetic Systems

- Classified based on *presumed* common ancestry
- Usually still use Linnaean hierarchy, but now more levels in common suggests a more recent divergence from a common ancestor.
- But since we don't actually know the ancestry above the level of genus or maybe family, still dependent upon degrees of similarity.
  - Comparative morphology & anatomy
  - Comparative embryology
  - Comparative biochemistry — proteins & DNA
- Much disagreement may be debated regarding which similarities and which differences are most phylogenetically significant!

IV. Phylogenetic Systems

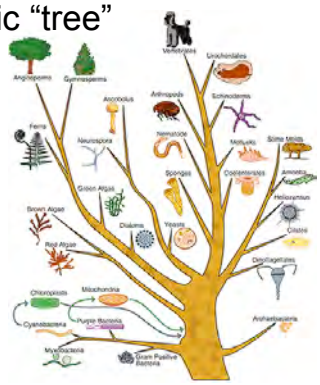
1. Classical (authoritative) phylogenetics
2. Phenetics
3. Cladistics
4. Synthetic systematics
   - Try to incorporate bits of all of the above

1. Classical phylogenetics

- "Traditional evolutionary taxonomy" (TET)
- Authoritative — Influential "experts" on each taxon pick which characters are most significant
  - Create "trees" (**dendrograms**)
  - Often arbitrary and contradictory
  - Certain popular trees get perpetuated when published in textbooks

A phylogenetic "tree"

- Aristotle's philosophy in a Darwinian context



2. Phenetics

- Morphometrics — carefully measure all dimensions of body form
- Phenogram (taxonomic cluster) — mathematic programs calculate degrees of similarity (cluster analysis — advent of available computers)
- TET purists argue that all body forms are not dependent upon ancestry, □ should not be included
  - **Homology vs. analogy**
- Pheneticists counter that since no one actually knows ancestry, at least metric methods are less arbitrary than TET.

Problem: Divergence vs. Convergence — Homology vs. Analogy

Similarity due to convergence is **analogy**.

(Similar adaptations to similar environments; not shared ancestry.)

3. Cladistics

- Traditional phylogeneticists get to have computer programs too!
- **Clade** ("branch") — replace traditional taxon
  - Groups of organisms presumed to be derived from a common ancestor are organized by bifurcating (two-way splitting) of a branch
  - Each bifurcation is based upon the acquisition of a new, unique character (**apomorphy**).
- **Maximum parsimony**: the branch pattern that can be created with the fewest required steps is most likely the most correct.

3. Cladistics

More vocabulary:

- A true **clade** must be **monophyletic**
  - must include an ancestor and all of the known descendants of that ancestor.
  - A grouping that only includes an ancestor and some of its descendants is **paraphyletic**.
  - A grouping that includes organisms from different ancestries is **polyphyletic**.
- Derived **apomorphic** characters shared by members of a clade are **synapomorphic**.
- Ancestral characteristics inherited prior to the branching of a clade are **plesiomorphic**.

Building Cladograms

Assemble a **table of character states**

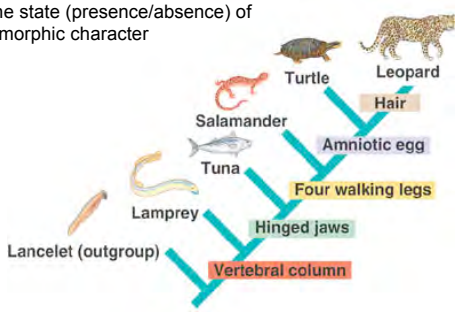
Major assumptions:

1. The group of organisms is monophyletic
2. The **outgroup** (used for comparison) is closely related to, but separate from your group
3. You can tell which character states are homologous or analogous.

	Lancelet (outgroup)	Lamprey	Tuna	Salamander	Turtle	Leopard
Hair	0	0	0	0	0	1
Amniotic (shelled) egg	0	0	0	0	1	1
Four walking legs	0	0	0	1	1	1
Hinged jaws	0	0	1	1	1	1
Vertebral column (backbone)	0	1	1	1	1	1

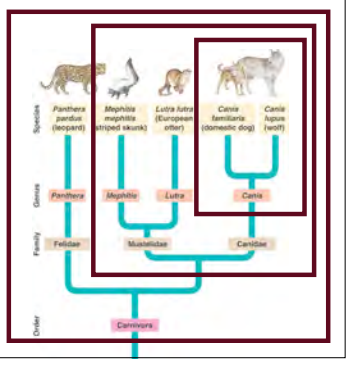
Building Cladograms

Each bifurcation of the branch is based upon the state (presence/absence) of an apomorphic character



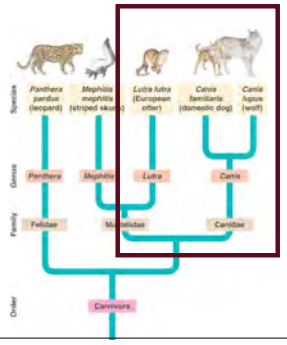
Cladograms

Monophyletic clades



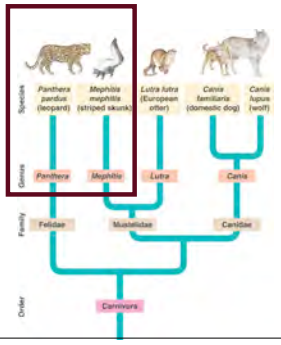
Cladograms

Paraphyletic grouping



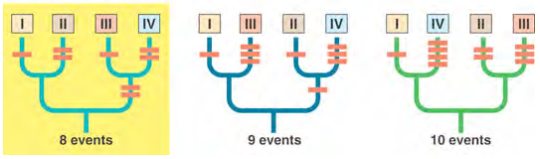
Cladograms

Polyphyletic grouping



Cladograms

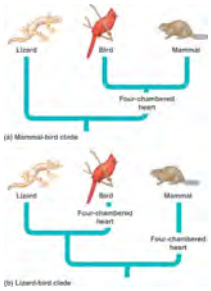
Rule of Parsimony:
The simplest explanation is the most likely explanation.



Cladograms

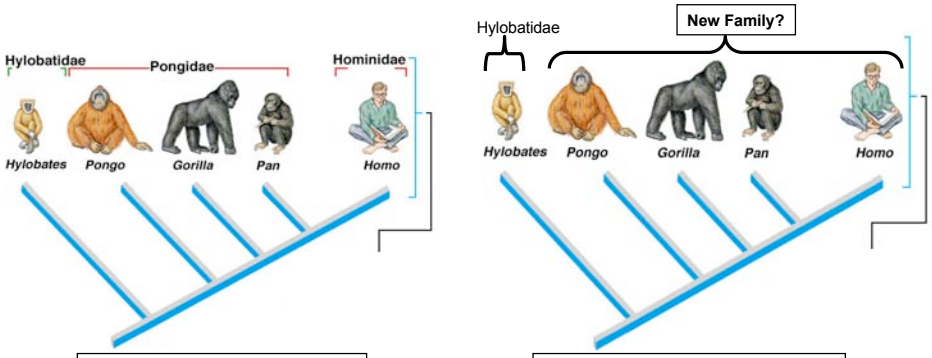
Rule of Parsimony:
The simplest explanation is the most likely explanation.

But not always!



Synthetic Systematics

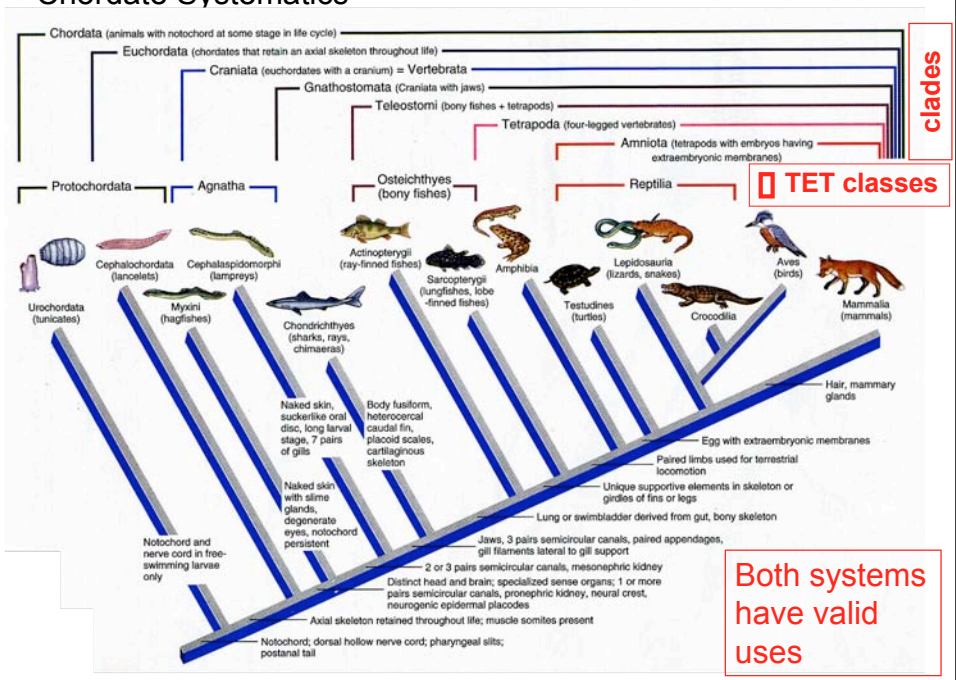
Correlating clades with hierarchal taxa



Model based upon morphometrics
— paraphyletic Pongidae?

Model based upon some molecular biology
— is this really better?

Chordate Systematics



Both systems have valid uses

Biological Kingdoms

Classification of Life on Earth

- Classical two-kingdom model
  - Plants
  - Animals

  Worked well for macroscopic terrestrial life. But became inadequate once microbial and oceanic ecosystems were explored
- Expanded five-kingdom model (Whittaker 1960s)

  Cells are the basic unit of life, so define types of life by the types of their cells
  - Monera
  - Protista
  - Fungi
  - Plantae
  - Animalia

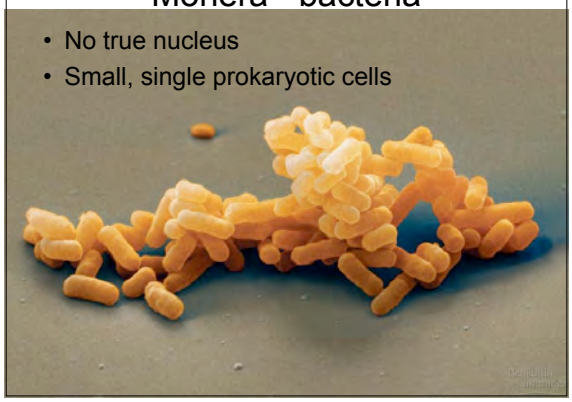
Biological Kingdoms

Cellular characteristics for the five-kingdom model:

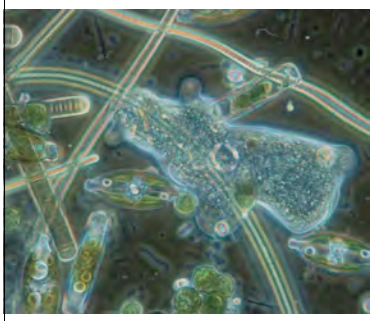
- Organelles: specialized compartments within the cells
  - Prokaryote: no nucleus or other membranous organelles
  - Eukaryote: nucleus & other organelles present
- Energy source
  - Autotrophic ("self feeding")
    - photosynthetic
    - chemosynthetic
  - Heterotrophic ("feed on others")
    - Intracellular digestion
    - Extracellular / external digestion and/or absorption
    - Extracellular / ingestion
- Cell wall — rigid surrounding structure outside of the cell
  - Present or absent
  - Chemical structure
- Tissues
  - Unicellular or generalized colonies
  - Differentiated into specialized tissue types

Monera - bacteria

- No true nucleus
- Small, single prokaryotic cells



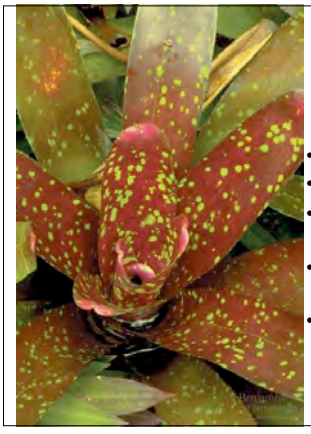
Protista



- single celled eukaryotic organisms
- i.e.:
  - Amoeba
  - algae
  - slime molds

Fungi

- Eukaryotic
- Multicellular (most)
- Cell wall — chitin
- Heterotrophic (cannot make own food)
  - External digestion
- i.e. yeast, mushrooms



Plants

- Eukaryotic
- Multicellular
- Photosynthetic
  - chloroplasts
- Cell wall
  - cellulose
- i.e. Trees, mosses, ferns

Animals

- Eukaryotic
- Multicellular, motile
- No cell walls
- Heterotrophic
  - ingestion
- i.e. worms, insects, vertebrates, "us"

Splitting a Kingdom

- 1970s, Woese, *et al*
- Structure of ribosomes (molecular machines necessary for translating DNA instructions to build proteins) among two groups of Monera very different
- Differences sufficient to separate Monera into two distinct kingdoms
  - **Eubacteria** - "typical" bacteria
  - **Archaebacteria** - "extremophile" bacteria

rRNA phylogeny

- 1990s, Woese, *et al*, proposed that archaebacteria were as different from eubacteria as from eukaryotic kingdoms.
- Grouped the kingdoms into three **domains**
  - **Bacteria** - Eubacteria
  - **Archaea** - Archaebacteria
  - **Eukarya** - Protista, Fungi, Plantae, & Animalia

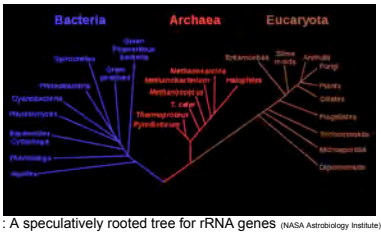


Fig. 1: A speculatively rooted tree for rRNA genes (NASA Astrobiology Institute)

Table 27.2 A Comparison of the Three Domains of Life

CHARACTER	DOMAIN		
	Bacteria	Archaea	Eukarya
Nuclear envelope	Absent	Absent	Present
Membrane-enclosed organelles	Absent	Absent	Present
Peptidoglycan in cell wall	Present	Absent	Absent
Membrane lipids	Unbranched hydrocarbons	Some branched hydrocarbons	Unbranched hydrocarbons
RNA polymerase	One kind	Several kinds	Several kinds
Initiator amino acid for protein synthesis	Formyl-methionine	Methionine	Methionine
Introns in genes	Very rare	Present in some genes	Present
Response to the antibiotics streptomycin and chloramphenicol	Growth inhibited	Growth not inhibited	Growth not inhibited
Histones associated with DNA	Absent	Present in some species	Present
Circular chromosome	Present	Present	Absent
Growth at temperatures > 100°C	No	Some species	No

Revisions of the concept of Biological Kingdoms

Linnaeus 1735	Haeckel 1866	Chatton 1937	Copeland 1956	Whittaker 1969	Woese *et al.* 1977	Woese *et al.* 1990
2 kingdoms	**3 kingdoms**	**2 empires**	**4 kingdoms**	**5 kingdoms**	**6 kingdoms**	**3 domains**
(not treated)		**Prokaryota**	**Monera**	**Monera**	**Eubacteria**	**Bacteria**
					Archae-bacteria	**Archaea**
	Protista	**Eukaryota**	**Protista**	**Protista**	**Protista**	**Eukarya**
				Fungi	**Fungi**	
Vegetabilia	**Plantae**		**Plantae**	**Plantae**	**Plantae**	
Animalia	**Animalia**		**Animalia**	**Animalia**	**Animalia**	

Kingdoms of Life

Previously: 5 Kingdom system

Currently: 6 Kingdoms into 3 Domains

The future?