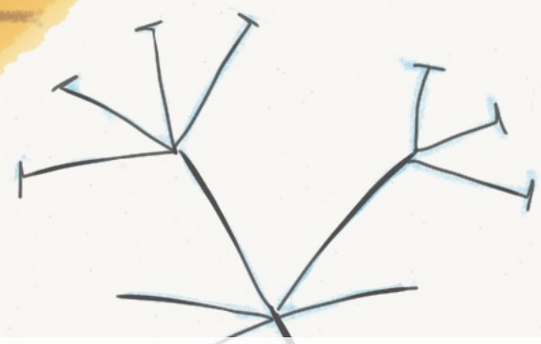
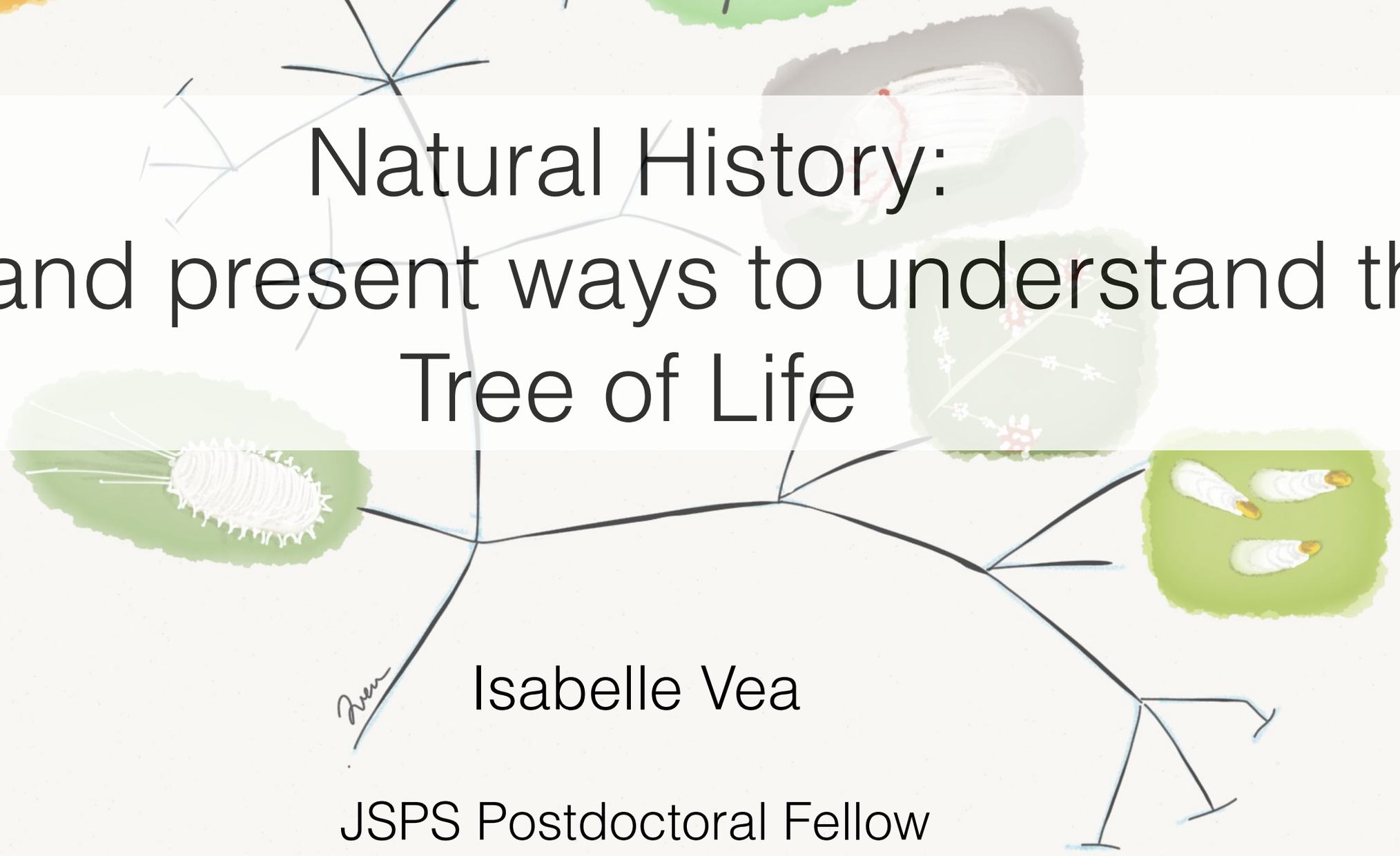
G30 Studium generale June 9 2016



I think

Natural History: past and present ways to understand the Tree of Life



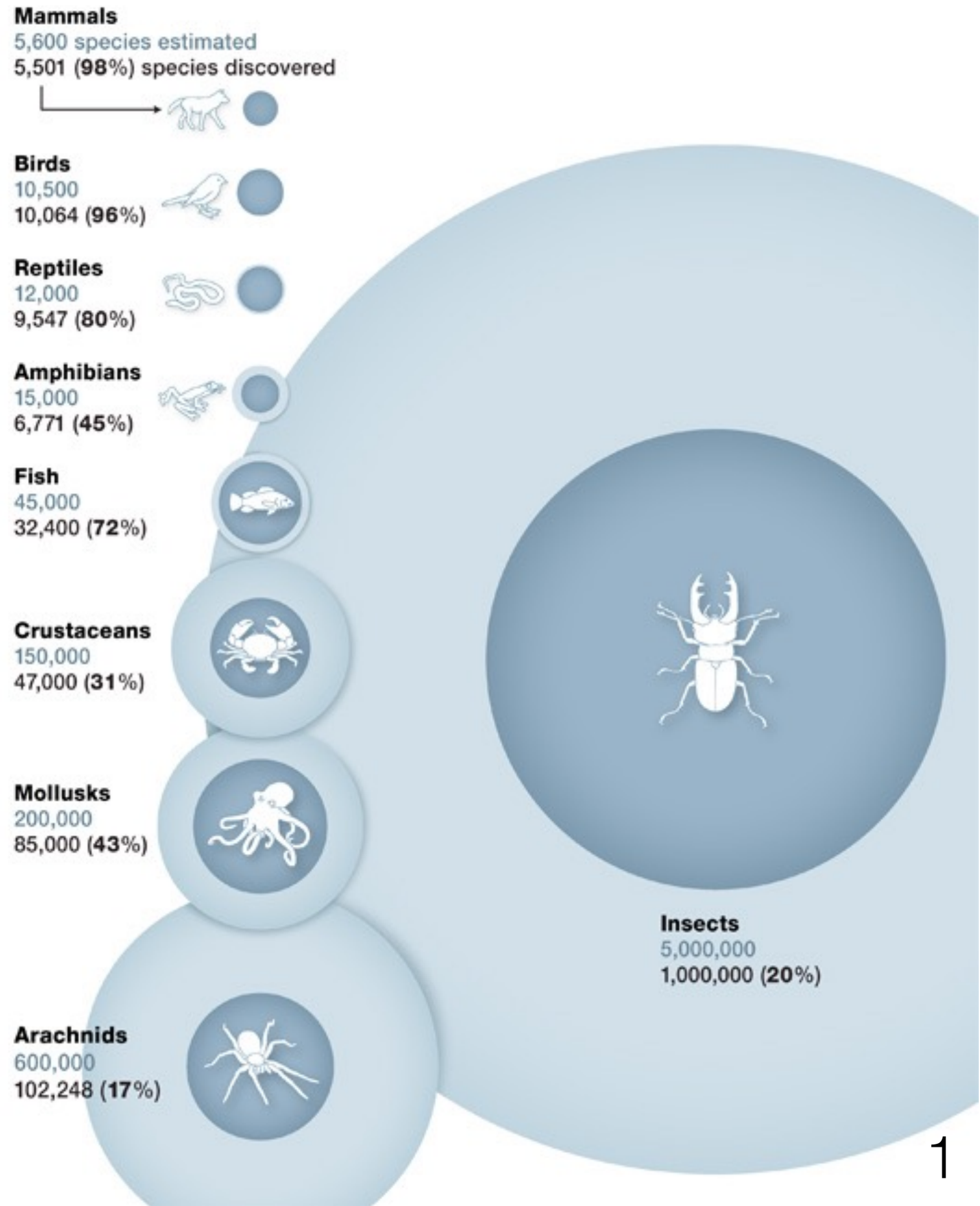
Isabelle Vea

JSPS Postdoctoral Fellow
Graduate School of Bioagricultural Sciences
Laboratory of Applied Entomology

How many species on Earth?

How many species on Earth?

About 2 million species described
Estimates: 10-300 million



5W INFOGRAPHICS; ALEXANDER STEGMAIER, NGM STAFF
SOURCES: IUCN; ARTHUR D. CHAPMAN, AUSTRALIAN BIODIVERSITY INFORMATION SERVICES

Natural History

- A subfield of natural sciences that involves the study of natural organisms in their environment and based on observation

- **Systematics**

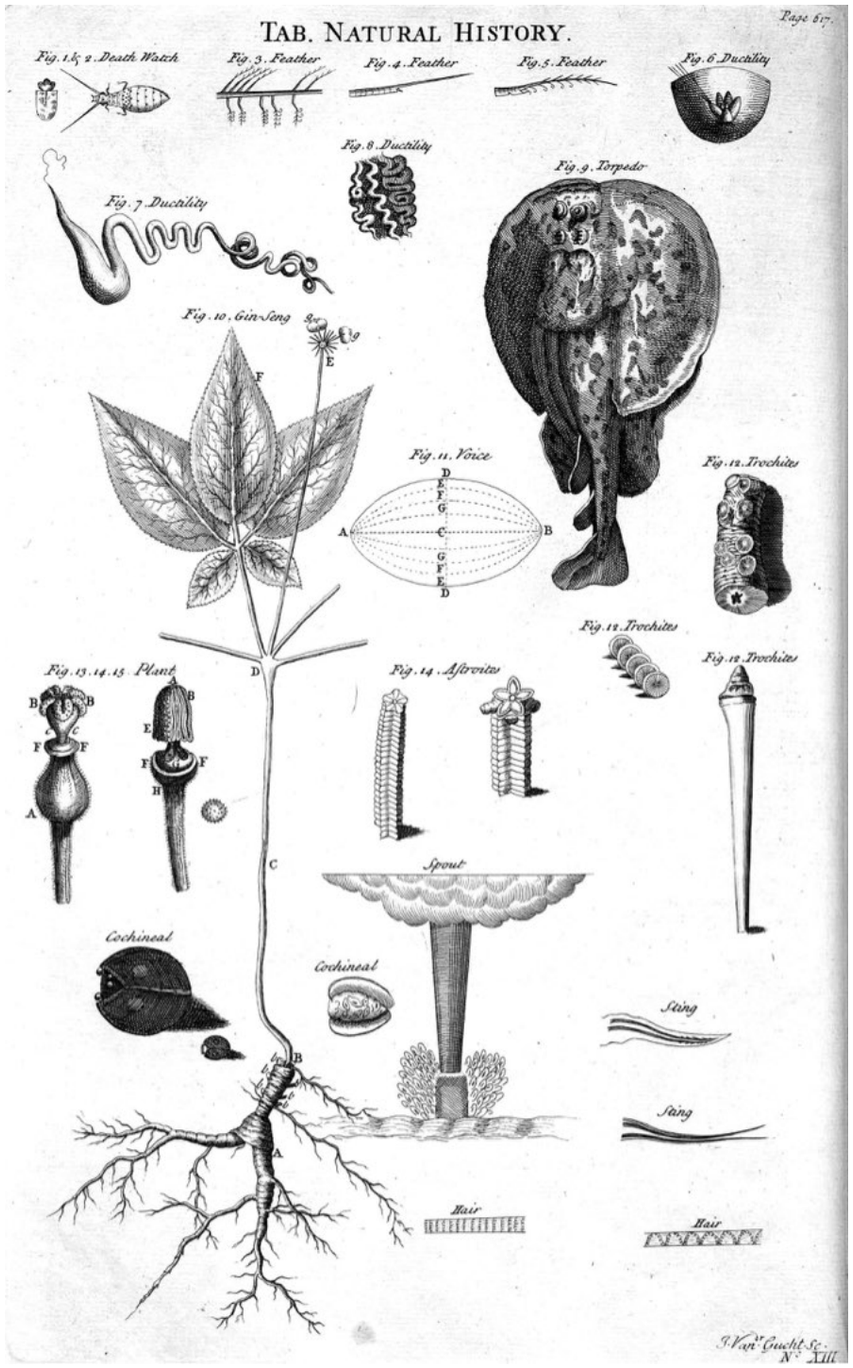
  - Taxonomy = describing and classifying species

  - Phylogenetics = assessing the evolutionary relationships

—>**phylogenies = phylogenetic trees**
(e.g., Tree of Life)

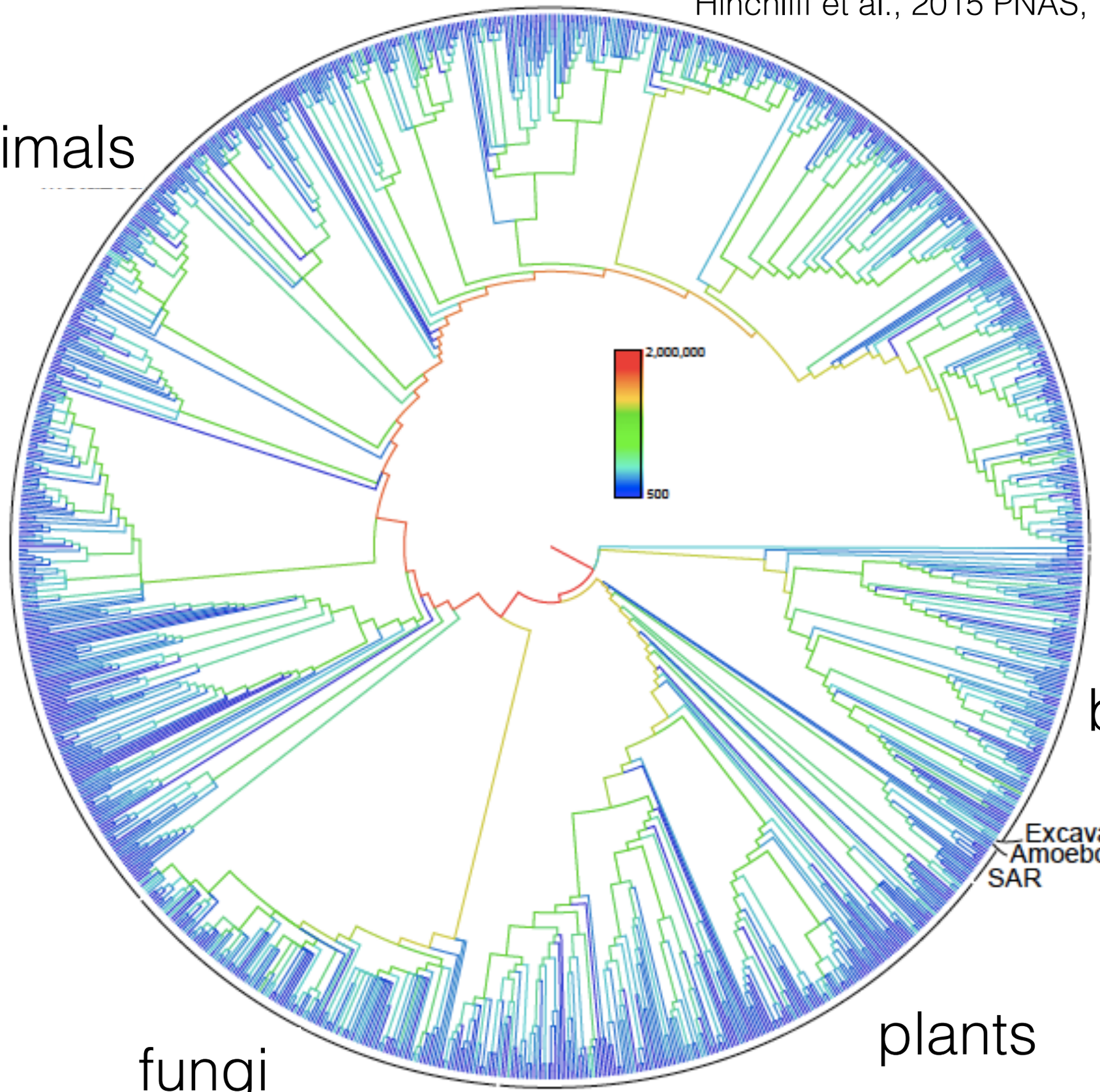
- zoology, botany, mycology, microbiology

- palaeontology and neontology



Ephraim Chambers (1728) Cyclopaedia

Hinchliff et al., 2015 PNAS, 112:41 (Figure 1B)



The Tree of Life in 2016

Why build the Tree of Life?

- Creates fundamental knowledge and provides a framework to answering evolutionary questions

- Allows to understand today's biodiversity

- Genetic diversity for food, origin of pathogens etc...

- Making decision in conservation biology

- Changes our self-perception in relation to other living things: we are a tiny part of a giant group of life on Earth

The origins of modern Natural History

Antiquity

- Aristotle 384–322 BC: first careful observer of diversity in the natural world (*Historia Animalium* with 520 species)

- Pliny the Elder (23–79 AD): *Naturalis historia* (on plants)

Middle Ages: *Scala Naturae* or *Chain of Being*

From Renaissance

- Jan Swammerdam (1637-1680) *Historia Insectorum Generalis*

- John Ray (1627-1680) *Historia insectarium*

Bust of Aristotle. Marble, Roman copy after a Greek bronze original by Lysippos from 330 BC; the alabaster mantle is a modern addition
Source: https://commons.wikimedia.org/wiki/File:Aristotle_Altemps_Inv8575.jpg

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Didacus Valades (1579) *Rhetorica Christiana*

The origins of modern Natural History

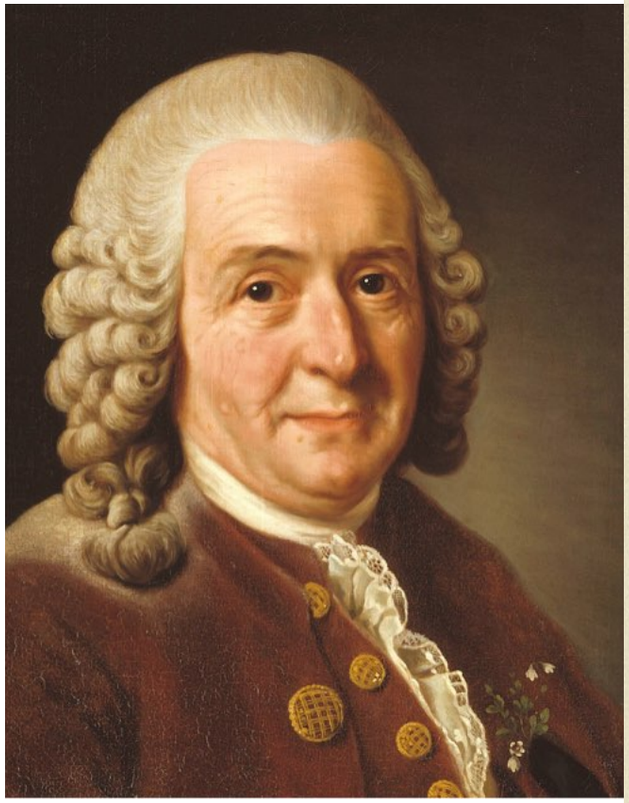
- First natural history museums (~1630)

Carl von Linné (1707-1778)

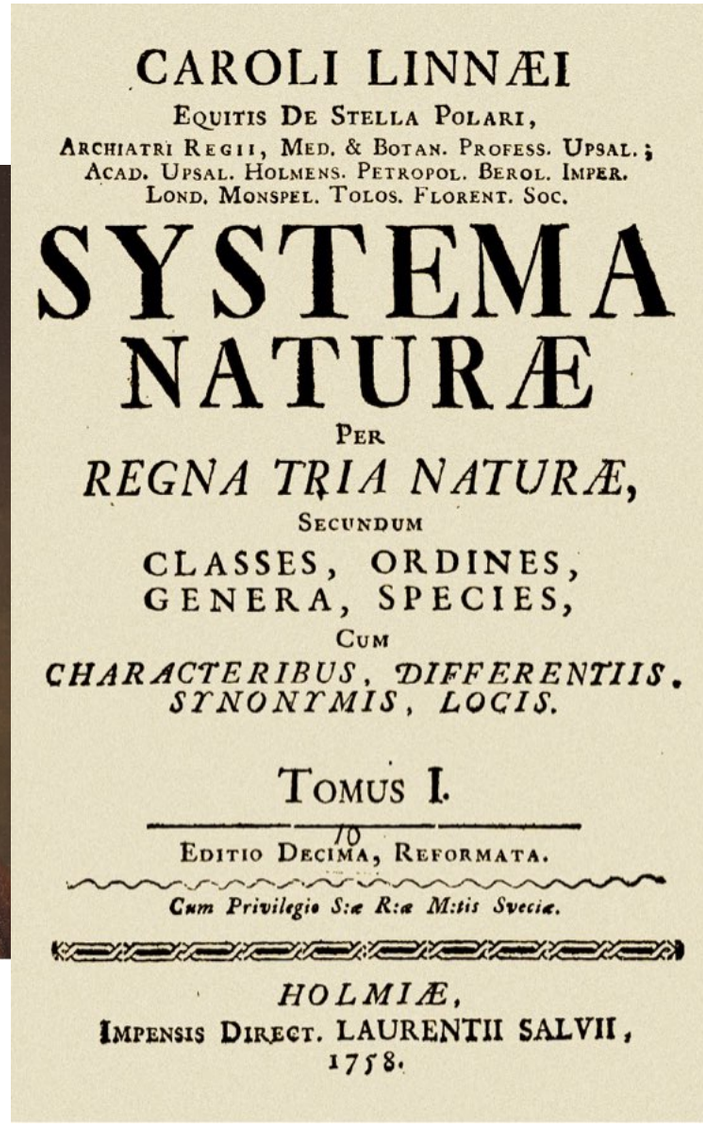
- **Basis of modern natural history**
- **Hierarchical classification**
- **Characters reflects natural classification**
- **Binomial names of species**

Adding the theory of evolution by natural selection: Wallace and Darwin (*On the Origin of Species*, 1859)

Formal phylogenetic methods (Willi Hennig, 1966)



Carl von Linné, Alexander Roslin, 1775 (oil on canvas, Gripsholm Castle)


CAROLI LINNÆI
EQUITIS DE STELLA POLARI,
ARCHIATRI REGII, MED. & BOTAN. PROFESS. UPSAL.;
ACAD. UPSAL. HOLMENS. PETROPOL. BEROL. IMPER.
LOND. MONSPEL. TOLOS. FLORENT. SOC.

SYSTEMA NATURÆ

PER
REGNA TRIA NATURÆ,
SECUNDUM
CLASSES, ORDINES,
GENERA, SPECIES,
CUM
CHARACTERIBUS, DIFFERENTIIS,
SYNONYMIS, LOCIS.

TOMUS I.

EDITIO DECIMA, REFORMATA.

Cum Privilegio S:æ R:æ M:tis Sveciæ.

HOLMIÆ,
IMPENSIS DIRECT. LAURENTII SALVII,
1758.

1758 edition of Linnaeus's Systema Naturæ
Source: http://www.biodiversitylibrary.org/bibliography/542#/summary

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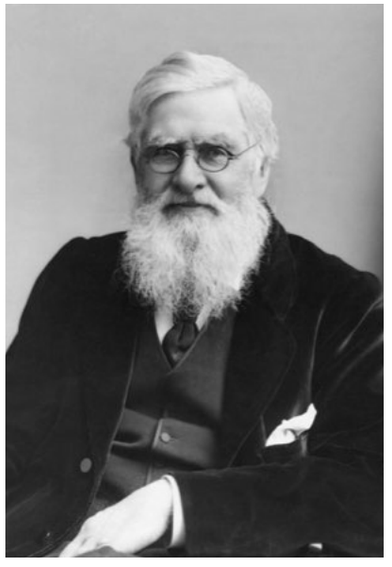
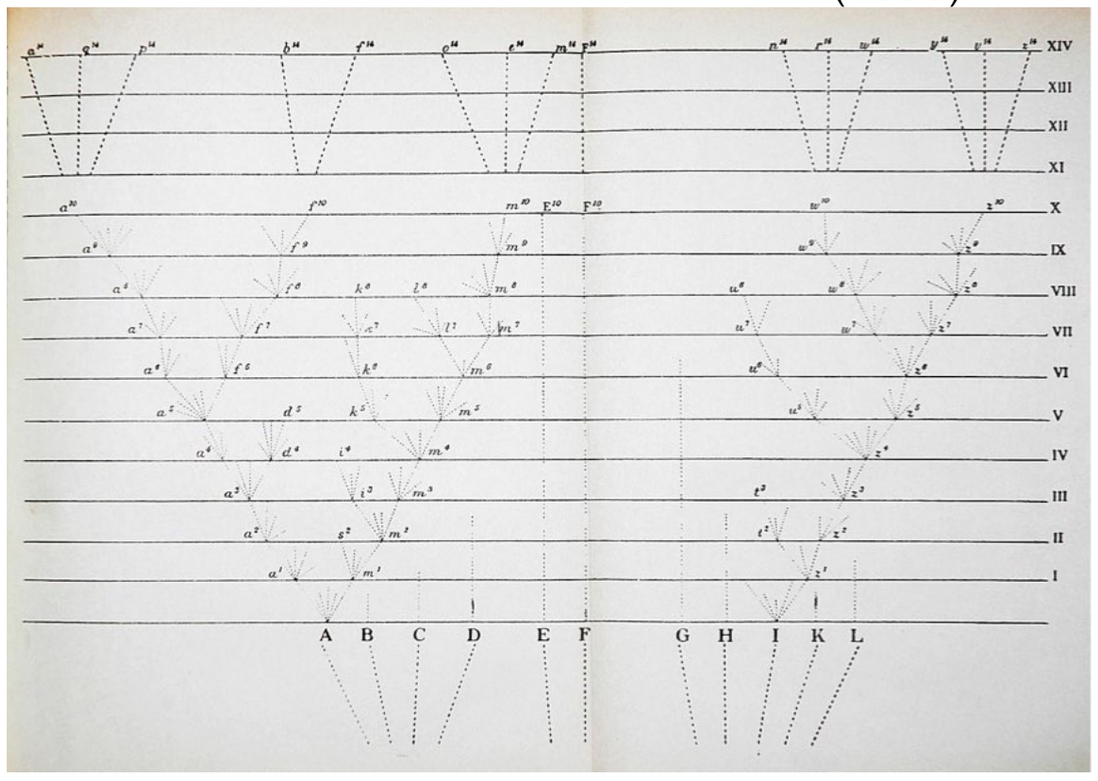
Charles Darwin
John Collier (1881)



Alfred Russell Wallace
London Stereoscopic & Photographic Company (1886)



Only figure in *On the Origin of Species* (1859)

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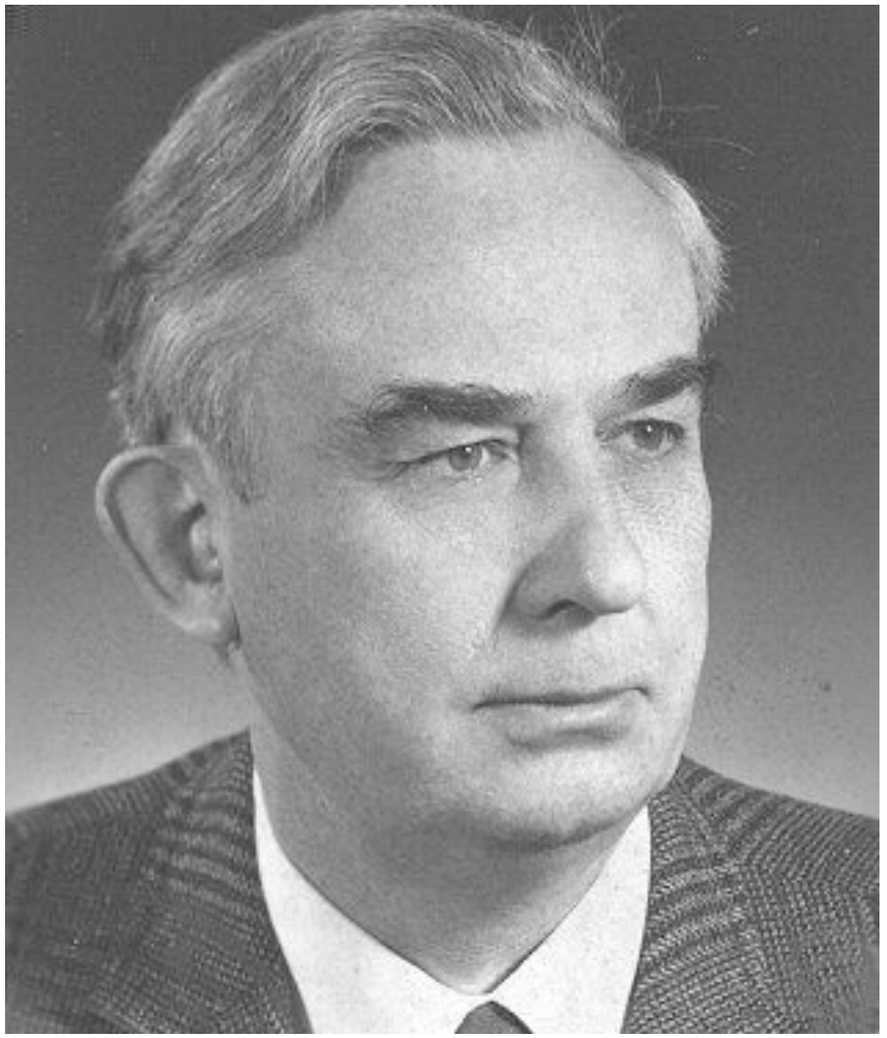
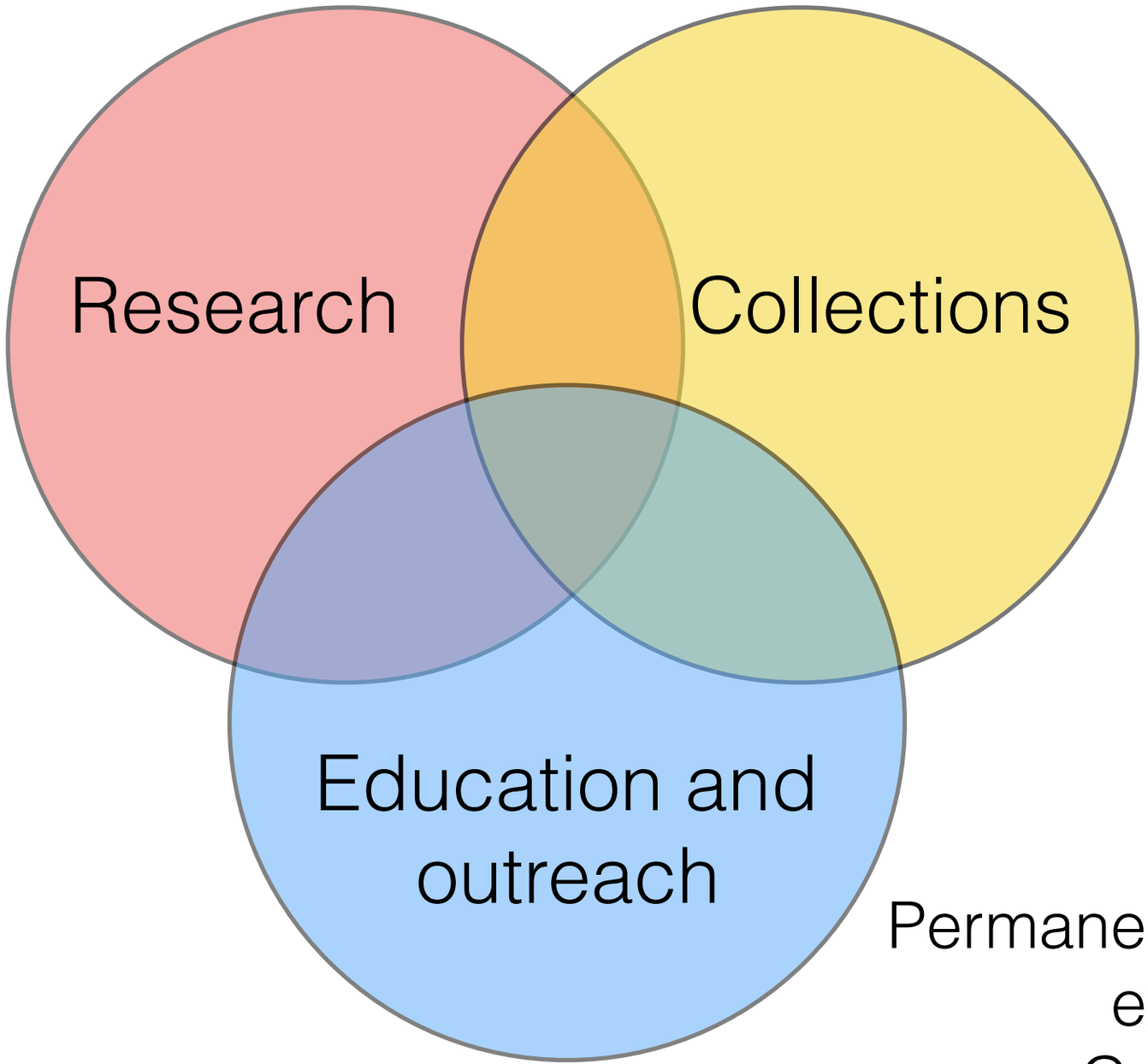


Willi Hennig, photo taken by his son Gerd Hennig in 1972 (CC BY-SA 3.0)

Natural History research today

Natural History Museums

Curators, researchers, technicians, students



- Herbarium
- Zoology
- Minerals

Dry, formol, alcohol, frozen

Permanent and temporary exhibitions
Conferences
Educational programs

Main activities of a naturalist

- **Collecting data (fieldwork and collection visits)**
- Preservation of specimens
- Record of data and management of collections
- Description/ interpretation of specimens : photos, drawings, microscope, sequencing DNA/ genomes , CT scan images
- Analysis: computational
- Output: descriptions of new species, phylogenies

Costa Rica 2010. Image: Isabelle Vea

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Image: Chip Clark
The Smithsonian National Museum of Natural History

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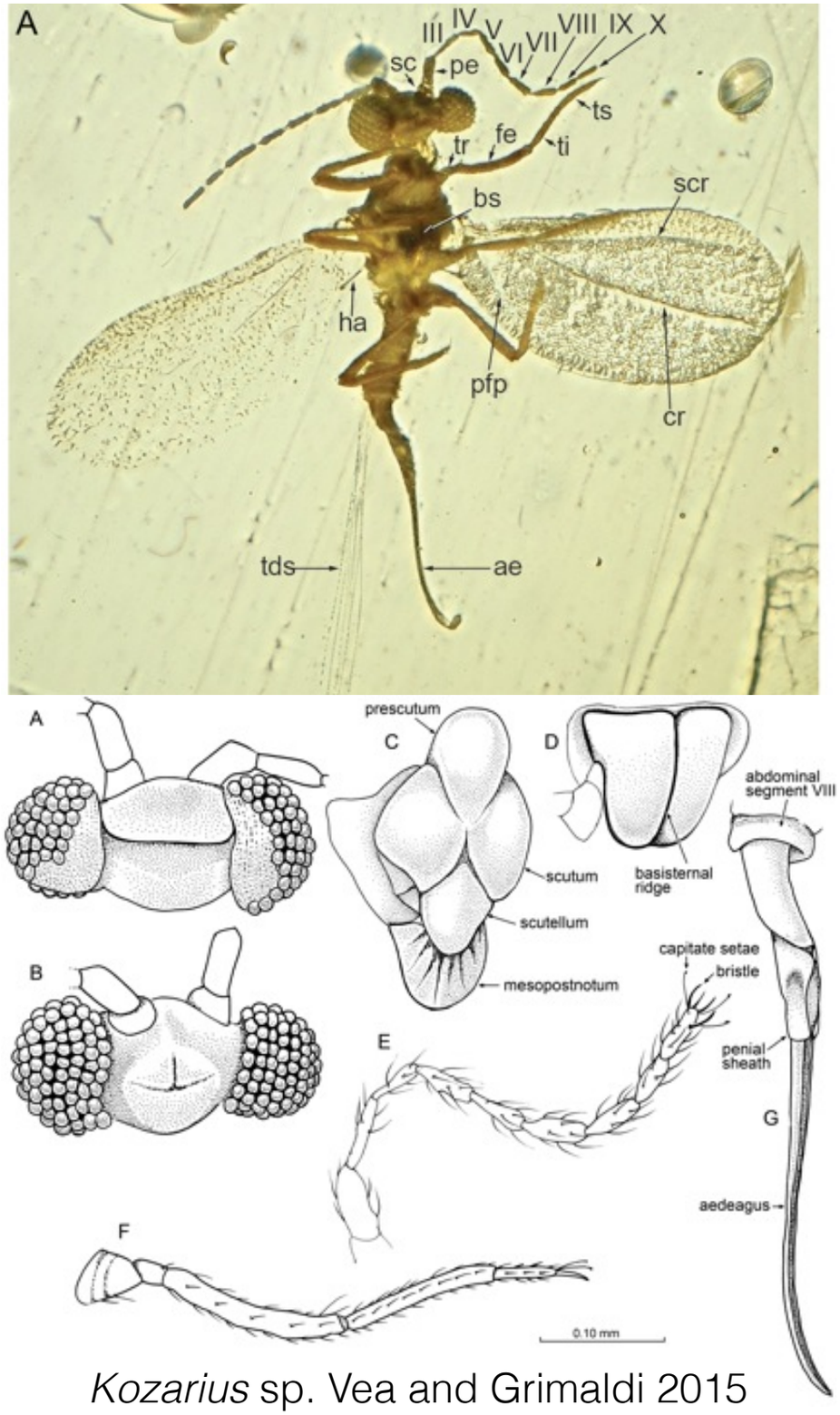


Kozarius sp. Vea and Grimaldi 2015
(from Burmese amber, 100 Myo)

Systematics

The study of biodiversity

TAXONOMY
CLASSIFICATIONS

Discover/describe/name biodiversity

PHYLOGENETICS

Assess evolutionary relationships of this biodiversity

Everyone can describe a species

Essential elements of a species description

- A binomial name
- A type specimen
- A diagnosis = minimum features that differentiates to other species
- A public distribution of the article (prints in libraries)

Additional elements

- Images, drawings
- Complete description
- Identification key

McGuire Center for Lepidoptera and Biodiversity (http://butterfliesofamerica.com/euphilotes_ancilla_purpura_types.htm)

What is a species scientific name?

Source: https://www.flickr.com/photos/kachnch/16364273038

Binomial name for the grey wolf

***Canis lupus* Linnaeus, 1758**

Genus *species* author description year

Hierarchical classification

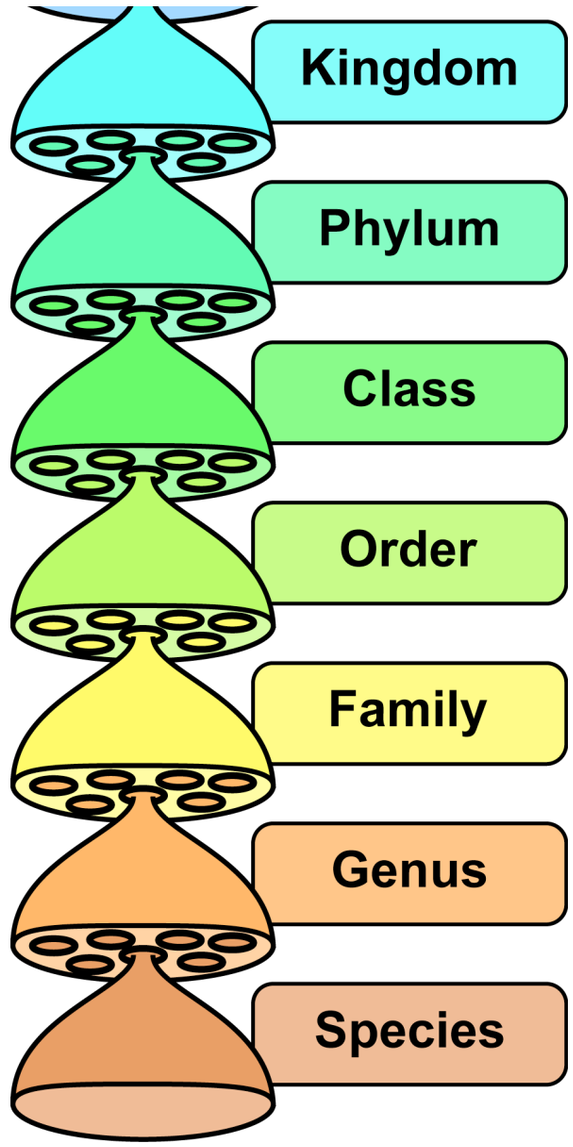
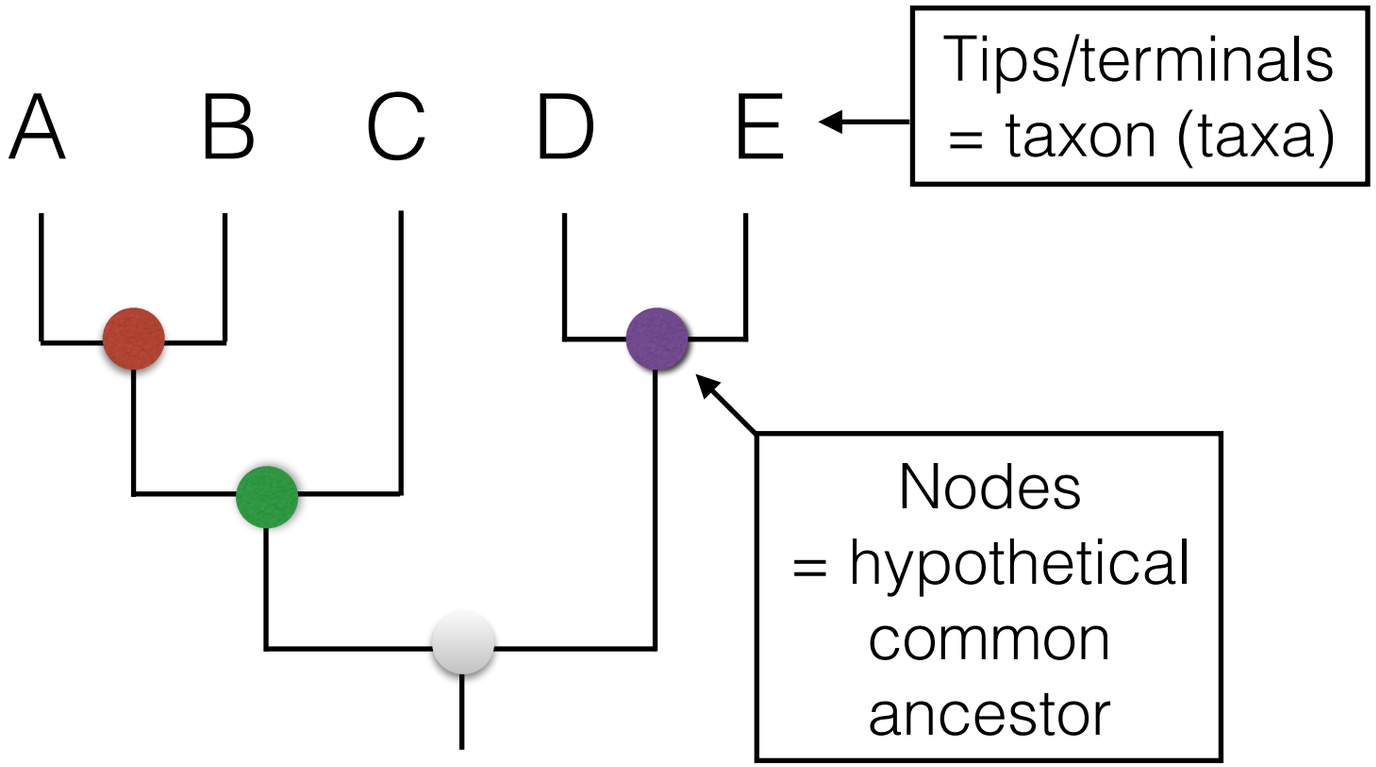


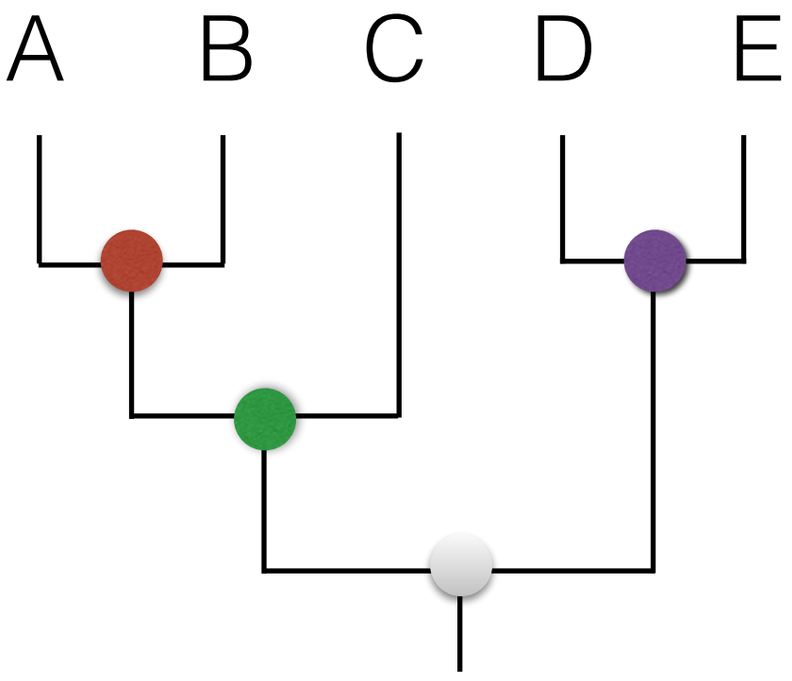
Image: Peter Halasz (https://en.wikipedia.org/wiki/File:Biological_classification_L_Pengo_vflip.svg)

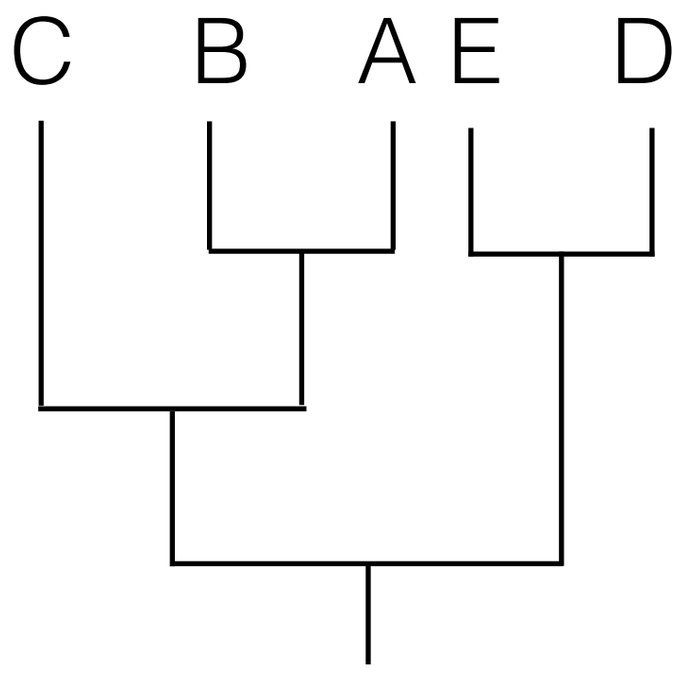
Can you read a phylogeny?



Taxon (pl. taxa)= a set/group of organisms (e.g., species, genus, family etc..)

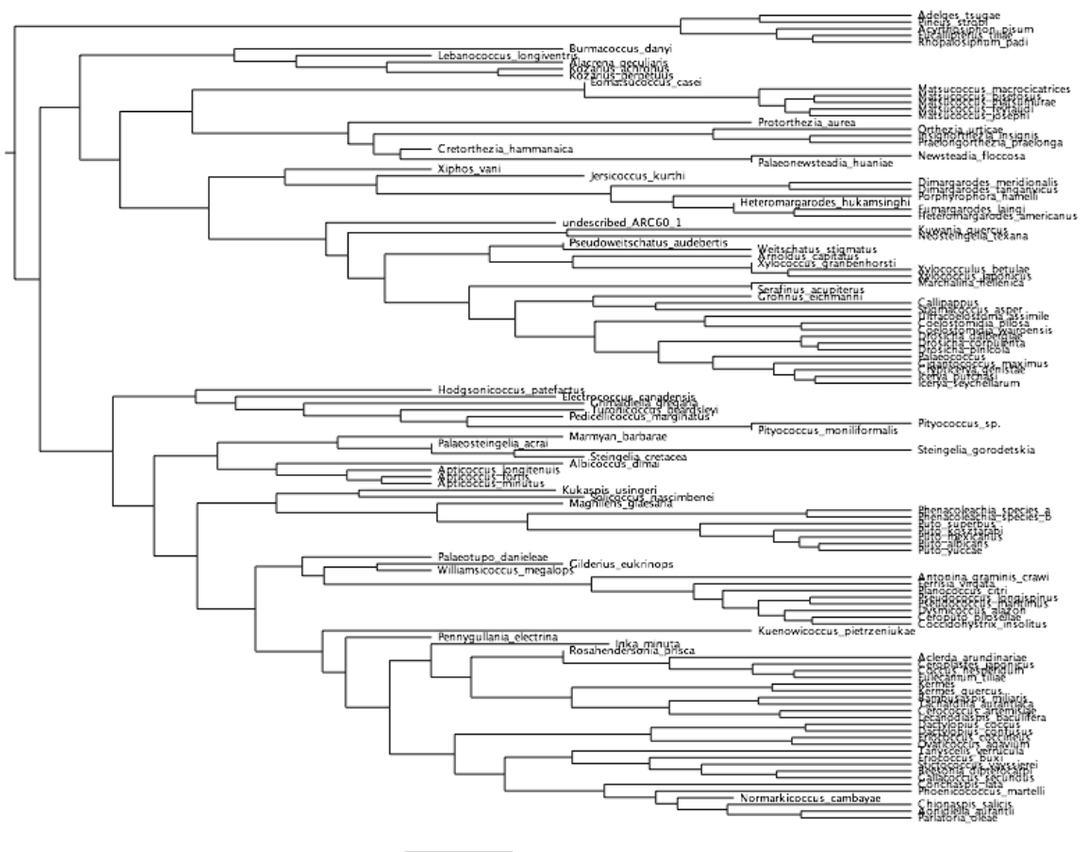
Can you read a phylogeny?

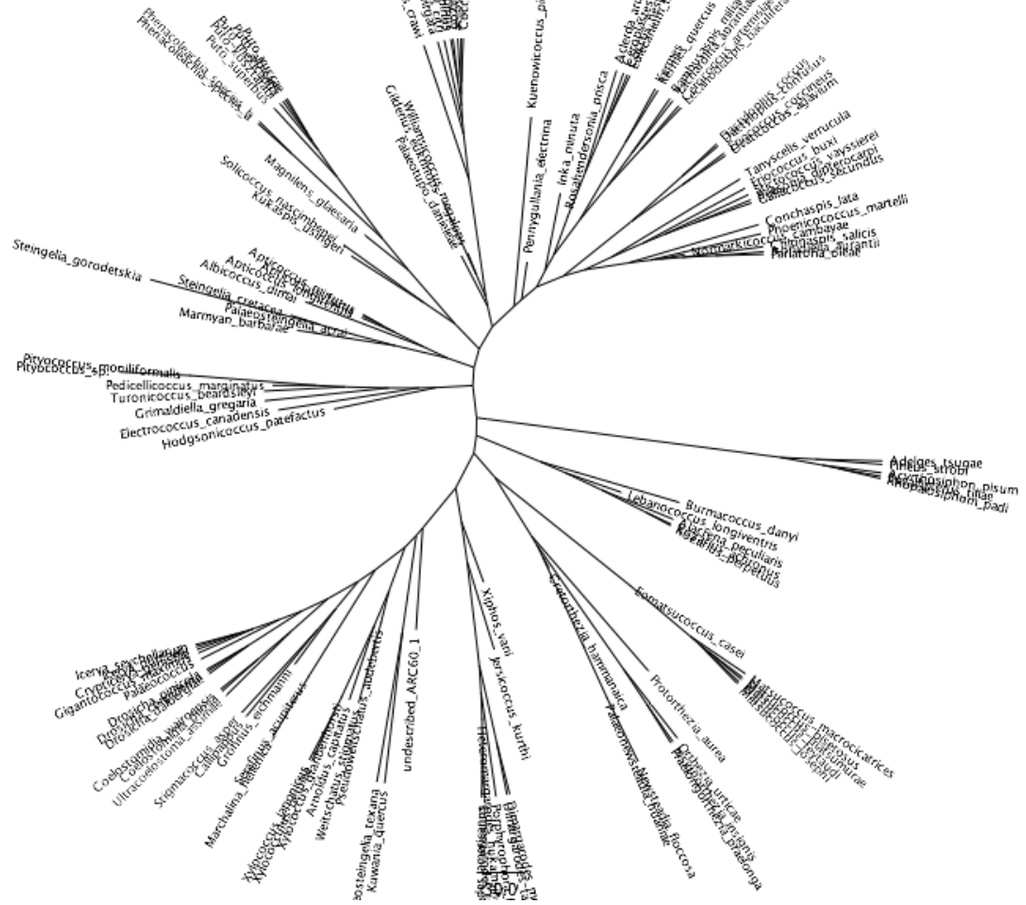




Same or different trees?

Taxon (pl. taxa)= a set/group of organisms (e.g., species, genus, family etc..)

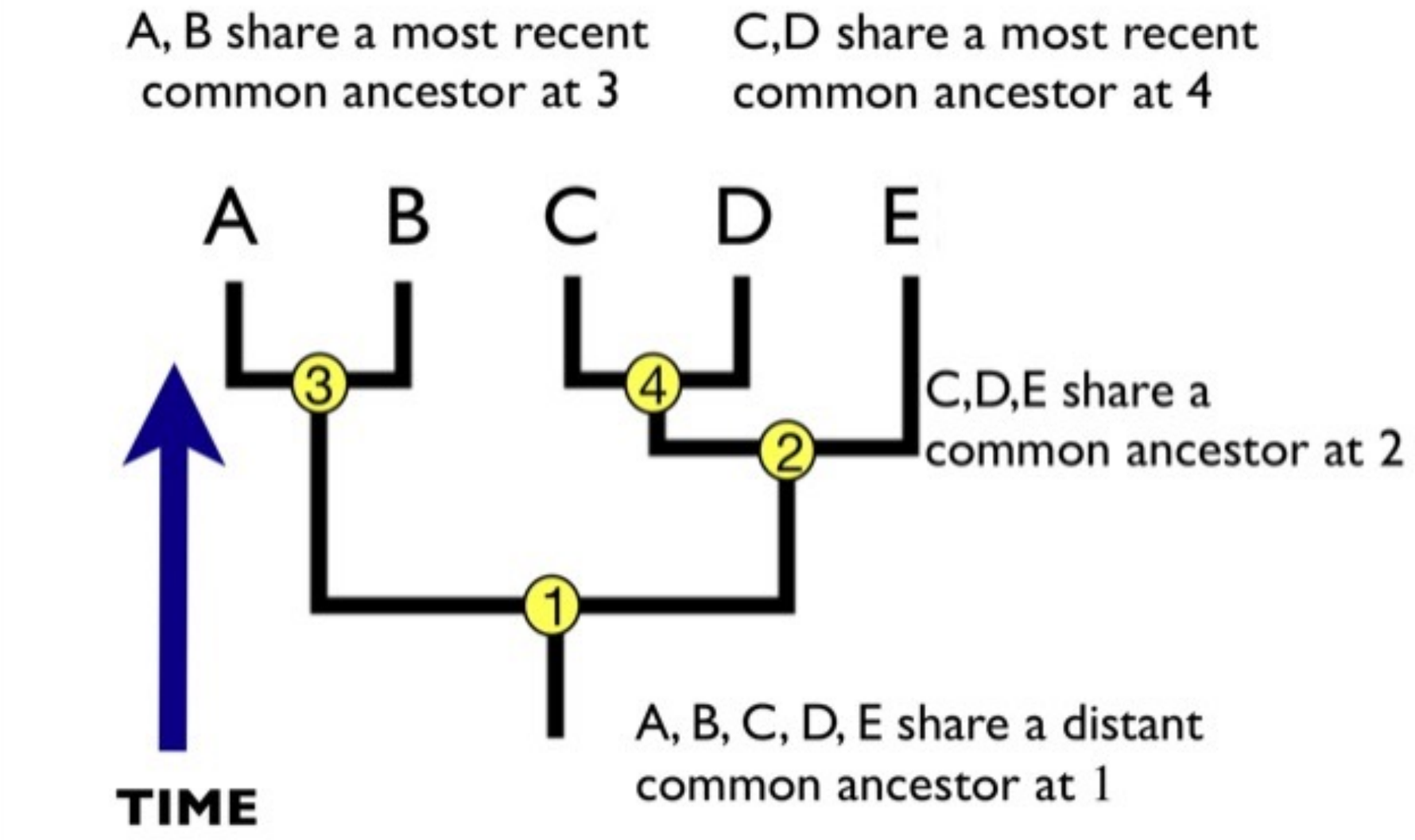




Phylogenies can look different even if they are the same

How do we build a Tree of Life?

Main principle: Related groups share a common hypothetical ancestor



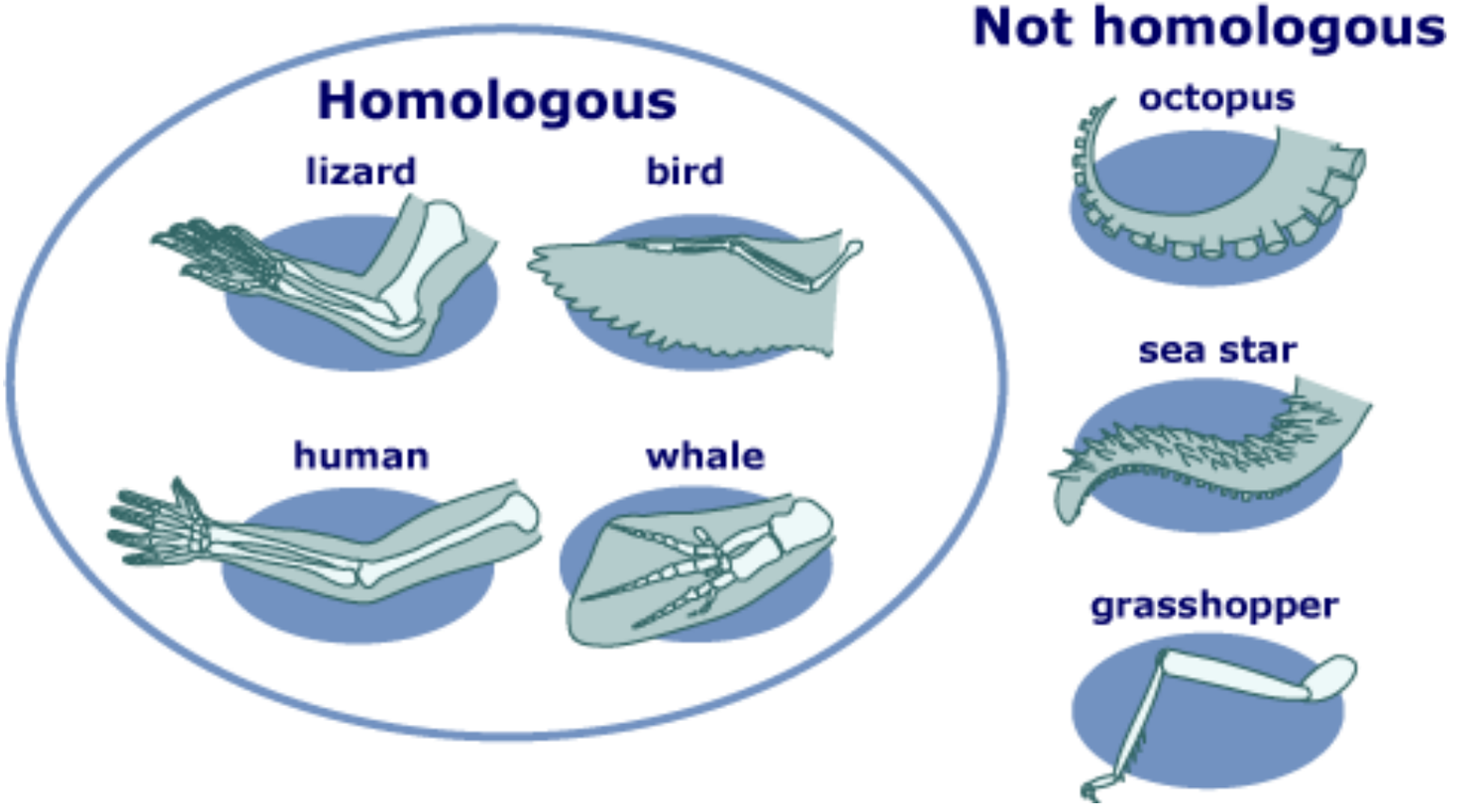
Source: http://bcrc.bio.umass.edu/intro/content/phylogeneticsmorphology-protocol

Similarity in evolution

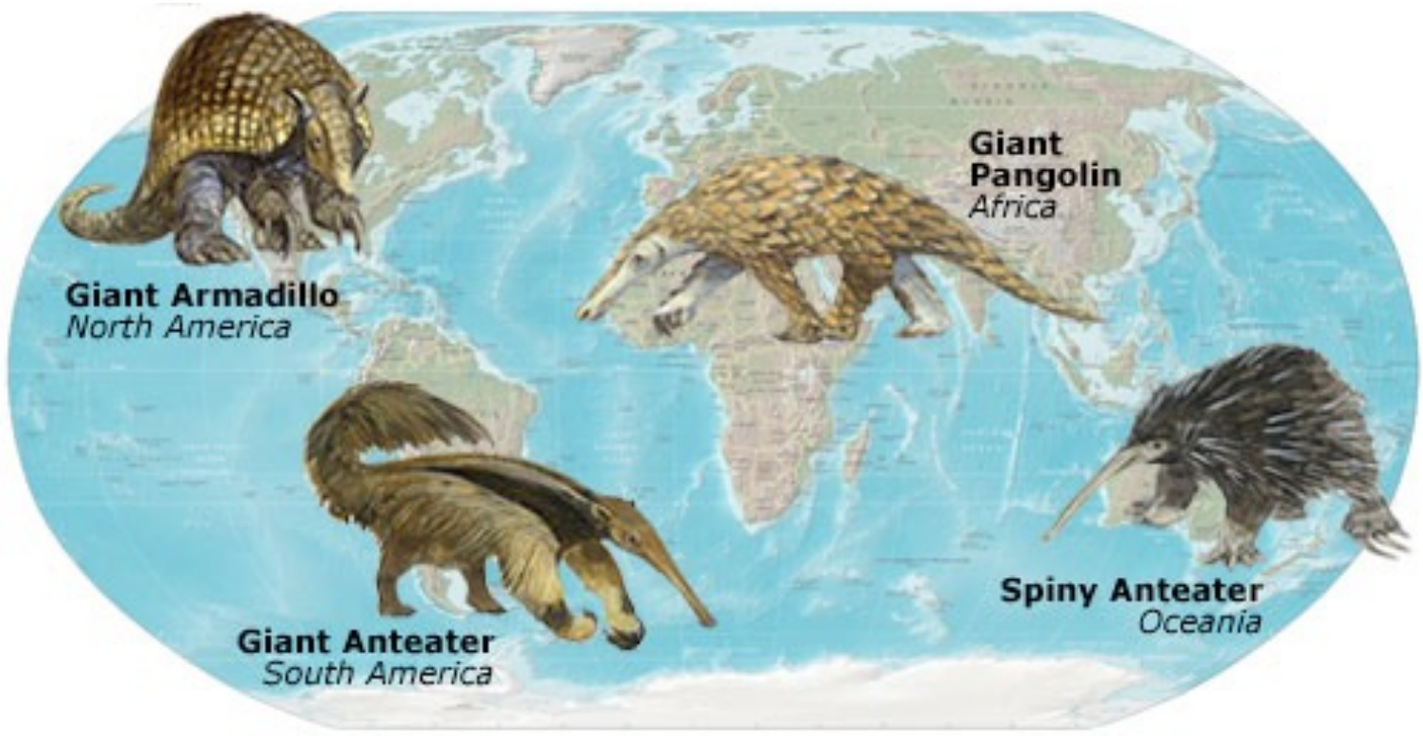
- **Homology**: feature that is inherited by the last common ancestor

- **Homoplasy**: similarity acquired from convergence (e.g., from same environment)

- It is important to distinguish each of the similarity and **homology is used in phylogenetics**



Source: University of California Museum of Paleontology's Understanding Evolution (http://evolution.berkeley.edu)

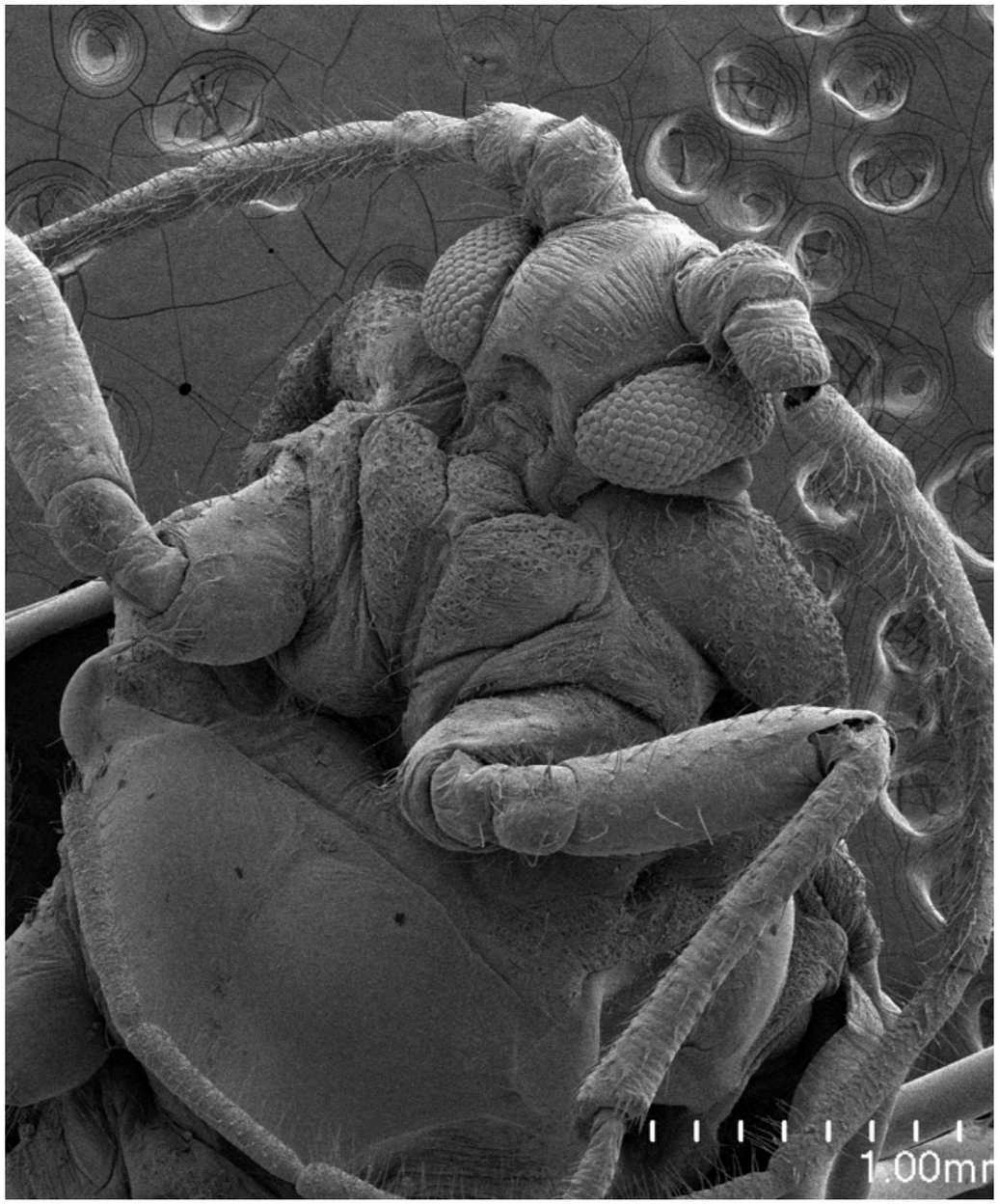


Source: Michael Rothmans (http://www.pbs.org/wgbh/evolution/library/01/4/l_014_01.html)

Technology and methods to acquire data

Scanning Electron Microscope (SEM)

- Morphological observation
  - **Seeing the small**
  - Seeing the hidden
  - Seeing more details
- DNA
  - genes (usually 1-5)
  - genomics/ transcriptomics



Male scale insect. Image: Isabelle Vea

provides high details of surfaces

Technology and methods to acquire data

Phase contrast X-ray synchrotron imaging

- Morphological observation
  - Seeing the small
  - **Seeing the hidden**
  - Seeing more details
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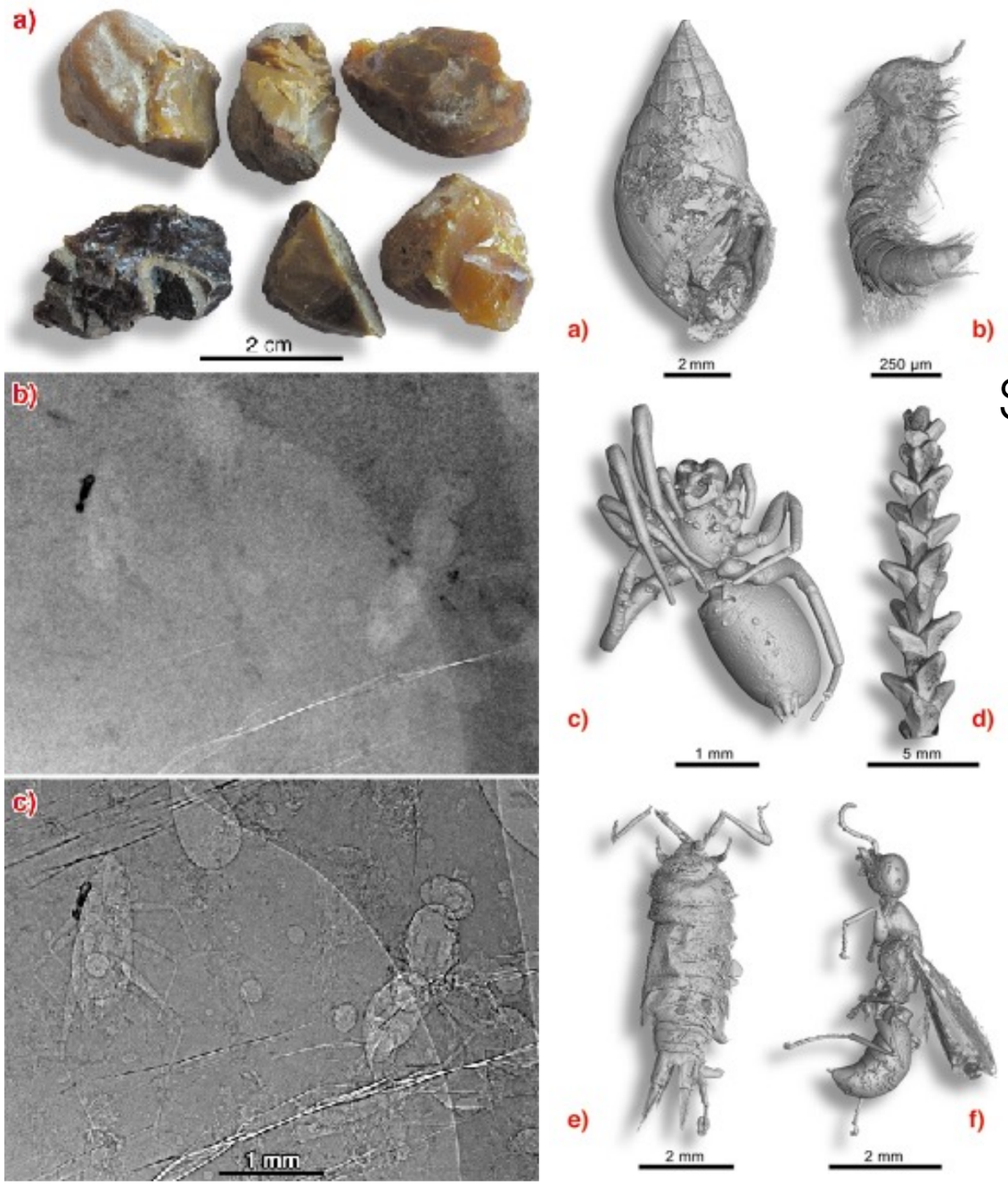

Synchrotron in Grenoble

Increase contrasts between materials

Source: http://www.esrf.eu/UsersAndScience/Publications/Highlights/2006/XIM/XIM10

Technology and methods to acquire data

- Morphological observation
  - Seeing the small
  - Seeing the hidden
  - **Seeing more details**
- DNA
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Computerised Tomography
= CT scan
uses X-rays

CT scanner at AMNH

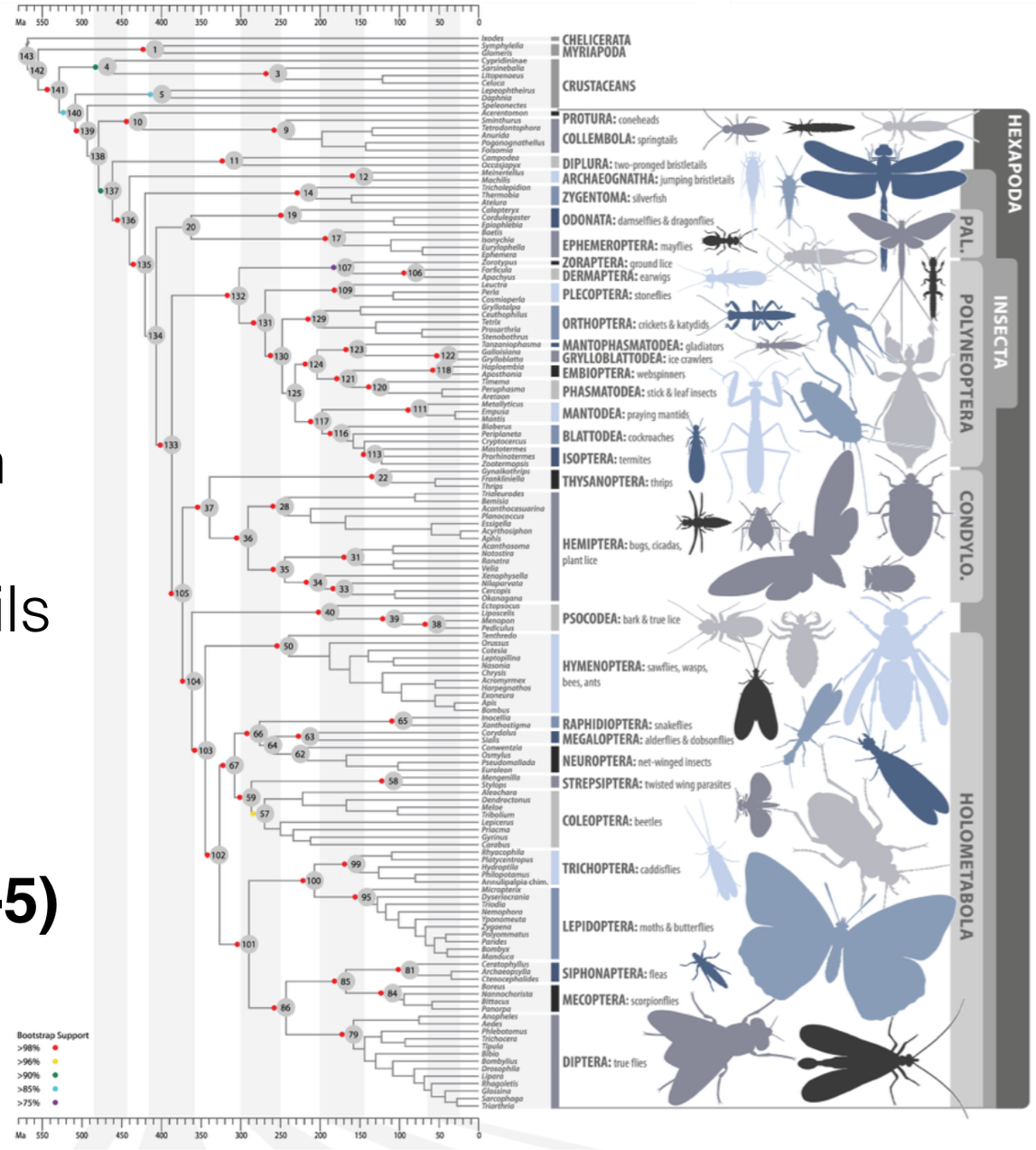
Image: http://research.amnh.org/mif/node/12

Cordylidae lizards. Credit: Ed Stanley

Technology and methods to acquire data

- Morphological observation
  - Seeing the small
  - Seeing the hidden
  - Seeing more details
- DNA
  - **genes (usually 1-5)**
  - **genomics/ transcriptomics**

Phylogenomics of insects



- 101 worldwide authors
- 2.5 Gb of transcriptome data (~1400 genes)
- 144 insects

Source: Misof et al., 2014.
Science 346(6210):763-7 (Figure 1)

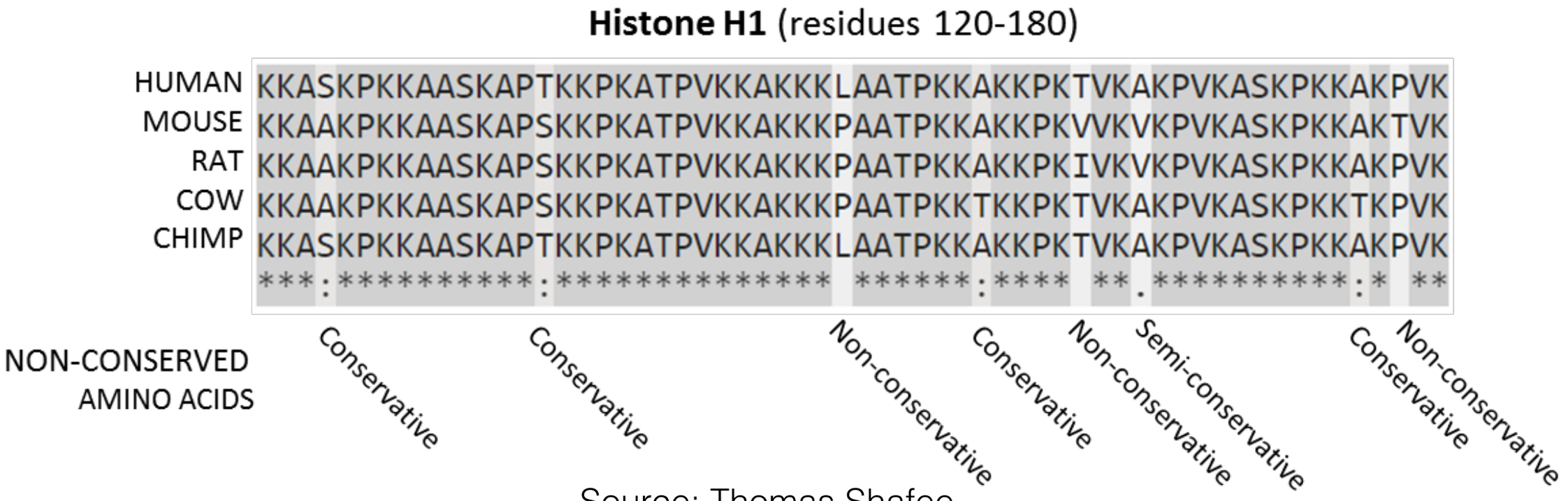
From observation to data

Morphological features compared and translated to a matrix

Aligned DNA/amino acid sequences

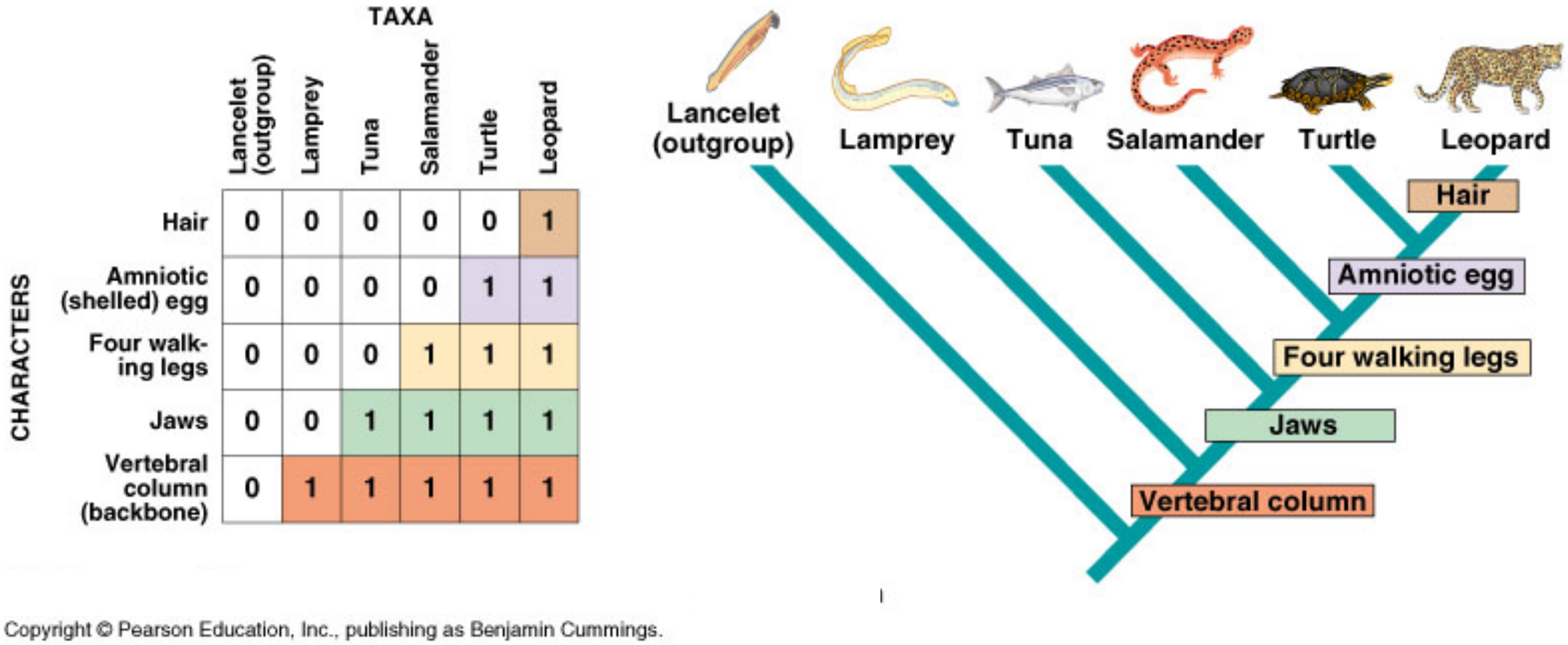
CHARACTERS	TAXA: Lancelet (outgroup)	Lamprey	Tuna	Salamander	Turtle	Leopard
Hair	0	0	0	0	0	1
Amniotic (shelled) egg	0	0	0	0	1	1
Four walking legs	0	0	0	1	1	1
Jaws	0	0	1	1	1	1
Vertebral column (backbone)	0	1	1	1	1	1

(a) Character table



Source: Thomas Shafee (https://en.wikipedia.org/wiki/Homology_(biology)#/media/File:Histone_Alignment.png)

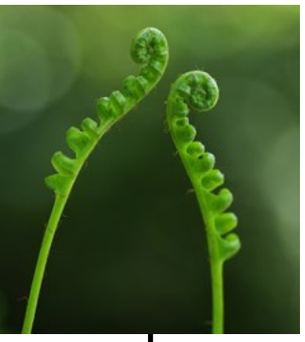
Analytical methods

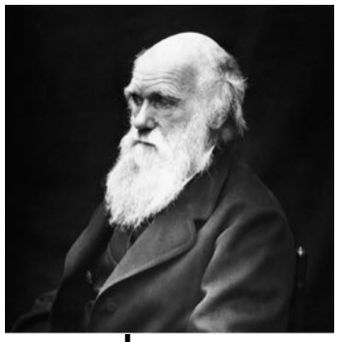


- More than 5-10 characters/5 taxa => need computers to find the trees
- Algorithms following different philosophies (parsimony, maximum likelihood, bayesian inference)
- Adding a time scale on phylogenies: DNA sequences have rates of evolution (molecular clock)
- Combining fossils and extant: provides time calibrations

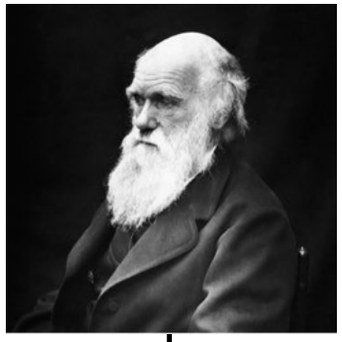
Let's play a game:
Which are more closely related?

plant mushroom animal

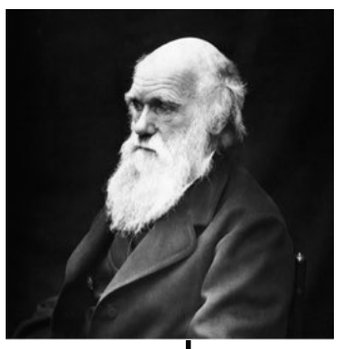
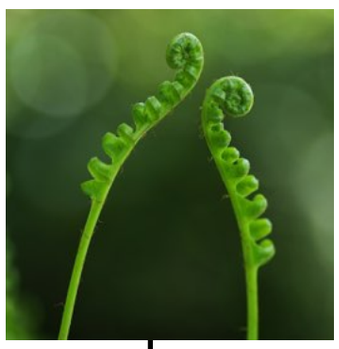




A


B


C

Images: CC0 Public Domain

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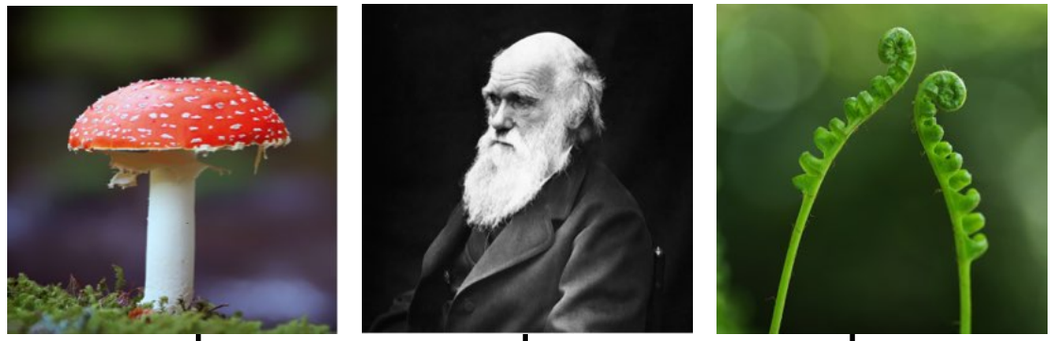
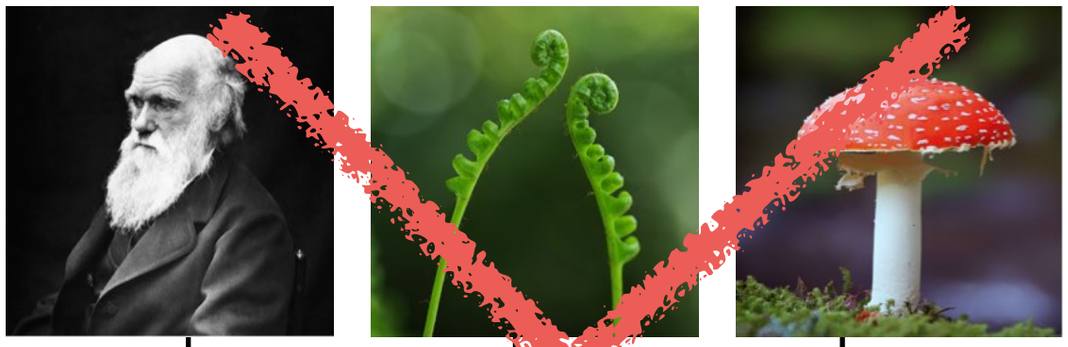
plant mushroom animal

A



B



C

Images: CC0 Public Domain

Let's play a game:
Which are more closely related?

lizard bird dinosaur



A



B



C

Images: CC0 Public Domain

Let's play a game:
Which are more closely related?

lizard bird dinosaur



A



B

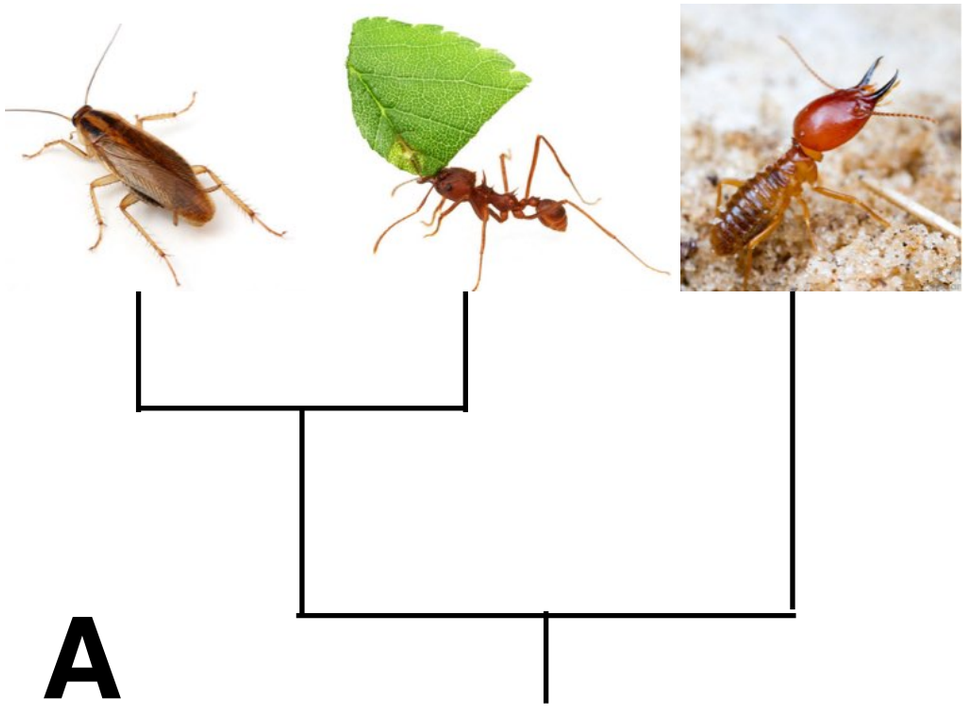


C

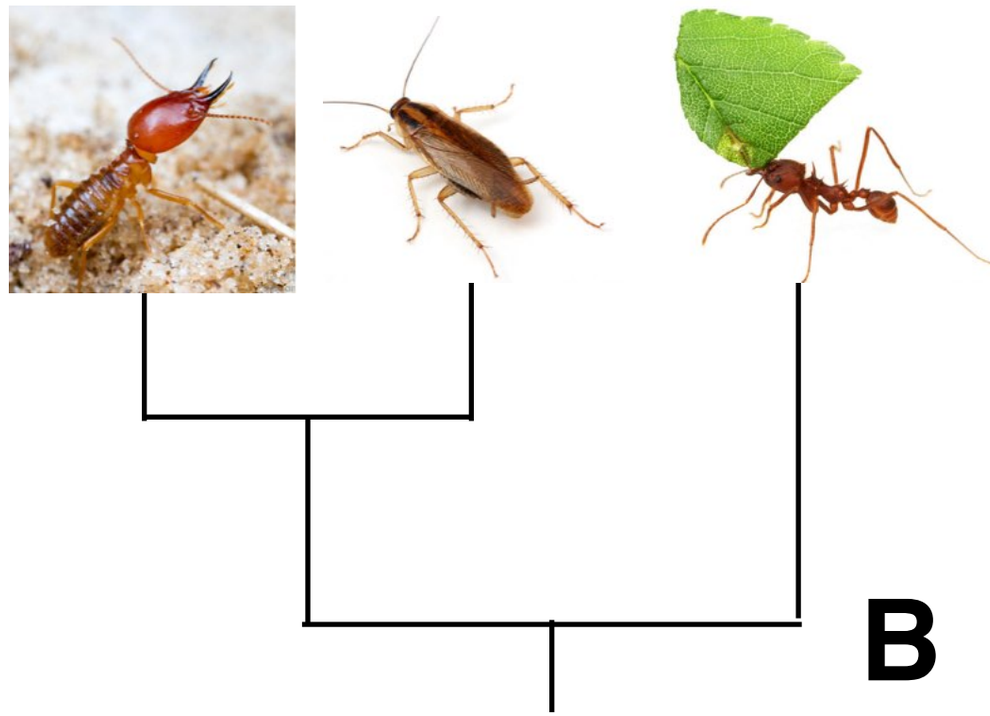
Images: CC0 Public Domain

Let's play a game:
Which are more closely related?

cockroach ant termite



A



B

C

Images: Alex Wild (http://www.alexanderwild.com/)

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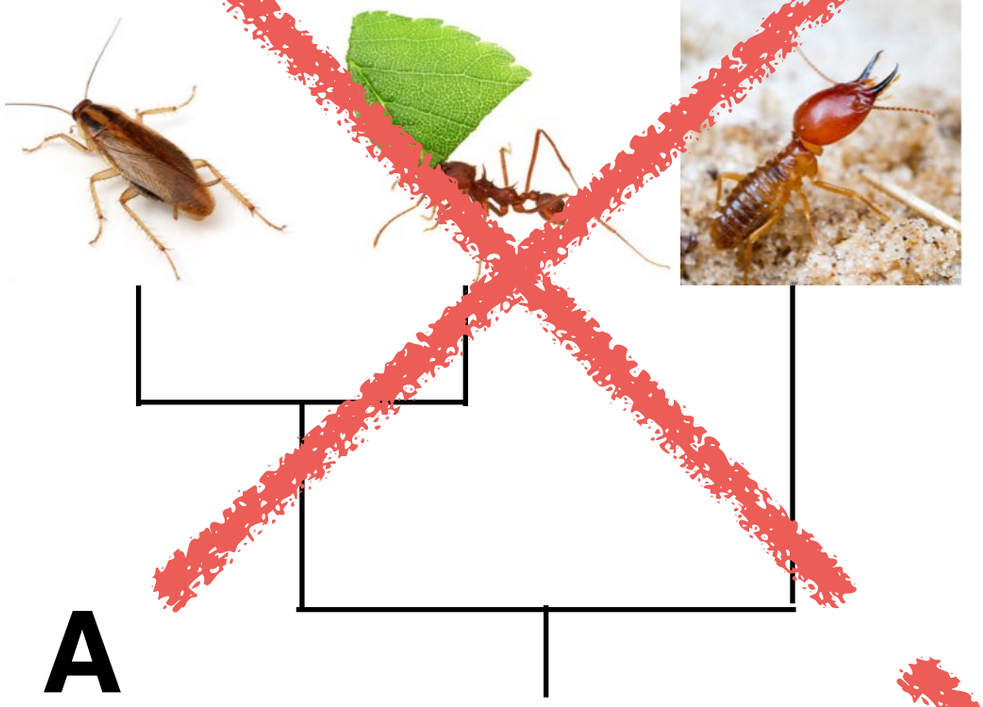

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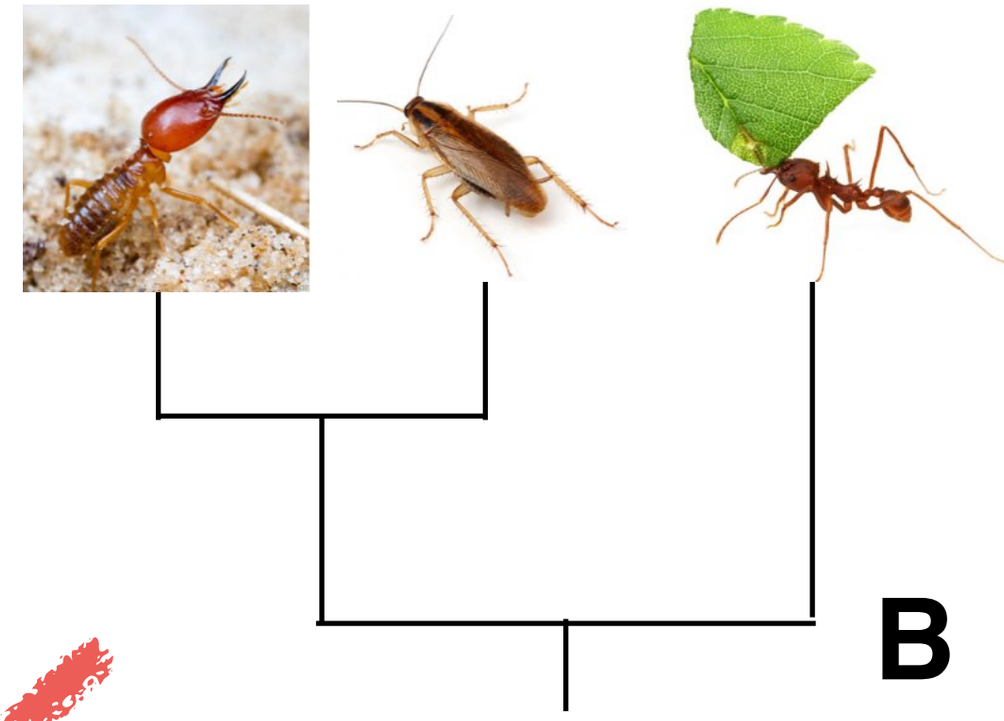
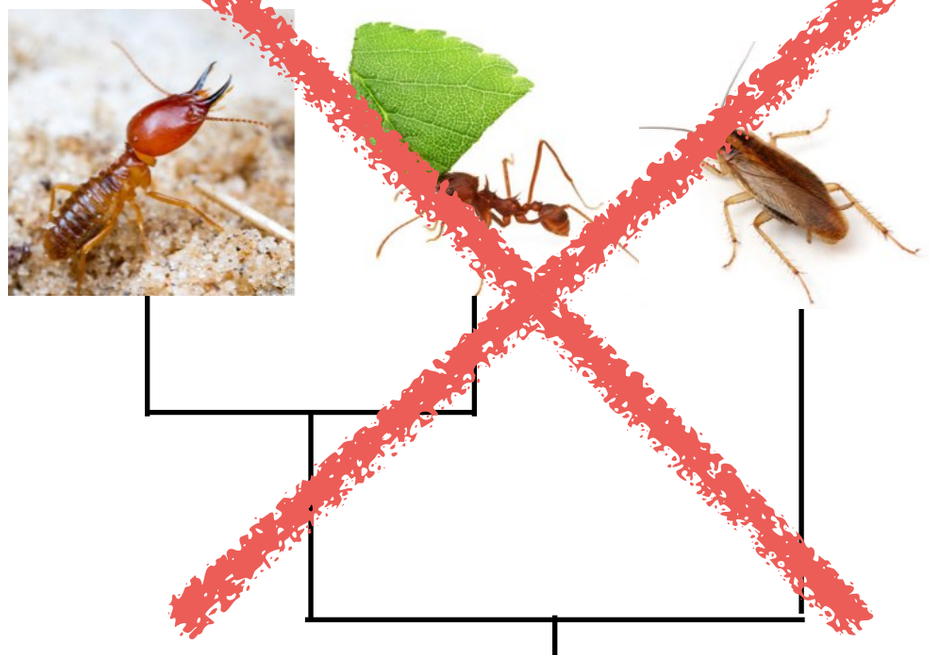


B

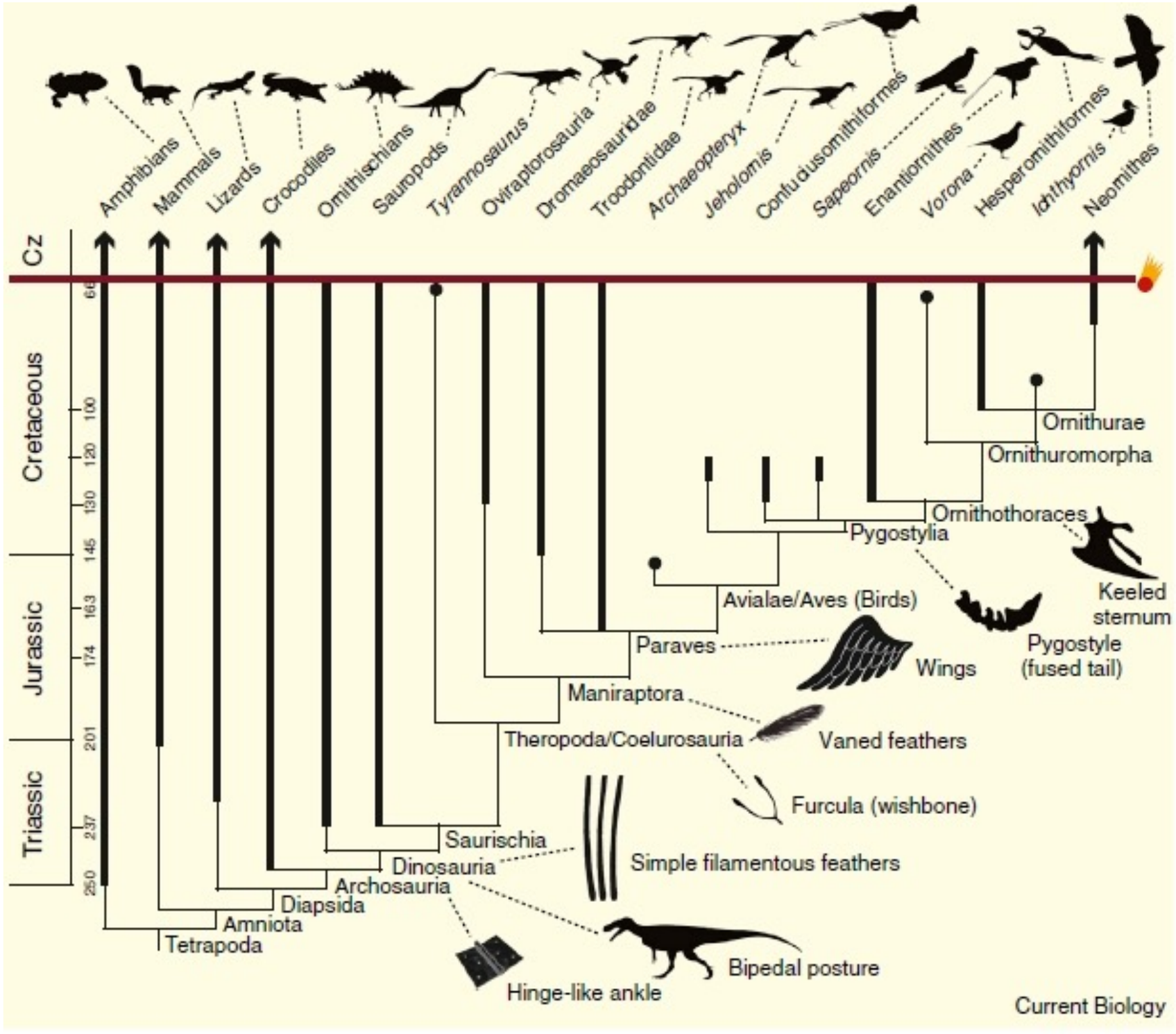


C

Images: Alex Wild (http://www.alexanderwild.com/)

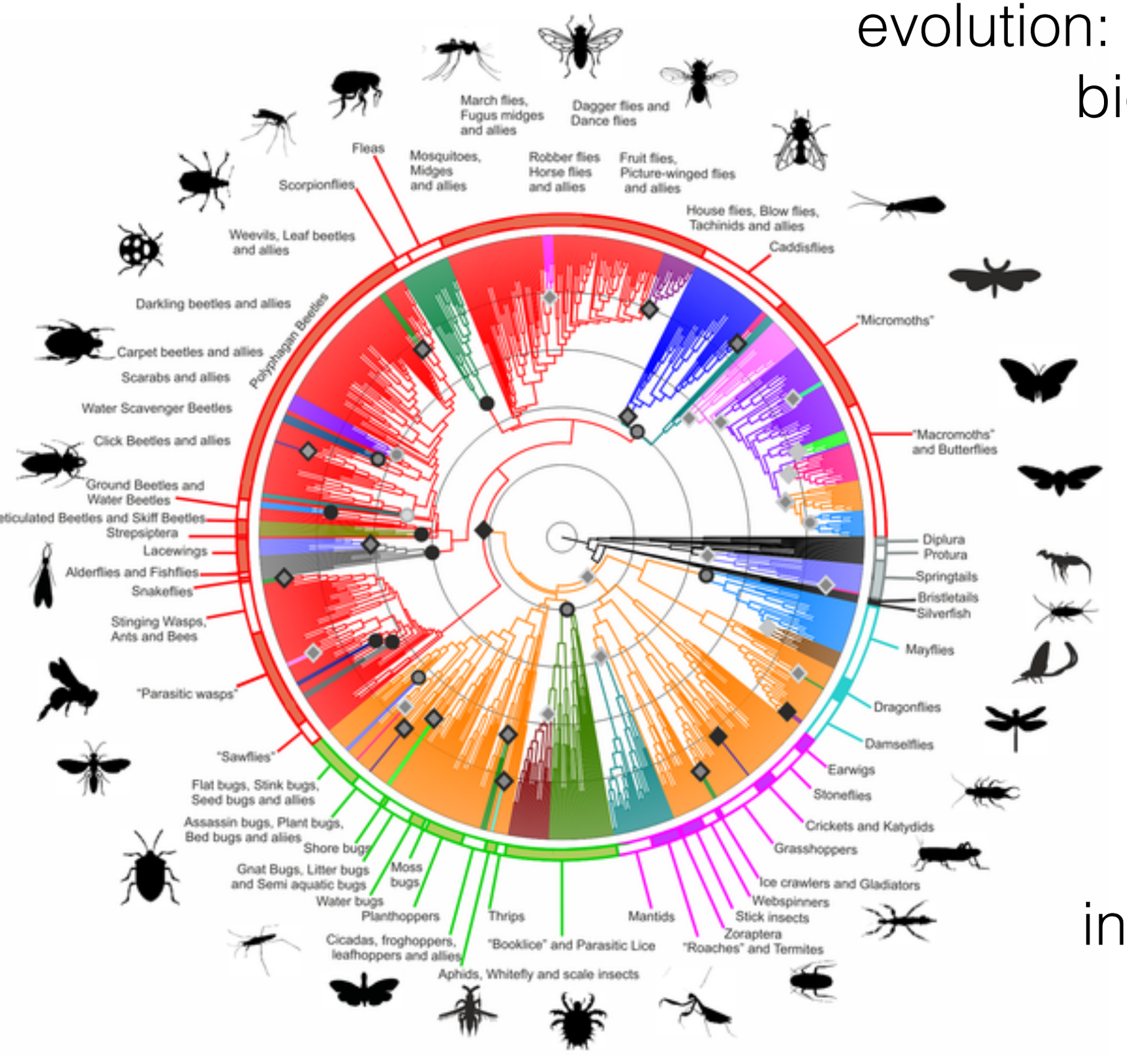
Other examples and applications

Understanding the origin of flight in birds



Source: Brusatte et al., 2015 Current Biology, 25(19):pR888–R898 (Figure 1)

Understanding the drivers of evolution: what made today's biodiversity?

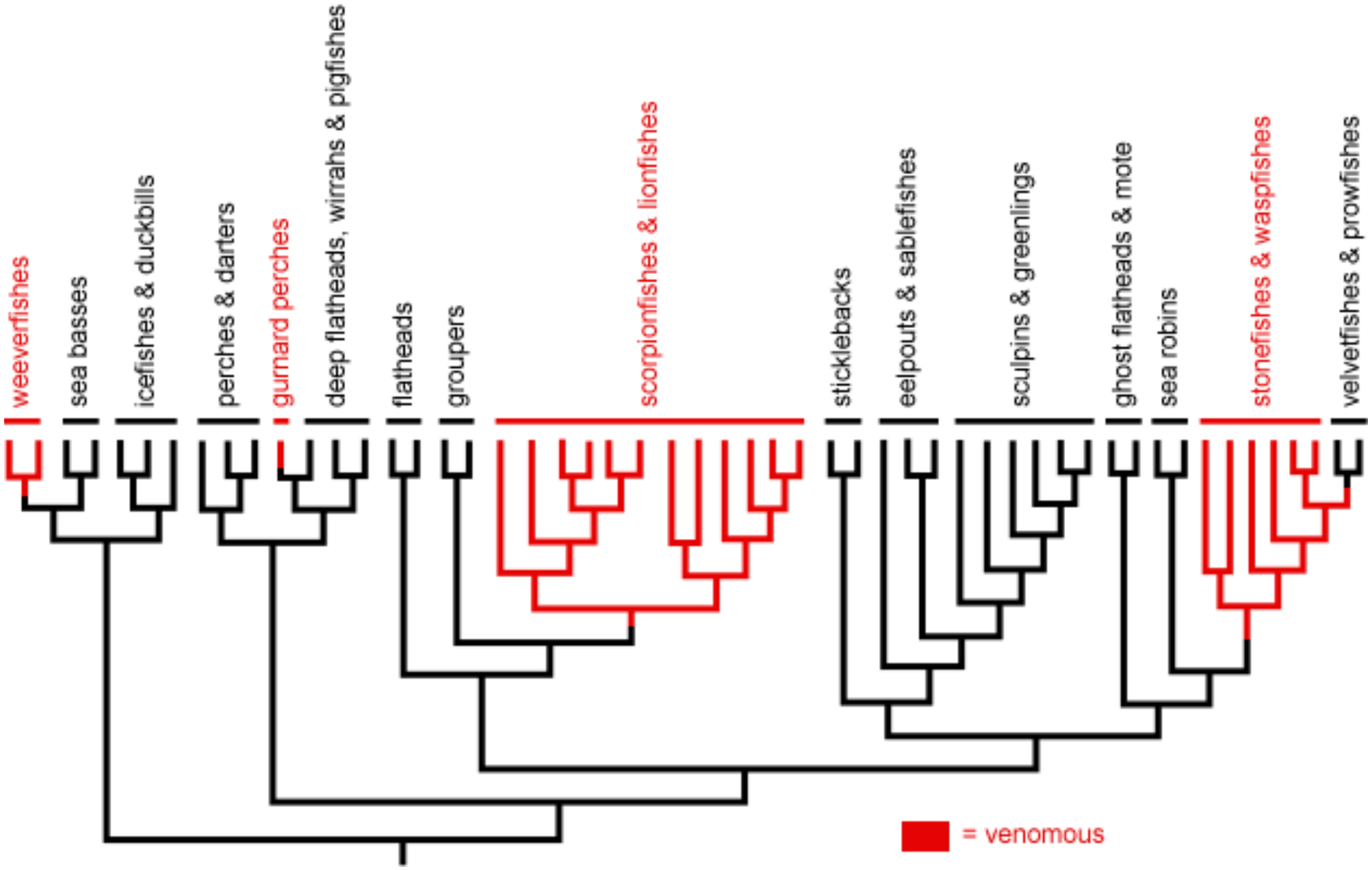


Complete metamorphosis triggered insect diversification

Rainford JL, Hofreiter M, Nicholson DB, Mayhew PJ (2014) Phylogenetic Distribution of Extant Richness Suggests Metamorphosis Is a Key Innovation Driving Diversification in Insects. PLoS ONE 9(10): e109085. doi:10.1371/journal.pone.0109085
http://journals.plos.org/plosone/article?id=info:doi/10.1371/journal.pone.0109085

Searching for new medicine

The tree of life can tell us where to look for new chemical compounds that can prevent/cure human diseases



Venom originated several times in fish evolution: potential branches to look for chemical compounds

Source: http://evolution.berkeley.edu/evolibrary/article/0_0_0/evotrees_treesmatter_05

The future of Natural History

If there are 10 million species on Earth and we described 2 million species in 2 centuries, do we need 8 more centuries?

- Human expertise vs. Barcode of Life ?
- Preserving specimens (infrastructures)
- Theory behind phylogenetic analyses (e.g., models of evolution for morphological characters)
- Bioinformatics in the age of genomics
  - Large scale data storage/sharing and analysis
  - Fast algorithms

Back to the Tree of Life

- The largest synthetic Tree of Life so far
  - https://tree.opentreeoflife.org/opentree/argus/opentree5.0@ott93302
- How far away are we from other species?
  - http://www.timetree.org/

Open question for you

While scientists are discovering new branches of the Tree of Life, other branches are being trimmed off from extinction

In your opinion, is it still worth discovering the natural world? Why?