

# Teach *The Tree*, or teach the science of the tree?

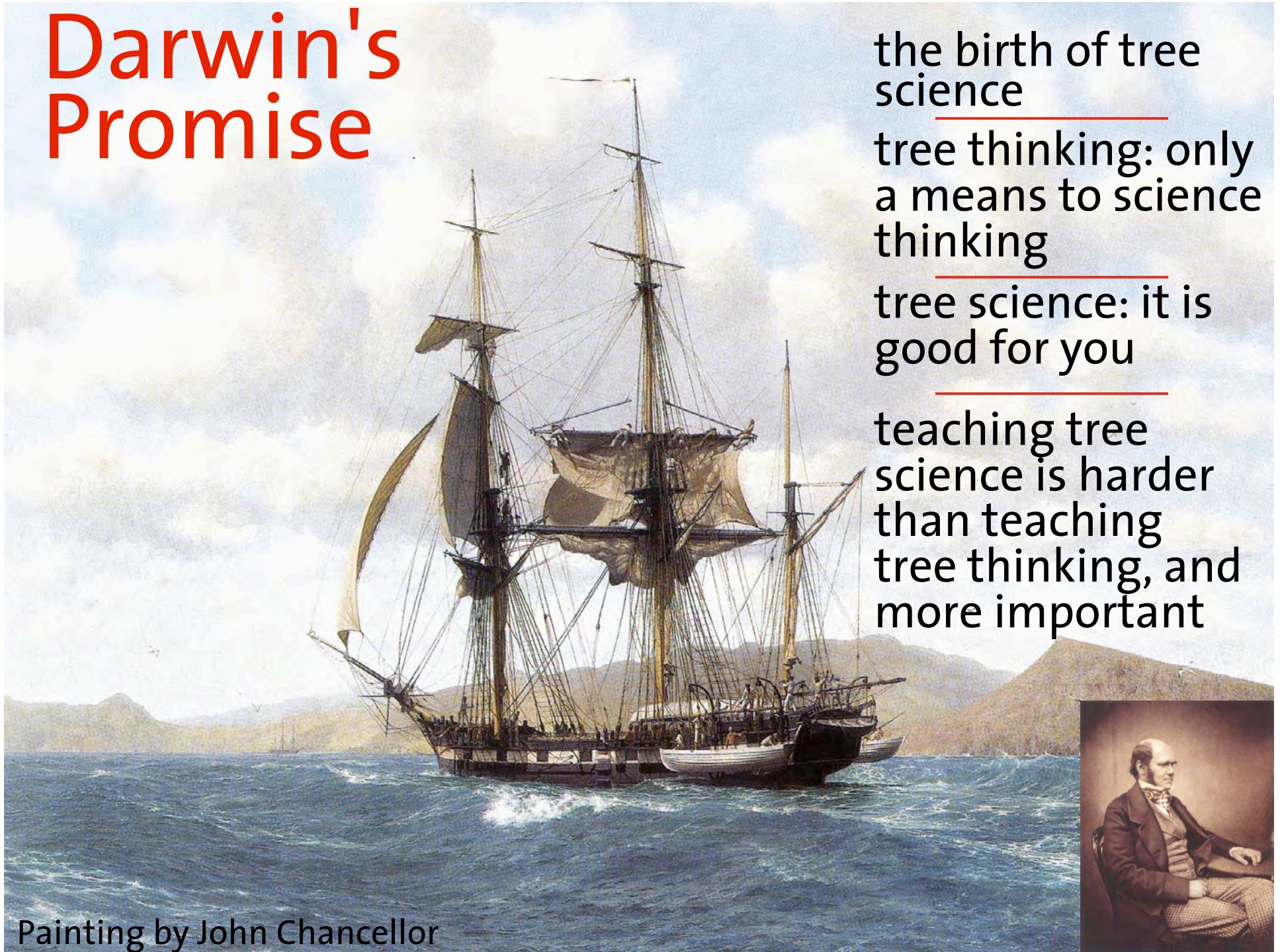


JOEL CRACRAFT  
AMERICAN MUSEUM  
OF NATURAL HISTORY



Photos © J Cracraft

# Darwin's Promise



the birth of tree  
science

tree thinking: only  
a means to science  
thinking

tree science: it is  
good for you

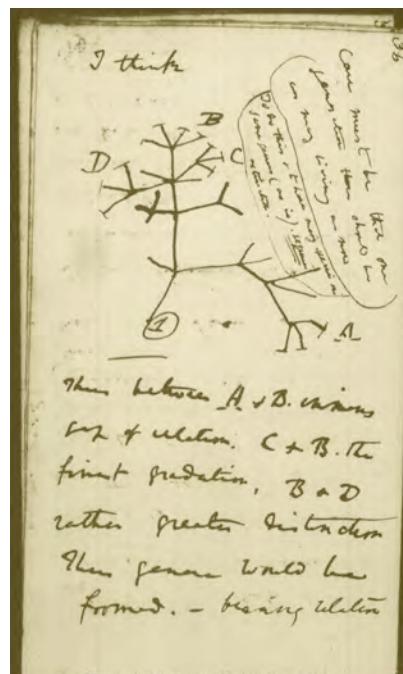
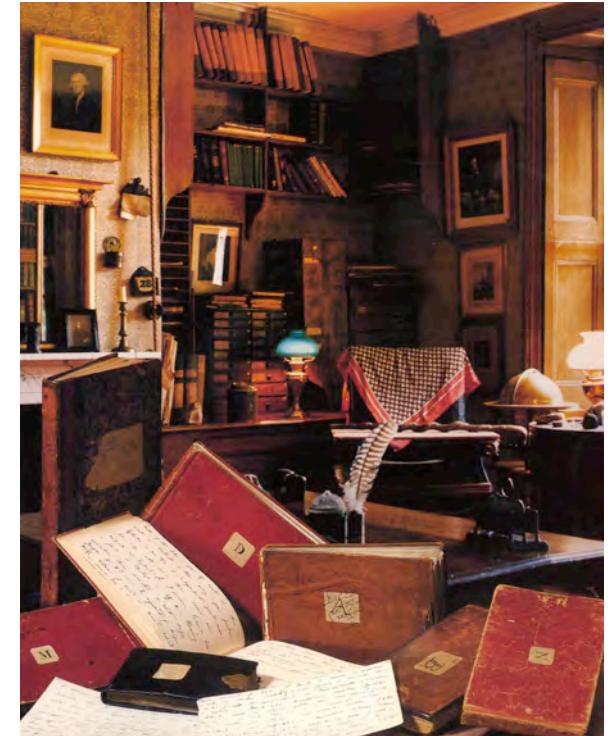
teaching tree  
science is harder  
than teaching  
tree thinking, and  
more important

Painting by John Chancellor

# Soon after the Beagle: two great ideas

"One may say there is a force like a hundred thousand wedges trying [to] force every kind of adapted structure into the gaps in the oeconomy of Nature, or rather forming gaps by thrusting out weaker ones" (*Notebook D*, 1838)

## ADAPTATION VIA NATURAL SELECTION



*Notebook B*  
1837, p. 36

"The affinities of all the beings of the same class have sometimes been represented by a great tree. I believe this simile largely speaks the truth" (*Origin*, 1859)

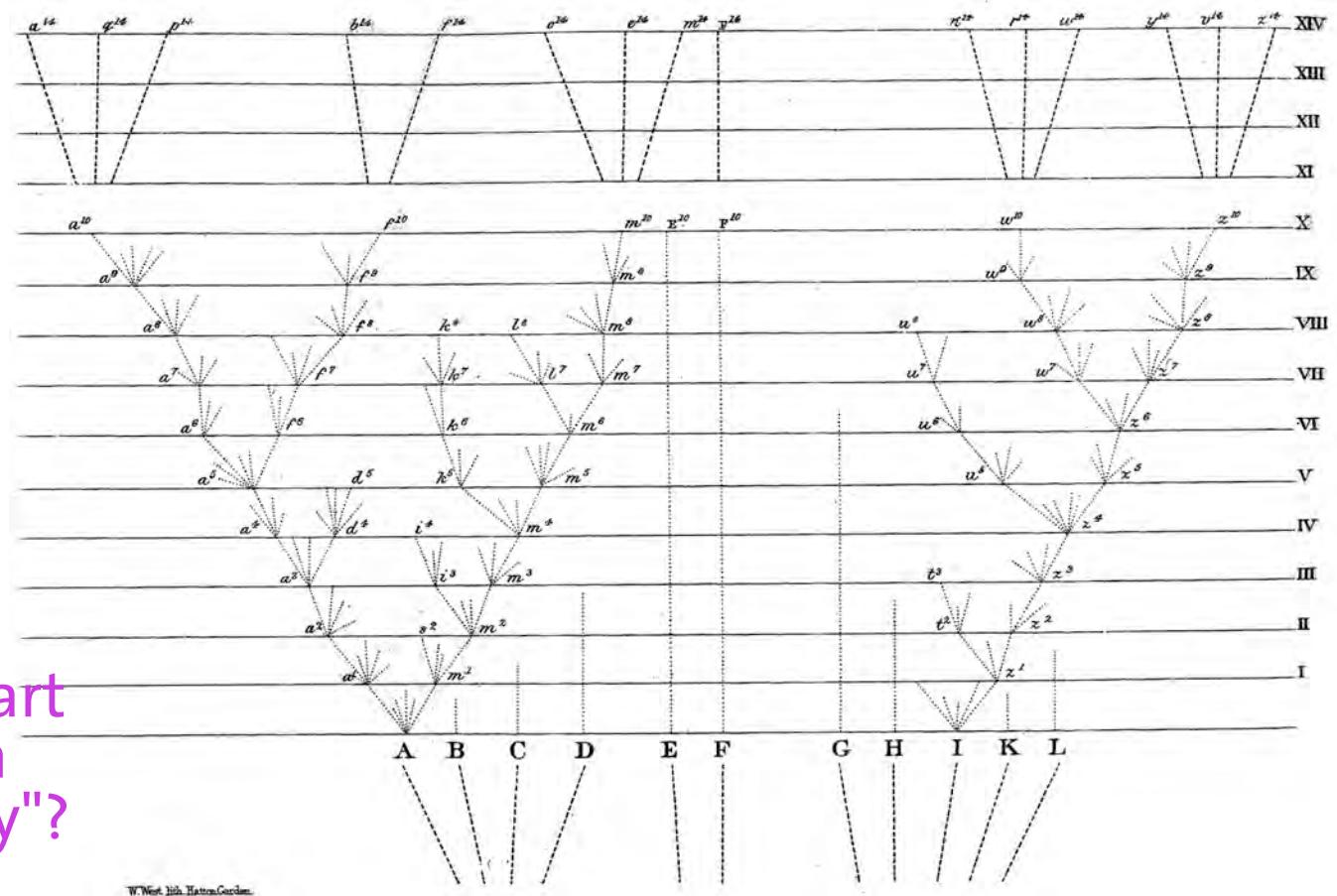
## DESCENT WITH MODIFICATION



CHARLES DARWIN

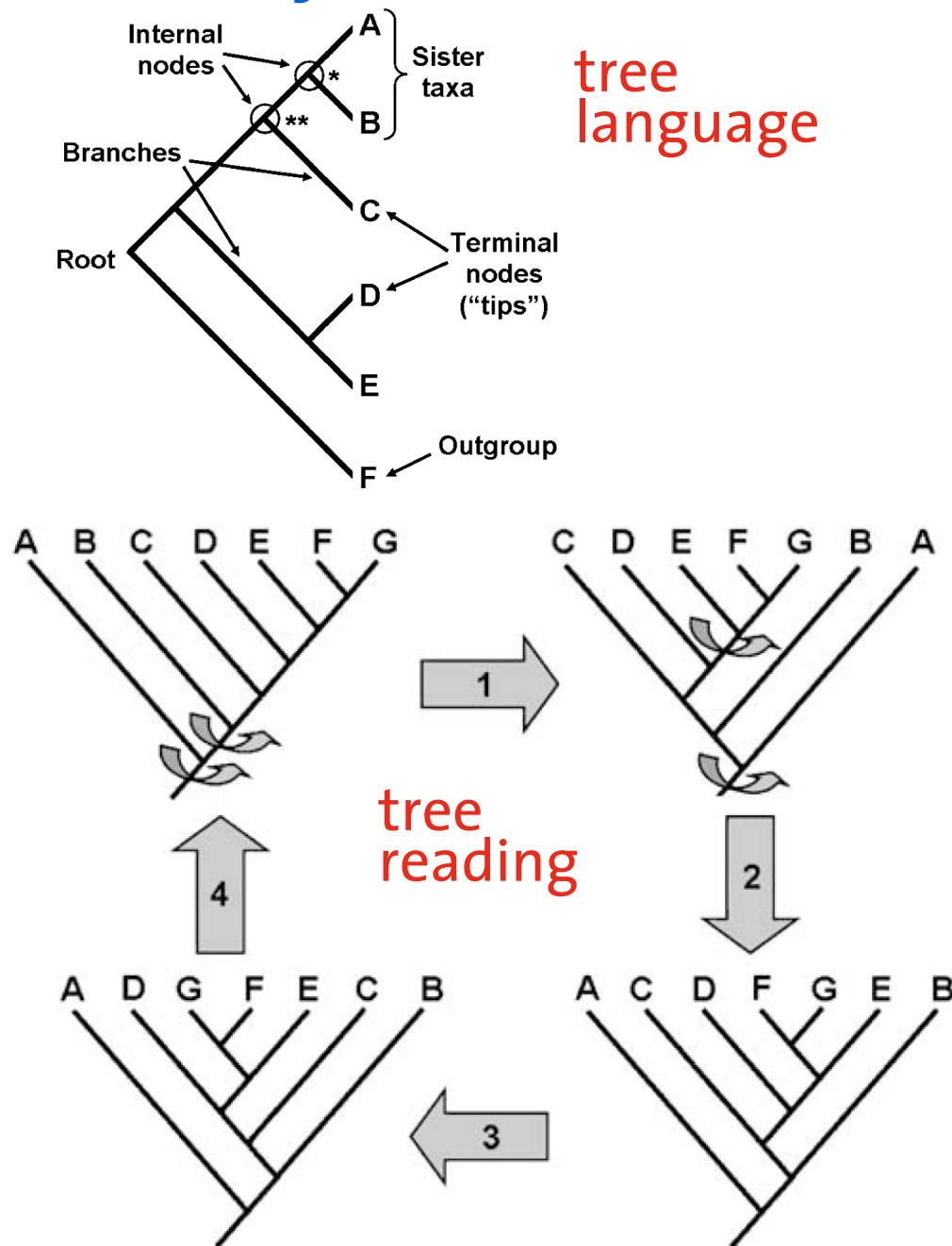
Did tree thinking start with Haeckel? With his word "phylogeny"?

# Tree thinking: only a means to science thinking

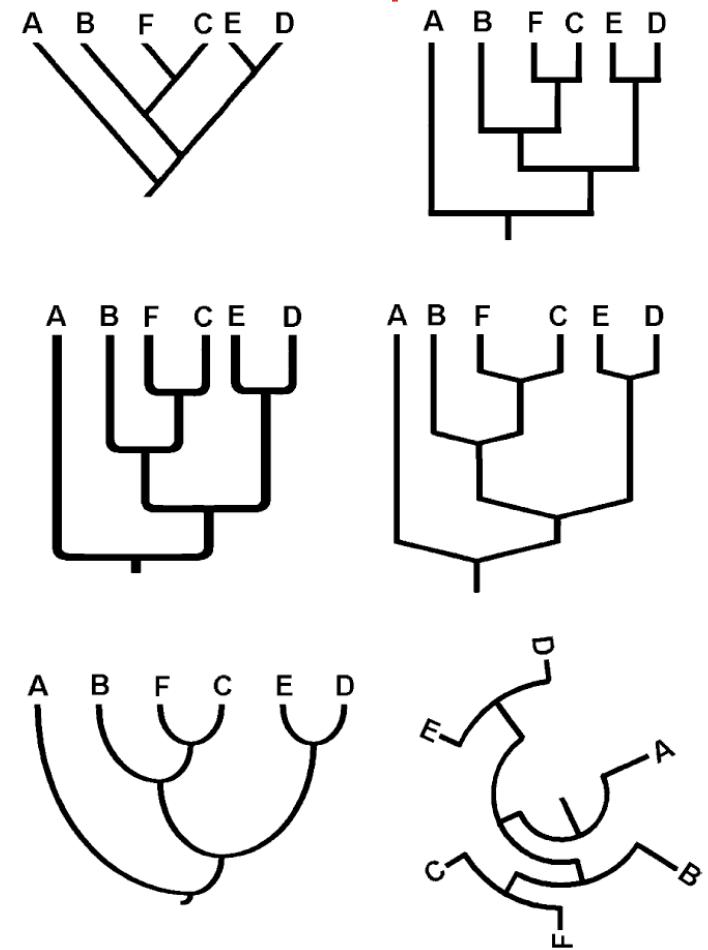


Darwin: "so by generation I believe it has been with the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever branching and beautiful ramifications."

# Definitely teach the basics of "tree thinking"



tree shapes

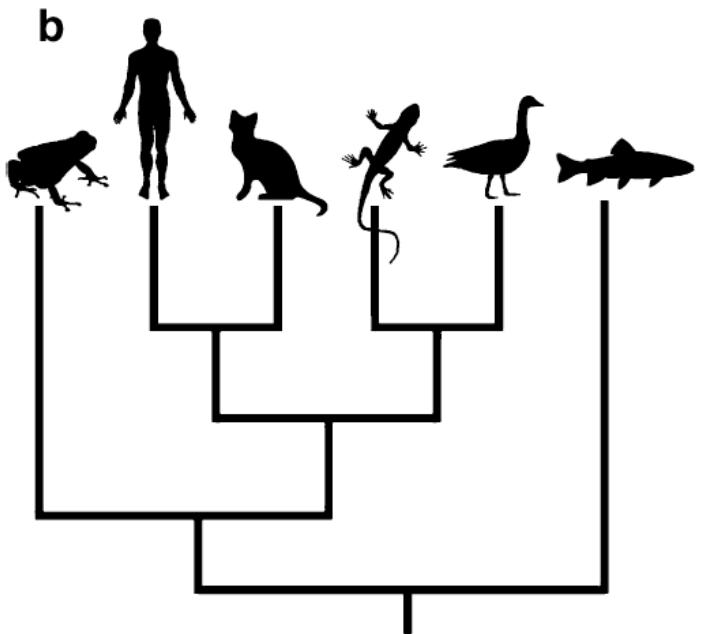
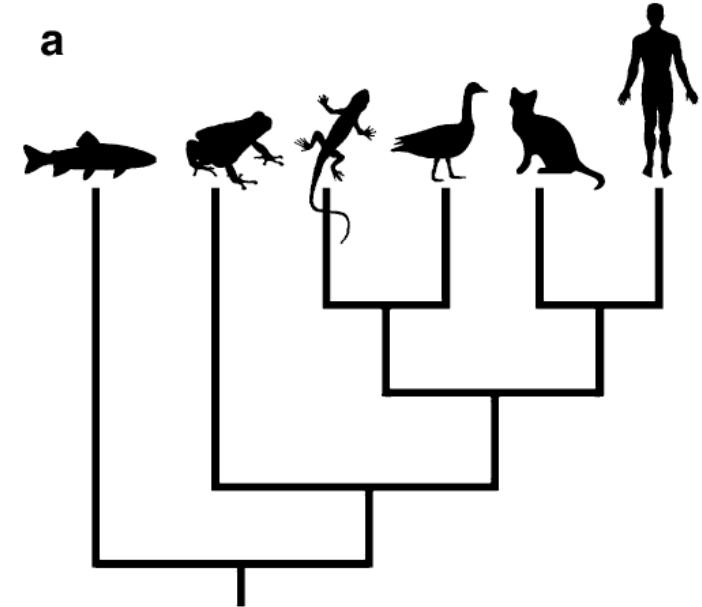


T. R. Gregory. 2008. *Evol. Edu. Outreach* 1:121-137.

# Teach tree interpretation

and misunderstandings:

- major vs minor lineage
- primitive-advanced
- progress
- basal taxon

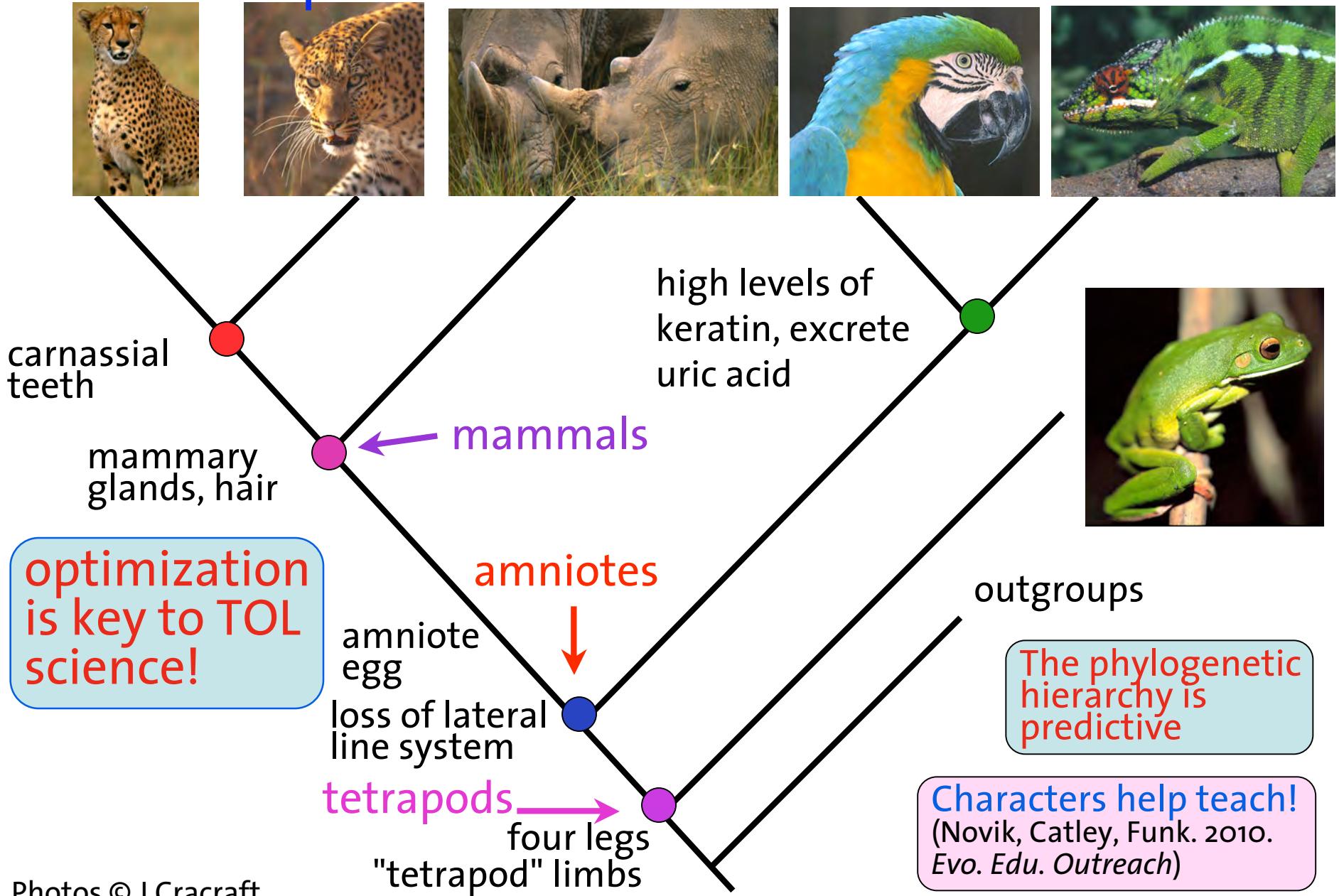


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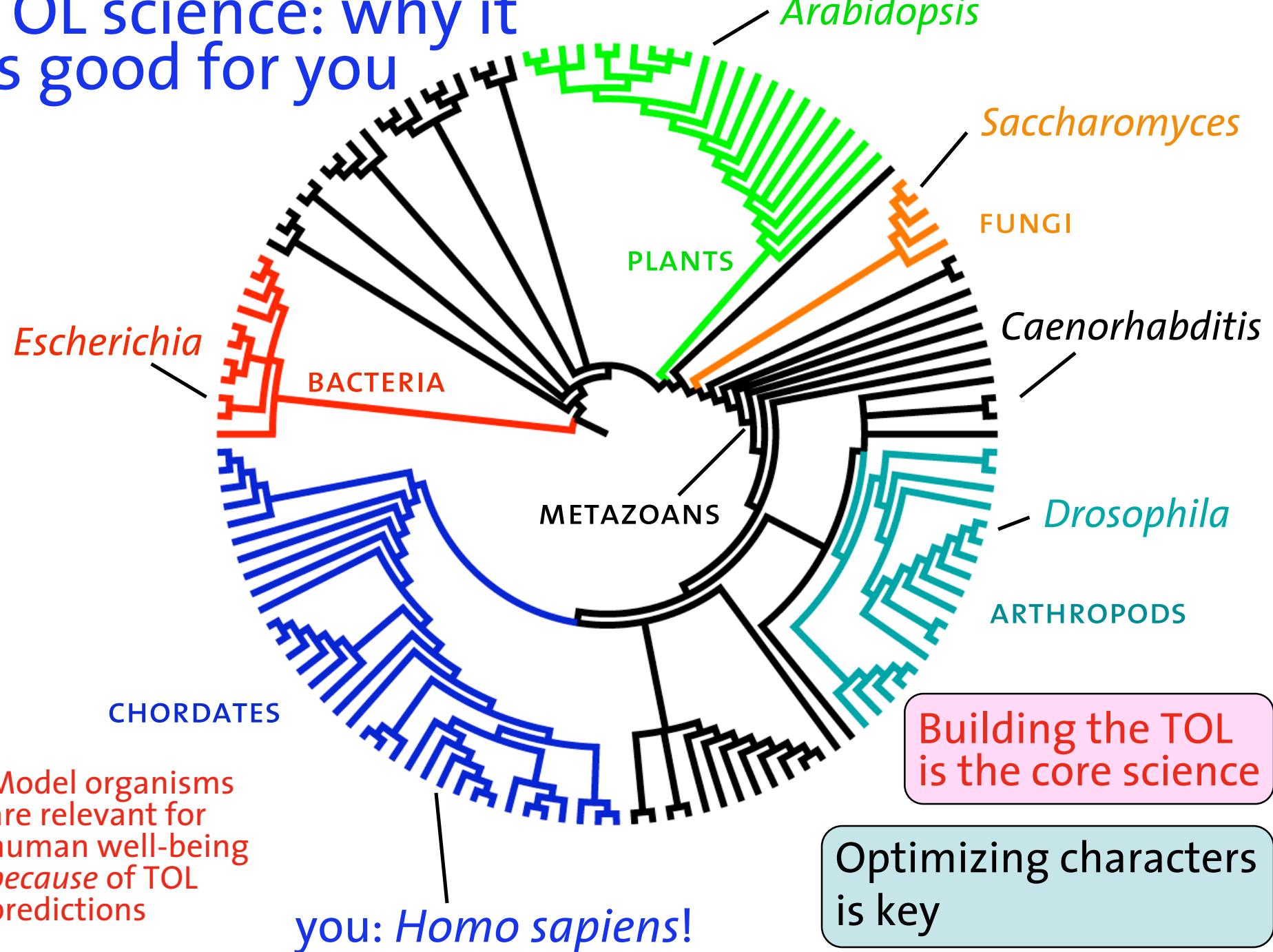
# A (tiny) bit of the science of tree science

- "Observations" vs hypotheses
- What is the tree? How are groups related?
- Thinking about things in nature (ontology): what are the things on trees?
- Relationships among things: how do we discover them?
  - attributes: similarity, homology (hierarchies of similarities)
  - characters: shared similarities
  - analytical methods: assumptions, nature of results
- Processes
  - what are these?
  - at what "levels" do these operate?

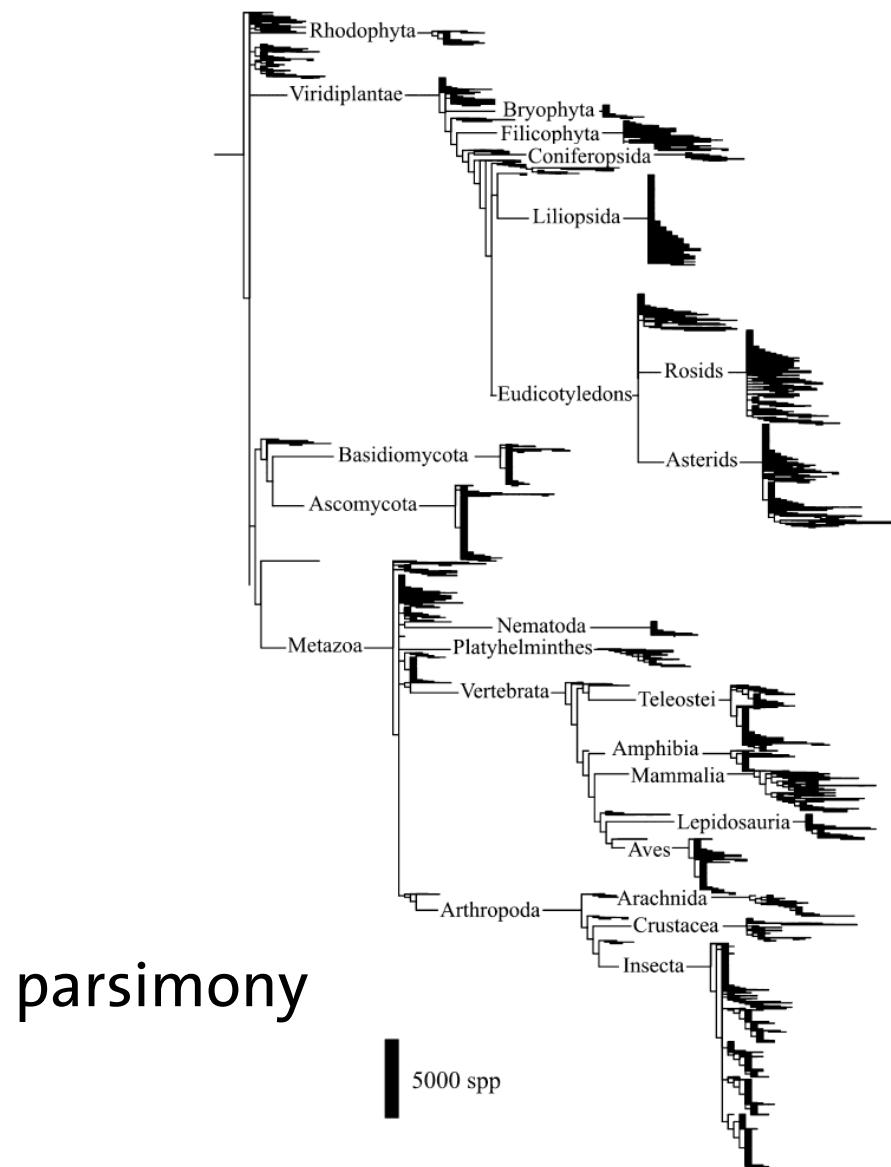
# Descent with modification: teach character optimization



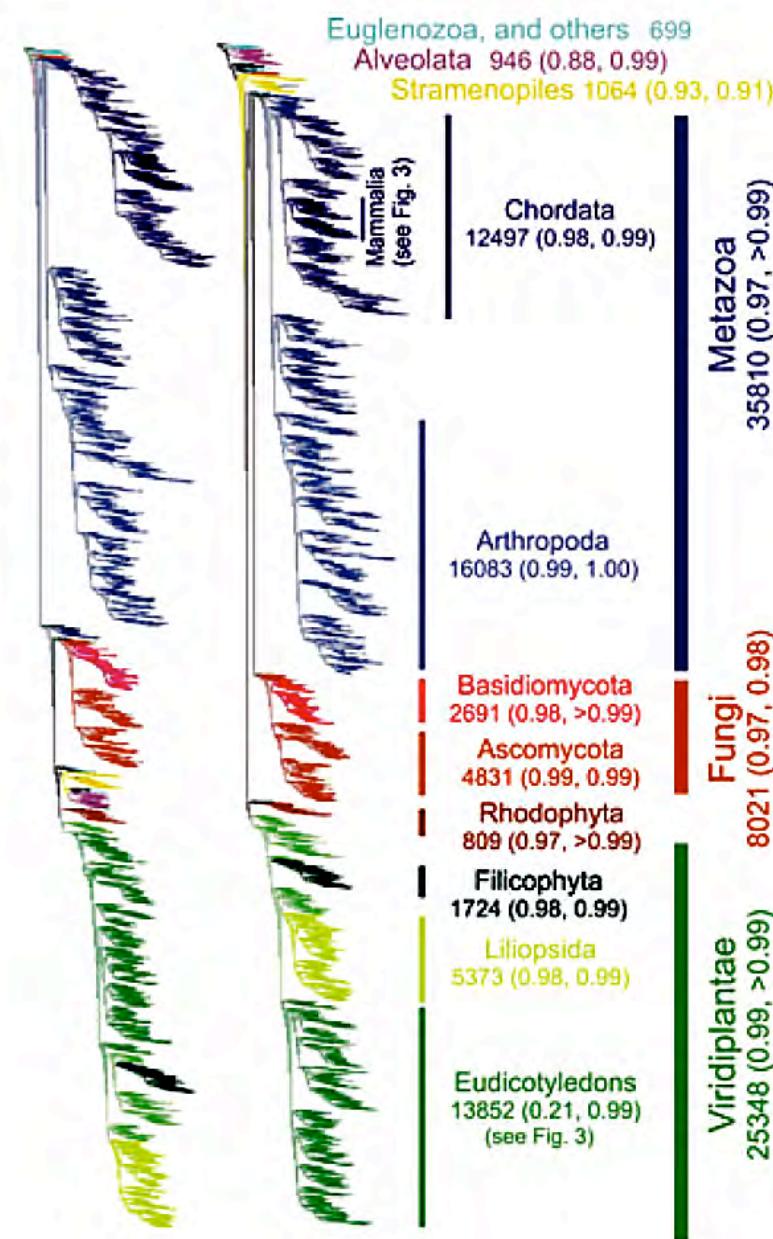
# TOL science: why it is good for you



# Trees are growing larger and harder to visualize



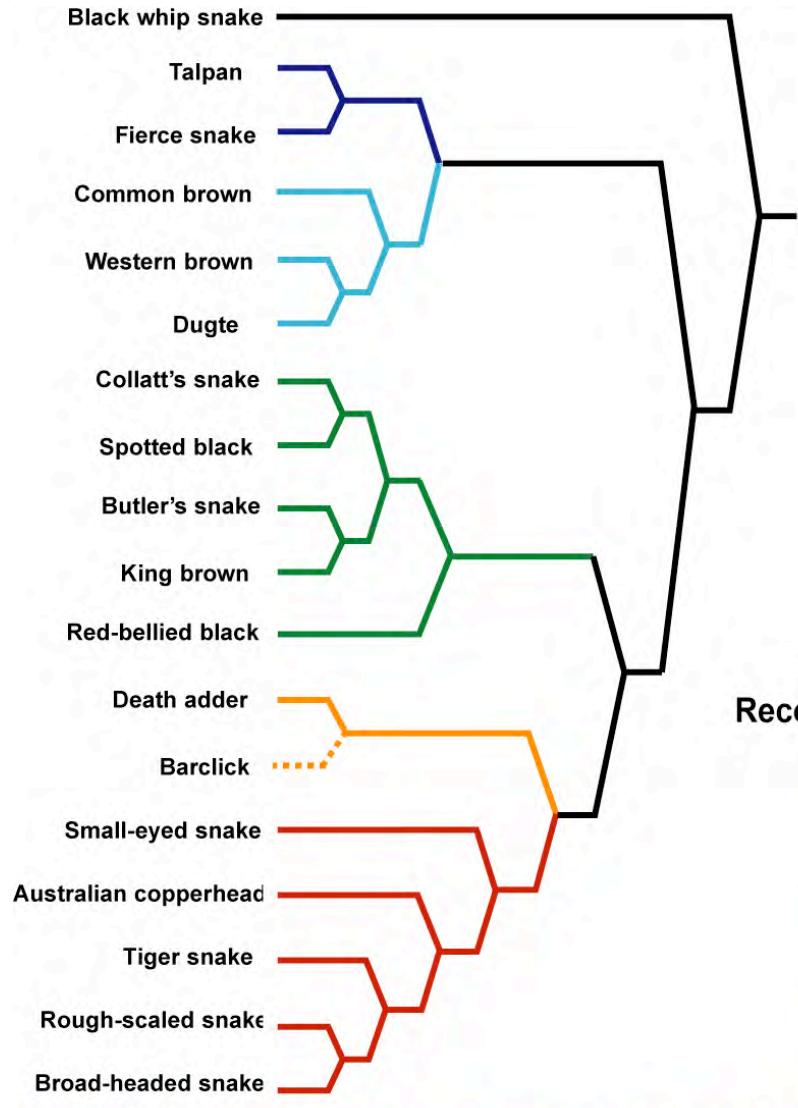
Goloboff et al. 2009. *Cladistics* 25:211-230



# SCIENCE BENEFITS OF THE TREE OF LIFE:

- Is the foundation for all of comparative biology:  
**basis for predictivity**
- Is essential for the discovery of new life forms
- Improves agriculture by linking wild relatives to  
domesticates
- Deepens understanding of developmental processes
- Helps trace the biogeographic origins of invasive  
species
- Helps identify emerging diseases
- Helps predict disease outbreaks
- **CONTRIBUTES TO FORENSIC SCIENCE**

**IT SAVES LIVES!**



# EVOLUTION SAVES LIVES! SNAKE ANTIVENENES

WHY?

Because evolution  
(descent with  
modification) is

**PREDICTIVE**

Recommended Antivenene

- █ Taipan
- █ Brownsnake
- █ Blacksnae
- █ Death adder
- █ Tiger snake



Western brown



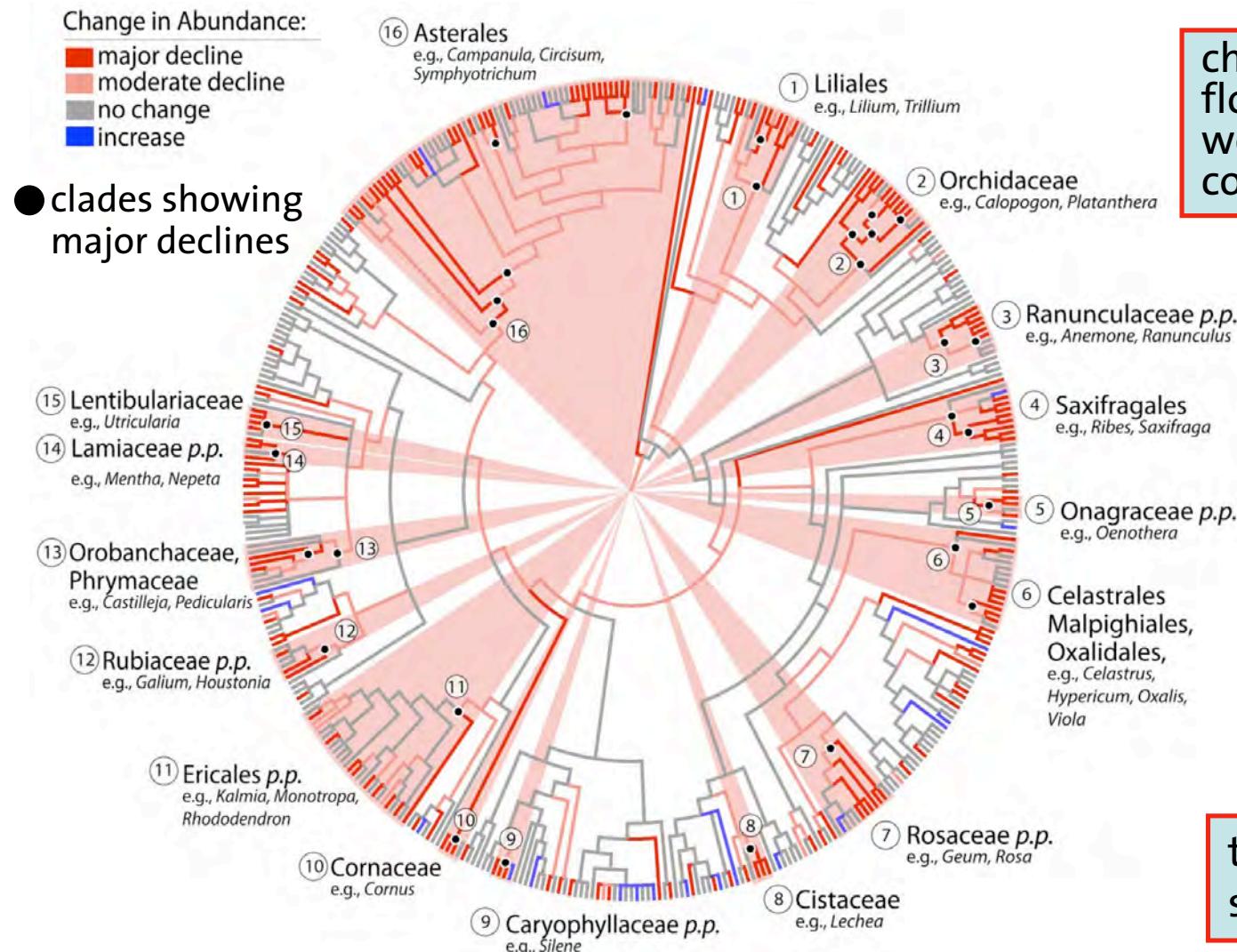
King brown



Red-bellied black

courtesy MSY Lee, S. Aust. Mus.

# TOL: Biodiversity Threat and Global Change



changes in abundance & flowering-time response were phylogenetically conserved

- clades showing major declines

phylogeny predicts response to climate change (global warming)

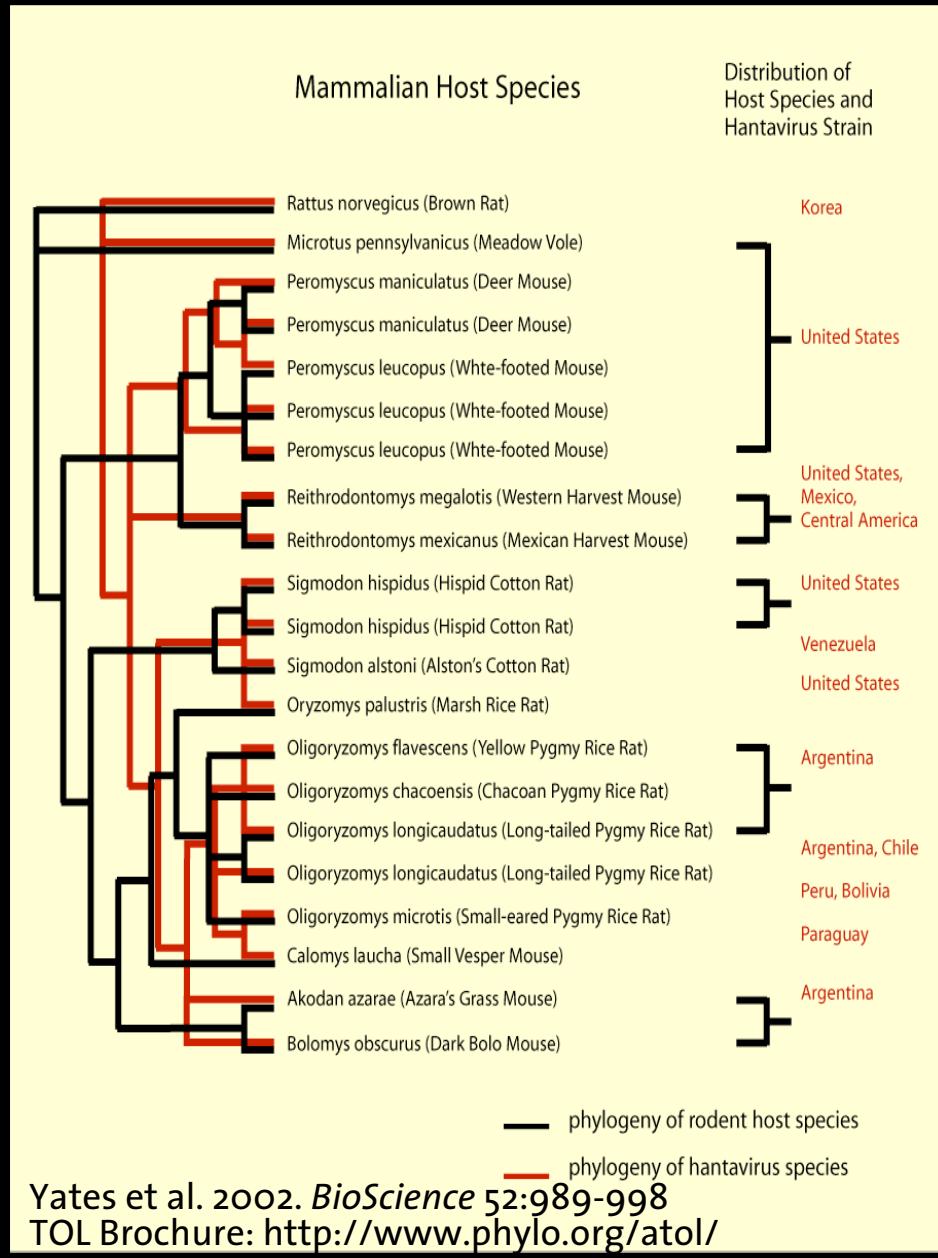
declining species are more closely related than by chance

there is phylogenetic selectivity to extinction

# Decline and extinction in Thoreau's woods

C. G. Willis et al. 2008. PNAS 105:17029-17033

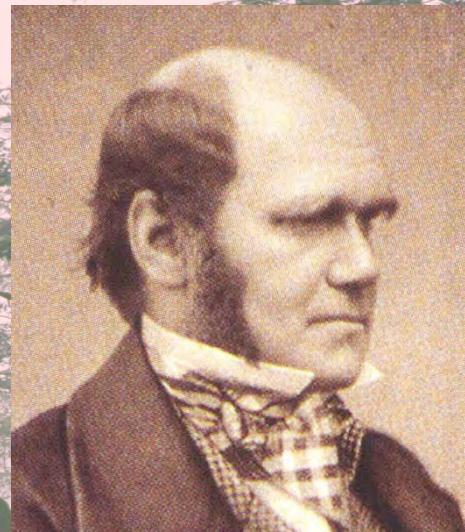
## Coevolution of host and virus is predictive



# TOL AND HUMAN HEALTH



# Why are we different?

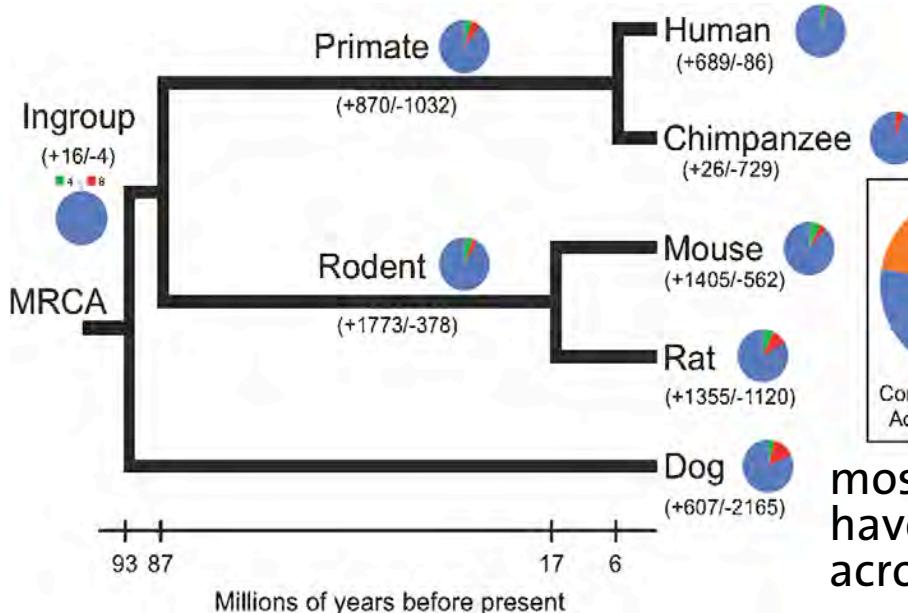


"We see gradations to mans mind in Vertebrate Kingdom in more instincts in rodents then in other animals & again in Mans mind... ?is not Elephant intellectually developed amongst Pachydermata. like Man amongst Monkeys... Man in his ignorance thinks himself a great work. worthy of the imposition of a deity, more humble & I believe true to consider him created from animals."

1838, Notebook C, pp. 196-197.

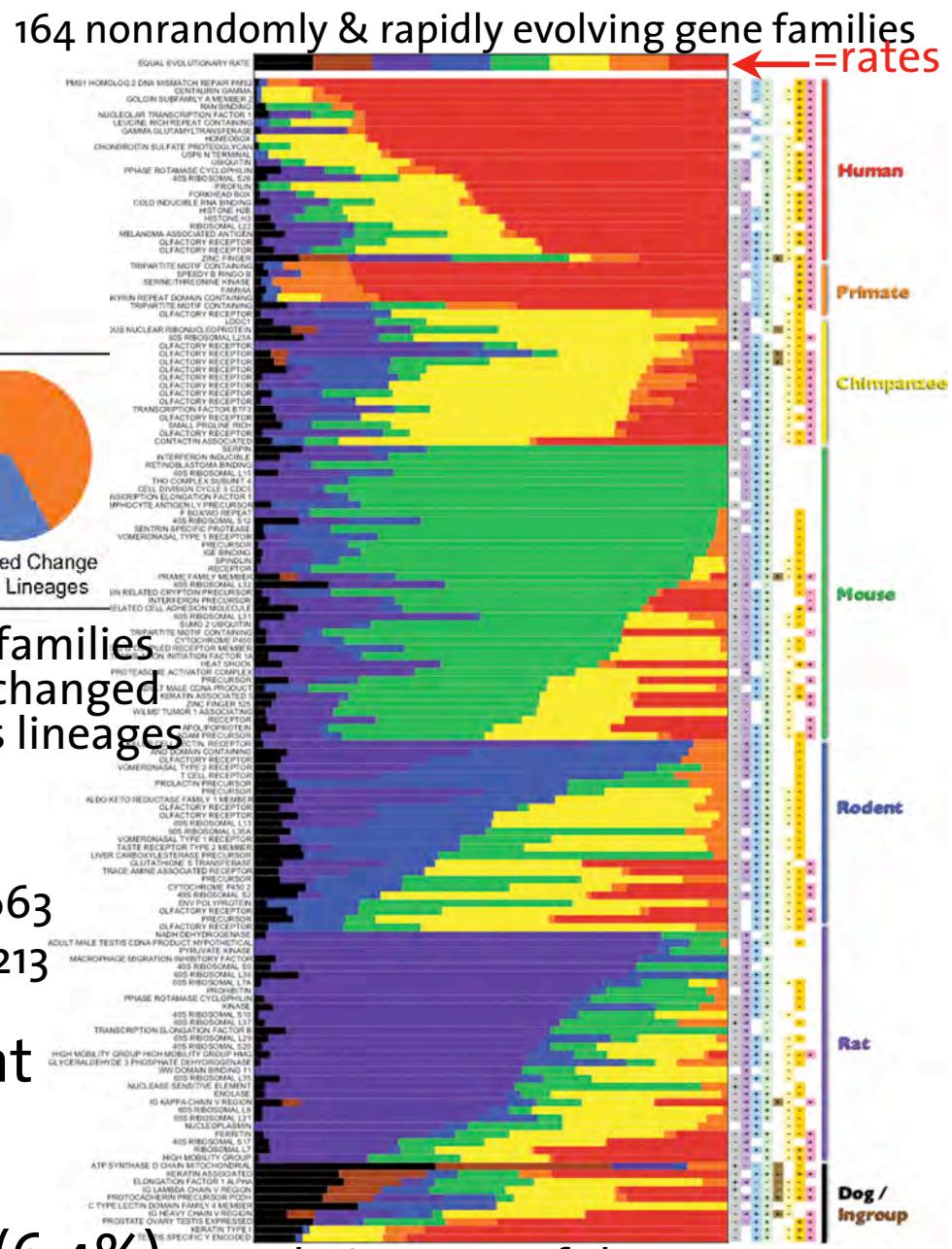
Photos © J Cracraft

# Genomics is pointing to some answers



	chimp	human	mouse	rat	dog
# families	9693	10349	11410	9969	9663
# genes	20947	22763	24502	22557	18213

- huge turnover in gene content (branch optimizations)
- humans and chimps differ in ~1418 nonorthologous genes (6.4%), in contrast to 2% sequence divergence



A photograph of a leopard resting on a large, curved tree branch. The leopard is positioned horizontally across the frame, its body angled slightly towards the left. Its characteristic black spots on a tan coat are clearly visible against the textured bark of the tree. The background is a soft-focus green and yellow, suggesting a natural, outdoor setting.

Should our science be spot-on, or can it be a  
bit spot-off to get a point  
across?

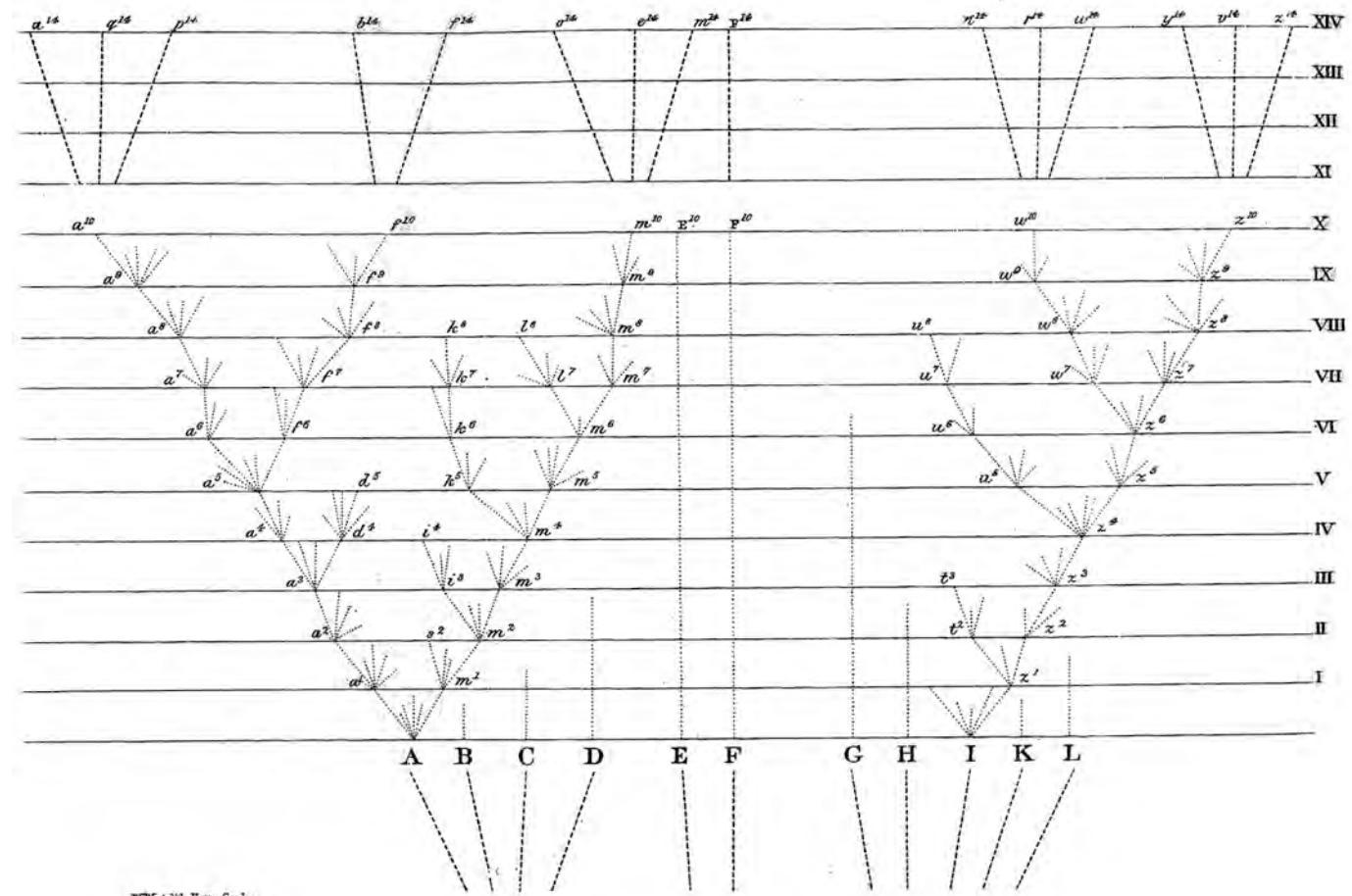
Tree-thinking vs science-thinking:  
what if the former is wrong-thinking?  
Some kinds of trees mislead

Photo © J Cracraft

# Darwin and ancestors (and our infatuation with them)

Darwin: ancestral species at nodes give rise to other species

Most species that ever existed are extinct



# The language and thinking of ancestor infatuation

- LUCA: Last Universal Common Ancestor
- MRCA: most recent common ancestor

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Notions about ancestry lead to fuzzy concepts:

- missing links
  - transitional forms
- 

And to thought-provoking questions:

- Are higher taxa ancestral?
- Are species ancestral?
- Do species really speciate?

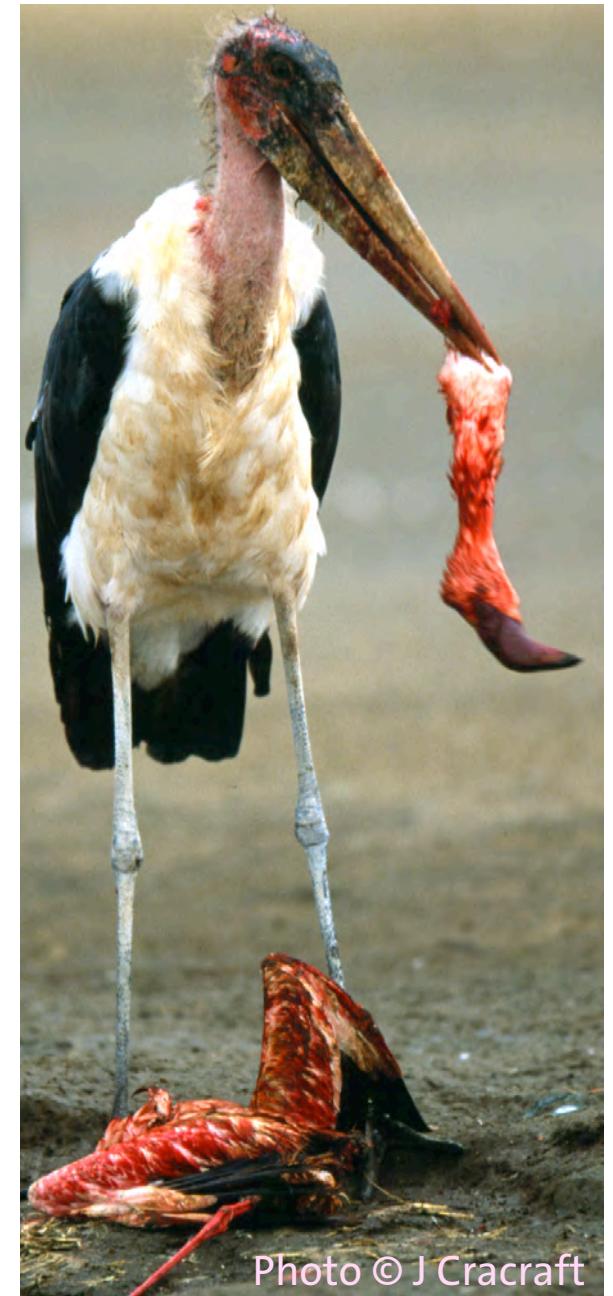
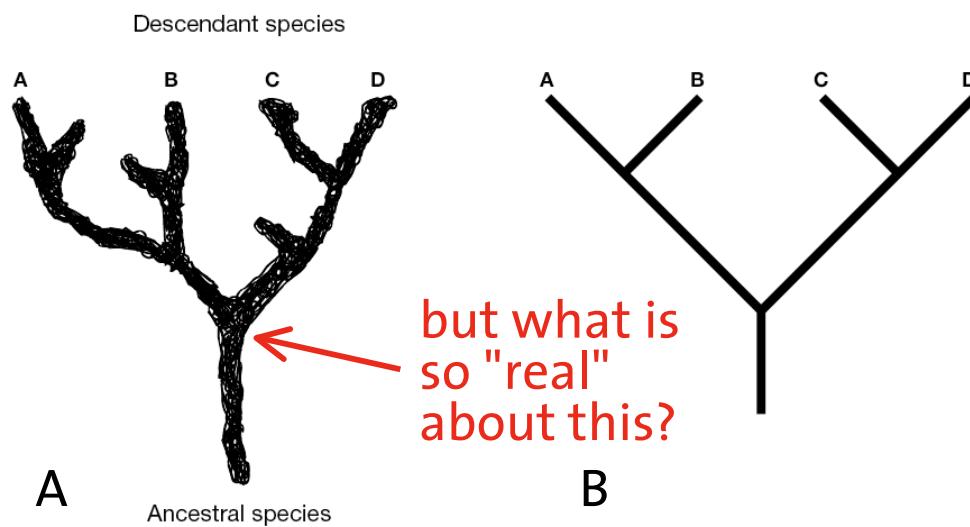
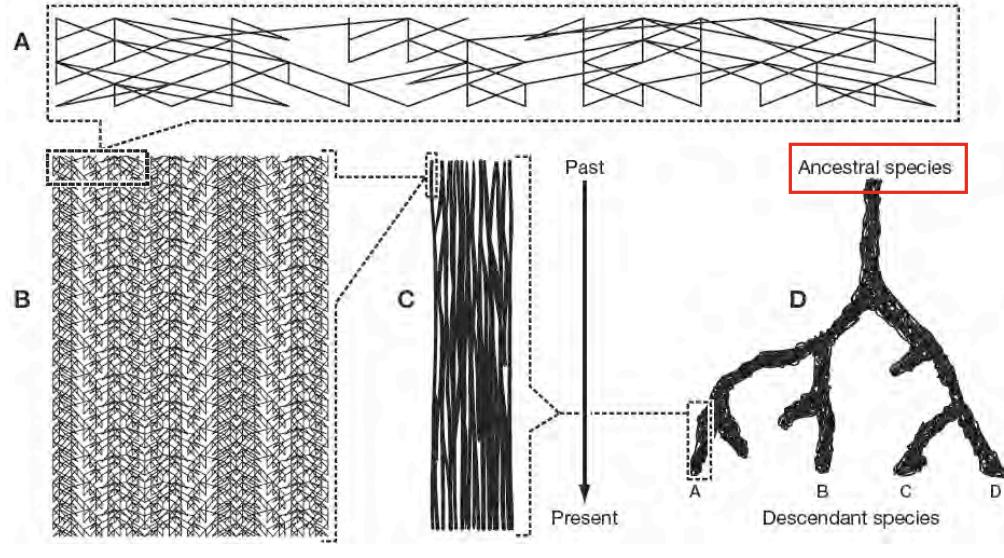


Photo © J Cracraft

# Trees (real) vs cladograms ("unreal"? trees)



D. Baum & S. Offner. 2008. Amer. Biol. Teacher 70:222-229

## Distinction is decades old

"Figure 2. An illustration of how the genealogy of a sexual population is included in a phylogenetic tree. A. The local population illustrated in Figure 1C. B. An expanded view showing the population over many generations, including the organisms and generations illustrated in Figure 2A. C. A species lineage consisting of population lineages that are interconnected by occasional interbreeding. D. A branching phylogeny in which one ancestral population gives rise to four living species."

"Figure 3. A tree diagram is meant to represent an actual history of evolutionary lineages that have branched over time. The most critical facts about the real history shown in panel A are summarized in panel B; namely that species A and B derived from an ancestral lineage that did not give rise to C and D, and vice versa."

Here, "trees" & "cladograms" have different ontologies

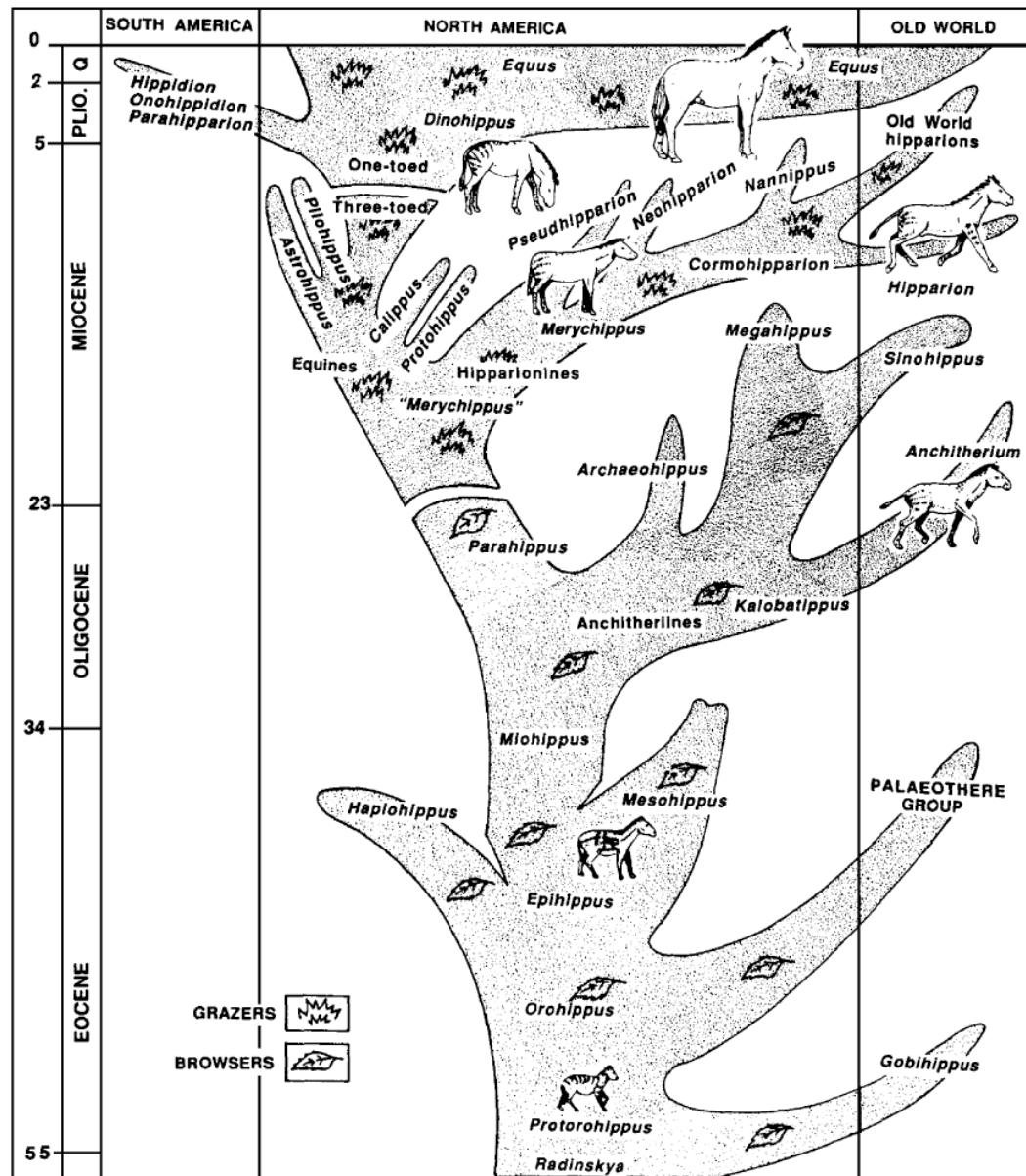
# Teaching trees: what about those ancestors?

Can some trees inadvertently teach the wrong things about evolution?

There are many examples in literature of higher taxa being considered ancestors, and many trees show this

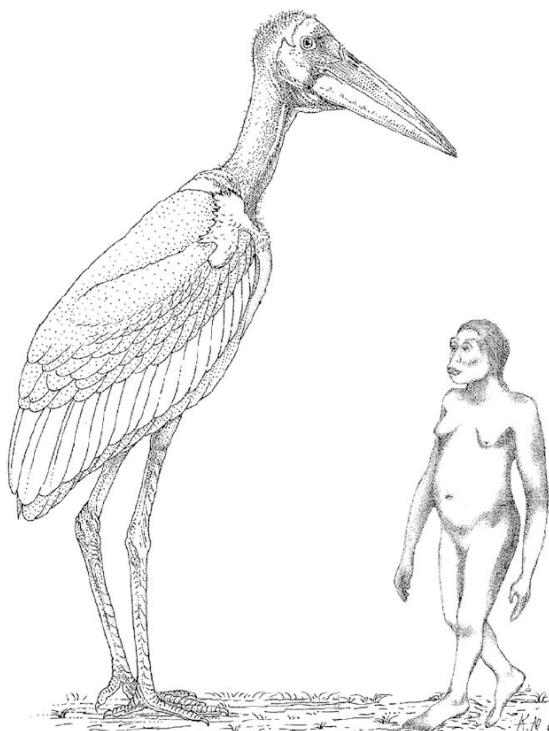
But for the sake of "demonstrating" evolution, should trees convey fuzzy thinking?

"A modern view of horse evolution"

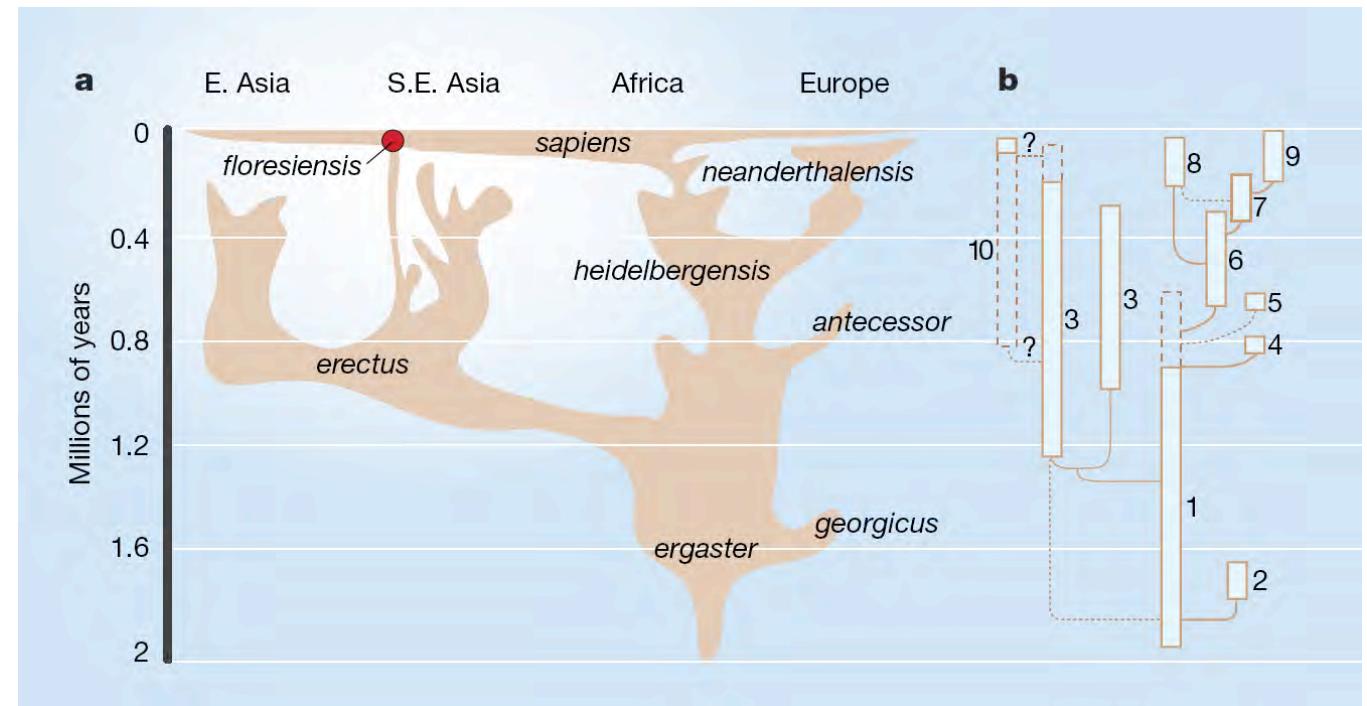


Genera as ancestors?

This is the story of the Hobbit and ancestors, but check out that Giant Stork!

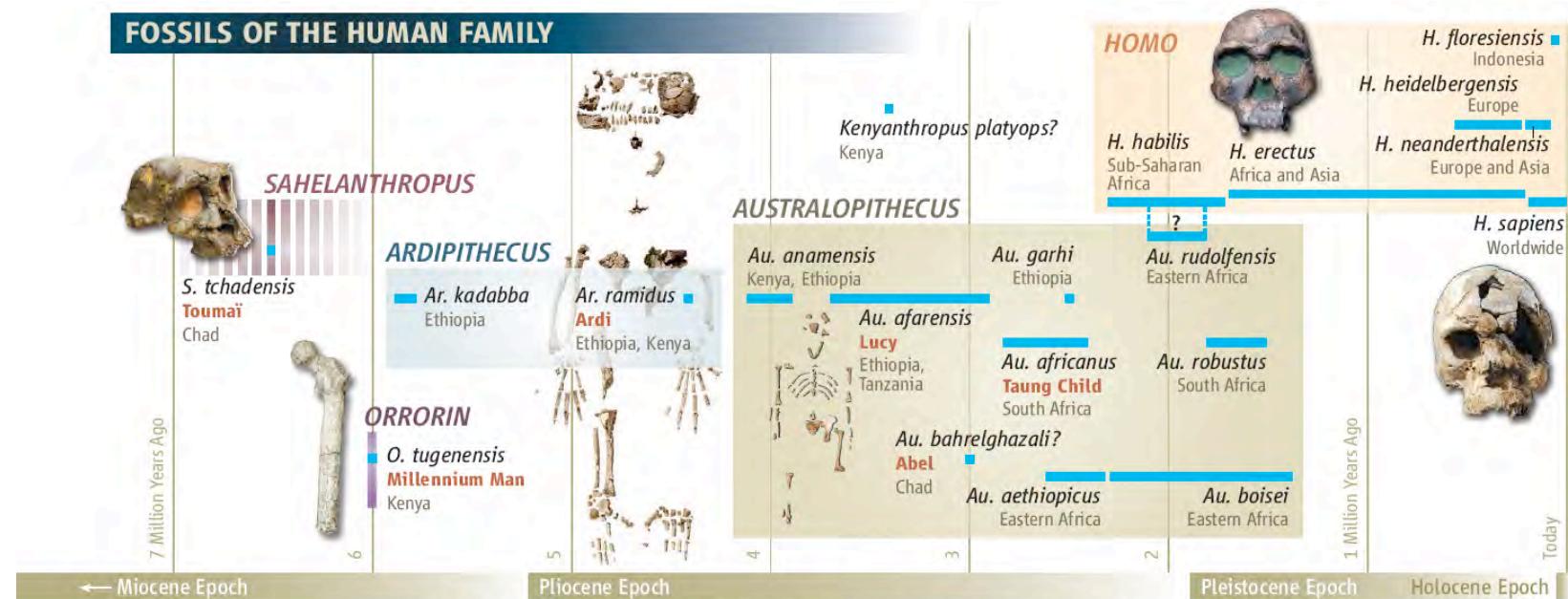


*Homo floresiensis*



These kinds of trees reflect the sometimes-ambiguous taxonomic status of fossils

# From fossils to ancestors

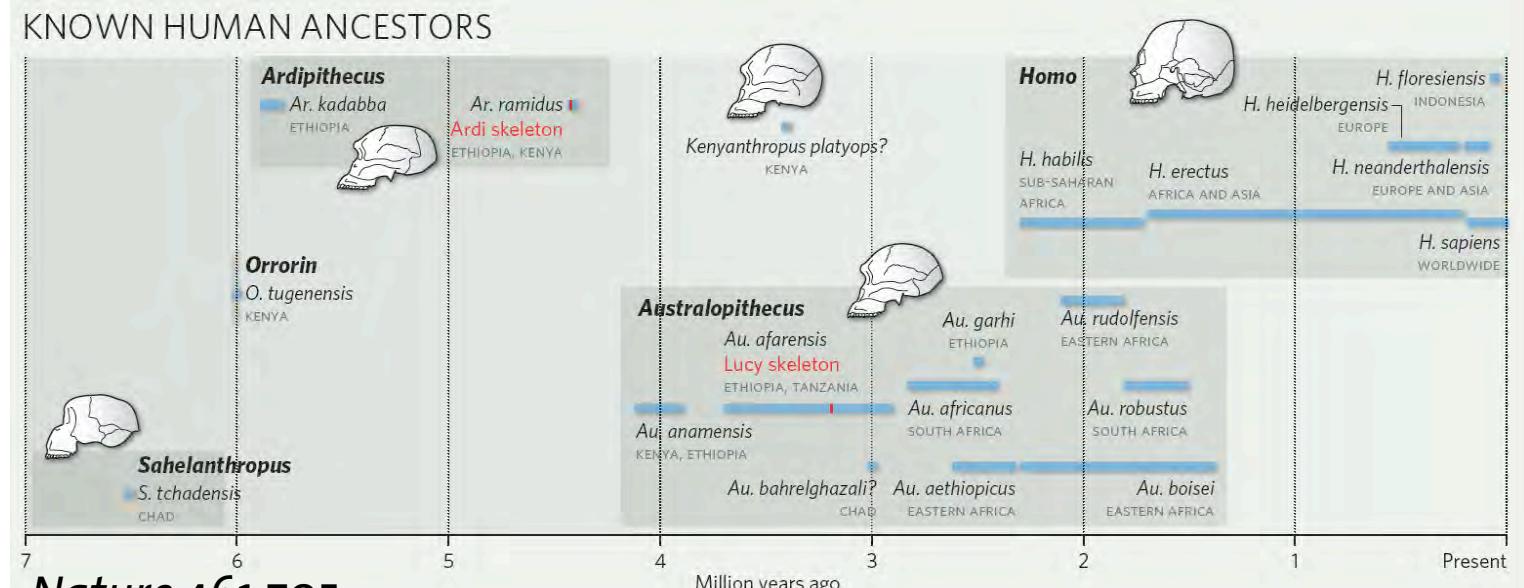


A. Gibbons. 2009. *Science* 326:38



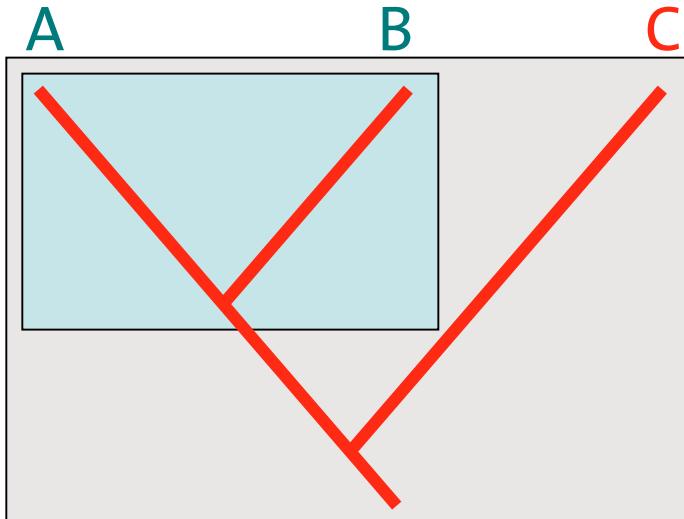
"Known  
human  
close  
relatives" !!

## KNOWN HUMAN ANCESTORS



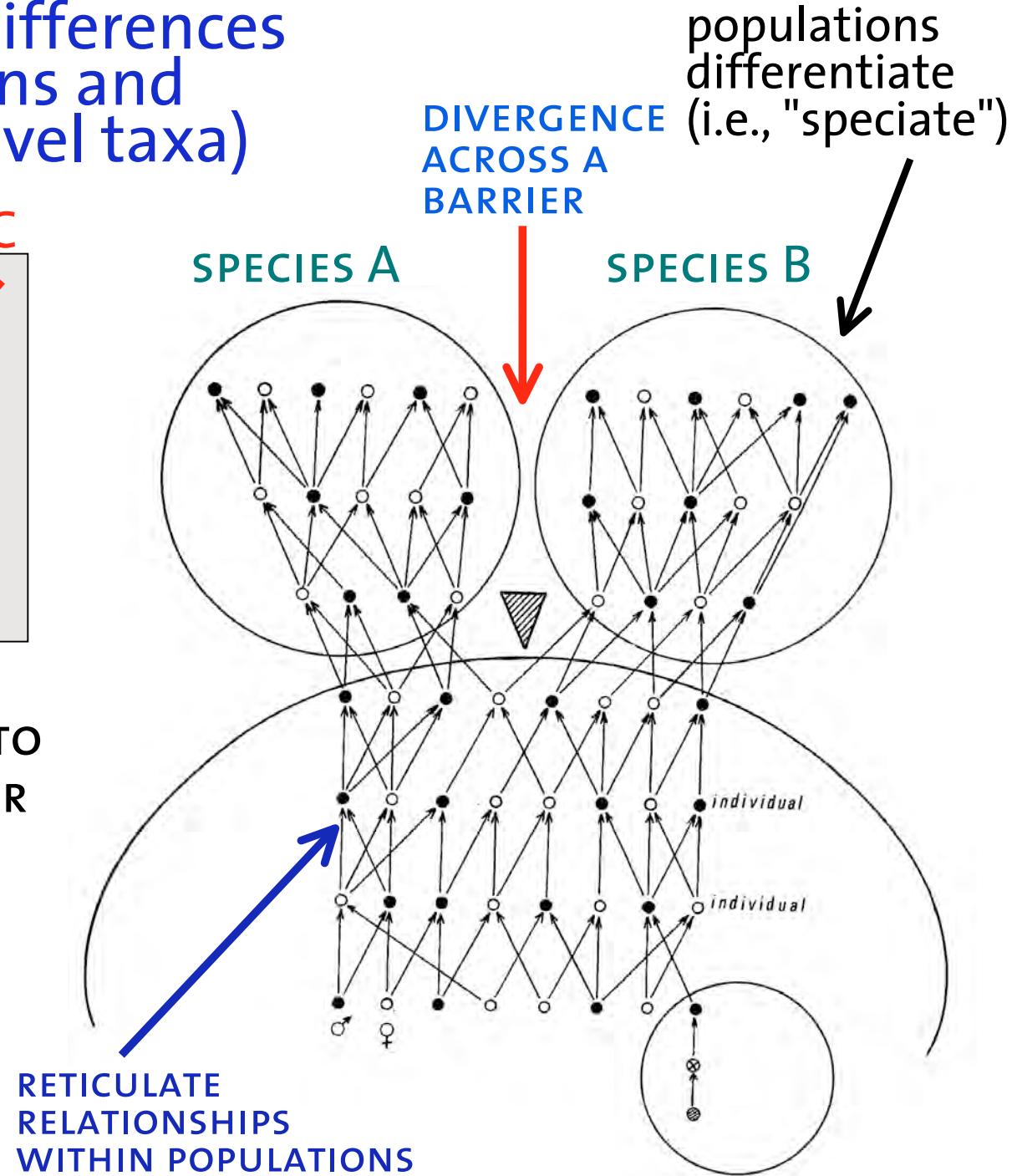
R. Dalton. 2009. *Nature* 461:705

We need to teach differences between populations and taxa (inc. species-level taxa)



TOL: TAXA A AND B ARE MORE CLOSELY RELATED TO EACH OTHER THAN EITHER IS TO TAXON C  
(A+B+C)D

CLADES: SEGMENTS OF THE TOL REPRESENTING RELATED TAXA



# Temporal History and Processes of Speciation

post-speciation mechanisms of speciation	Temporal Patterns	Potential Processes
	1. Attaining allopatry	1A. Long-distance dispersal 1B. Vicariance/ distributional fragmentation (tectonics: geomorphological change, shifting rivers, orogeny/ climatic/ecological change)
	2. Genetic/phenotypic novelties arise in isolated populations	2A. Mutations of small effect 2B. Mutations of large effect 2C. Recombination/ developmental change using existing variation
	3. Fixation of novelties (differentiation)	3A. Drift 3B. Natural selection 3C. Sexual selection
	4. Geographic range expansion	4A. Long-distance dispersal 4B. Demographic dispersion
	5. Contact with sister- and other species	5A. Nothing happens 5B. Ecological/behavioral shift-- phenotypic change 5C. Hybridization

Thinking about "pattern" versus "process" in speciation analysis

# WHAT ARE TAXA?



## EVOLUTIONARY TAXONOMY:

"A taxon is a taxonomic group of any rank that is sufficiently distinct to be worthy of being assigned to a definite category" [Mayr 1969, *Principles of Systematic Zoology*, p. 4]

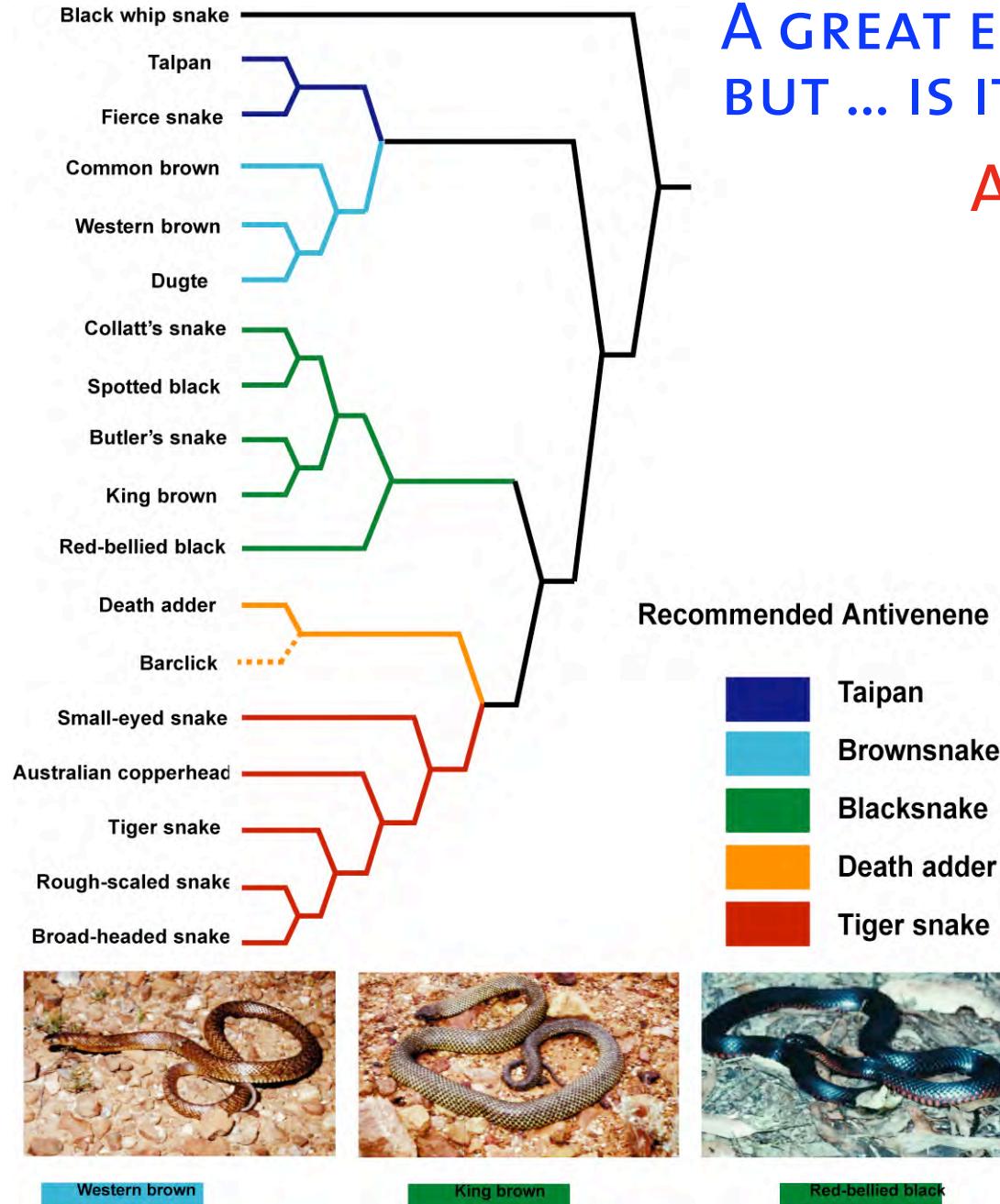
## PHYLOGENETIC TAXONOMY:

A natural taxon is a real/historical group of populations or lineage(s) having a formal taxonomic name

[Thus]

"Natural taxa exist whether or not there are any systematists around to perceive or name them...Because they exist in nature, natural taxa must be discovered, they cannot be invented."

[Wiley 1981, *Phylogenetics*, pp. 72-73]



A GREAT EXAMPLE...  
BUT ... IS IT "TRUE"?

All trees are hypotheses

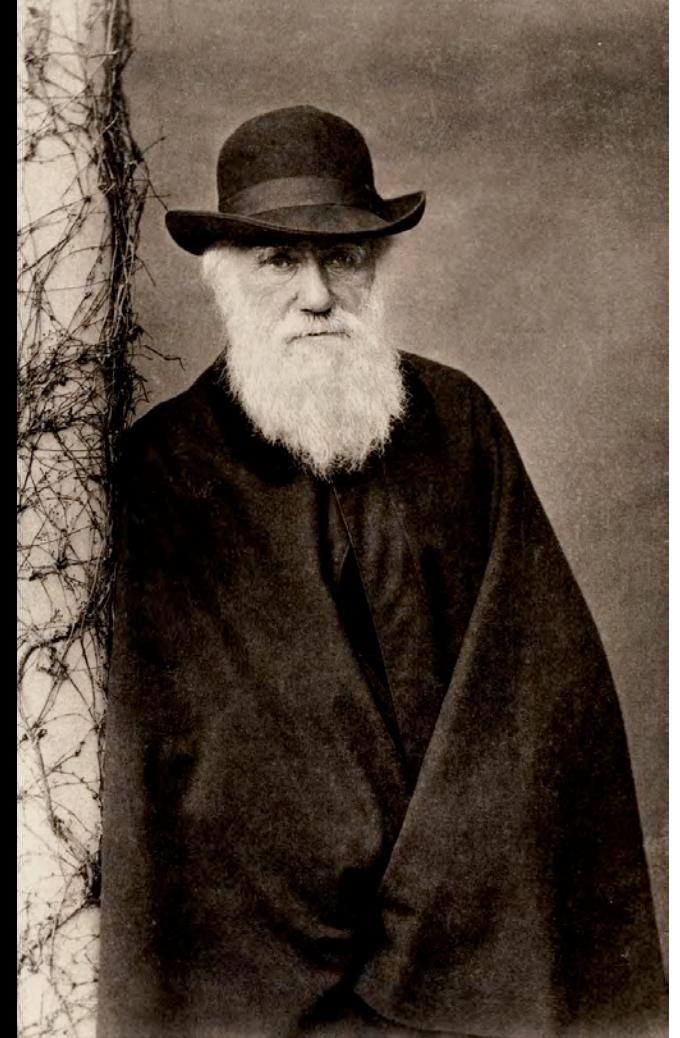
- Relationships and branch support may be uncertain
- Taxon-character sampling may be inadequate
- Knowledge about biochemistry may be incomplete

So teach uncertainty as a normal part of science!

courtesy MSY Lee, S. Aust. Mus.

# Profound observations about the TOL

- Life is connected by a great Tree of Life
- Life is really old
- Life is really diverse
- Earth is really old
- The TOL has consequences:  
it saves lives



# But in teaching the TOL

- Let's teach the science of the TOL
- And use TOL science to teach the nature of science

