Ontogeny, Phylogeny, & Heterochrony

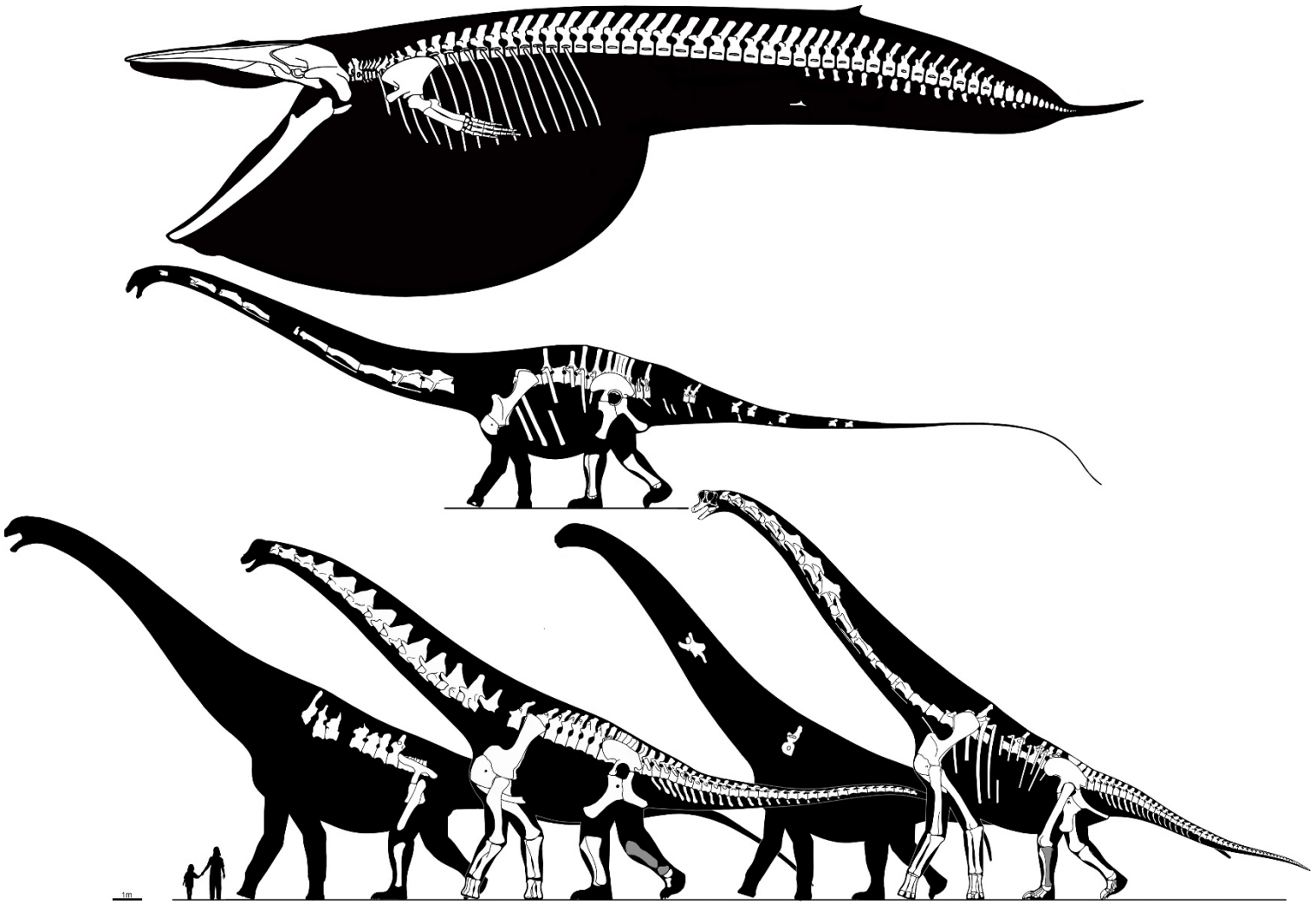
Ontogeny, Phylogeny, & Heterochrony

…in 50 minute or less

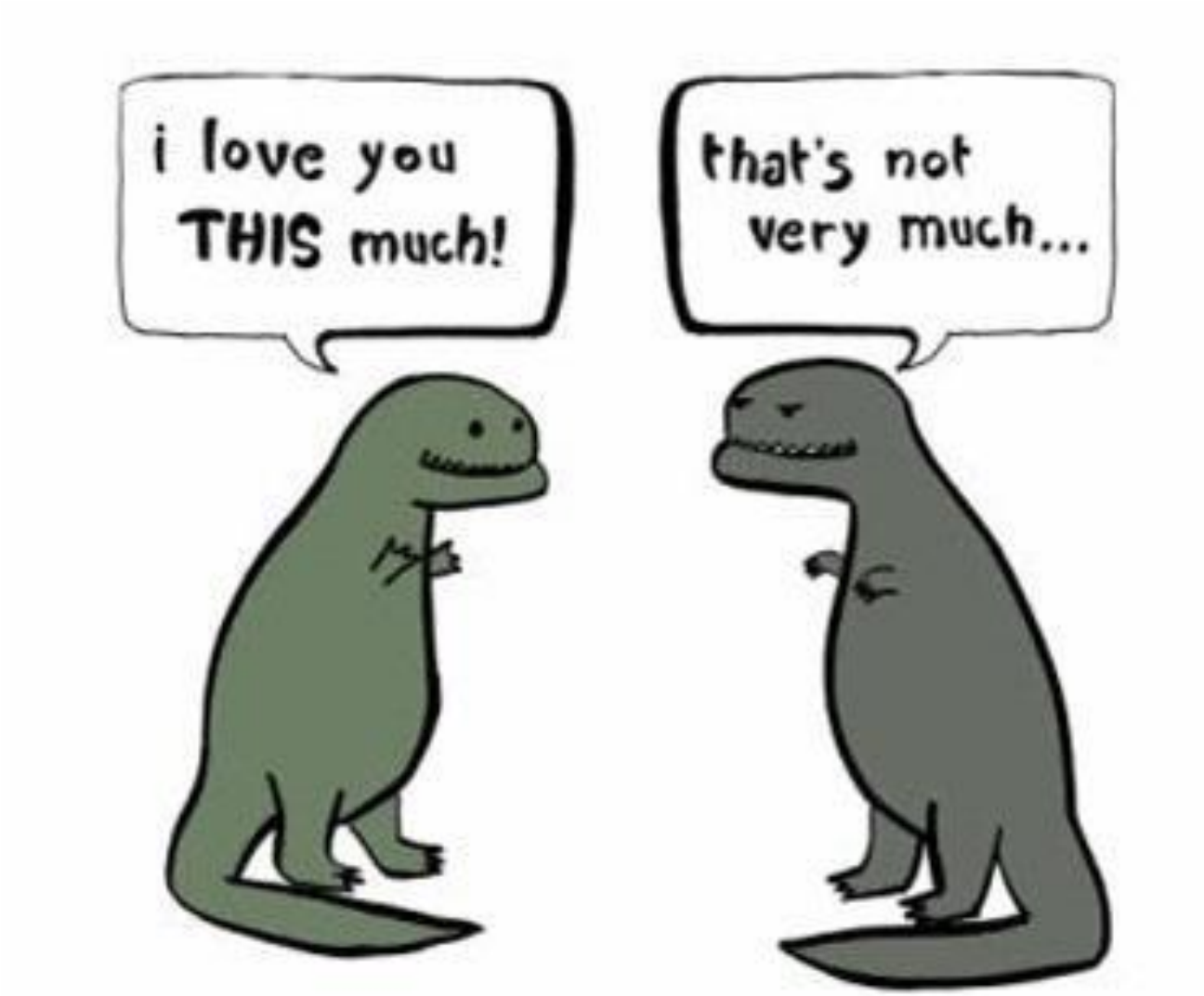
Who is this dude talking to us?

Who is this dude talking to us?

Which means working on charismatic megafauna…



…and that people send you anything remotely dinosaur related from Facebook.



How to think about today's subjects

Ontogeny:

Phylogeny:

Heterochrony:

How to think about today's subjects

Ontogeny: History of your growth and development.

Phylogeny:

Heterochrony:

How to think about today's subjects

Ontogeny: History of your growth and development.

Phylogeny: History of who you evolved from.

Heterochrony:

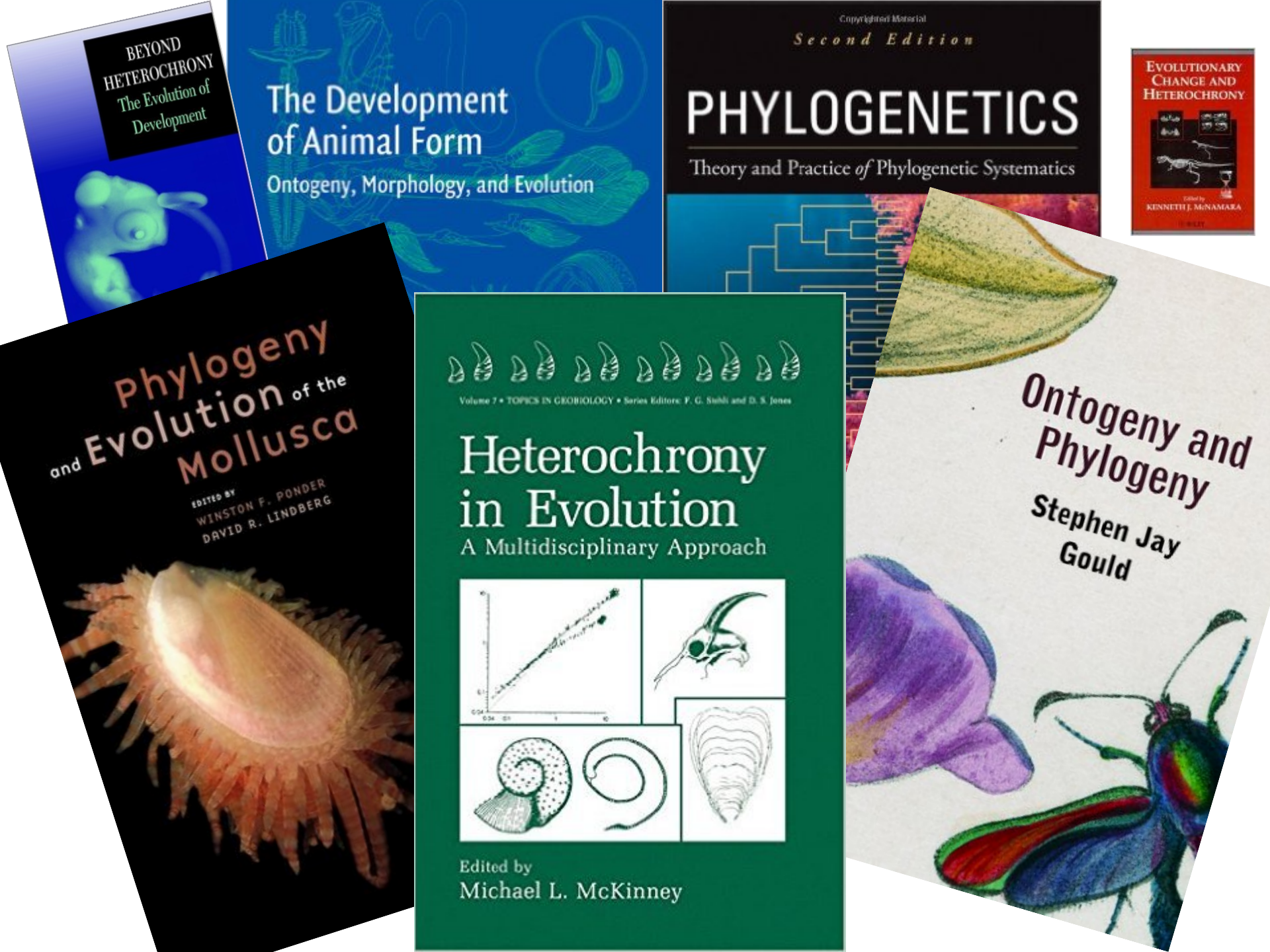
How to think about today's subjects

Ontogeny: History of your growth and development.

Phylogeny: History of who you evolved from.

Heterochrony: How that developmental sequence changed over evolutionary time.

One caveat…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The Evolution of Development
The Development of Animal Form
Ontogeny, Morphology, and Evolution
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Second Edition
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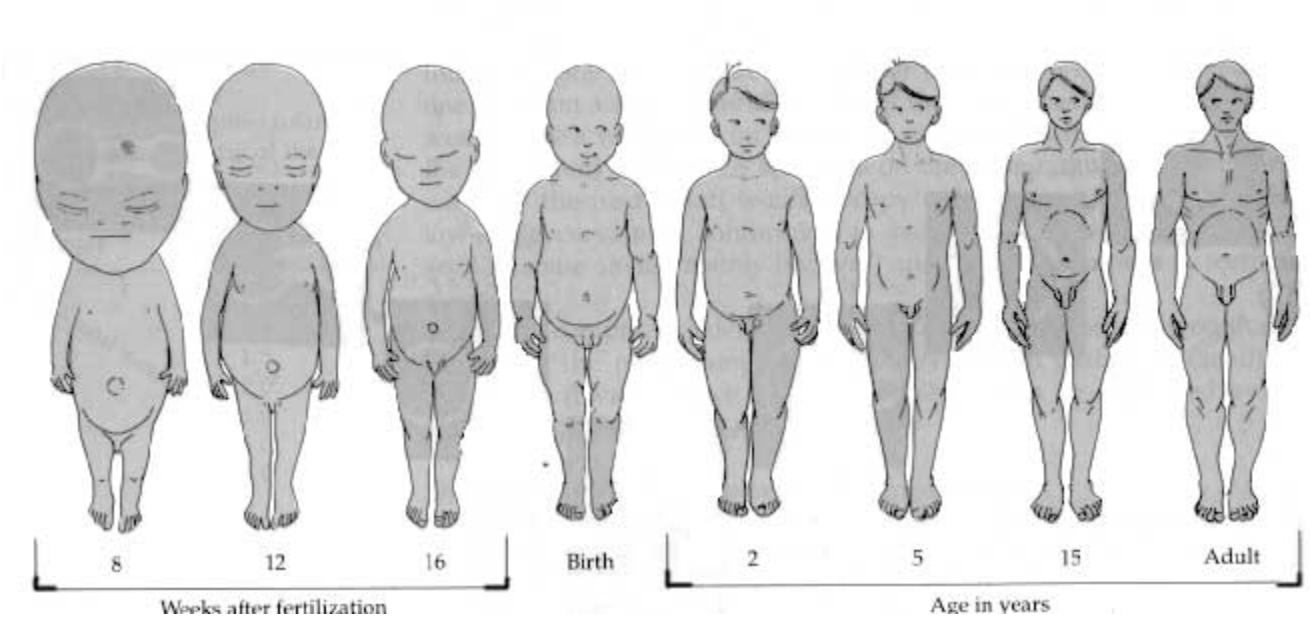
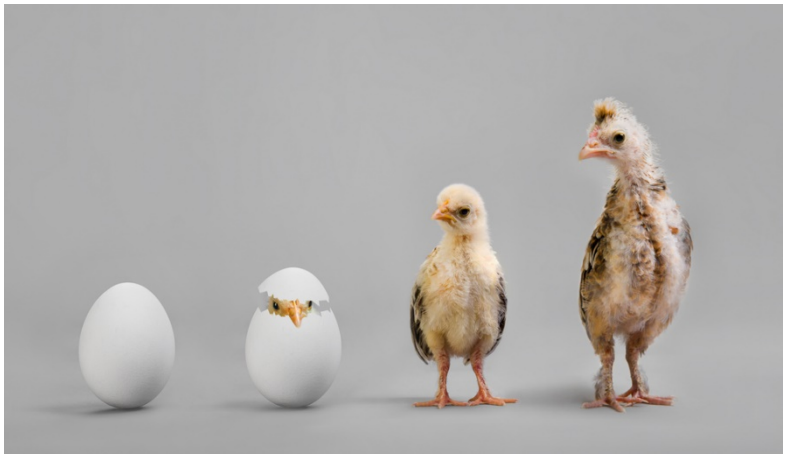
Ontogeny and Phylogeny
Stephen Jay Gould

Ontogeny

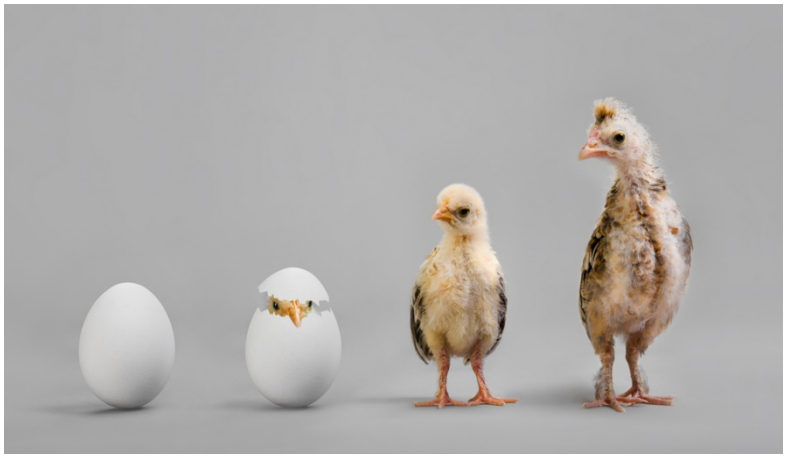
Ontogeny

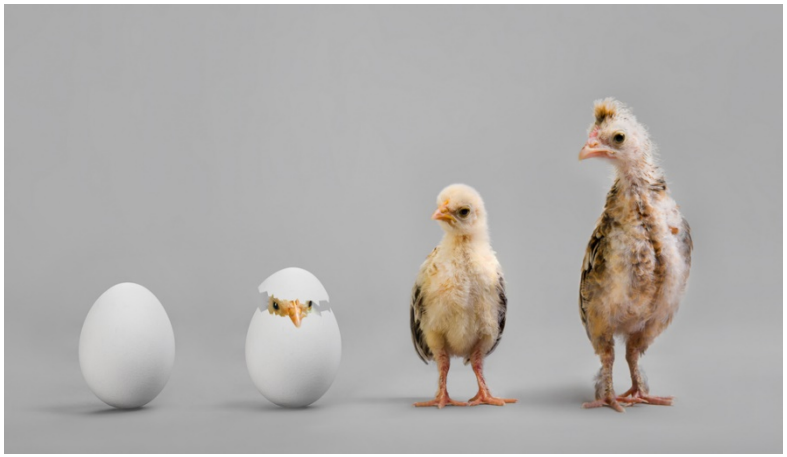
The sequence of stages an organism goes through from conception to maturity





And sometimes the entire lifespan of the organism





Ontogeny

Refers to genetically mediated changes, *not* "epi-genetic" changes.

One day old
Newly born kittens cannot see and have very little control over their body movements.

Ten days old
A kitten's eyes usually open at about ten days.

Three weeks old
The kitten will start to experiment with solid food at this age.

Five weeks old
By now the kitten will be able to run and balance well.

Eight weeks old
The kitten will have learnt how to socialize with his siblings, and other pets in the household.

Fourteen weeks old
The kitten's motor skills have improved, his ability to balance is at its peak.

Five months old
Sexual maturity may be reached from this age, though it does vary from cat to cat.

Adult cat
Full size and maturity are reached at about one year of age.

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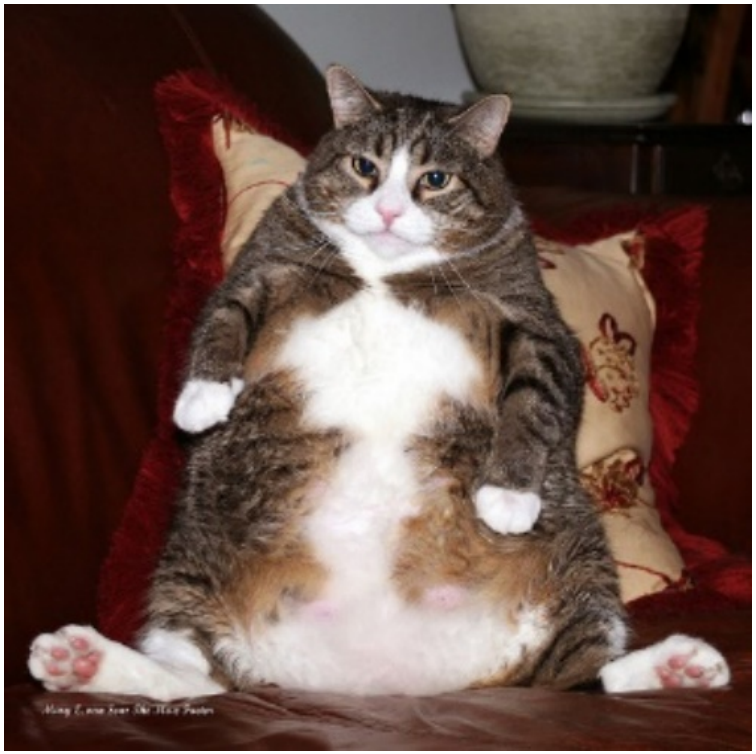
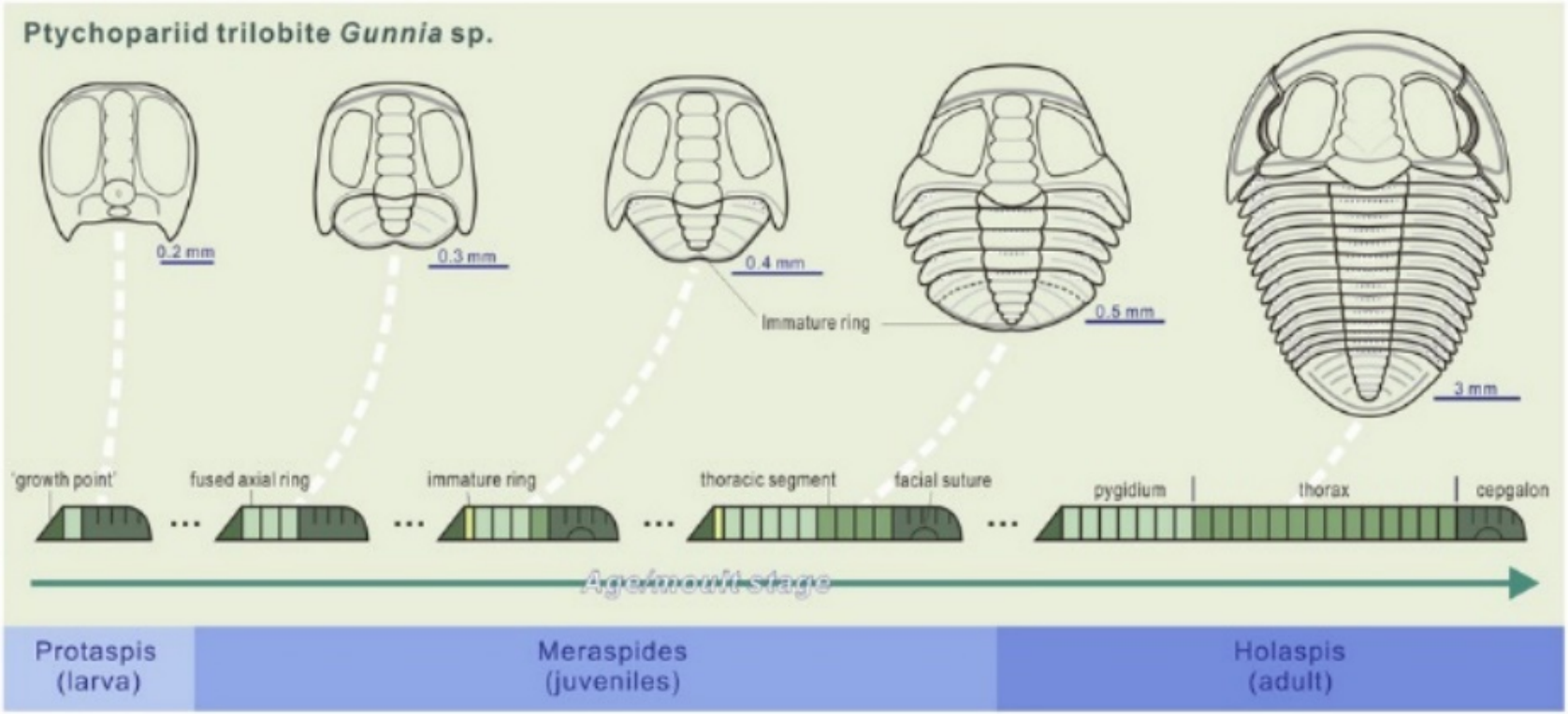
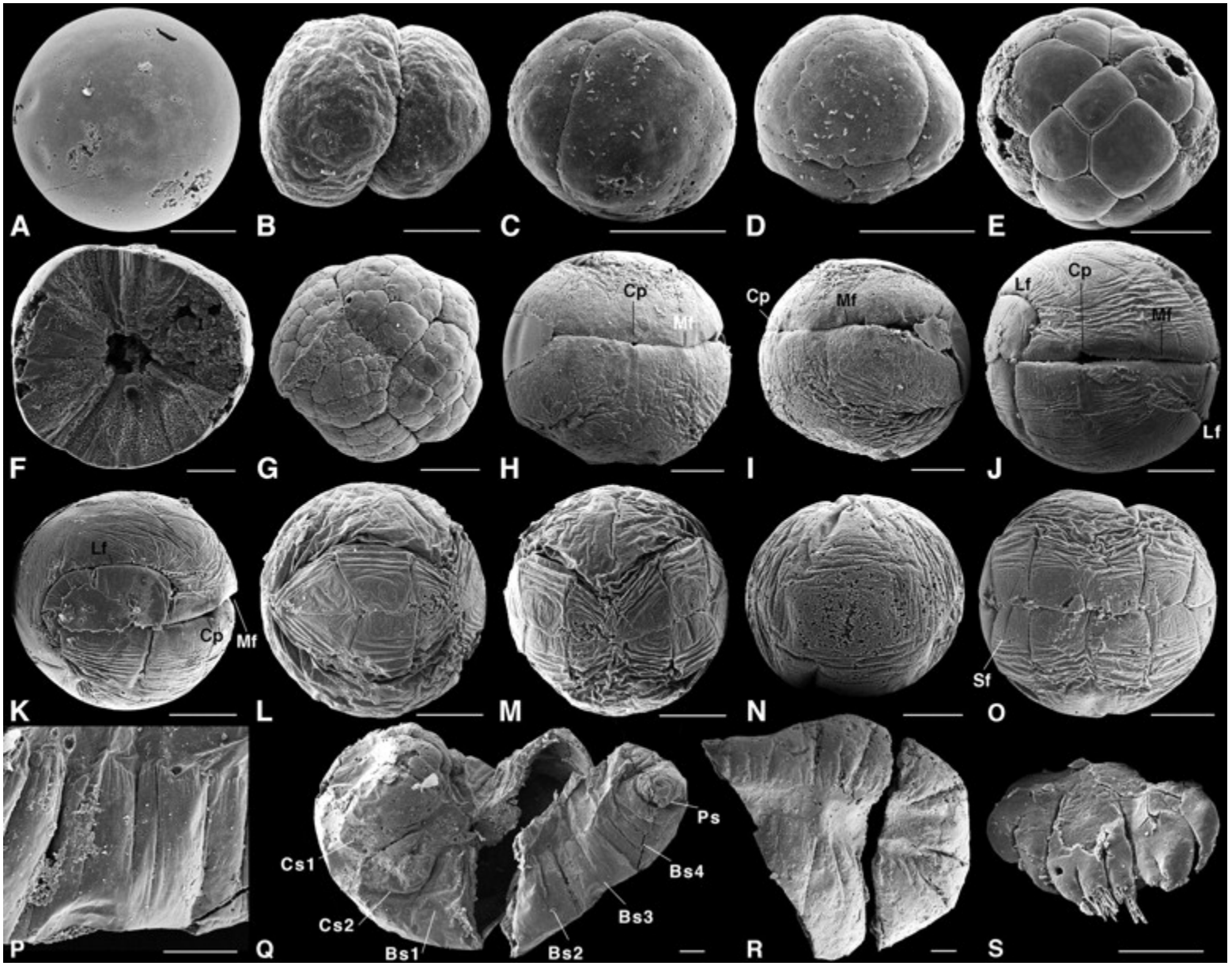


Ontogeny – Let's apply it to paleobiology

Ontogeny – Let's apply it to paleobiology

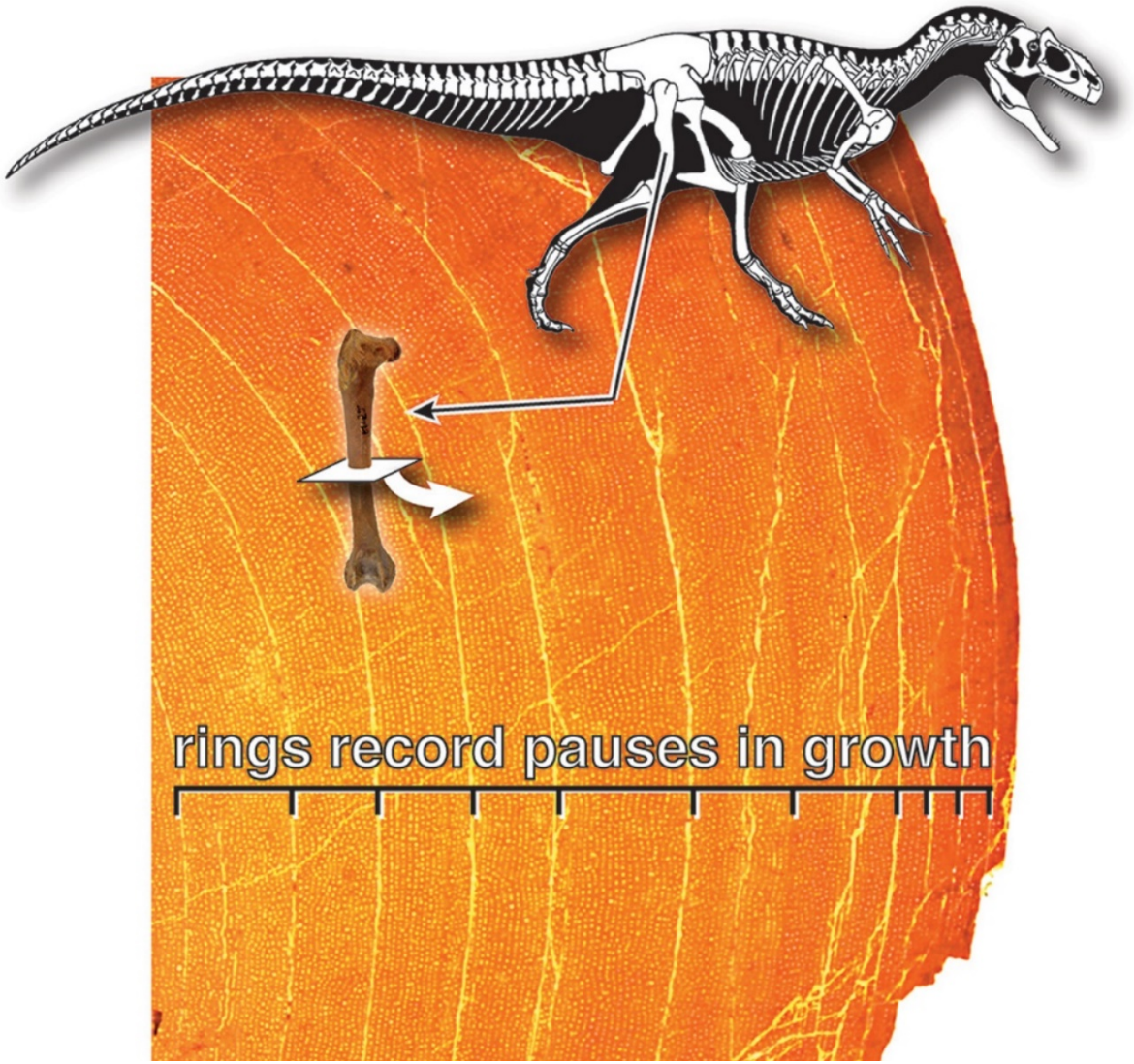
We (often) have to use morphology



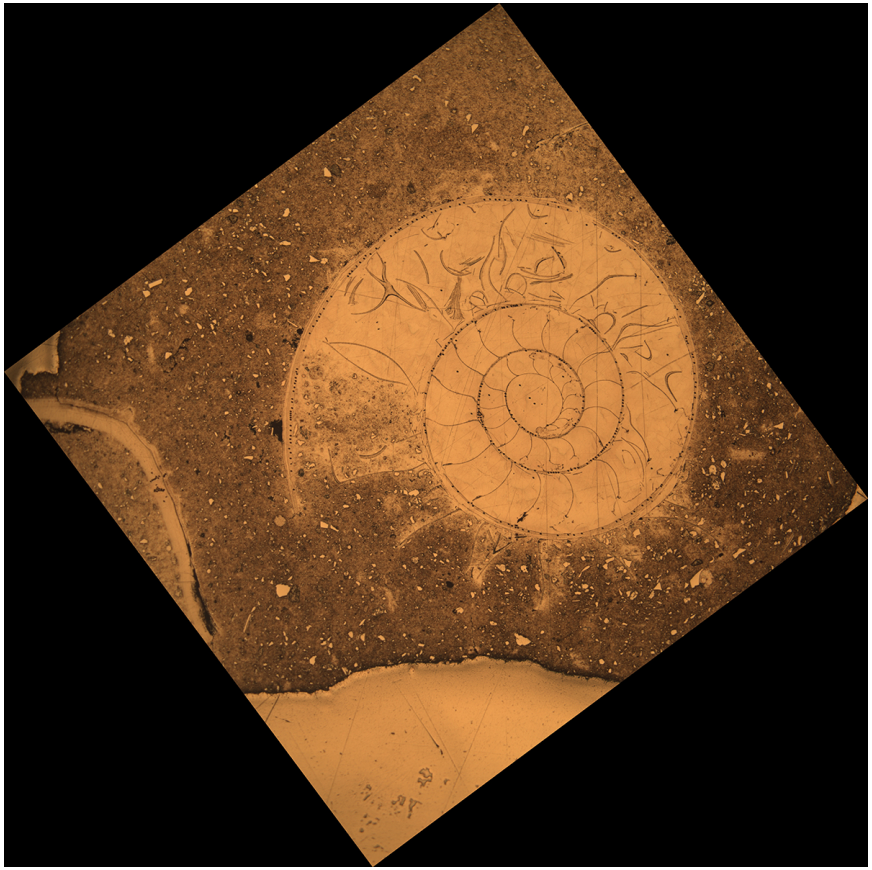


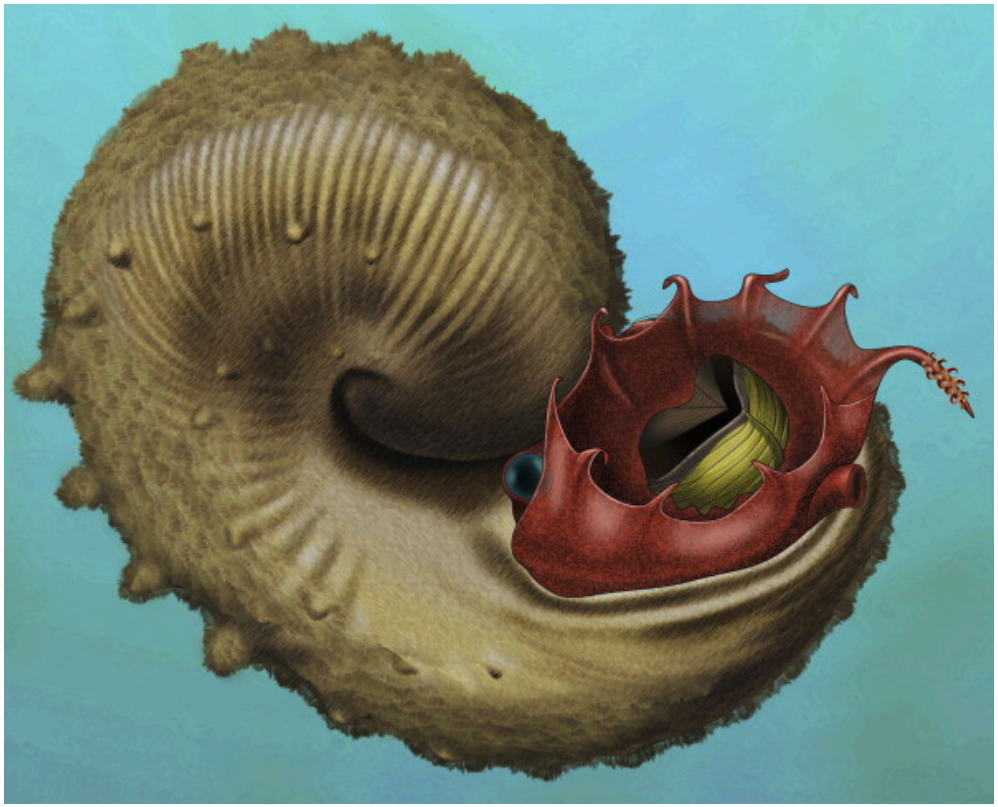
Precambrian Doushantuo Formation

We also can study tissue development



And we can infer ontogeny from geochemistry





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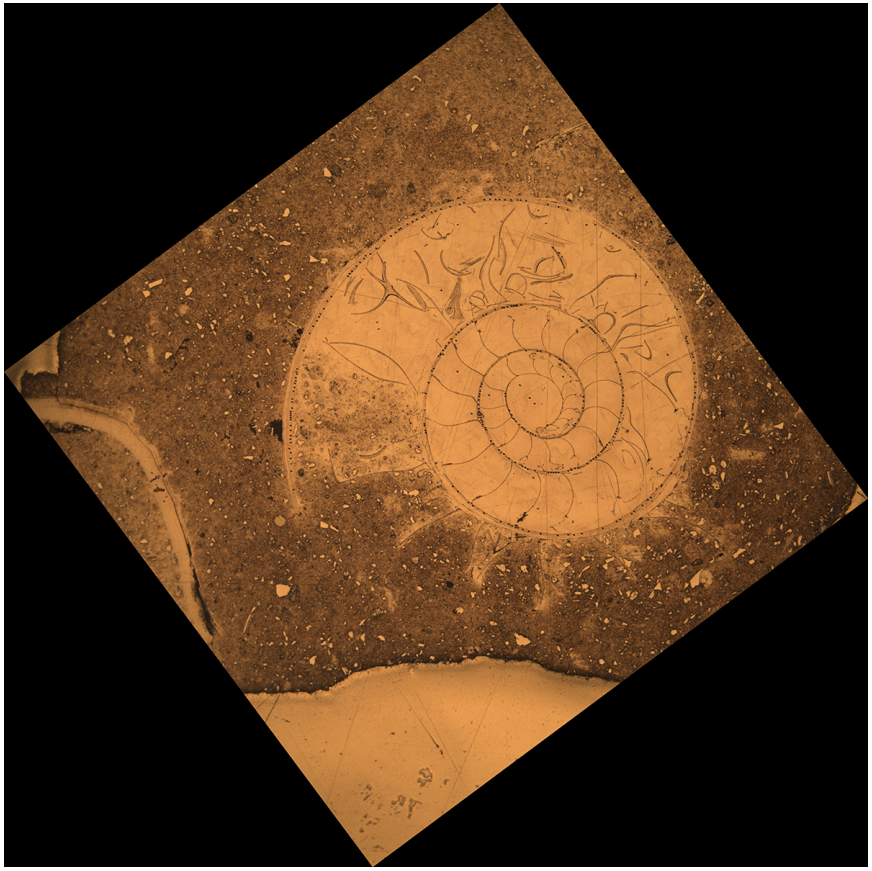
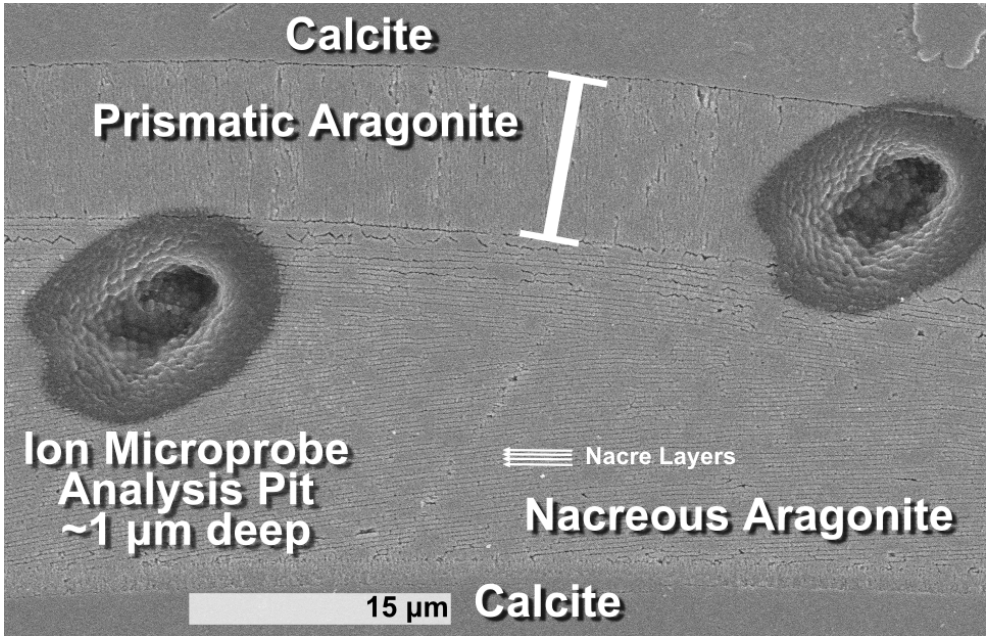
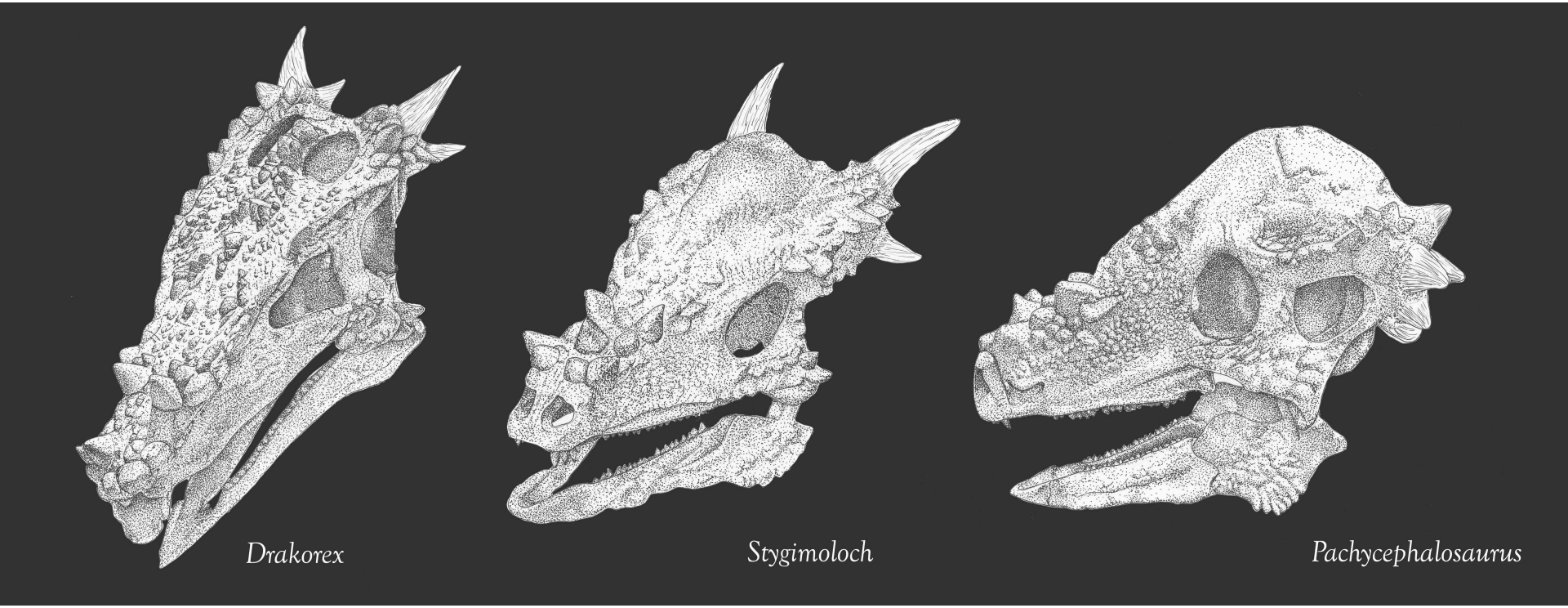


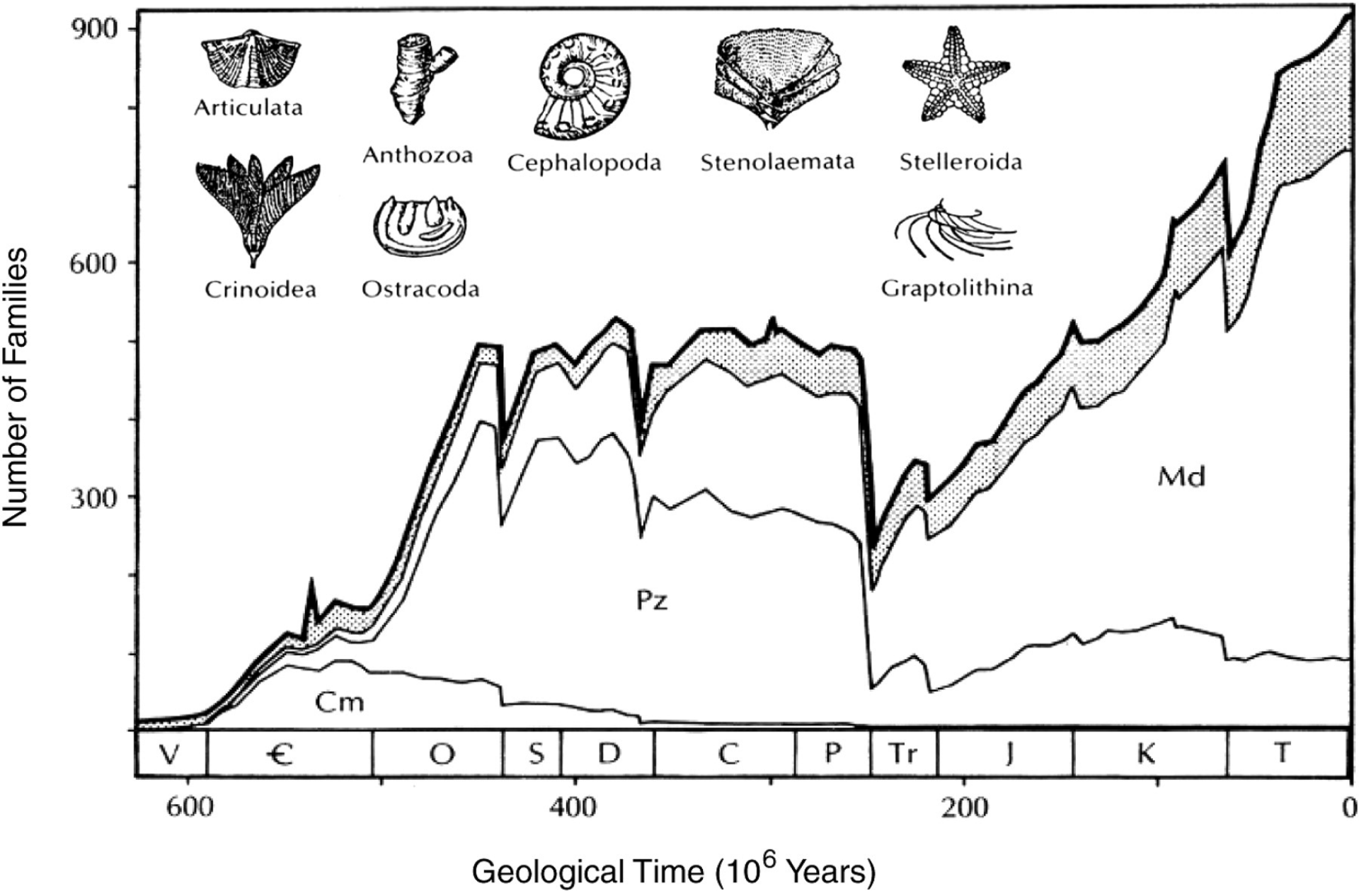


Broader paleobiology implications:

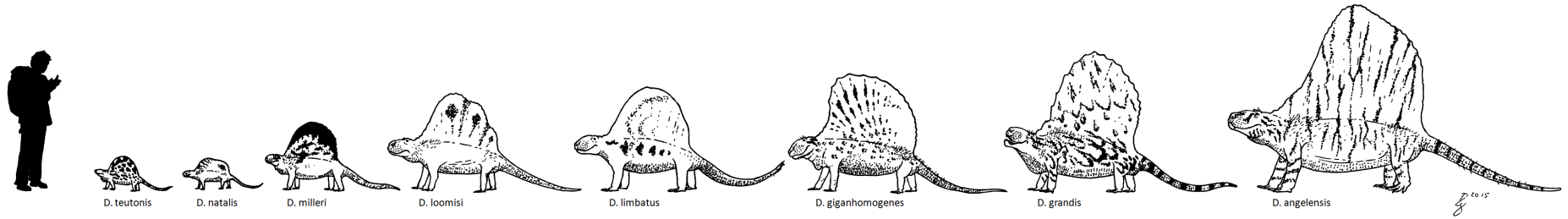


Broader paleobiology implications:

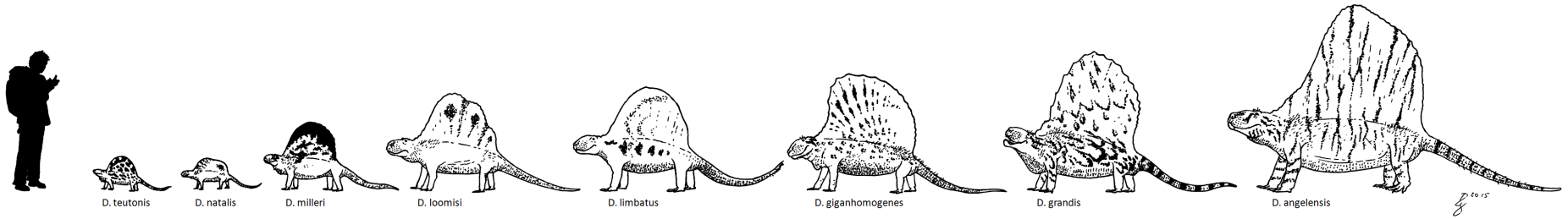

natgeotv.com

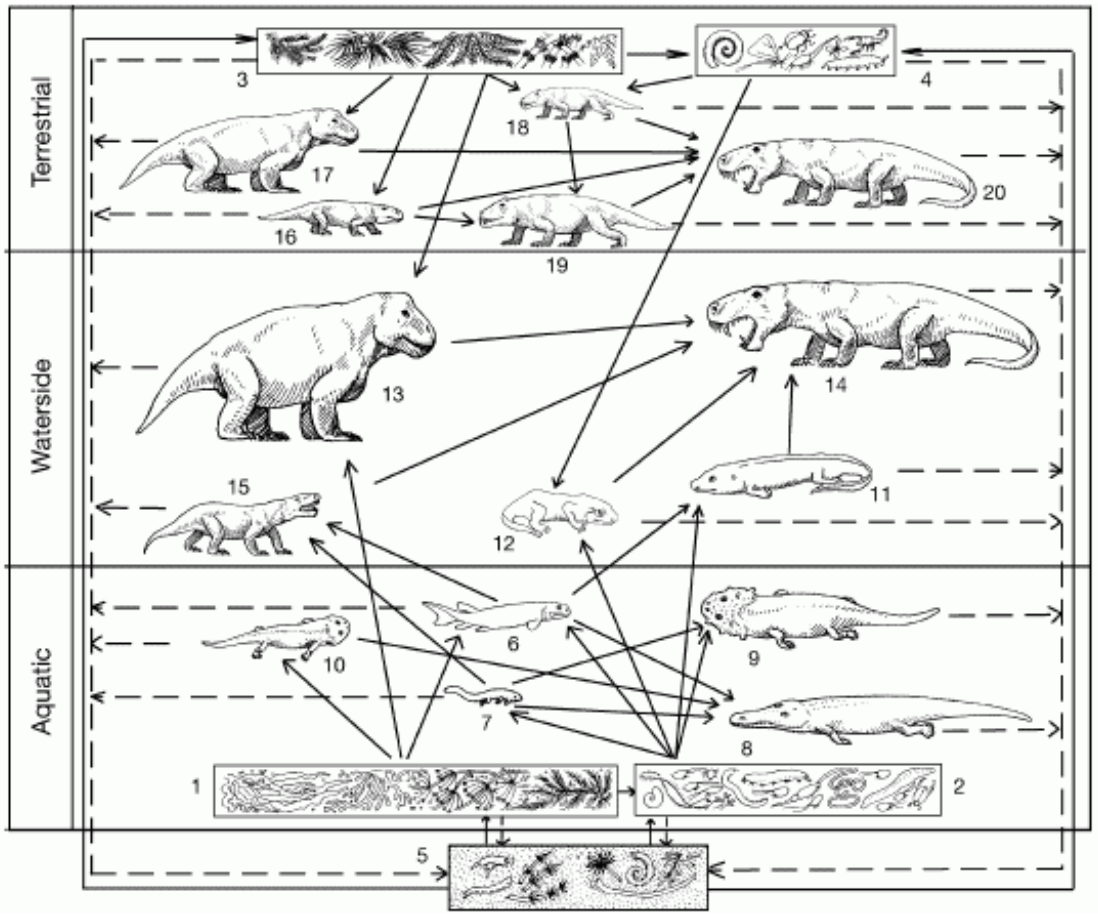

900
600
300
Number of Families
Articulata
Anthozoa
Cephalopoda
Stenolaemata
Stelleroida
Crinoidea
Ostracoda
Graptolithina
Md
Pz
Cm
V
€
O
S
D
C
P
Tr
J
K
T
600
400
200
0
Geological Time (10^6 Years)

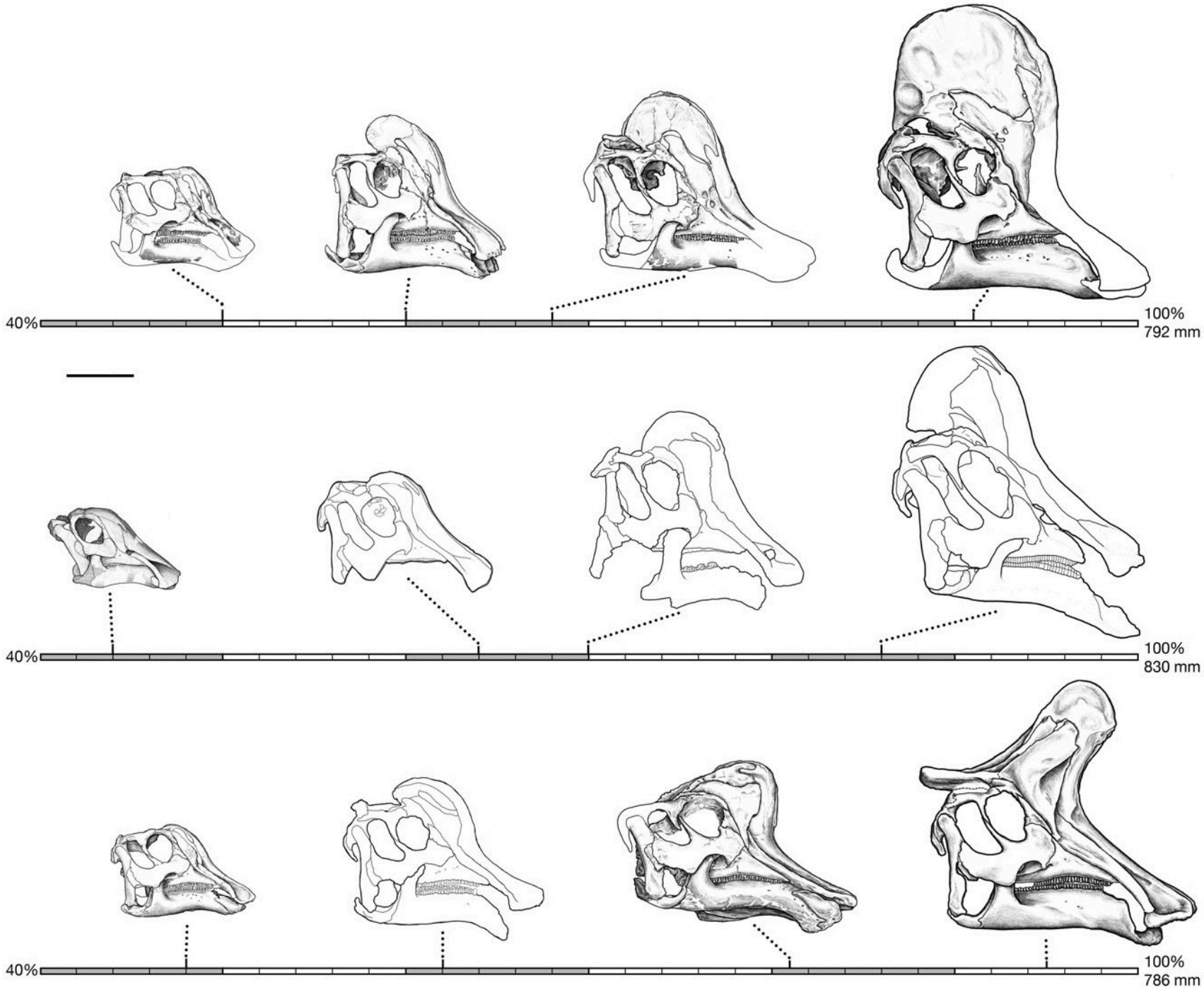
Dimetrodon sp.



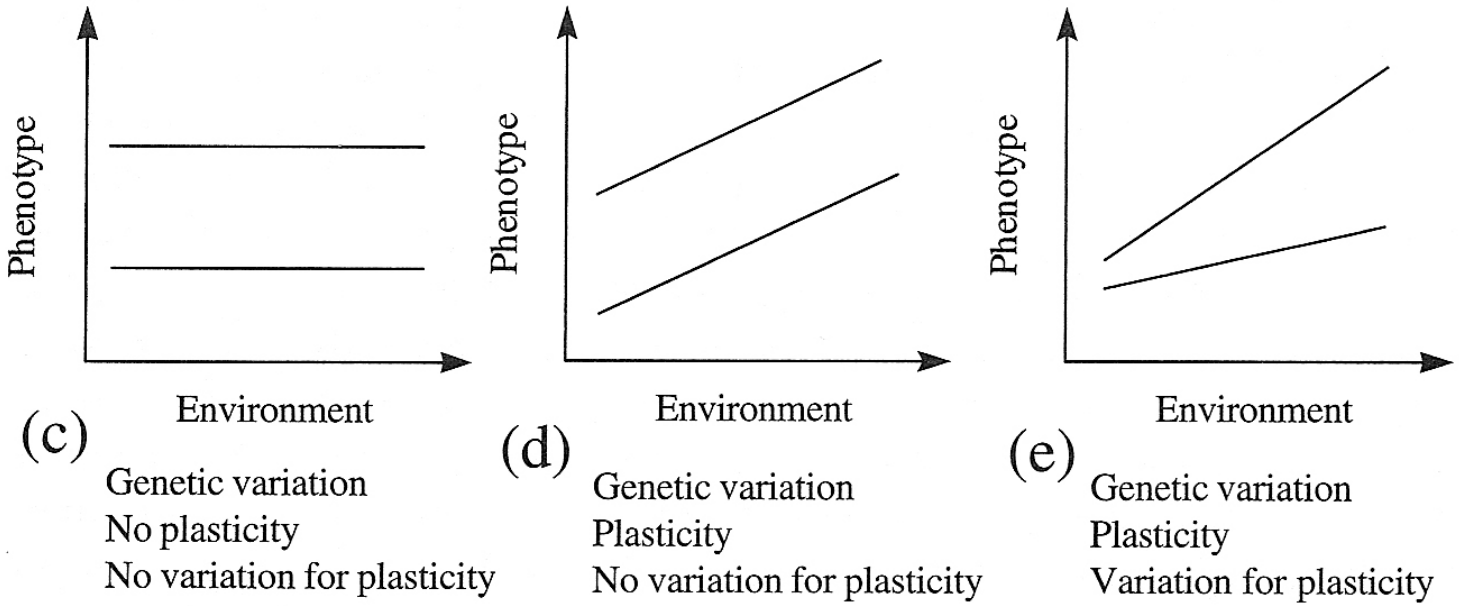
Dimetrodon sp.

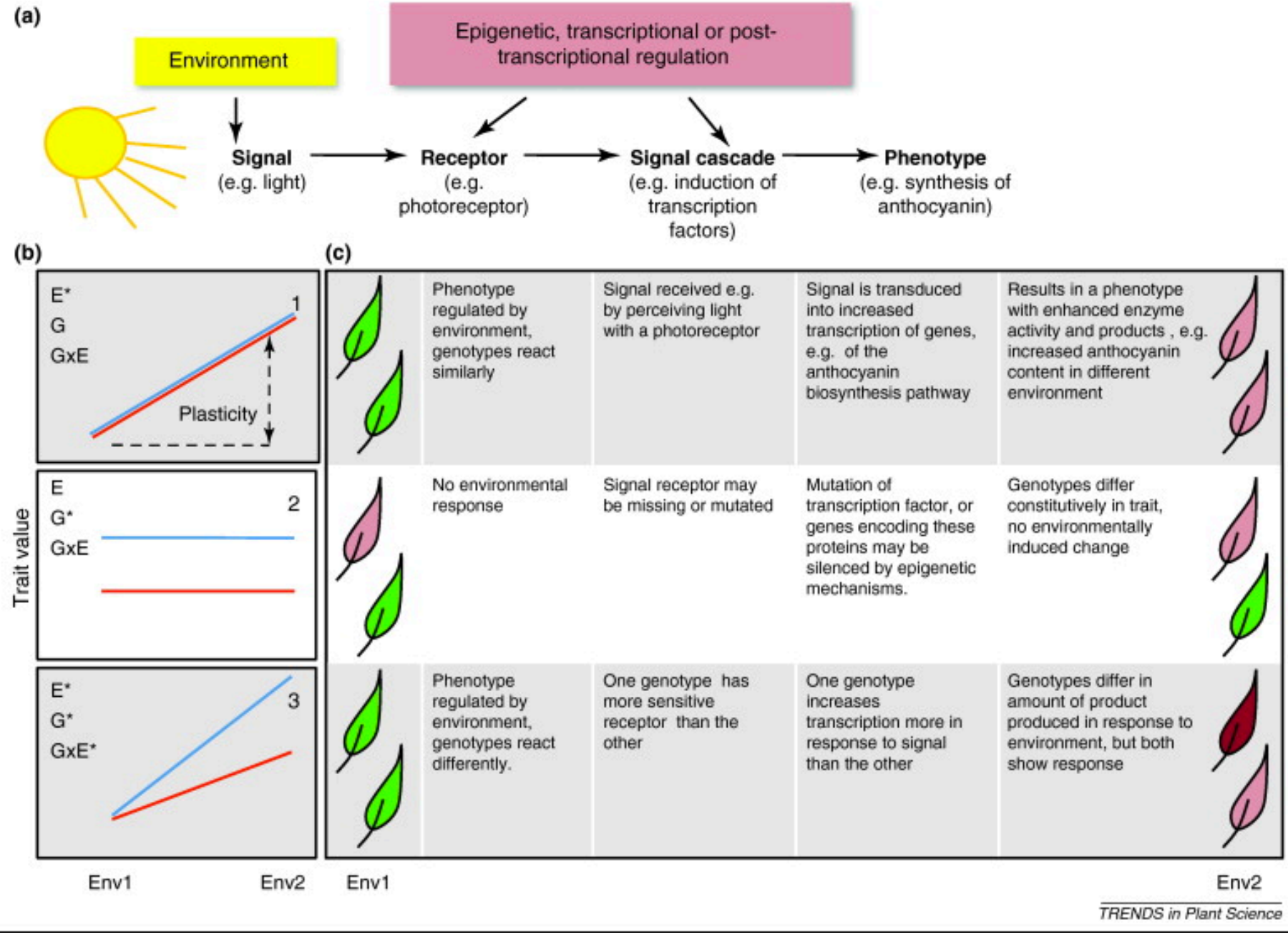





40%
100%
792 mm
40%
100%
830 mm
40%
100%
786 mm

A special case – phenotypic plasticity




(a)
Environment
Epigenetic, transcriptional or post-transcriptional regulation
Signal
(e.g. light)
Receptor
(e.g. photoreceptor)
Signal cascade
(e.g. induction of transcription factors)
Phenotype
(e.g. synthesis of anthocyanin)
(b)
(c)
E*
G
GxE
1
Plasticity
E
G*
GxE
2
E*
G*
GxE*
3
Trait value
Phenotype regulated by environment, genotypes react similarly
Signal received e.g. by perceiving light with a photoreceptor
Signal is transduced into increased transcription of genes, e.g. of the anthocyanin biosynthesis pathway
Results in a phenotype with enhanced enzyme activity and products , e.g. increased anthocyanin content in different environment
No environmental response
Signal receptor may be missing or mutated
Mutation of transcription factor, or genes encoding these proteins may be silenced by epigenetic mechanisms.
Genotypes differ constitutively in trait, no environmentally induced change
Phenotype regulated by environment, genotypes react differently.
One genotype has more sensitive receptor than the other
One genotype increases transcription more in response to signal than the other
Genotypes differ in amount of product produced in response to environment, but both show response
Env1
Env2
Env1
Env2
TRENDS in Plant Science

Ontogeny Recap:

Ontogeny – the stages an organism goes through from conception to maturity (or beyond)

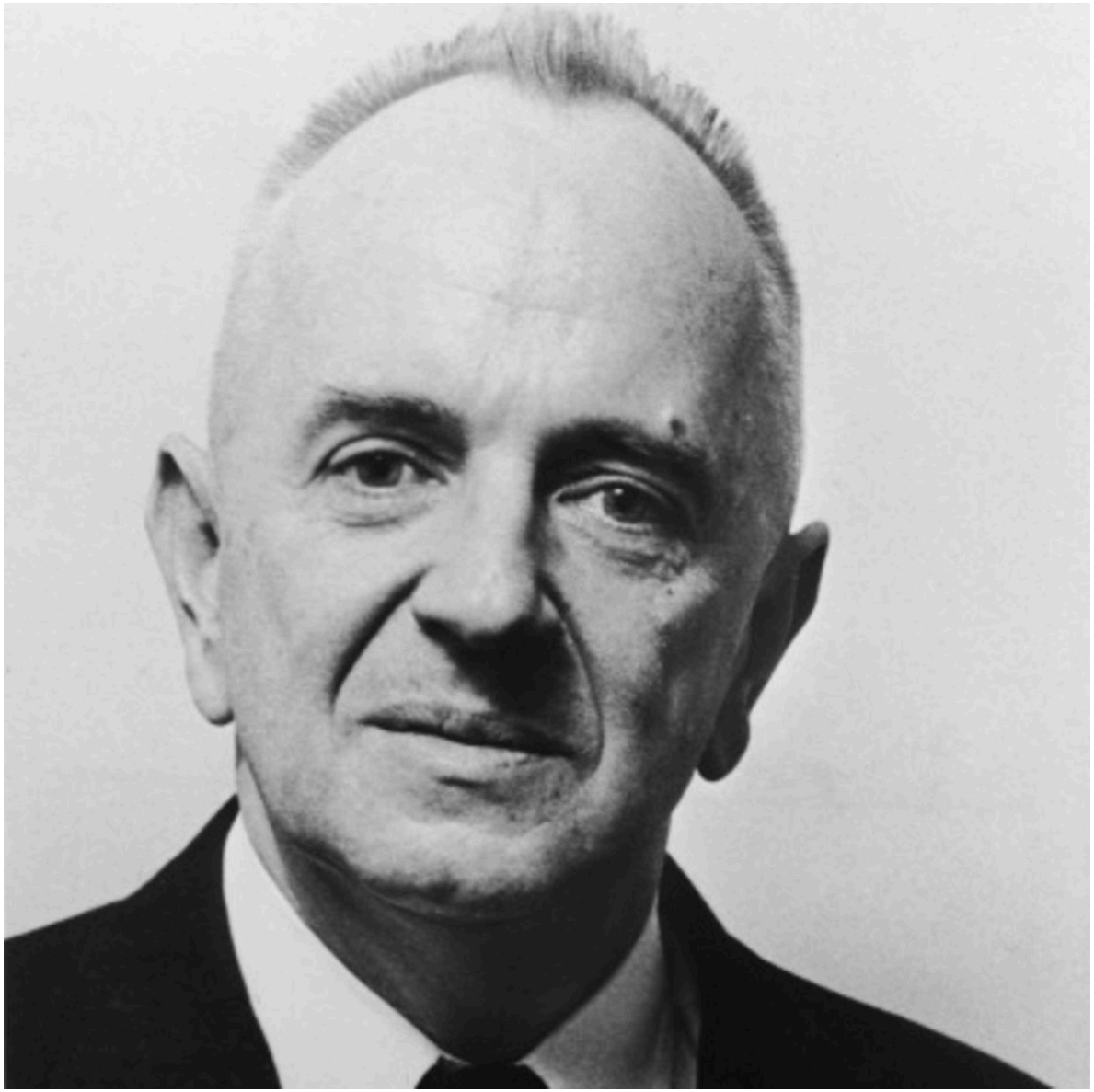
At times neglected by paleontologists, it has major implications for taxonomy, diversity, niche partitioning & paleo foodwebs, and patterns of extinction.

Phylogeny

Phylogeny

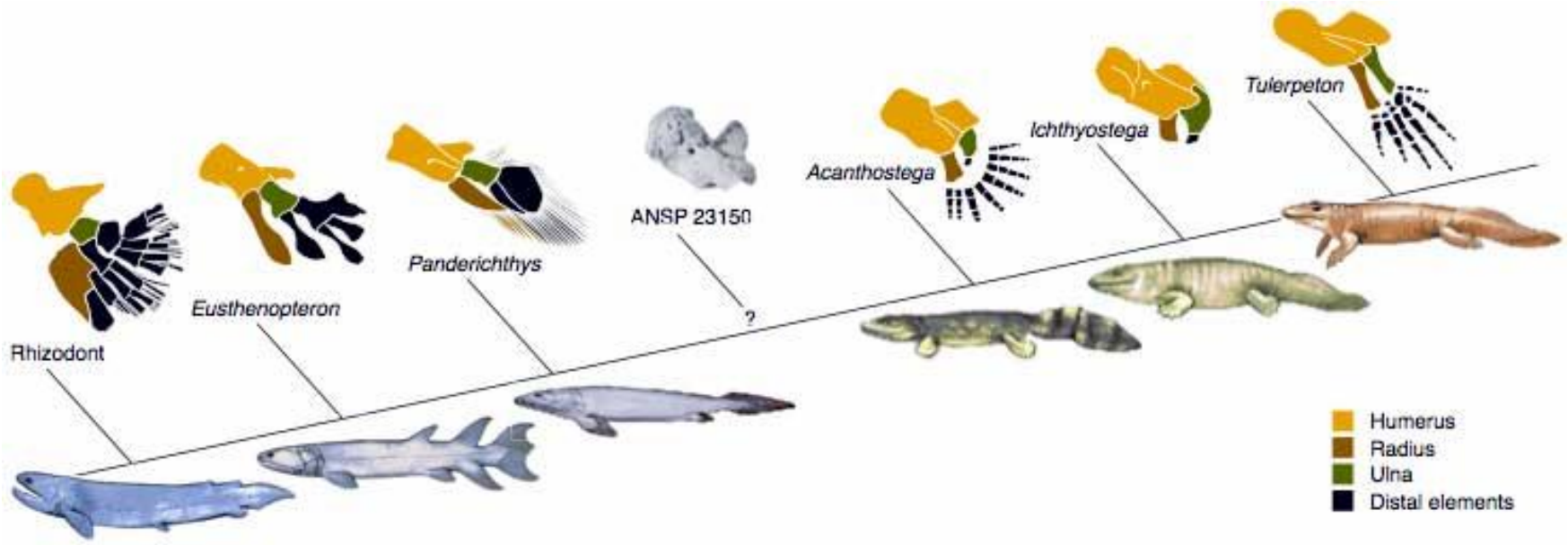
Who is related to whom?

"Nothing in biology makes sense except in the light of evolution"

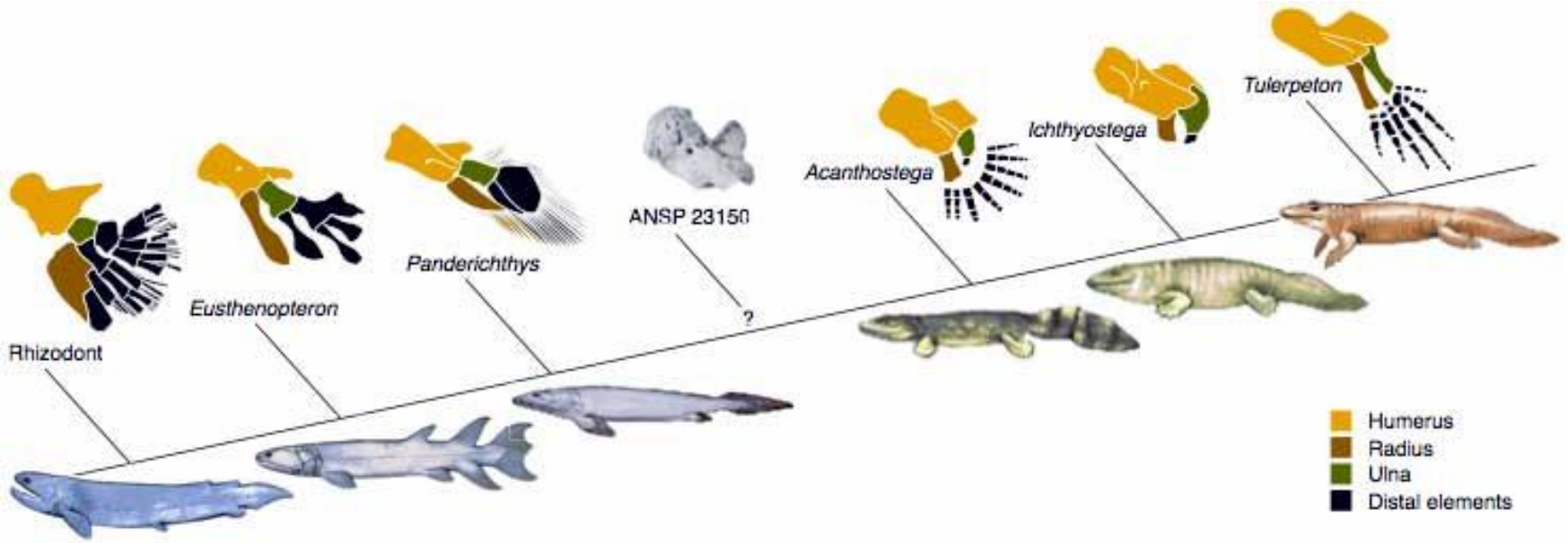


Theodosius Dobzhansky

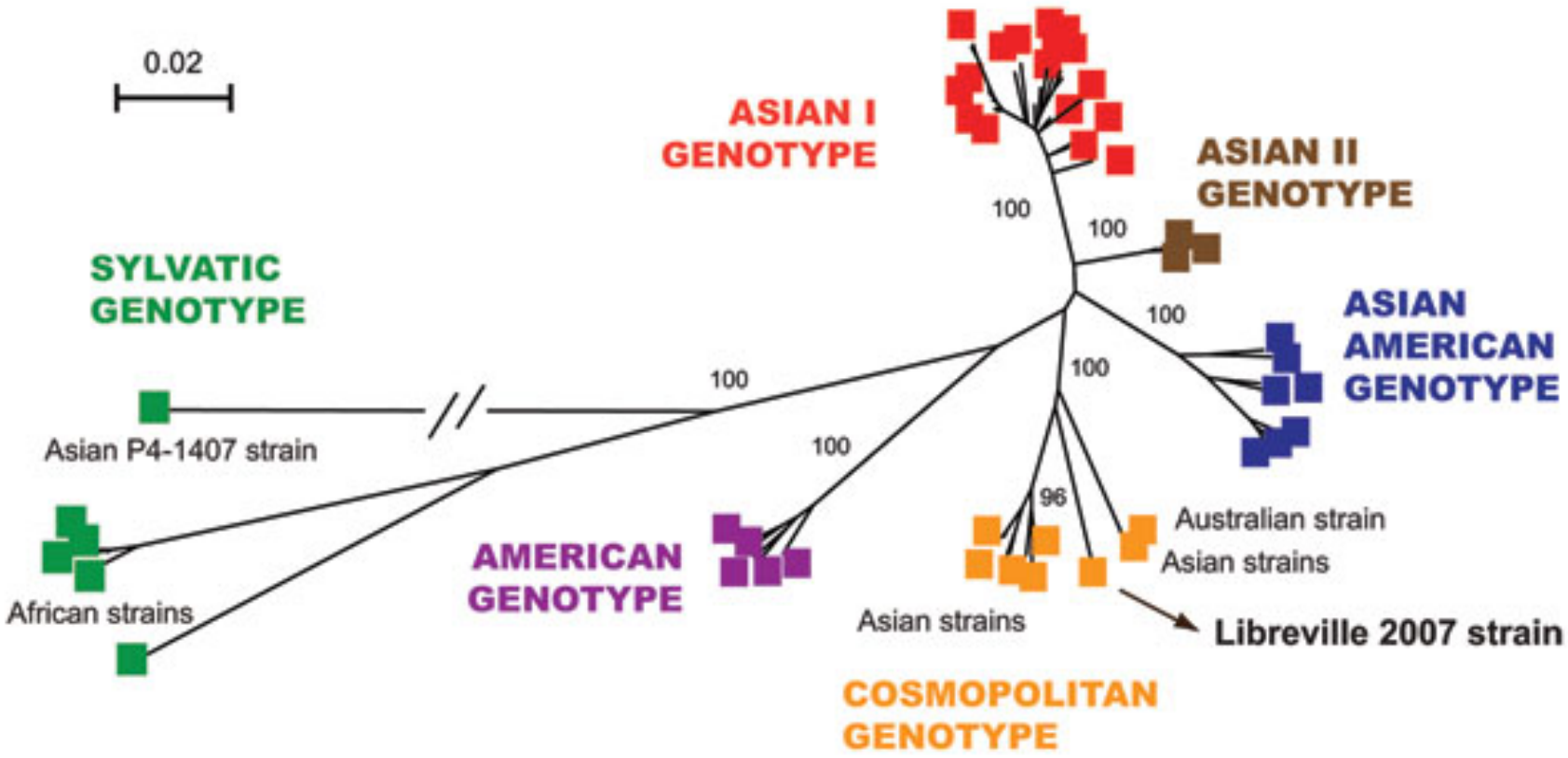
Origin of tetrapods



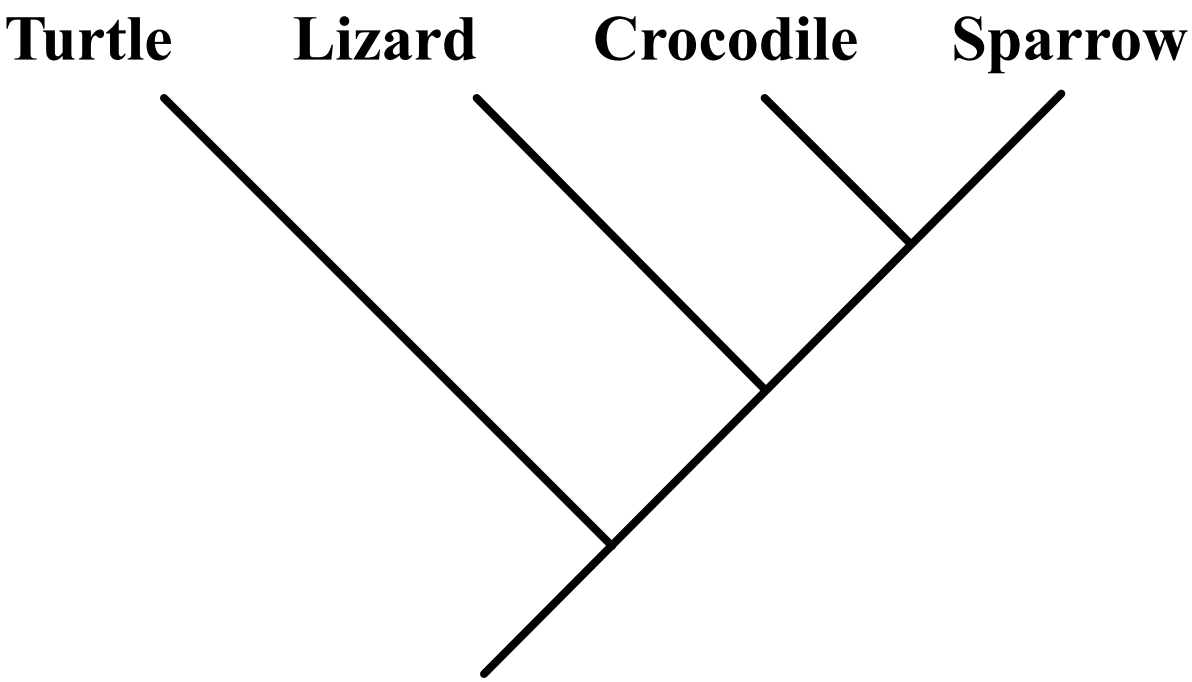
Phylogeny is not just an esoteric interest



Dengue 2 (DENV-2) Viral Relationships



So…how do we read these things?



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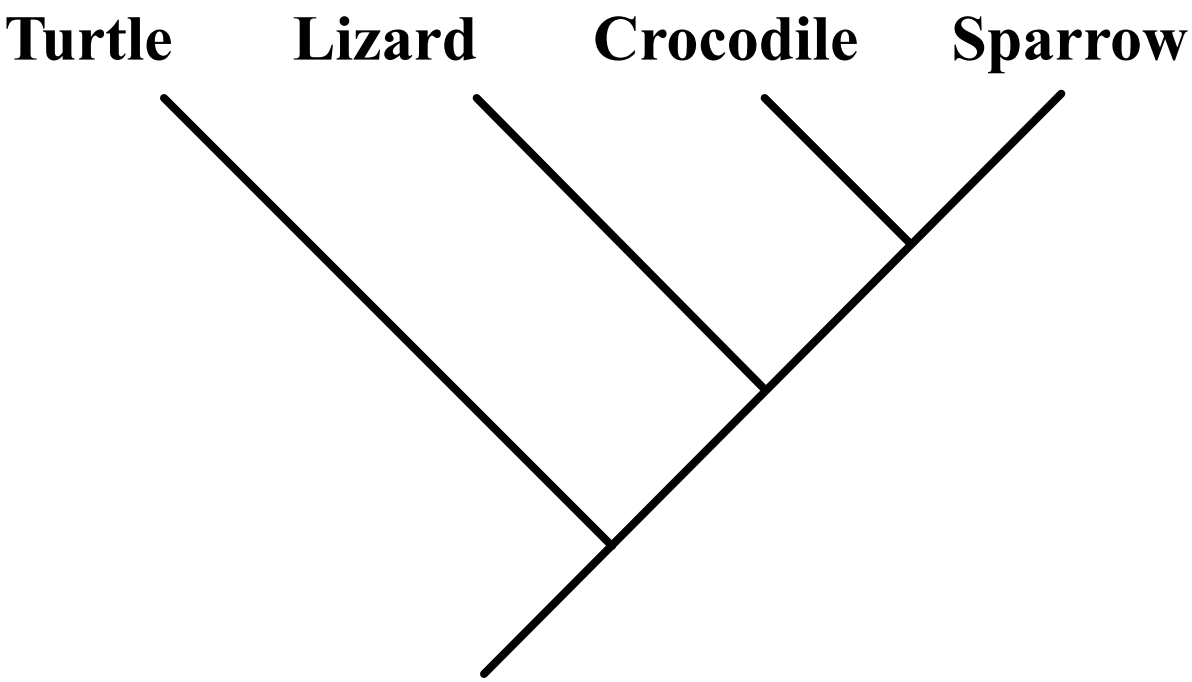
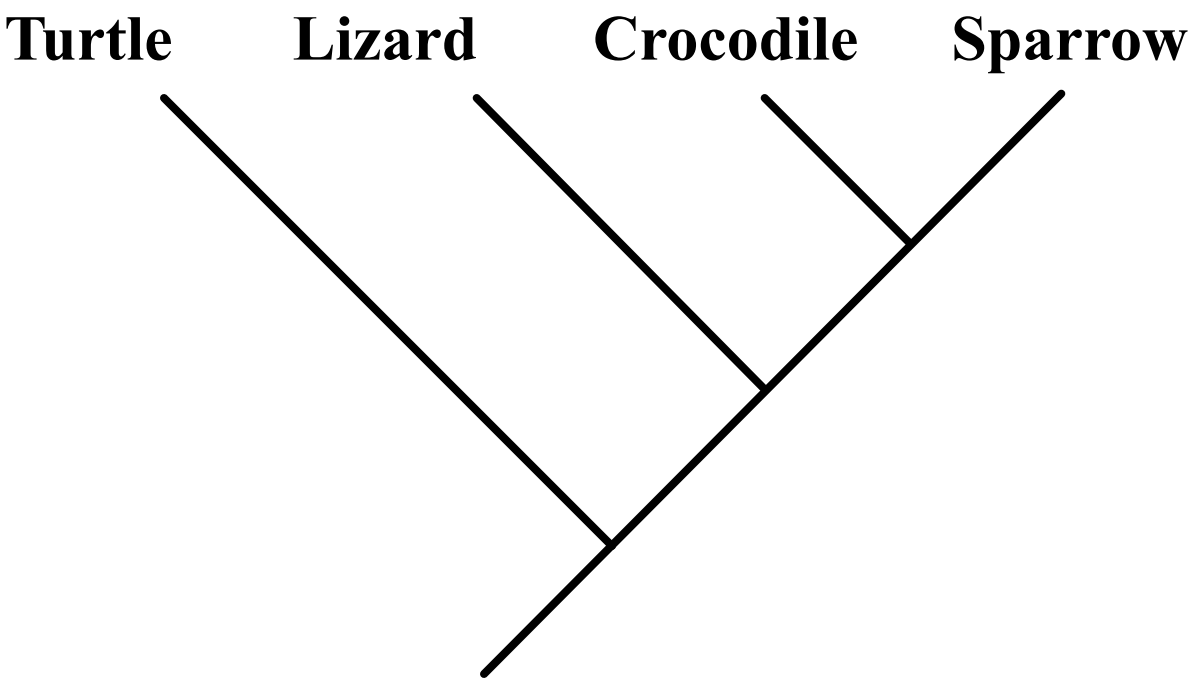


Is a crocodile more closely related to a lizard or a sparrow?

All that matters is the branching pattern.



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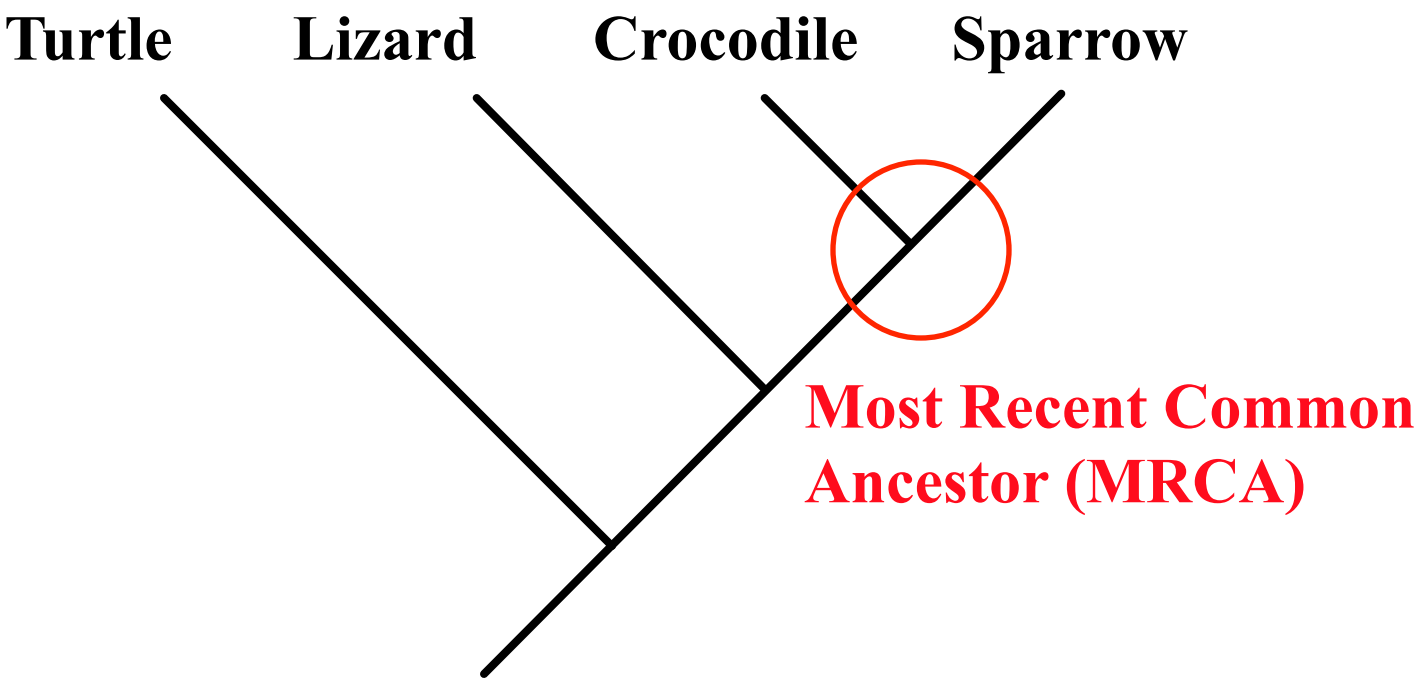
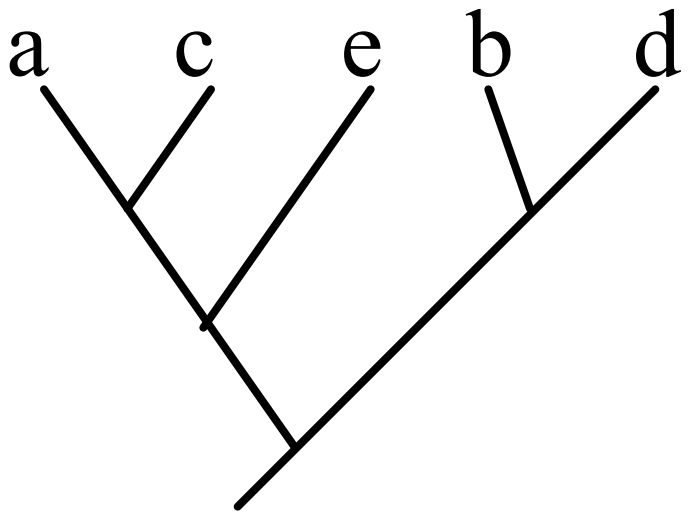
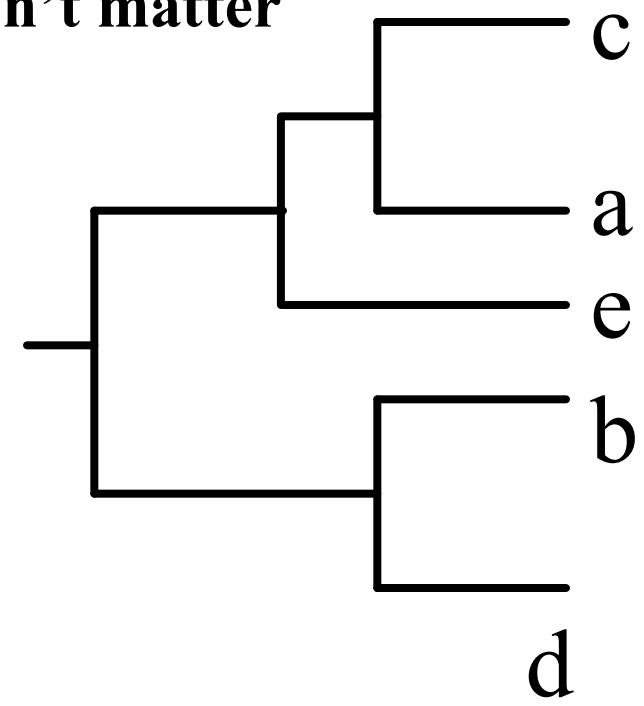


Is a crocodile more closely related to a lizard or a sparrow?

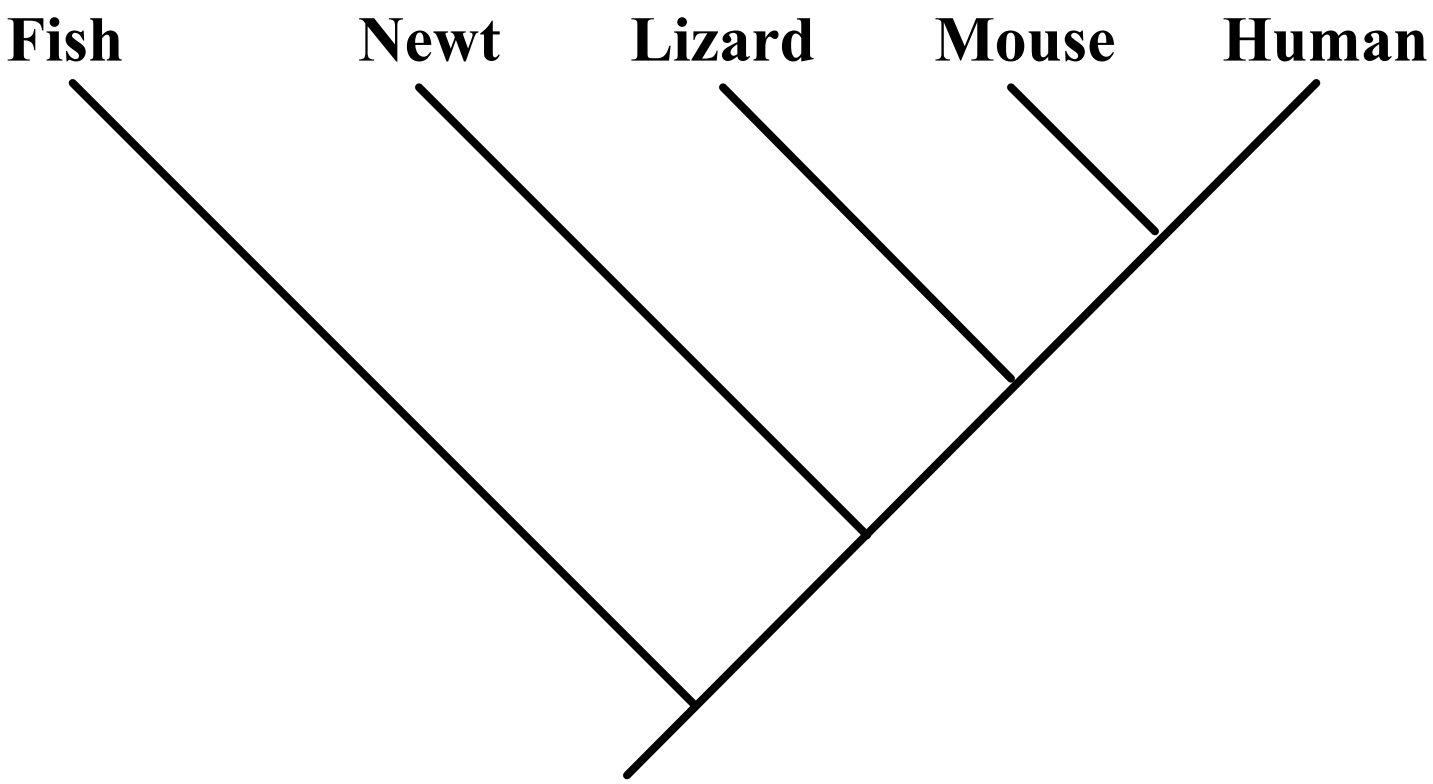
Are these trees the same?

The shape of the tree doesn't matter



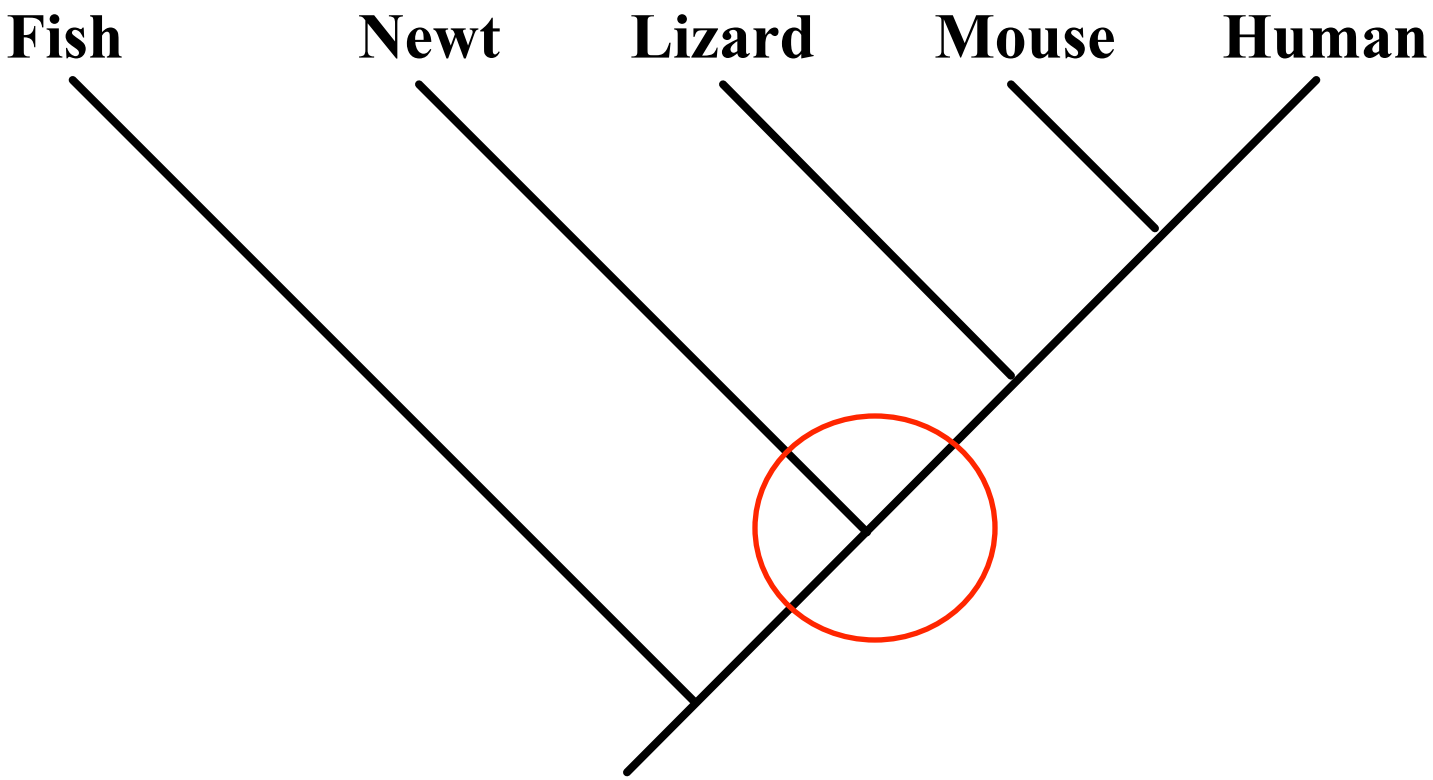


Is a newt more closely related to a lizard or a human?

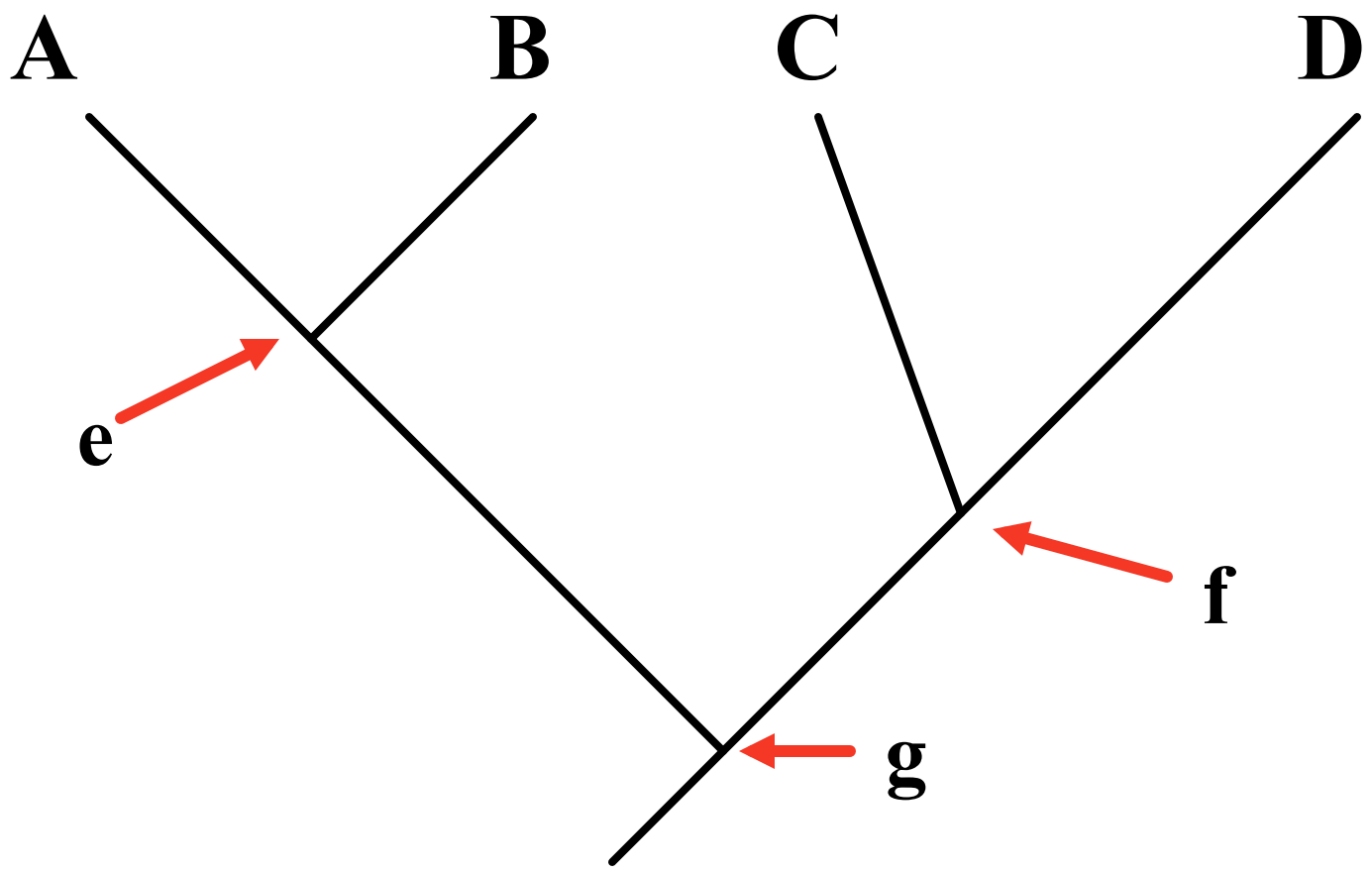


Is a newt more closely related to a lizard or a human?

The newt shares the same MRCA with the lizard and human.



Unless stated otherwise, assume that absolute time is NOT represented

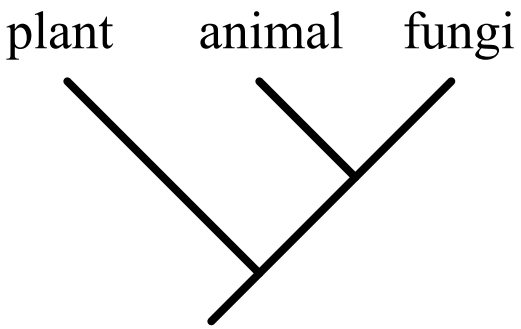


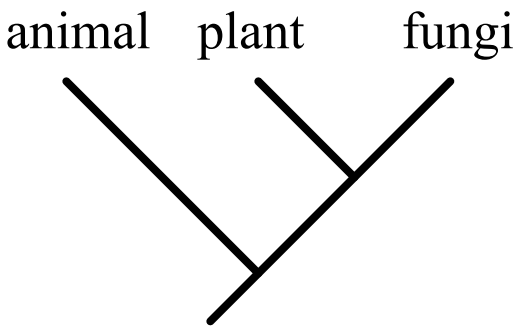
Was e before or after g?

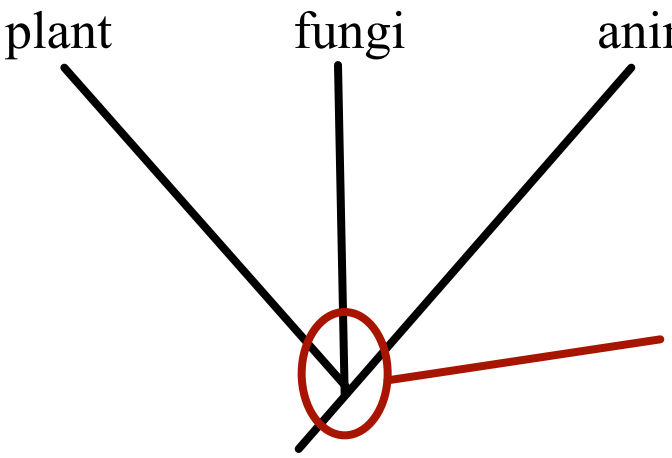
Was e before or after f?

Polytomies:

Maybe we are unsure which of these is true:

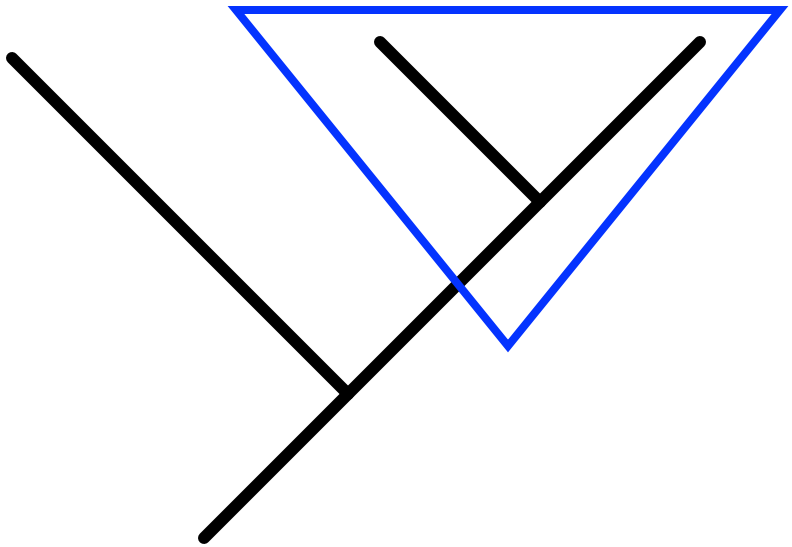




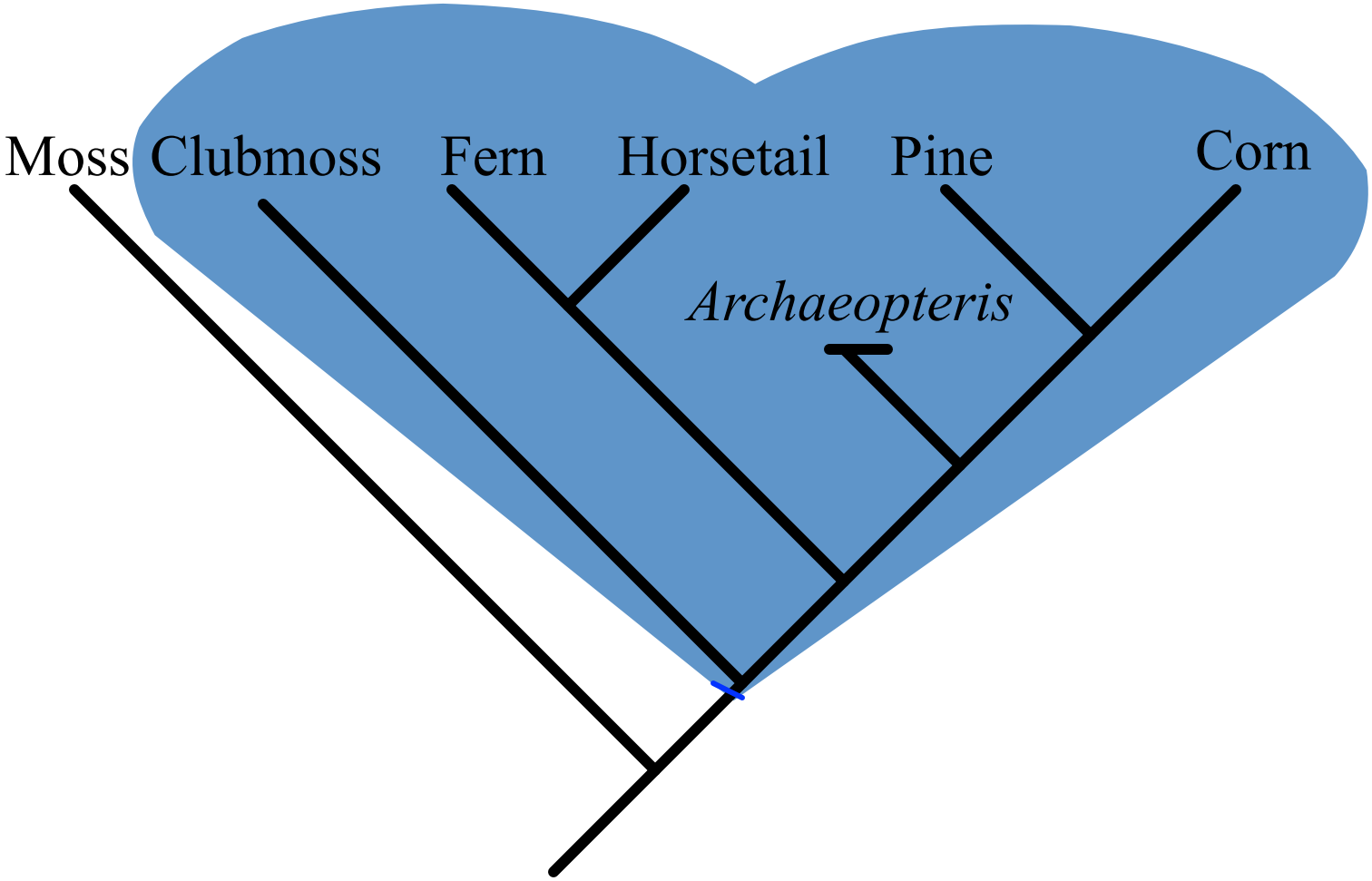


A polytomy indicates we do not know how these three lineages relate to each other

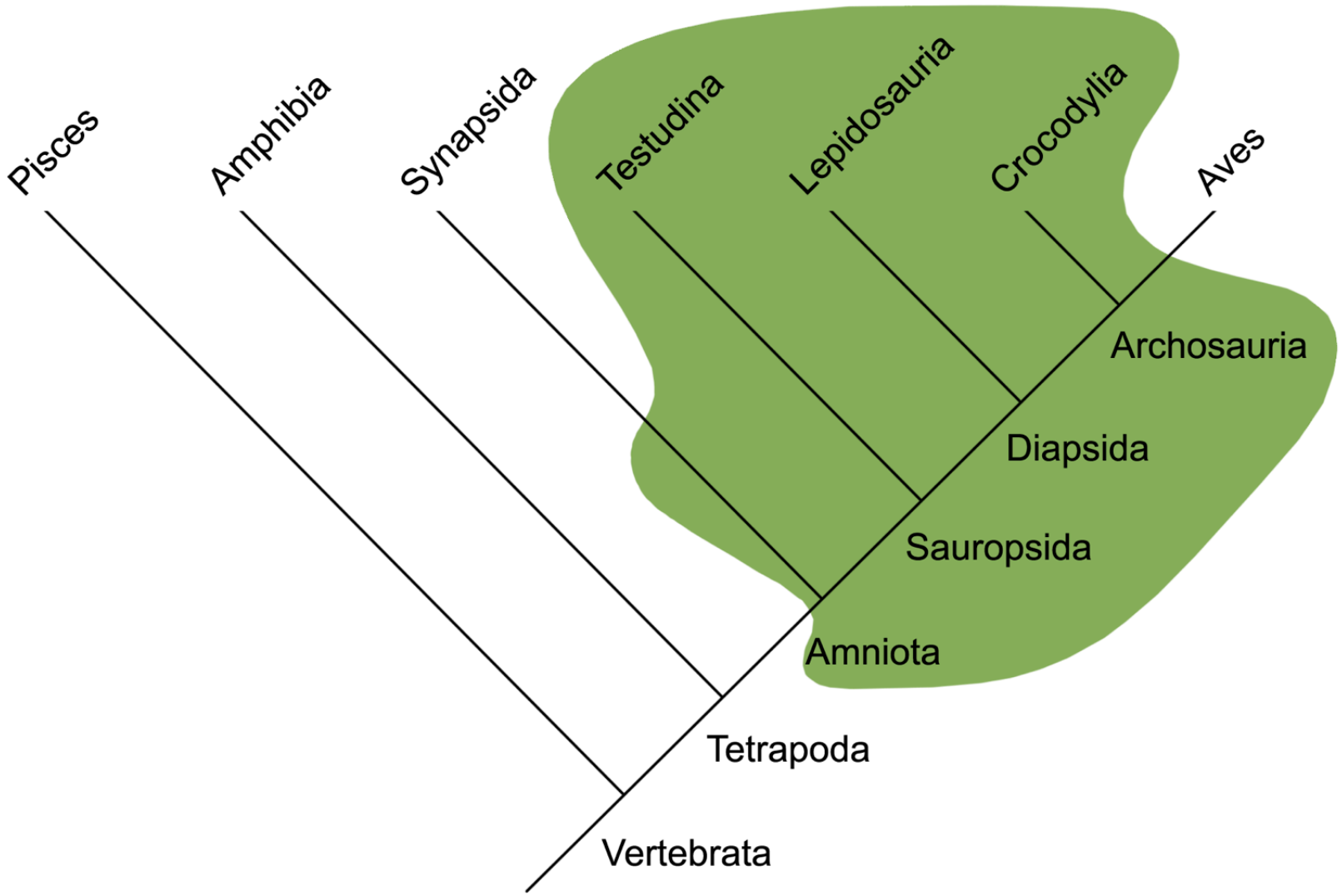
Monophyletic group (clade)



A monophyletic clade is the basic unit of classification.



Sometimes monophyly messes with us



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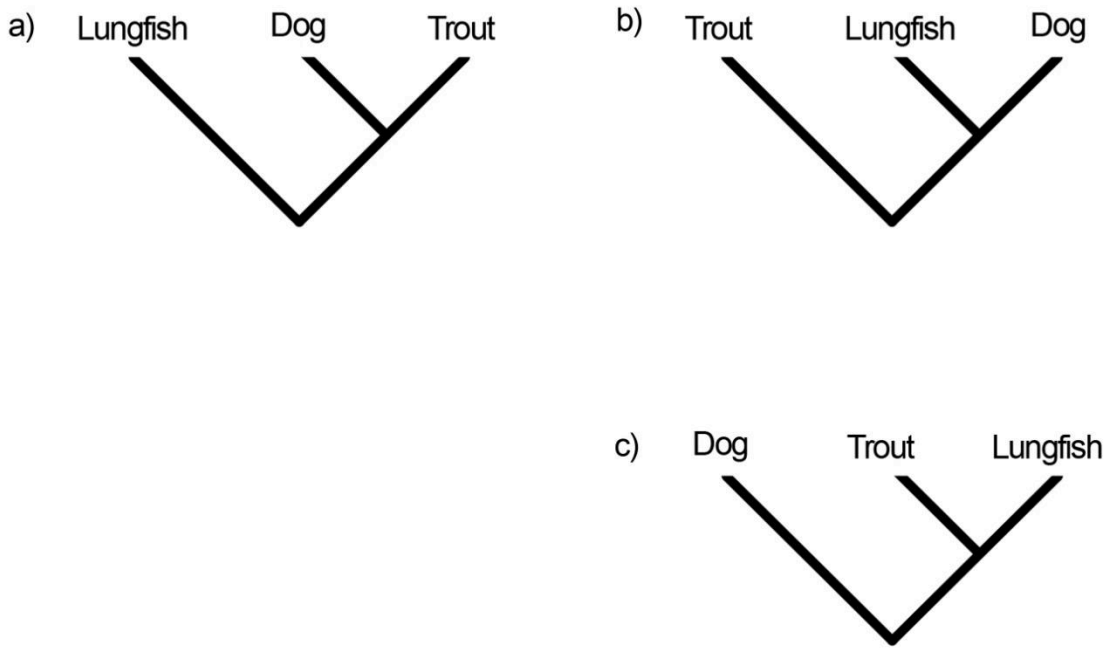

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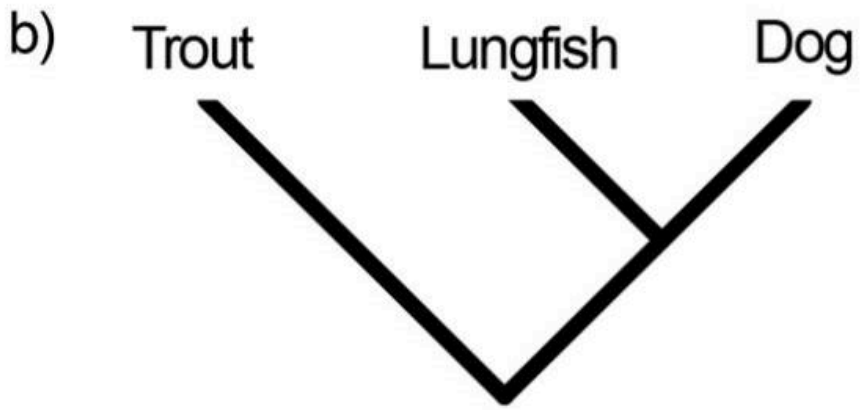

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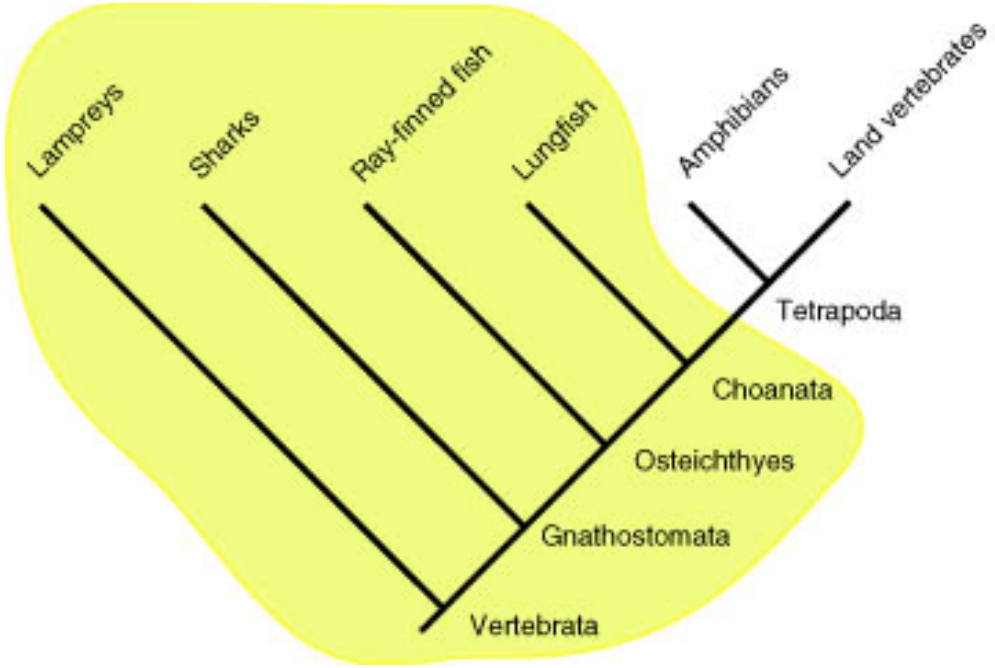
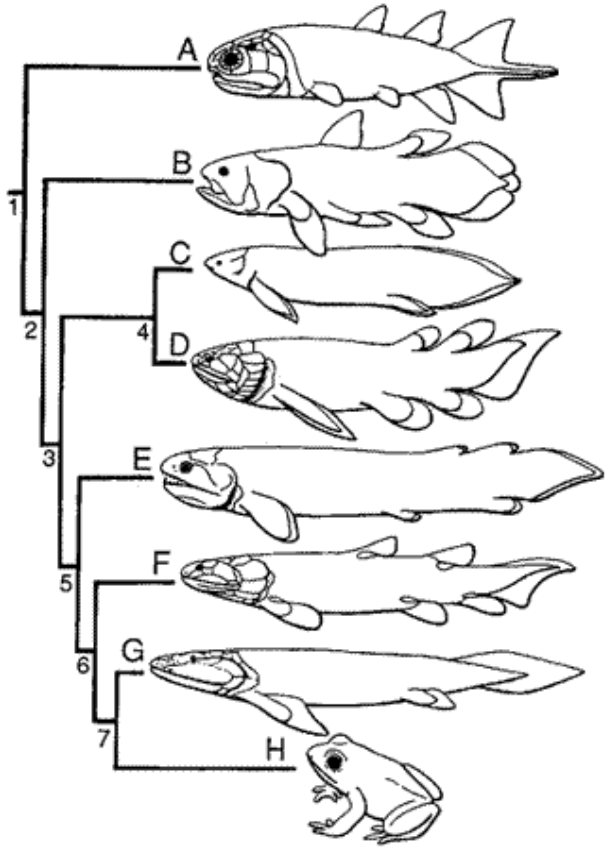
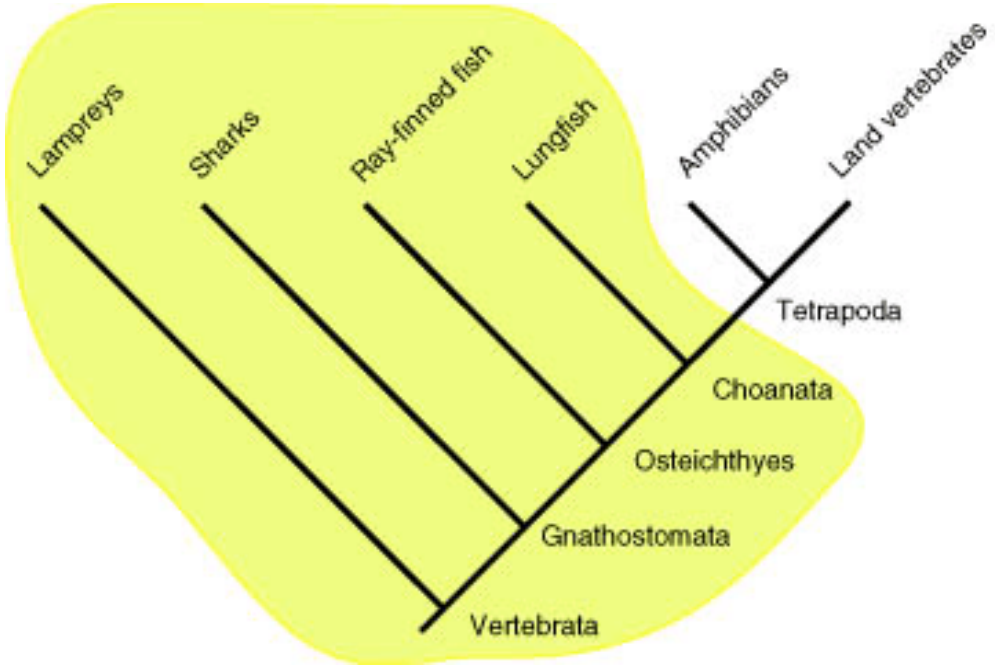
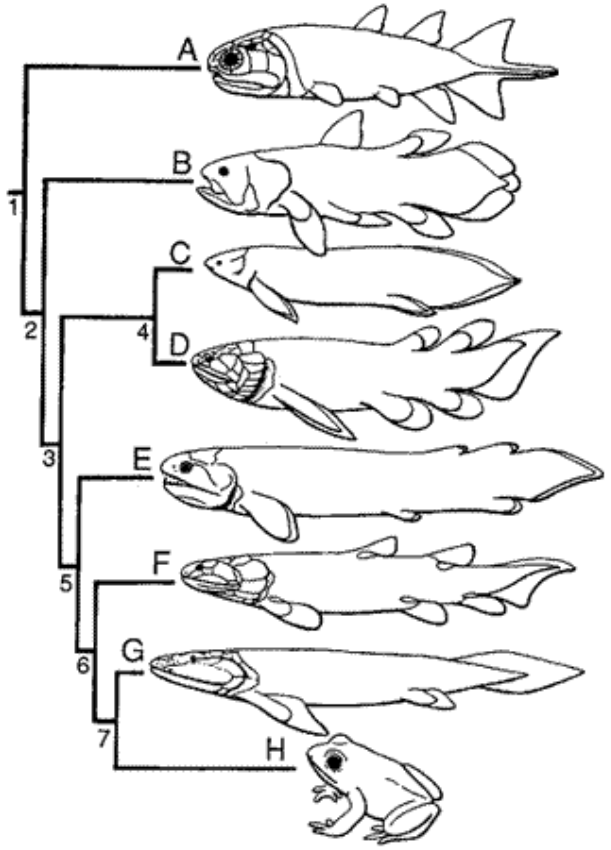


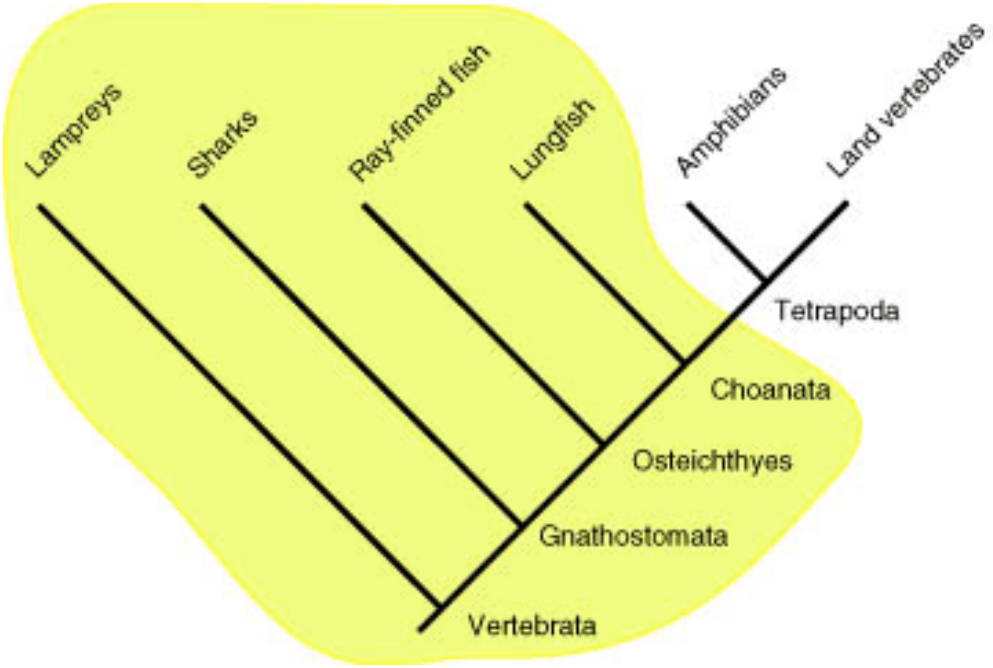


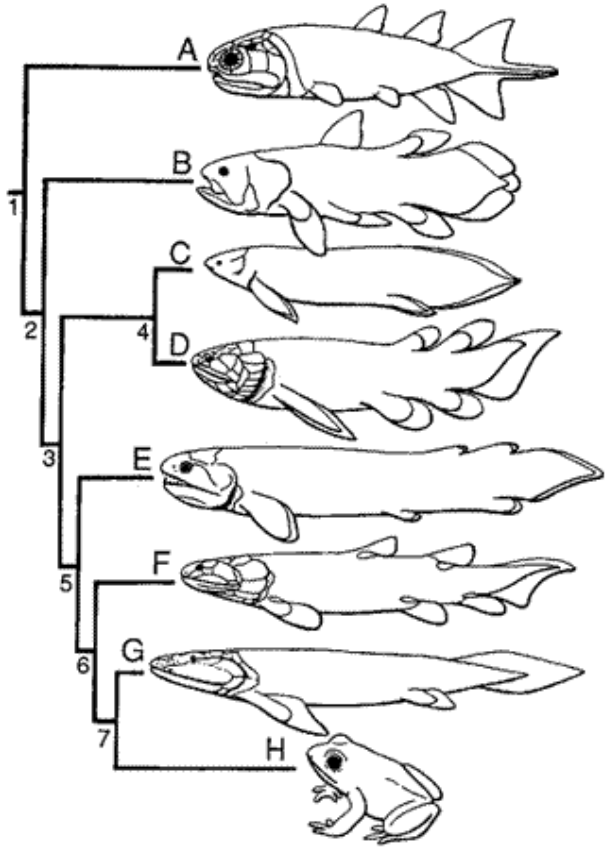
So either we're all fish, or…





…there's no such thing as a "fish"!





How to Phylogeny

Fossil phylogenies are usually based on morphological characters.

They depend on breaking up characters into “advanced” and “primitive” conditions

These types of analyses are often referred to as “cladistics”

How to Phylogeny in four easy steps!

Cladistics: Find morphological characters

Cladistics: Synapomorphies and Plesiomorphies

- **Character list**
- Vaned feathers on forelimb symmetric (0) or asymmetric (1). The barbs on opposite sides of the rachis differ in length; in extant birds, the barbs on the leading edge of flight feathers are shorter than those on the trailing edge.

Cladistics

- **Character list**
- Vaned feathers on forelimb symmetric (0) or asymmetric (1). The barbs on opposite sides of the rachis differ in length; in extant birds, the barbs on the leading edge of flight feathers are shorter than those on the trailing edge.

- Allosaurus_fragilis
- ?1100?100000?001000100000111011001000000001001000000001000000000101010010000000100100000000001000000?01??0000000000000000?
000001001000001000000000000000011000000100000000000000-0?001001?011000000000000?000?00
- Ingenia_yanshini
- ?010?????????????1?????1?????????????????????????????2120100?01111--------?????????????????1??01-????2?0???00110011??0000??1000000101?????
032010011107101101?0000?00010?0000000????????-0??1??????00??02110?1000 1?0
- Oviraptor_mongoliensis
- ?010?????????????1?1???1?11?00010????00?0?????0??12120100??1111--------?????????????????????0?????210??????1??1???0?0???10??000111???
11?????????????1???????0????0??0?0??????00?0-?11-0?1?0???0?00??0?11?0??????0
- Oviraptor_philoceratops
- ?010?????01????0??11?01011???0???111???0??0??01?12120100?01?11--------?????????????????????0?????????????????1??1????00???1?0??00?01?
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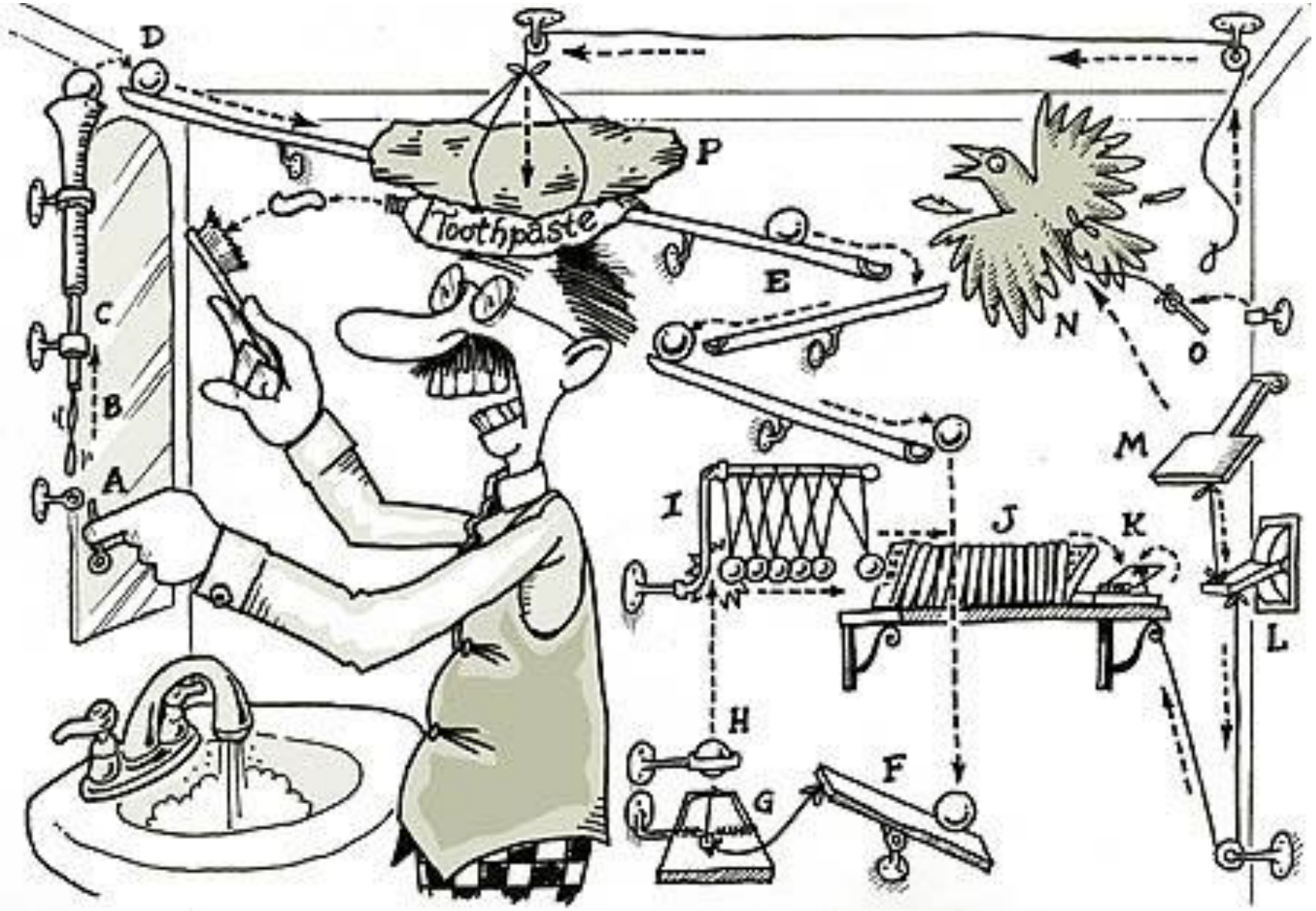
- Conchoraptor_gracilis
- ?010?????????????01?1???1?11?000??21110?00????10??121201?0?01111--------?????????010?1?013110??1???????1???100110001000????????00111001-10???
10???1001?11010?0????0??0?0000??000?0-01?-0?1???????00?1021100100??00
- 'IGM_100/42'
- ?0100100001-2210111100101 1?000102111000010001010121201001011 11--------10111011001011100 1?201-?00210111?011001101010 0?1100100010110 0??032010??
11011?2101000000000?0000000000010-011-0?0110??000011021100100 0100
- Chirostenotes_pergracilis (incl. Caenaganthus)
- ????1??0?011?????11001?????????????????????0101????2120000?01??1--------???????1101?1????112???0?????????????????01?1???????????00?1????0?1?
032010111?01??0??????????00?100?001000????????-0?1?100-0??01?02?10???00?00
- Dromaeosaurus_albertensis
- ?0?001100000001???0?1???01110????1????000?10010?
000000111100000010100 1???1??1111?1??11???
000010??????000???????-
- Deinonychus_antirrhopus
- ?010????????????1?0?011000011100011???0????0?00100000?0011?100001010100 0?1100011 00?111011???0011011?11??????1101110100111001000101101110220?
0111?010?1111100000000010001101 00?1????1111?011??1?10011220000?111010
- Velociraptor_mongoliensis
- ?0100110000020120101100001110001211 0?000000001000000000111?000010101000011?
00110011110111100011011111111001011111101001110010001011011102201011121101111?000000000101011010011111?111110111111100112200001111010
- Mononykus_olecranus
- ?????00?????112?????????????????????????????10?????????????????2?--0?????????1?1?1110001????10?2?????1???20?00020030110-1122011 0????1??
000-1????2??0?2101001110112110000200 0????????????0?????0?0?1??1????0??0-?0
- Shuuvuia_deserti
- ?0101000000011210?0??00-111-11002101011000010-1100010000210 0?022--000??011111101110?0??120101201221100?20?
00020030 11?-112201100--21-2000-1002122-0?2101001110112110000200000101 00?10?0000?0??0011?101010000-00
- Patagonykus_puertai
- ???11????????10?2?????????????00200301 10?110??110????1??????
1????10?0?11?1?00???00011?0??0?????????????????????????1???????????0?-


D
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Toothpaste
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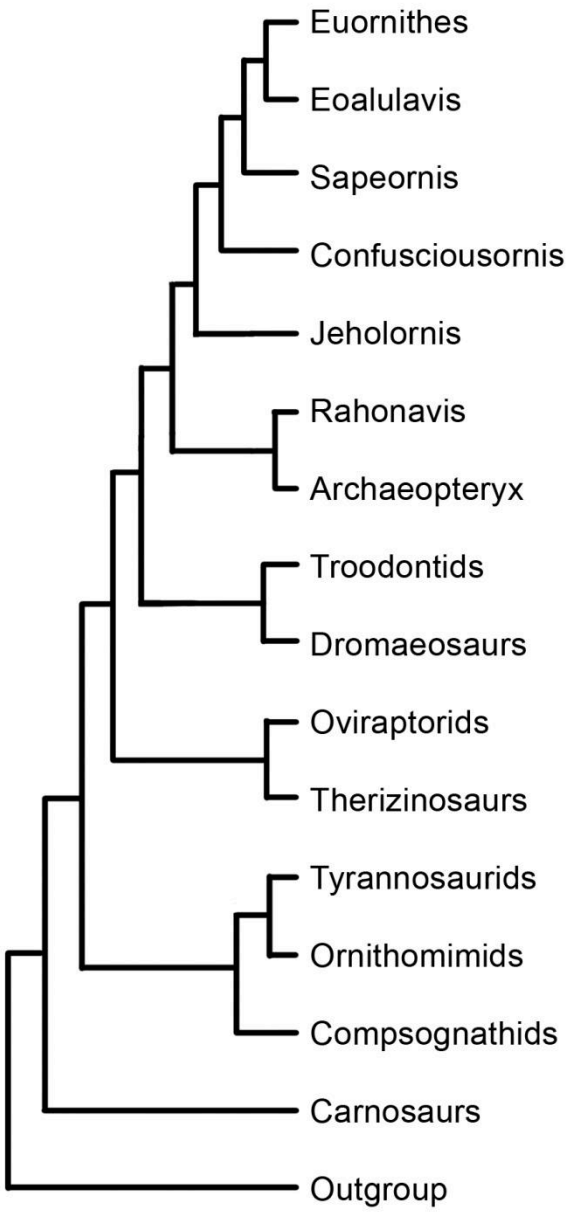
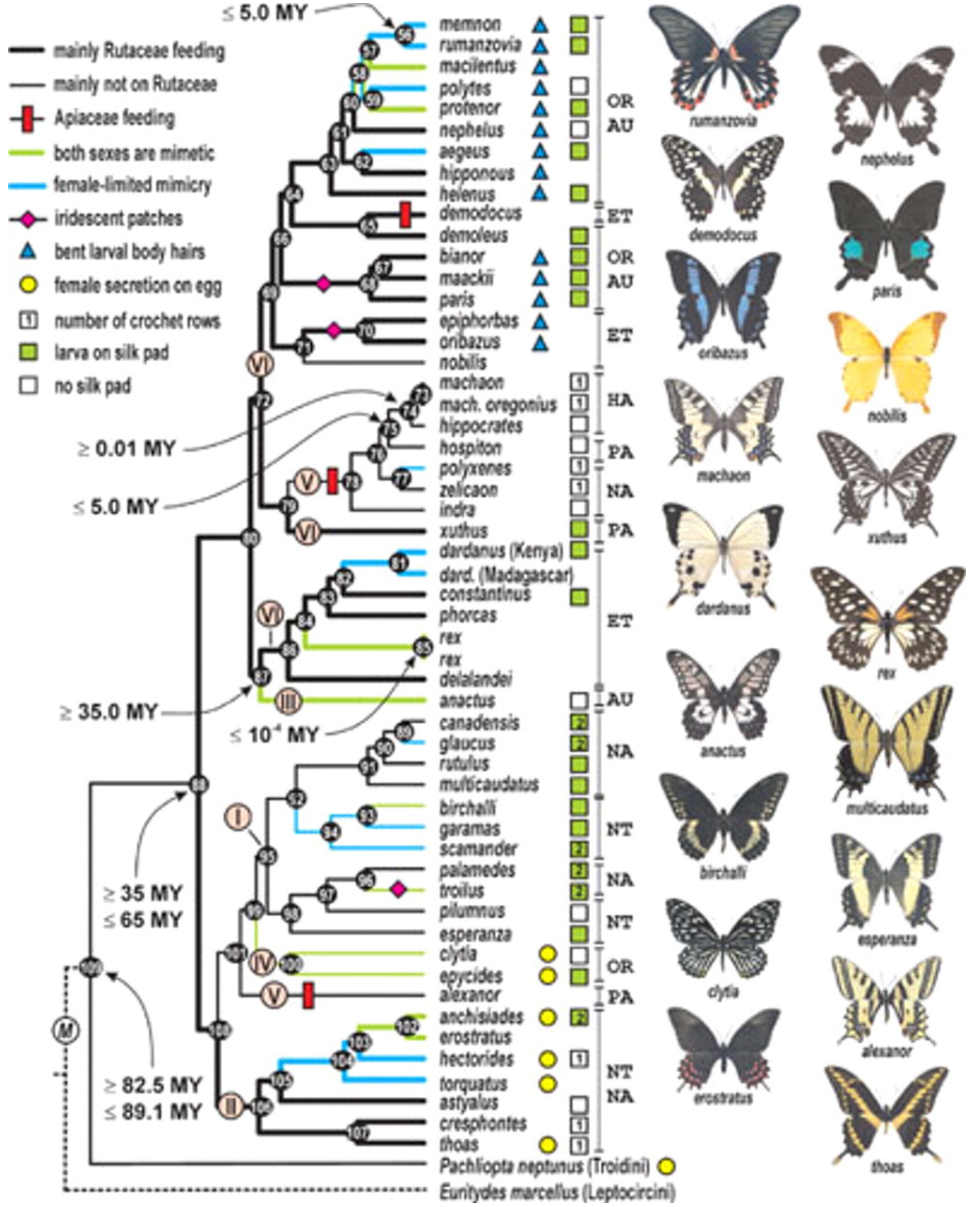

Euornithes
Eoalulavis
Sapeornis
Confusciousornis
Jeholornis
Rahonavis
Archaeopteryx
Troodontids
Dromaeosaurs
Oviraptorids
Therizinosaurs
Tyrannosaurids
Ornithomimids
Compsognathids
Carnosaurs
Outgroup

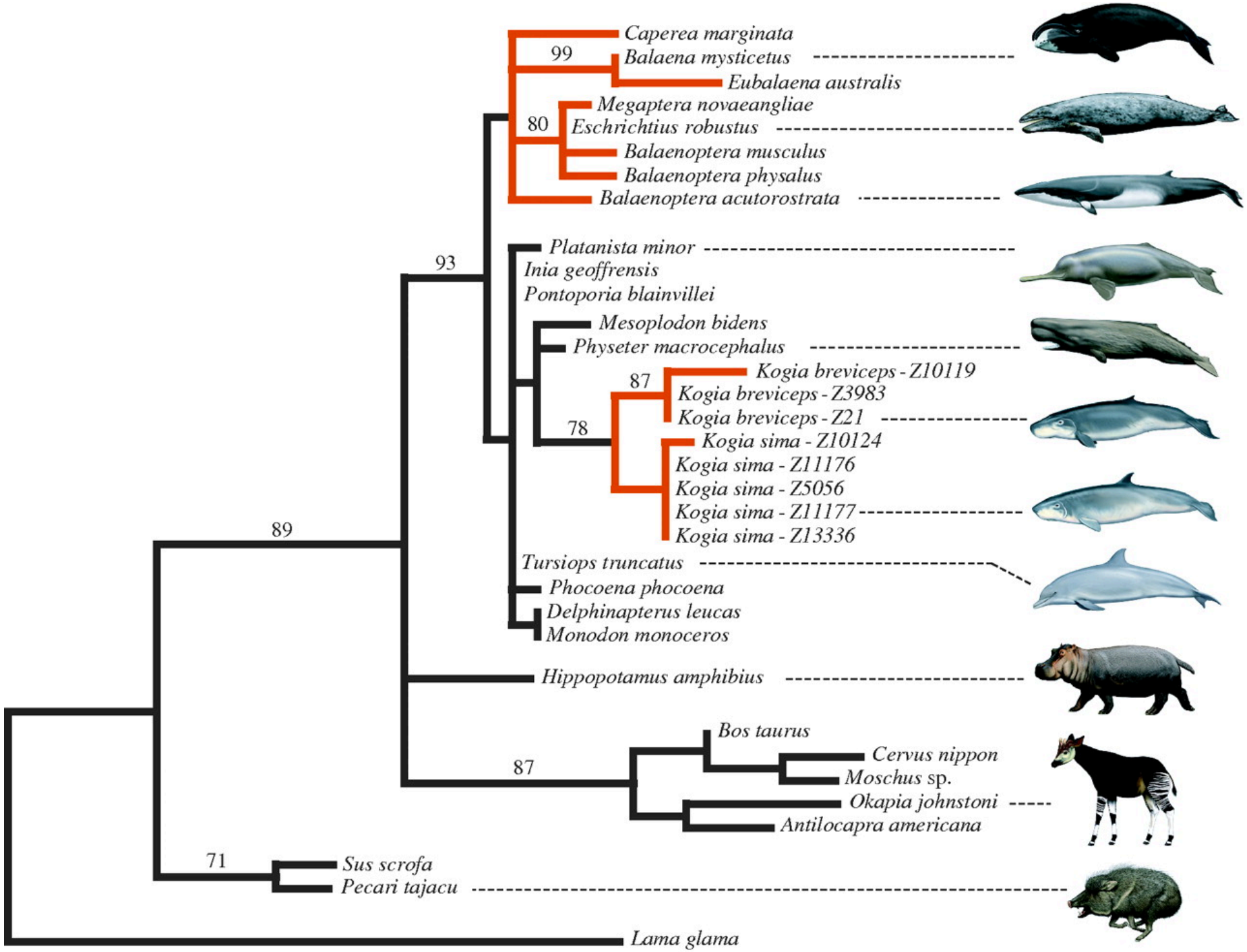
Morphological cladistics is great

Morphological cladistics is great



Molecular phylogeny

Molecules VS. Morphology


Caperea marginata
99
Balaena mysticetus
Eubalaena australis
Megaptera novaeangliae
80
Eschrichtius robustus
Balaenoptera musculus
Balaenoptera physalus
Balaenoptera acutorostrata
Platanista minor
93
Inia geoffrensis
Pontoporia blainvillei
Mesoplodon bidens
Physeter macrocephalus
Kogia breviceps - Z10119
87
Kogia breviceps - Z3983
Kogia breviceps - Z21
78
Kogia sima - Z10124
Kogia sima - Z11176
Kogia sima - Z5056
Kogia sima - Z11177
Kogia sima - Z13336
89
Tursiops truncatus
Phocoena phocoena
Delphinapterus leucas
Monodon monoceros
Hippopotamus amphibius
Bos taurus
Cervus nippon
87
Moschus sp.
Okapia johnstoni
Antilocapra americana
71
Sus scrofa
Pecari tajacu
Lama glama

Molecular Phylogeny

Actually have more modeling assumptions

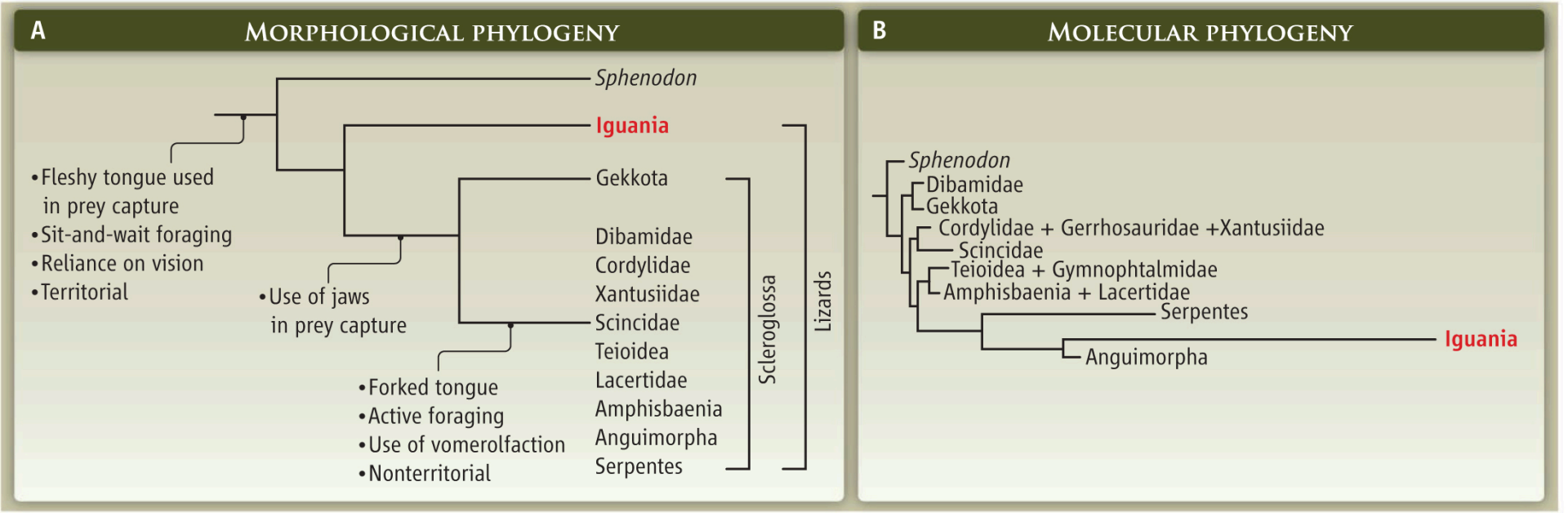
-e.g. rate(s) of mutation, likelihood of reversals, non-equal character change likelihood, etc.

Molecular Phylogeny

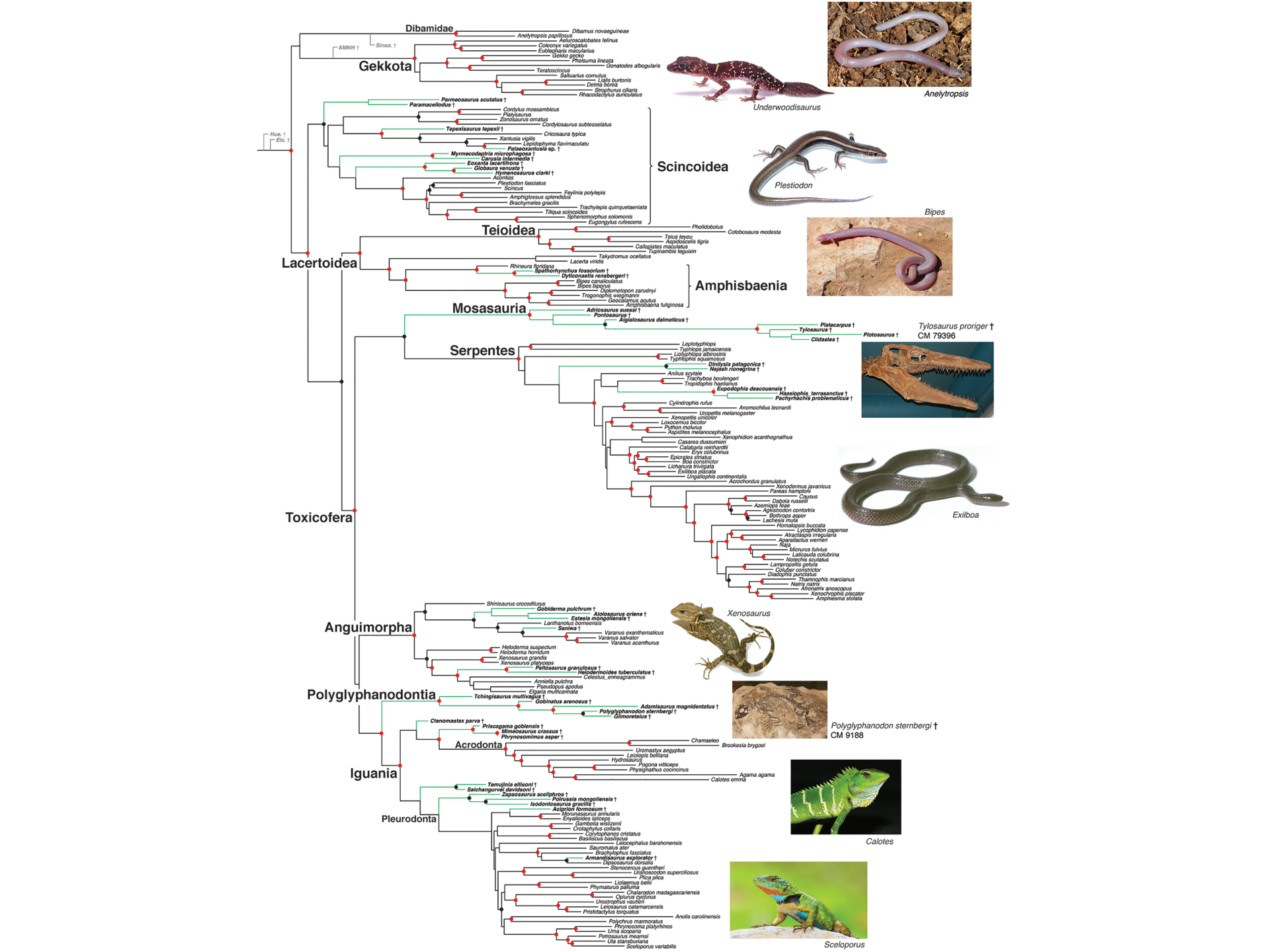
Actually have more modeling assumptions

-e.g. rate(s) of mutation, likelihood of reversals, non-equal character change likelihood, etc.

-But! They also have better taxon sampling and more data in general.



Evolutionary conundrum. (**A**) In the morphology-based phylogeny, many key characters in iguanians are inferred to represent the retained ancestral state. *Sphenodon* is the closest living relative to lizards. [Phylogeny based on (*14*)] (**B**) In the molecular phylogeny, iguanians are placed high in the tree; their supposedly ancestral characters are attributed to evolutionary reversals. Branch lengths are proportional to the number of morphological reversals required by this tree.


Dibamidae
Dibamus novaeguineae
Anelytropsis papillosus
Aeluroscalabotes felinus
Coleonyx variegatus
Eublepharis macularius
Gekko gecko
Phelsuma lineata
Gonatodes albogularis
Teratoscincus
Saltuarius cornutus
Lialis burtonis
Delma borea
Strophurus ciliaris
Rhacodactylus auriculatus
Gekkota
AMNH †
Sineo. †
Parmeosaurus scutatus †
Paramacellodus †
Cordylus mossambicus
Platysaurus
Zonosaurus ornatus
Cordylosaurus subtesselatus
Tepexisaurus tepexil †
Cricosaura typica
Xantusia vigilis
Lepidophyma flavimaculatu
Palaeoxantusia sp. †
Myrmecodaptria microphagosa †
Carusia intermedia †
Eoxanta lacertifrons †
Globaura venusta †
Hymenosaurus clarki †
Acontias
Plestiodon fasciatus
Scincus
Feylinia polylepis
Amphiglossus splendidus
Brachymeles gracilis
Tiliqua scincoides
Sphenomorphus solomonis
Eugongylus rufescens
Scincoidea
Hue. †
Elc. †
Teioidea
Pholidobolus
Colobosaura modesta
Teius teyou
Aspidoscelis tigris
Callopistes maculatus
Tupinambis teguixin
Takydromus ocellatus
Lacerta viridis
Lacertoidea
Rhineura floridana
Spathorhynchus fossorium †
Dyticonastis rensbergeri †
Bipes canaliculatus
Bipes biporus
Diplometopon zarudnyi
Trogonophis wiegmanni
Geocalamus acutus
Amphisbaena fuliginosa
Amphisbaenia
Mosasauria
Adriosaurus suessi †
Pontosaurus †
Aigialosaurus dalmaticus †
Platecarpus †
Tylosaurus †
Clidastes †
Plotosaurus †
Leptotyphlops
Typhlops jamaicensis
Liotyphlops albirostris
Typhlophis squamosus
Dinilysia patagonica †
Najash rionegrina †
Anilius scytale
Trachyboa boulengeri
Tropidophis haetianus
Eupodophis descouensis †
Haasiophis terrasanctus †
Pachyrhachis problematicus †
Serpentes
Cylindrophis rufus
Anomochilus leonardi
Uropeltis melanogaster
Xenopeltis unicolor
Loxocemus bicolor
Python molurus
Aspidites melanocephalus
Xenophidion acanthognathus
Casarea dussumieri
Calabaria reinhardtii
Eryx colubrinus
Epicrates striatus
Boa constrictor
Lichanura trivirgata
Exiliboa placata
Ungaliophis continentalis
Acrochordus granulatus
Xenodermus javanicus
Pareas hamptoni
Causus
Daboia russelii
Azemiops feae
Agkistrodon contortrix
Bothrops asper
Lachesis muta
Homalopsis buccata
Lycophidion capense
Atractaspis irregularis
Aparallactus werneri
Naja
Micrurus fulvius
Laticauda colubrina
Notechis scutatus
Lampropeltis getula
Coluber constrictor
Diadophis punctatus
Thamnophis marcianus
Natrix natrix
Afronatrix anoscopus
Xenochrophis piscator
Amphiesma stolata
Toxicofera
Shinisaurus crocodilurus
Gobiderma pulchrum †
Aiolosaurus oriens †
Estesia mongoliensis †
Lanthanotus borneensis
Saniwa †
Varanus exanthematicus
Varanus salvator
Varanus acanthurus
Anguimorpha
Heloderma suspectum
Heloderma horridum
Xenosaurus grandis
Xenosaurus platyceps
Peltosaurus granulosus †
Helodermoides tuberculatus †
Celestus_enneagrammus
Anniella pulchra
Pseudopus apodus
Elgaria multicarinata
Tchingisaurus multivagus †
Gobinatus arenosus †
Adamisaurus magnidentatus †
Polyglyphanodon sternbergi †
Glimoreteius †
Polyglyphanodontia
Ctenomastax parva †
Priscagama gobiensis †
Mimeosaurus crassus †
Phrynosoomimus aspar †
Chamaeleo
Brookesia brygooi
Acrodonta
Uromastyx aegyptus
Leiolepis belliana
Hydrosaurus
Pogona vitticeps
Physignathus cocincinus
Agama agama
Calotes emma
Iguania
Temujinia ellisoni †
Salchangurvel davidsoni †
Zapsosaurus sceilphros †
Polrussia mongoliensis †
Isodontosaurus gracilis †
Acipiion formosum †
Morusaurus annularis
Enyalioides laticeps
Gambelia wislizenii
Crotaphytus collaris
Corytophanes cristatus
Basiliscus basiliscus
Leiocephalus barahonensis
Sauromalus ater
Brachylophus fasciatus
Armandisaurus explorator †
Dipsosaurus dorsalis
Stenocercus guentheri
Uranoscodon superciliosus
Plica plica
Liolaemus bellii
Phymaturus palluma
Chalarodon madagascariensis
Oplurus cyclurus
Urostrophus vautieri
Leiosaurus catamarcensis
Pristidactylus torquatus
Anolis carolinensis
Polychrus marmoratus
Phrynosoma platyrhinos
Uma scoparia
Petrosaurus mearnsi
Uta stansburiana
Sceloporus variabilis
Pleurodonta
Underwoodisaurus
Anelytropsis
Plestiodon
Bipes
Tylosaurus proriger †
CM 79396
Exiliboa
Xenosaurus
Polyglyphanodon sternbergi †
CM 9188
Calotes
Sceloporus

Phylogeny Recap

- How we place organisms into an evolutionary context

- Not just for nerdy academics, phylogenetics can literally mean life and death for people

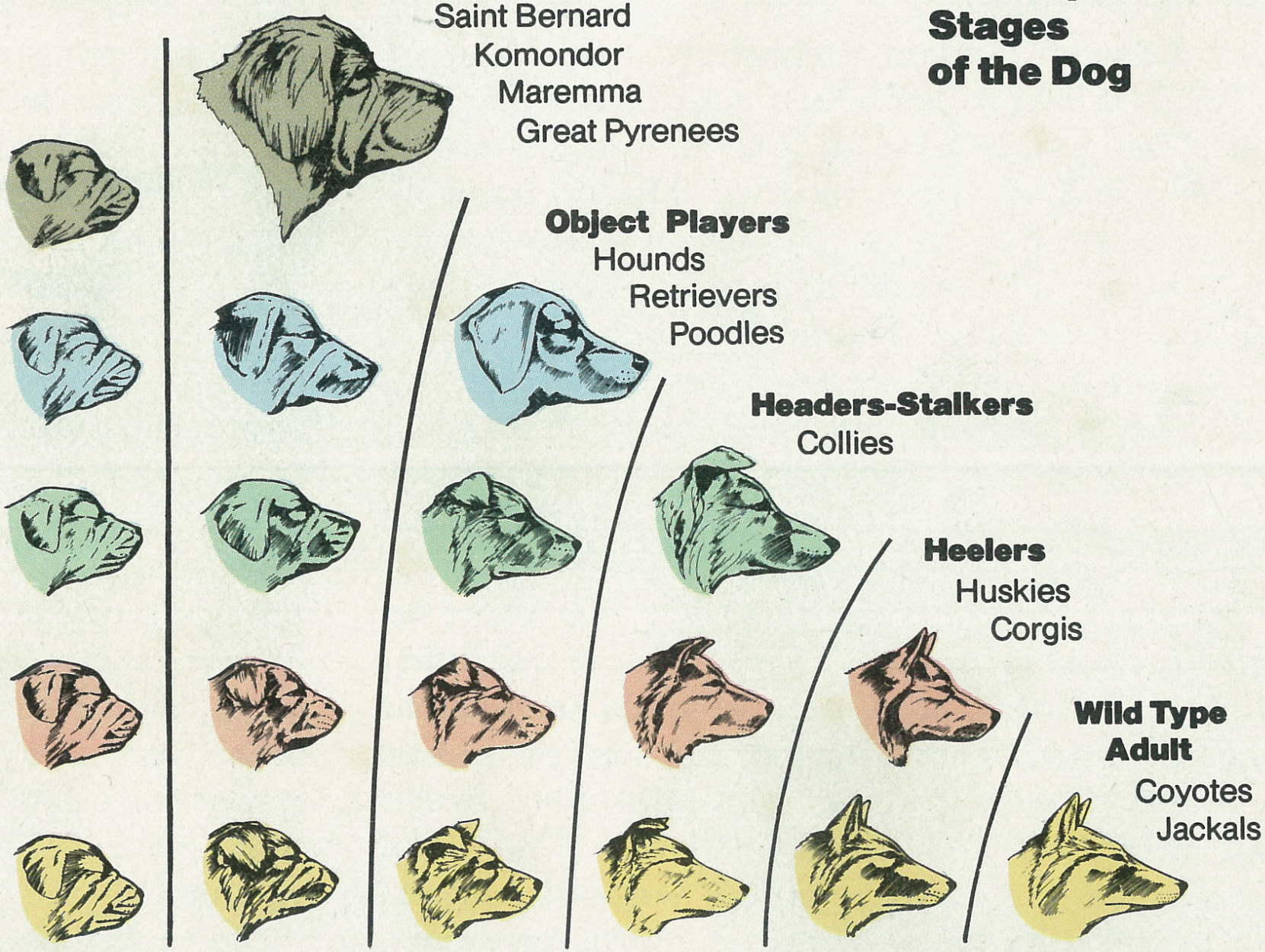
- Monophyletic clades are the fundamental unit of all types of phylogenies

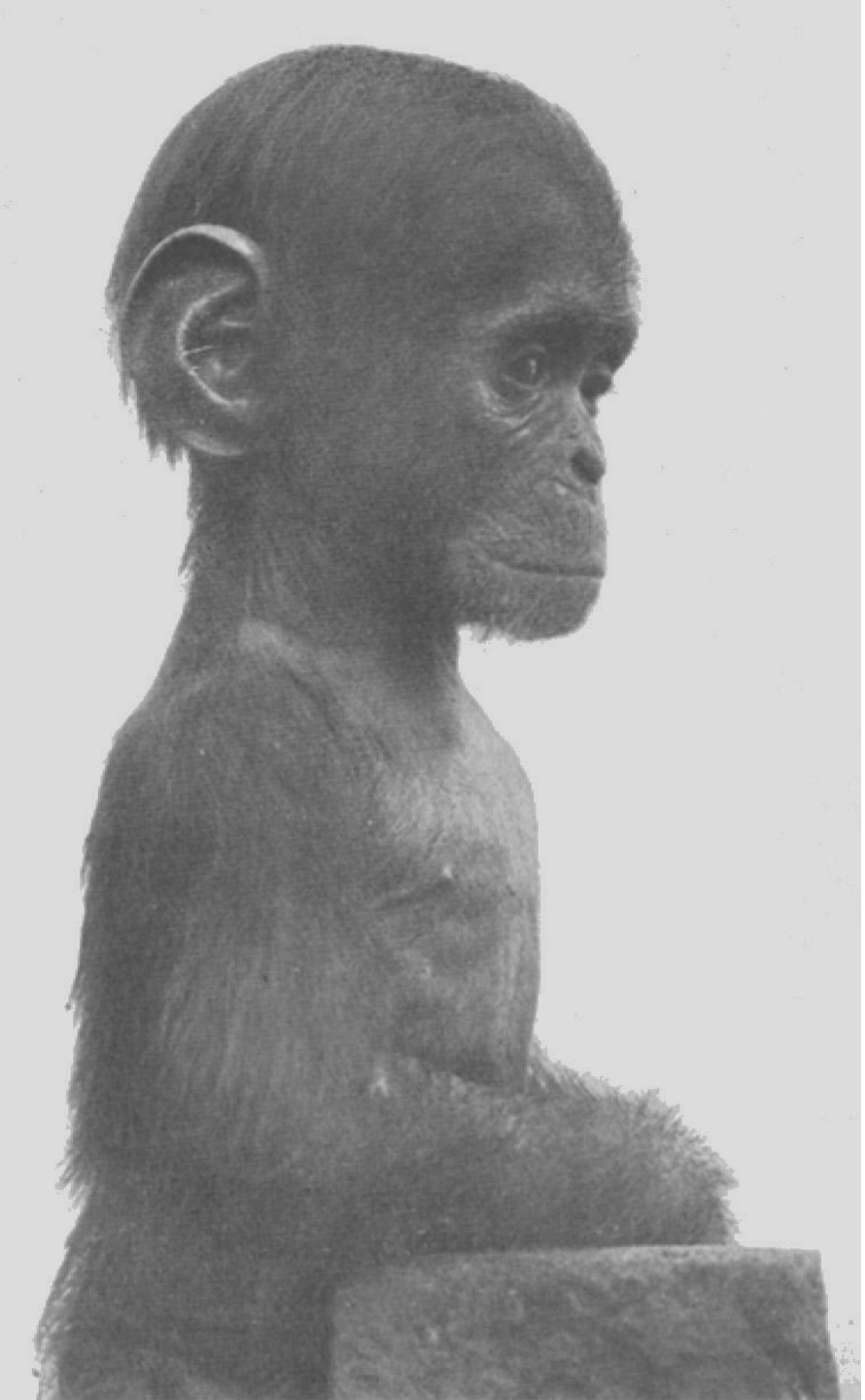
Heterochrony

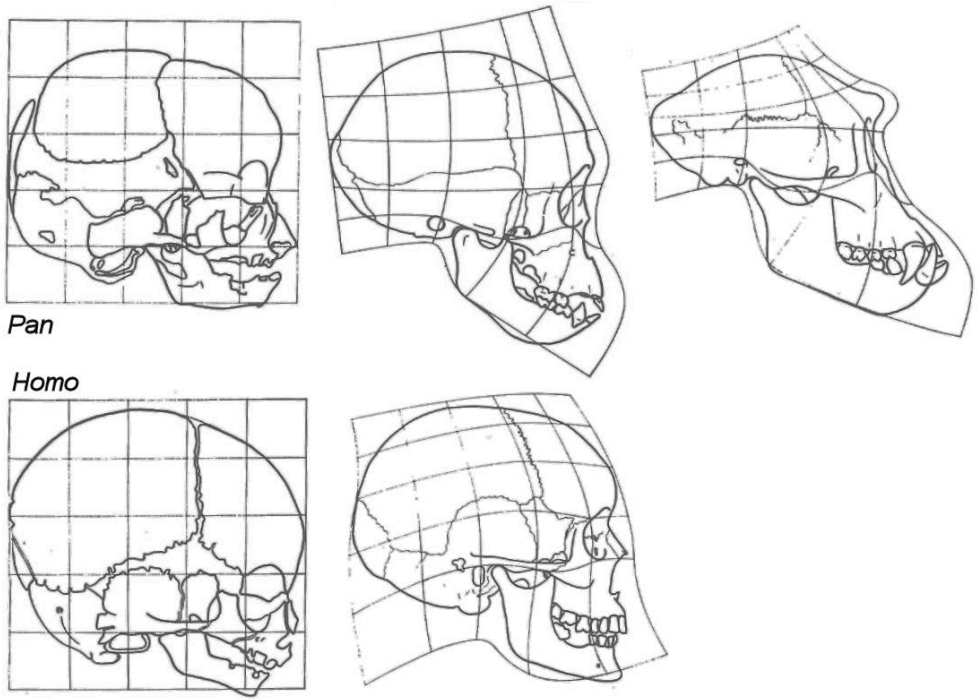
How ontogenies change during evolution

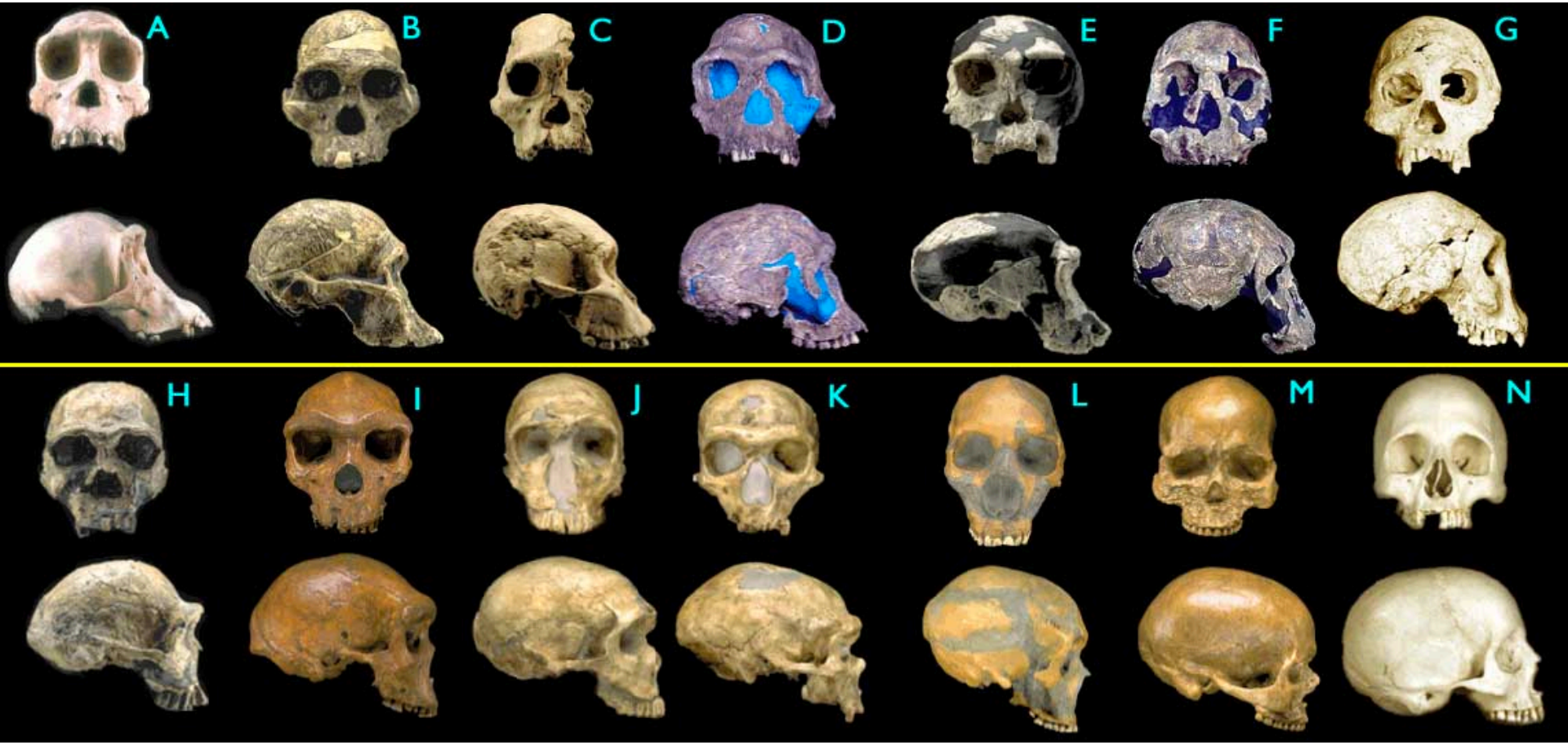
(literally: “hetero” = different, “chrony” = time)

Developmental Stages of the Dog






Pan
Homo


A
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Heterochrony - terms

Paedomorphosis – retention of “juvenile” characters into adulthood

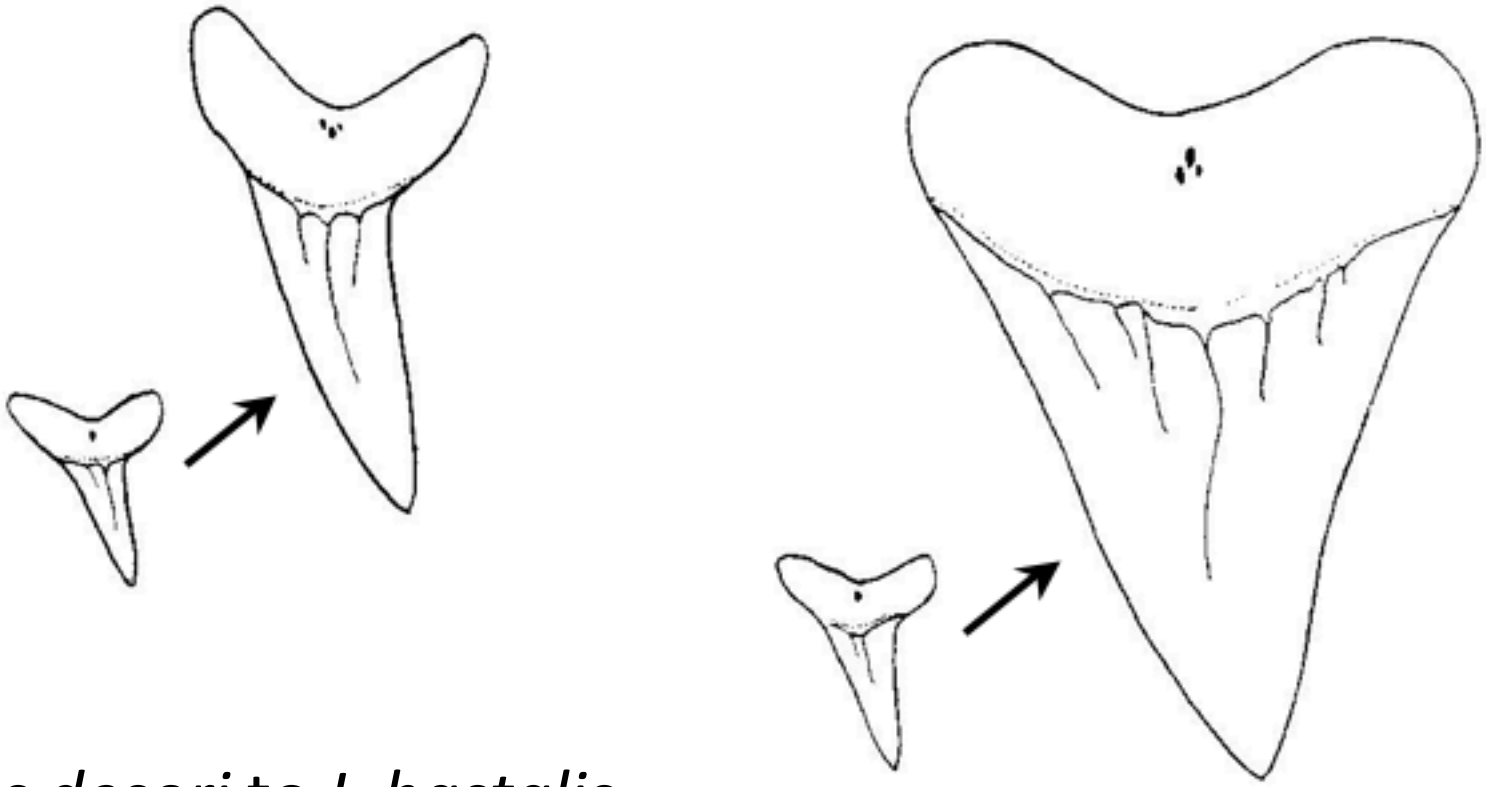
Peramorphosis – increased expression of “adult” characters

Padeomorphosis

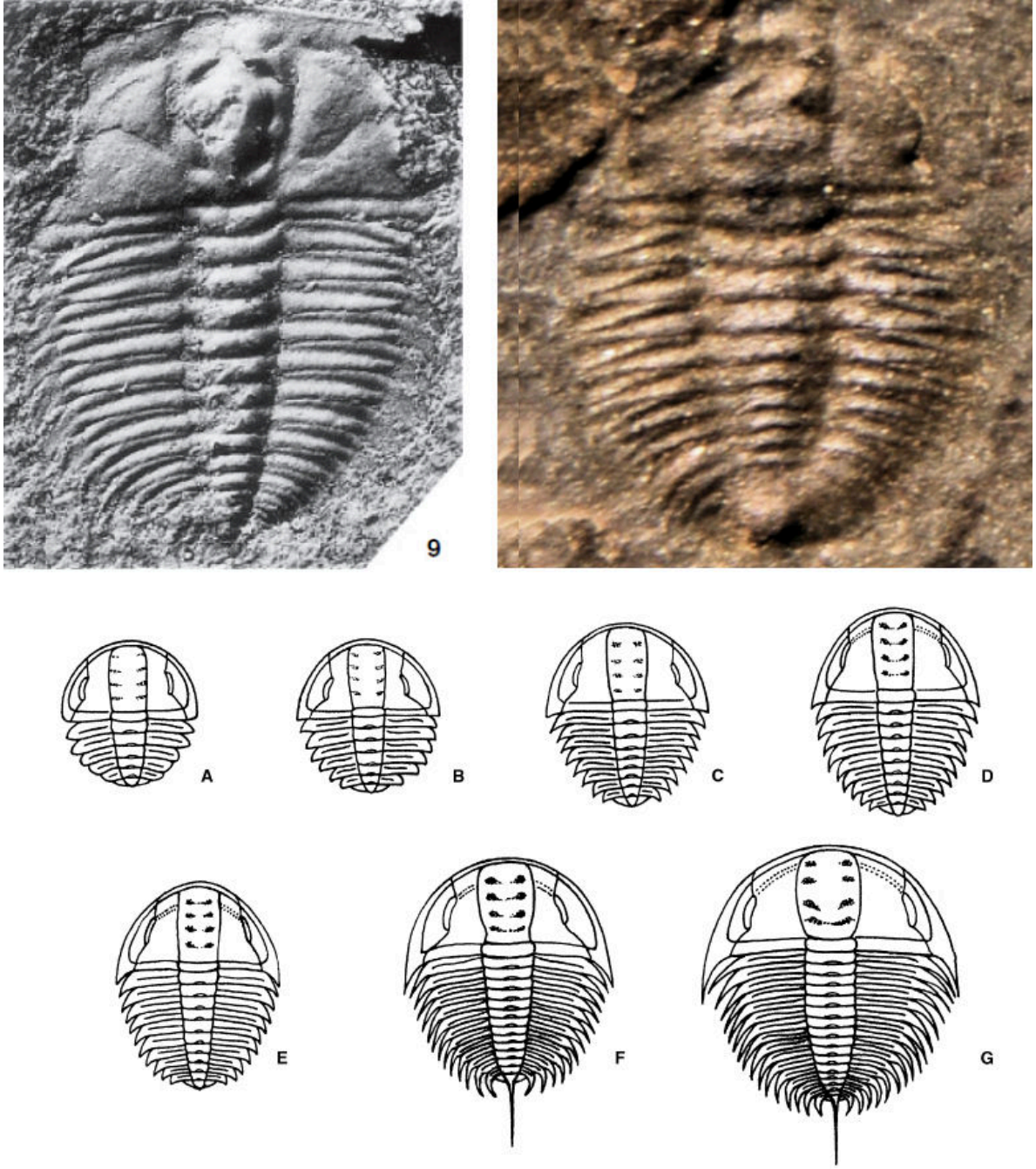
Peramorphosis

I. desori (ancestor)

I. hastalis (descendent)



Isurus desori to *I. hastalis*

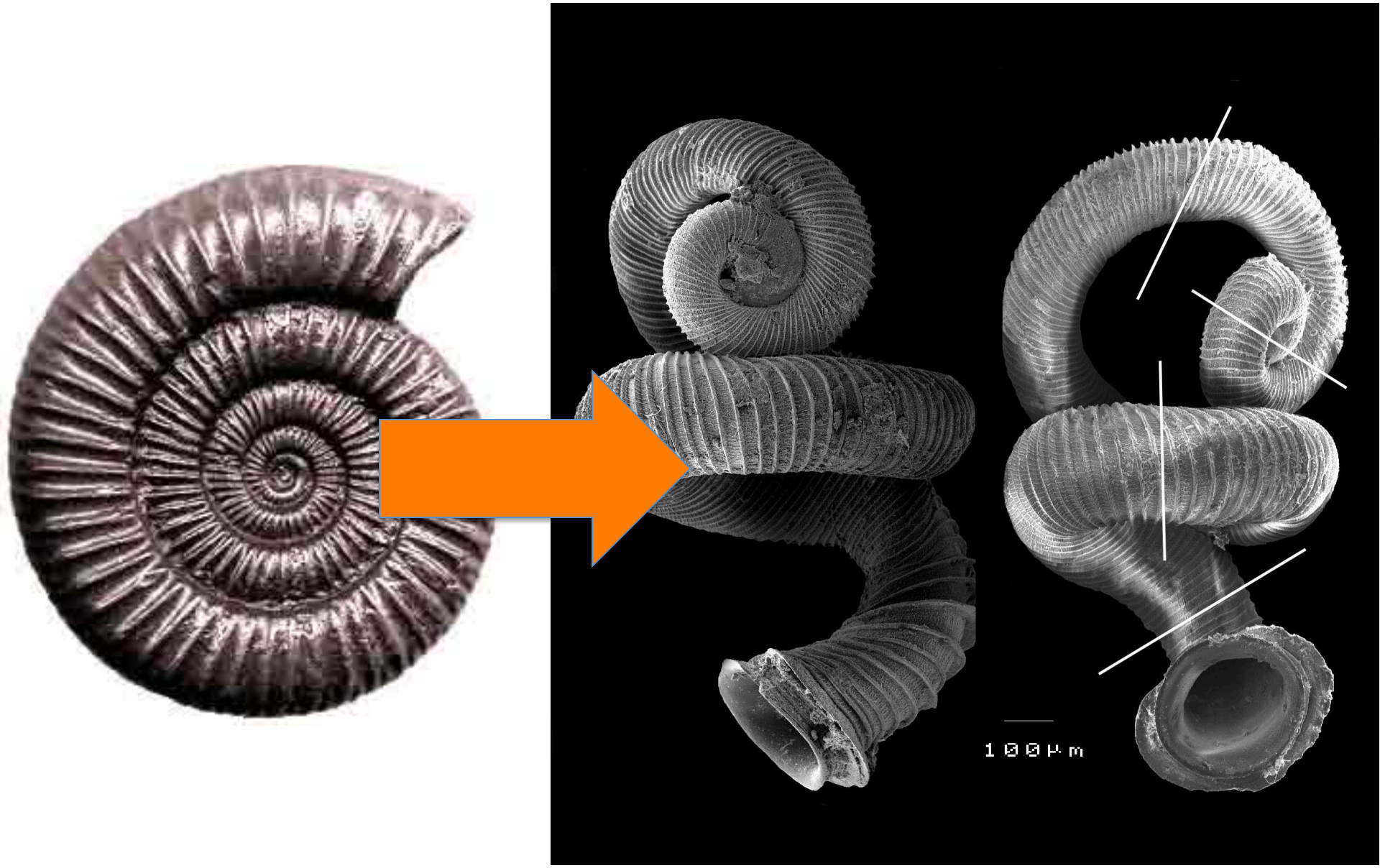


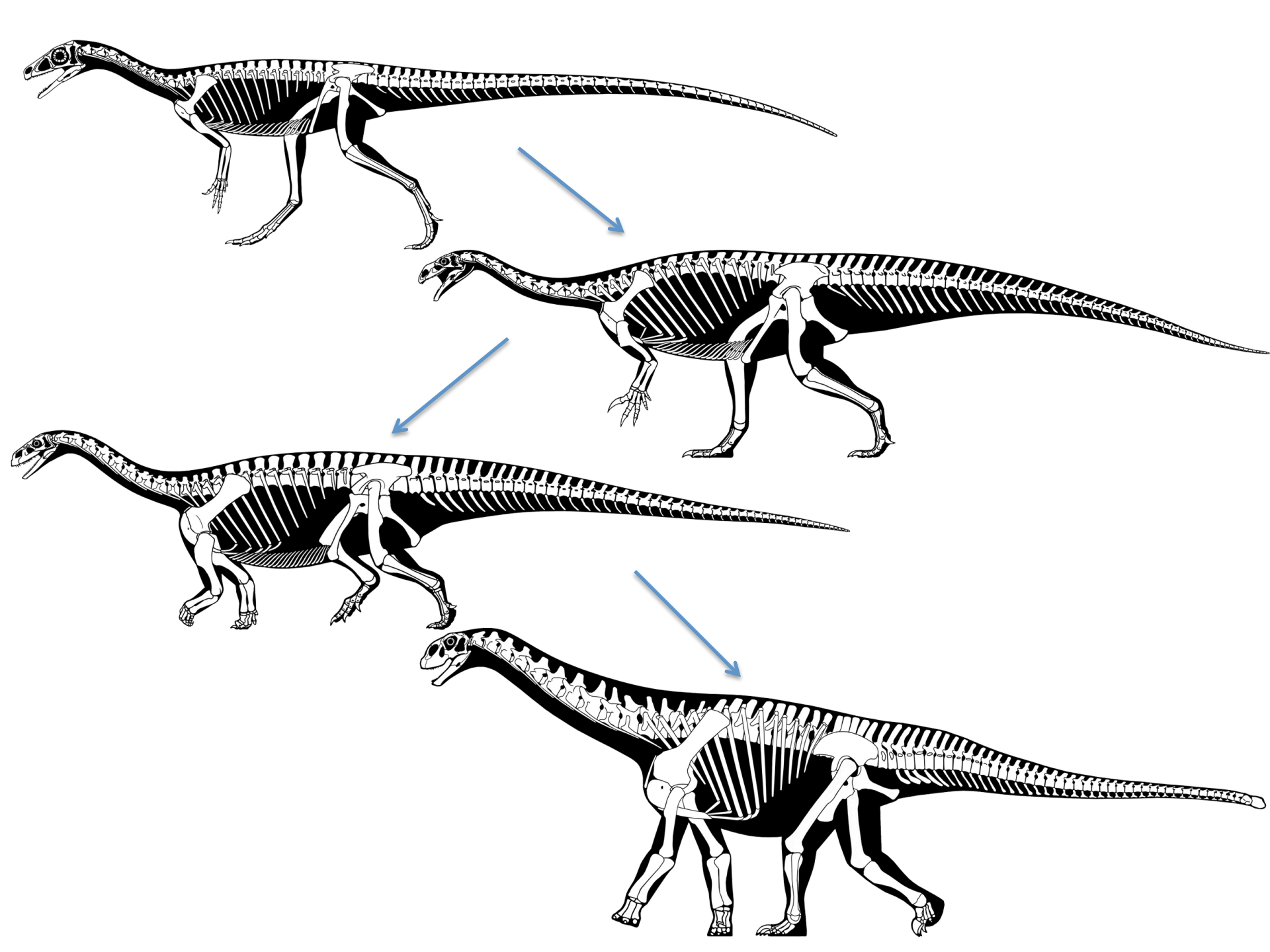
TEXT-FIG. 4. *Changaspis elongata* Lee, *in* Chien 1961. Morphological changes in dorsal exoskeleton during ontogeny, reconstructed from specimens in Plate 1, figures 1–11 and Text-figure 3. A, meraspis Degree 5; ×20. B, meraspis Degree 6; ×18. C, meraspis Degree 8; ×16. D, meraspis Degree 9; ×12. E, meraspis Degree 10; ×10. F, meraspis Degree 13; ×8. G, holaspis; ×6·5.

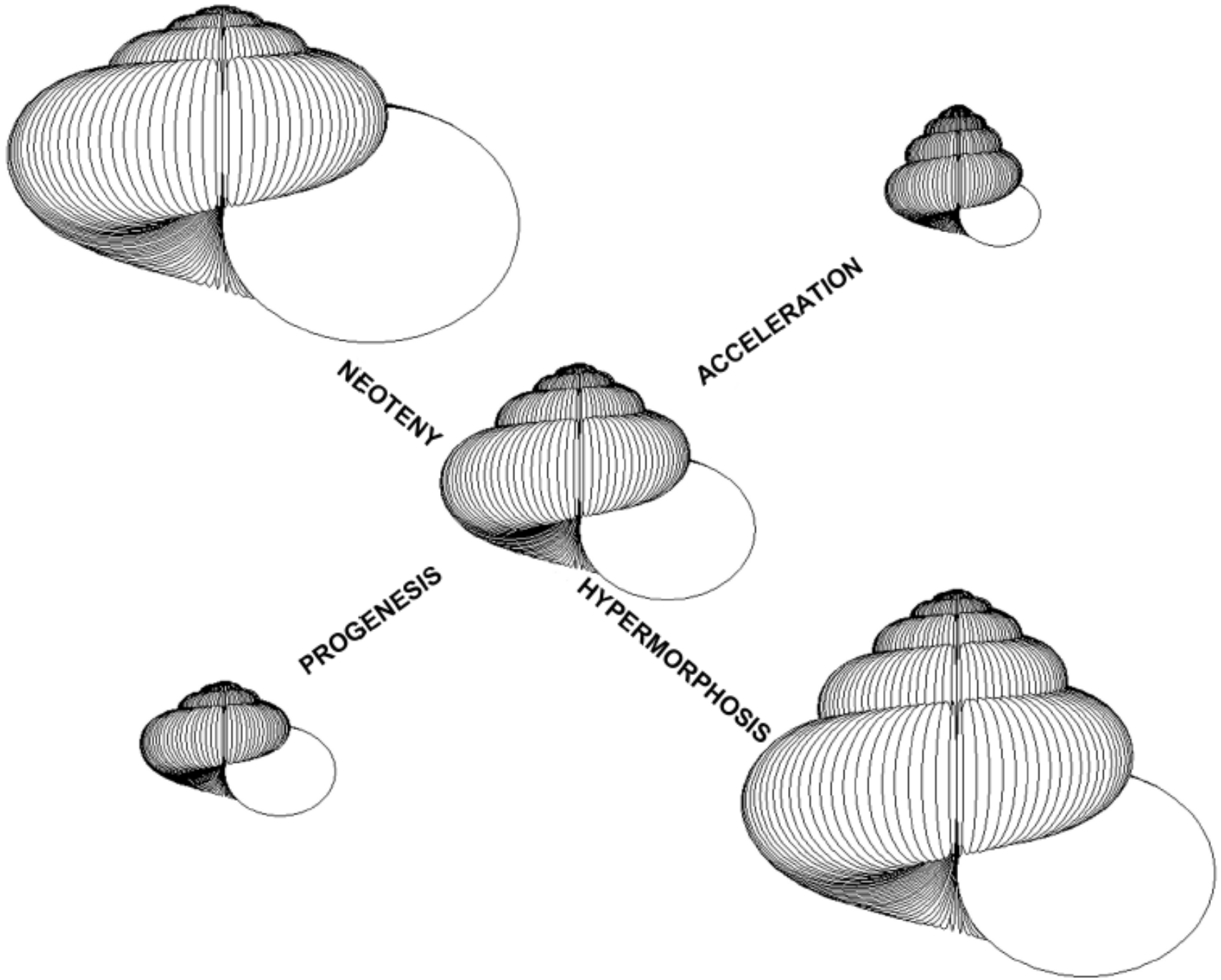
Heterochrony- not just a passive process

Heterochrony- not just a passive process, but a source of phenotypic diversity

Many of the features we are interested in studying are all timing-based


100µm



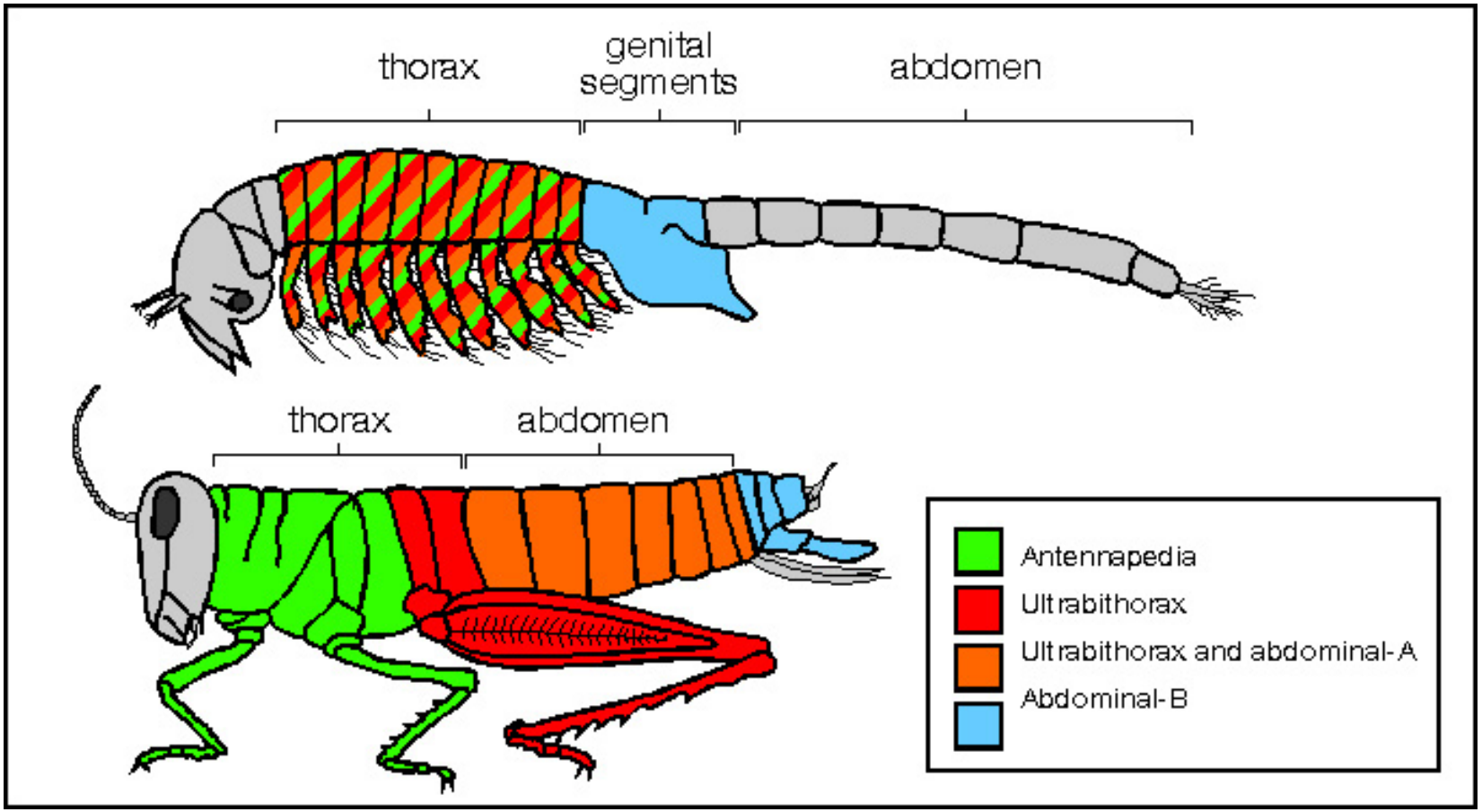

NEOTENY
ACCELERATION
PROGENESIS
HYPERMORPHOSIS

Evolutionary developmental genetics

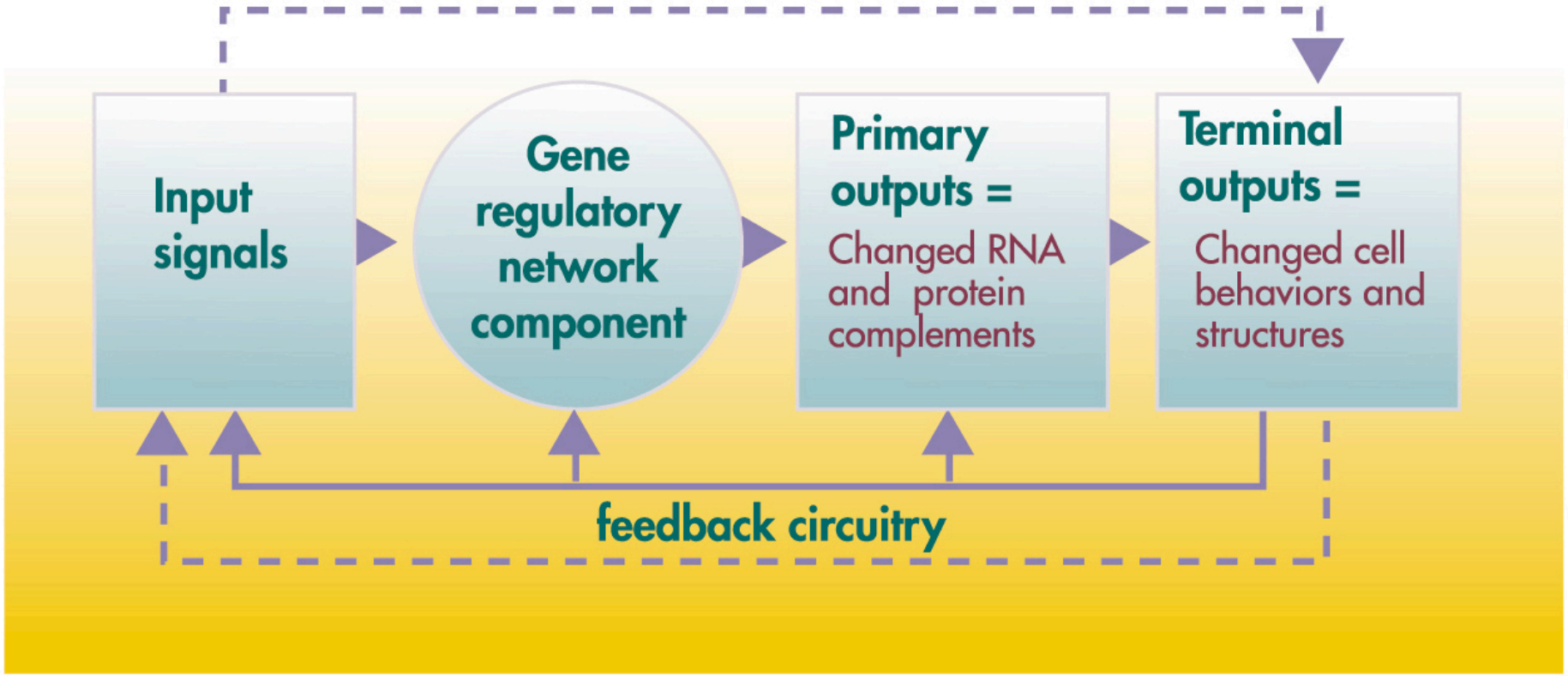
Or “Evo Devo” for short

Or “Evo Devo” for short

High level patterning genes and repeating elements (metamerism) can have major impacts on development

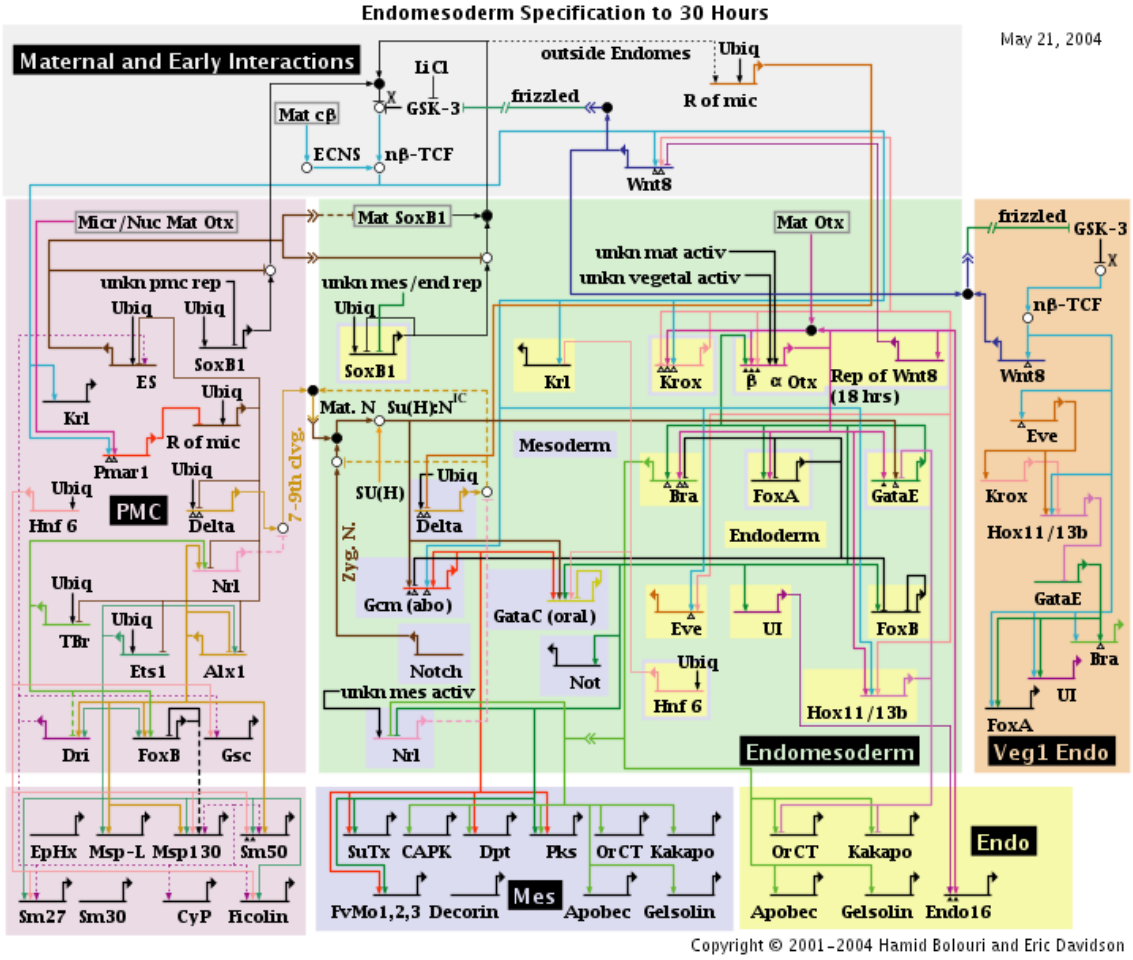


But gene regulation and gene networks allow for more gradual timing-based changes

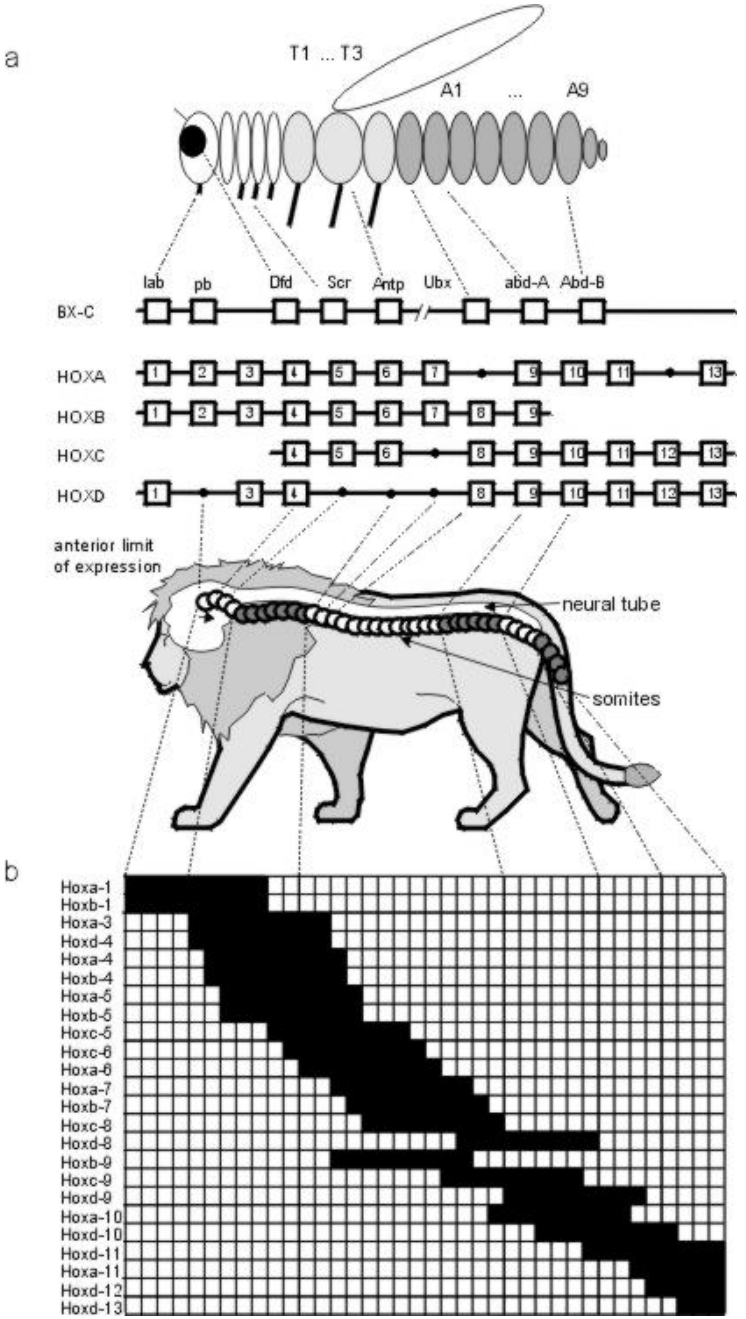


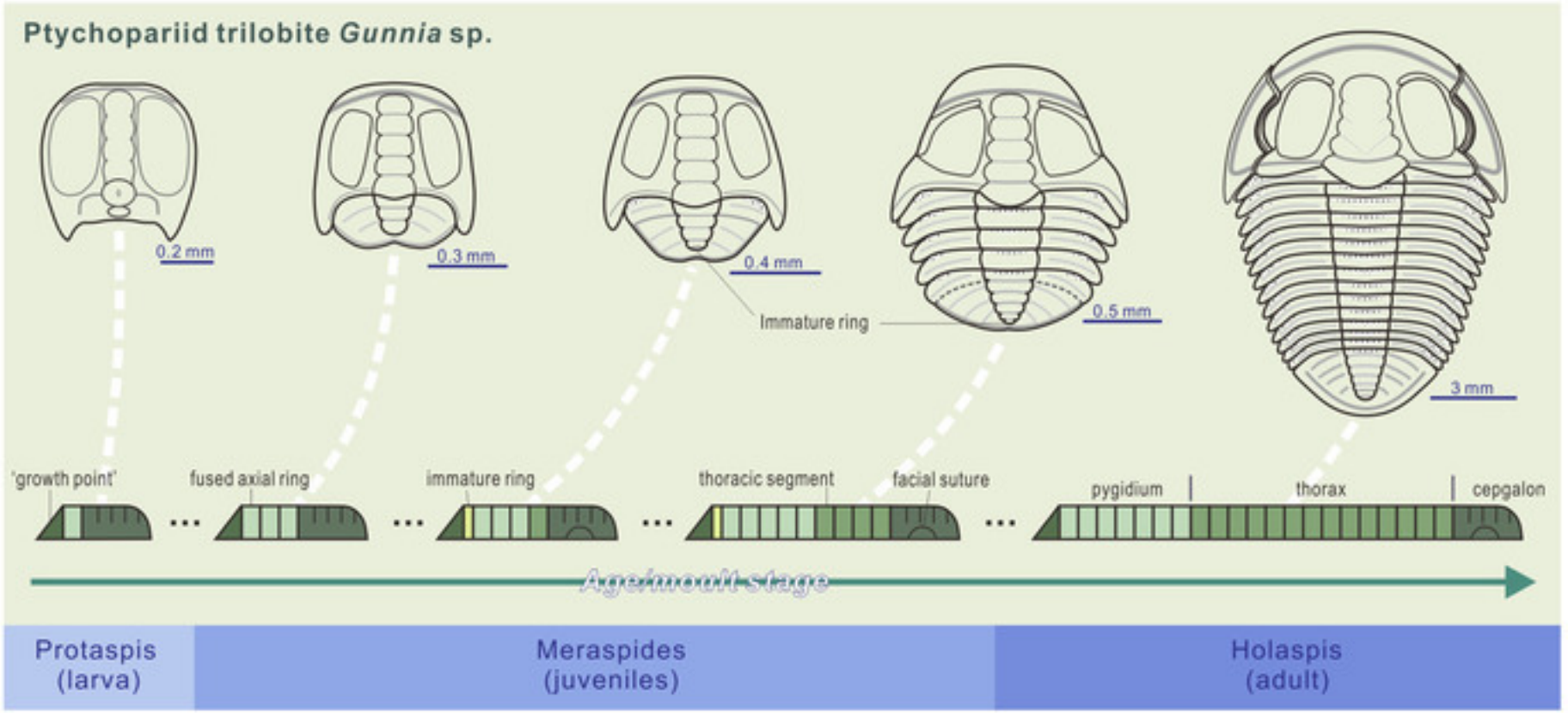
YGG 01-0086

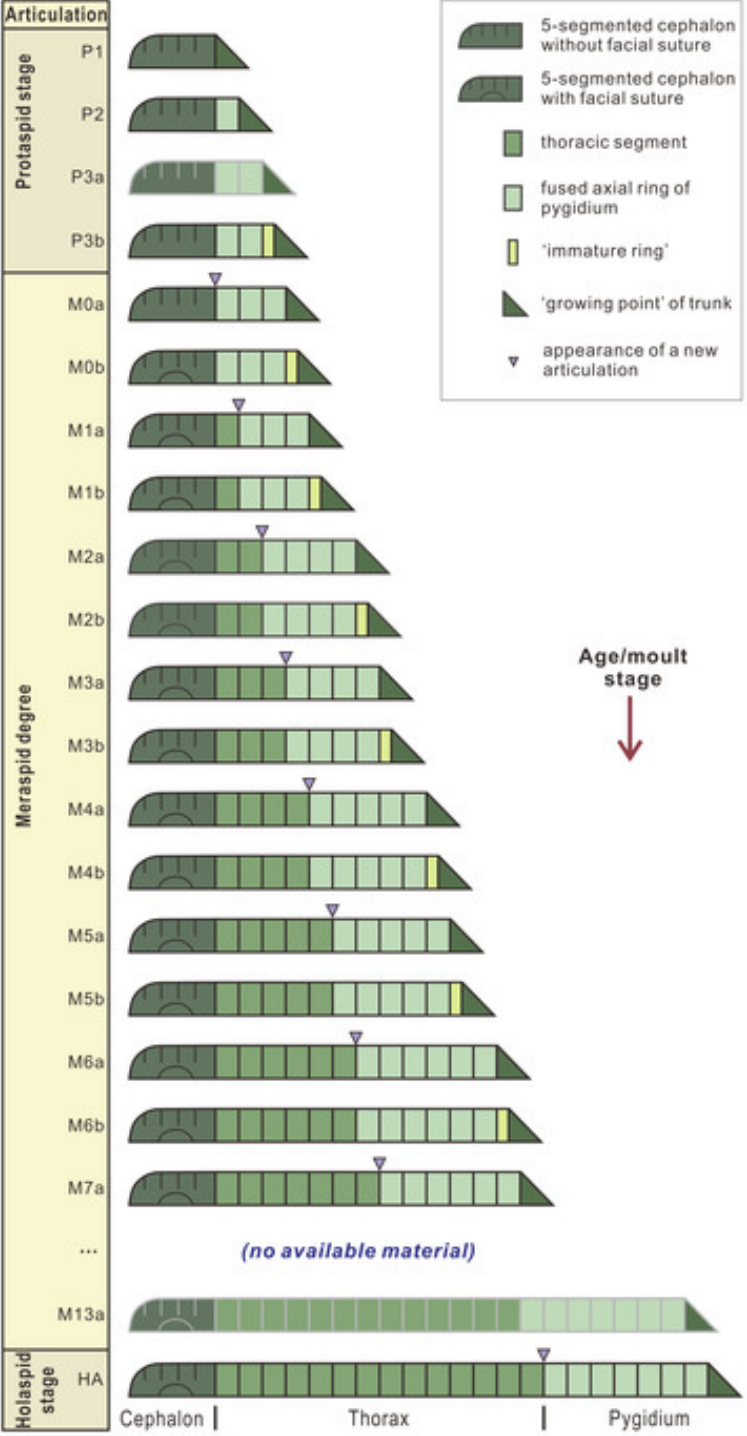
Realistic view of a simple gene hierarchy.

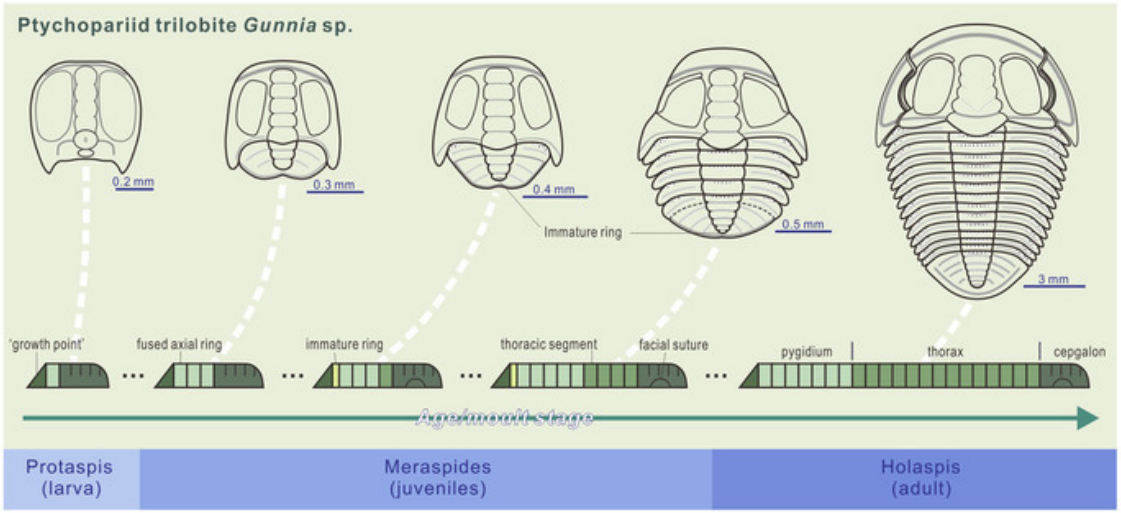


Conserved genes mean that we can even start to apply developmental genetics to the fossil record




Ptychopariid trilobite *Gunnia* sp.
0.2 mm
0.3 mm
0.4 mm
Immature ring
0.5 mm
3 mm
'growth point'
fused axial ring
immature ring
thoracic segment
facial suture
pygidium
thorax
cepgalon
Ontogenetic stage
Protaspis (larva)
Meraspides (juveniles)
Holaspis (adult)


Articulation
Protaspid stage
P1
P2
P3a
P3b
Meraspid degree
M0a
M0b
M1a
M1b
M2a
M2b
M3a
M3b
M4a
M4b
M5a
M5b
M6a
M6b
M7a
...
M13a
Holaspid stage
HA
5-segmented cephalon without facial suture
5-segmented cephalon with facial suture
thoracic segment
fused axial ring of pygidium
'immature ring'
'growing point' of trunk
appearance of a new articulation
Age/moult stage
(no available material)
Cephalon
Thorax
Pygidium


Ptychopariid trilobite Gunnia sp.
0.2 mm
0.3 mm
0.4 mm
Immature ring
0.5 mm
3 mm
'growth point'
fused axial ring
immature ring
thoracic segment
facial suture
pygidium
thorax
cepgalon
Age/moult stage
Protaspis (larva)
Meraspides (juveniles)
Holaspis (adult)

Heterochrony Recap:

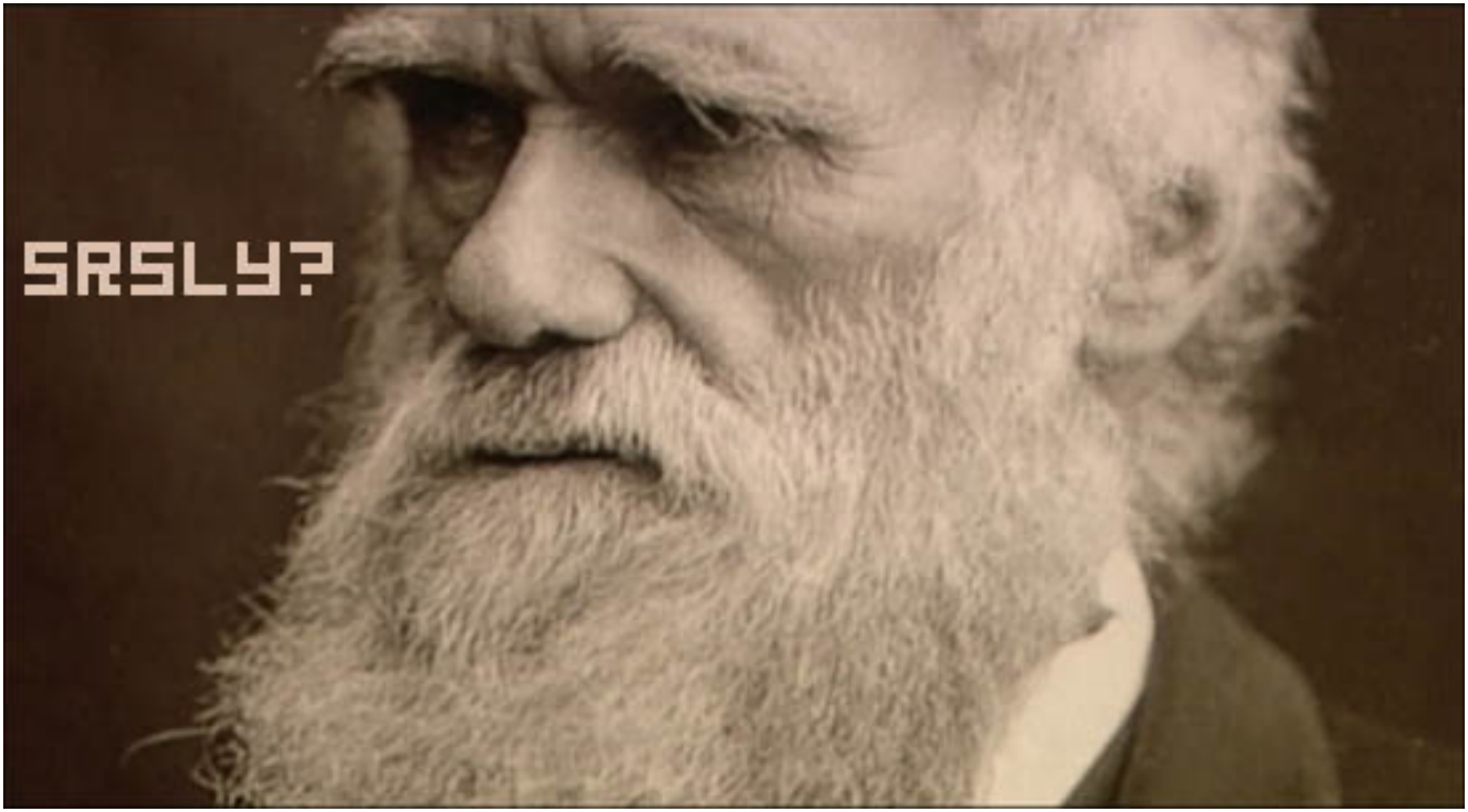
-How ontogenetic sequences evolve

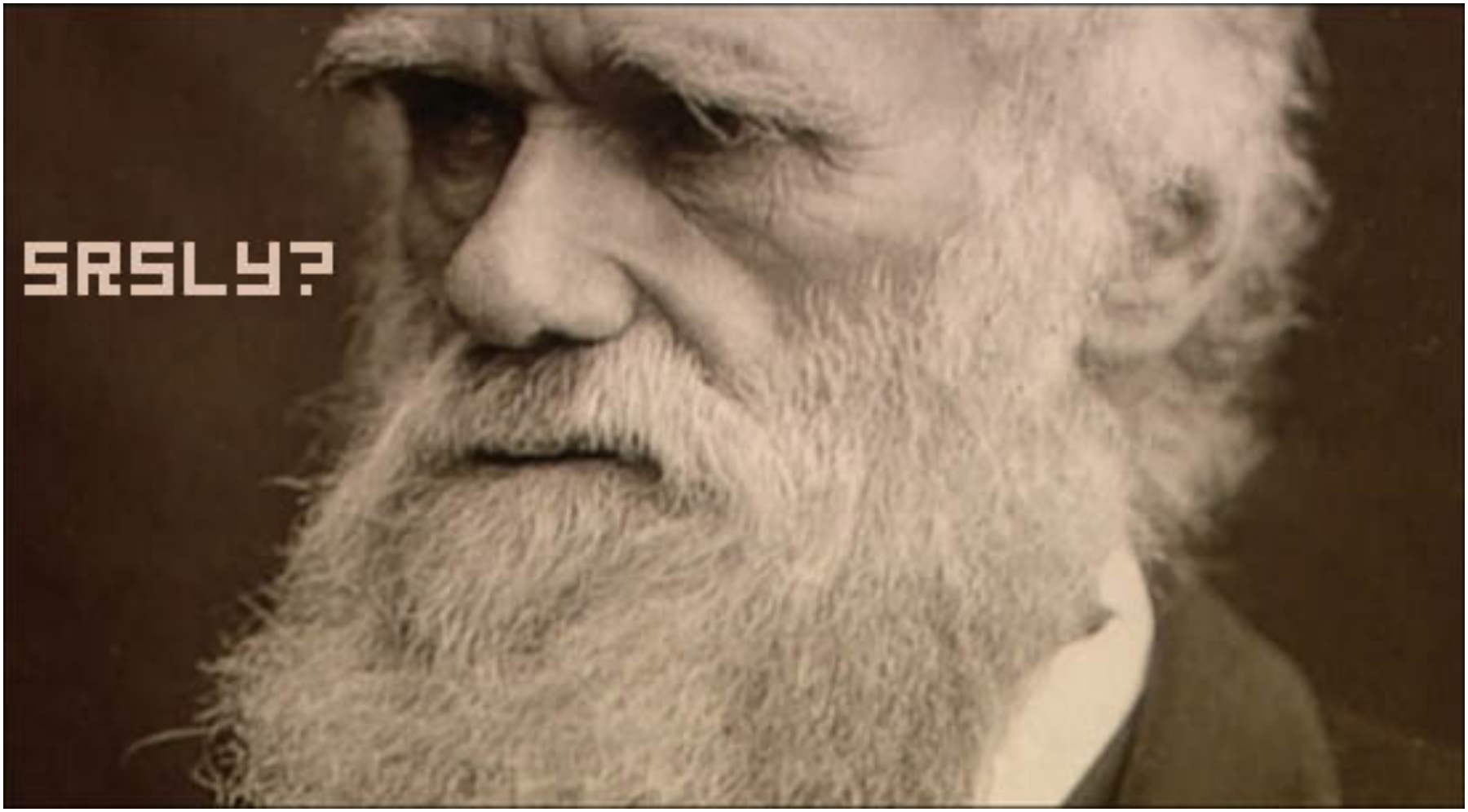
-Combined with Evo Devo we can sometimes tie fossil phylogenies to explicit changes in developmental genetics

-Most macroevolutionary changes stem from changes in developmental timing, so heterochrony is also the study of the origin of variation that natural selection can act on.

Thought for the day:

Combining ontogeny, phylogeny, and heterochrony with breakthroughs in developmental genetics means that in some cases we are looking at hypotheses that directly link genes to fossil macroevolutionary sequences.


SRSLY?



Thank you!