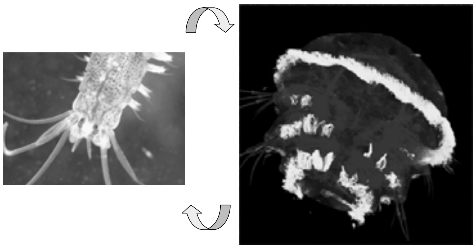
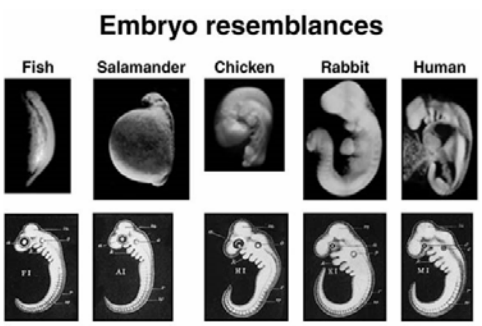
Evo-Devo

Gene expression during development molds morphology.



The metatrochophore larve of the polychaete annelid *Platynereis dumerilii*.
The larva has been labeled with phalloidin which binds to actin (in red)
and anti-Tubulin antibodies (in green).

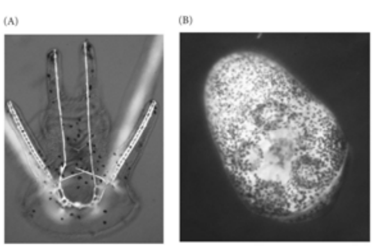
Similarities in early development indicate organisms are derived from a similar plan



Ontogeny recapitulates Phylogeny?

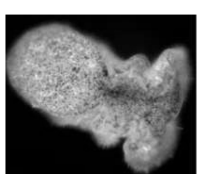
Developmental genes reveal different routes to similar outcomes

Indirect vs. Direct development



Pluteus stage

Hybrid Larva
(resembles seastar)



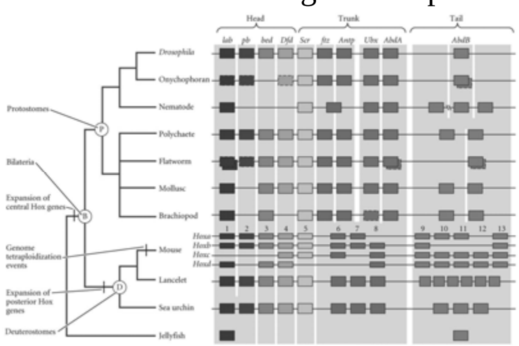
Homology and Homoplasy Revisited

• **Homology:** refers to morphologic traits, behaviors, genes, etc., originating from a common ancestor. **Synapomorphies** and **orthologous genes** fit this concept.

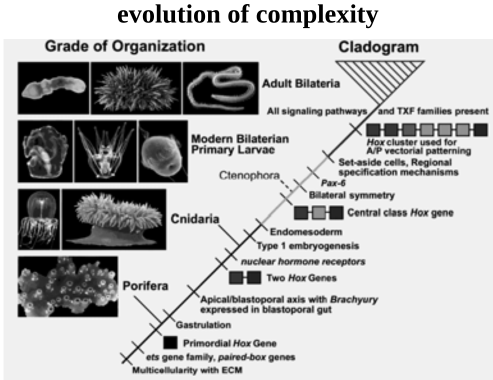
• **Serial Homology:** initially existing structures were gradually modified via discrete intermediary steps until such time as an evolutionary novelty (e.g., jaws) appeared. The body segments of many animals (vertebrates, arthropods etc), are examples of gene duplication on regulatory genes such as homeobox genes, followed by evolution differentiating the duplicated genes.

• **Homoplasy:** Convergence, Parallelism, Reversals. Occurs when characters are similar or analogous, but not originating from a common ancestor.

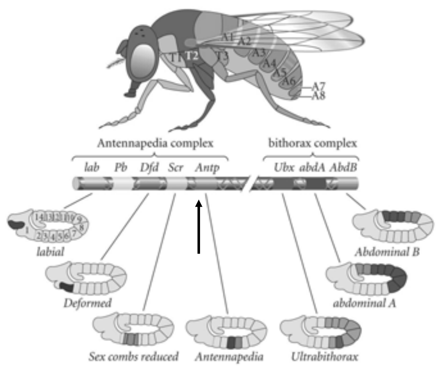
Probable evolution of the metazoan Homeobox or Hox gene complex



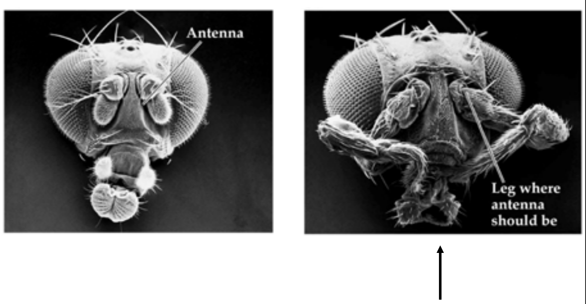
Developmental genes reveal clues about the evolution of complexity



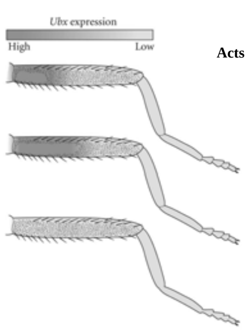
Hox gene expression in *Drosophila*



Developmental genes reveal the basis for alterations of the common plan

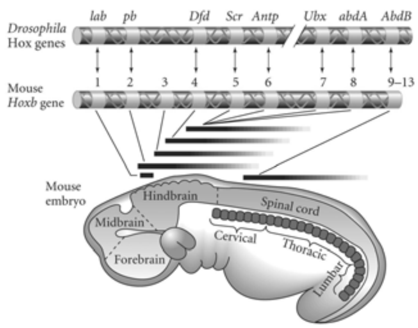


Role of *Ubx* in the evolution of the pattern of epidermal cell hairs in the T3 leg of *Drosophila*



Acts as Transcription Factor

Segment-specific patterning functions of Hox genes in the vertebrate hindbrain



Molecular Evidence for Deep Precambrian Divergences Among Metazoan Phyla

Gregory A. Wray,* Jeffrey S. Levinton, Leo H. Shapiro†

A literal reading of the fossil record suggests that the animal phyla diverged in an "explosion" near the beginning of the Cambrian period. Calibrated rates of molecular sequence divergence were used to test this hypothesis. Seven independent data sets suggest that invertebrates diverged from chordates about a billion years ago, about twice as long ago as the Cambrian. Protostomes apparently diverged from chordates well before echinoderms, which suggests a prolonged radiation of animal phyla. These conclusions apply specifically to divergence times among phyla; the morphological features that characterize modern animal body plans, such as skeletons and coeloms, may have evolved later.

Science 1996. 274:568-573.

Origin of the metazoan phyla: Molecular clocks confirm paleontological estimates

Francisco José Ayala*, Andrey Rzhetsky†, and Francisco J. Ayala‡

*Institute of Molecular Evolutionary Genetics, Pennsylvania State University, University Park, PA 16802; †Columbia Genome Center, Columbia University, New York, NY 10032; and ‡Department of Ecology and Evolutionary Biology, University of California, Irvine, CA 92697

ABSTRACT The time of origin of the animal phyla is controversial. Abundant fossils from the major animal phyla are found in the Cambrian, starting 544 million years ago. Many paleontologists hold that these phyla originated in the late Neoproterozoic, during the 160 million years preceding the Cambrian fossil explosion. We have analyzed 18 protein-coding gene loci and estimated that protostomes (arthropods, annelids, and mollusks) diverged from deuterostomes (echinoderms and chordates) about 670 million years ago, and chordates from echinoderms about 600 million years ago. Both estimates are consistent with paleontological estimates. A published analysis of seven gene loci that concludes that the corresponding divergence times are 1,200 and 1,000 million years ago is shown to be flawed because it extrapolates from slow-evolving vertebrate rates to faster-evolving invertebrate rates, as well as in other ways.

PNAS 1998. 95:606-611.

The Cambrian "explosion": Slow-fuse or megatonnage?

Simon Conway Morris*

Department of Earth Sciences, University of Cambridge, Cambridge CB2 3EQ, United Kingdom

Clearly, the fossil record from the Cambrian period is an invaluable tool for deciphering animal evolution. Less clear, however, is how to integrate the paleontological information with molecular phylogeny and developmental biology data. Equally challenging is answering why the Cambrian period provided such a rich interval for the redeployment of genes that led to more complex bodyplans.

William Buckland knew about it, Charles Darwin characteristically agonized over it, and still we do not fully understand it. "It," of course, is the seemingly abrupt appearance of animals in the Cambrian "explosion." The crux of this evolutionary problem can be posed as a series of interrelated questions. Is it a real event or simply an artifact of changing fossilization potential? If the former, how rapidly did it happen and what are its consequences for understanding evolutionary processes? The Cambrian explosion addresses problems of biology as diverse as the origin of metazoan bodyplans, the role of developmental genetics, the validity of molecular clocks, and the influence of extrinsic factors such as ocean chemistry and atmospheric oxygen.

PNAS 2000. 97:4426-4429.

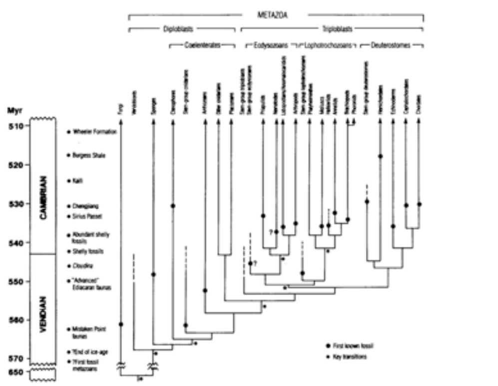


Fig. 1. Principal events across the Vendian-Cambrian boundary, spanning an interval of approximately 60 Myr (570–510 Myr), in the context of the early evolution of metazoans.

Three-dimensional preservation of algae and animal embryos in a Neoproterozoic phosphorite

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** Botanical Museum, Harvard University, 26 Oxford Street, Cambridge, Massachusetts 02138, USA*
† College of Life Sciences, Beijing University, Beijing 100871, People's Republic of China

Phosphorites of the late Neoproterozoic (570 ± 20 Myr BP) Doushantuo Formation, southern China, preserve an exceptional record of multicellular life from just before the Ediacaran radiation of macroscopic animals. Abundant thalli with cellular structures preserved in three-dimensional detail show that latest-Proterozoic algae already possessed many of the anatomical and reproductive features seen in the modern marine flora. Embryos preserved in early cleavage stages indicate that the divergence of lineages leading to bilaterians may have occurred well before their macroscopic traces or body fossils appear in the geological record. Discovery of these fossils shows that the early evolution of multicellular organisms is amenable to direct palaeontological inquiry.

Nature 1998. 391:553-558.

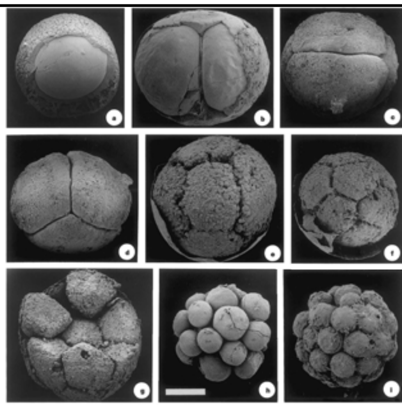
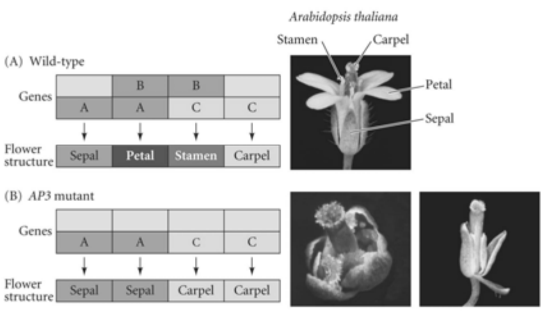


Figure 5 Fossil embryos preserving different stages of cleavage from the Doushantuo phosphorite. **a**, Fertilized (?) egg with thick membrane. **b**, Two-cell stage. **c**, **d**, Four-cell stage, **c** and **d** show different views of the same specimen, illustrating the tetrahedral geometry. **e**, Eight-cell stage. **f**, **g**, Later cleavage stages showing faceted cell geometry and, in **g**, the three-dimensional distribution of cells. **h**, **i**, Multicellular structures that record later cleavage stages or, especially possible for **h**, colonial protists. Scale bar (in **h**): 200 µm for **a**, **e**, **f**, **g**, **h** and **i**; 150 µm for **b**; and 240 µm for **c** and **d**.

The ABC model of flower development



Adaptive radiations: twice with land plants, Silurian/Devonian and again in Cretaceous.

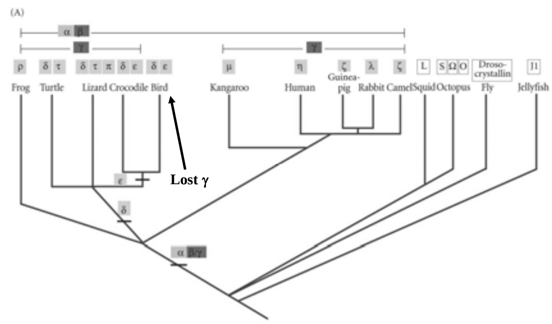
Co-option and Evolution of Novel Characters

Exaptation: novel uses of pre-existing morphological traits.

Co-option: novel uses of genes and developmental pathways.

Examples:
- Crystallins derived from heat-shock proteins, etc.
- Pigmentation “eye-spots” in butterfly wings.
- Development of tetrapod appendages.

Diversity of animal lens crystallin proteins

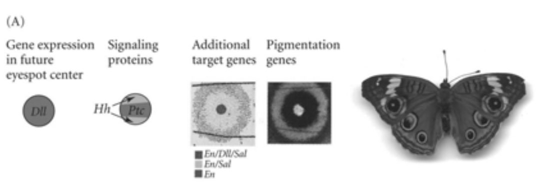


Diversity of animal lens crystallin proteins

(B)

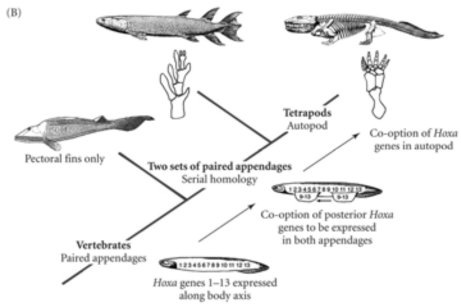
Crystallin	Ancestral protein function
α	Small heat shock proteins
β/γ	Related to bacterial stress protein
ρ	NADPH-dependent reductase
δ	Arginosuccinate lyase
τ	α-Enolase
π	Glyceraldehyde phosphate dehydogenase
ε	Lactate dehydrogenase
μ	Similar to bacterial ornithine deaminase
η	Aldehyde dehydrogenase
ζ	Alcohol dehydrogenase
λ	Hydroxyacyl-CoA dehydrogenase
L	Aldehyde dehydrogenase
S	Glutathione-S-transferase
Ω	Aldehyde dehydrogenase
O	Similar to yeast TSF1
Drosocrystallin	Insect cuticle protein
J1	Similar to chaperonin/60 kd hsp

Co-option of developmental circuits in the evolution of novelties

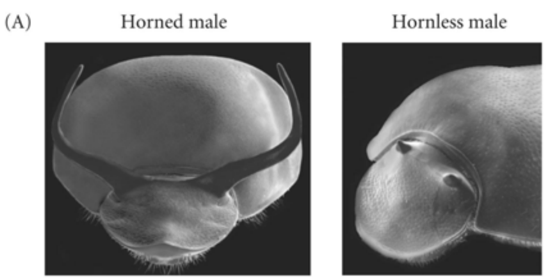


Signaling proteins: Hedgehog (Hh), Patched (Ptc)
Transcription Factors: Distalless (Dll), Spalt (Sal), Engrailed (En)

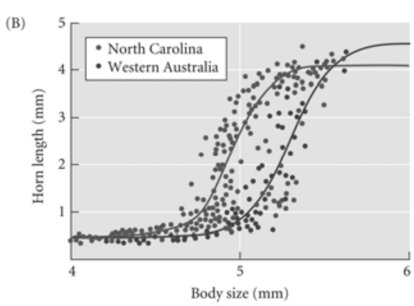
Co-option of developmental circuits in the evolution of novelties



Rapid evolution of an **allometric threshold** in the dung beetle



Rapid evolution of an **allometric threshold** in the dung beetle



Both originated from Europe to reduce pasture poop.