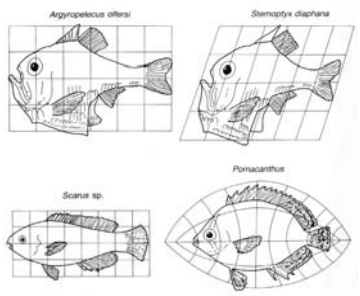
ORIGIN OF EVOLUTIONARY NOVELTIES

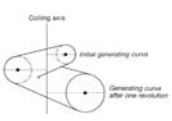
- What are the origins of novel phenotypes?
- Can small quantitative changes lead to large qualitative phenotypic alterations?

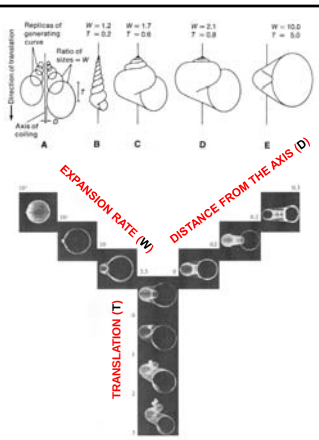
CHANGES IN RELATIVE GROWTH RATES CAN RESULT IN COMPLEX TRANSFORMATIONS OF THE PHENOTYPE



FROM: D'Arcy Thompson (1942)

- SIMPLE SHAPE GENERATING CURVES CAN YIELD A DIVERSE ARRAY OF SHELL MORPHOLOGIES





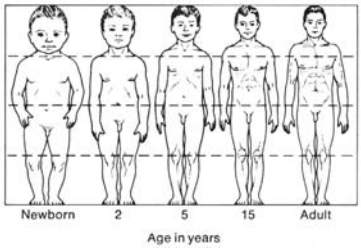
INCORPORTING A DEVELOPMENTAL PERSPECTIVE

Small changes in the patterns of growth and development can lead to dramatic evolutionary modifications of the phenotype.

Two ways to describe developmental relationships:

- **ALLOMETRY:** The relative rate of growth of traits in an organism during development.
- **HETEROCHRONY:** An evolutionary change in the timing or rate of developmental events.

ALLOMETRIC GROWTH IN HUMANS



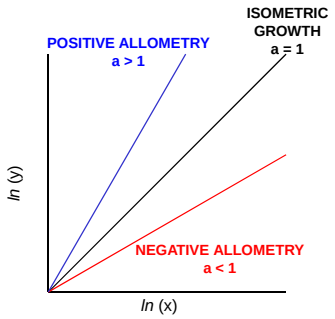
THERE ARE PRONOUNCED DIFFERIENCES IN THE GROWTH RATE AMONG BODY PARTS

ALLOMETRY

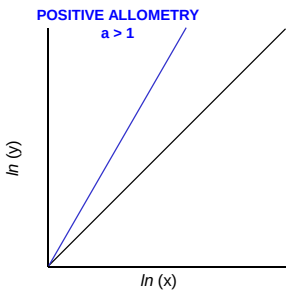
- Consider two correlated traits: **x** & **y**
- A non-linear growth relationship between them can be expressed:

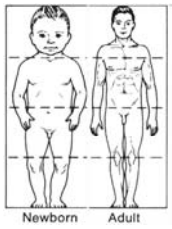
$$y = bx^a$$

- Where **a** is the *allometric coefficient*.



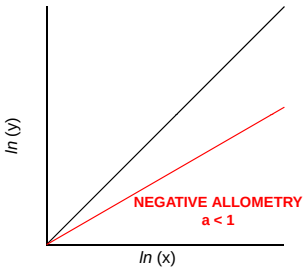
POSITIVE ALLOMETRY: y GROWS RAPIDLY RELATIVE TO x

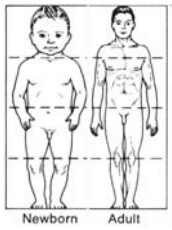




- Legs grow rapidly relative to the torso.

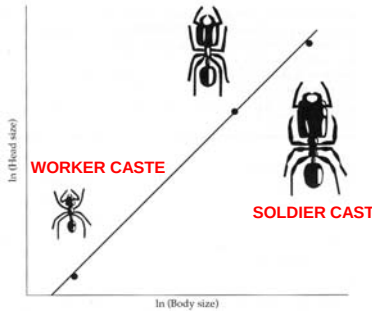
NEGATIVE ALLOMETRY: y GROWS SLOWLY RELATIVE TO x





- Head grows slowly relative to the torso.

ALLOMETRIC GROWTH AND THE DEVELOPMENT OF CASTES IN THE ANT *Pheidole instabilis*

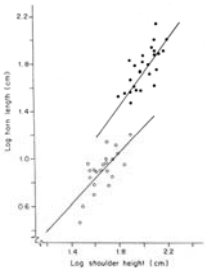


BASED ON HUXLEY 1932

- **The allometric coefficient often exhibits intraspecific variation. In addition, this variation can have a heritable genetic basis.**
- **Thus, allometry can be the fuel for adaptive evolution by natural selection.**

- **ALLOMETRIC GROWTH IN UNGULATES**

Dik-dik



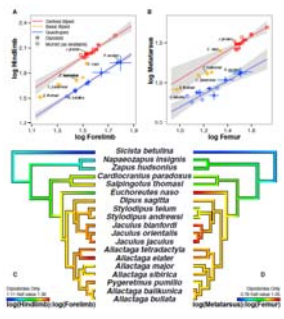
HORN LENGTH AND BODY SIZE IN AFRICAN ANTELOPE SPECIES

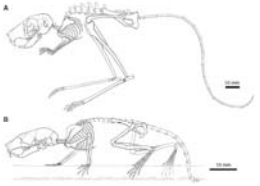
Irish Elk (*Megaloceros*)

Multiple Phylogenetically Distinct Events Shaped the Evolution of Limb Skeletal Morphologies Associated with Bipedalism in the Jerboas

Current Biology Article

Talia Y. Moore,[1] Chris L. Organ,[2] Scott V. Edwards,[1] Andrew A. Biewener,[1] Clifford J. Tabin,[3] Farish A. Jenkins, Jr.,[1] and Kimberly L. Cooper[3,*]

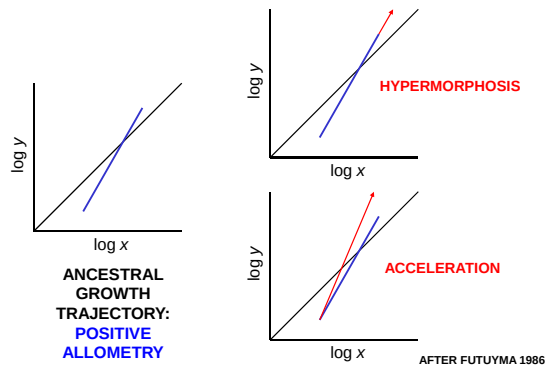




- Allometric Scaling between limbs and within hindlimb elements illustrates the complex evolution of proportion

Current Biology 25, 1–10, November 2, 2015

EVOLUTIONARY CHANGES IN DEVELOPMENT:
PATTERN 1: PERAMORPHOSIS



AFTER FUTUYMA 1986

PATTERN 1: PERAMORPHOSIS

- **HYPERMORPHOSIS**: ***EXTENSION*** **OF ANCESTRAL GROWTH PERIOD LEADS TO AN EXAGGERATION OF ADULT CHARACTERS.**
- **ACCERERATION**: ***INCREASE*** **IN THE RATE OF DEVELOPMENT LEADS TO AN EXAGERATION OF ADULT CHARACTERS.**

HYPERMORPHOSIS IN FOSSIL TITANOTHERES

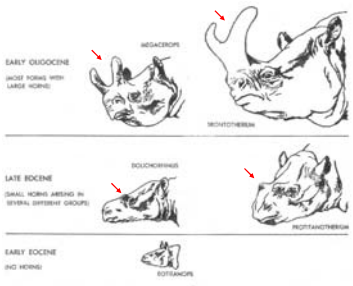


Fig. 28. Evolution of titanothere horns. Only a few of many different lines are shown. (Data from Osborn.)

BRAIN – BODY SIZE RELATIONSHIP IN PRIMATES

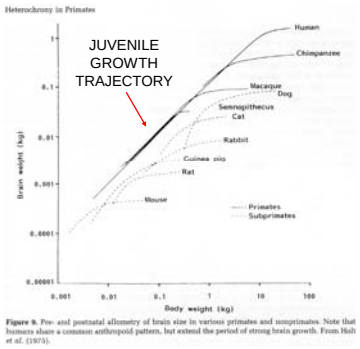
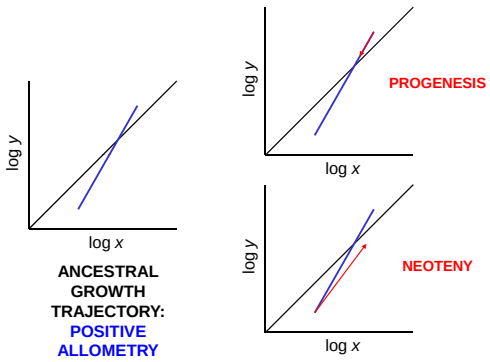


Figure 9. Pre- and postnatal allometry of brain size in various primates and nonprimates. Note that humans share a common anthropoid pattern, but extend the period of strong brain growth. From Holt et al. (1975).

EVOLUTIONARY CHANGES IN DEVELOPMENT: PATTERN 2: PAEDOMORPHOSIS



AFTER FUTUYMA 1986

PATTERN 2: PAEDOMORPHOSIS

- **PROGENESIS**: ***TRUNCATION*** **OF ANCESTRAL GROWTH PERIOD THE LEADS TO THE RETENTION OF JUVENILE CHARACTERS.**
- **NEOTENY**: ***DECREASE*** **IN THE RATE OF DEVELOPMENT LEADS TO THE RETENTION OF JUVENILE CHARACTERS.**

AMPHIBIAN METAMORPHOSIS: A MODEL FOR HETEROCHRONY

TYPICAL LARVAL TIGER SALAMANDER (Ambystoma tigrinum)

NORMAL METAMORPHIC ADULT TIGER SALAMAMDER (Ambystoma tigrinum)

ACCELERATION OF DEVELOPMENT

- **Many amphibian species have lost the free-living larval stage by accelerating development in the egg stage and hatching as fully formed juvenile adults.**

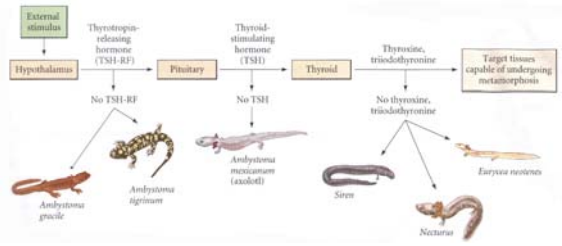
A NUMBER OF SPECIES OF AMBYSTOMATID SALAMANDERS HAVE LOST THE METAMORPHIC ADULT STAGE

A. mexicanum

A. dumerilii

These **NEOTENIC** adult salamanders retain juvenile morphology while becoming sexually mature adults. There is a *disassociation* between developmental systems.

GENETIC BASIS OF METAMORPHIC FAILURE



- This is a common, and independently repeated, theme across a wide diversity of salamander families

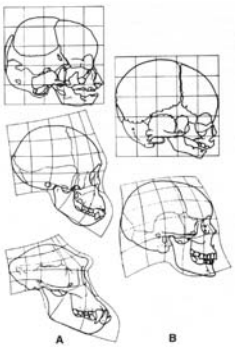
HUMANS AS THE RESULT OF NEOTENIC DEVELOPMENT?

"Of all animal pictures known to me, this is the most manlike." (Naef, 1926)

JUVENILE CHIMPANZEE ADULT CHIMPANZEE

CHIMPANZEE ONTOGENY

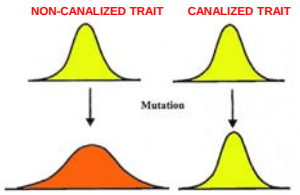
HUMAN ONTOGENY



CANALIZATION AND GENETIC ASSIMILATION

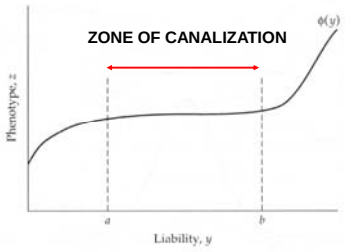
Not all mutations produce mutant phenotypes. Rather, development appears to be buffered so that slight perturbations of the genotype or slight perturbations of the environment do not lead to abnormal phenotypes.

This phenomenon is called **CANALIZATION** (Waddington 1942).



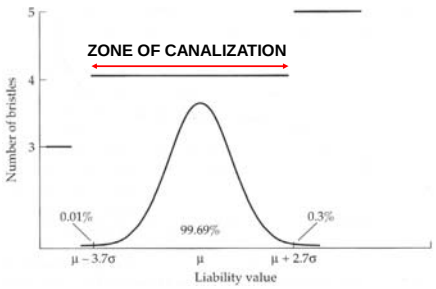
Phenotype

ILLUSTRATION OF CANALIZATION USING A DEVELOPMENTAL MAP



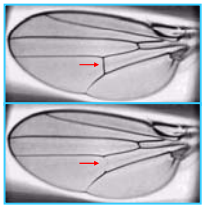
- **LIABILITY = GENOTYPIC VALUE + ENVIRONMENTAL EFFECTS**

DEVELOPMENTAL MAP OF BRISTLE NUMBER IN DROSOPHILA

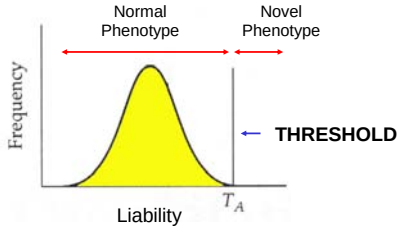


GENETIC ASSIMILATION

- Waddington noticed that *environmental stress* (such as heat shock) could "break" the canalization and result in the production of novel phenotypes.
- These novel phenotypes could then be selected on to produce a population that expressed the new type without the environmental stimulus.
- He called this phenomenon ***genetic assimilation***.

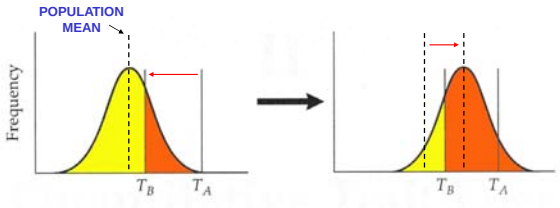


WING VEINATION IN DROSOPHILA CAN BE MODELED AS A THRESHOLD TRAIT



- Under typical environmental conditions *all* of the individuals have the normal wing phenotype

- Heat shock moves the threshold so that now some individuals exhibit the novel wing phenotype.
- Selection on the novel type advances the population mean so that now some individuals exhibit the novel phenotype even without heat shock.



Evolution of a Polyphenism by Genetic Accommodation

Yuichiro Suzuki and H. Frederik Nijhout

Fashion statement. Tobacco hornworms can evolve a finely tuned sensitivity to heat that causes them to emerge green instead of black.

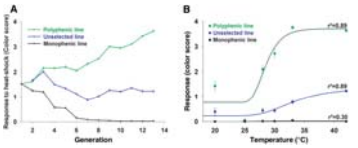
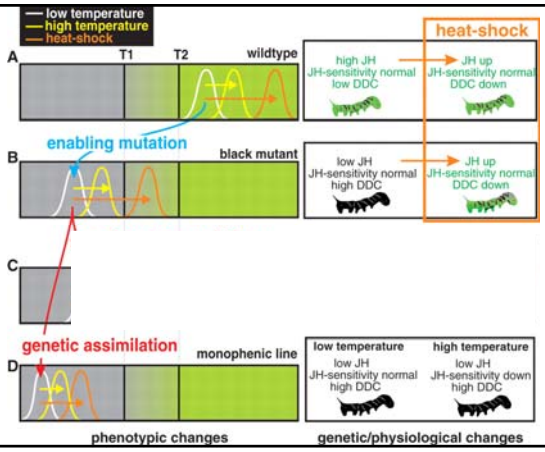


Fig. 2. Effect of selection on temperature-mediated larval color change. (**A**) Changes in the mean coloration of heat-shocked larvae in response to selection for increased (green) and decreased (black) color response to heat-shock treatments, and no selection (blue). (**B**) The reaction norm of generation 13 lines reared at constant temperatures between 20°C and 33°C, and heat-shocked at 42°C. The curves are sigmoidal regressions on the mean data points. Error bars represent 1 SE.

Science 3 FEB 2006 311:650-652

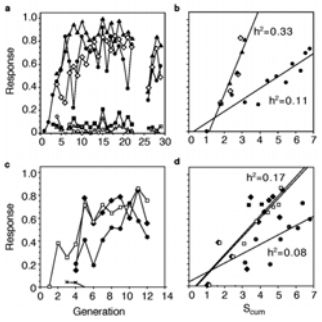


HEAT-SHOCK PROTEIN Hsp90 AS A CAPACITOR OF MORPHOLOGICAL EVOLUTION

FROM:Rutherford & Lundquist. 1998. *Nature* 396:336-342

HERITABLE DEFECTS IN MORPHOLOGY IN RESPONSE TO STRESS

- **Selection for deformed-eye trait.** →
- **Selection for wing-vein trait.** →



FROM:Rutherford & Lundquist. 1998. *Nature* 396:336-342

Hsp90 PROVIDES A MECHANISM FOR PROMOTING EVOLUTIONARY CHANGE IN CHANALIZED DEVELOPMENTAL SYSTEMS

- **The normal function of Hsp90 is to stabilize signal transduction proteins that are important components of numerous developmental pathways.**
- **Heat shock causes other proteins in the cell to become unstable and Hsp90 is recruited away from its normal function to the more generalized function of stabilizing these partially denatured proteins.**
- **As a result less Hsp90 is available to maintain normal developmental pathways.**
- **Hsp90m may also play a role in suppressing transposon activity and reducing incoming mutations.**

Hsp90 prevents phenotypic variation by suppressing the mutagenic activity of transposons

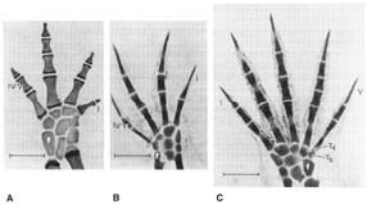
Valeria Specchia[1], Lucia Piacentini[1], Patrizia Tritto[1], Laura Fanti[1], Rosalba D'Alessandro[1], Giacchino Palumbo[1], Sergio Pimpinelli[1] & Mario P. Bozzetti[1]

nature Vol 463|4 February 2010|doi:10.1038/nature08739

THE EVOLUTIONARY LOSS OR REDUCTION OF COMPLEX STRUCTURES IS A COMMON PATTERN.

- **EXAMPLE: CAVE-DWELLING ORGANISMS**

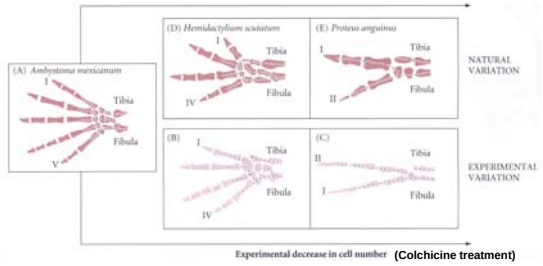
REDUCTION IN DIGIT NUMBER



DERIVED PATTERN

ANCESTRAL PENTADACTYL PATTERN

EVOLUTIONARY REDUCTION IN DIGIT # ⟶



EXPERIMENTAL REDUCTION IN DIGIT # ⟶

Hampé's Experimental Reconstitution of an Ancestral Phenotype

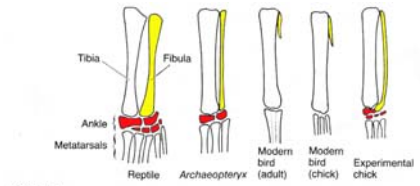


FIGURE 29
The development of the leg and ankle bones of Hampé's experimental chicks (right), compared to their state in reptiles, *Archaeopteryx*, and the normal condition in modern birds. (From Frazzetta 1975)

ORIGIN OF MAJOR EVOLUTIONARY NOVELTIES

- **Almost all macro-evolutionary change can be attributed to the gradual modification of existing structures, e.g., changes in allometric growth patterns, and heterochronic changes in the relative timing of developmental events.**
- **Small changes in regulatory/developmental pathways can be magnified into major changes in the phenotype.**
- **Canalized traits can be reservoirs of "hidden" genetic variation which can lead to the sudden appearance of novel phenotypes.**