The New Field of

Evo-Devo

How evolution re-wires genomes
to re-program development
to re-configure anatomy.

Lewis Held
Texas Tech

Outline

Anatomy ≈ Geometry

Cellular Programming

Constraints on Evolution → Developmental / Genetic

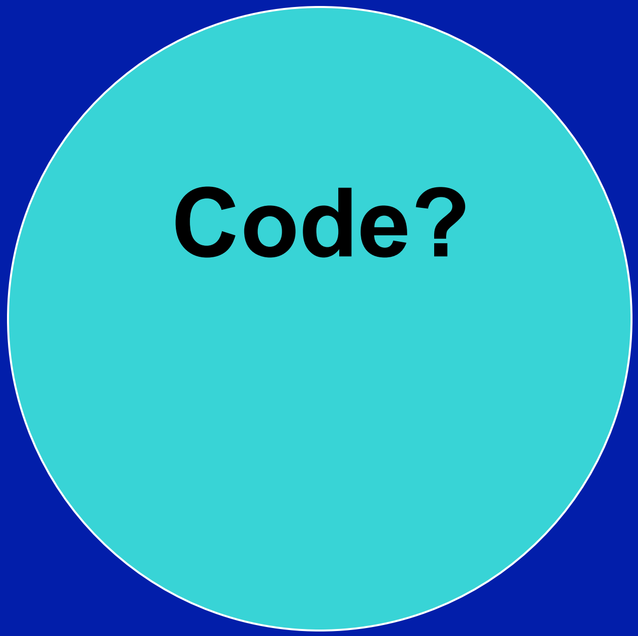
Human Evolution

- Why are we so naked?
- How did we get so brainy?

Anatomy =
Coding of cells in the body

Geometry =
Coding of points in space

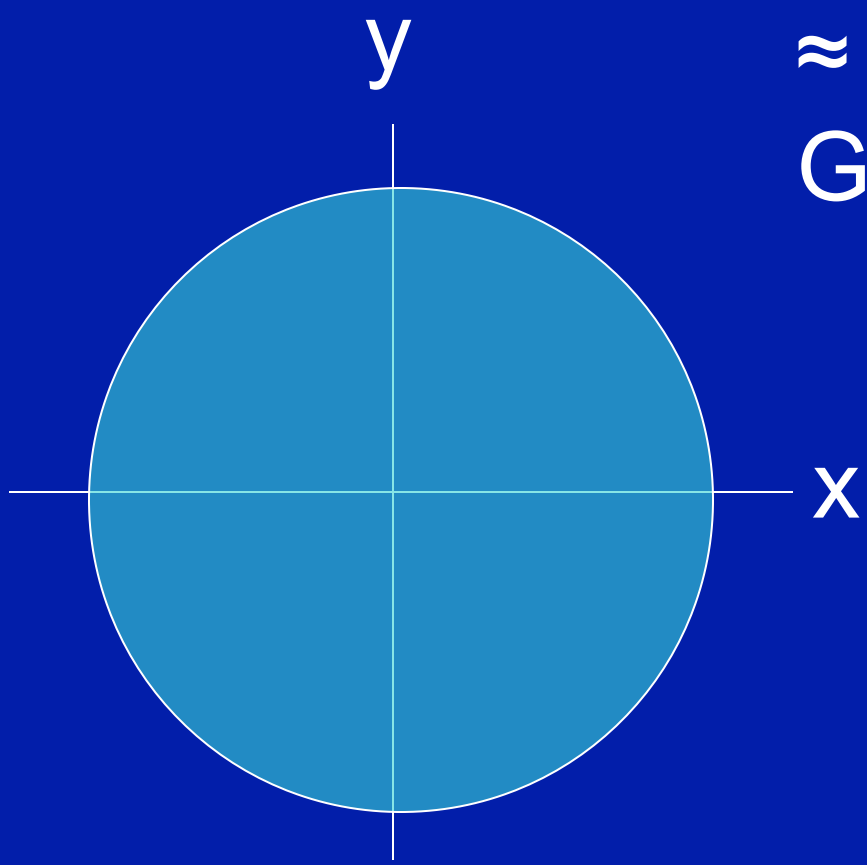
Example:
Circle

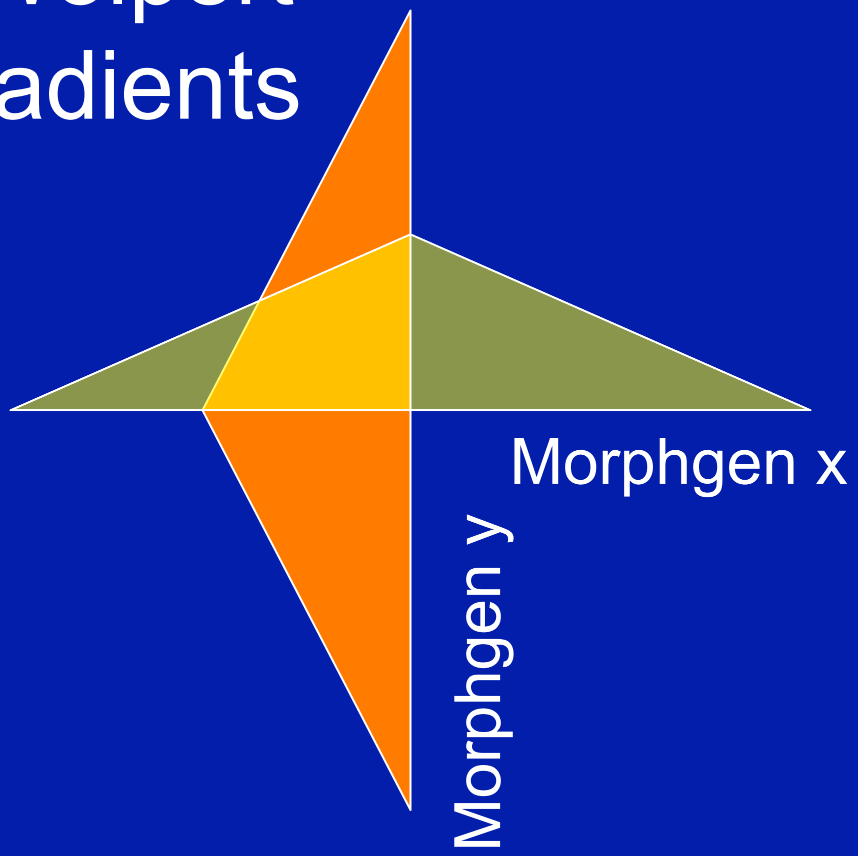


Code = Cartesian Coordinates?

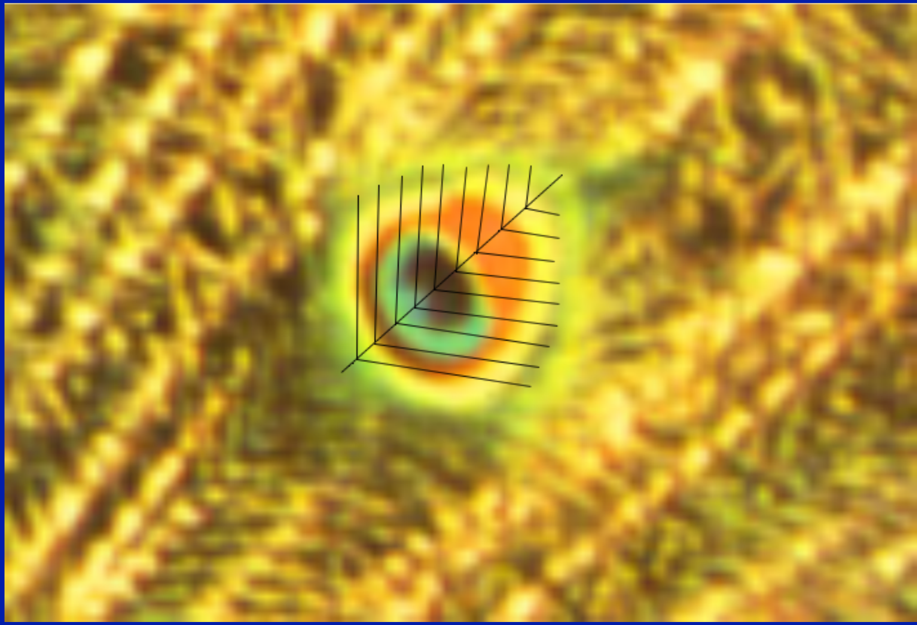
Plot all (x,y), where $x^2 + y^2 = r^2$.

≈ Wolpert Gradients





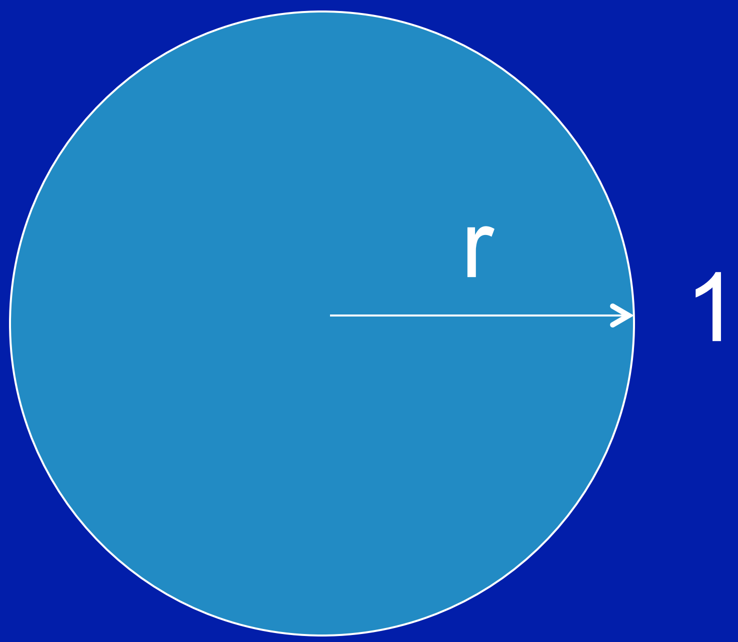
Hmmm …



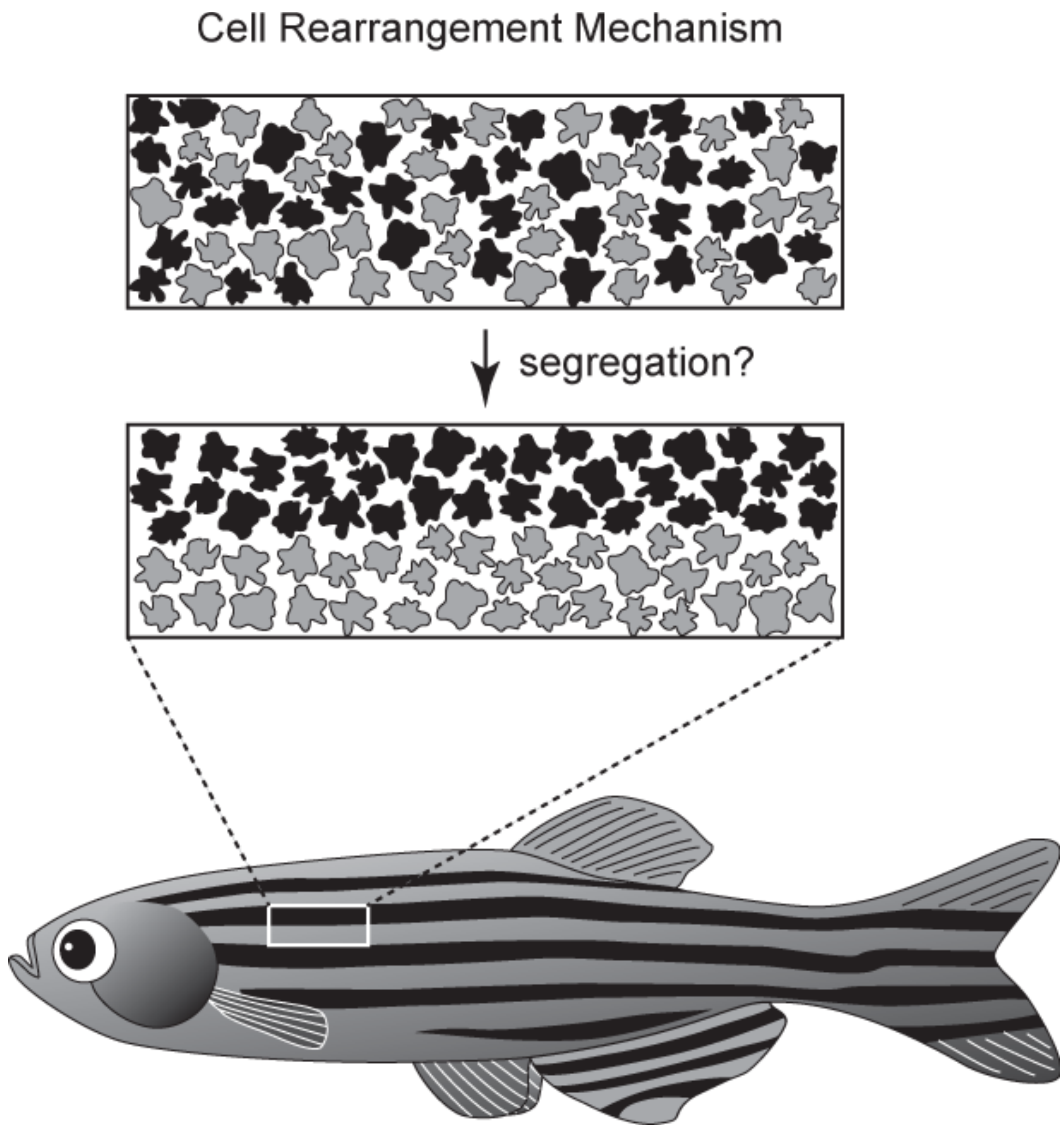

Cartesian? Really?
Try Polar Coordinates!
r
θ

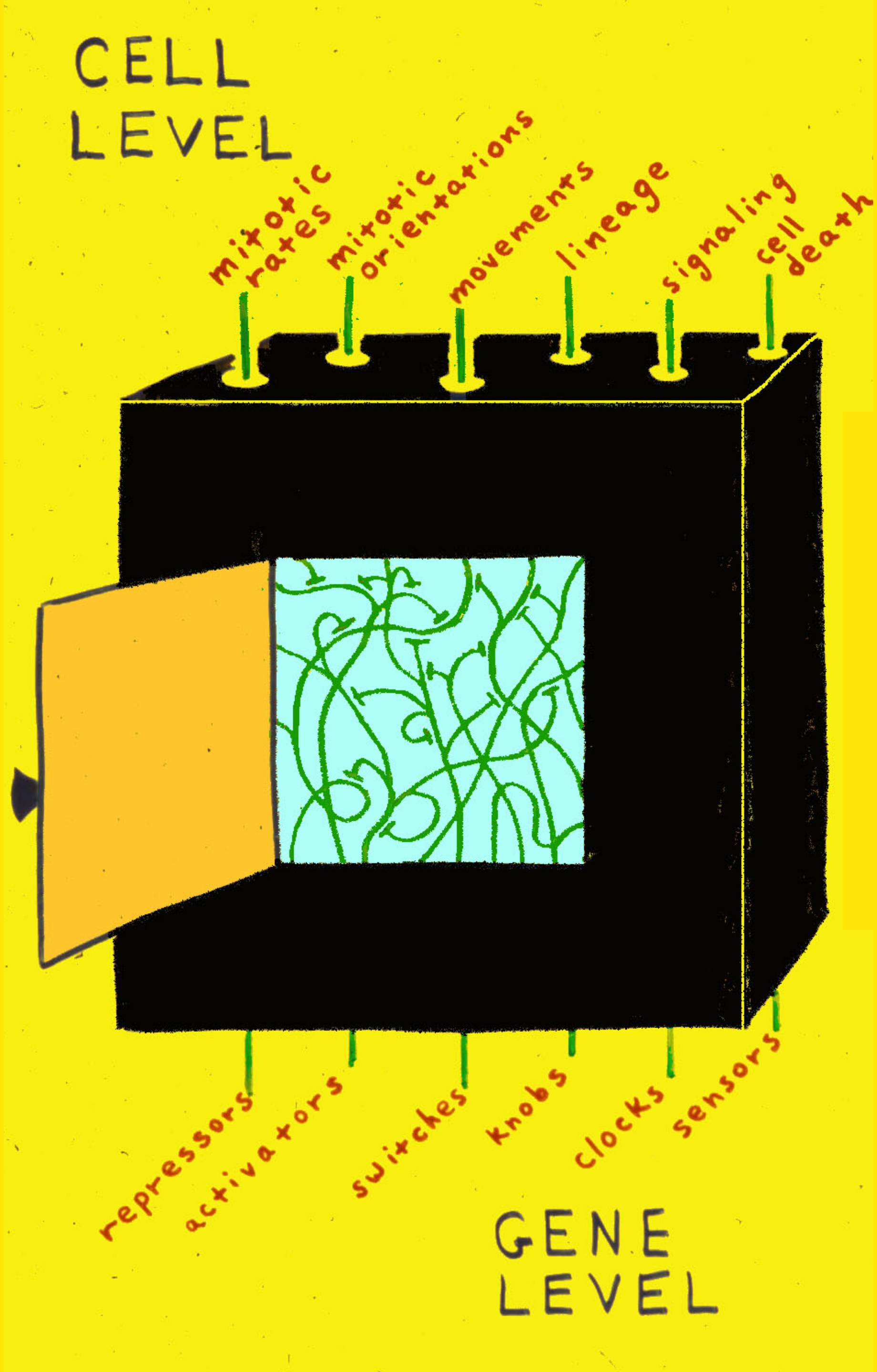
Code = Polar Coordinates?

Plot all (r, θ), where $r < 1$.



… but cells can be active (not just passive)!



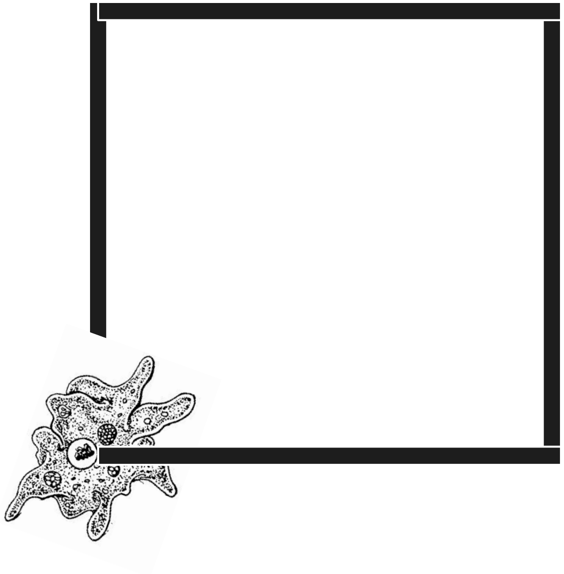


CELL LEVEL
mitotic rates
mitotic orientations
movements
lineage
signaling
cell death
repressors
activators
switches
knobs
clocks
sensors
GENE LEVEL

Cell Commands:

Square

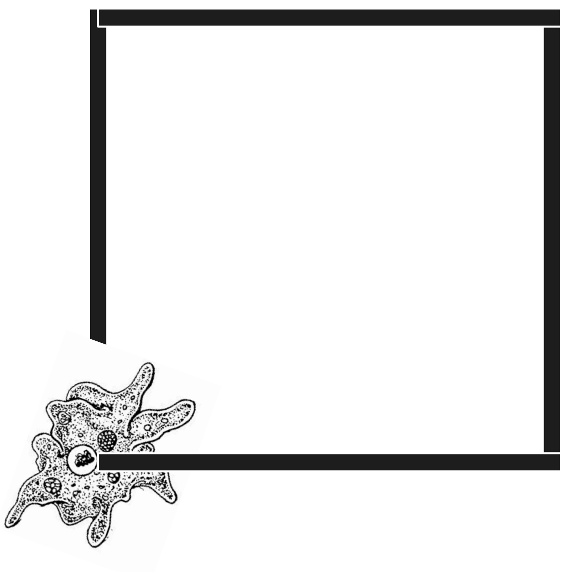
Crawl forward 100 units.
Turn right 90 degrees.
Repeat 4 times.



Cell Commands:

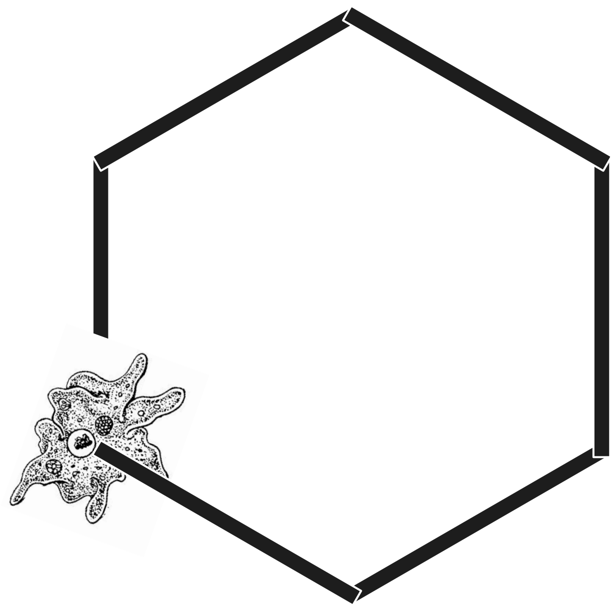
Square

Crawl forward 100 units.
Turn right 90 degrees.
Repeat 4 times.



Hexagon

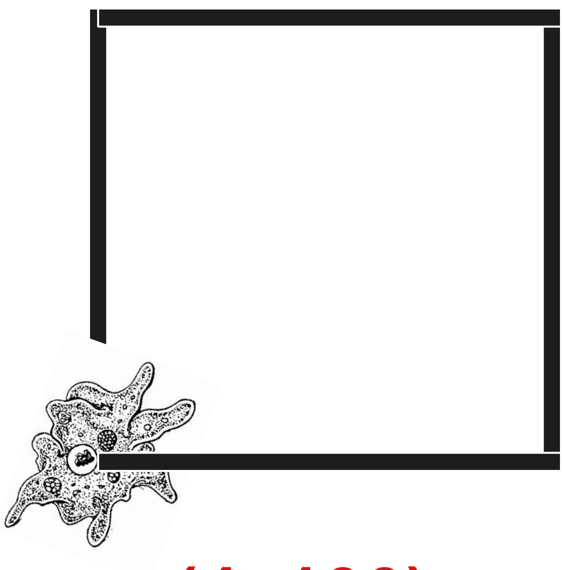
Crawl forward 60 units.
Turn right 60 degrees.
Repeat 6 times.



Cell Commands:

Square

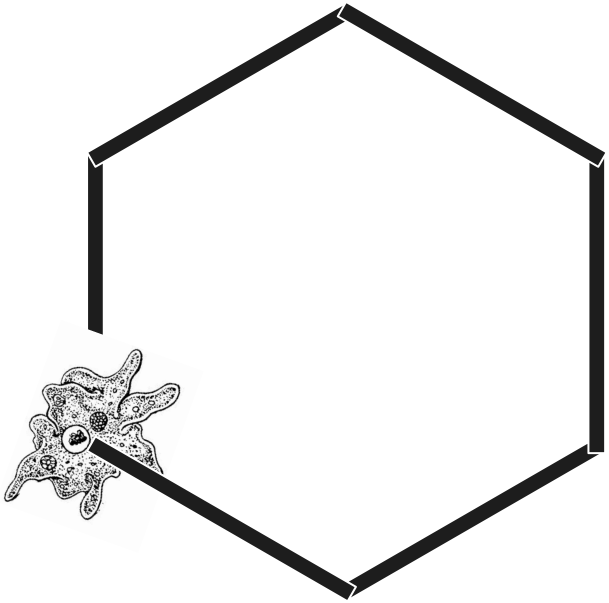
Crawl forward 100 units.
Turn right 90 degrees.
Repeat 4 times.



(4, 100)

Hexagon

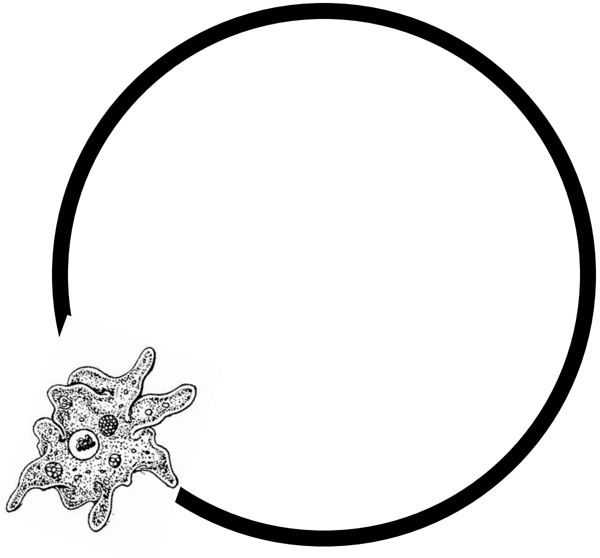
Crawl forward 60 units.
Turn right 60 degrees.
Repeat 6 times.



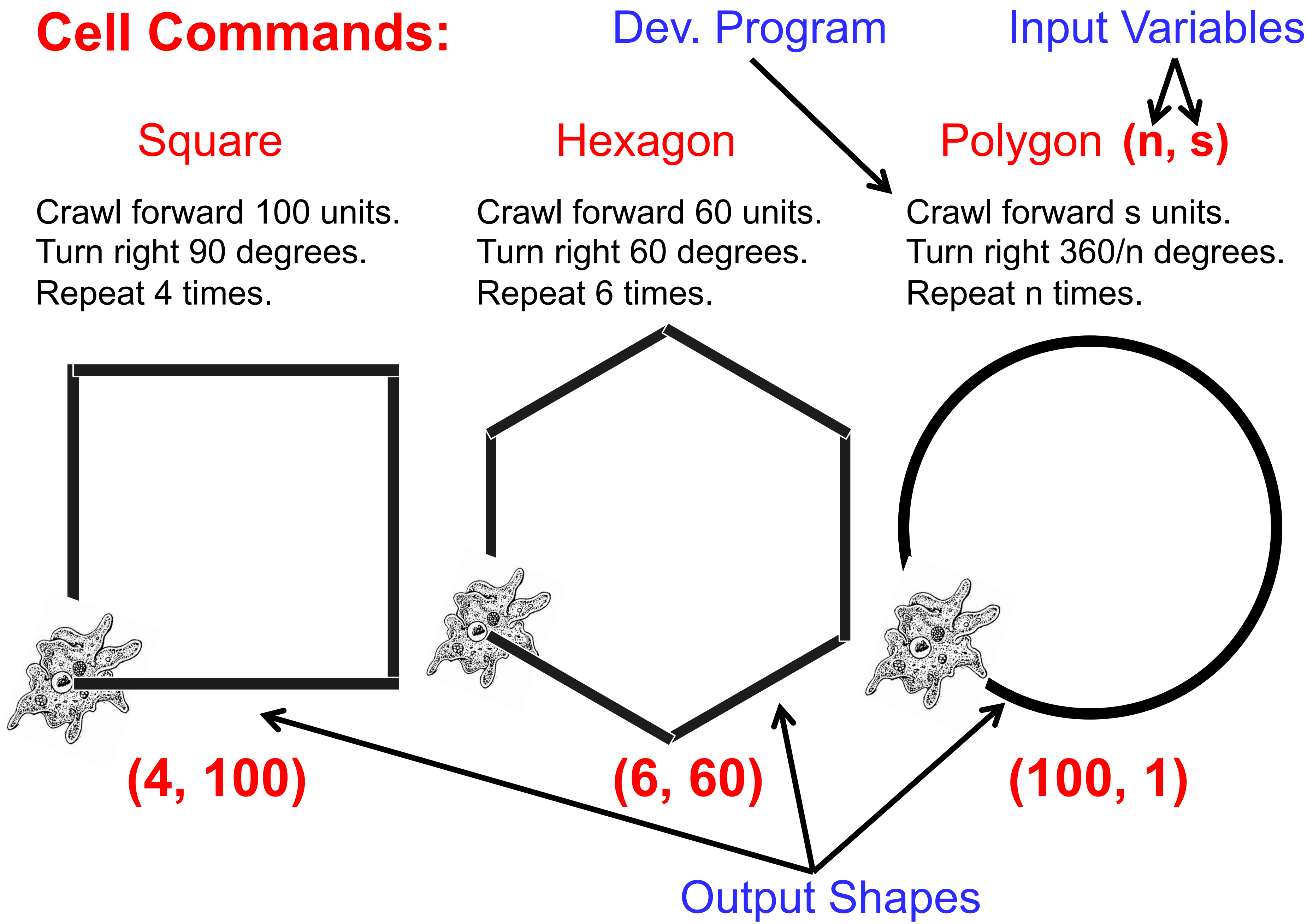
(6, 60)

Polygon **(n, s)**

Crawl forward s units.
Turn right 360/n degrees.
Repeat n times.



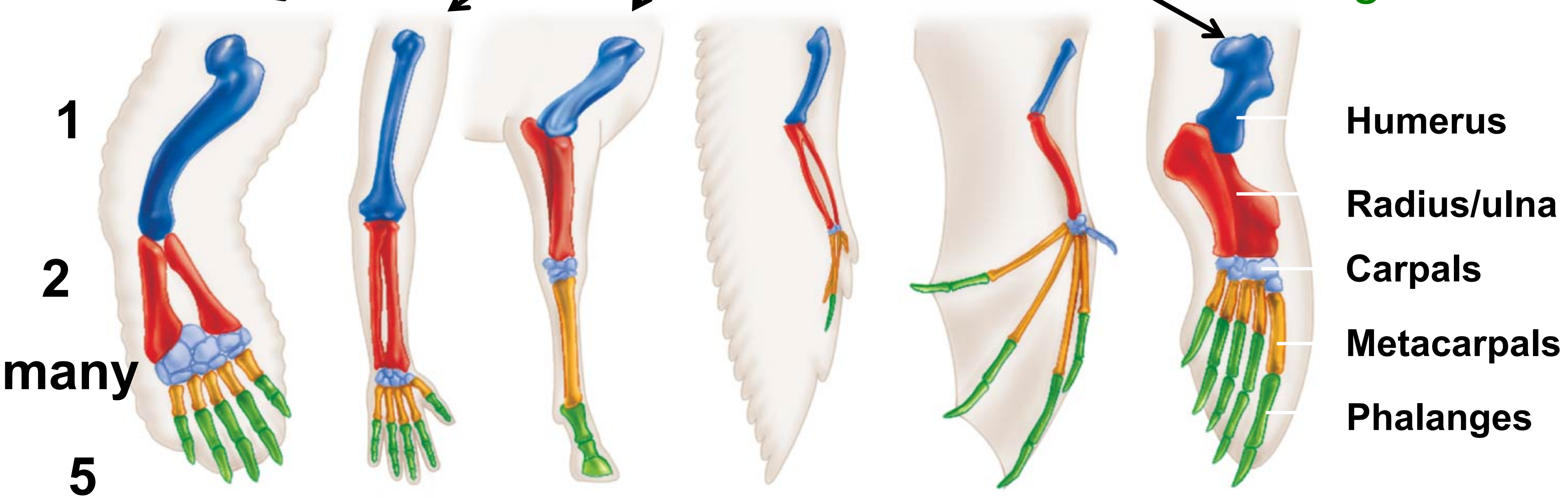
(100, 1)


Cell Commands:
Dev. Program
Input Variables
Square
Hexagon
Polygon (n, s)
Crawl forward 100 units.
Turn right 90 degrees.
Repeat 4 times.
Crawl forward 60 units.
Turn right 60 degrees.
Repeat 6 times.
Crawl forward s units.
Turn right 360/n degrees.
Repeat n times.
(4, 100)
(6, 60)
(100, 1)
Output Shapes

Homology =
Similarity due to ➔ **Descent … with modification**

Dev. Program — Input Variables

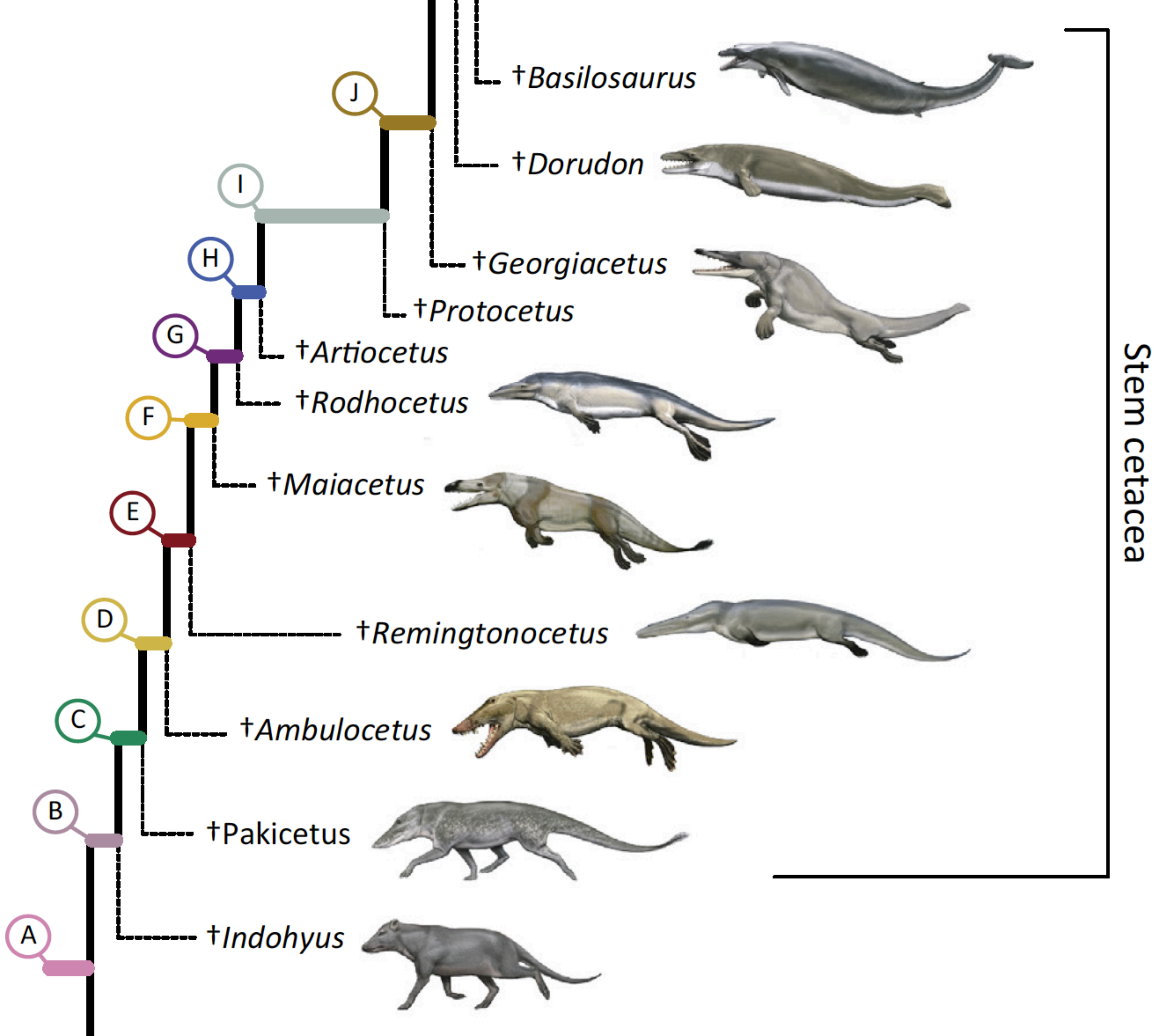
Cell Commands: 1:2:many:5 — Limb **(n, s)** → Bone sizes, Joint angles



Output Anatomies

Q: How does evolution rewire the genome?

A: By changing the inputs to a conserved program, which changes anatomy.


J
†Basilosaurus
†Dorudon
I
†Georgiacetus
H
†Protocetus
G
†Artiocetus
†Rodhocetus
F
†Maiacetus
E
D
†Remingtonocetus
C
†Ambulocetus
B
†Pakicetus
A
†Indohyus
Stem cetacea

Review

Trends in Ecology & Evolution June 2014, Vol. 29, No. 6

Molecular evolution tracks macroevolutionary transitions in Cetacea

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[2] Department of Biology, University of California-Riverside, Riverside, CA 92521, USA

Cetacea (whales, dolphins, and porpoises) is a model group for investigating the molecular signature of macroevolutionary transitions. Recent research has begun to reveal the molecular underpinnings of the remarkable anatomical and behavioral transformation in this clade. This shift from terrestrial to aquatic environments is arguably the best-understood major morphological transition in vertebrate evolution. The ancestral body plan and physiology were extensively modified and, in many cases, these crucial changes are recorded in cetacean genomes. Recent studies have highlighted cetaceans as central to understanding adaptive molecular convergence and pseudogene formation. Here, we review current research in cetacean molecular evolution and the potential of Cetacea as a model for the study of other macroevolutionary transitions from a genomic perspective.

A poster child for macroevolution

The evolution of cetaceans (see Glossary) has emerged as a poster child for macroevolution, and is one of the best-

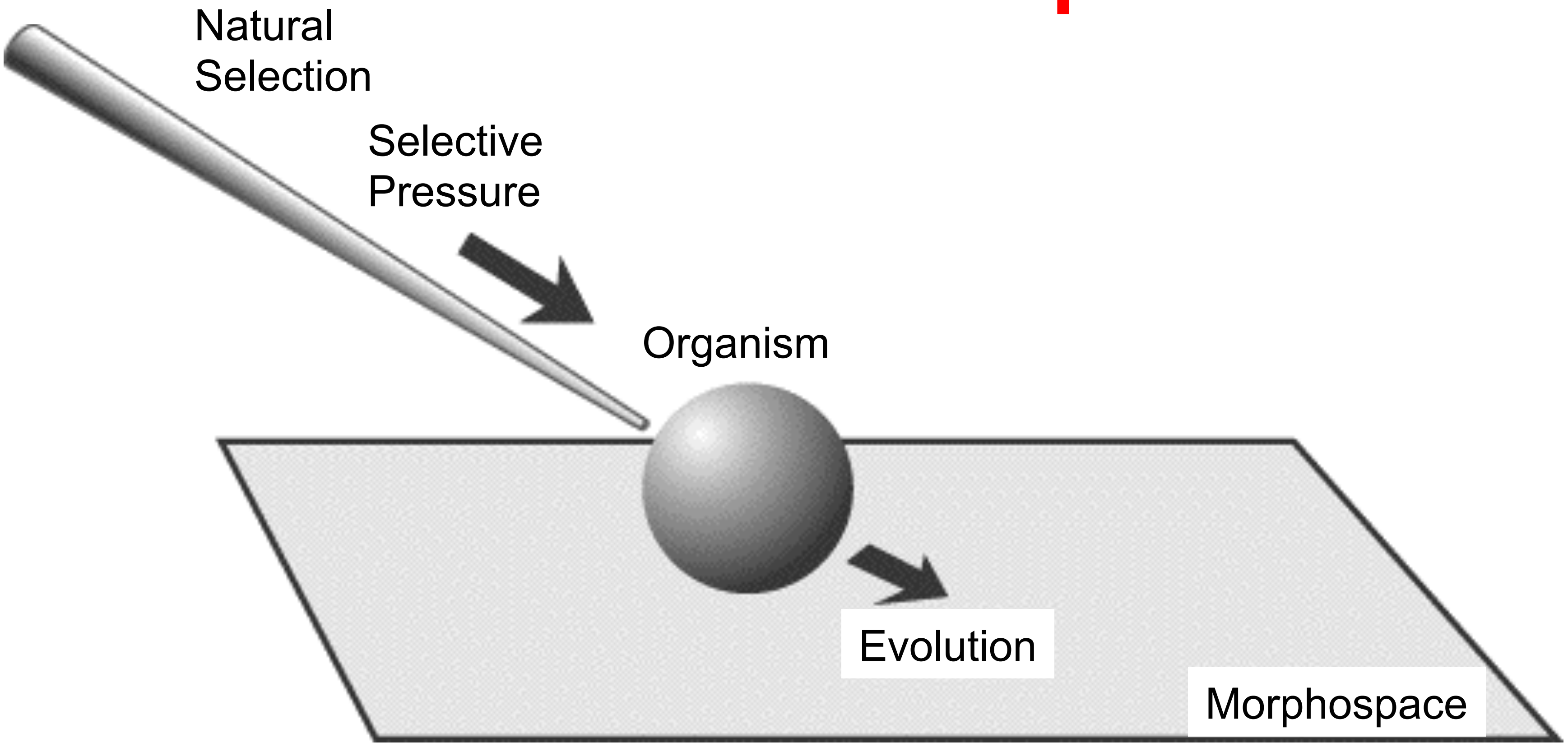
Cetacea offers notable advantages relative to other taxa that also have experienced major anatomical and ecological reorganizations. Phylogenetic hypotheses for extinct and extant taxa are well developed (Figure 1), and include molecular divergence times among extant species with integration of extensive fossil data [4–8]. Semiaquatic hippopotamids (hippopotamuses), potential extant 'intermediate forms,' share multiple aquatic traits with cetaceans (Figure 2A,B) and might provide critical genetic insights into the early evolution of Cetacea (Figure 1).

Glossary

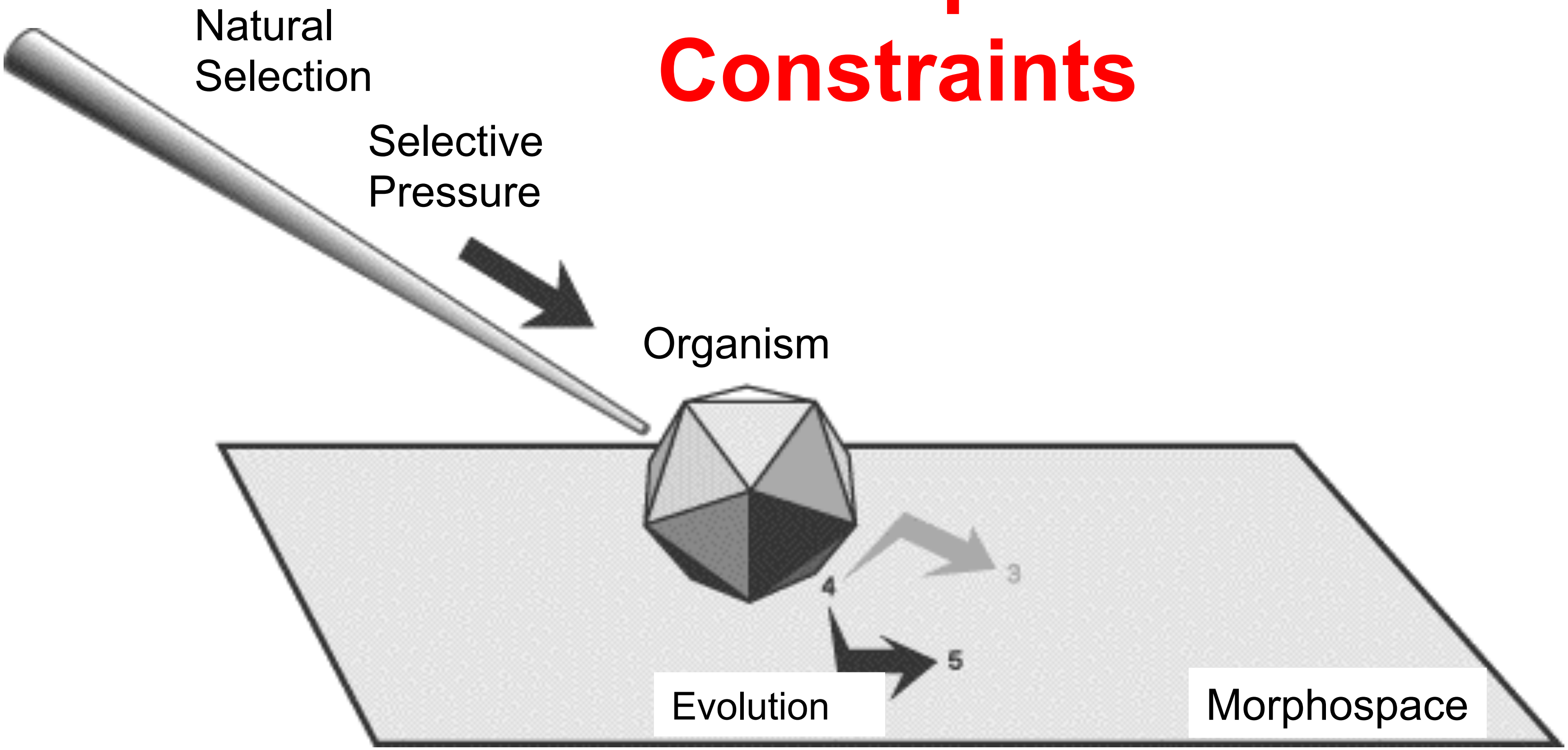
Cetaceans: a clade of mammals that includes whales, dolphins, and porpoises; the approximately 90 extant species are characterized by a wholly aquatic lifestyle.
Cetartiodactyls: a clade of mammals that includes camels, pigs, peccaries, cattle, antelope, deer, chevrotains, giraffes, hippopotamuses, and cetaceans.
Convergent recruitment: evolutionary change whereby an orthologous gene is utilized in two or more independent lineages to effect a similar phenotypic outcome in each lineage.
Convergent substitution: independent molecular evolution of the same state at a homologous position of the same gene and/or locus in two or more

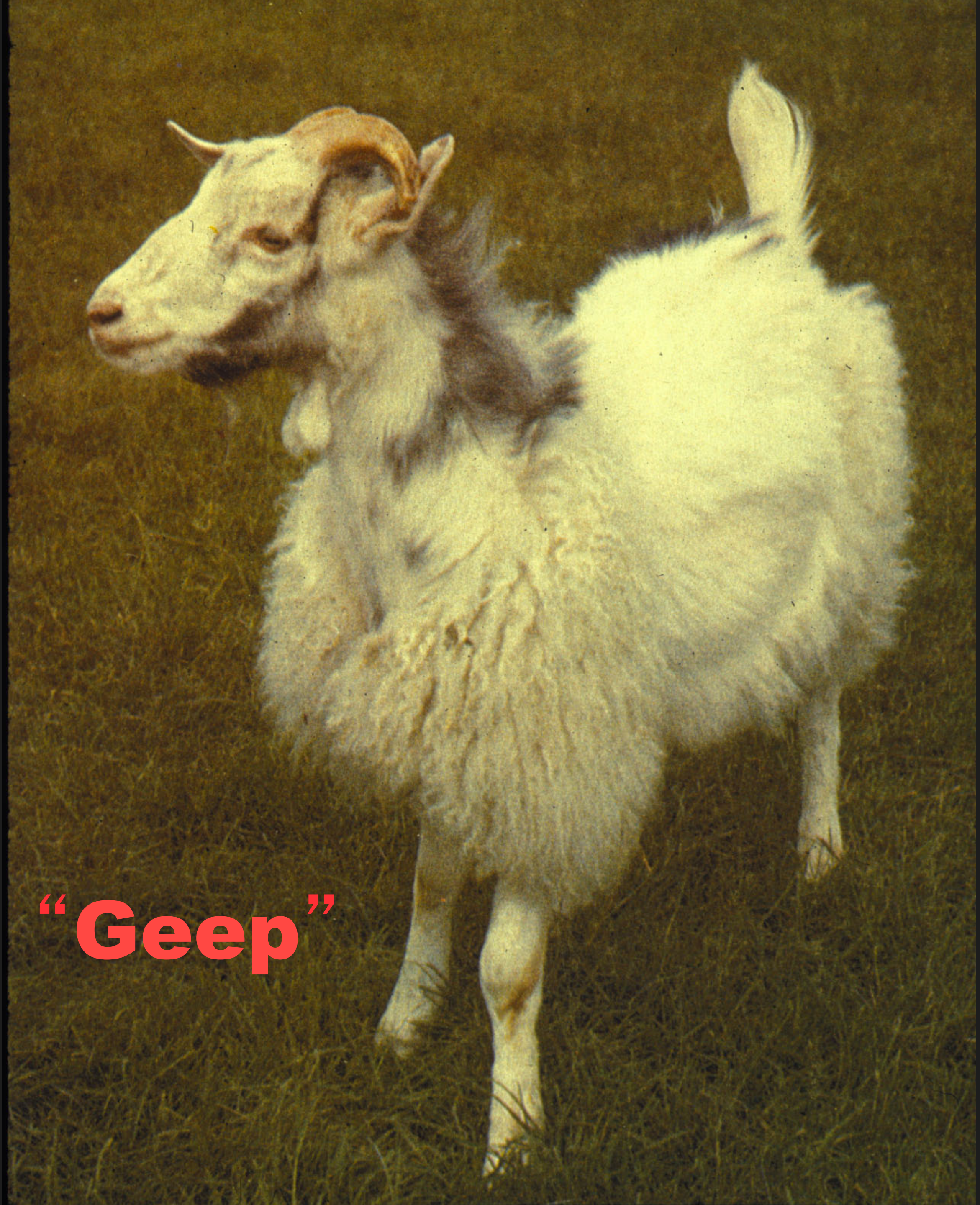
Why are some traits conserved … while others change very easily?

Misconception



Developmental Constraints



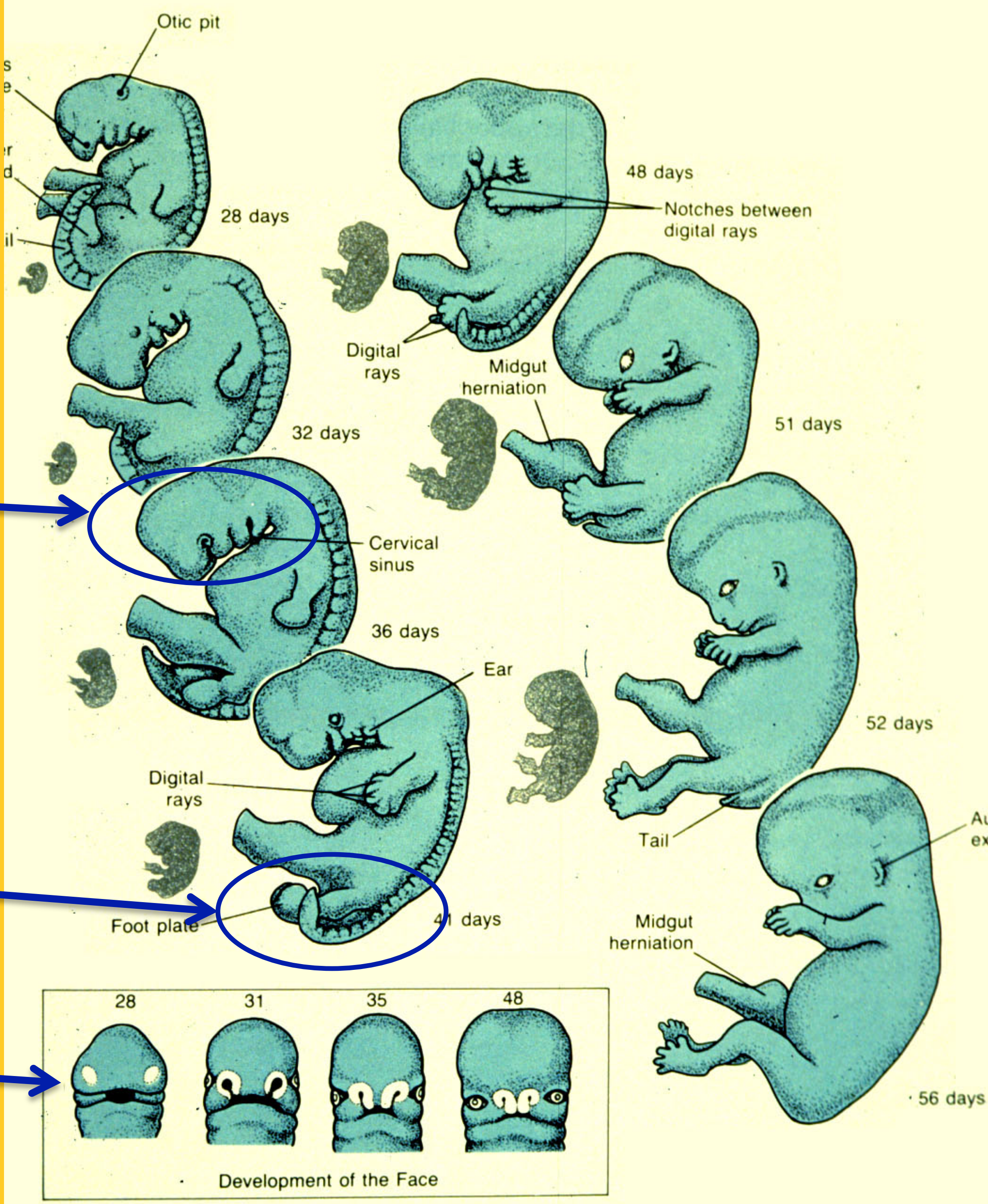

"Geep"

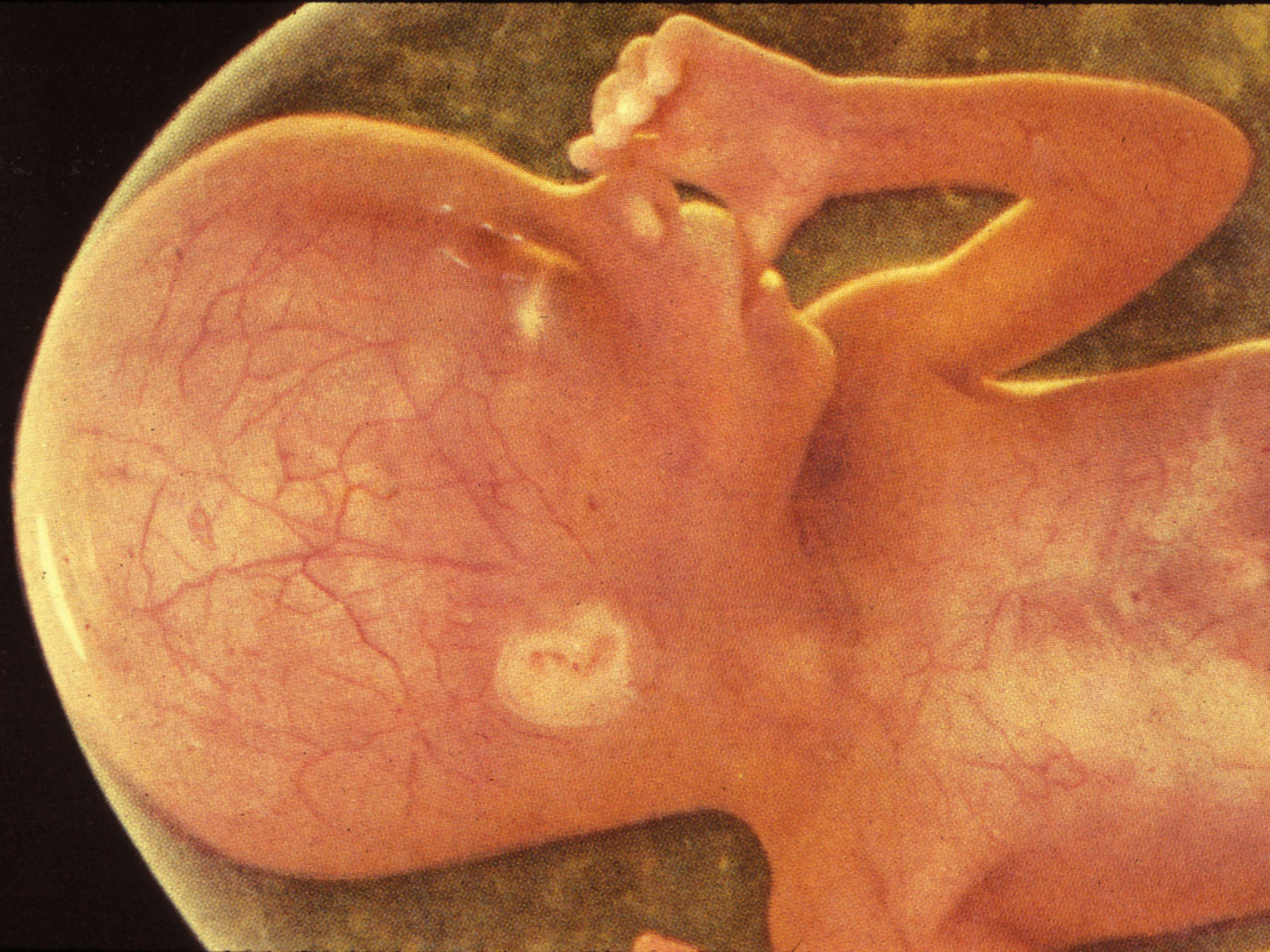
Ontogeny Recapitulates Phylogeny

Gill slits (like a fish)

Tail (like a monkey)

Eyes on side (≈ fish)

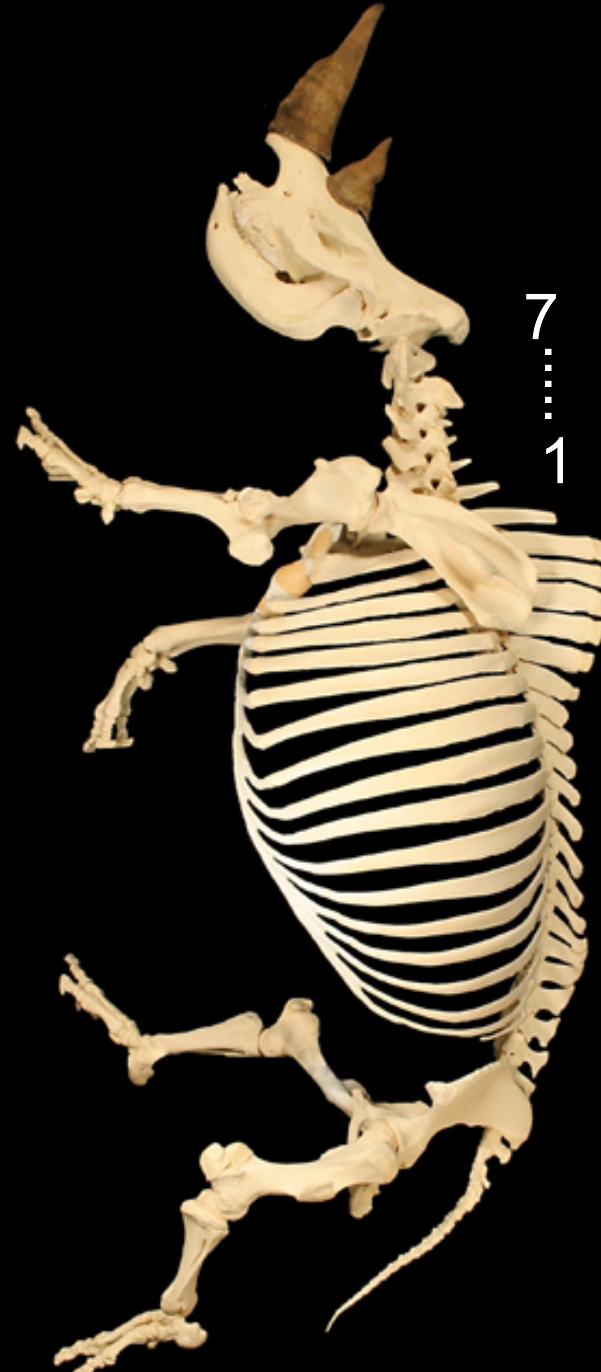




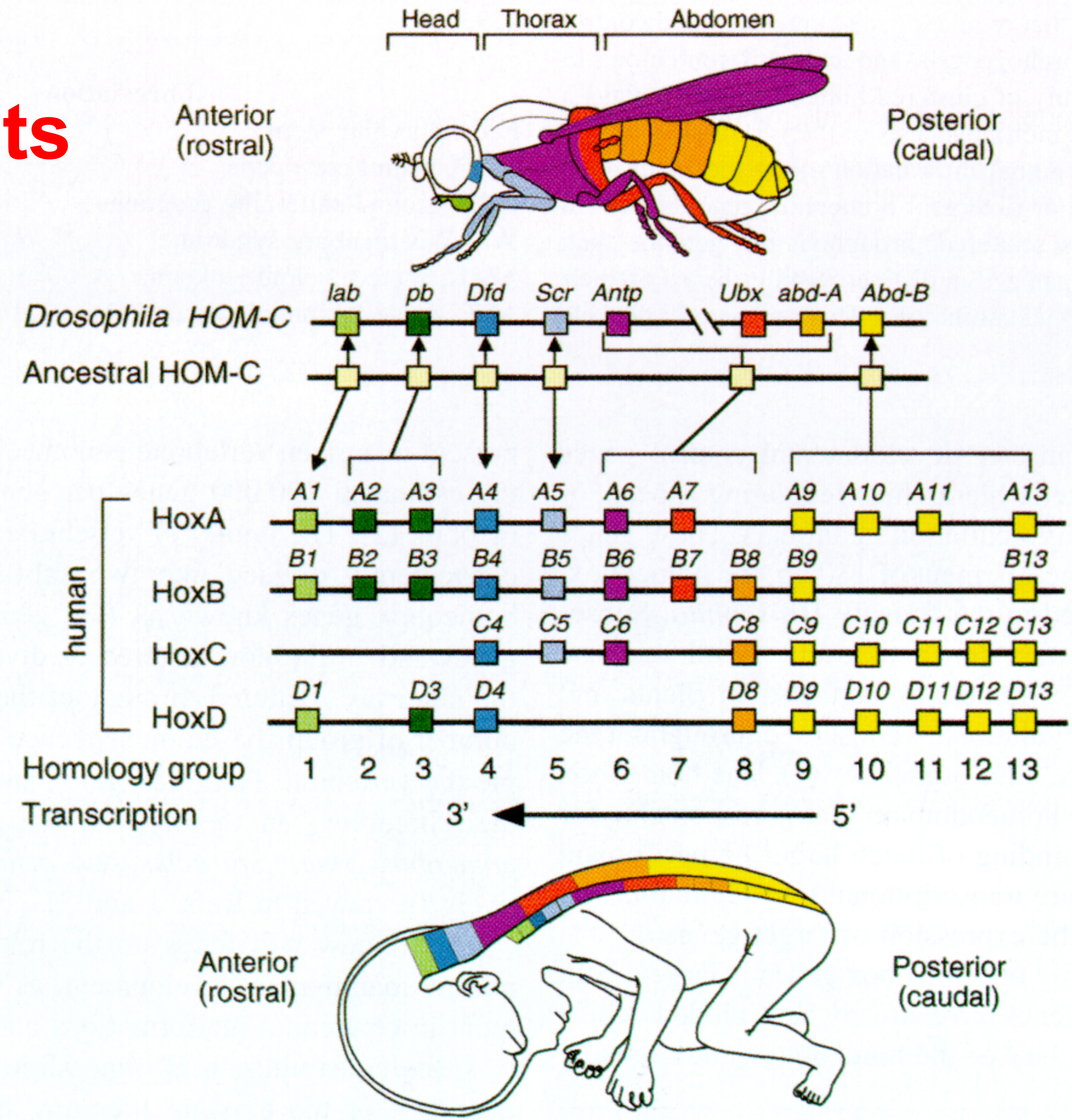
The number of neck vertebrae
Is conserved in mammals.

Q: Why?

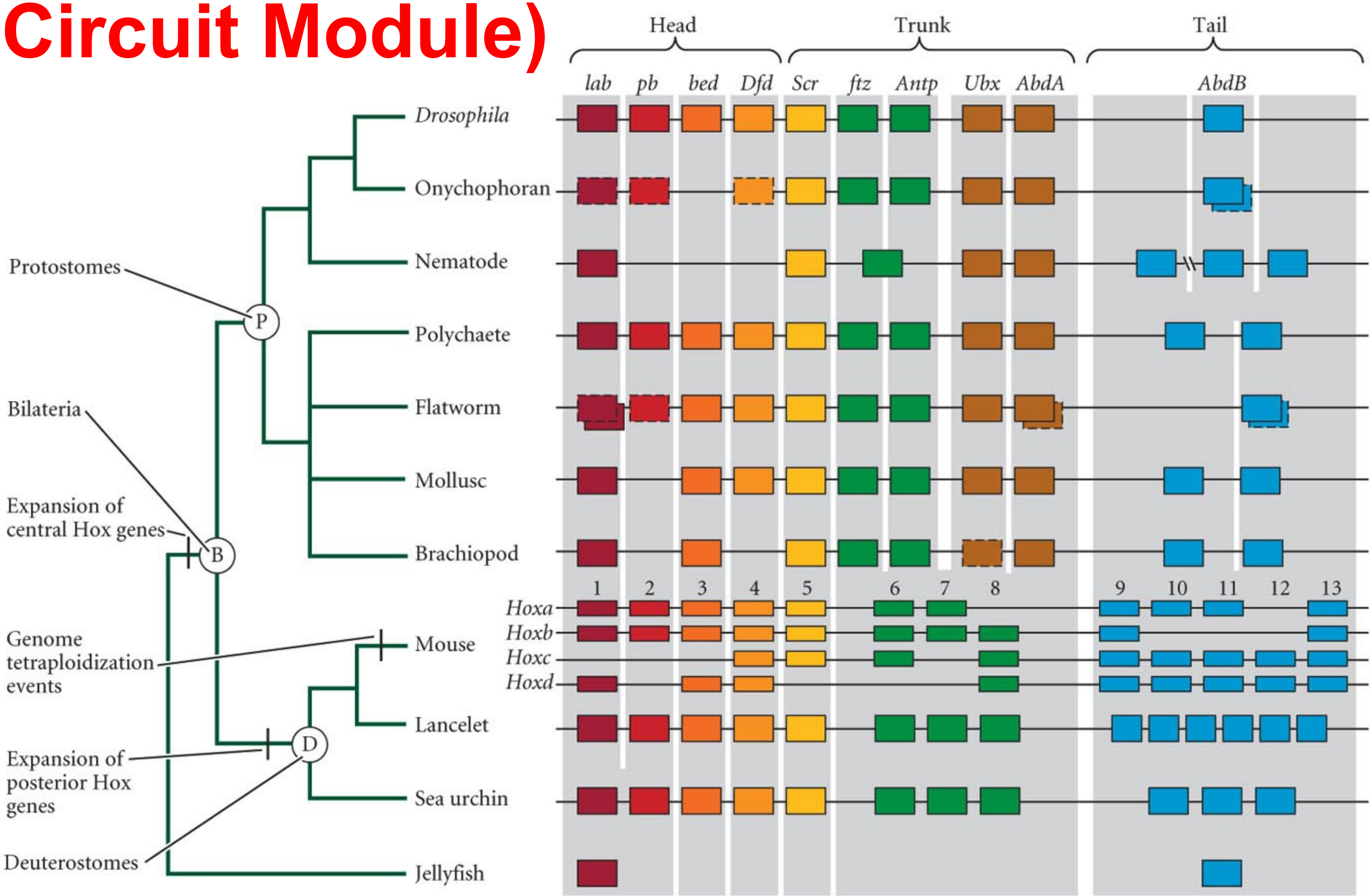
A: Diaphragm!



Genetic Constraints



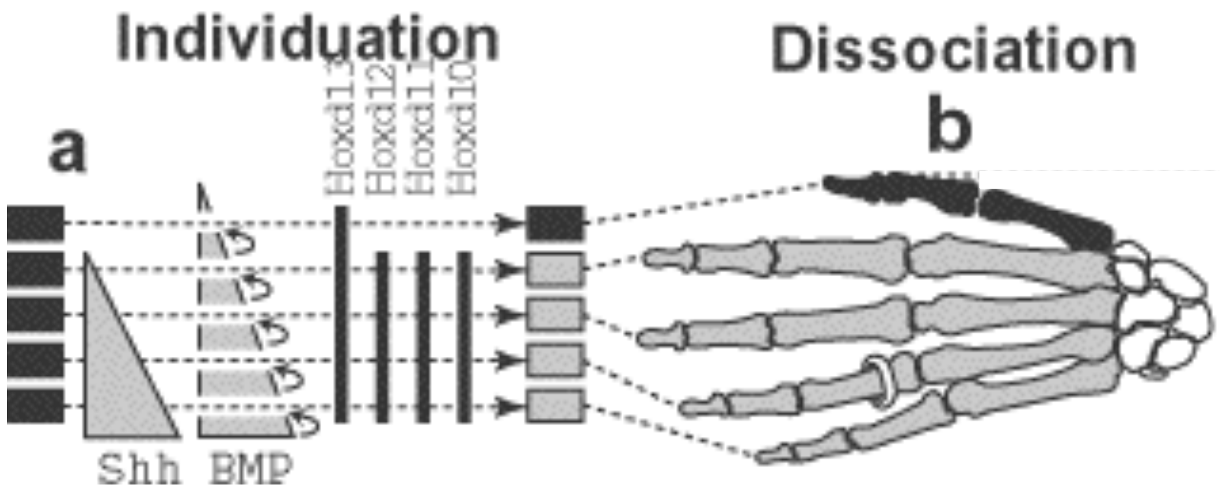
600 Million Yrs. Old! (Circuit Module)



EVOLUTION, Figure 20.5

Co-option:

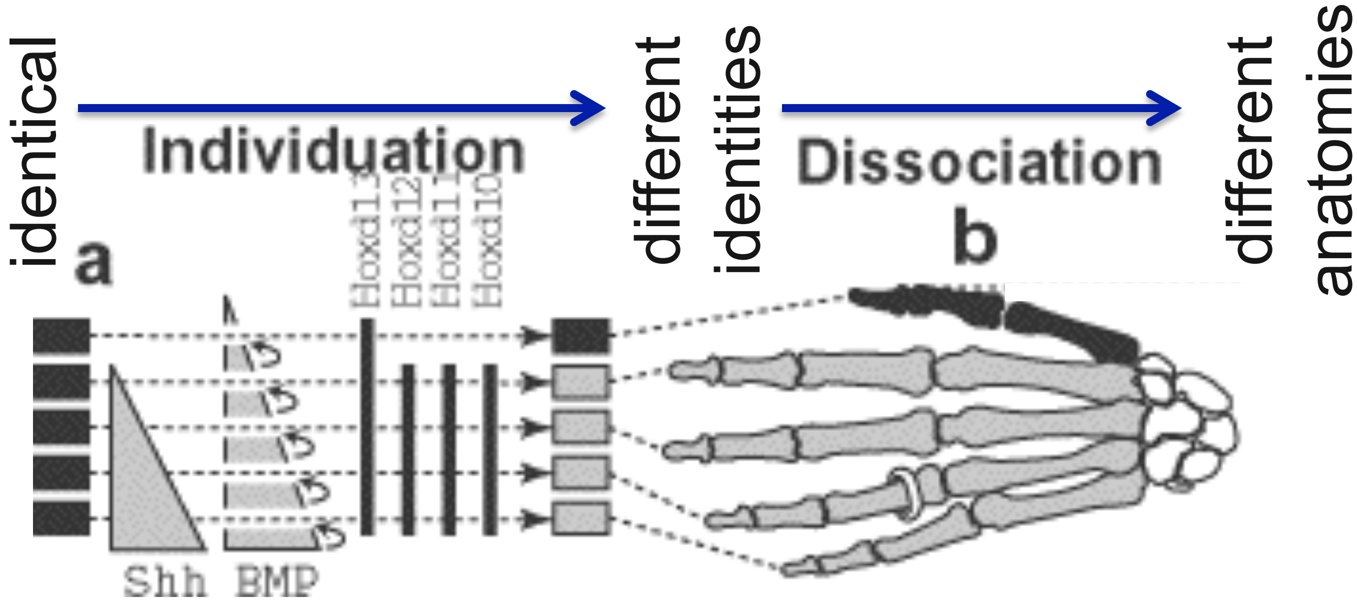
Re-wiring of an old circuit (Hox) for a new function (fingers).



Morphogen (Shh or BMP) = a (diffusible) signaling molecule.

Gradient = assigning cell positions by morphogen concentrations.

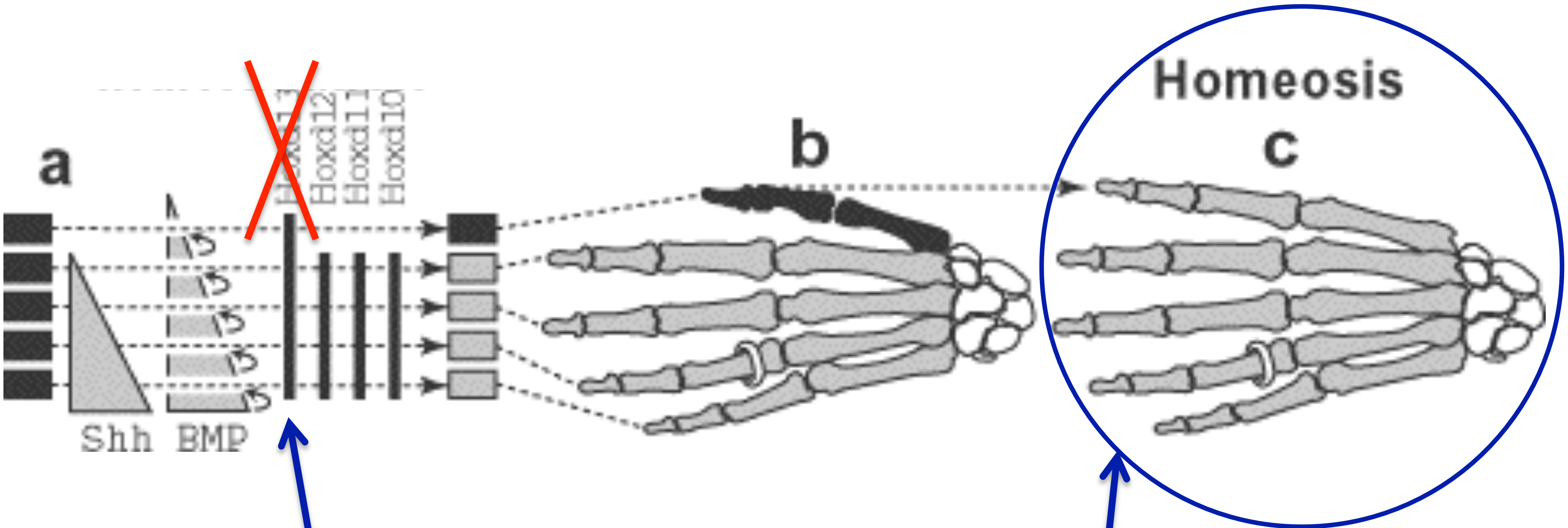
Individuation: Giving different identities to similar structures (via genes).



Dissociation: The independent evolution of ≥ 1 members of a series.

Individuation (in development) allows dissociation (in evolution).

Homeosis: Changing one body part (thumb) to resemble another (finger).



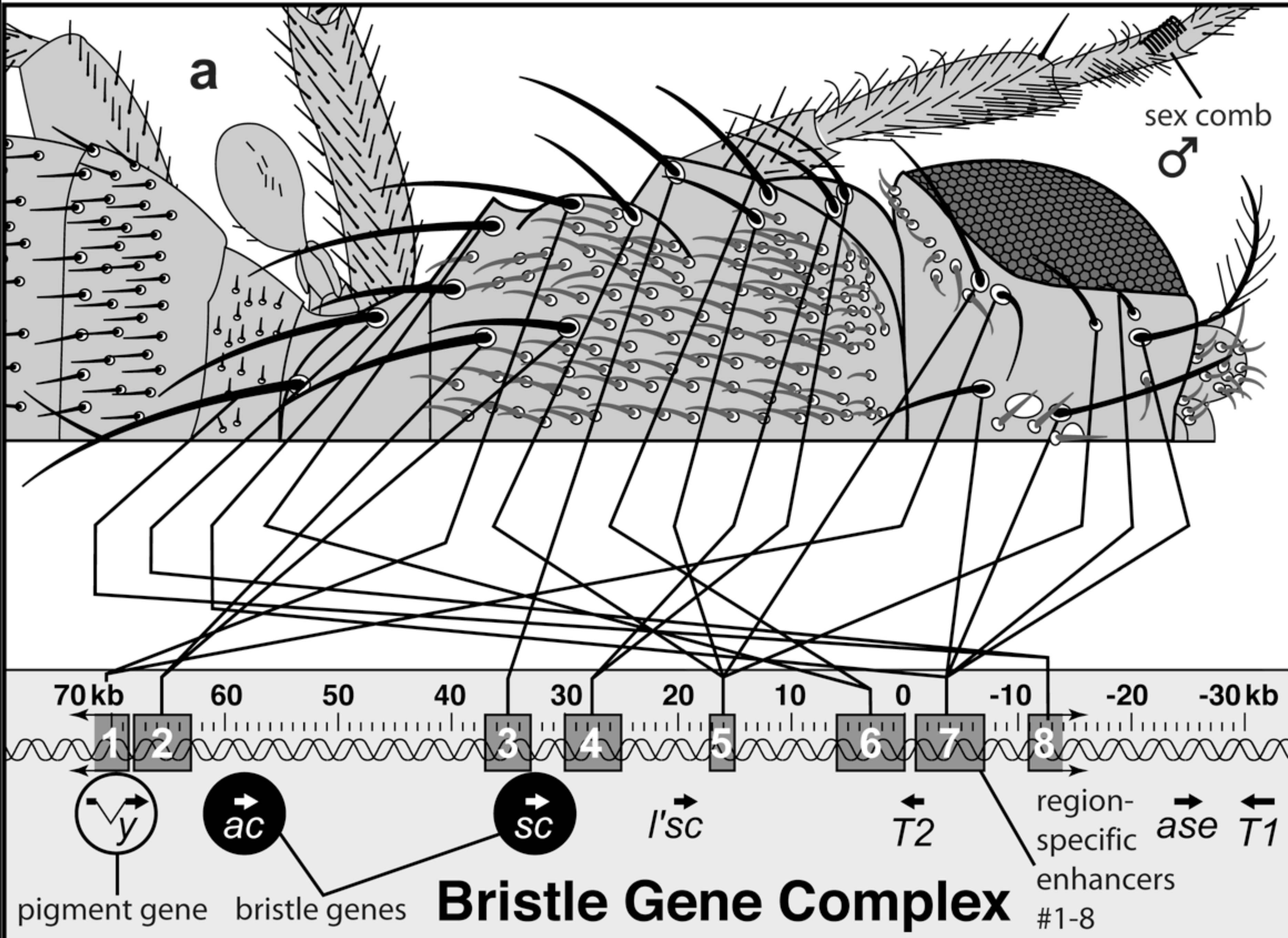
Mutations in Hoxd13 cause a “bear claw” phenotype!

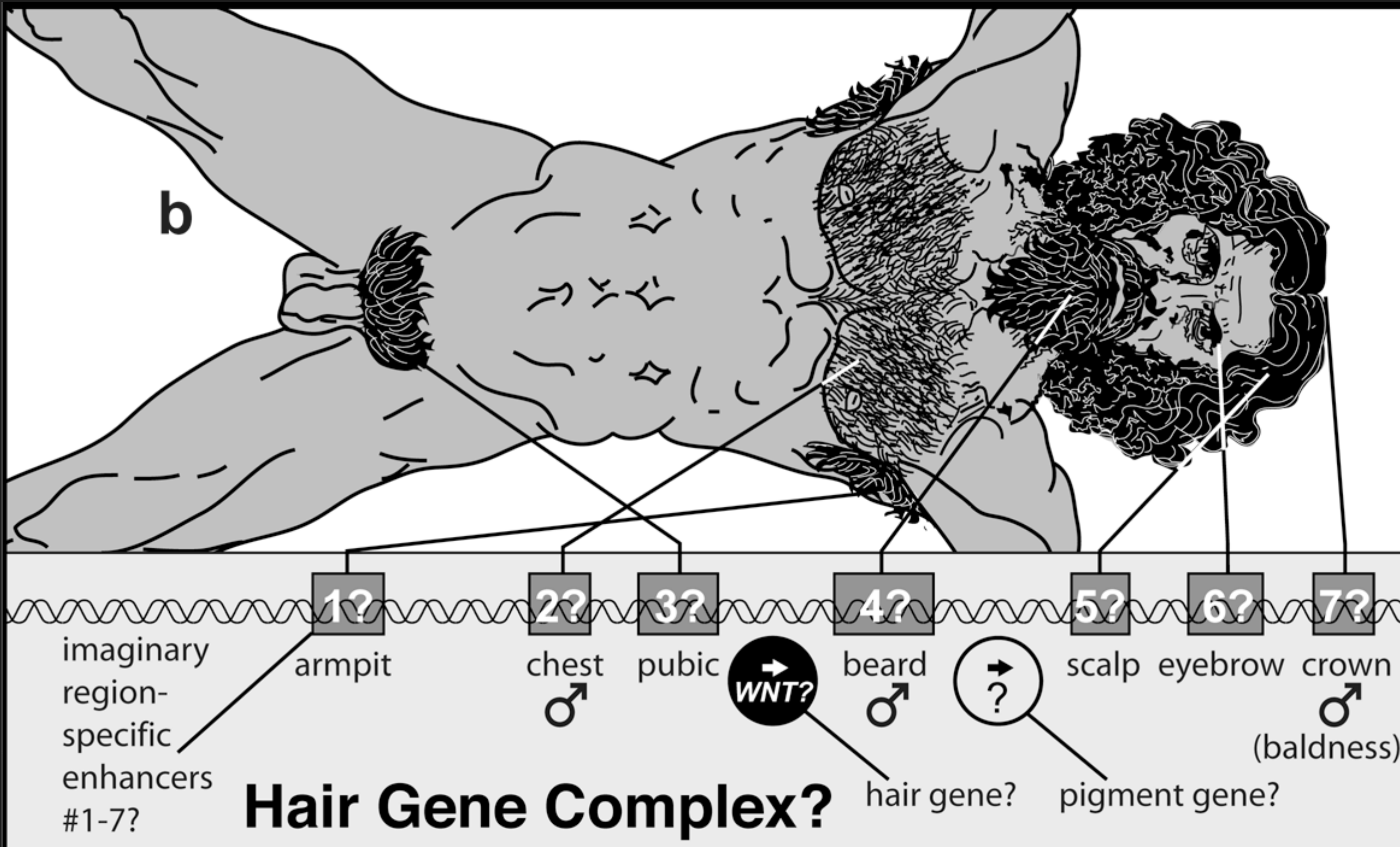
≈

Q: How does evolution rewire the genome?

A: By co-opting old circuits for new functions.

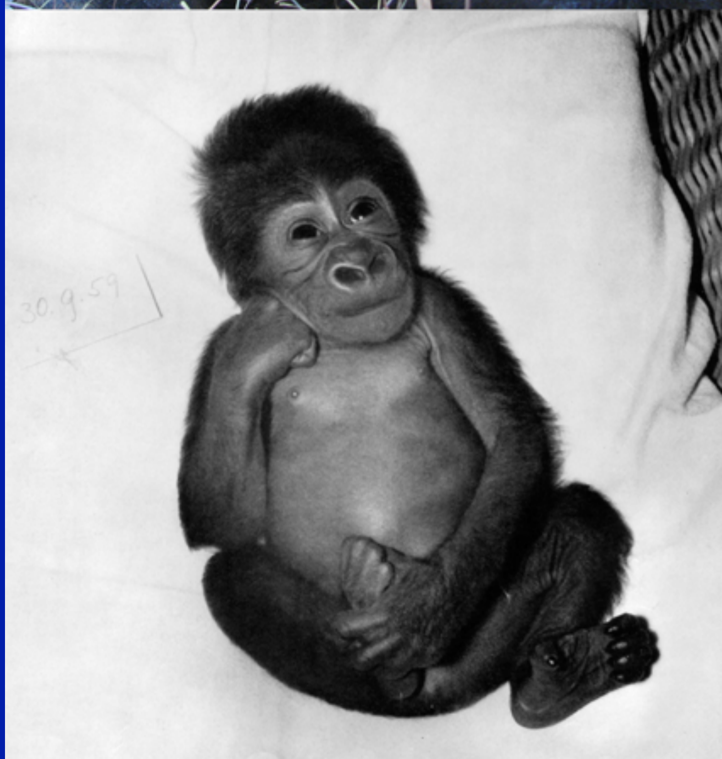
Human Evolution

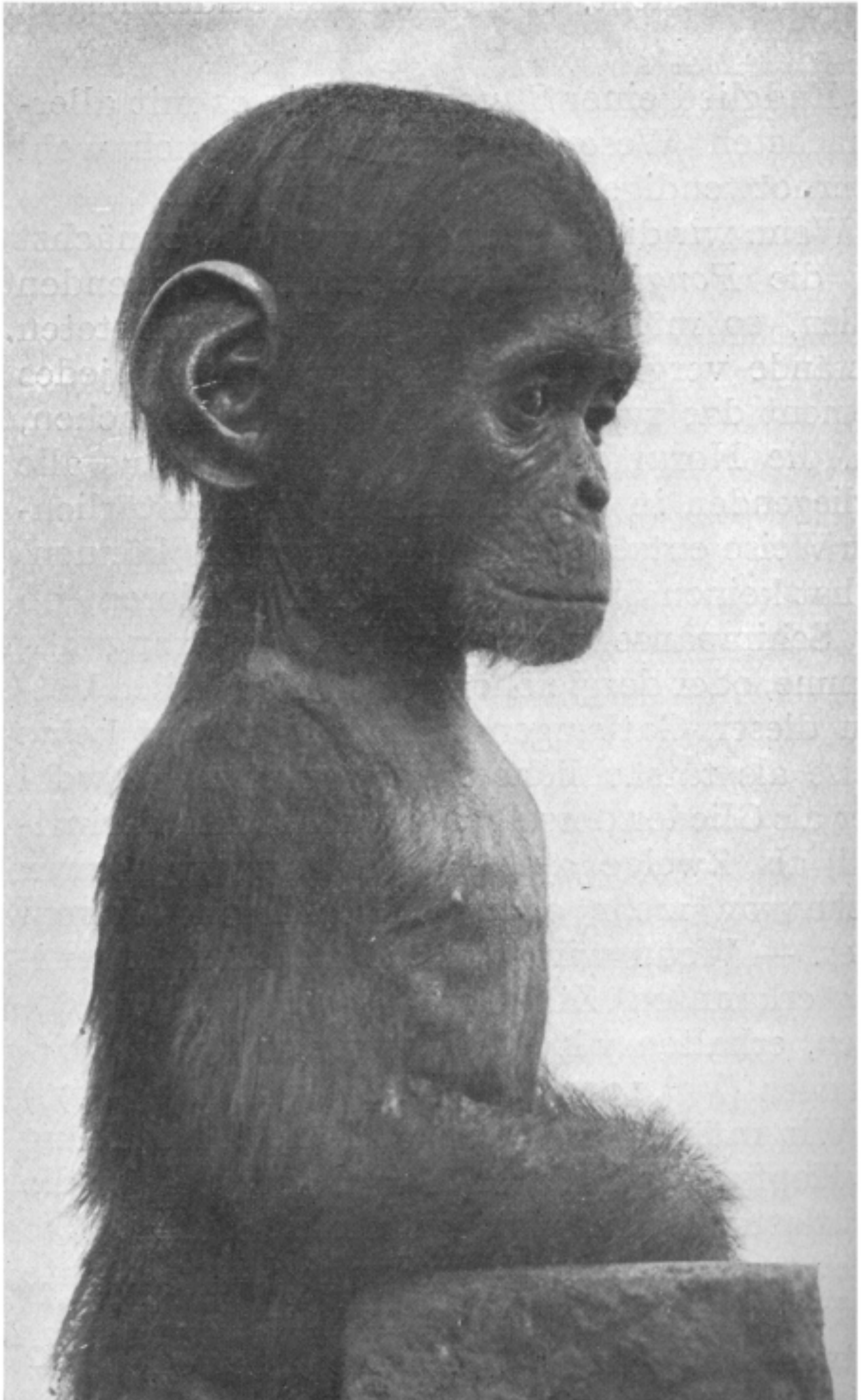

a
sex comb
♂
70 kb
60
50
40
30
20
10
0
-10
-20
-30 kb
1
2
3
4
5
6
7
8
y
ac
sc
l'sc
T2
region-specific enhancers #1-8
ase
T1
pigment gene
bristle genes
Bristle Gene Complex

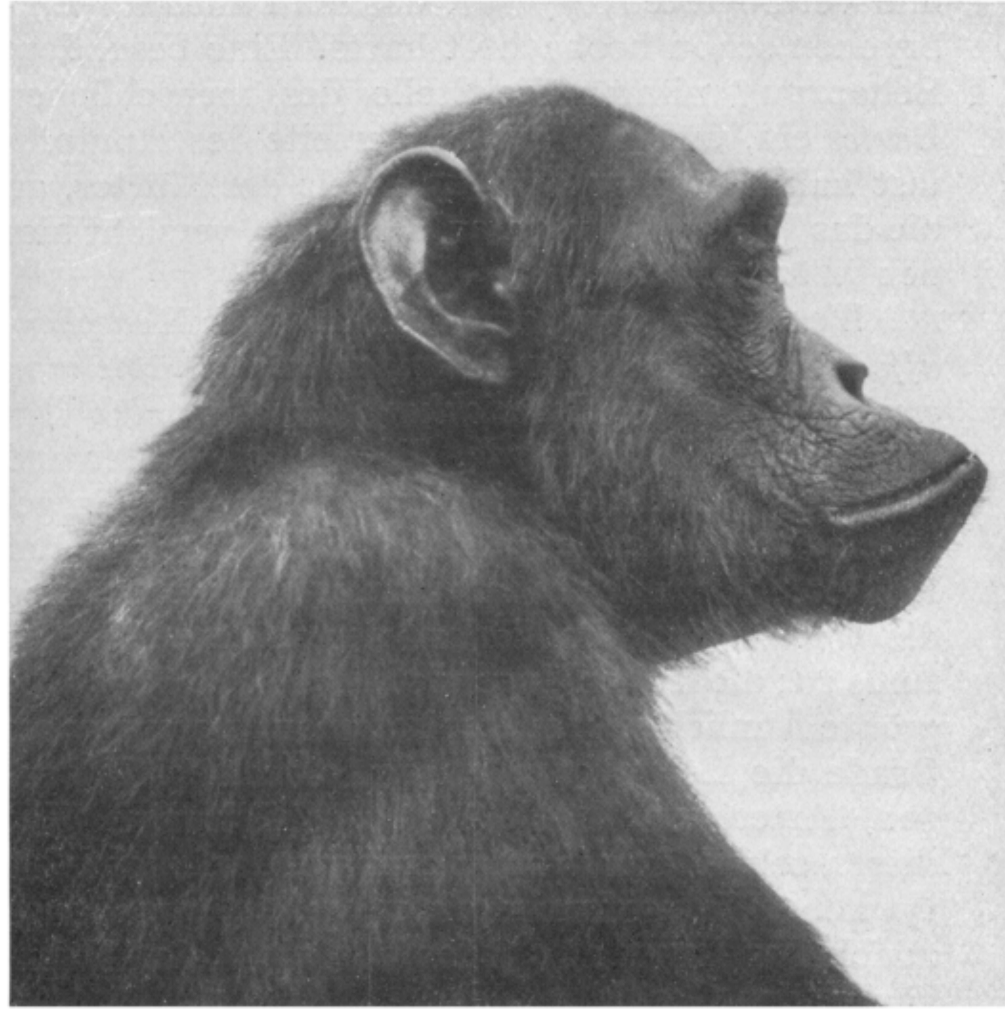

b
1?
2?
3?
4?
5?
6?
7?
armpit
chest ♂
pubic
WNT?
beard ♂
?
scalp
eyebrow
crown ♂
(baldness)
imaginary region-specific enhancers #1-7?
Hair Gene Complex?
hair gene?
pigment gene?

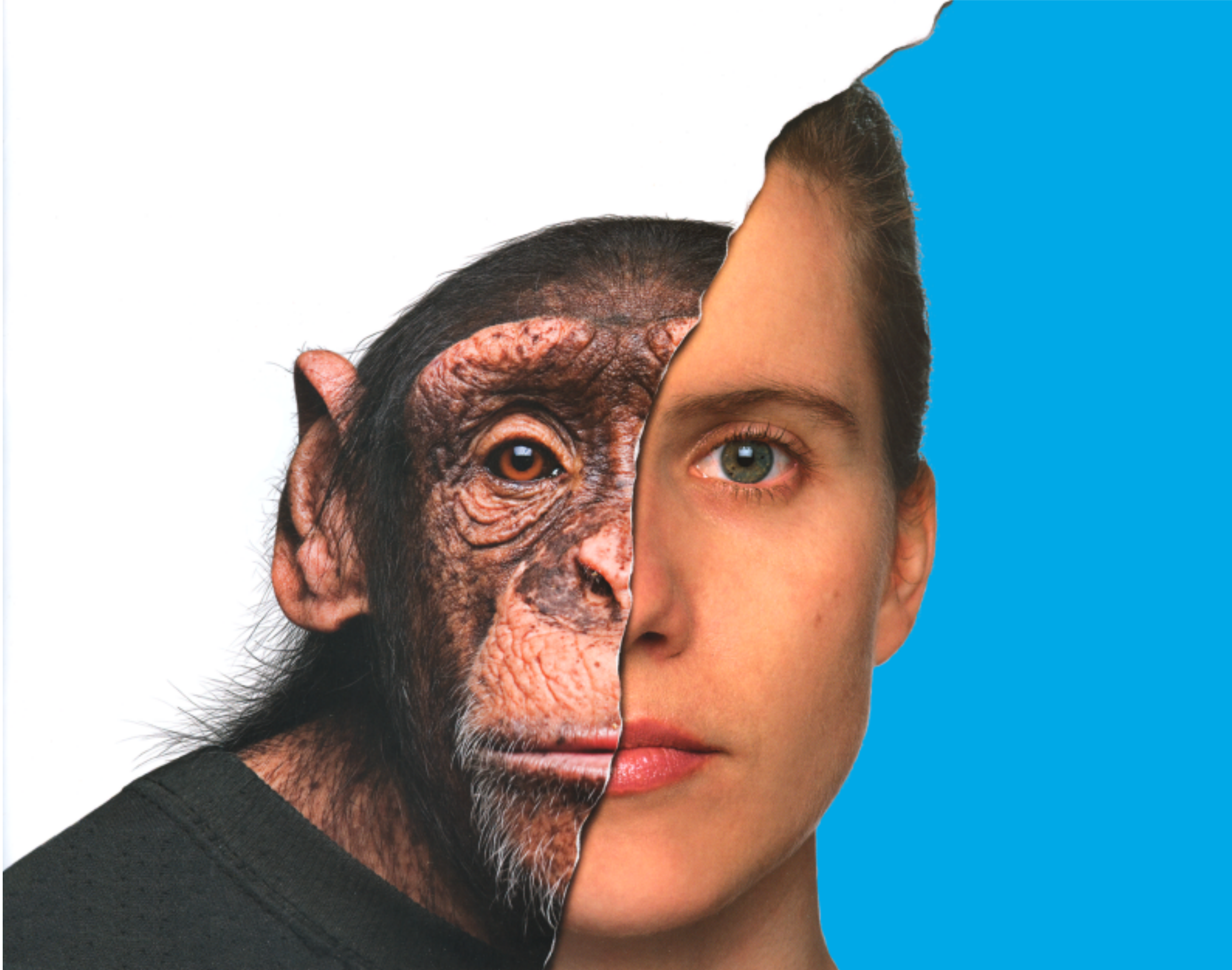
Q: How does evolution rewire the genome?

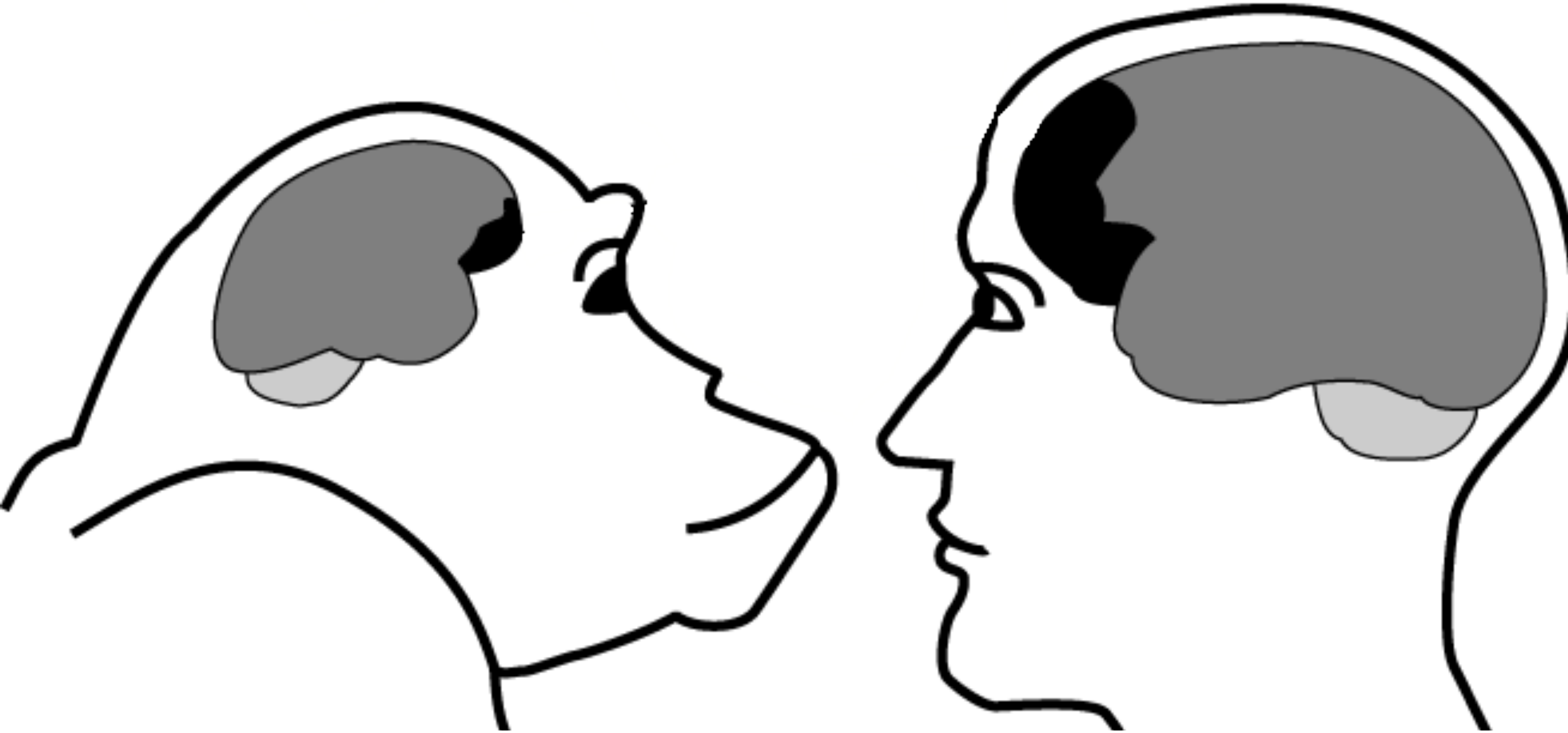
A: By tweaking cis-regulatory elements for area codes.

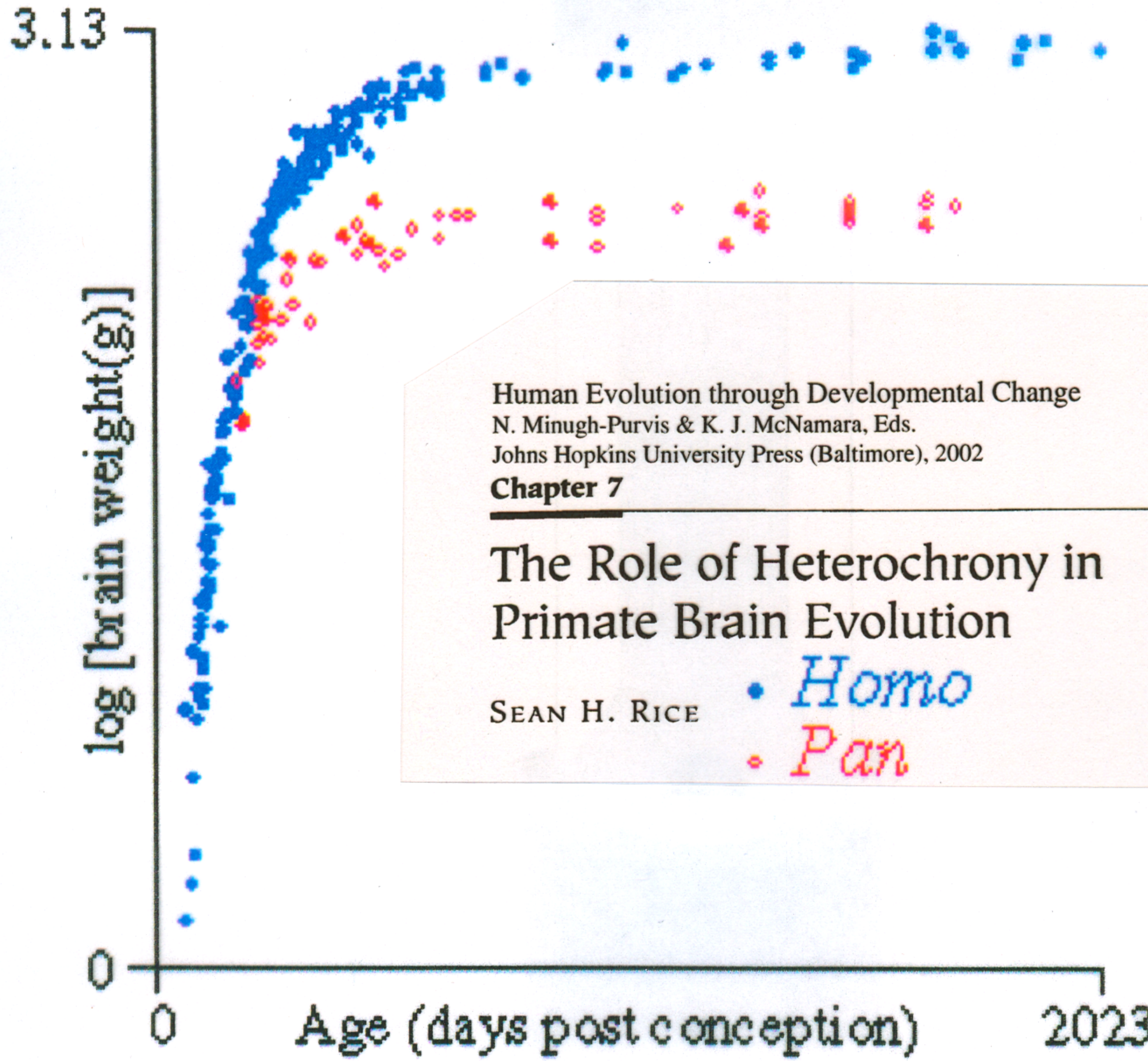

30.9.59







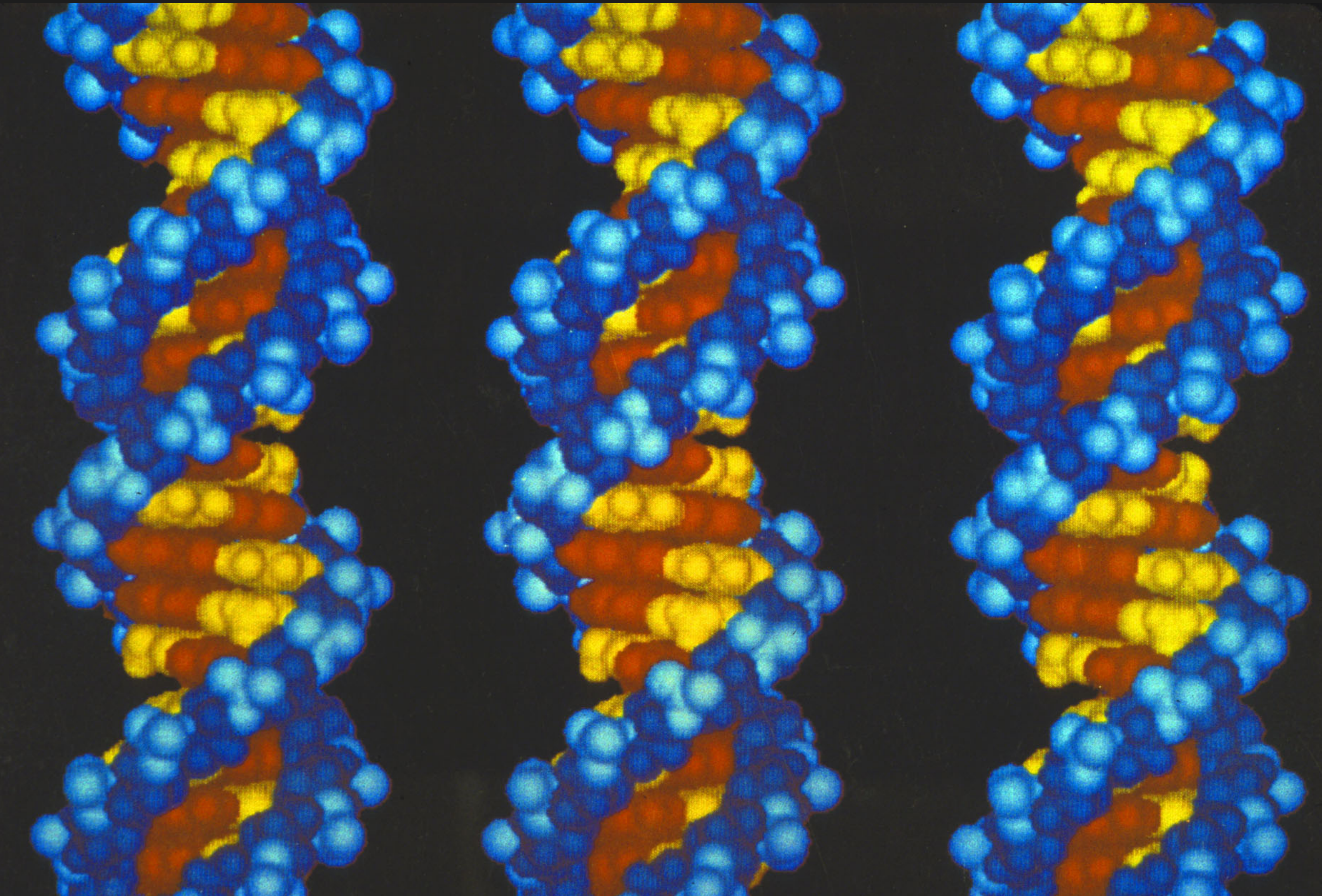



3.13
0
log [brain weight(g)]
0
Age (days post conception)
2023
Human Evolution through Developmental Change
N. Minugh-Purvis & K. J. McNamara, Eds.
Johns Hopkins University Press (Baltimore), 2002
Chapter 7
The Role of Heterochrony in Primate Brain Evolution
SEAN H. RICE
Homo
Pan

Q: How does evolution
rewire the genome?

A: By changing the timing
of gene expression
(= Heterochrony).

The history of evolution is written in our genomes!



Summary

How does evolution re-wire the genome
to re-program development
to re-configure anatomy?

- By changing the inputs to a conserved program.
- By co-opting old circuits for new functions.
- By tweaking cis-regulatory elements for area codes.
- By changing the timing of gene expression.