The Origin of Intelligence

The Origin of Intelligence

f_i : Fraction of life-bearing planets where Intelligence develops

What is intelligence?

Propose: "The ability to model the world, including the organism itself"

$\Rightarrow$ Intelligence as continuum

related to complexity of organism

milestone: human-level intelligence

Information as Measure of Intelligence

Evolution of intelligence $\simeq$ increase in information

DNA: model of organism, the program

A quantitative measure: # of bits of information

Bit: Information in the answer to a yes/no question

e.g.,

Purines	Pyrimidines
Adenine (A)	Cytosine (C)
Guanine (G)	Thymine (T)

Information Content

Unit	# of Bits	# of Pages	# of Books
1 base	2		
1 codon	6		
Virus	$\sim 10^3$	1	
Bacterium	10^6	1000	
Amoeba	5×10^8		500
H. Sapiens*	6×10^9		small library

*$\sim$ 2% codes for proteins

$\Rightarrow$ 1.2×10^8 bits

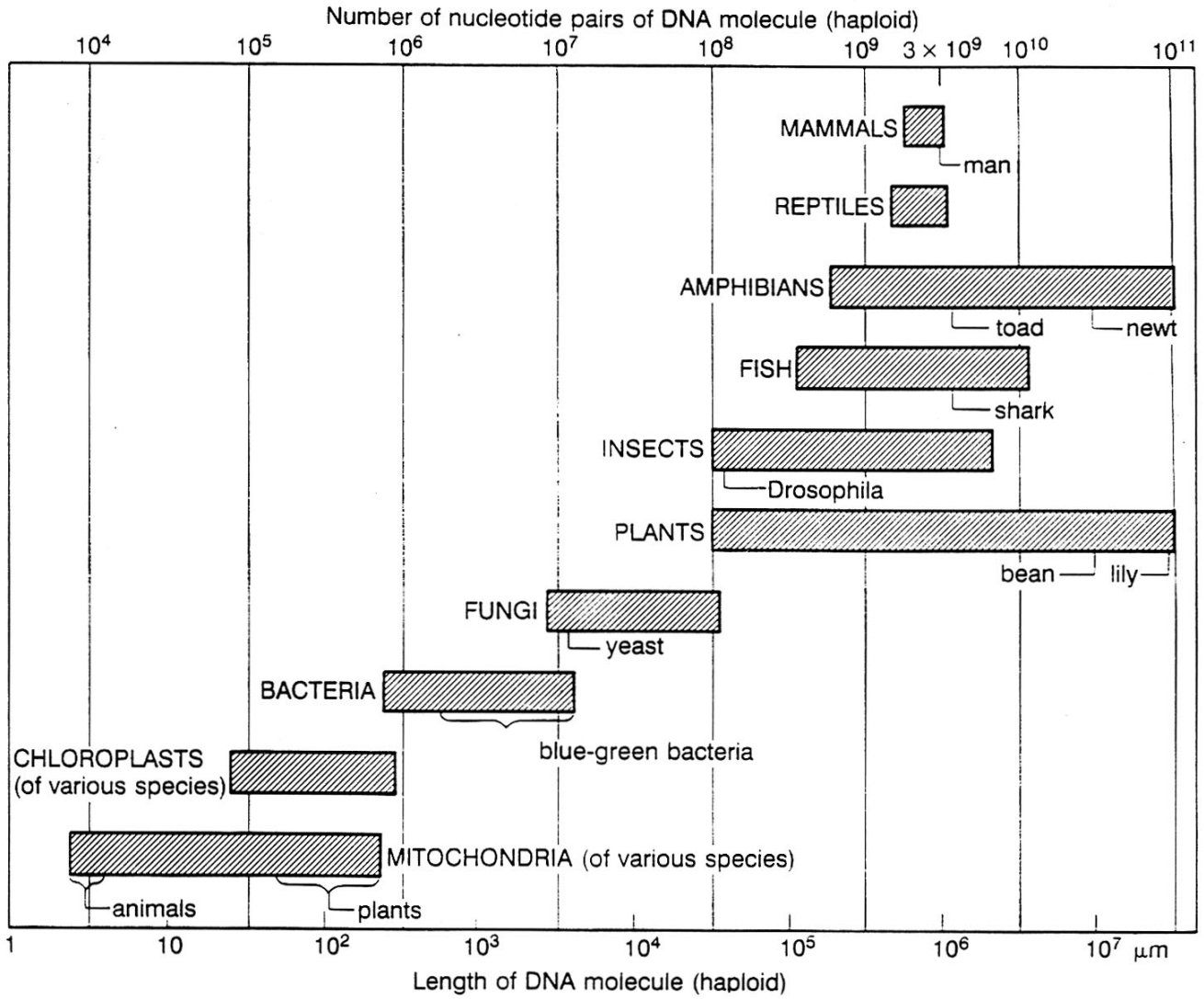
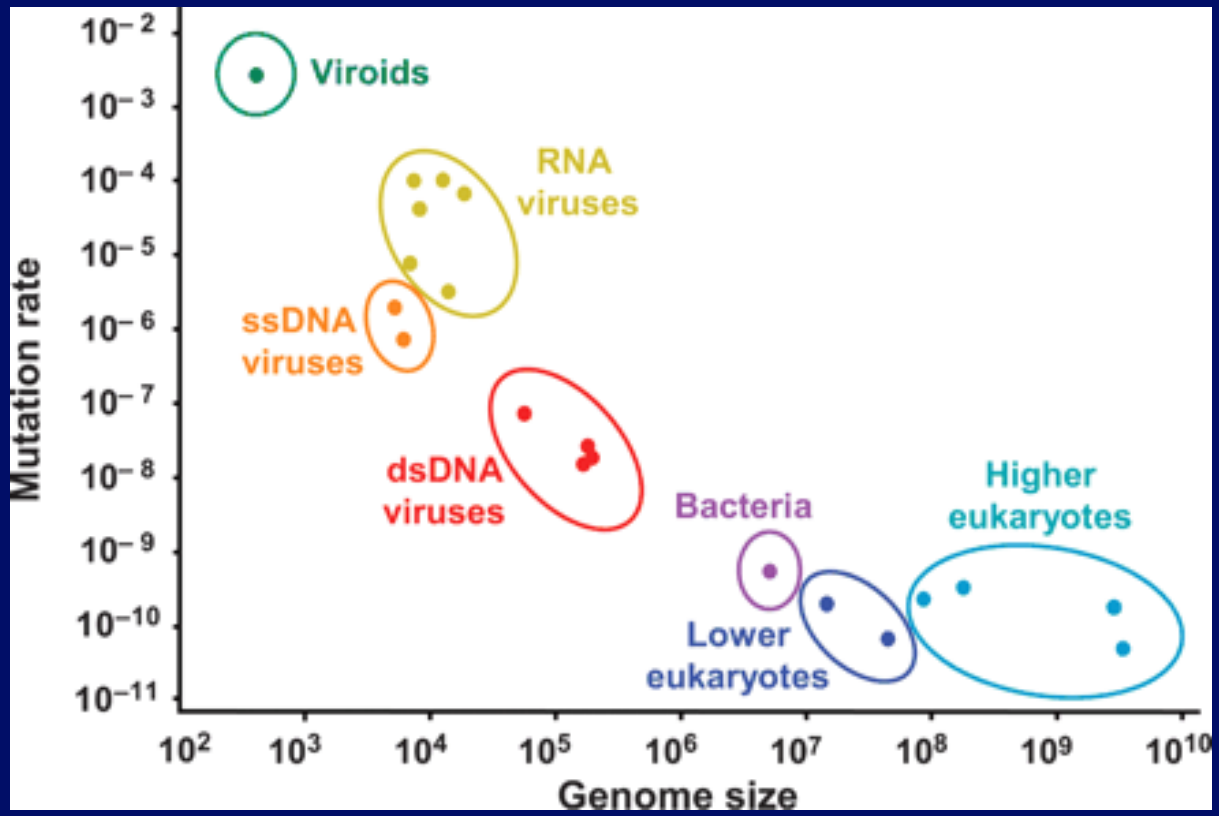


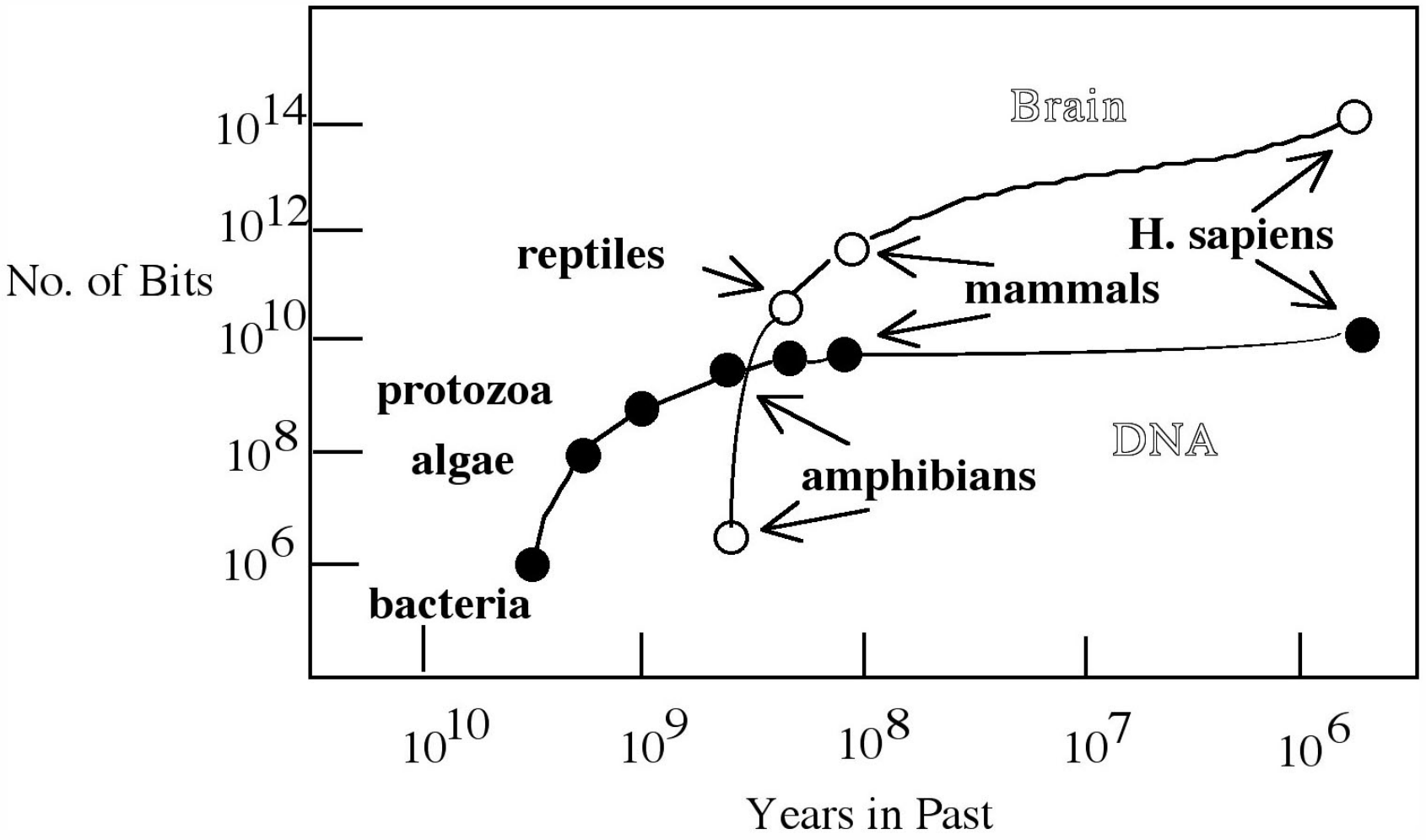
Figure 7.18. Length of DNA molecules. Note that the DNA of some plants and amphibians is longer than that of bacteria by a factor of 10^4 to 10^5. The total length of human DNA is approximately 10^6 μm or 1 m, which is equivalent to roughly 3×10^9 nucleotide pairs or 10^9 codons. Obviously, the length of DNA carried by an organism is not necessarily related to its phenotypic complexity. We may conclude that DNA does not carry useful information over its entire length. Much of its coding is "nonsense." (Adapted from Alberts, et al. 1983, 405, 530.)

Evolution produced Increase in information

Information stored in DNA limited by fidelity of Replication. The bigger the genome, the smaller the mutation rate must be.



Gago et al. 2009, Science, 323, 1308



Based on Sagan

Dragons of Eden

Why Brains?

To get more than 10^{10} bits (or 10^{8}?), need extra-genetic storage

Neurons led to brains

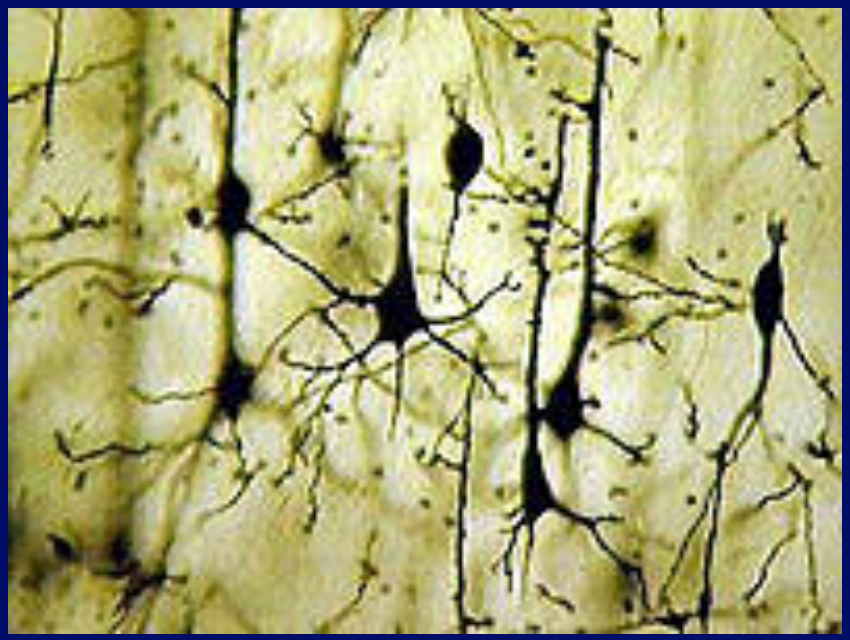
How is information stored in brains?

Not entirely clear

Neuron fires or not: 1 bit/neuron

Yes or No

Neurons are the building blocks



From slice of life project

Neuron has many inputs from dendrites.
Some favor firing, some inhibit firing.
Based on balance, the neuron fires (or not).
Electrical signal travels along axon (output).
Releases neurotransmitters in synapse.
They affect another neuron.

Further complication: reverse signalling.
Receiving neuron can release chemicals that inhibit the neurons that sent “don’t fire” signals. Involved in learning.

Brains are Different

Neuron firing controlled by many (~10^3) inputs - synapses

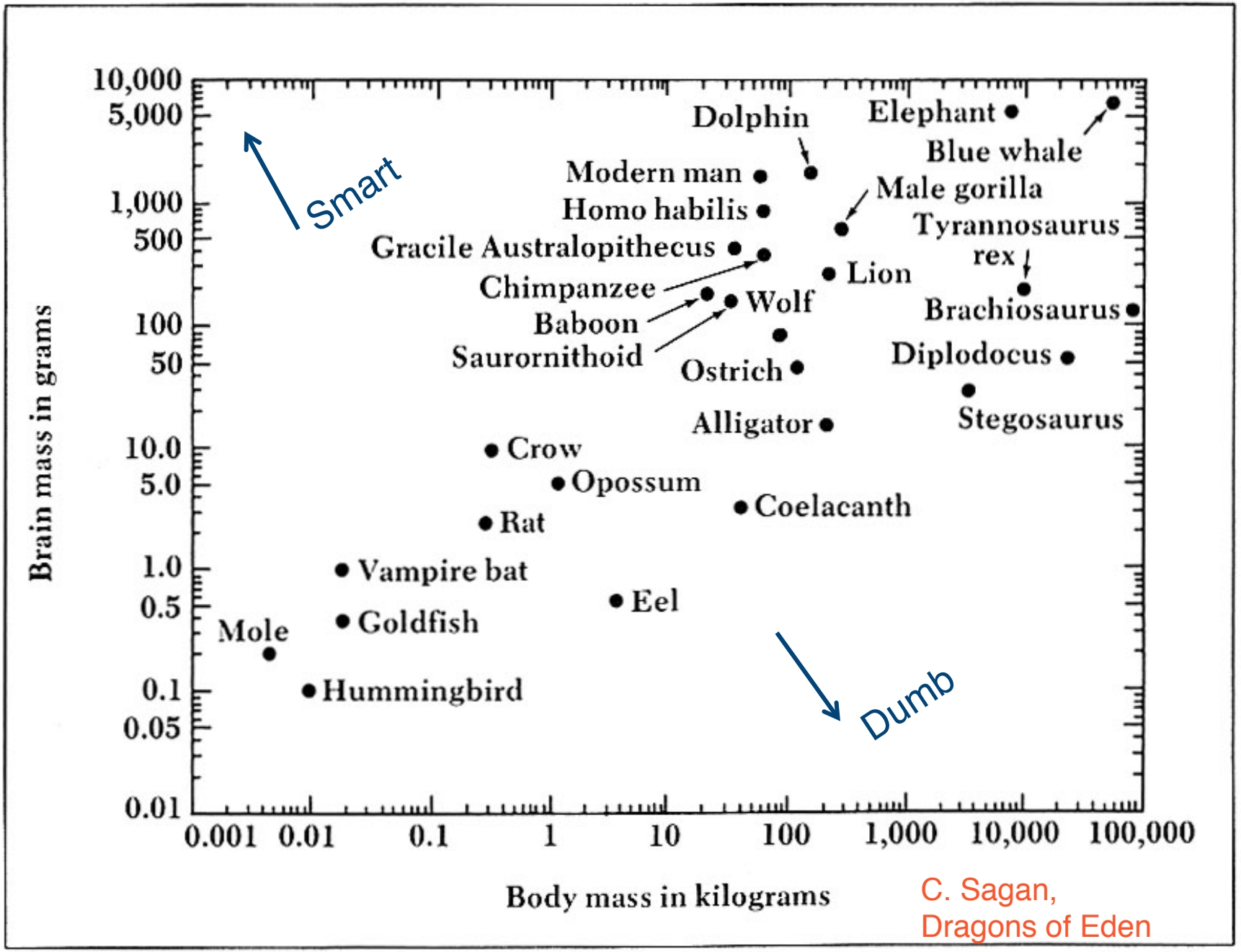
An **analog** computer ⇒ Hard to count

~ 10^{11} neurons, 10^{14} synapses

Corresponds to 20×10^6 books = NY public library

Surrogate Measure:

Brain size or Brain mass/body mass



C. Sagan,
Dragons of Eden

Brain organization

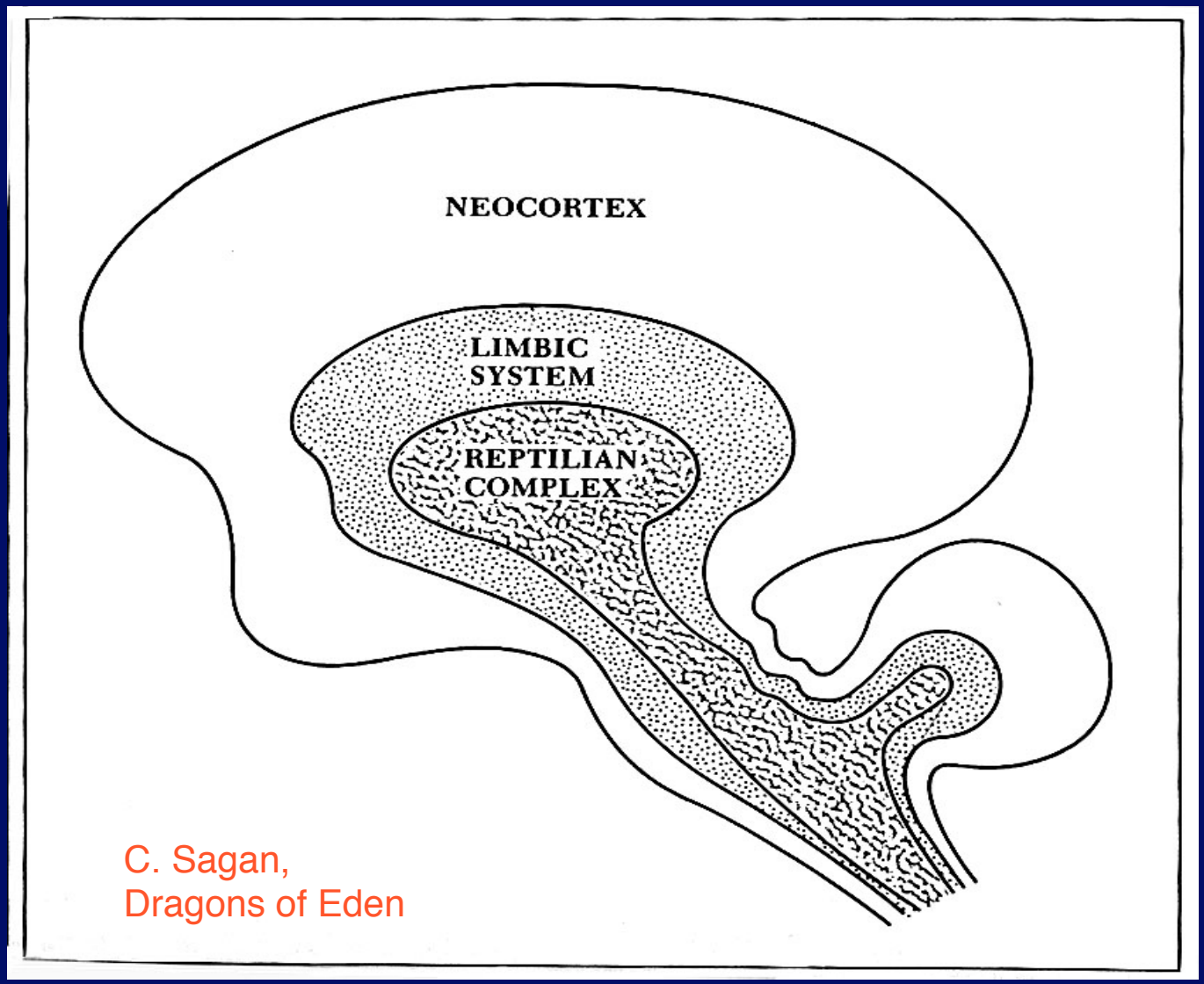
Brain is reprogrammable, unlike genes
$\Rightarrow$ **Individual** can learn

Two hemispheres
Many functions parallel, but some specialized

Many ways to divide brain
Layered brain: reptilian brain
limbic system (mammals)
cortex
Brain size has increased (in some species) with time

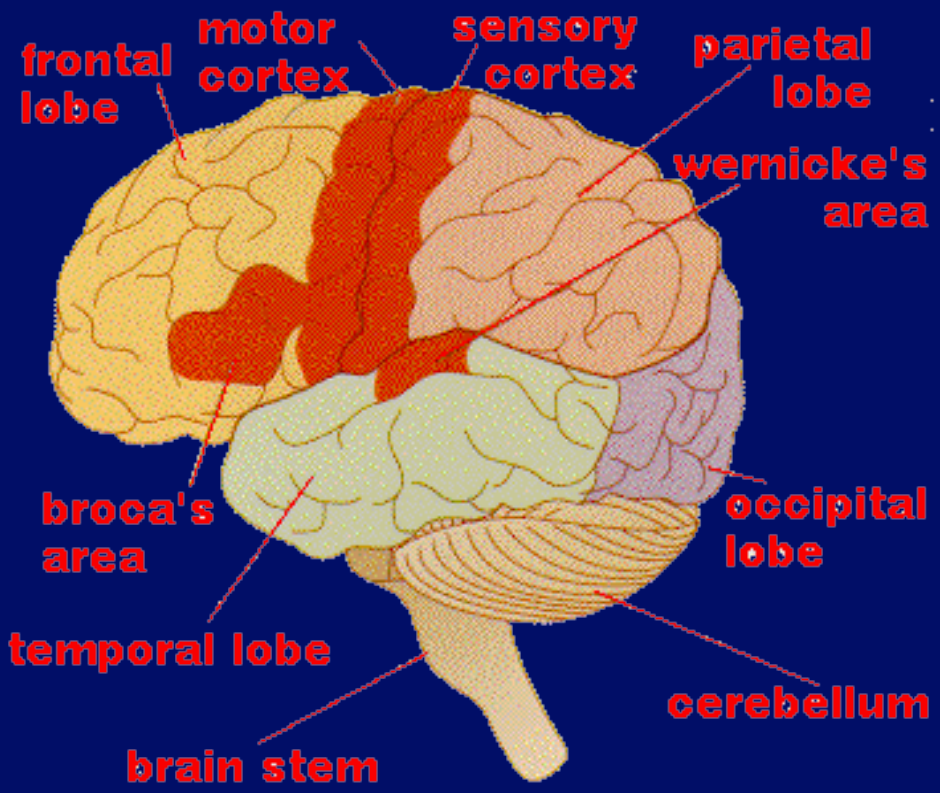
$\stackrel{?}{\Rightarrow}$ Evolution favors higher intelligence (sometimes)

A highly schematic representation of the reptilian complex, limbic system and neocortex in the human brain, after MacLean.



C. Sagan,
Dragons of Eden

The Big Brain



Human Evolution

Phylum: chordata - vertebrates - bilateral symmetry

~ 500 Myr ago

Class: mammals arose in Triassic period

~ 225 Myr ago

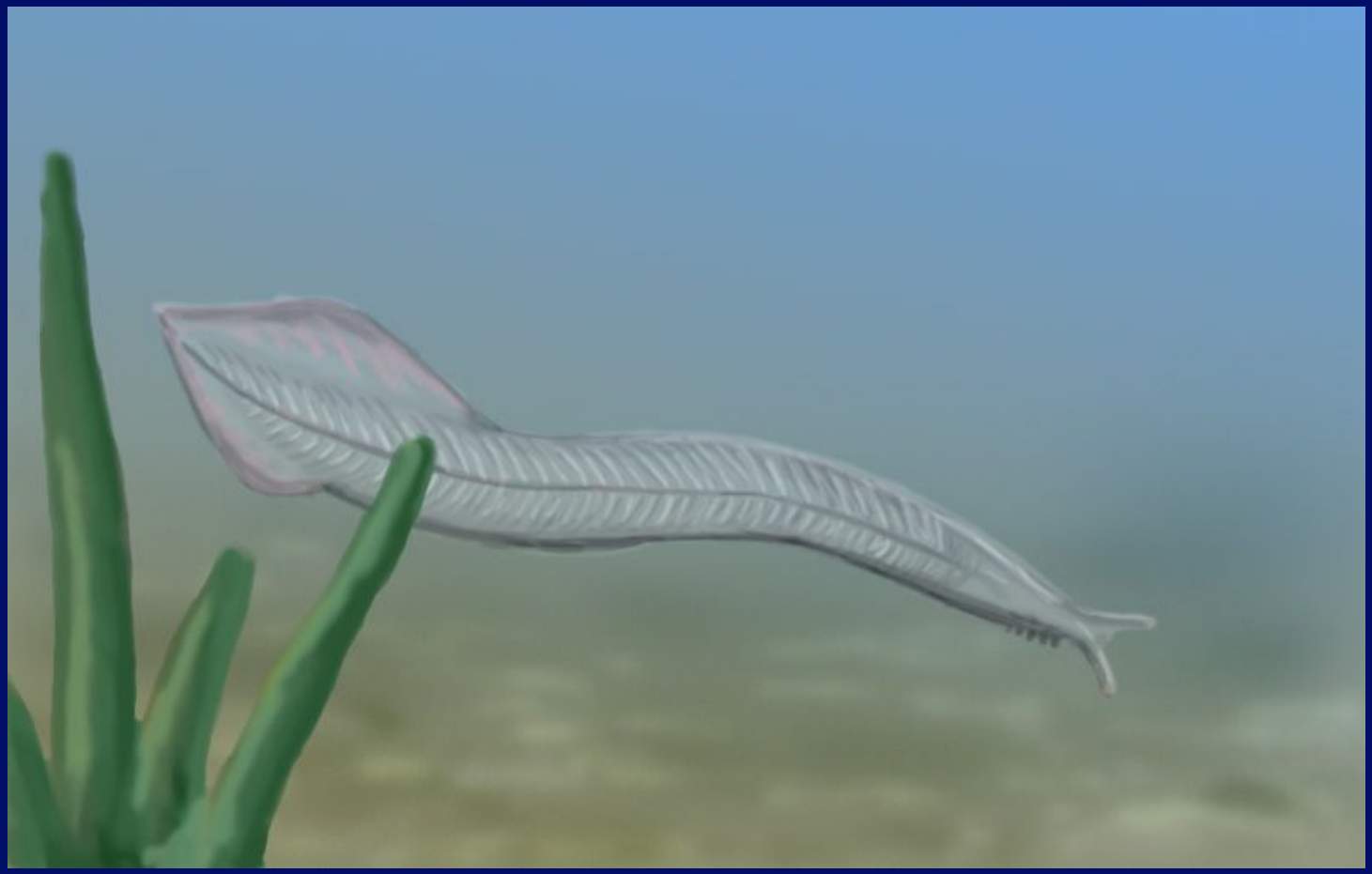
Proliferated and “radiated” at end of cretaceous

(66 Myr ago) after extinction of dinosaurs

Giant asteroid impact at that time

Order: primates - late cretaceous ~ 80 Myr ago

Pikaia (from Burgess Shale)

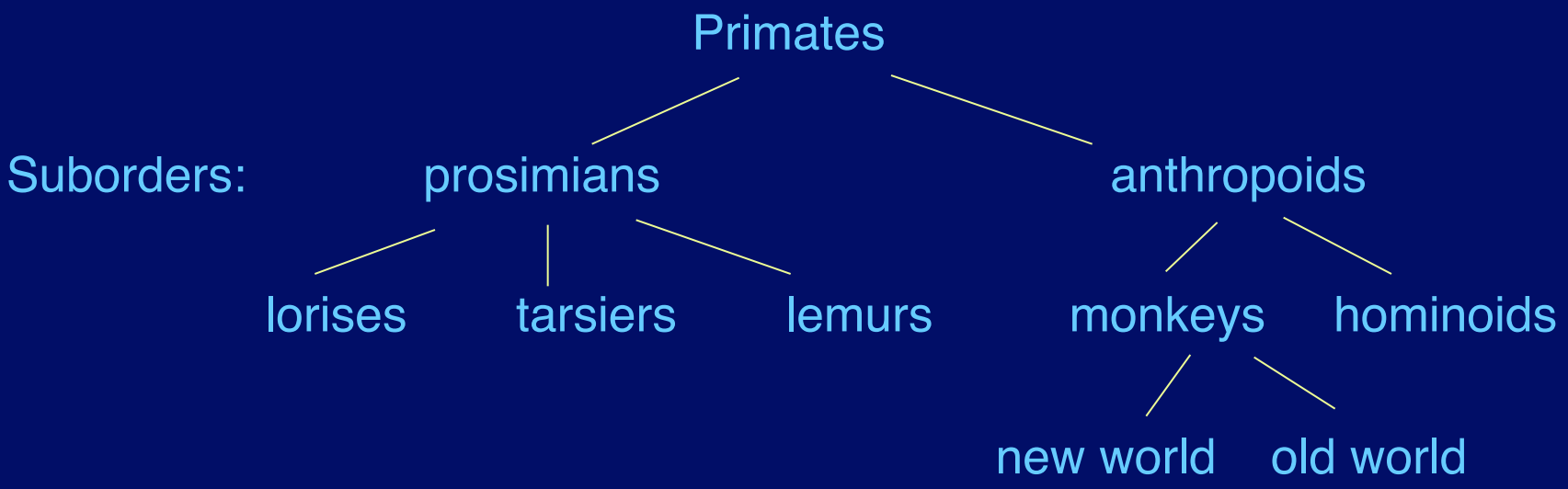


Primate Characteristics

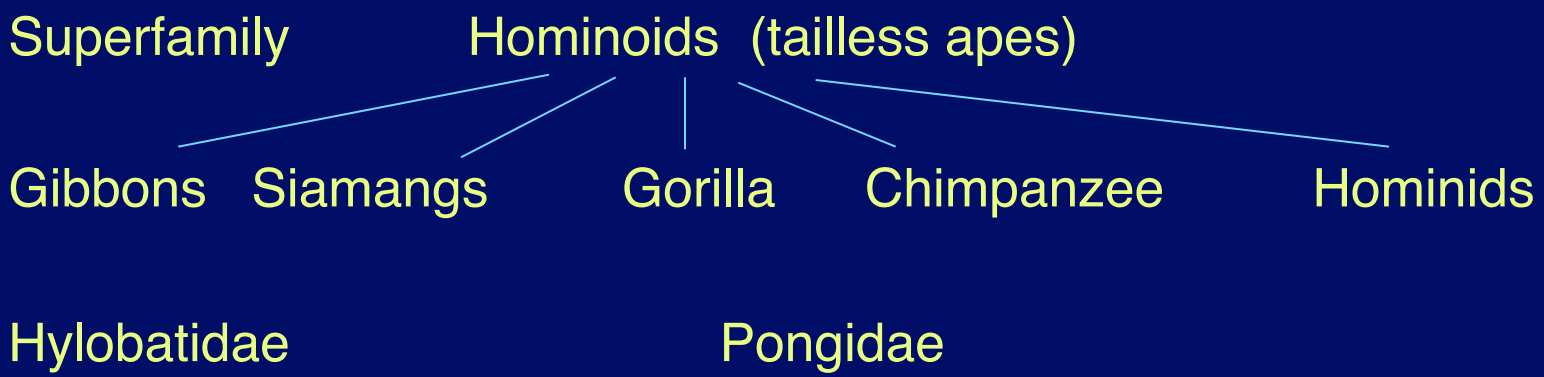
Few anatomical specializations

Flat fingernails, eyes in front

Adapted to life in trees



The Hominoids



“Recent” fossil record

Cenozoic Era (recent life)
Divided into Tertiary (3rd stage) and
Quaternary (4th stage) Periods

Tertiary further divided into 5 epochs:
dates (in million years ago) are rough.

Era	Period	Epoch	Time at beginning (Myr ago)	Events, Fossils of Note
Cenozoic		Recent	~12,000 yrs	Historical Records Homo sapiens Homo erectus
	Quaternary	Pleistocene	2.5	Homo habilis
			4.2	Australopithecus
			5.5	Ardipithecus
		Pliocene	5.5	Sahelanthropus
				Gap
		Miocene	23	Ramapithecus Dryopithecine Apes
				Gap
		Oligocene	34	Aegyptopithecus
		Eocene	56	Tarsiers
				Lemurs
	Tertiary	Paleocene	65	Tree Shrews - Primates Proliferation of Mammals Origin of Many Orders
Mesozoic	Cretaceous			

Early Primate Evolution

Adapting to life in trees

Claws → nails, grasp branches

independent big toe, thumb

Nocturnal → diurnal

Smell → vision stereo vision

(eyes in front)

Color vision

More complicated information processing

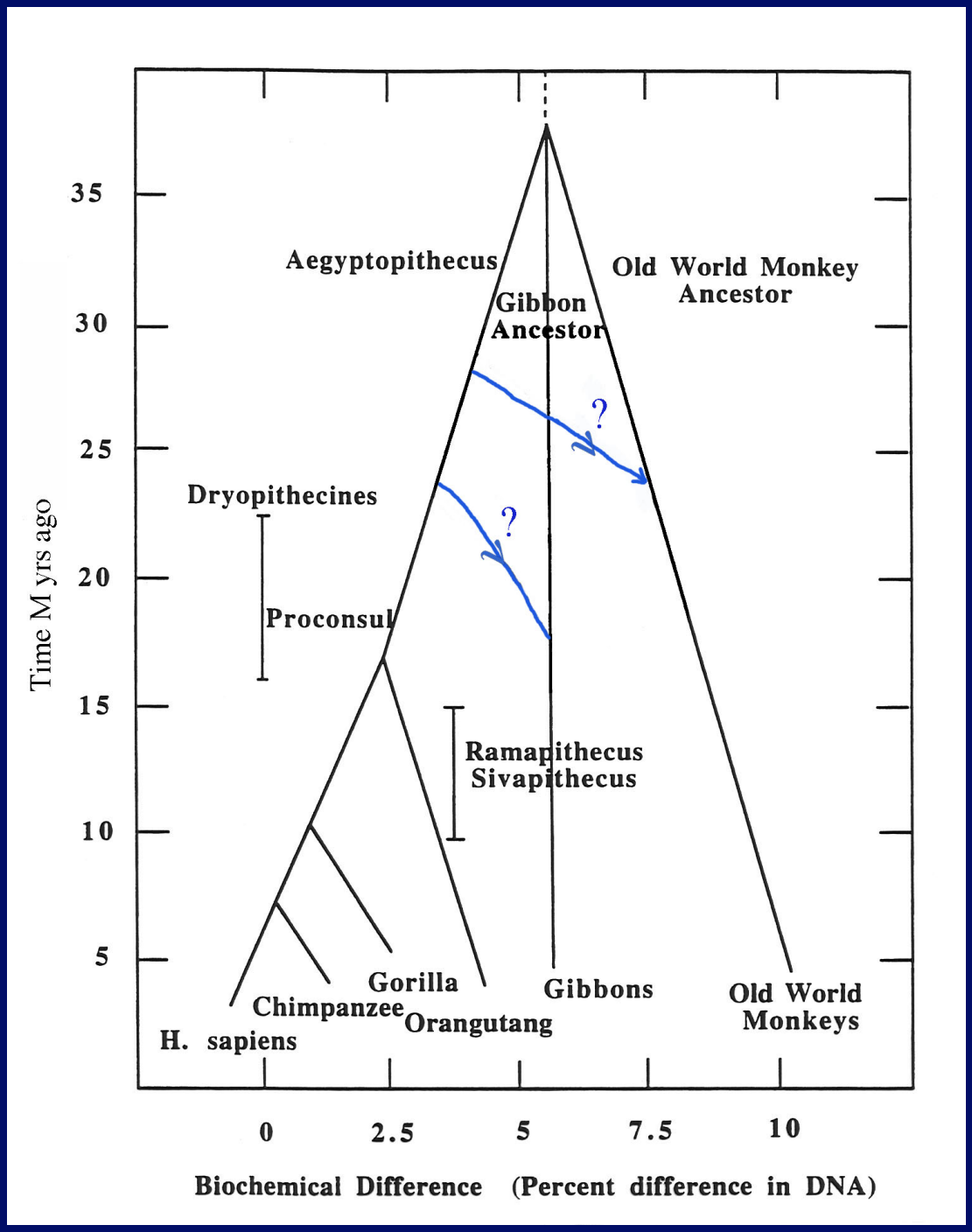
Tool use becomes possible

Origin of Anthropoids

Eocene transition to oligocene ~ 37 Myr ago
cooler, more grasslands

More diurnal, some leave trees, lose tail

Fayum beds - Egypt 33 Myr ago
Early anthropoid fossil: aegyptopithecus
Used to be considered first hominoid, but now suspect monkey/ape split was later


35
30
25
20
15
10
5
Time M yrs ago
Aegyptopithecus
Old World Monkey
Ancestor
Gibbon
Ancestor
?
?
Dryopithecines
Proconsul
Ramapithecus
Sivapithecus
Gorilla
Chimpanzee
Orangutang
Gibbons
Old World
Monkeys
H. sapiens
0
2.5
5
7.5
10
Biochemical Difference (Percent difference in DNA)

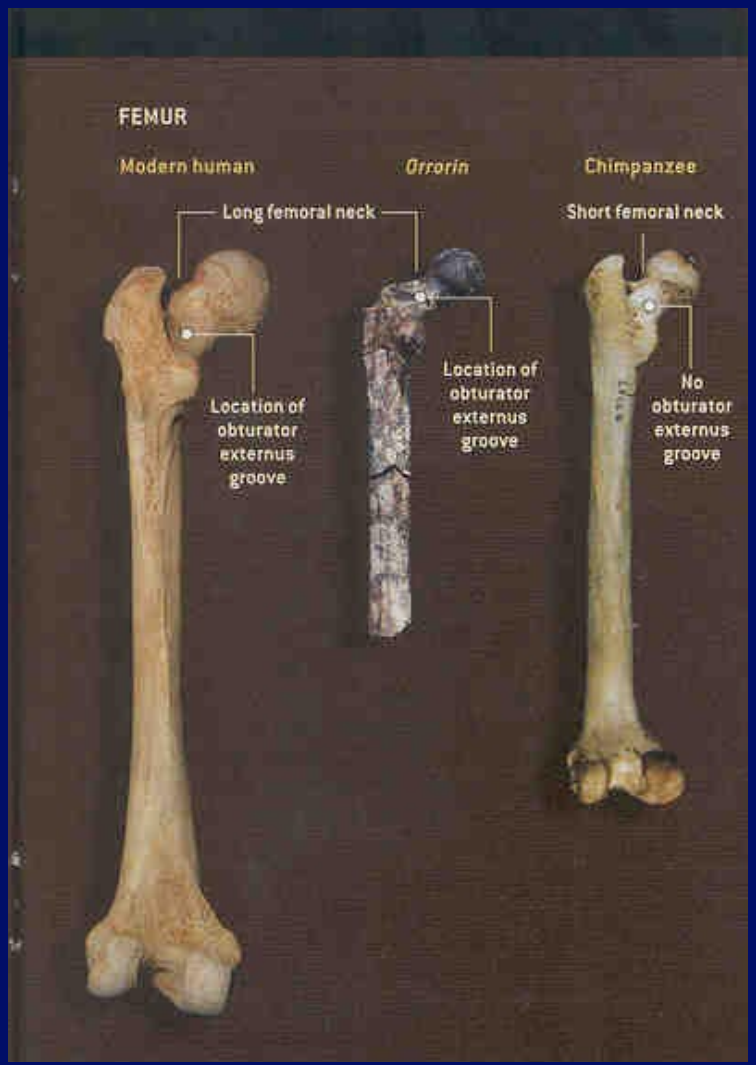
Hominid Evolution

Fossils now known back to ~ 7 Myr
Genetic dating of chimp - hominid split 5-7 Myr

Many variations now known
many species co-existed in Africa
Earlier species show mosaic of human-ape traits

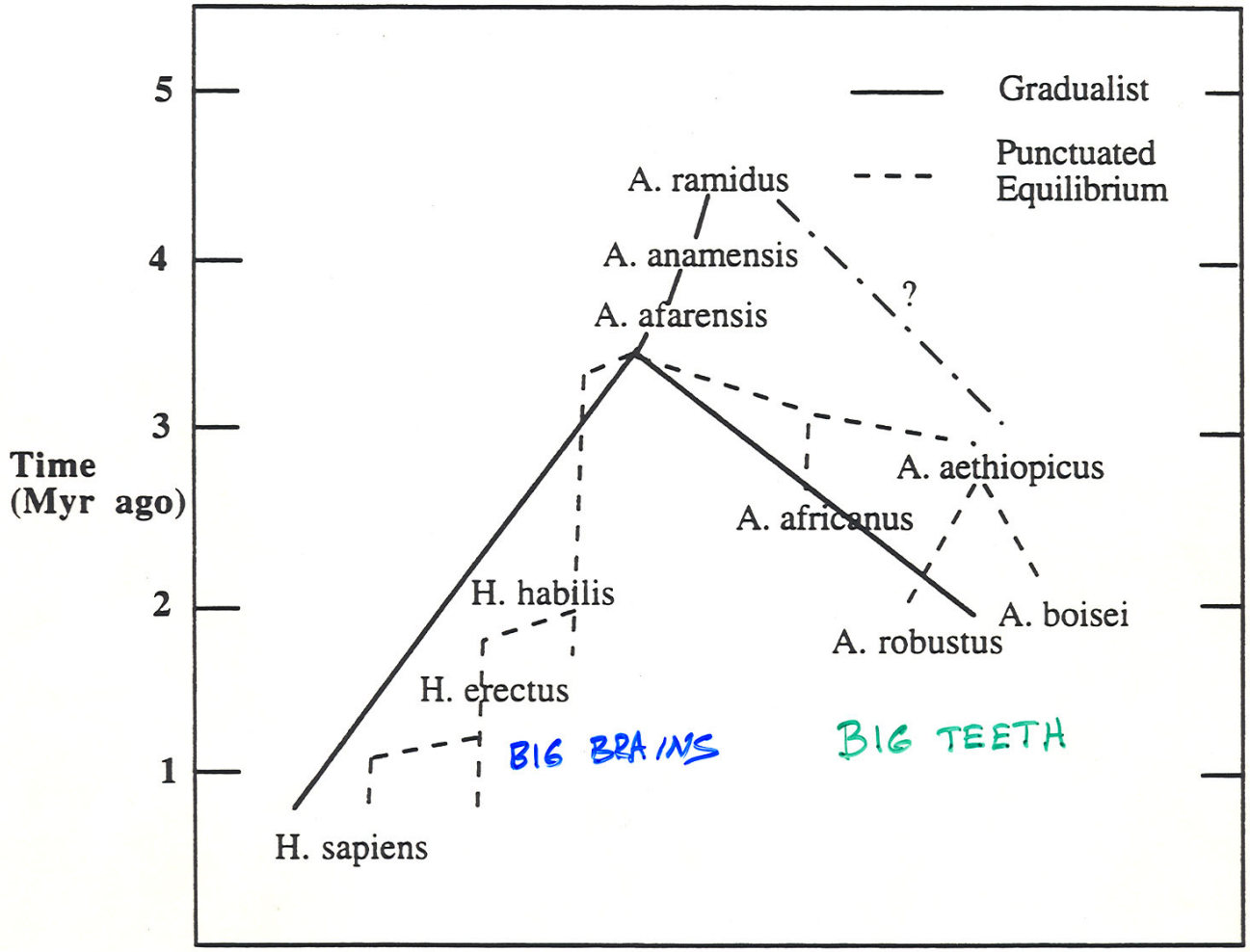
Upright walking preceded brain growth, tool making

Comparison of Femurs



Femur adapted to bipedality already by 6 Myr ago

Scientific American
Jan. 2003

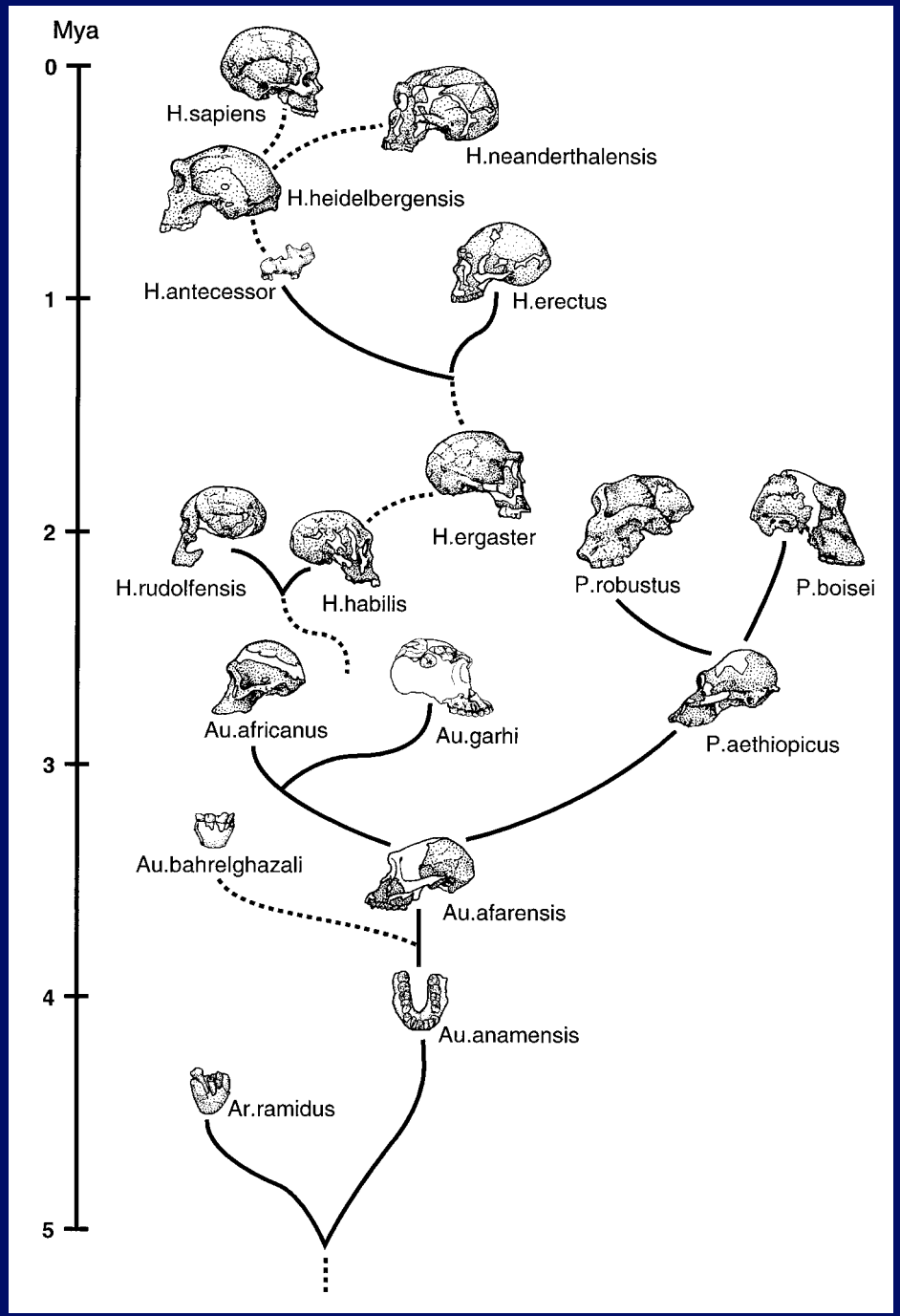


The last 4.5 Myr of hominid evolution are summarized in the accompanying figure. The solid lines in the figure indicate the lines of descent in a gradualist picture, while the dashed lines indicate the picture of punctuated equilibrium.

More Fossils, more complex picture with many possible species.

Main point: there was a major radiation, but only one species survived.

Were big brains highly selected?
(Did we kill our “cousins”?)
If so, argue for large f_i
Or was it chance that we survived?
If so, argue for small f_i



Consequences of New Fossils

1. Even more clear that bipedal locomotion far preceded big brains

2. Bipedality not clearly connected to savanna

3. Several of the oldest hominids are very close to Ape - Human split

4. Bipedality looks like key change that separated human and ape

Humans and Chimpanzees: 1

- Draft of chimp genome released in 2003
- Base substitutions: 1.23% difference
- Gene copies indicate bigger differences
  - Up to 6.4% in terms of duplications and losses
  - Some seem important in brain development.
- Split from gorillas: 6-7 Myr ago
- Human split from chimp: 5-6 Myr ago

Our Closest Living Relative

Chimpanzees

H. Sapiens (Darwin)

Humans and Chimpanzees: 2

- Paper by Wildman et al. (2003)
  - PNAS, 100, 7181
- Wildman et al.'s "modest proposal"
  - Family Hominidae includes all extant apes
  - Genus Homo includes chimps
  - "We humans appear as only slightly remodeled chimpanzee-like apes."

Humans and Chimpanzees: 3

- On the other hand…
- Cargill et al. (2003) Science, 302, 1960
- Studied what genes evolved fast
  - Chimps: fast changes in skeleton, skin
  - Humans: smell, hearing, speech, digestion
    - Adaptation to consuming more meat

Humans and Chimpanzees: 4

- J. Zhang 2003 in Genetics, 165, 2063
  - Rapid evolution in ASPM gene
    - Mutations in this gene cause microcephaly
    - Brain about size of Australopithicus
    - So important for brain size
  - Rapid evolution in primates
  - Especially in line leading to humans
    - 15 changes since human-chimp split
    - May explain factor of 3 increase in size

More Developments

- Several other genes involved in brain growth
  - Evidence for rapid evolution
  - Some may have evolved as recently as 6000 years ago (update on ASPM gene)
- Differences in brain microstructure
  - Special (fast) neurons (VENS) in apes
  - Humans have many more
  - Some large whales also have VENS

(brain story in Science 2007, 315, 1208)

The Last Steps to Modern H. sapiens

Origin of Modern H. Sapiens

Many anthropologists now believe that H. erectus were replaced by a new wave "out of Africa" ~ 100,000 yrs ago.

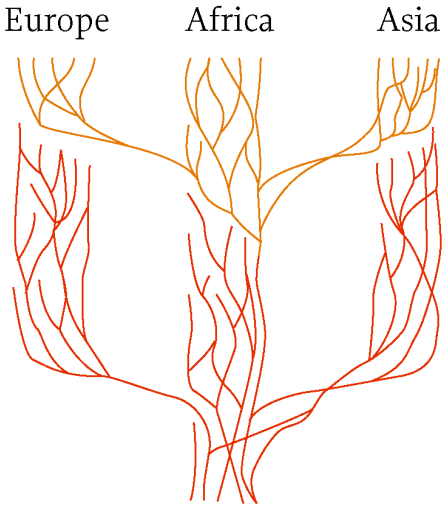
Alternative: Multiregional model

Separate groups of H. erectus leading to H. Sapiens (looks less likely)

Evidence: Genetic, linguistic, fossil

Two Models

Out of Africa

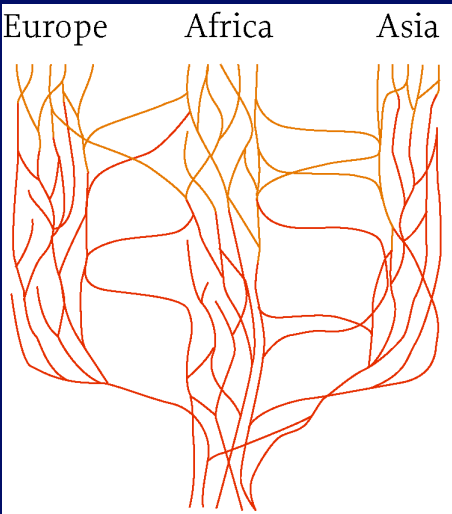


Out of Africa model

Anatomically modern *H. sapiens* evolves in Africa and then spreads to Europe and Asia.

H. erectus disperses from Africa.

Multiregional



Multiregional model

Anatomically modern *H. sapiens* genes arise in many populations.

H. erectus disperses from Africa.

Genetic: humans are **very** homogeneous
greatest diversity is in Africa

$\Rightarrow$ Evolved in Africa, population bottleneck
a small group left Africa, spread over Earth

Linguistic: Good correlation of linguistic family tree with genetic one

Fossil: Oldest fossils of modern H. sapiens are found in Africa

Genetic Analysis: Out of Africa

March 2002

Genetic comparisons of more DNA sequences

(mitochondrial DNA, Y-chromosome, X Chromosome, …)

female male female

Indicate 3 migrations out of Africa

1.7-1.9 Myr H. erectus

~ 650,000 Archaic

~ 130,000 Modern humans

Neanderthals and Us

- In 2009, analysis of DNA from Neanderthals
  - Science 13 February 2009:
    Vol. 323. no. 5916, pp. 866 - 871
  - 38,000 yr old fossils from cave in Croatia
  - Some evidence of inter-breeding with modern H. sapiens outside of Africa
  - 1-4% of modern human DNA may be from Neanderthals
  - Controversial because of possible contamination and degradation of the DNA

Questions

1. What **selected** for the increase in brain size over the last 6 Myr?
   - Adaptation to climate changes?
   - Cooperation and language (large-animal hunting)?
   - Intergroup conflict?

2. What **limited** the increase?
   - Size of birth canal (bipedalism **decreases** size)
   - Birth when less developed, so more care needed
   - Consequences of need for more care
     - pair bonding, more parental care available
     - slower development led to greater intelligence?

3. How intelligent are other species?
   (Chimpanzees, gorillas, … dolphins, whales)
   Recent evidence for weapon construction and use by Chimpanzees.

- What features of H. sapiens would we expect in ETI?
  Bilateral symmetry, bear young alive, bipedal, opposable thumb, …

$f_i = ?$

Contingency

Does evolution produce greater complexity?

What would happen if we replayed the tape with random changes?

Stephen J. Gould vs. Conway Morris

Contingency vs. convergent evolution

Extinction of Early Chordata

↓

No intelligence

Other precursors

↓

intelligence in other shapes

Who is Right?

- Can’t rewind the tape for macroevolution
- But remember the E. Coli 25 year experiment?
- Some samples were frozen every 75 days (500 generations)
- Could thaw out and rerun (bacteria survive freezing)
- 4 out of 72 developed citrate use
- Sometimes the rewind produces the same result!

Estimating f_i

1. Galactic habitable zone (GHZ)
   Gonzales, Ward, Brownlee
   and Ward and Brownlee in *Rare Earth*

   Complex life requires more benign conditions
   more stars closer to center of galaxy (stars
   closer together) Supernovae, X-rays, Gamma-rays
   could extinct complex life

   If "animal" life has to avoid inner galaxy, this would
   decrease f_i

2. Timescales

Time to evolve human-level intelligence

~ 1/2 lifetime of stars like Sun

$\Rightarrow$ rule out much more massive stars

(already done in n_e)

~ 1/2 lifetime of galaxy so far

? $\Rightarrow$ intelligent life is rare

Brandon Carter

? Statistics of <u>one</u> are suspect

Summary

- Values for f_i can range from very small (e.g., 10^{-6}) to 1
- Consider contingency vs. convergence
- Need for stable conditions
- The particular evolution that led to H. sapiens
- Consider other ways to get to intelligence
- Other species on Earth that may be very intelligent