

The Origin of Intelligence

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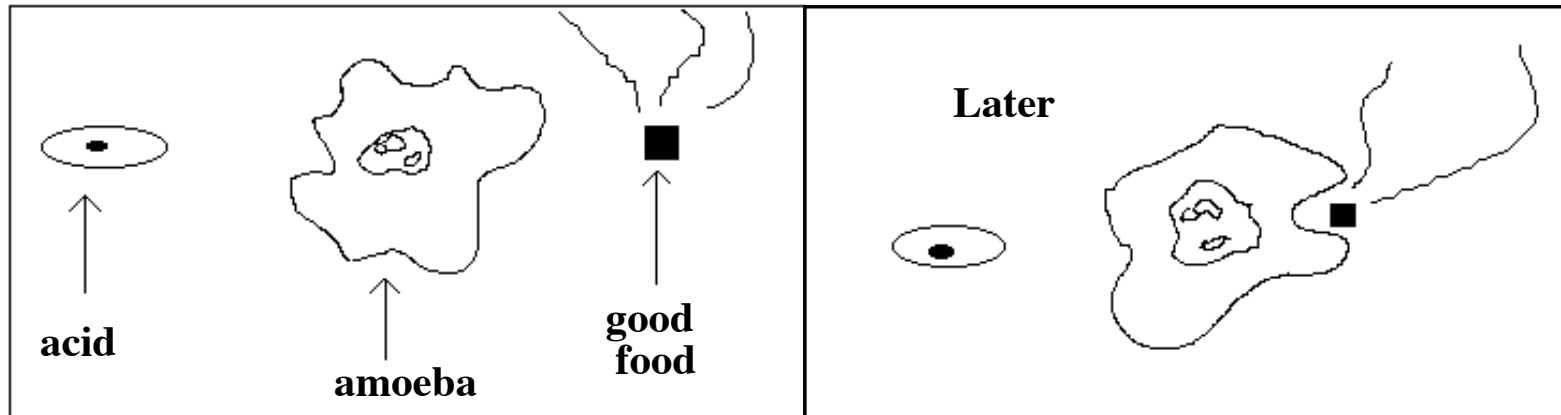
f_i : Fraction of life-bearing planets where
Intelligence develops

What is intelligence?

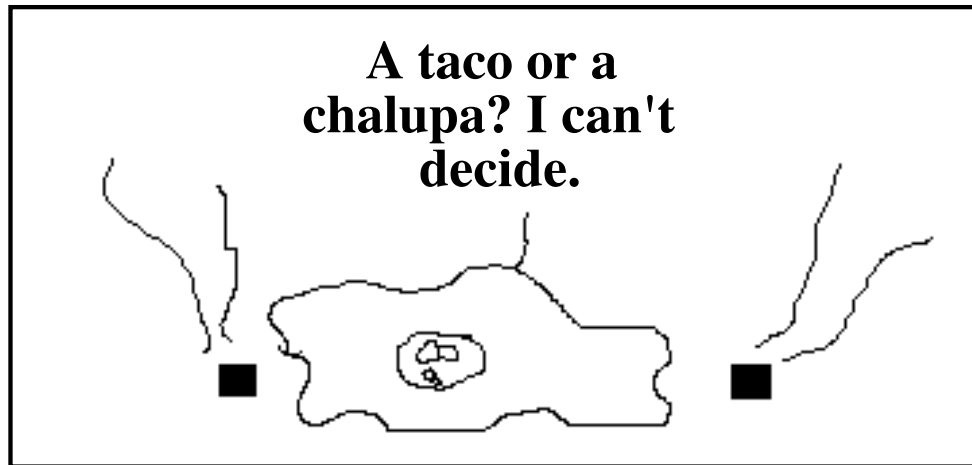
Propose: “The ability to model the world,
including the organism itself”

⇒ Intelligence as continuum
related to complexity of organism
milestone: human-level intelligence

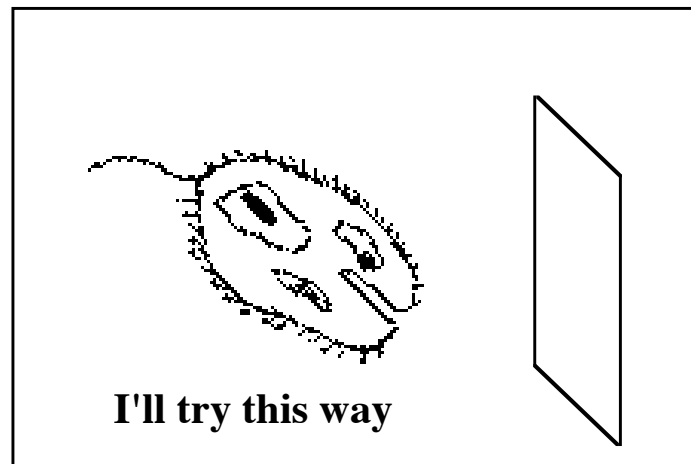
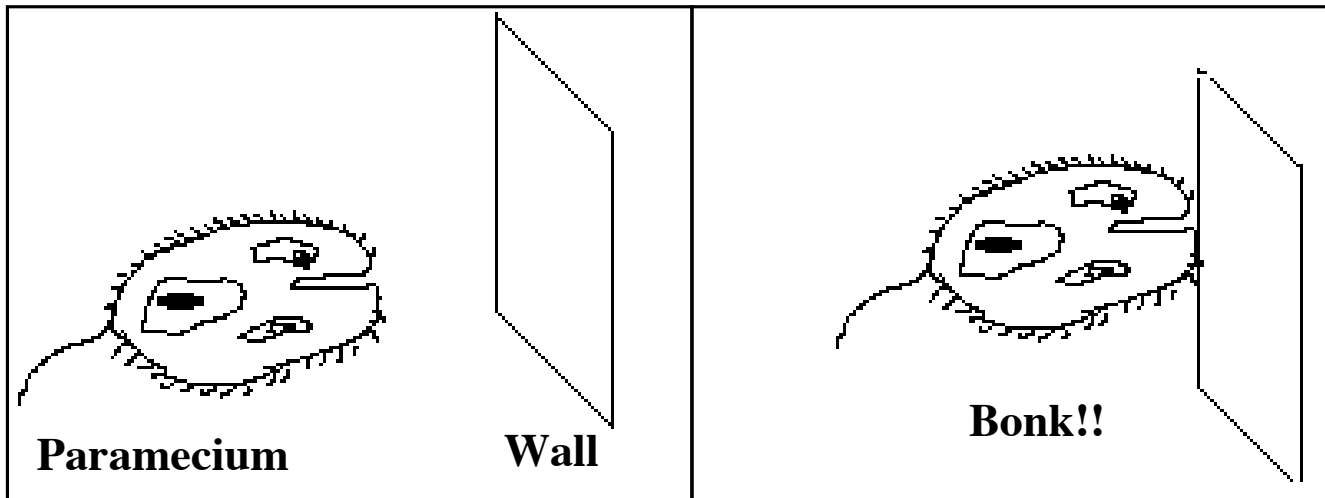
Amoeba intelligence



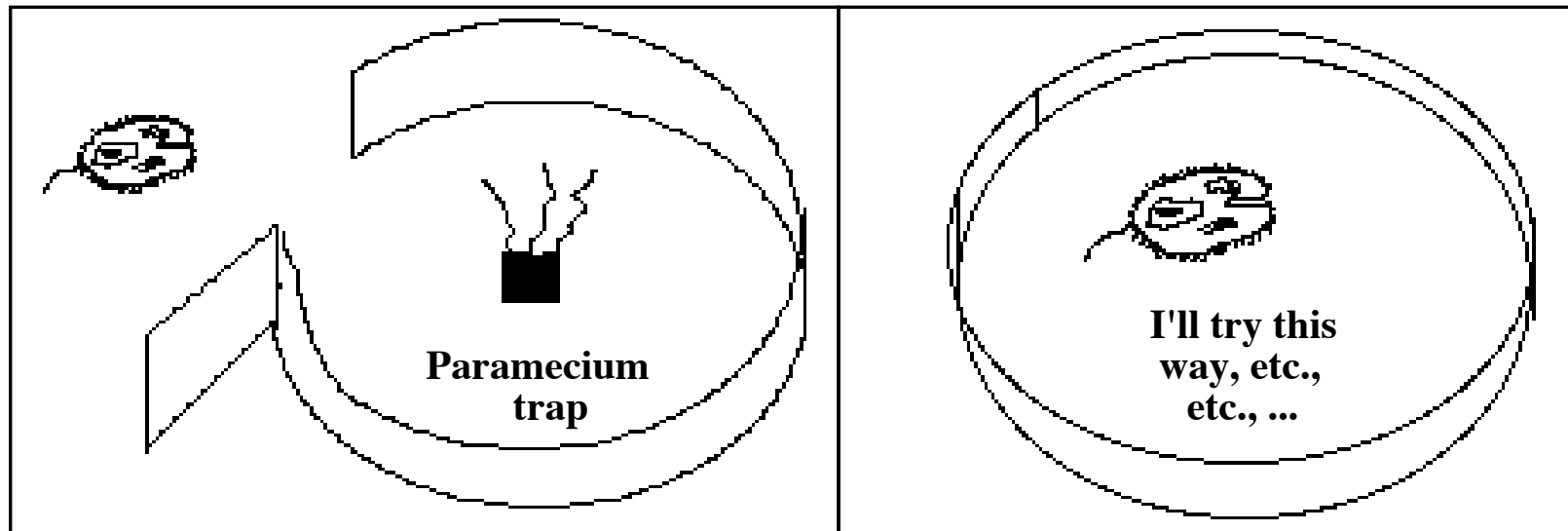
The Amoeba's dilemma



The smarter Paramecium



But not THAT smart...



Information as Measure of Intelligence

Evolution of intelligence \approx 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

* ~ 2% codes for proteins

$\Rightarrow 1.2 \times 10^8$ bits

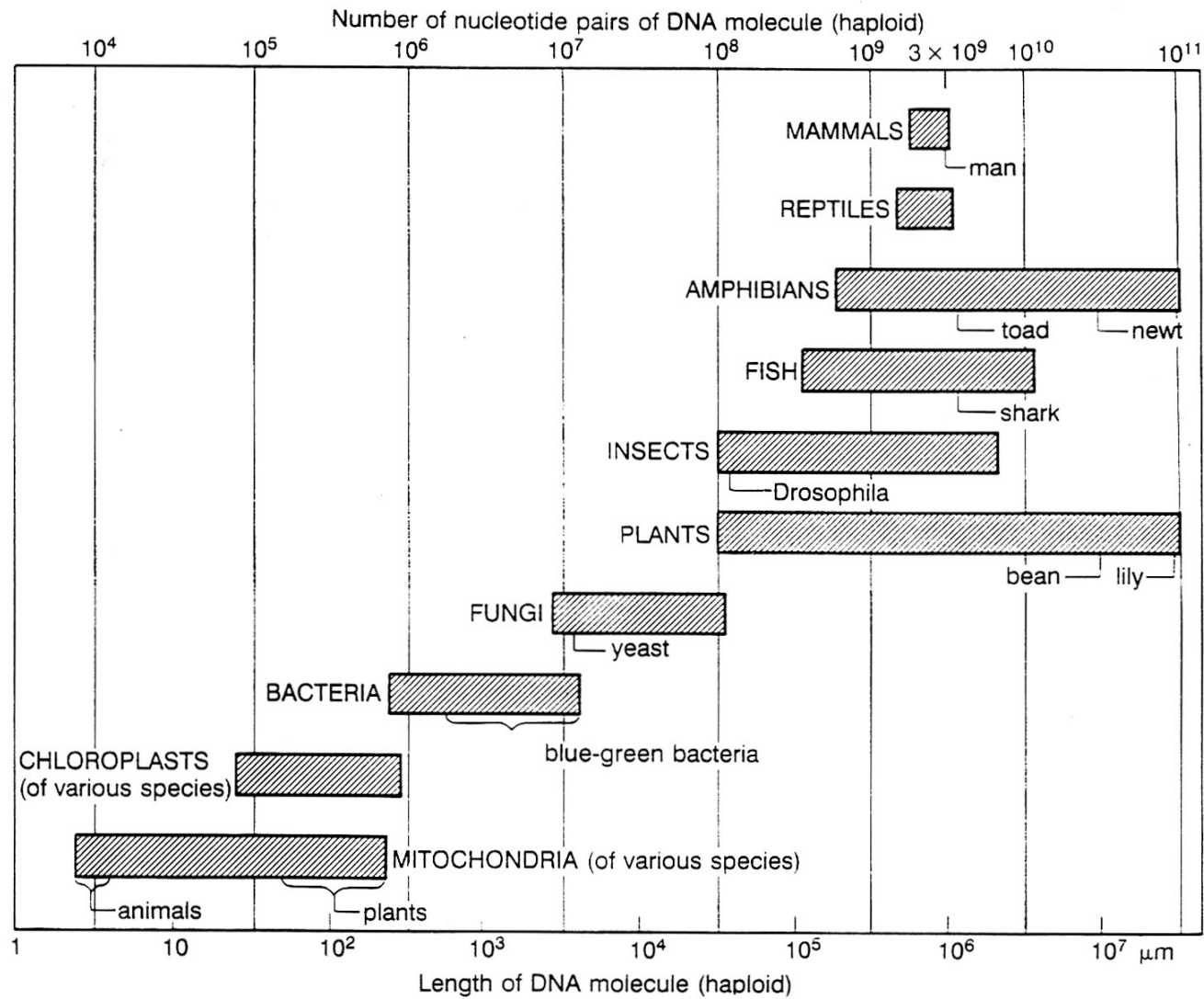
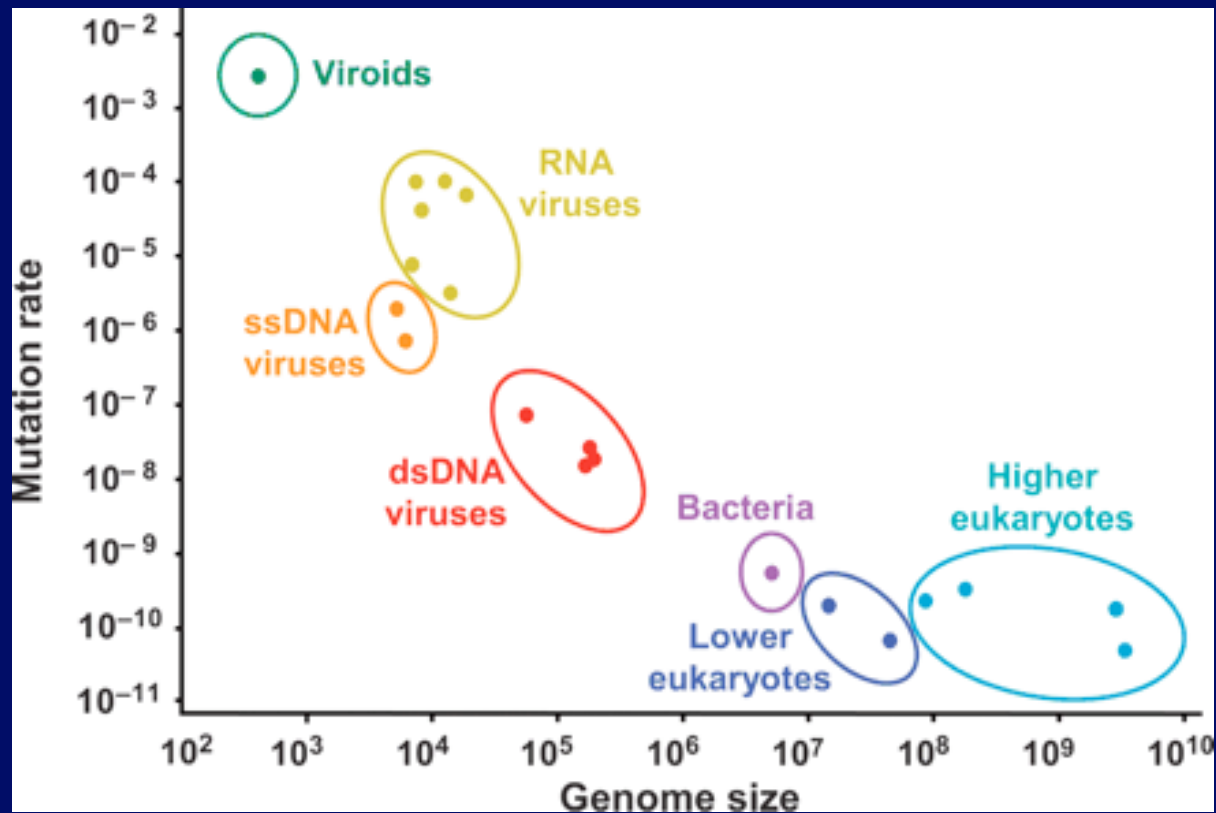


Figure 7.18. Length of DNA molecules. Note that the DNA of some plants and amphibians is longer than that of bacteria by a factor of 10^4 to 10^5 . The total length of human DNA is approximately 10^6 μm or 1 m, which is equivalent to roughly 3×10^9 nucleotide pairs or 10^9 codons. Obviously, the length 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

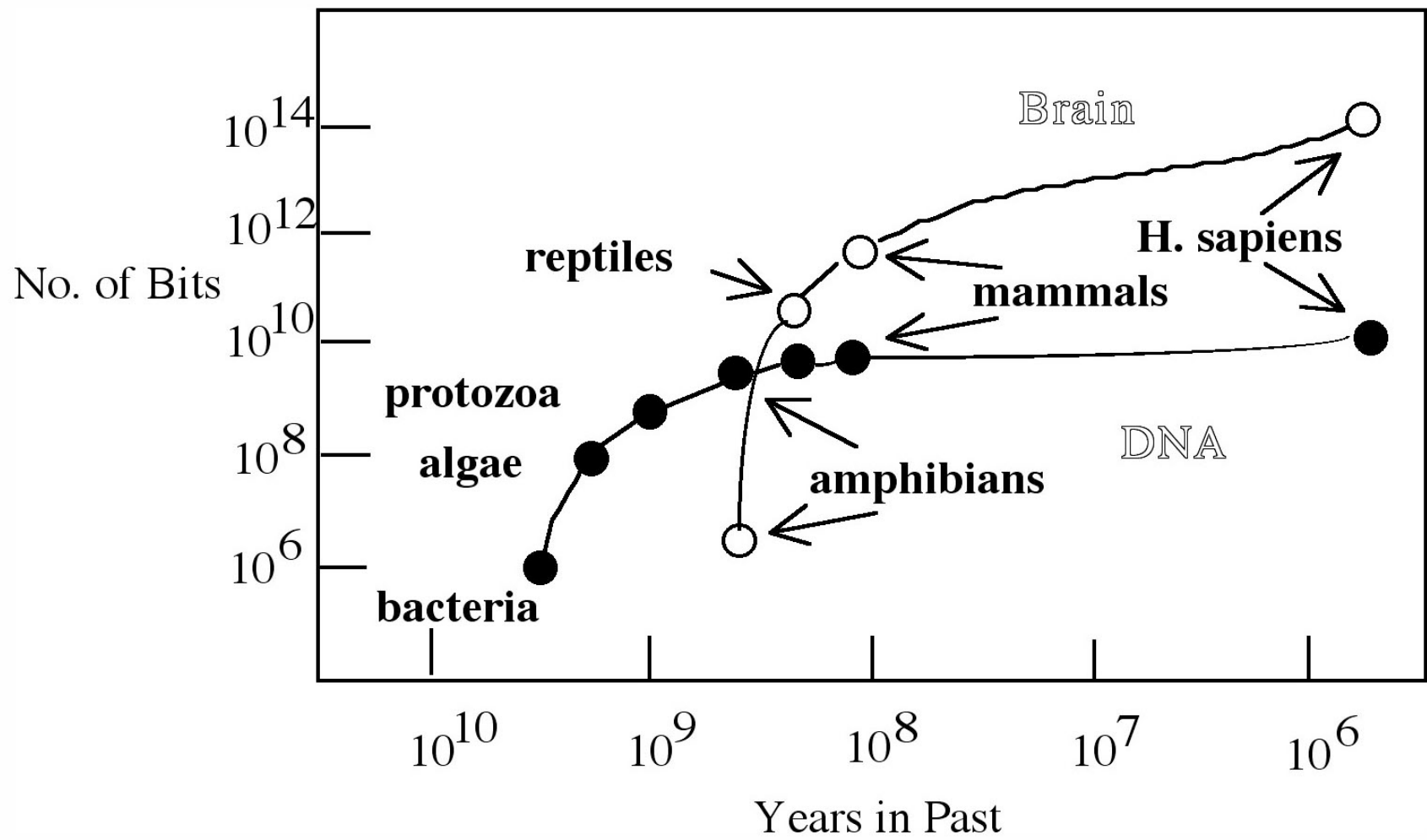
Information stored in DNA limited by fidelity of Replication. The bigger the genome, the smaller the mutation rate must be.



Gago et al. 2009, Science, 323, 1308

Further Complications...

- Humans make about 90,000 kinds of protein
- Now it seems we have only 25,000 genes
- What's going on?
- One gene can lead to different proteins
 - The mRNA is edited to remove introns
 - Sometimes exons are left out or introns in
 - Splicing controls gene expression
 - More common in more complex organisms



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

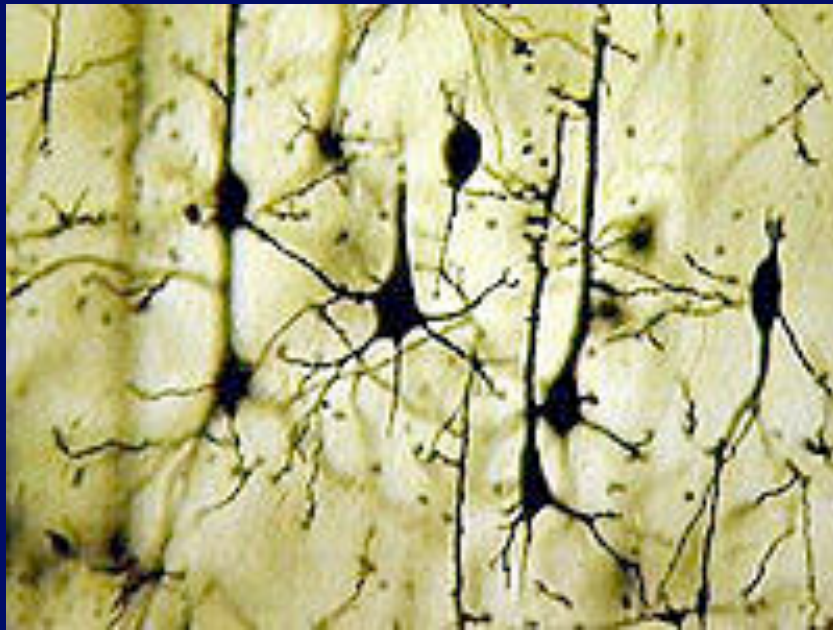
How is information stored in brains?

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 ($\sim 10^3$) inputs - synapses

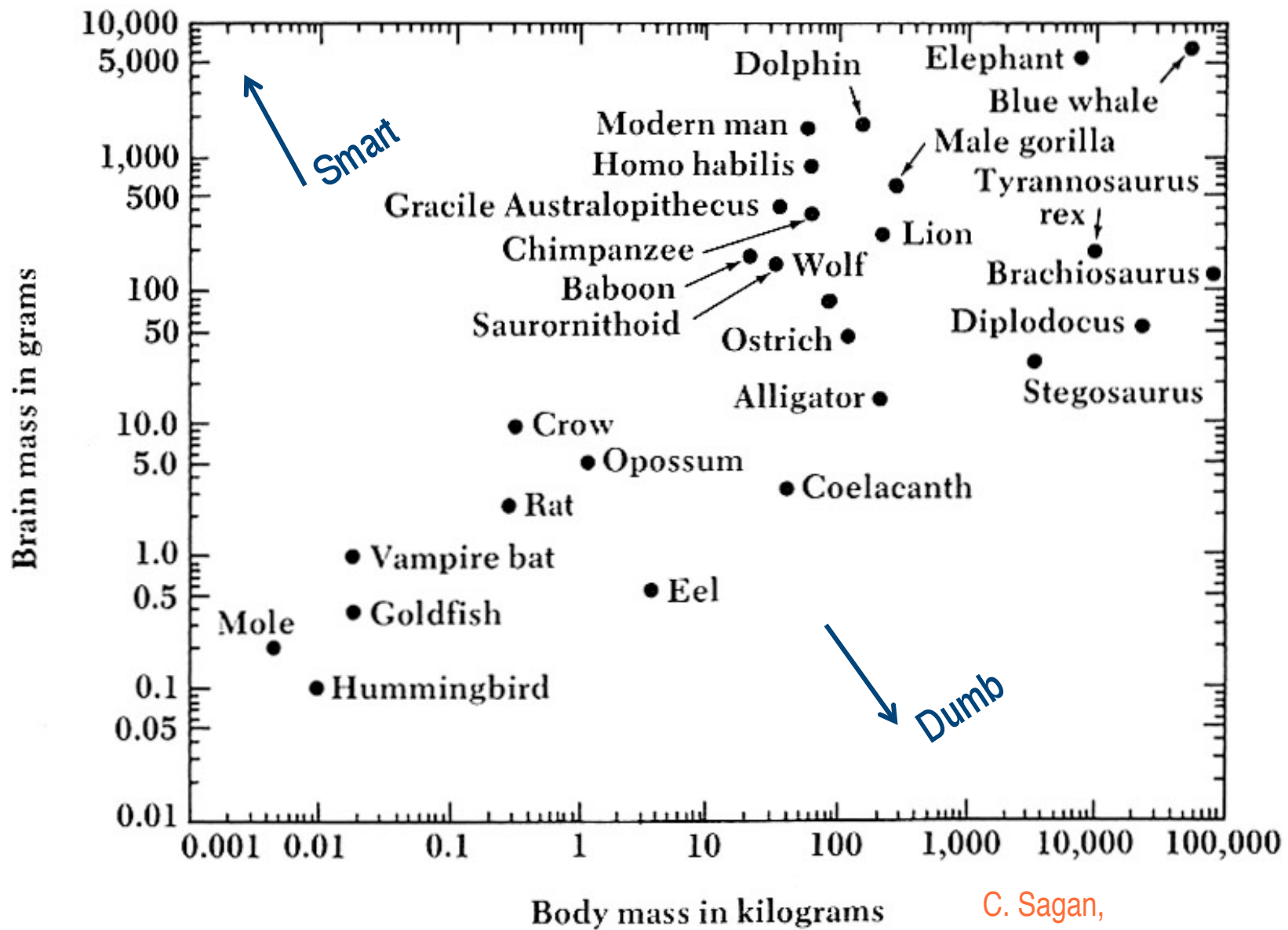
An **analog** computer \Rightarrow Hard to count

$\sim 10^{11}$ 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

⇒ **Individual** can learn

Two hemispheres

Many functions parallel, but some specialized

Many ways to divide brain

Layered brain: reptilian brain

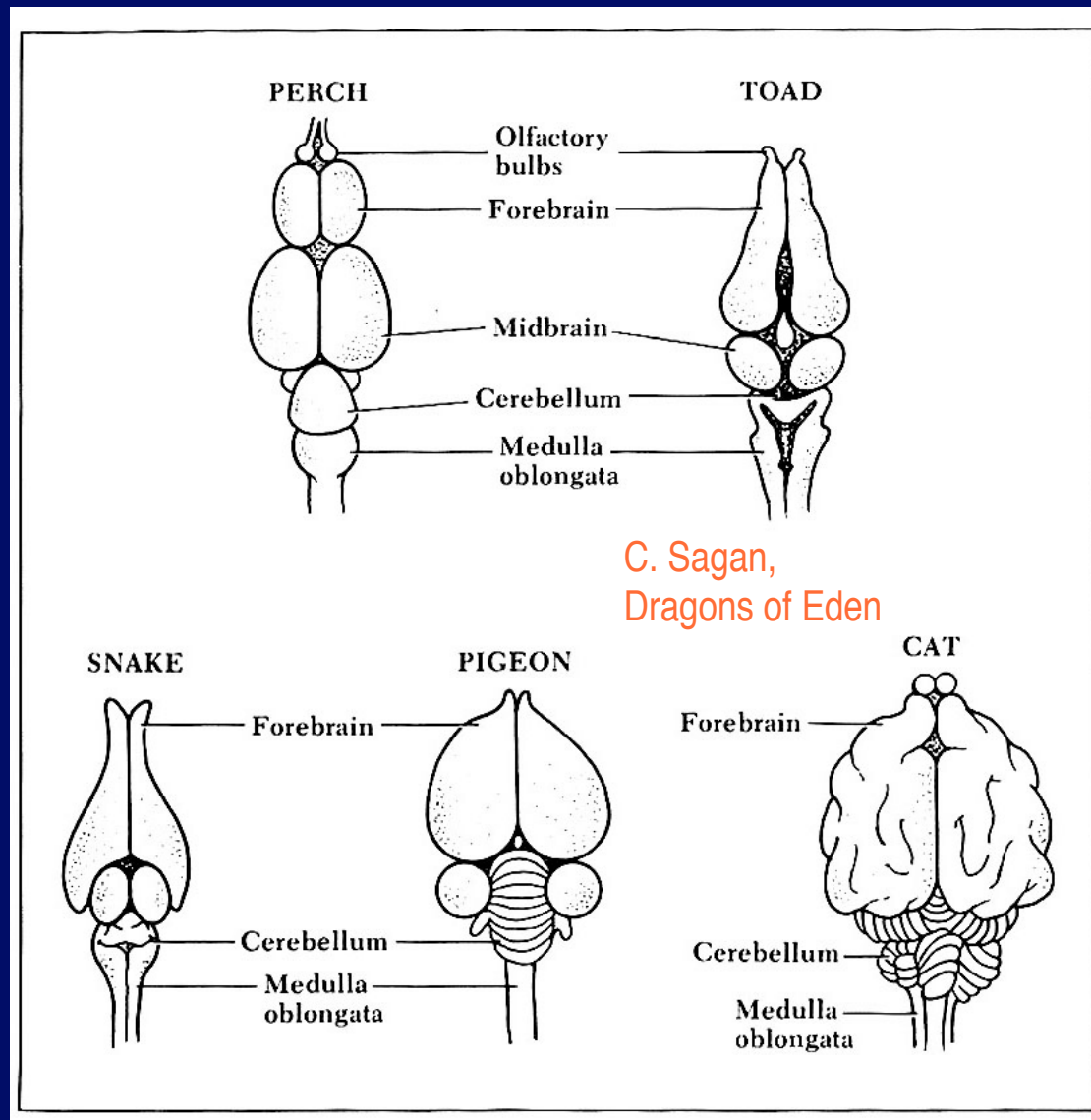
limbic system (mammals)

cortex

Brain size has increased (in some species) with time

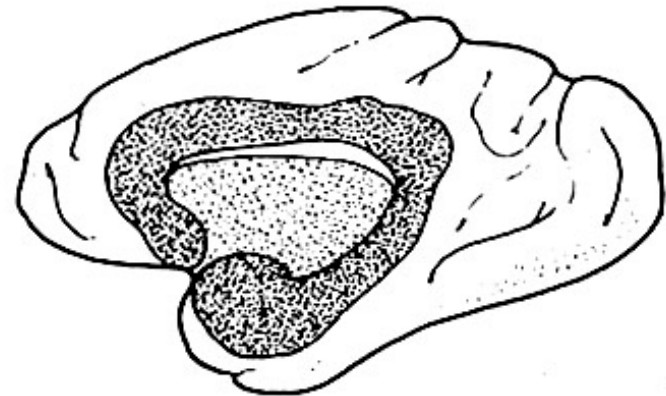
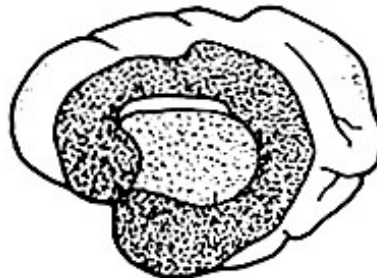
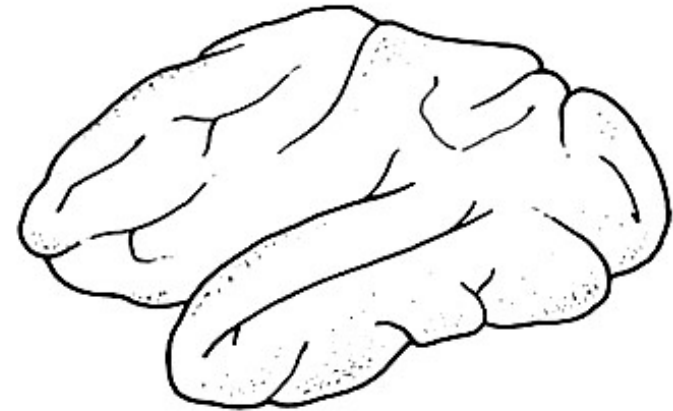
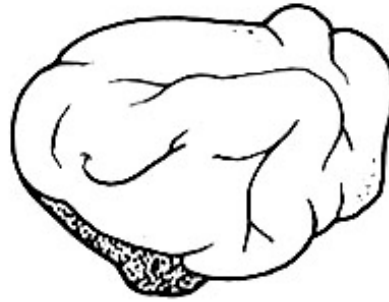
?

⇒ Evolution favors higher intelligence (sometimes)



Schematic diagrams comparing the brain of a fish, an amphibian, a reptile, a bird, and a mammal. The cerebellum and medulla oblongata are parts of the hindbrain.

C. Sagan,
Dragons of Eden



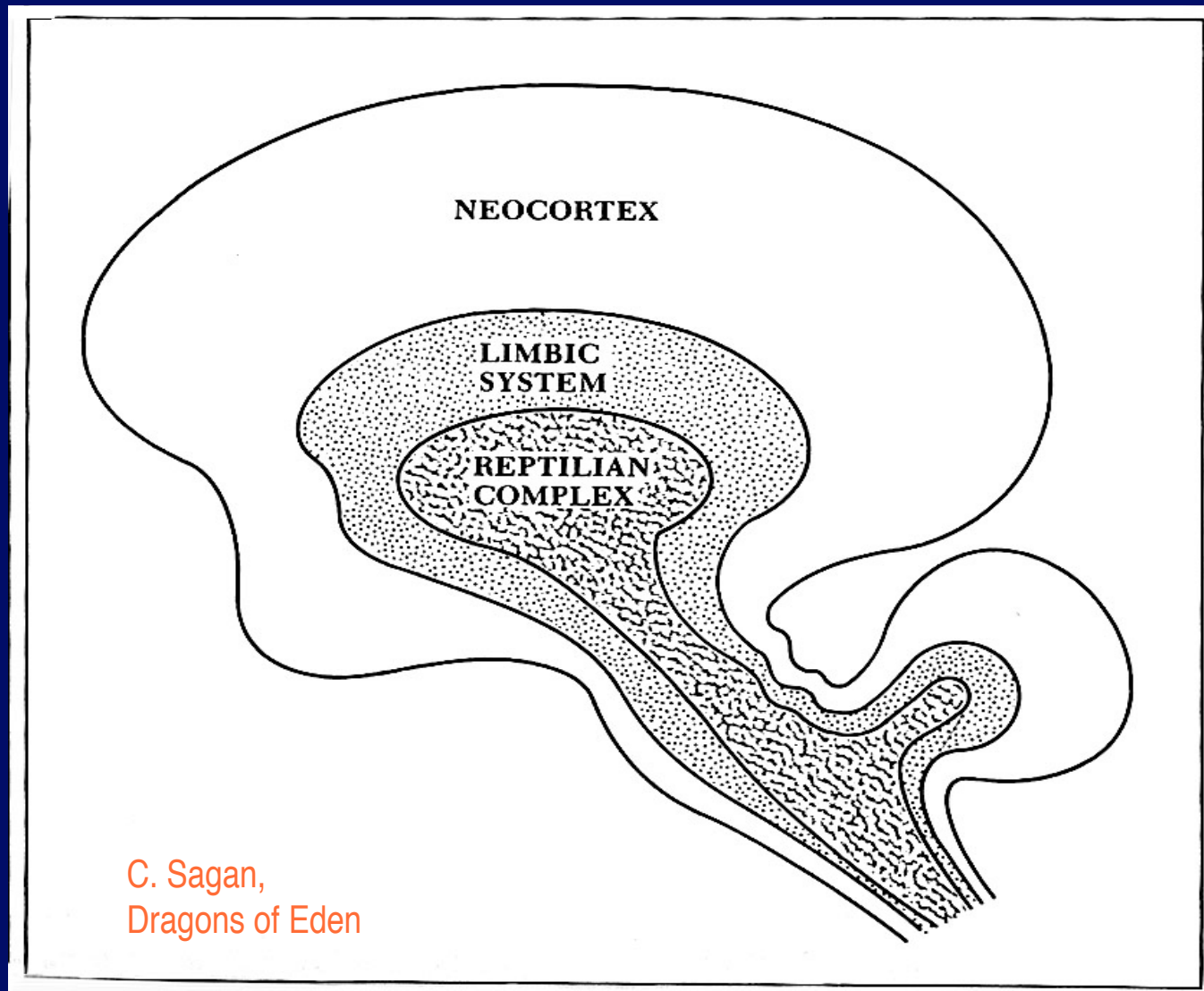
Rabbit

Cat

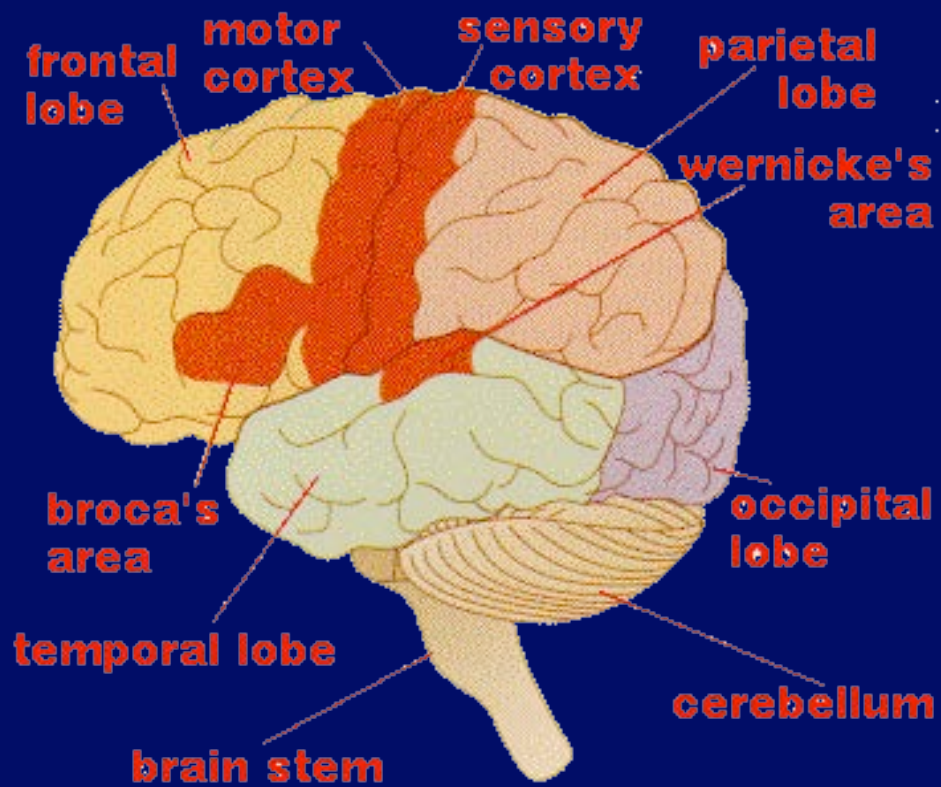
Monkey

Schematic views from the top and from the side of the rabbit, cat, and monkey brains. The dark stippled area is the limbic system, seen most easily in the side views. The white furrowed regions represent the neocortex, visible most readily in the top views.

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



The Big Brain



Human Evolution

Phylum: chordata - vertebrates - bilateral symmetry

~ 500 Myr ago

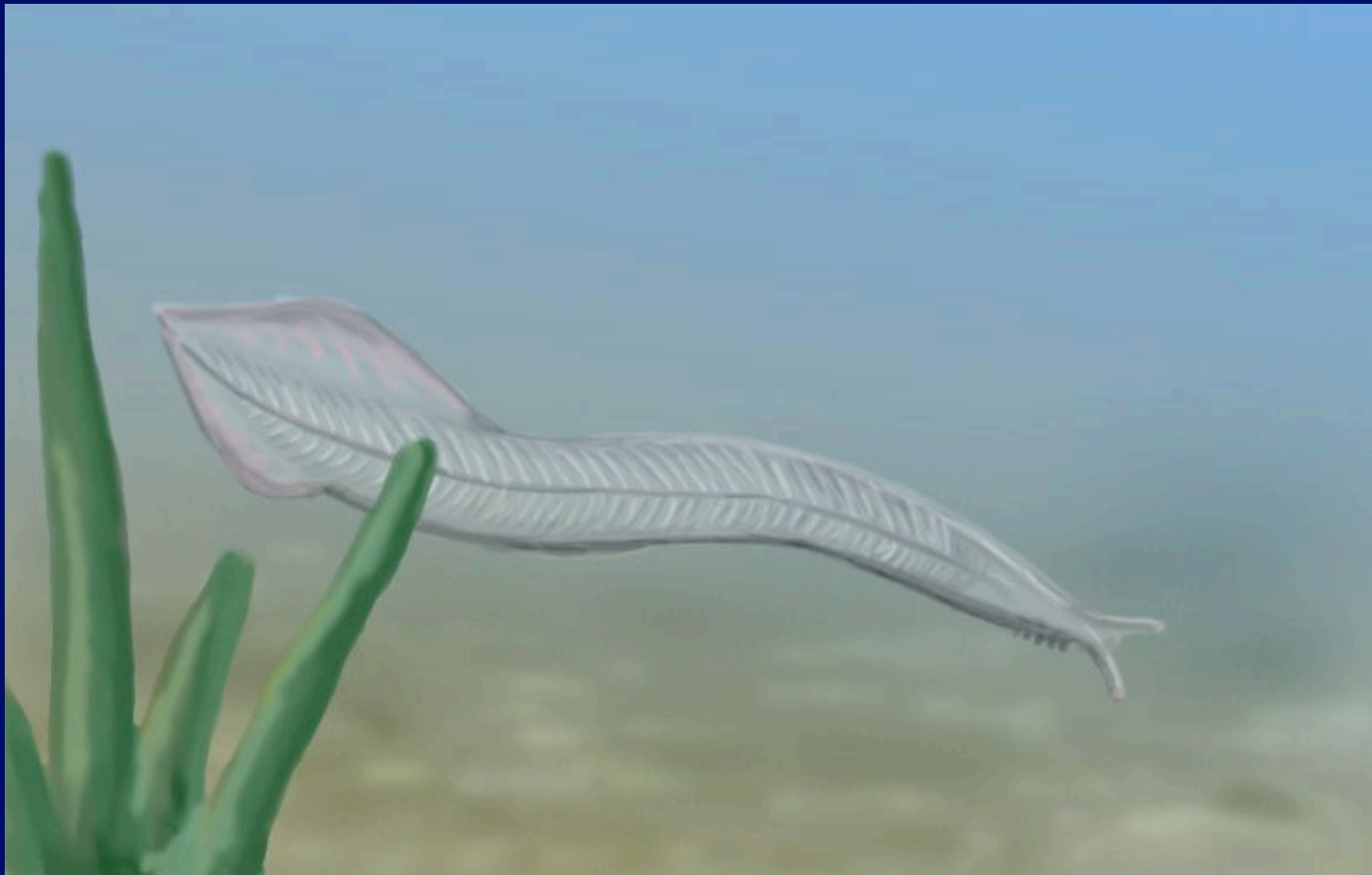
Class: mammals arose in Triassic period

~ 225 Myr ago

Proliferated and “radiated” at end of cretaceous
(~ 65 Myr ago) after extinction of dinosaurs

Order: primates - late cretaceous ~ 80 Myr ago

Pikaia (from Burgess Shale)

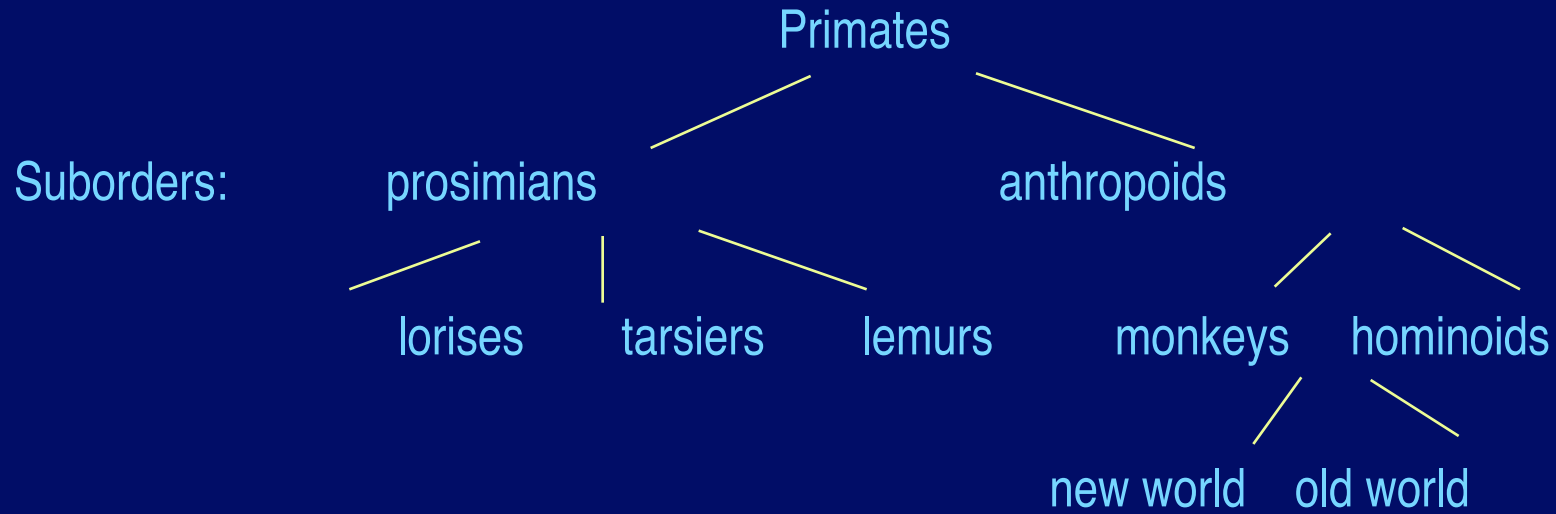


Primate Characteristics

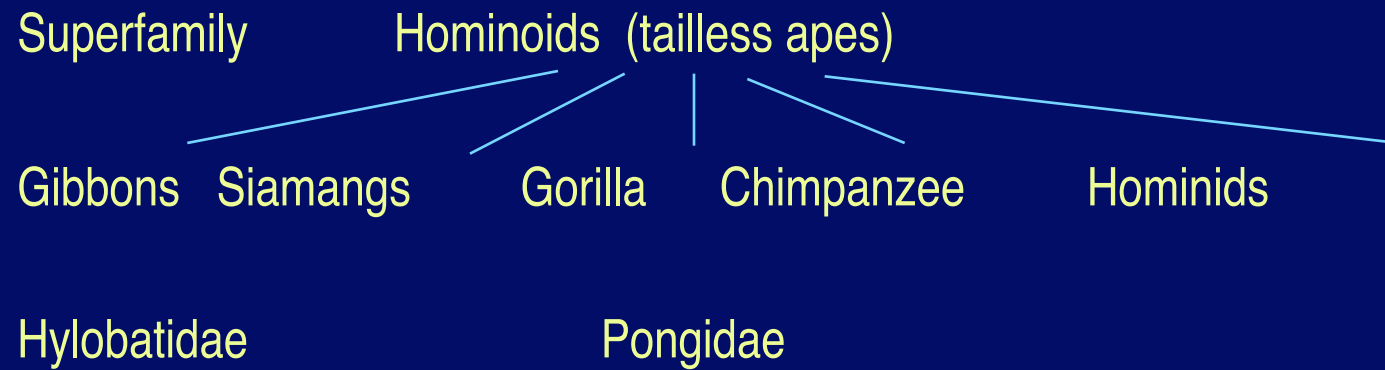
Few anatomical specializations

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	Quaternary	Recent	5000 yrs	Historical Records Homo sapiens Homo erectus
		Pleistocene	1.8–2.5	Homo habilis
	Tertiary	Pliocene	4.2	Australopithecus
			5.5	Ardipithecus
		6–7	Sahelanthropus	
		Gap		
		Miocene	23–26	Ramapithecus Dryopithecine Apes
		Gap		
	Tertiary	Oligocene	37–38	Aegyptopithecus
			Eocene	54
Paleocene		65	Lemurs 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

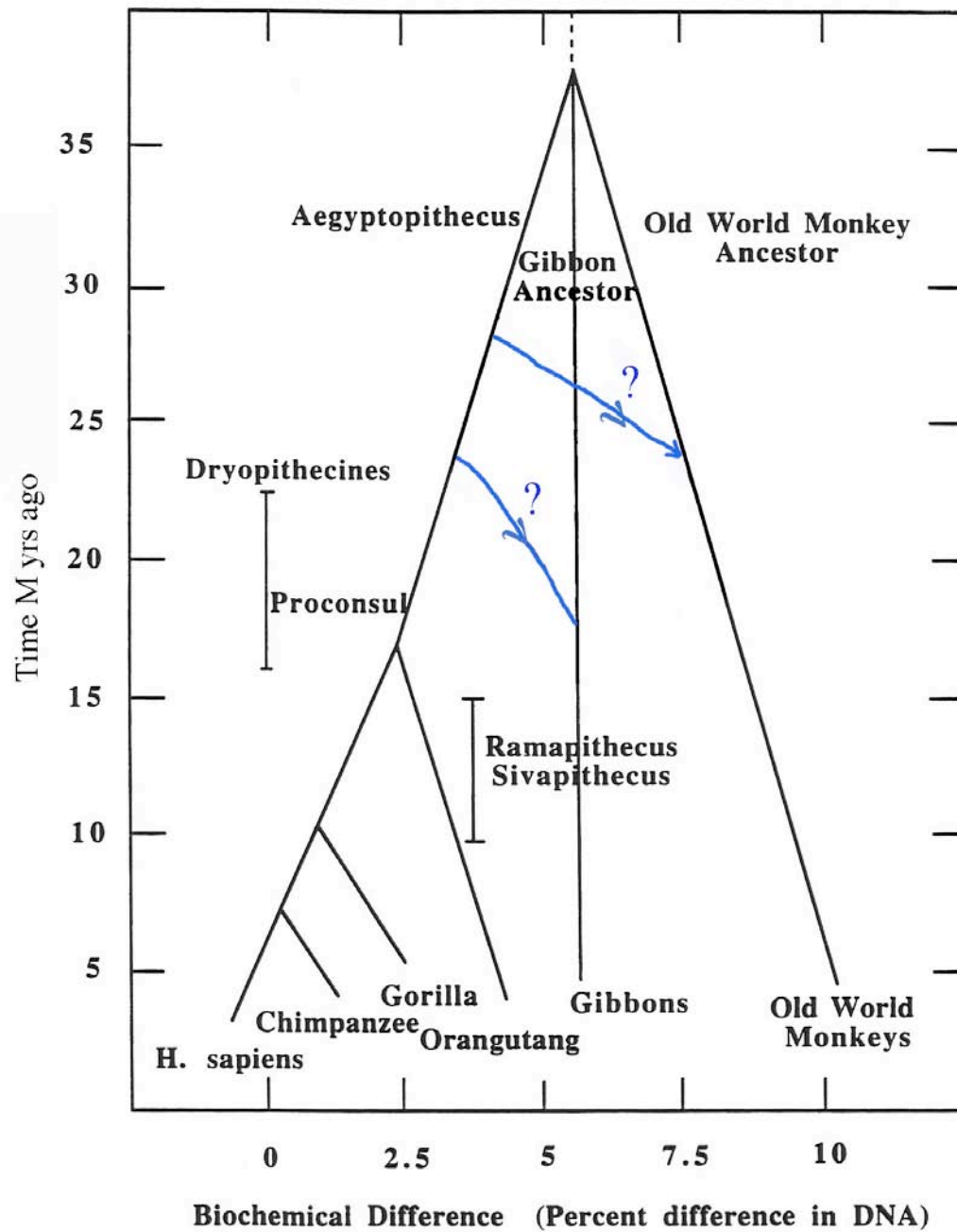
Eocene transition to oligocene ~ 37 Myr ago
cooler, more grasslands

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



Hominid Evolution

Fossils now known back to ~ 6 Myr

Molecular dating of chimp - hominid split 5-7 Myr

Many variations now known

many species co-existed in Africa

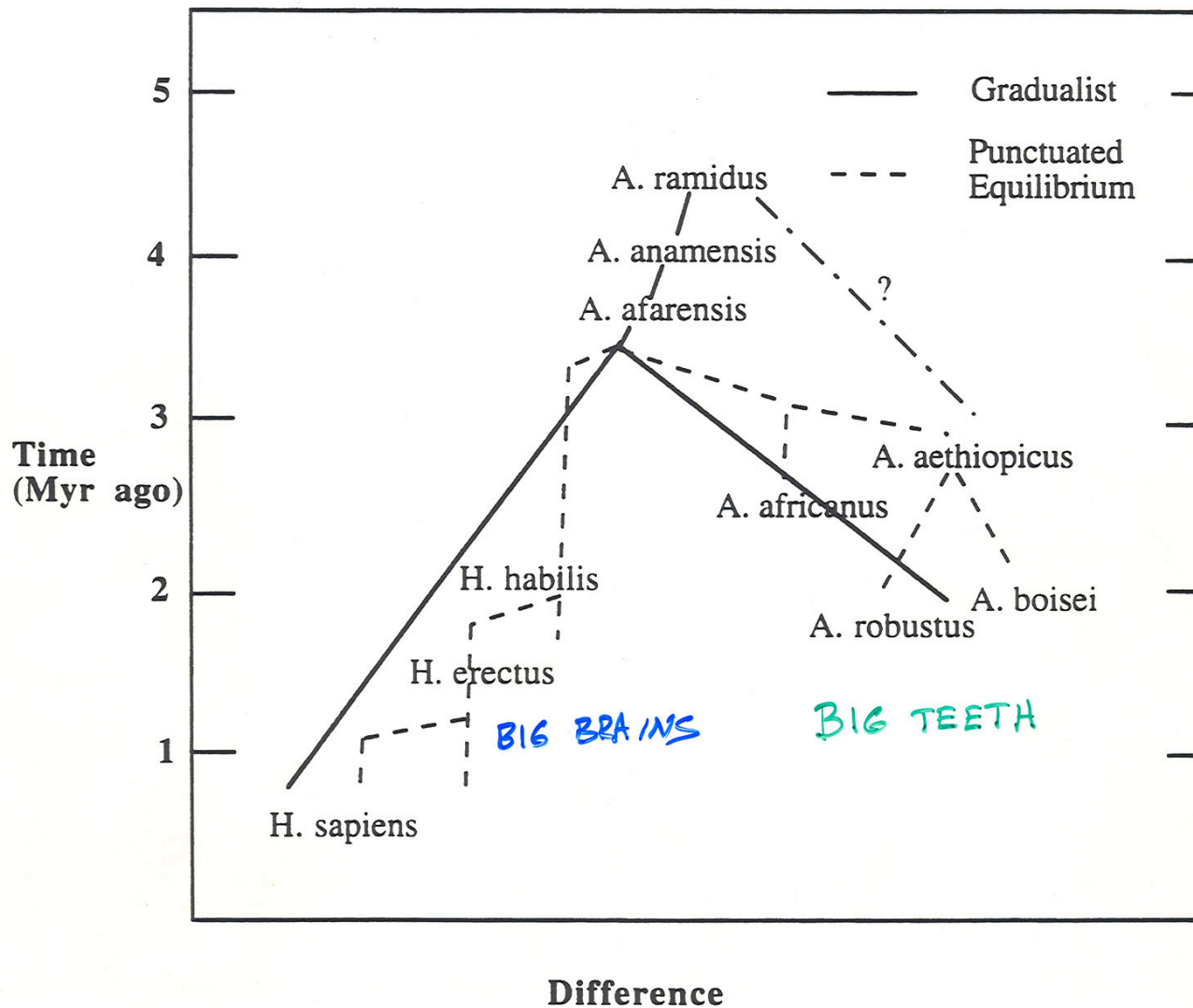
Earlier species show mosaic of human-ape traits

Upright walking preceded brain growth, tool making

May not have arisen on savanna

Looks like “radiation”: many species arising

All but one extinct now



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.

Hominids in Africa

RECENT FINDS from Africa could extend in time and space the fossil record of early human ancestors. Just a few years ago, remains more than 4.4 million years old were essentially unknown, and the oldest specimens all came from East Africa. In 2001 paleontologists working in Kenya's Tugen Hills and Ethiopia's Middle Awash region announced that they had discovered hominids dating back to nearly six million years ago (*Orrorin tugenensis* and *Ardipithecus ramidus kadabba*, respectively). Then, last July, University of Poitiers

paleontologist Michel Brunet and his Franco-Chadian Paleoanthropological Mission reported having unearthed a nearly seven-million-year-old hominid, called *Sahelanthropus tchadensis*, at a site known as Toros-Menalla in northern Chad. The site lies some 2,500 kilometers west of the East African fossil localities. "I think the most important thing we have done in terms of trying to understand our story is to open this new window," Brunet remarks. "We are proud to be the pioneers of the West."

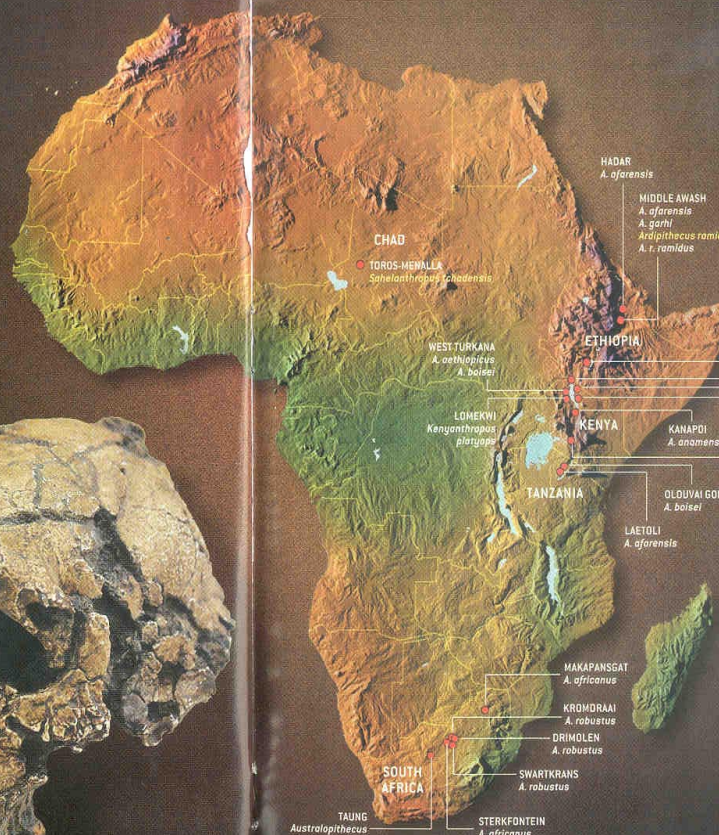
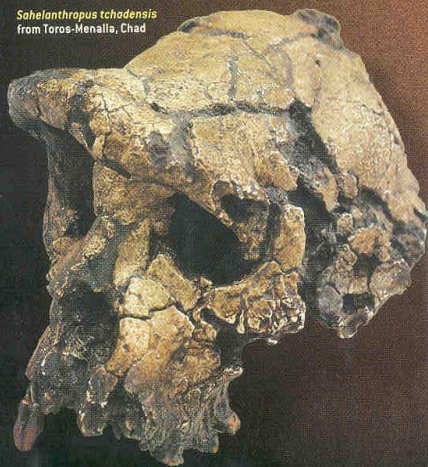
Ardipithecus ramidus kadabba
from Middle Awash, Ethiopia



Orrorin tugenensis
from Tugen Hills, Kenya

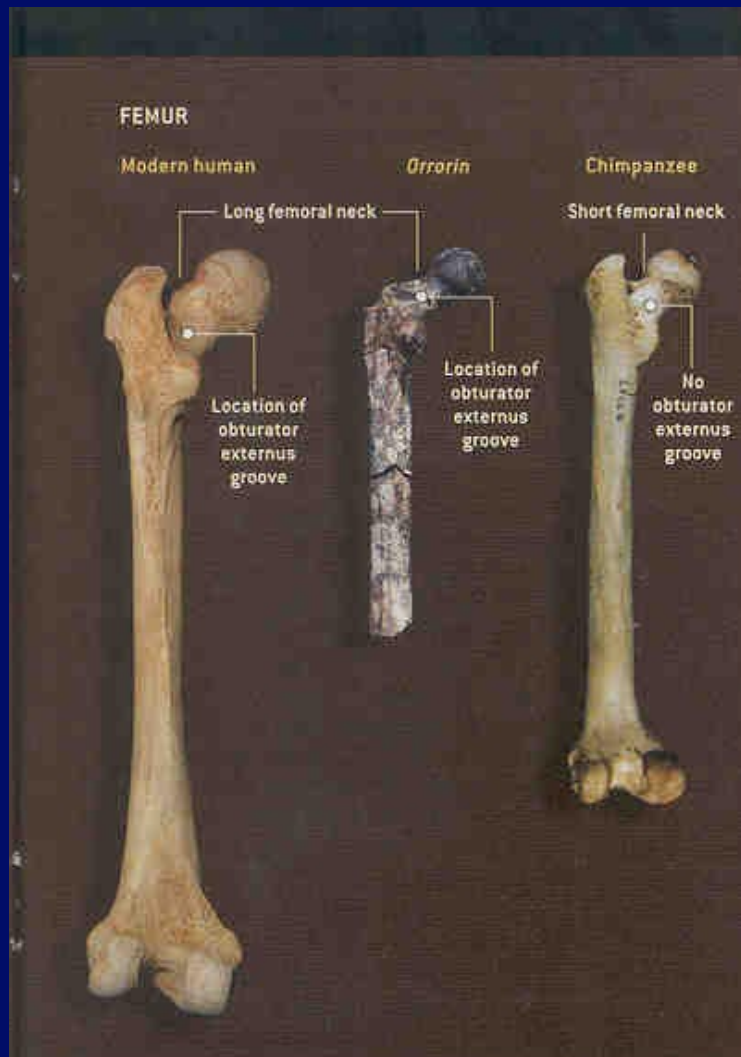


Sahelanthropus tchadensis
from Toros-Menalla, Chad



Scientific
American
Jan. 2003

Comparison of Femurs



Femur adapted to bipedality already by 6 Myr ago

Scientific
American
Jan. 2003

Various Family Trees

Hominids in Time

FOSSIL RECORD OF HOMINIDS shows that multiple species existed alongside one another during the later stages of human evolution. Whether the same can be said for the first half of our family's existence is a matter of great debate among paleoanthropologists, however. Some believe that all the fossils from between seven million and three million years ago fit comfortably into the same evolutionary lineage. Others view these specimens not only as members of mostly different lineages but also as representatives of a tremendous early hominid diversity yet to be discovered. [Adherents to the latter scenario tend to parse the known hominid remains into more taxa than shown here.]

The branching diagrams (inset) illustrate two competing hypotheses of how the recently discovered *Sahelanthropus*, *Orrorin* and *Ardipithecus ramidus kadabba* are related to humans. In the tree on the left, all the new finds reside on the line leading to humans, with *Sahelanthropus* being the oldest known hominid. In the tree on the right, in contrast, only *Orrorin* is a human ancestor. *Ardipithecus* is a chimpanzee ancestor, and *Sahelanthropus* a gorilla forebear in this view.



Scientific
American
Jan. 2003

Consequences of New Fossils

1. Even more clear that bipedal locomotion far preceded big brains
2. Bipedality not clearly connected to savanna
4. Several of the oldest hominids are very close to Ape - Human split
4. Bipedality looks like key change that separated human and ape

Ideas for Origin of Bipedality

X

1. Tool use, big brain feedback

??

2. Predator avoidance on savanna (adaptations for long-distance running unique to humans)

3. Food acquisition (carry food)

4. Reproductive Success (carry food & infants)
("Bringing home the bacon")

Humans and Chimpanzees: 1

- Recent data on genes of chimpanzees
 - Draft of chimp genome released in 2003
 - 99.4% the same as humans
 - For nonsynonymous sites (important)
 - Split from gorillas: 6-7 Myr ago
 - Human split from chimp: 5-6 Myr ago

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 Australopithecus
 - 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
 - Last change about 200,000 yr ago
 - Further developments are cultural (much faster)

Still more recent 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)

Human-Chimp differences

- Latest numbers (Science 2007, 316, 1836)
 - 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
 - Shows limitations of just comparing base substitutions without knowing what genes do what.

The Last Steps to Modern H. sapiens

Origin of Modern H. Sapiens

Many anthropologists now believe that Neanderthals 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

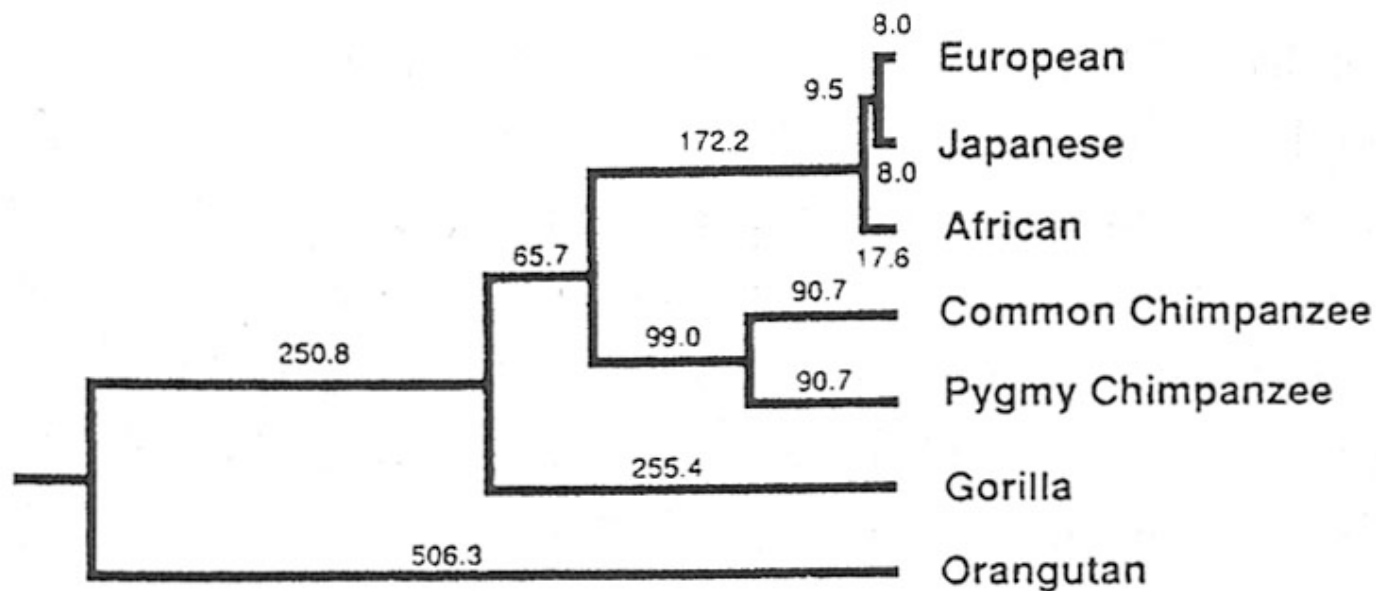
Genetic: humans are **very** homogeneous
greatest diversity is in Africa

⇒ Evolved in Africa, population bottleneck
a small group left Africa, spread over Earth

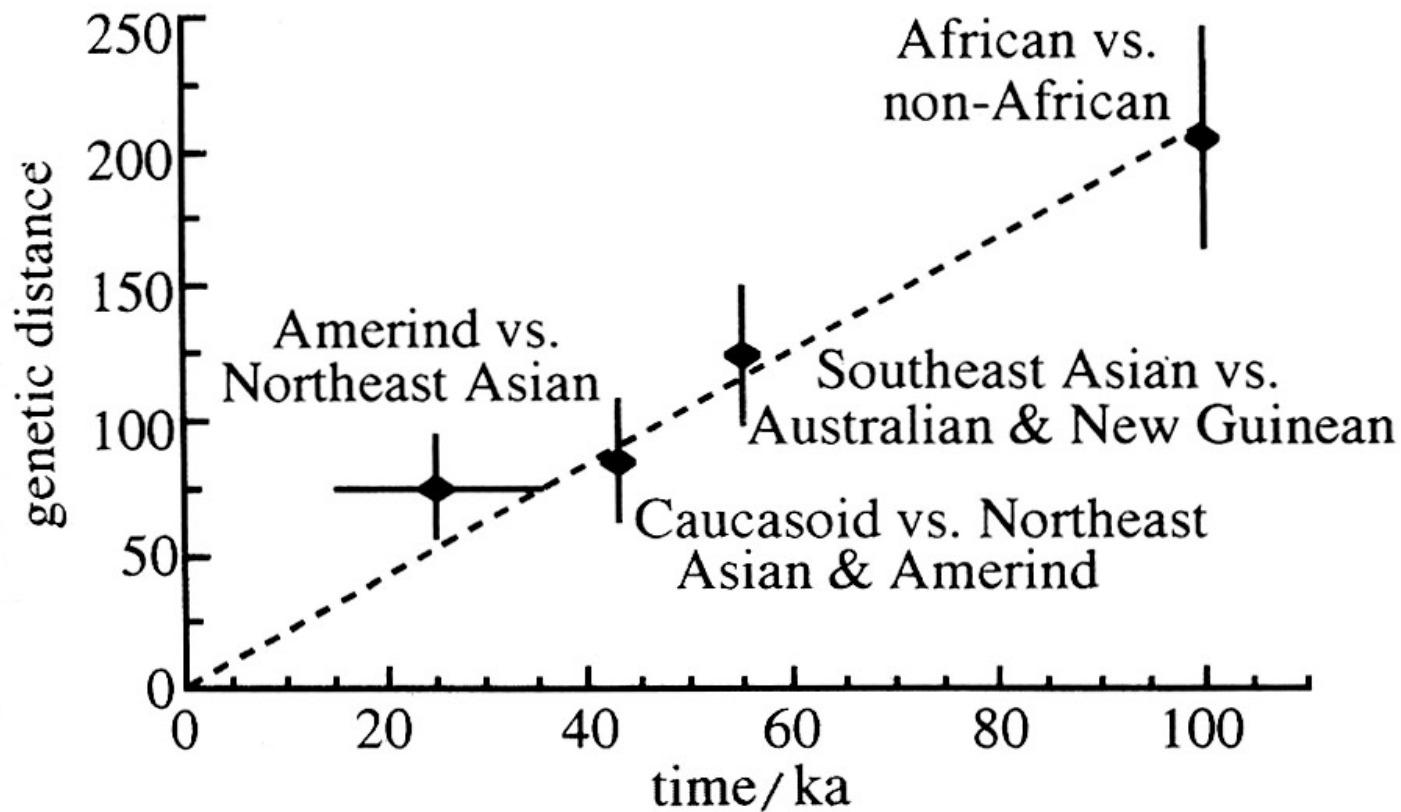
Linguistic: Good correlation of linguistic family
tree with genetic one

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

From Stringer & McKie - *African Exodus*



38 Horai's mtDNA tree is based on complete sequences from both apes and humans (see pages 131–32). Note the shallow separation of the three human samples.



- 40 Joanna Mountain and Cavalli-Sforza compared genetic distances between modern peoples with archeological and fossil evidence of their separations. They match well over a timescale of 100,000 years but would not fit much longer divergence times.

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 Myr H. erectus

~ 350,000 “Neanderthal”

~ 100,000 Modern humans

Neanderthals and Us

- In 2009, analysis of DNA from Neanderthals
 - 38,000 yr old fossils from cave in Croatia
 - Very difficult to avoid contamination
 - Early evidence of inter-breeding with modern *H. sapiens* due to contamination
 - Now little evidence of inter-breeding
 - Despite long overlap in time and space
 - Last to survive maybe 38,000 yr ago on Gibraltar
 - Science 13 February 2009:
Vol. 323. no. 5916, pp. 866 - 871

From J. Diamond: *Guns, Germs & Steel*

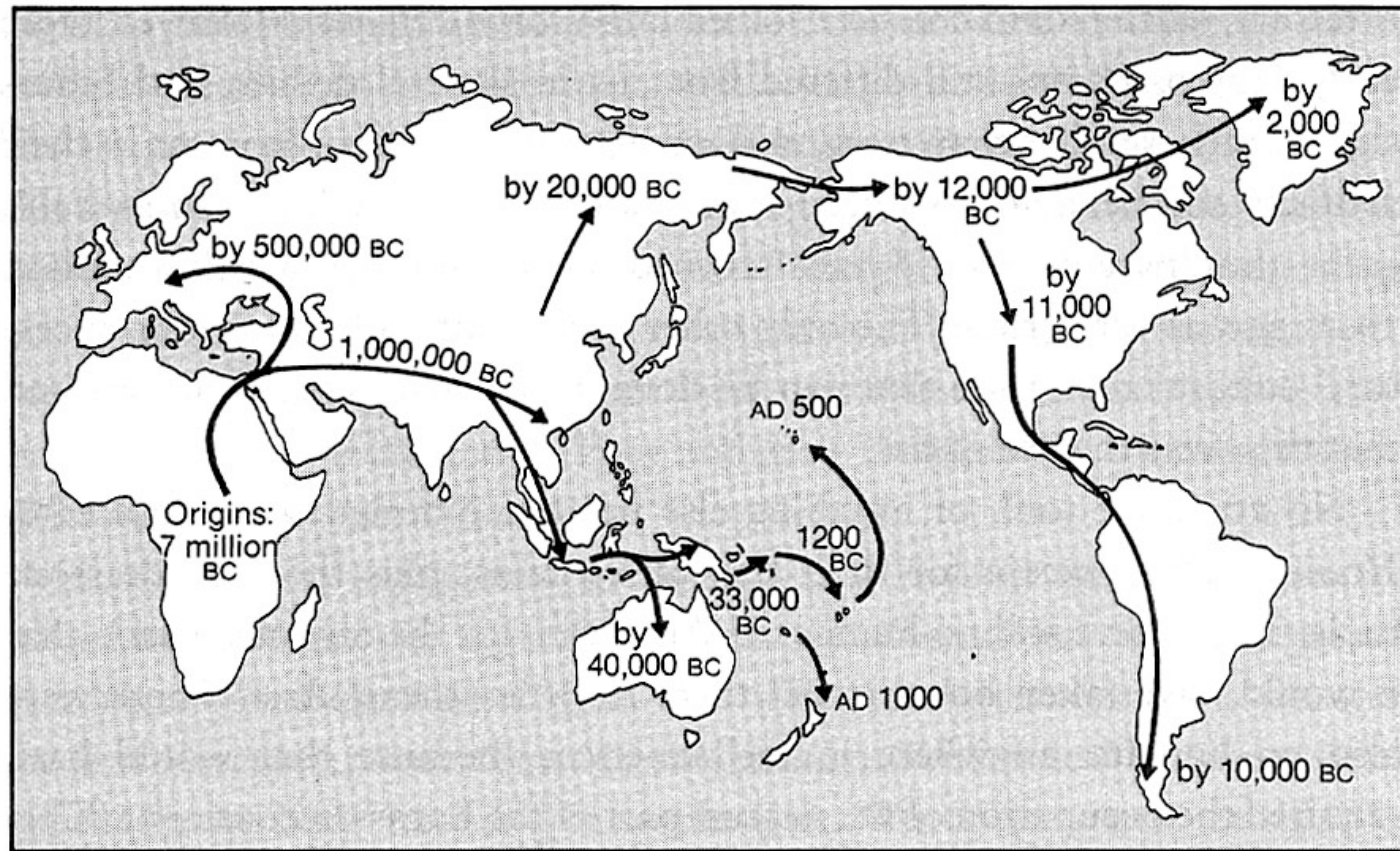


Figure 1.1. The spread of humans around the world.

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?

3. 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

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

Too few heavy elements in outer galaxy (would affect f_p or n_e).

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

⇒ rule out much more massive stars

(already done in n_e)

~ 1/2 lifetime of galaxy so far

? ⇒ intelligent life is rare

Brandon Carter

? Statistics of one are suspect