The Origin of Intelligence

The Origin of Intelligence

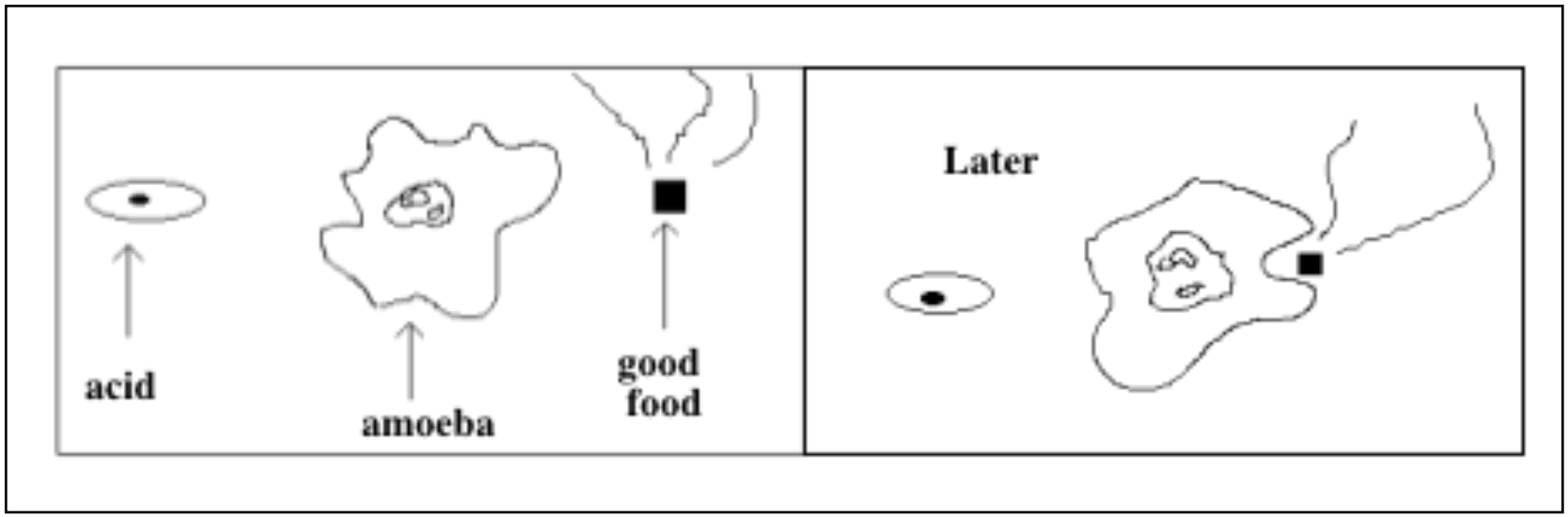
f_i : Fraction of life-bearing planets where Intelligence develops

What is intelligence?

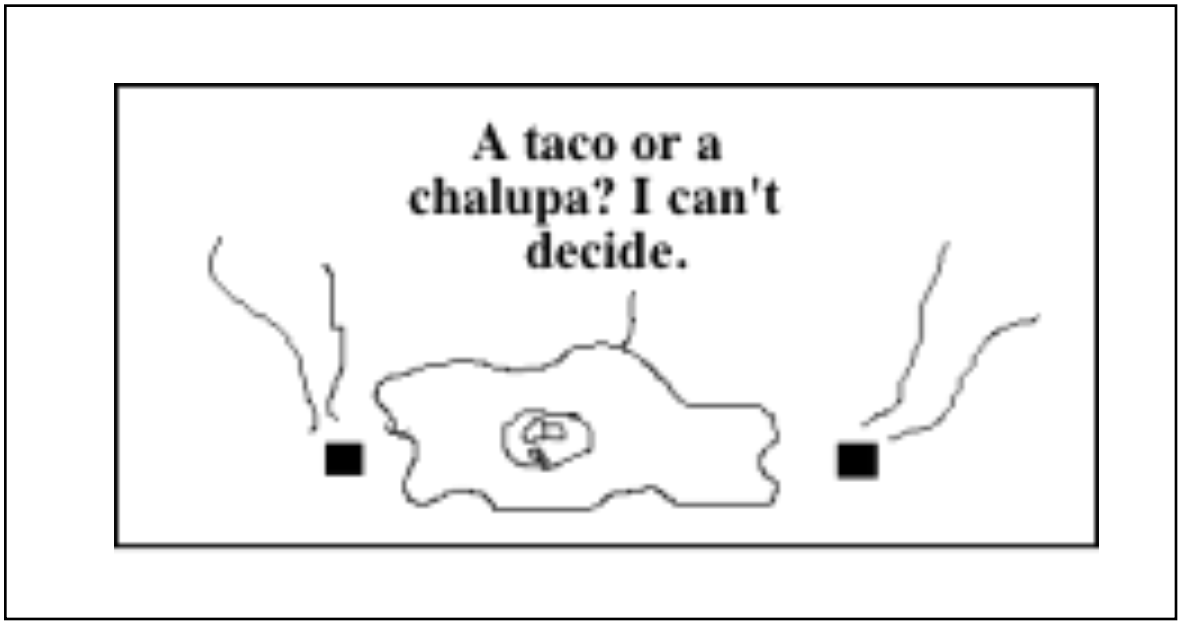
Propose: "The ability to model the world, including the organism itself"

$\Rightarrow$ Intelligence as continuum
related to complexity of organism
milestone: human-level intelligence

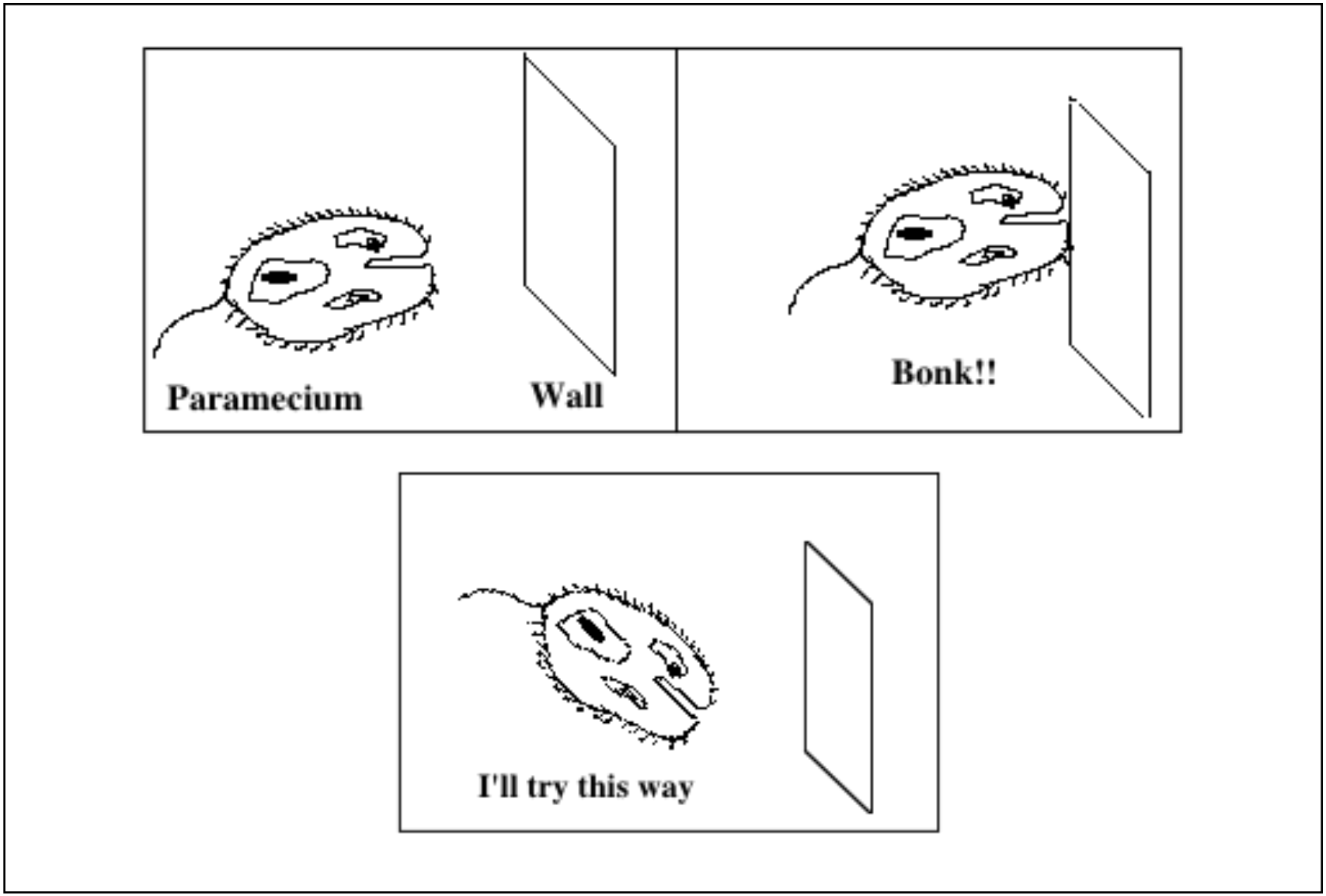
Amoeba intelligence



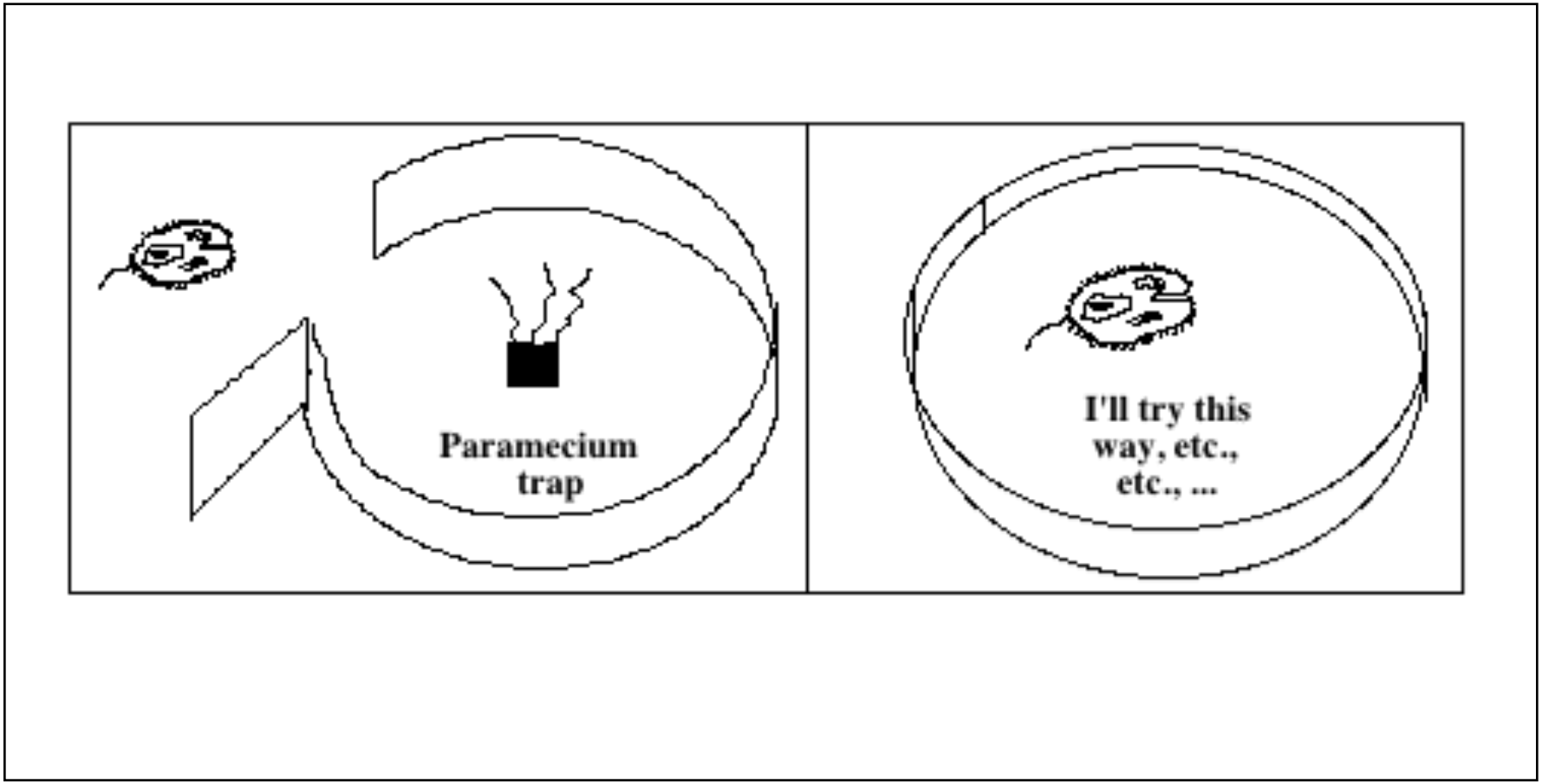
The Amoeba's dilemma



The smarter Paramecium



But not THAT smart…



Information as Measure of Intelligence

Evolution of intelligence $\underline{\sim}$ 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

$\Rightarrow$ 1.2×10^8 bits

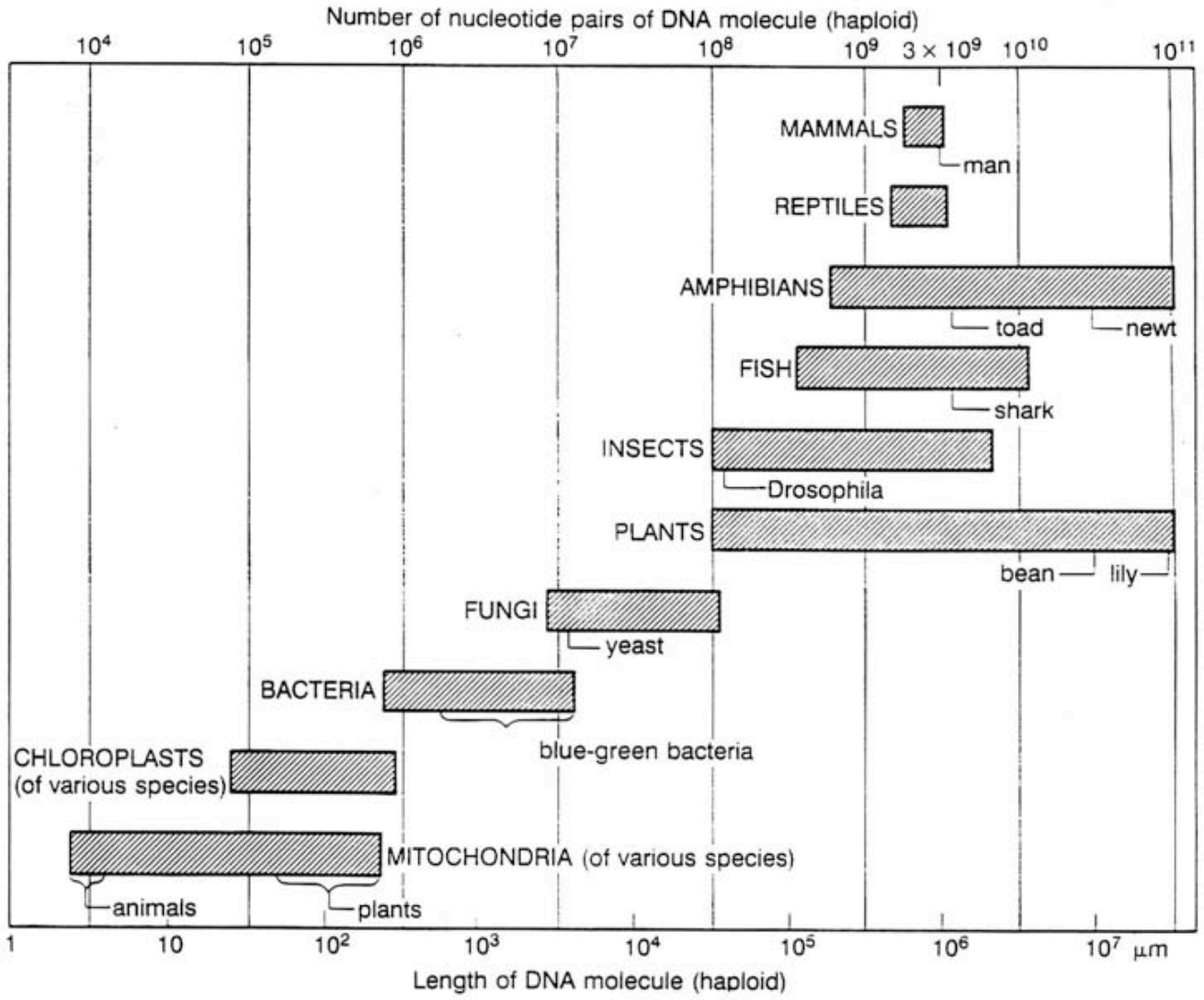
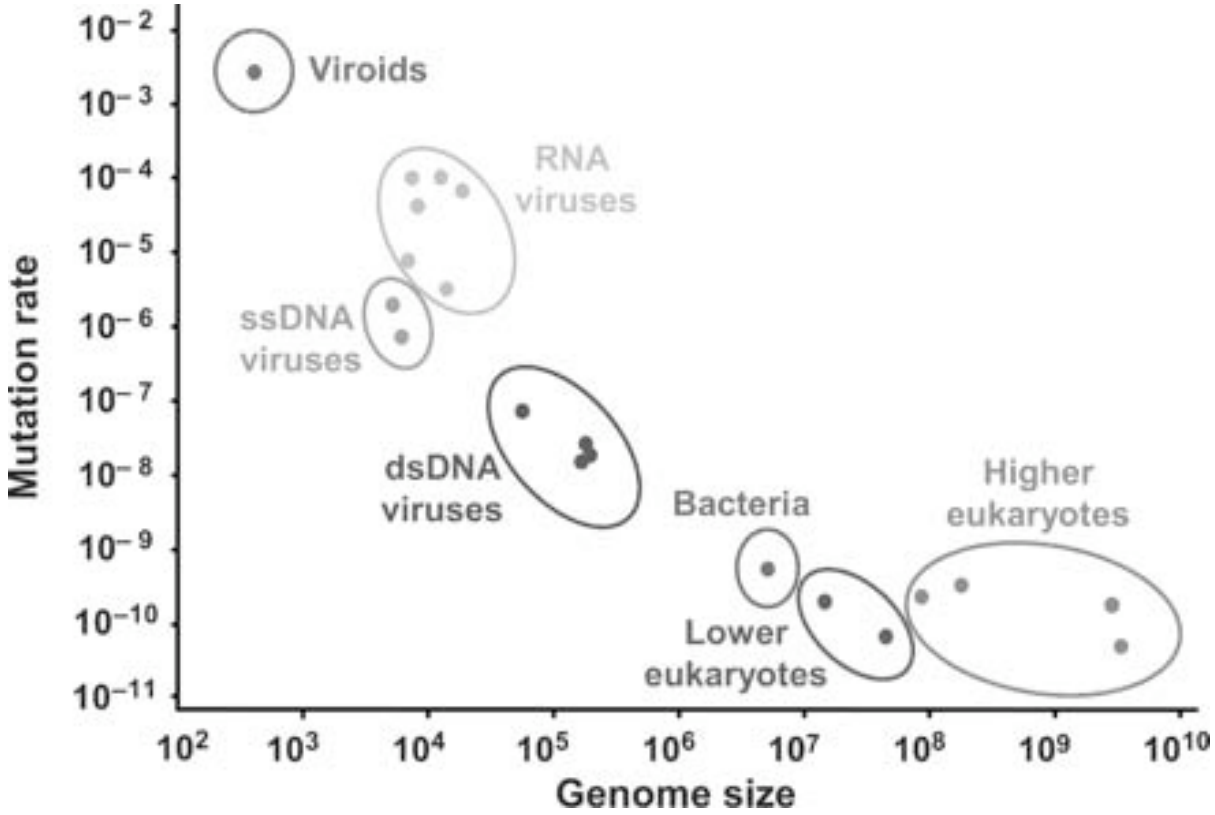


Figure 7.18. Length of DNA molecules. Note that the DNA of some plants and amphibians is longer than that of bacteria by a factor of 10^4 to 10^5. The total length of human DNA is approximately 10^6 μm or 1 m, which is equivalent to roughly 3×10^9 nucleotide pairs or 10^9 codons. Obviously, the length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

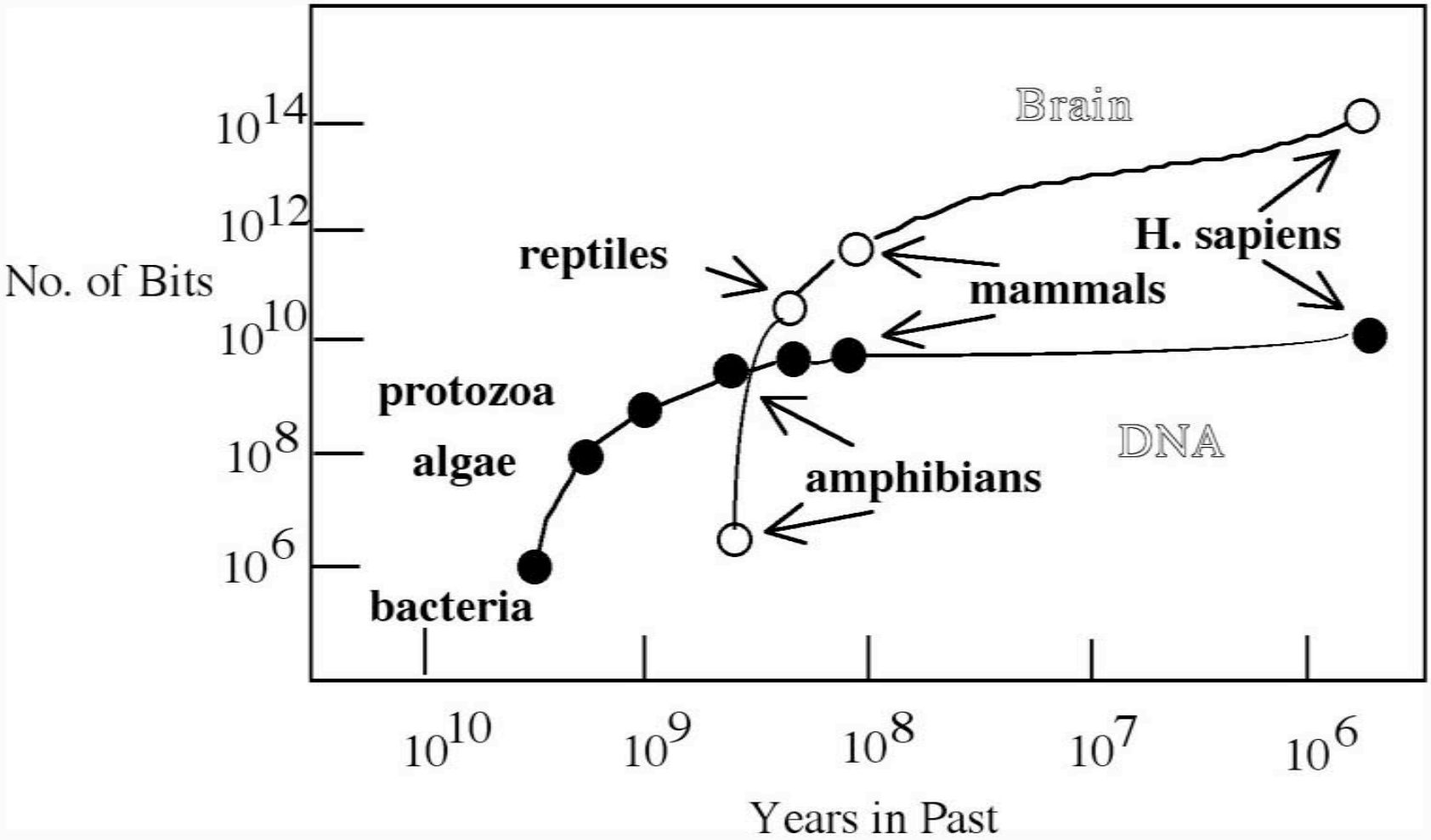
Replication. The bigger the genome, the smaller the mutation rate must be.



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

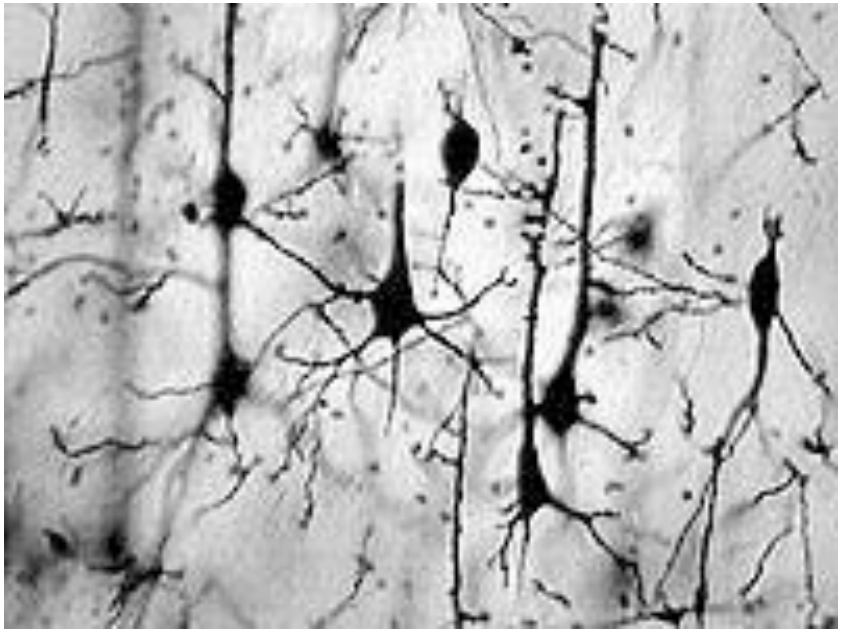
How is information stored in brains?

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

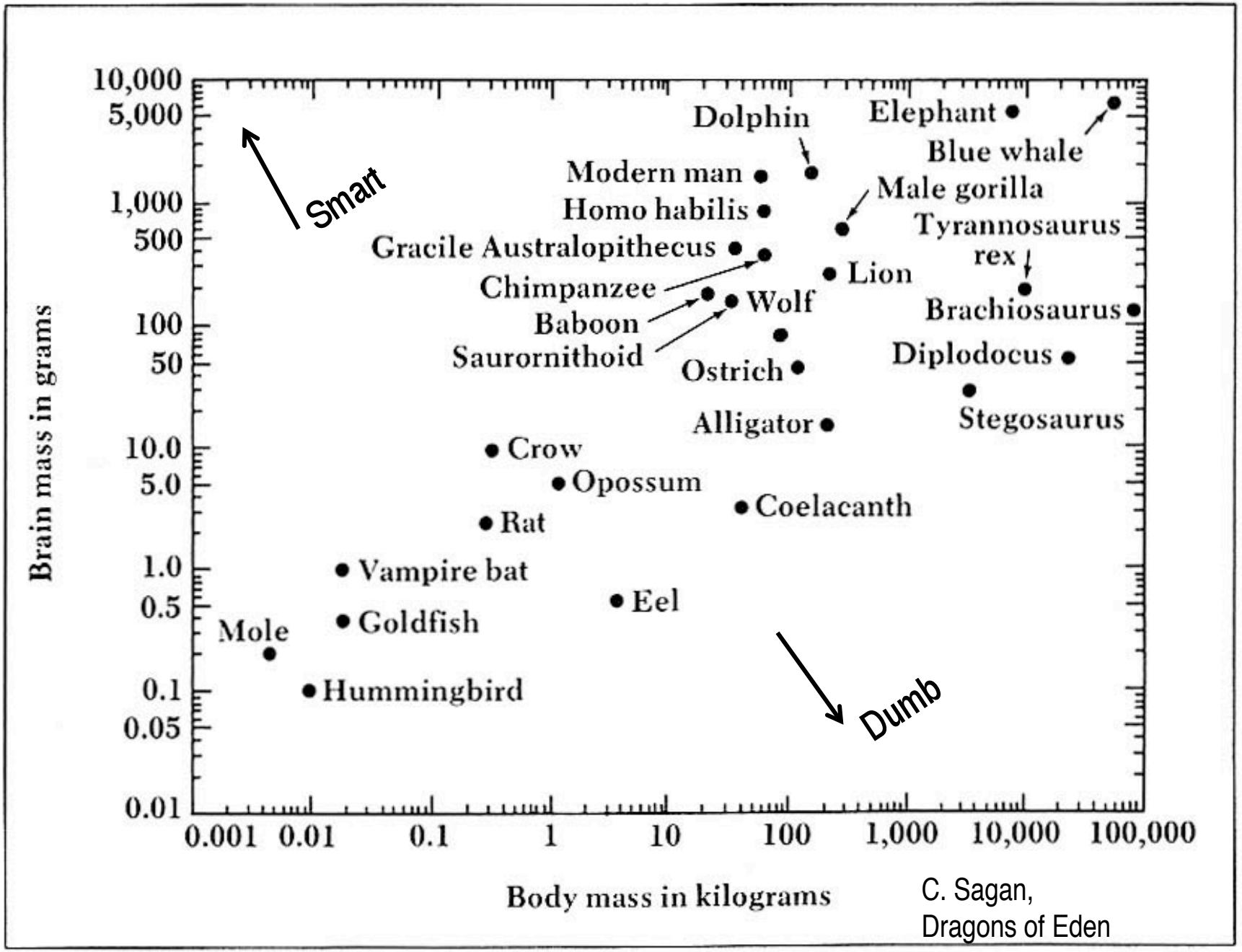
An **analog** computer $\Longrightarrow$ Hard to count

$\sim 10^{11}$ 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

$\Rightarrow$ **Individual** can learn

Two hemispheres

Many functions parallel, but some specialized

Many ways to divide brain

Layered brain: reptilian brain

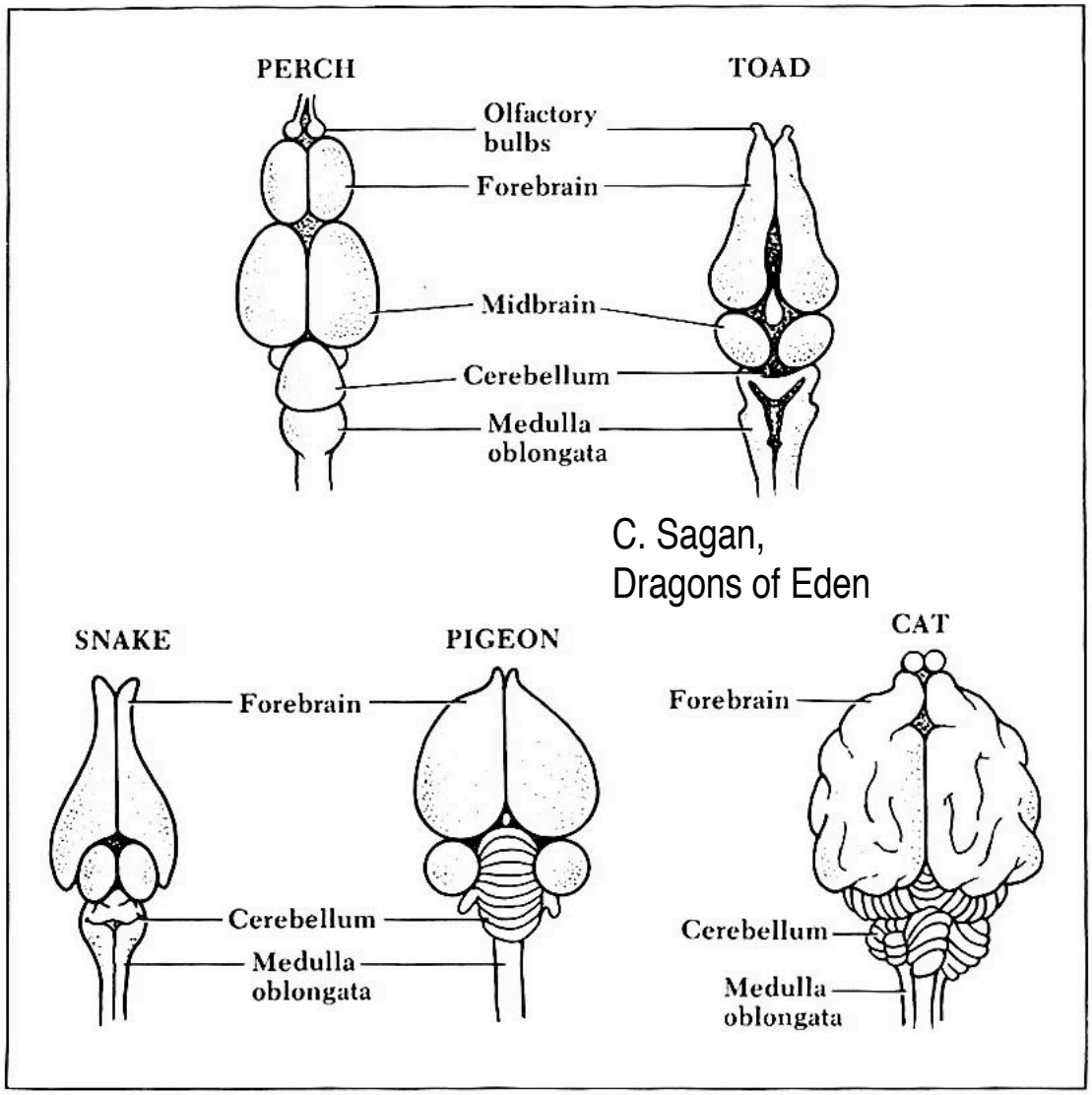
limbic system (mammals)

cortex

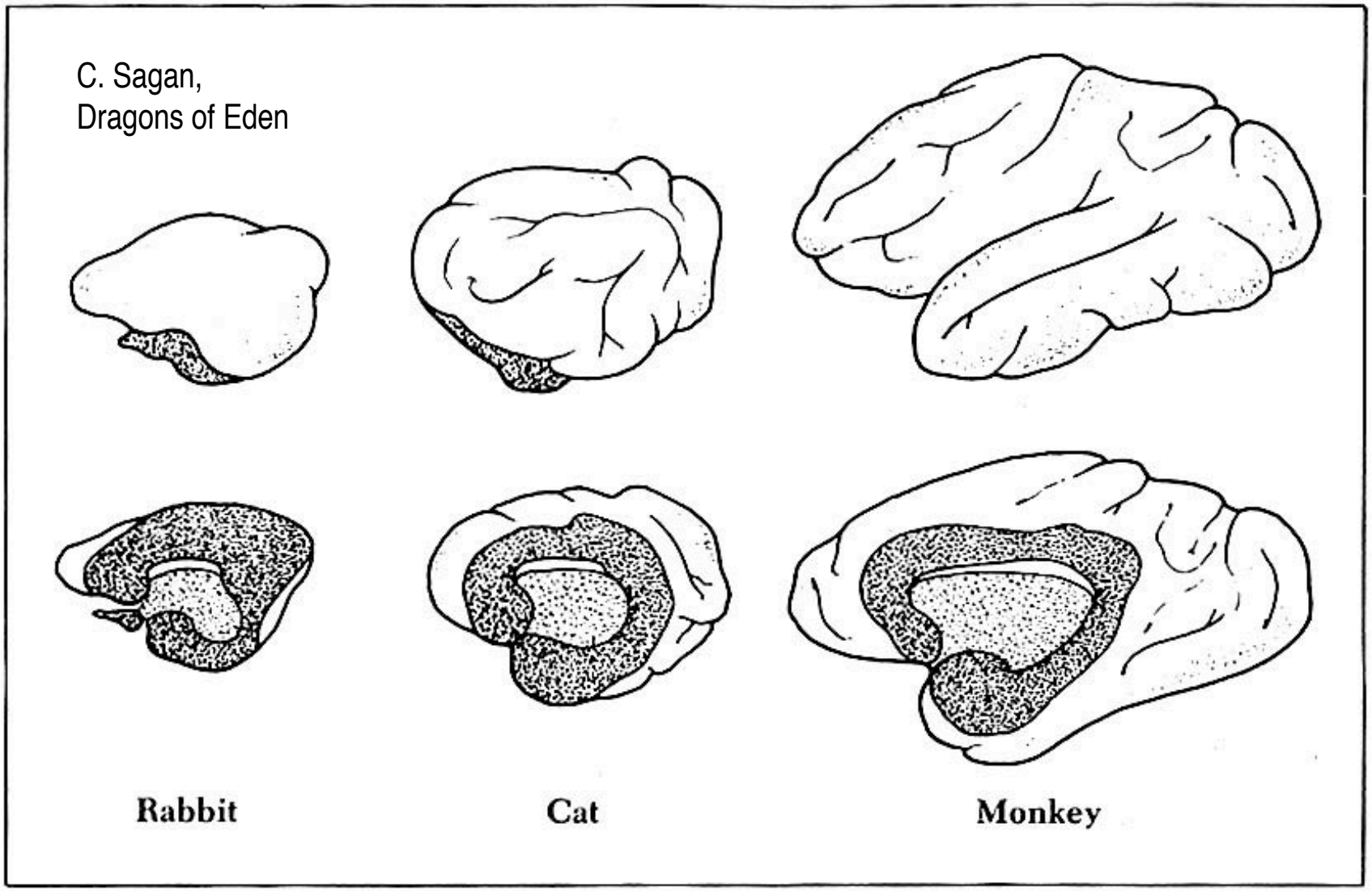
Brain size has increased (in some species) with time

?

$\Rightarrow$ Evolution favors higher intelligence (sometimes)

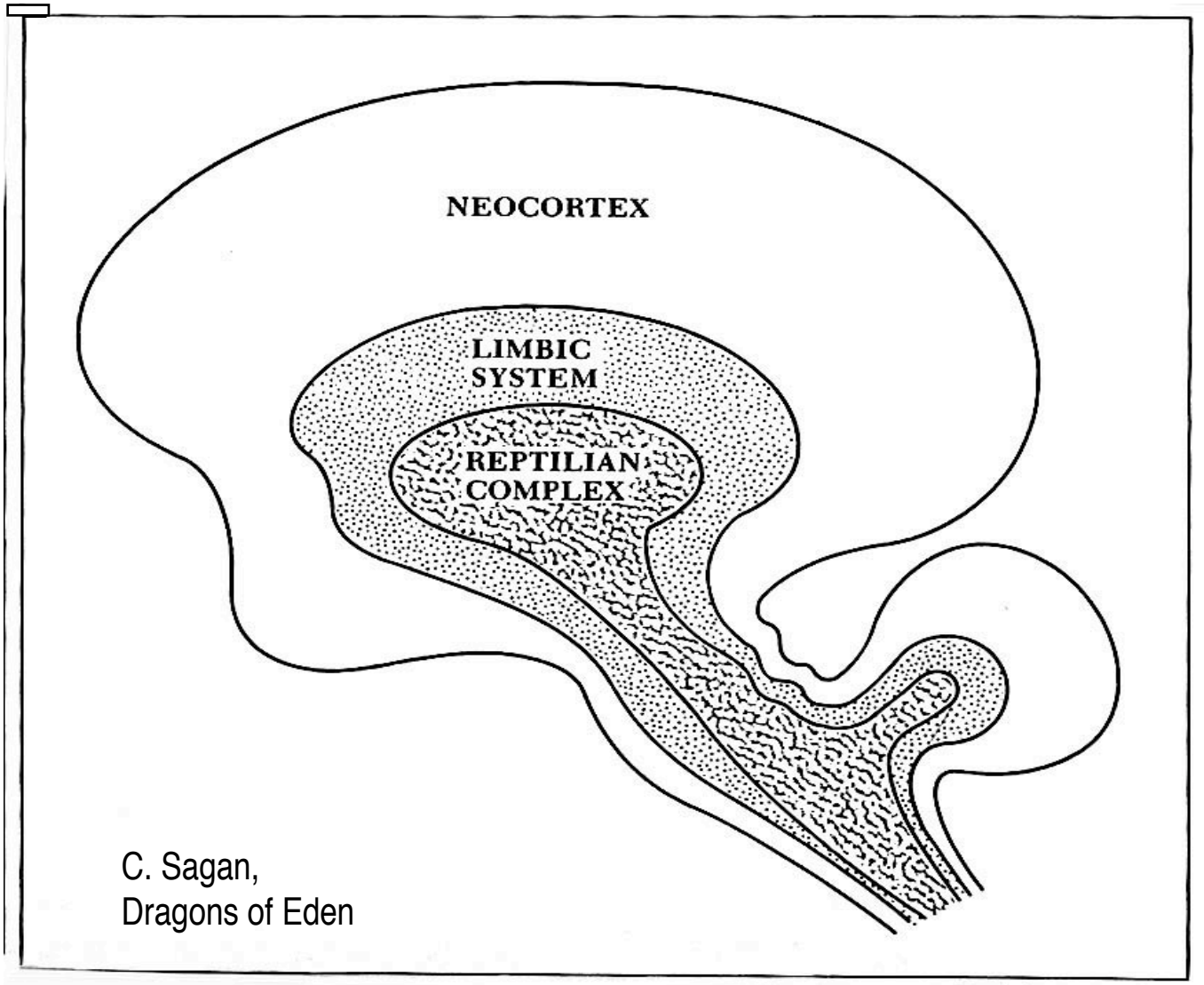


Schematic diagrams comparing the brain of a fish, an amphibian, a reptile, a bird, and a mammal. The cerebellum and medulla oblongata are parts of the hindbrain.

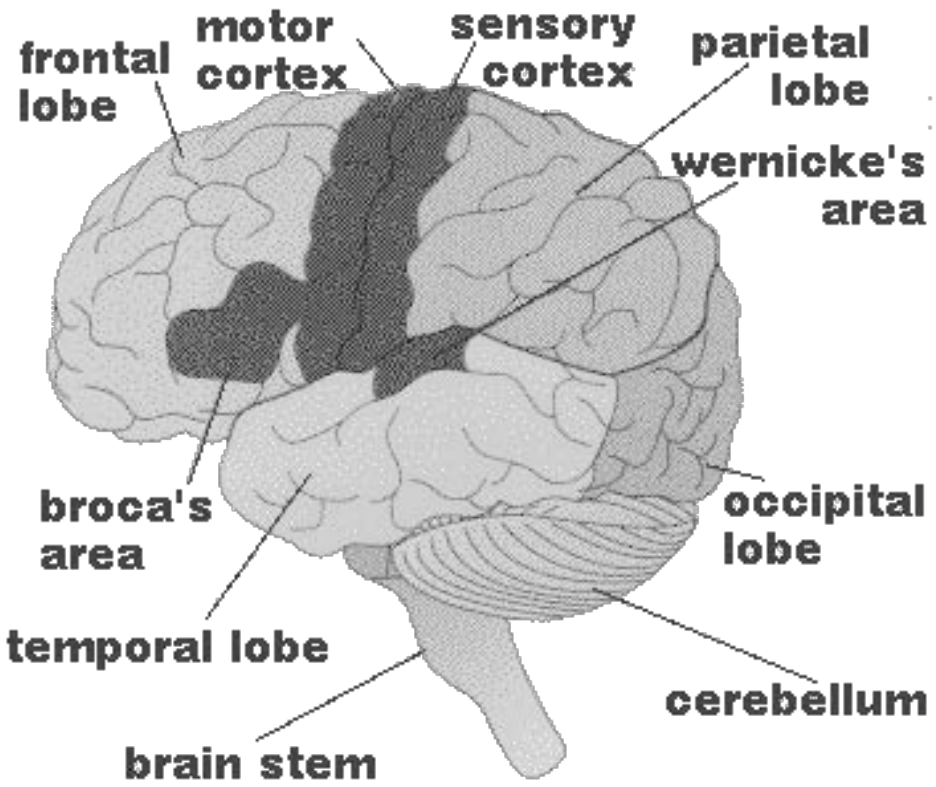


Schematic views from the top and from the side of the rabbit, cat, and monkey brains. The dark stippled area is the limbic system, seen most easily in the side views. The white furrowed regions represent the neocortex, visible most readily in the top views.

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

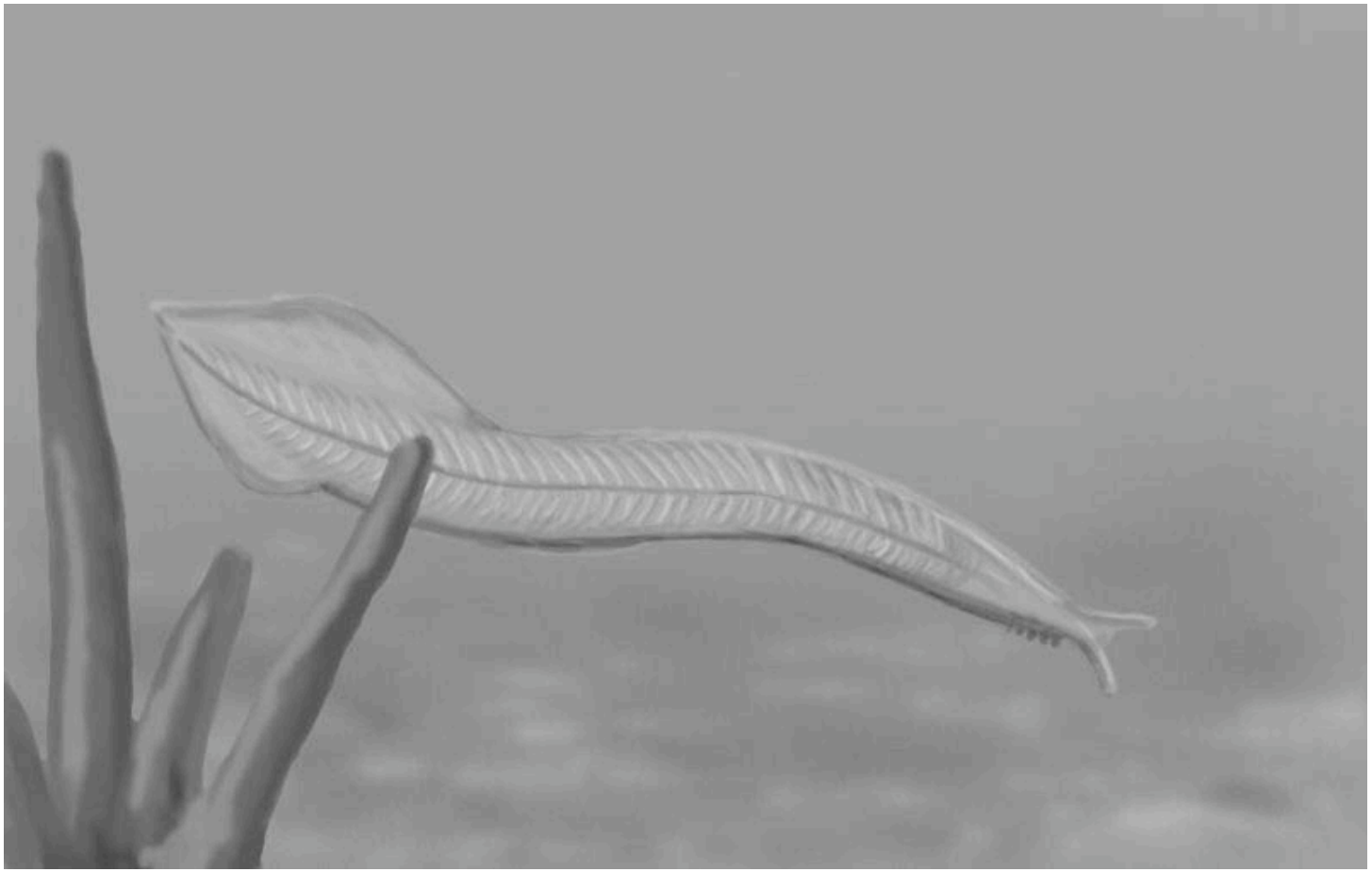
~ 225 Myr ago

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)

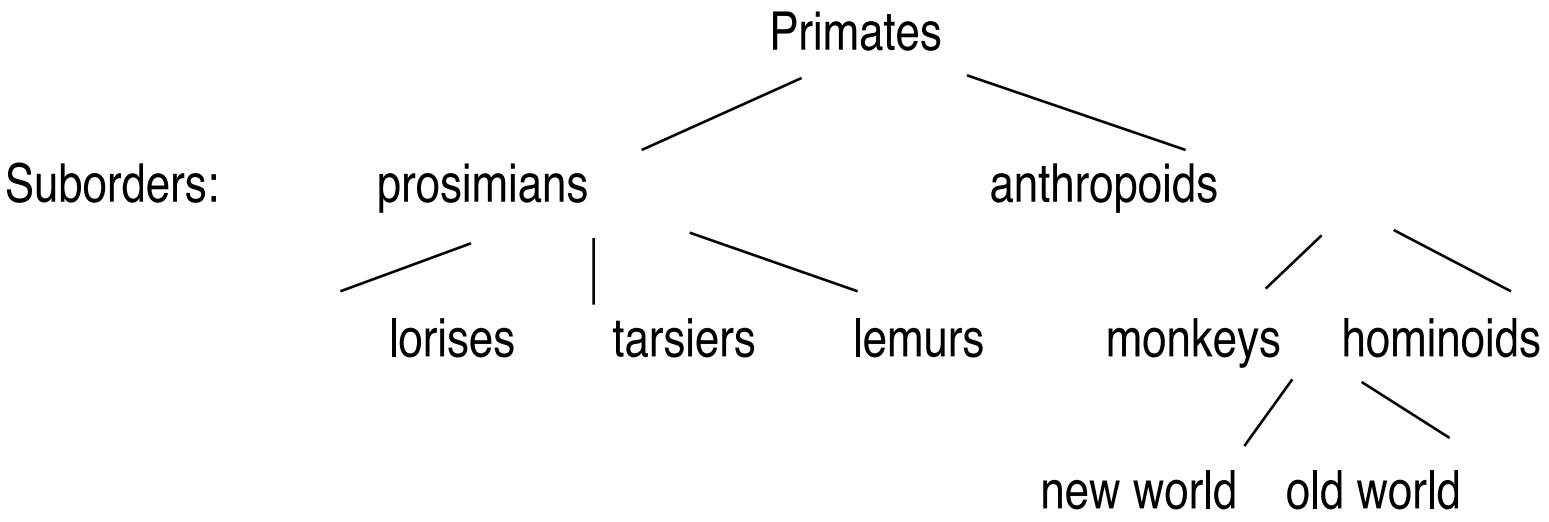


Primate Characteristics

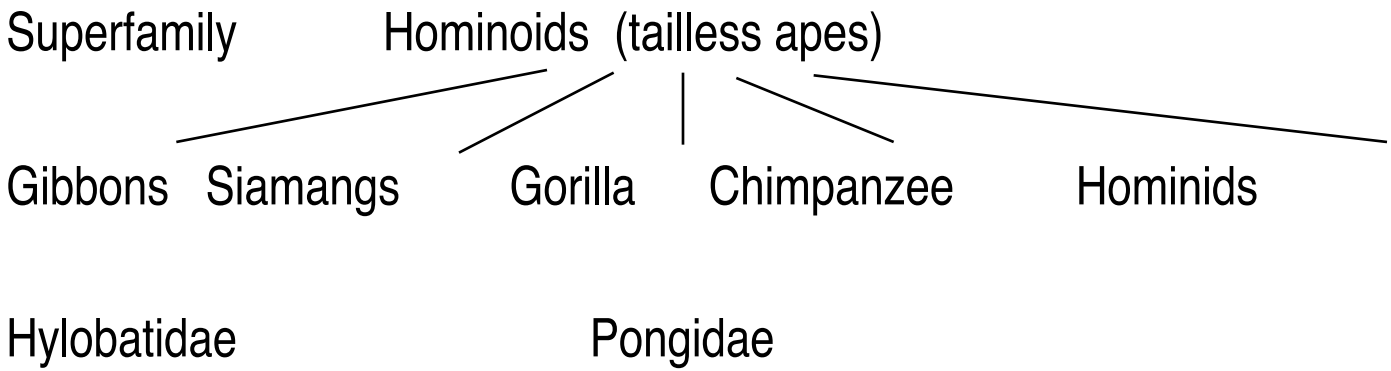
Few anatomical specializations

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		Recent	3000 yrs	Historical Records
				Homo sapiens
				Homo erectus
	Quaternary	Pleistocene	1.8–2.5	Homo habilis
			4.2	Australopithecus
			5.5	Ardipithecus
		Pliocene	6–7	Sahelanthropus
				Gap
		Miocene	23–26	Ramapithecus
				Dryopithecine Apes
				Gap
		Oligocene	37–38	Aegyptopithecus
		Eocene	54	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

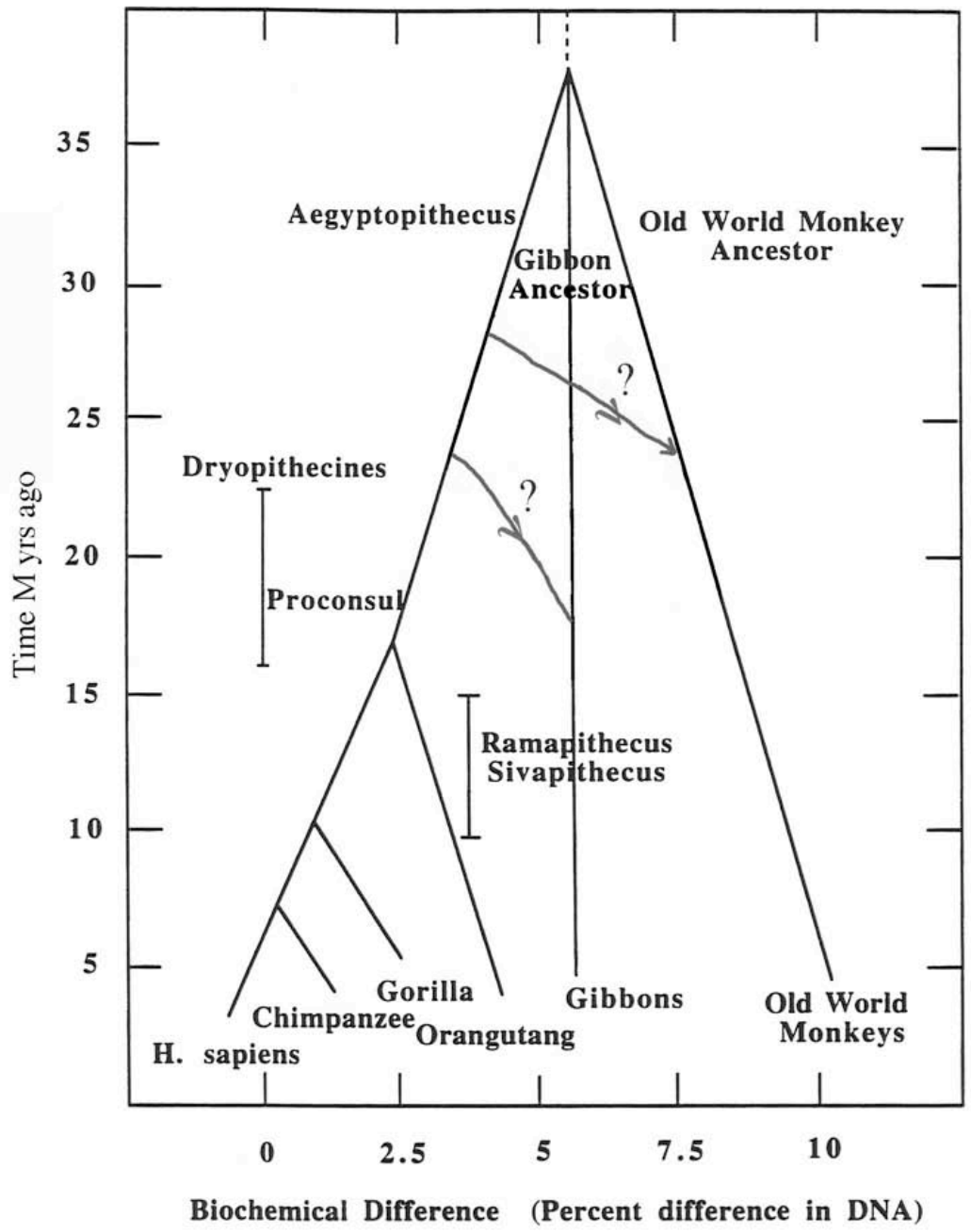
More complicated information processing, tool use becomes possible

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

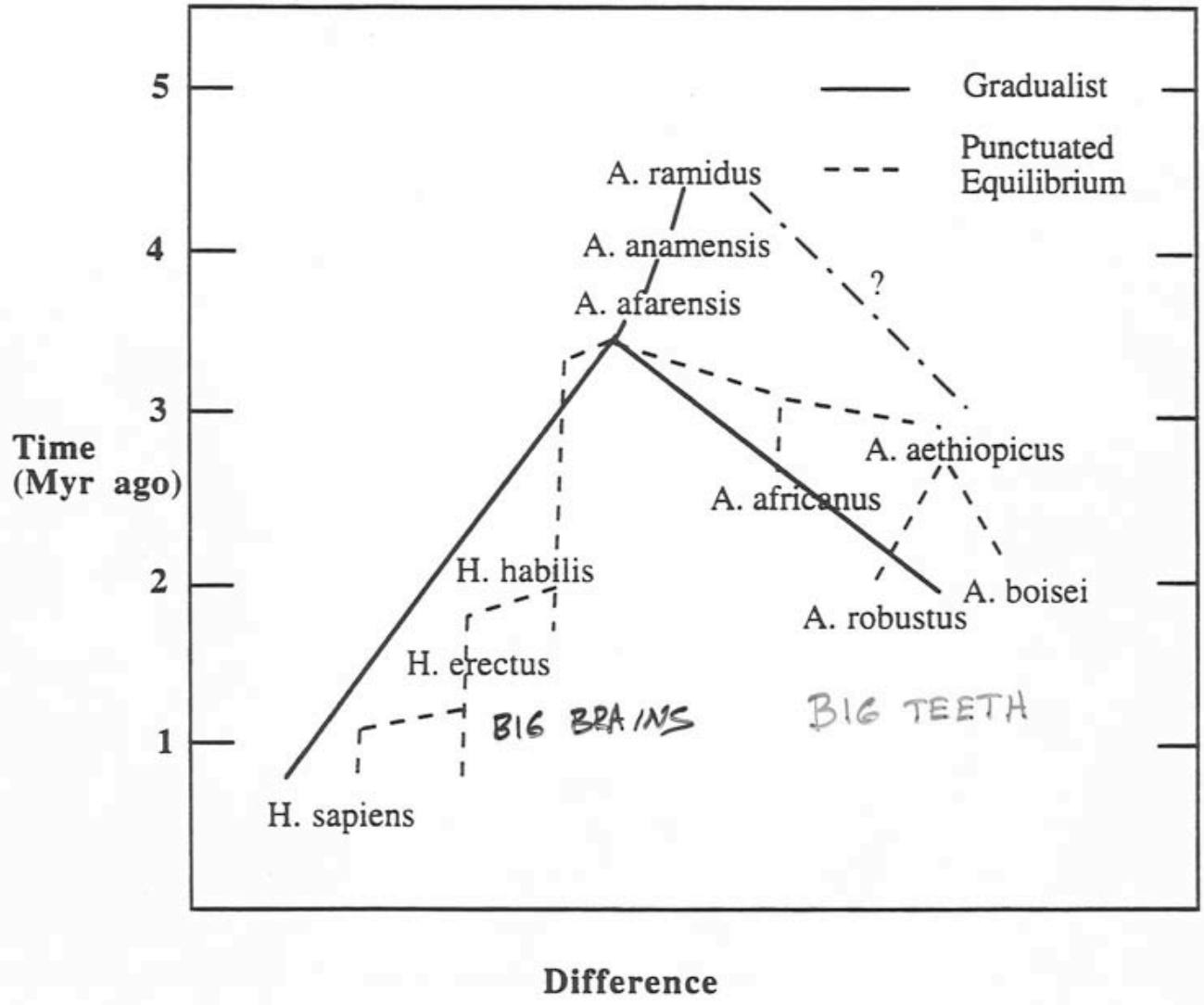

35
30
25
20
15
10
5
Time M yrs ago
Aegyptopithecus
Old World Monkey Ancestor
Gibbon Ancestor
?
?
Dryopithecines
Proconsul
Ramapithecus
Sivapithecus
Gorilla
Chimpanzee
Orangutang
Gibbons
Old World Monkeys
H. sapiens
0
2.5
5
7.5
10
Biochemical Difference (Percent difference in DNA)

Hominid Evolution

Fossils now known back to ~ 6 Myr
Molecular dating of chimp - hominid split 5-7 Myr

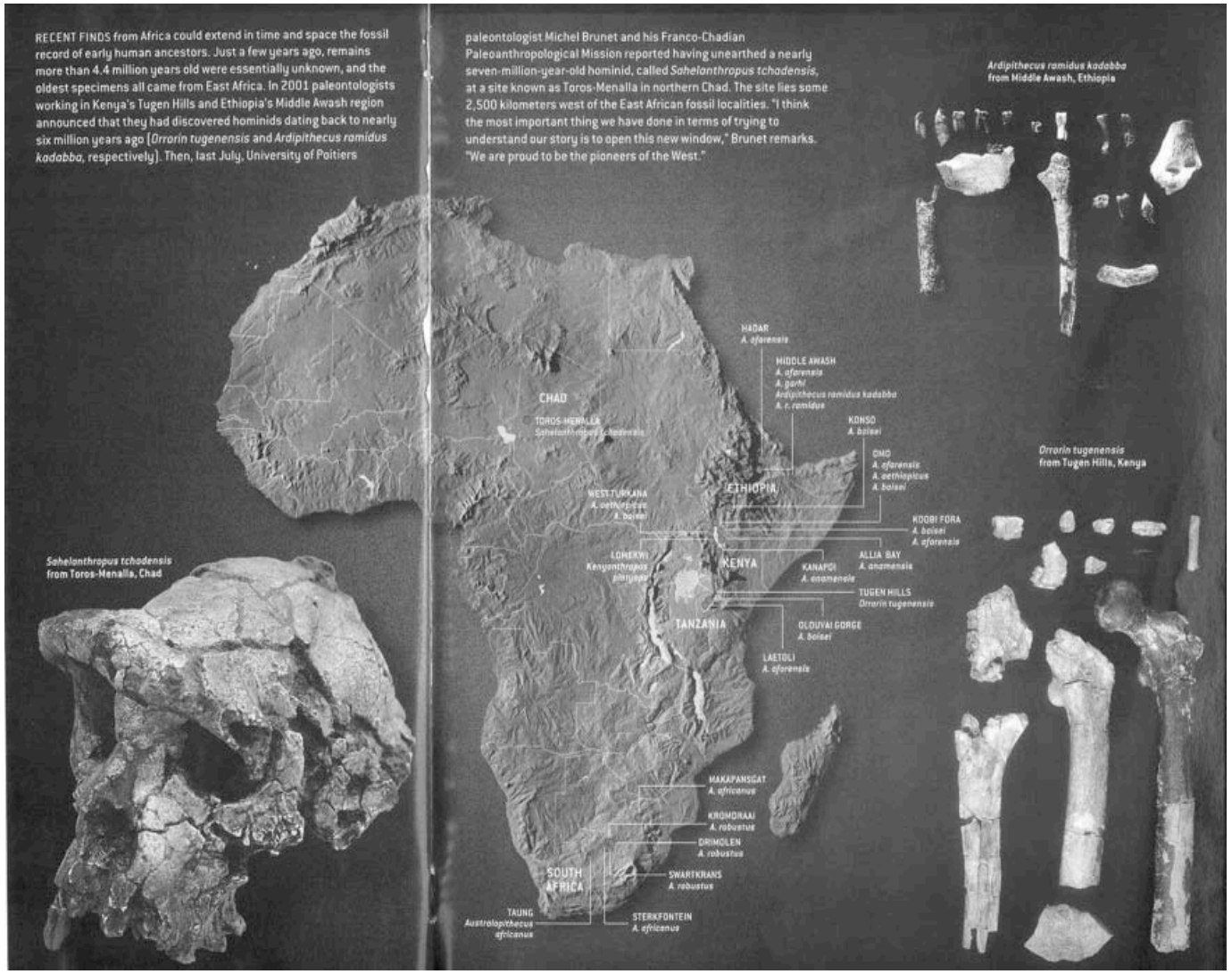
Many variations now known
many species co-existed in Africa
Earlier species show mosaic of human-ape traits

Upright walking preceded brain growth, tool making
May not have arisen on savanna
Looks like “radiation”: many species arising
All but one extinct now



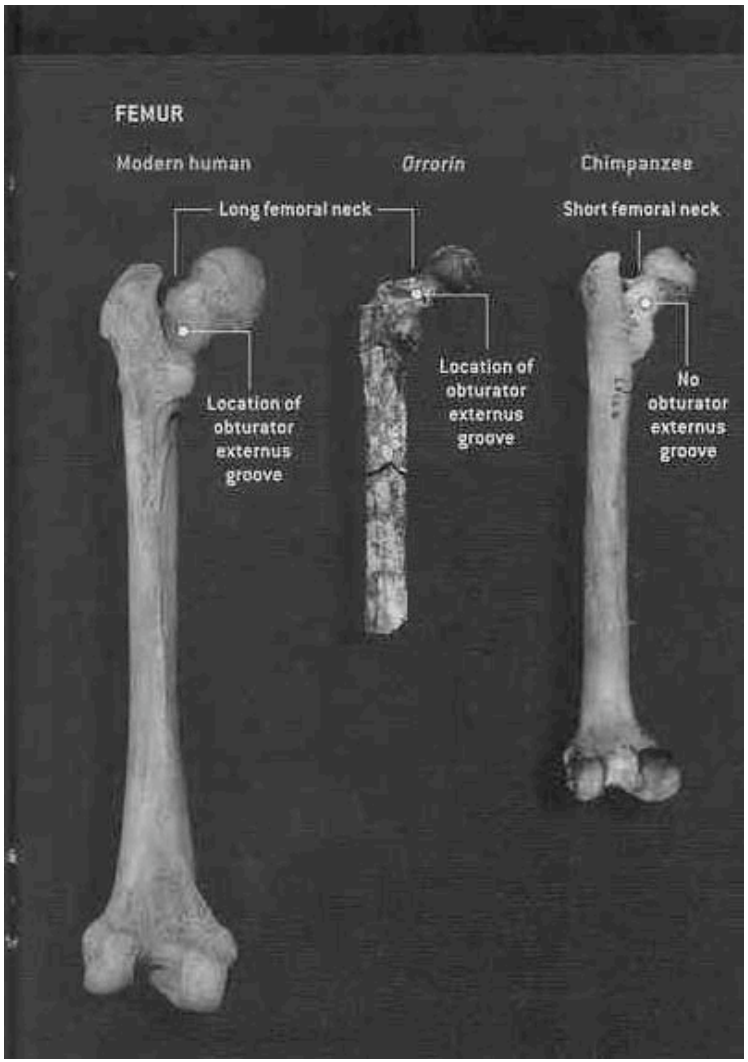
The last 4.5 Myr of hominid evolution are summarized in the accompanying figure. The solid lines in the figure indicate the lines of descent in a gradualist picture, while the dashed lines indicate the picture of punctuated equilibrium.

Hominids in Africa



Scientific American Jan. 2003

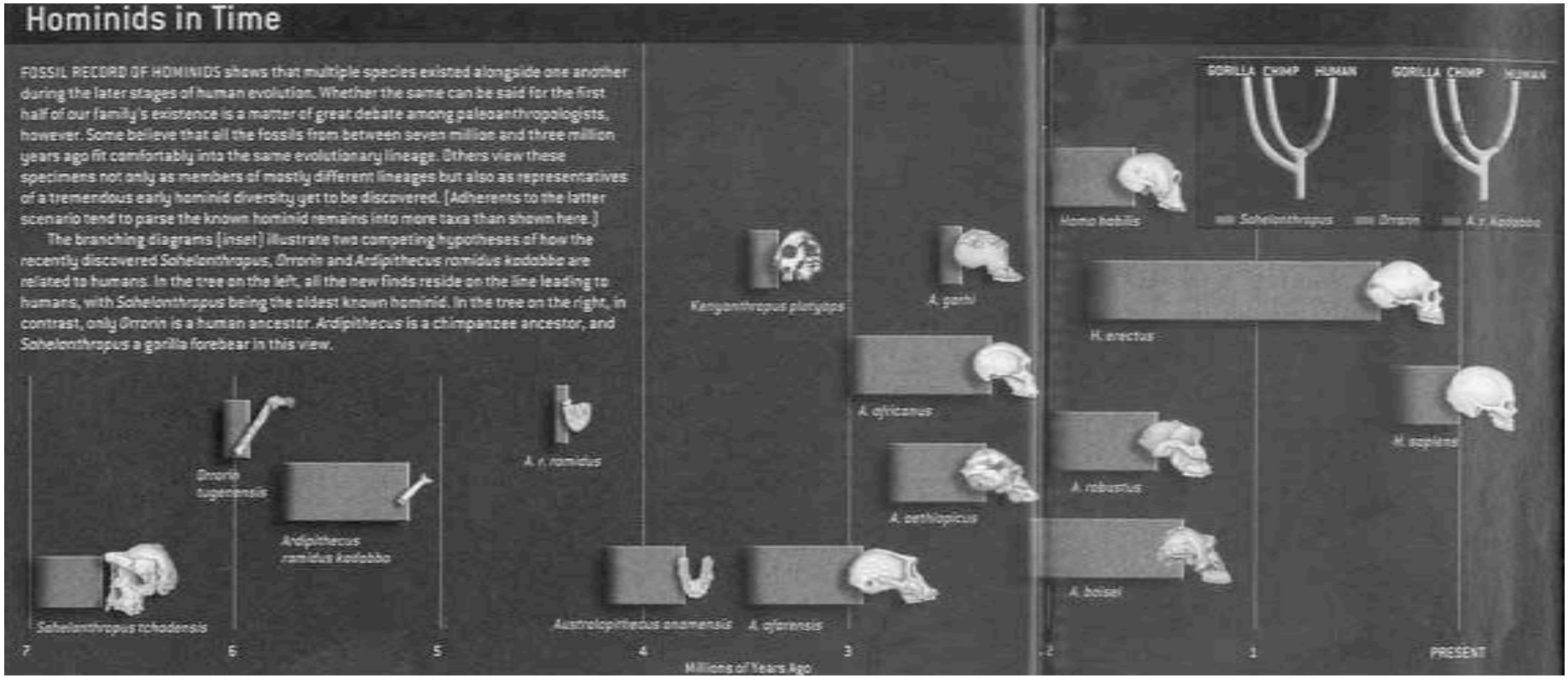
Comparison of Femurs



Femur adapted to bipedality already by 6 Myr ago

Scientific American
Jan. 2003

Various Family Trees



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 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
    - 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

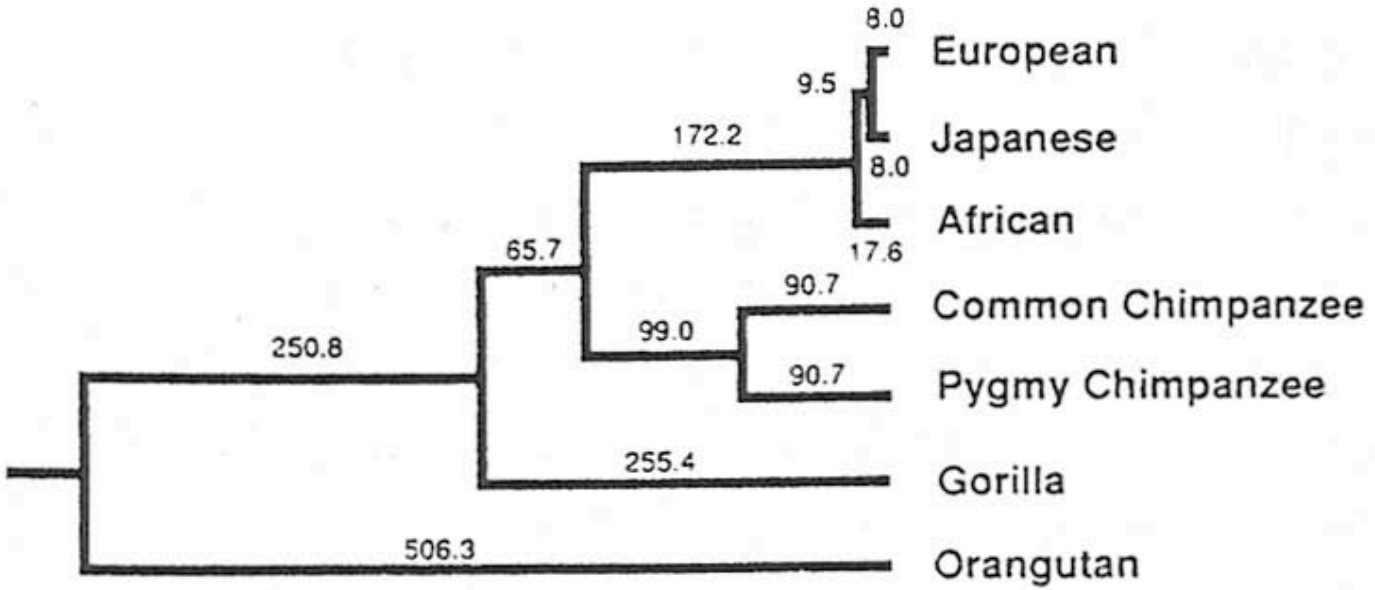
$\Rightarrow$ Evolved in Africa, population bottleneck

a small group left Africa, spread over Earth

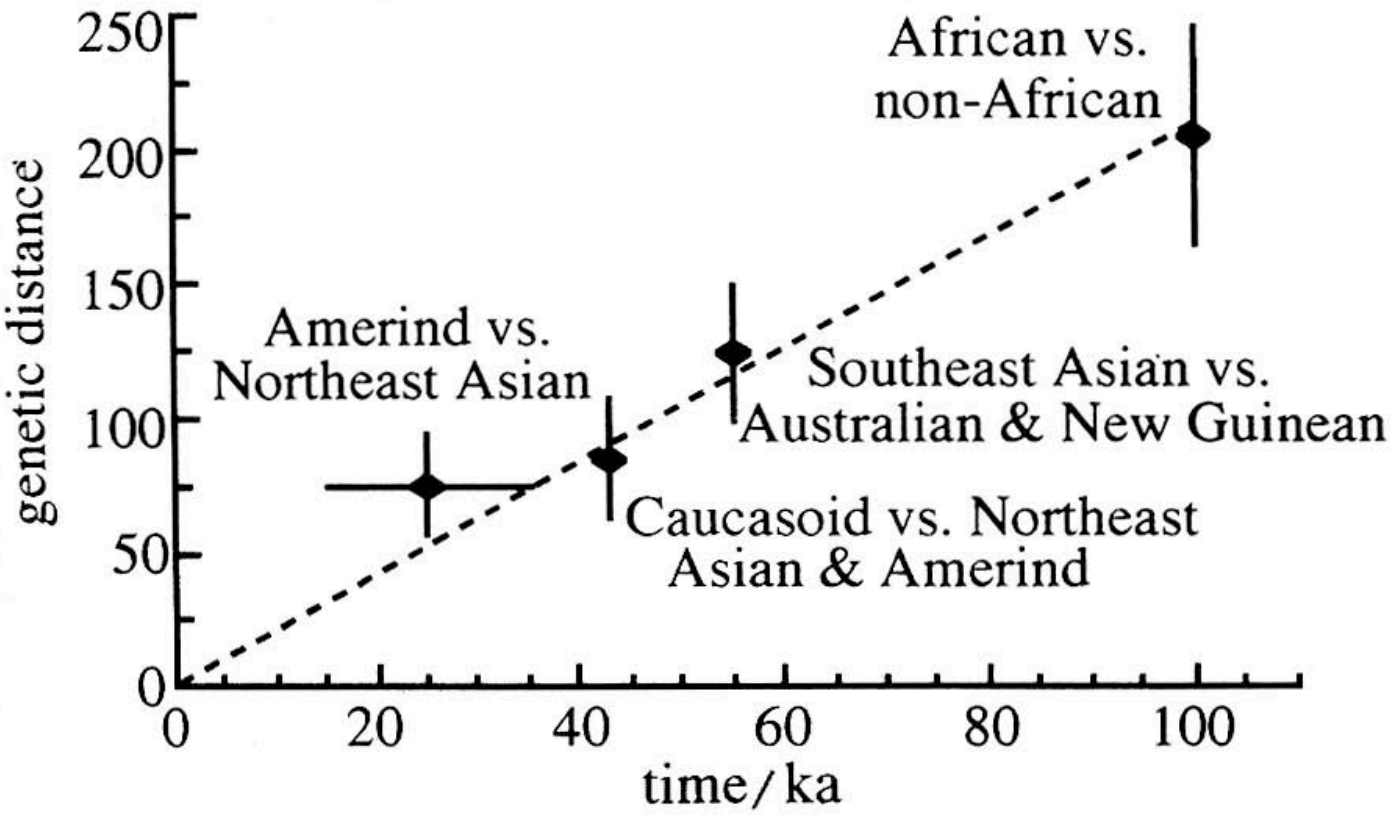
Linguistic: Good correlation of linguistic family tree with genetic one

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

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.

Stringer and McKie
African Exodus

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 Gibralter
  - Science 13 February 2009: Vol. 323. no. 5916, pp. 866 - 871

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

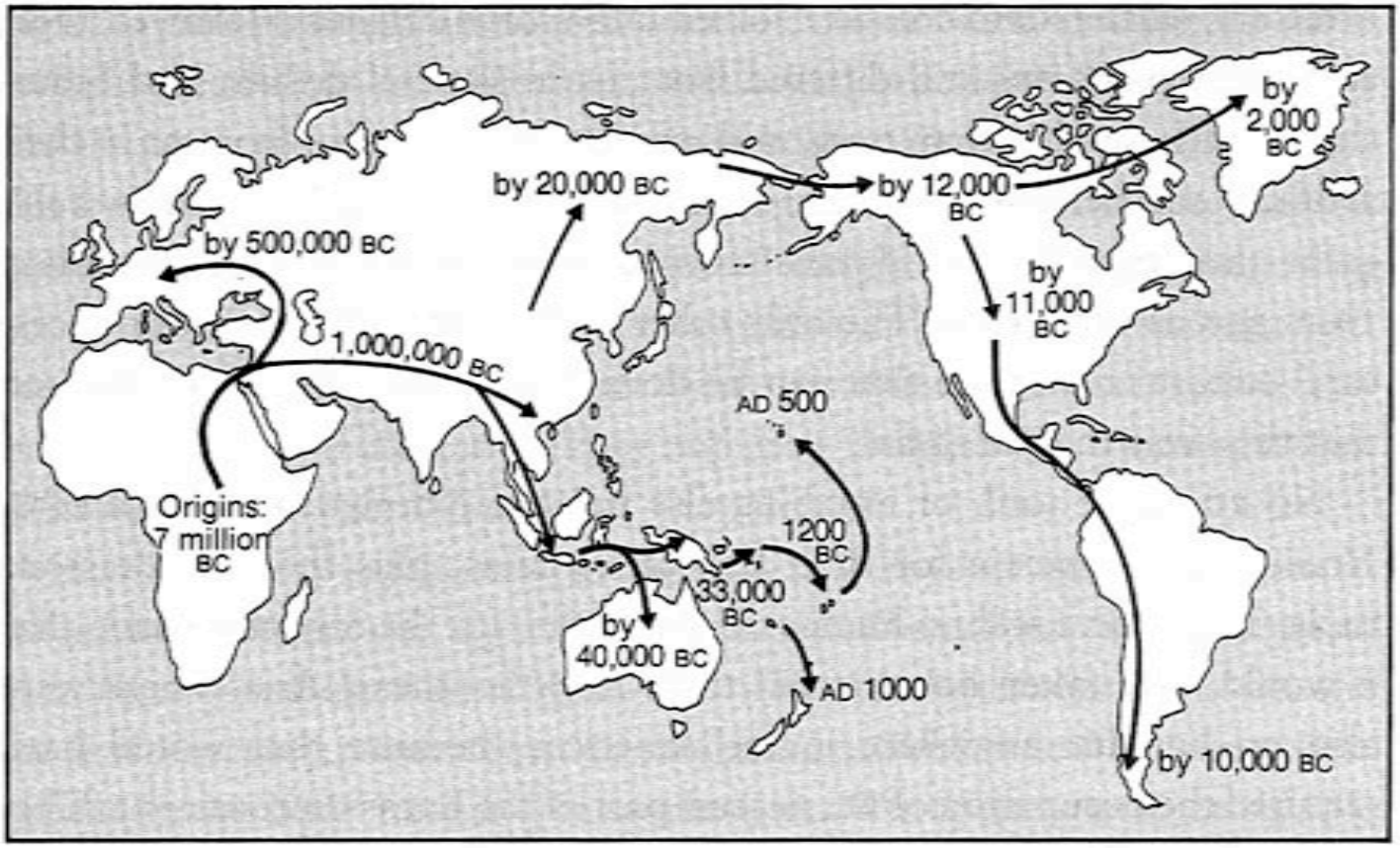


Figure 1.1. The spread of humans around the world.

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

$\Rightarrow$ 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