# The Origin of Intelligence

# The Origin of Intelligence

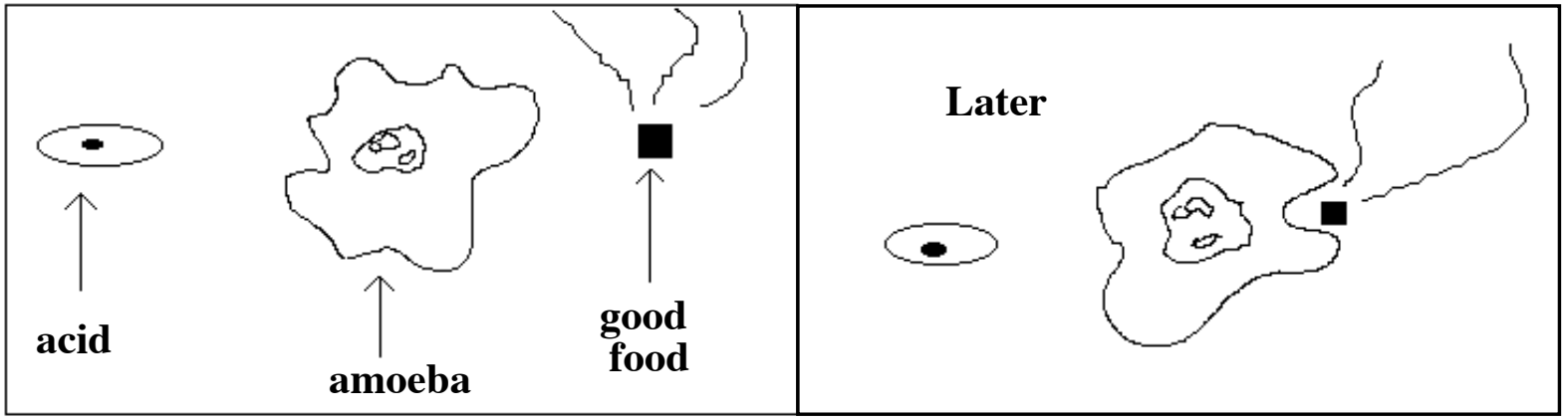
$f_i$ : Fraction of life-bearing planets where Intelligence develops

What is intelligence?

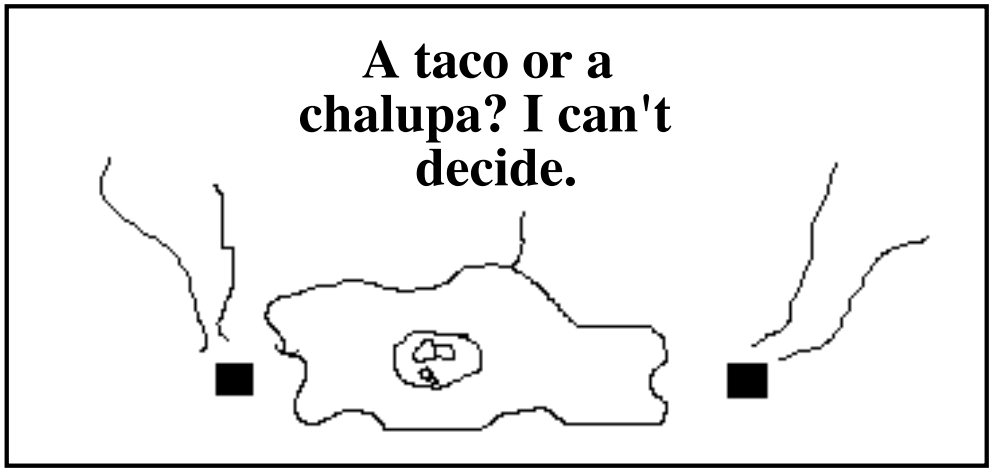
Propose: "The ability to model the world, including the organism itself"

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

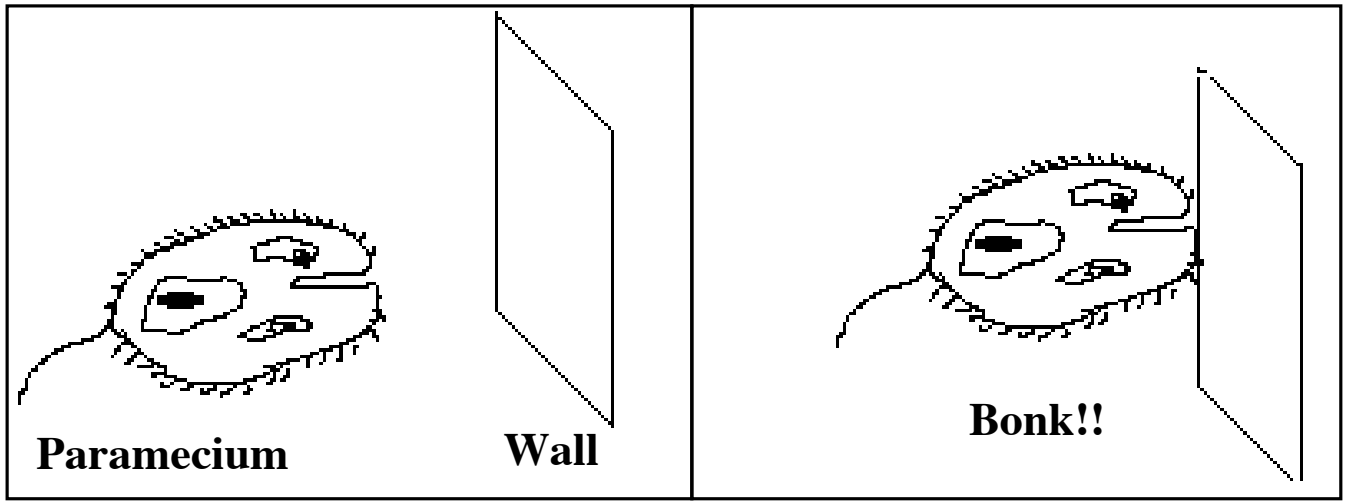
# Amoeba intelligence



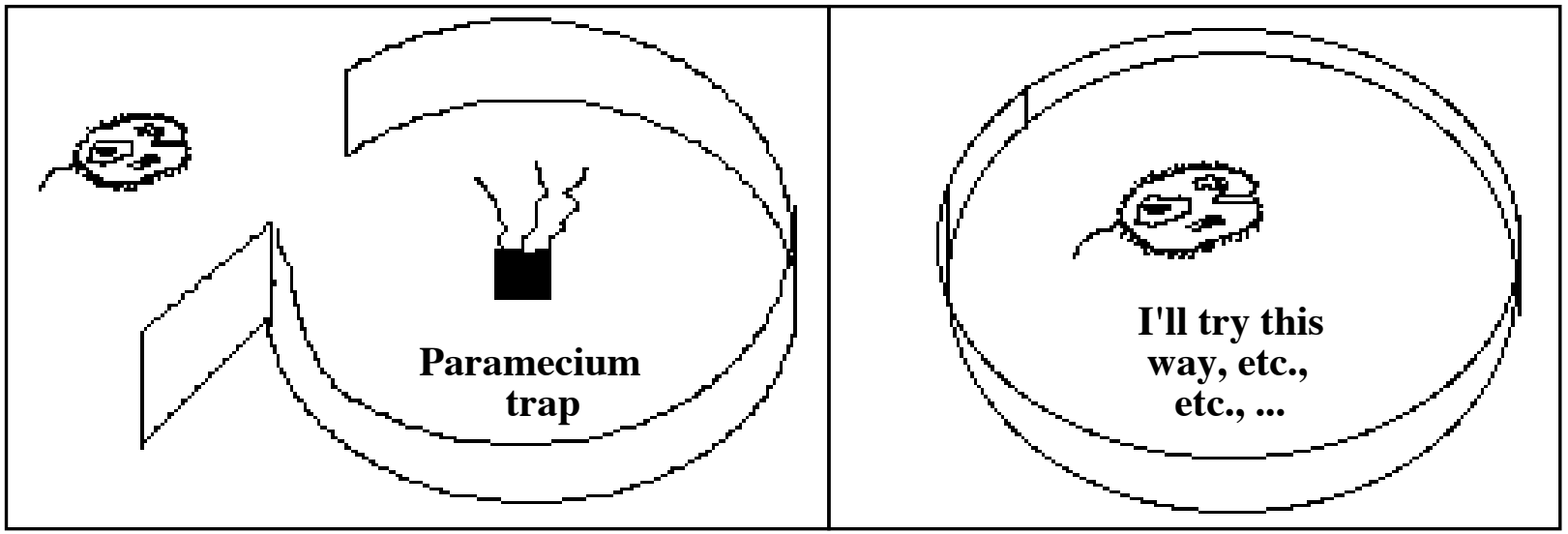
# The Amoeba’s dilemma



# The smarter Paramecium



# But not THAT smart…



# Information as Measure of Intelligence

Evolution of intelligence $\simeq$ 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 | $5 \times 10^8$ | | 500 |
| H. Sapiens* | $6 \times 10^9$ | | small library |

*~ 2% codes for proteins

$\Rightarrow$ $1.2 \times 10^8$ bits

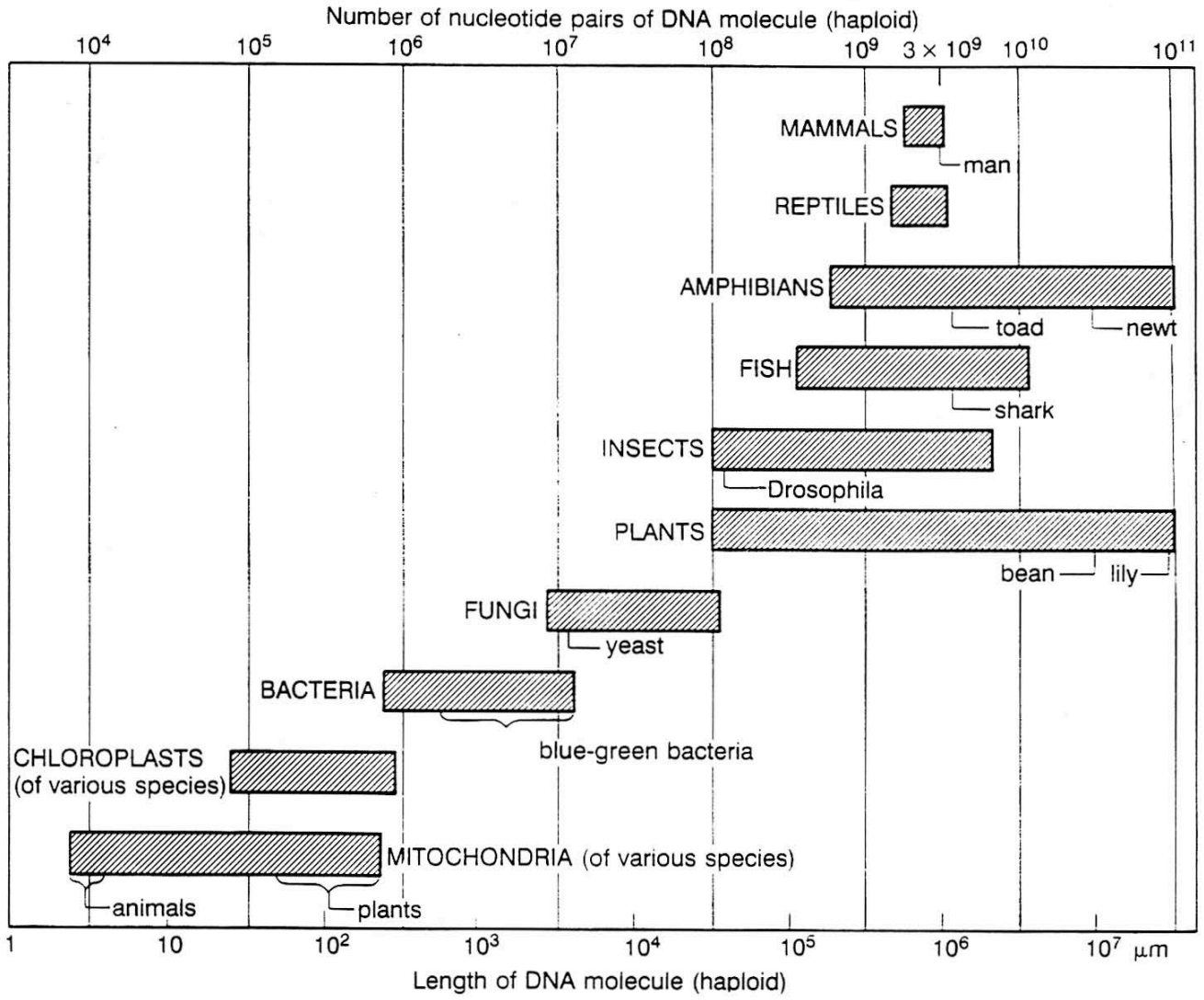



***Figure 7.18.*** Length of DNA molecules. Note that the DNA of some plants and amphibians is longer than that of bacteria by a factor of $10^4$ to $10^5$. The total length of human DNA is approximately $10^6$ μm or 1 m, which is equivalent to roughly $3 \times 10^9$ nucleotide pairs or $10^9$ codons.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

Caveat:

much of DNA is “non-coding” □ hard to count

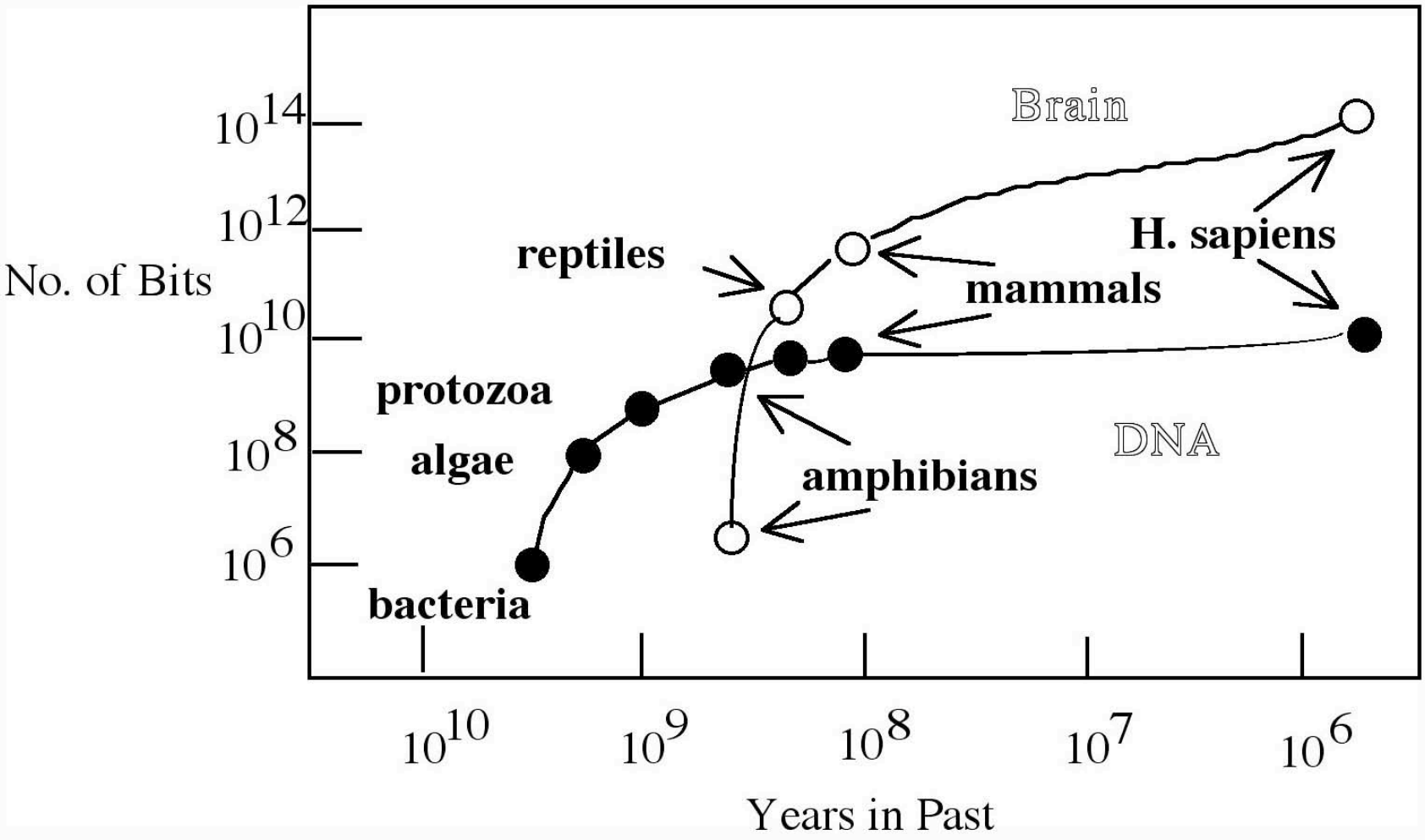
Information stored in DNA limited by fidelity of replication

| Organism | Error Rate | # of Bits |
|---|---|---|
| Virus | $10^{-3}$ | $10^{4}$ |
| Bacterium | $10^{-6}$ | $10^{6}$ - $10^{7}$ |
| Eukaryotes | $10^{-9}$ - $10^{-8}$ | $10^{8}$ - $10^{10}$ |

Sexual reproduction provides safety measure for mutations in recessive genes

# 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

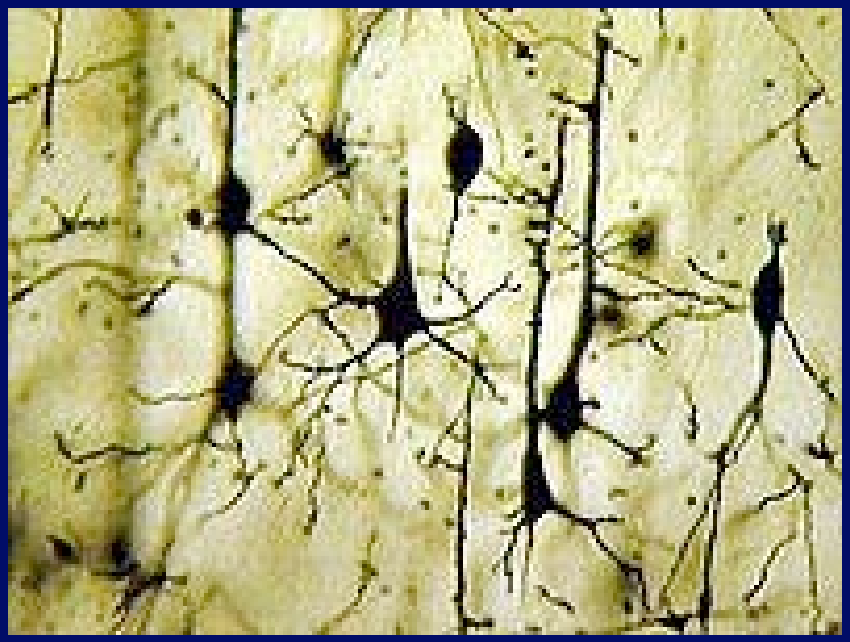
How is information stored in brains?

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 (~$10^3$) inputs - synapses

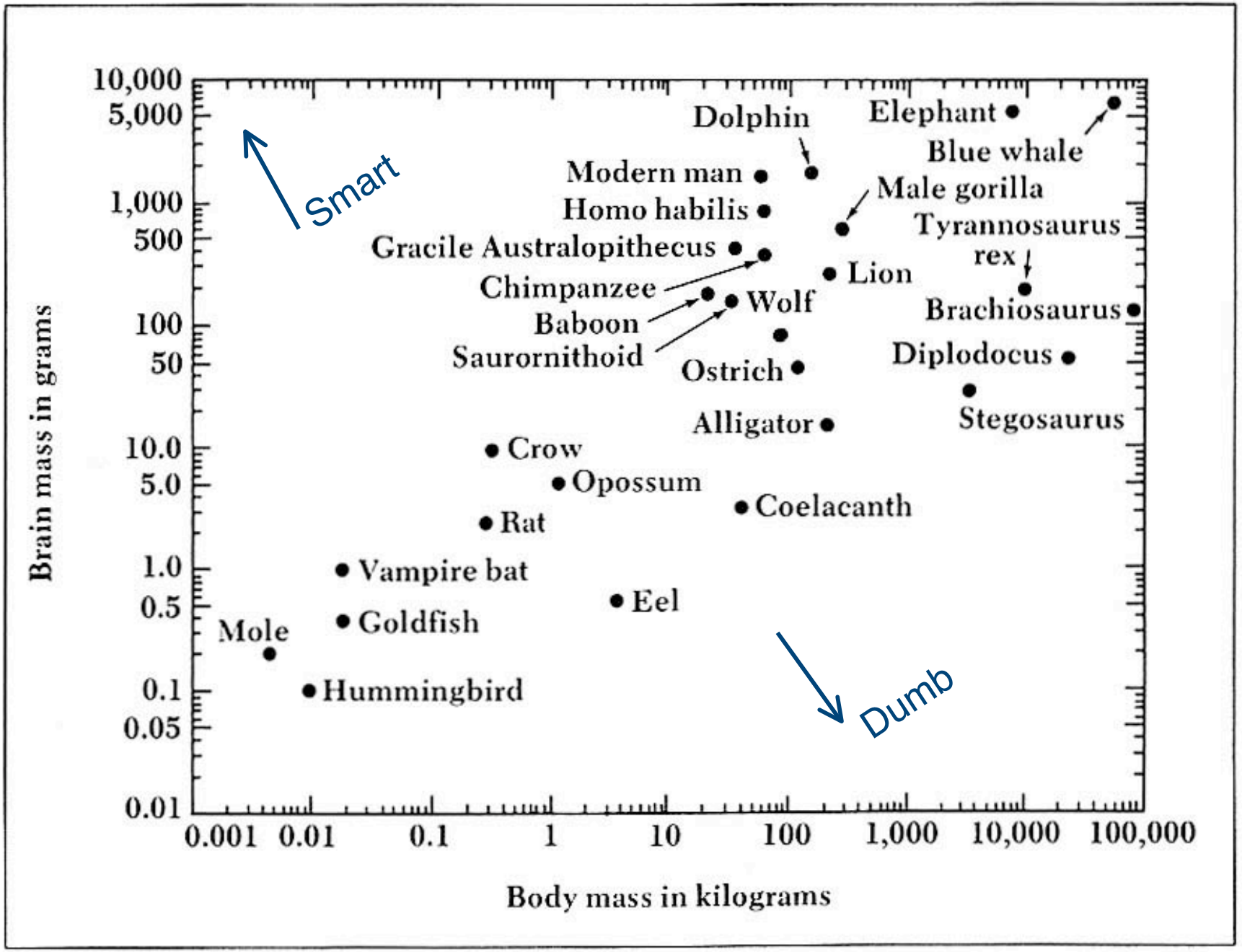
An analog computer  Hard to count

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

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

Surrogate Measure:

Brain size or Brain mass/body mass


Brain mass in grams
10,000
5,000
1,000
500
100
50
10.0
5.0
1.0
0.5
0.1
0.05
0.01
0.001
0.01
0.1
1
10
100
1,000
10,000
100,000
Body mass in kilograms
Smart
Dumb
Dolphin
Elephant
Blue whale
Modern man
Male gorilla
Homo habilis
Tyrannosaurus rex
Gracile Australopithecus
Lion
Chimpanzee
Wolf
Brachiosaurus
Baboon
Saurornithoid
Ostrich
Diplodocus
Stegosaurus
Alligator
Crow
Opossum
Coelacanth
Rat
Vampire bat
Eel
Goldfish
Mole
Hummingbird

# Brain organization

Brain is reprogrammable , unlike genes

 Individual can learn

Two hemispheres

Many functions parallel, but some specialized

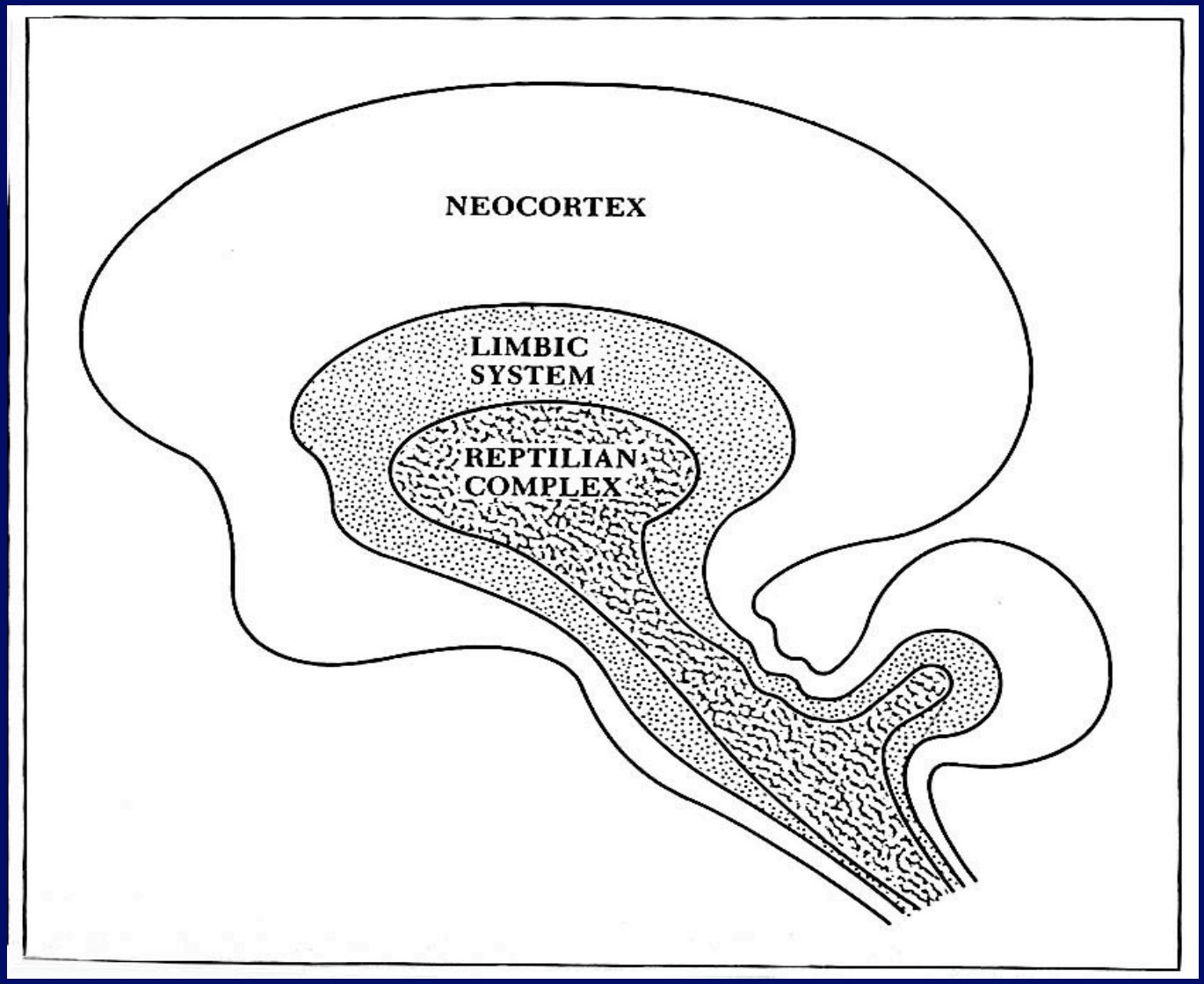
Many ways to divide brain

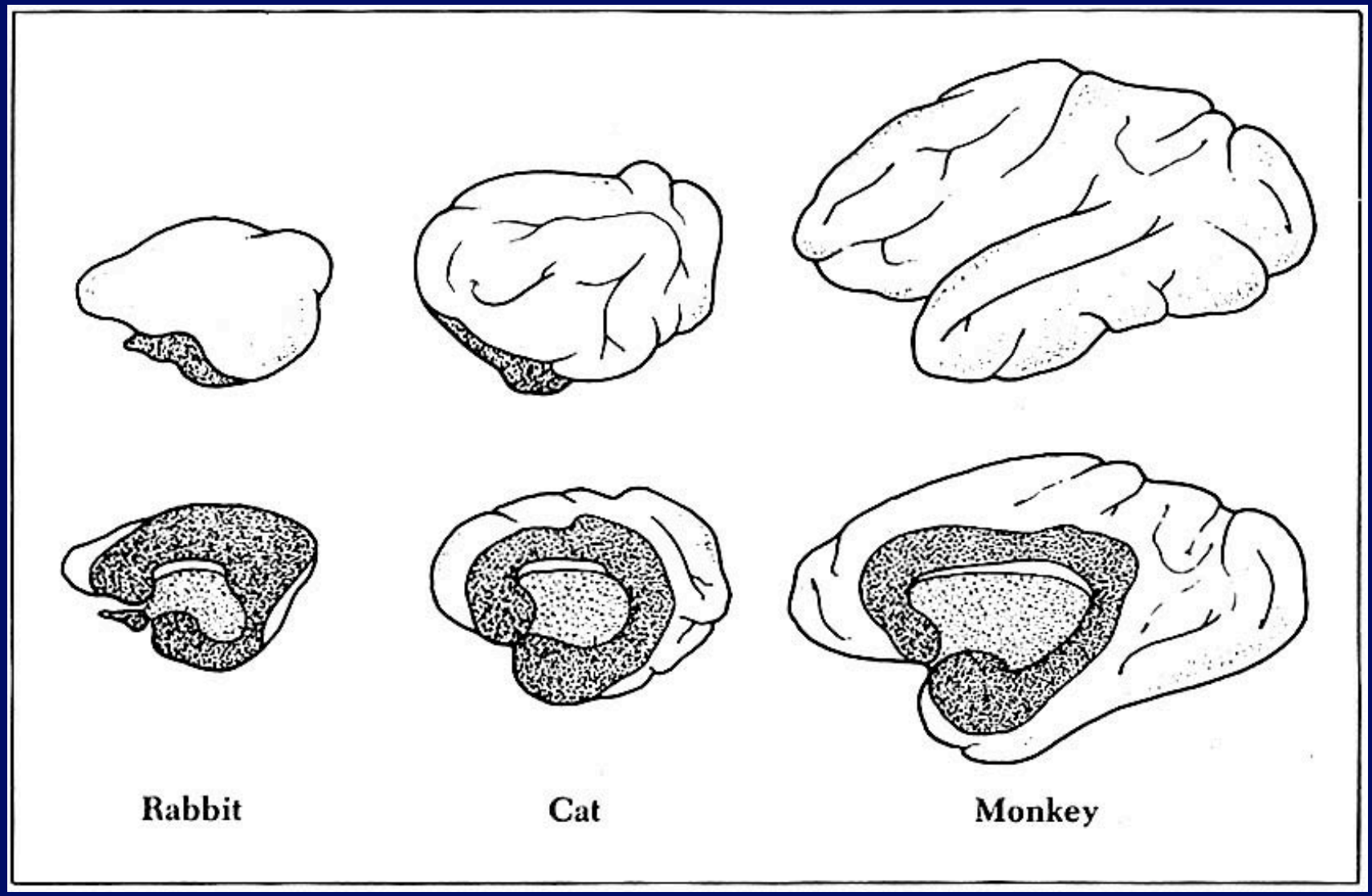
Layered brain: reptilian brain
limbic system (mammals)
cortex

Brain size has increased (in some species) with time

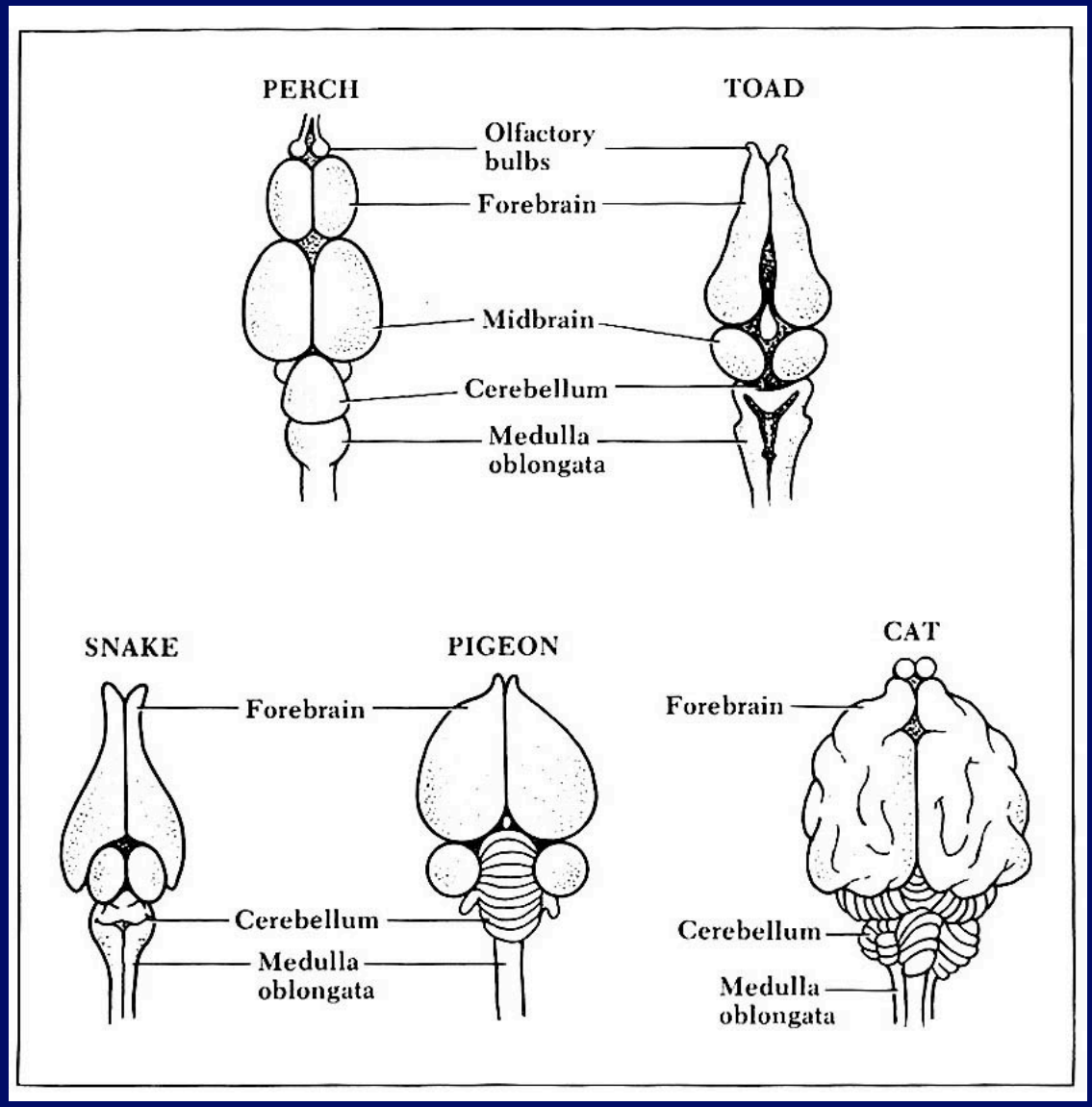
 Evolution favors higher intelligence (sometimes)

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



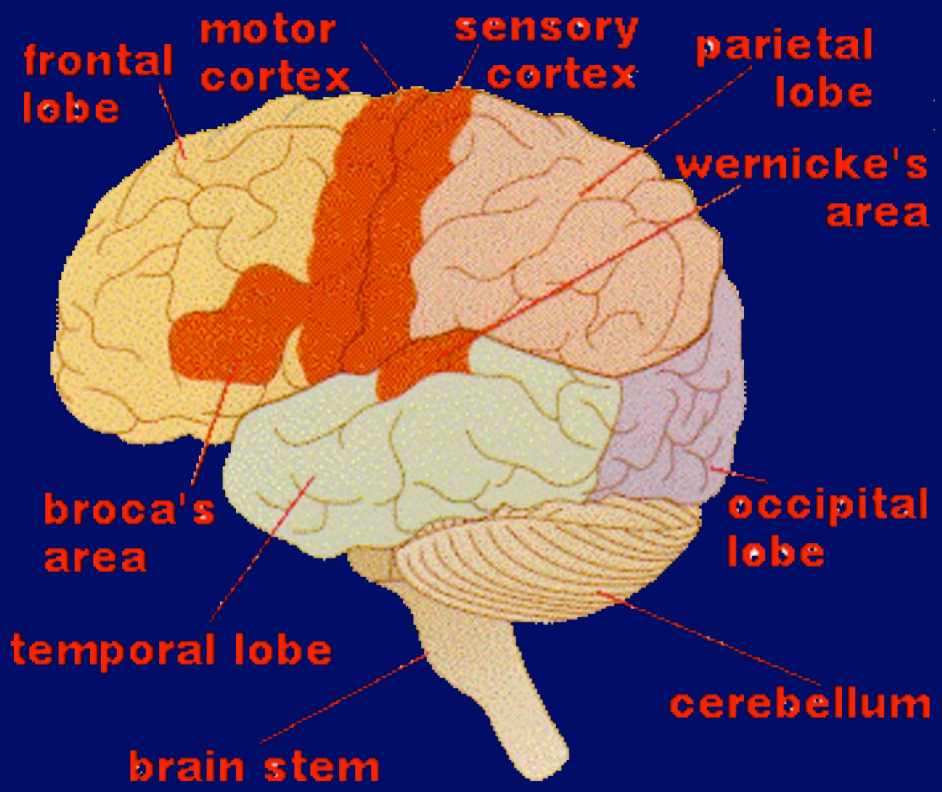



Schematic views from the top and from the side of the rabbit, cat, and monkey brains. The dark stippled area is the limbic system, seen most easily in the side views. The white furrowed regions represent the neocortex, visible most readily in the top views.




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.

# The Big Brain



# Human Evolution

Phylum: chordata - vertebrates - bilateral sym.

Class: mammals arose in Triassic period

~ 225 Myr ago

Proliferated and “radiated” at end of cretaceous

(~ 65 Myr ago) after extinction of dinosaurs

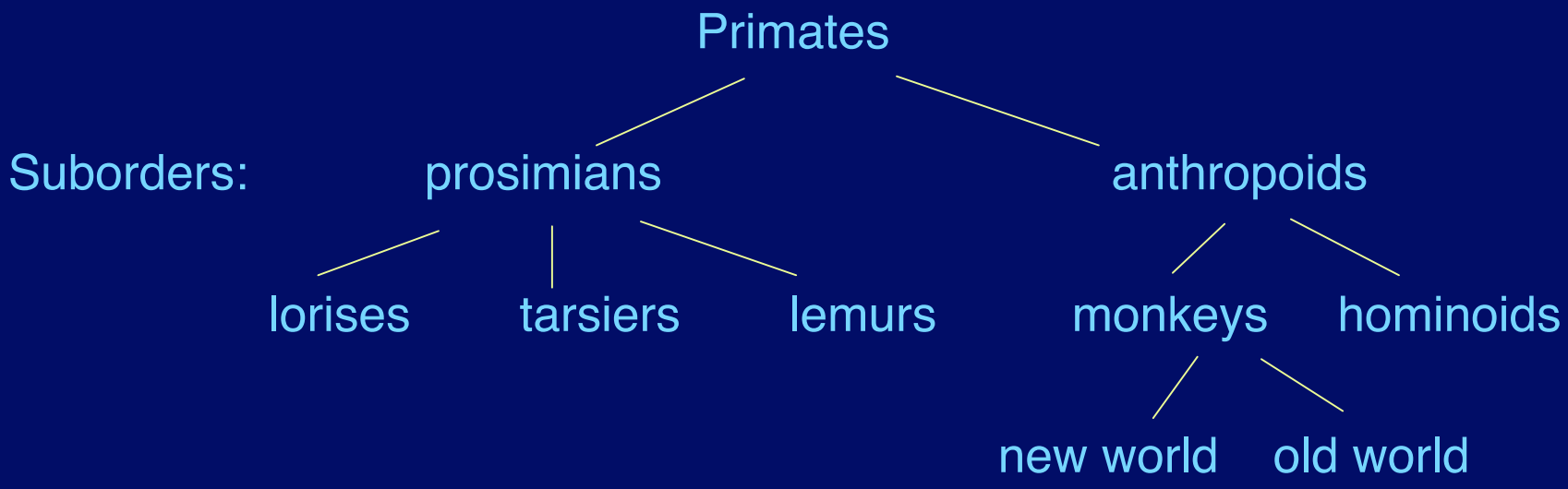
Order: primates - late cretaceous ~ 80Myr ago

# Primate Characteristics

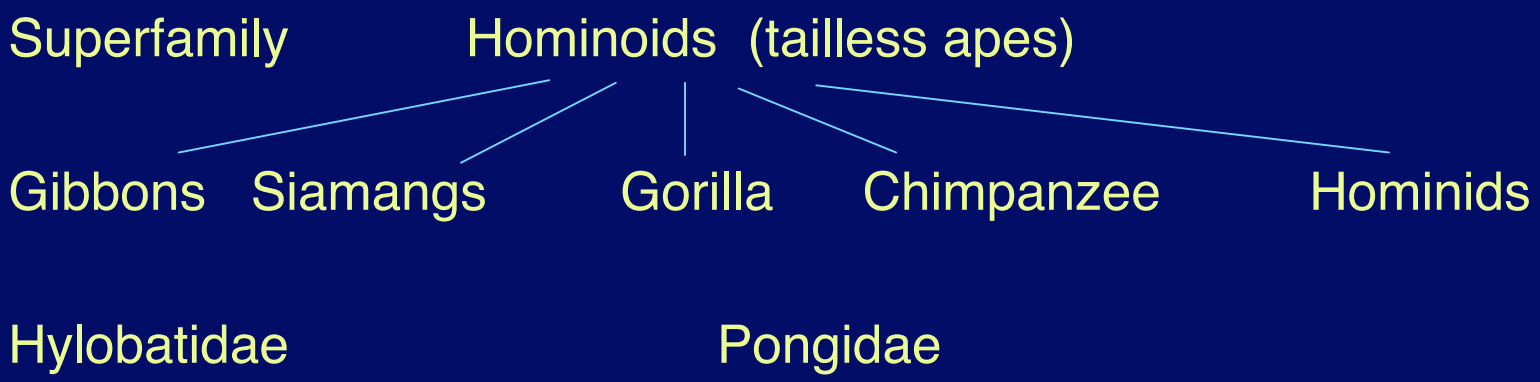
Few anatomical specializations

Flat fingernails, eyes in front

Adapted to life in trees



# There are alternative schemes



# “Recent” fossil record

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

Tertiary further divided into 5 epochs
as follows:  - dates (in million yrs. ago) are
rough.

| Era | Period | Epoch | Time at beginning (Myr ago) | Events, Fossils of Note |
|---|---|---|---|---|
| Cenozoic | | Recent | 5000 yrs | Historical Records<br>Homo sapiens<br>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<br>Dryopithecine Apes |
| | | | | Gap |
| | | Oligocene | 37–38 | Aegyptopithecus |
| | | Eocene | 54 | Tarsiers |
| | | | | Lemurs |
| | Tertiary | Paleocene | 65 | Tree Shrews - Primates<br>Proliferation of Mammals<br>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

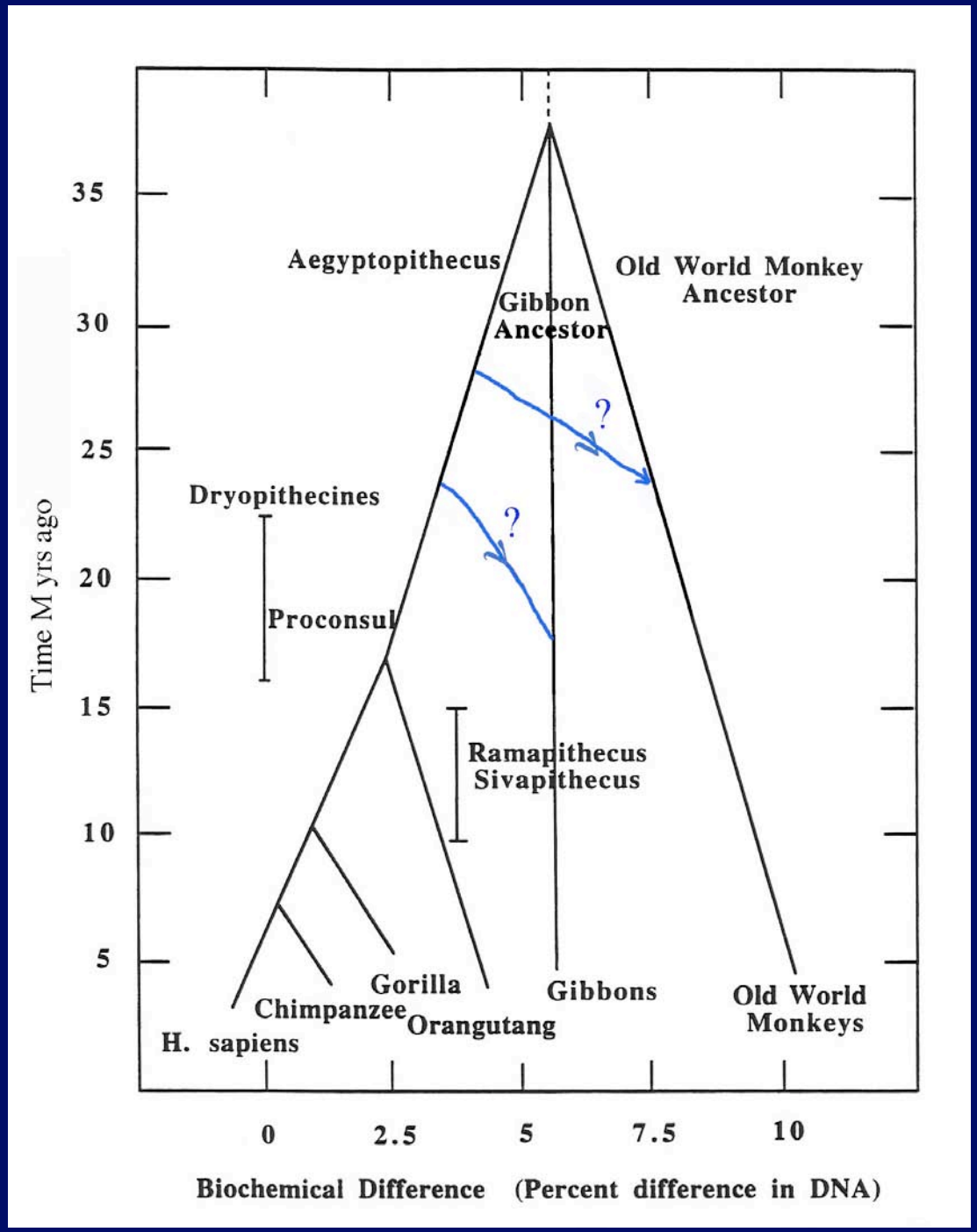
More complicated information processing, tool use becomes possible

# Origin of Anthropoids

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

More diurnal, some leave trees, lose tail

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

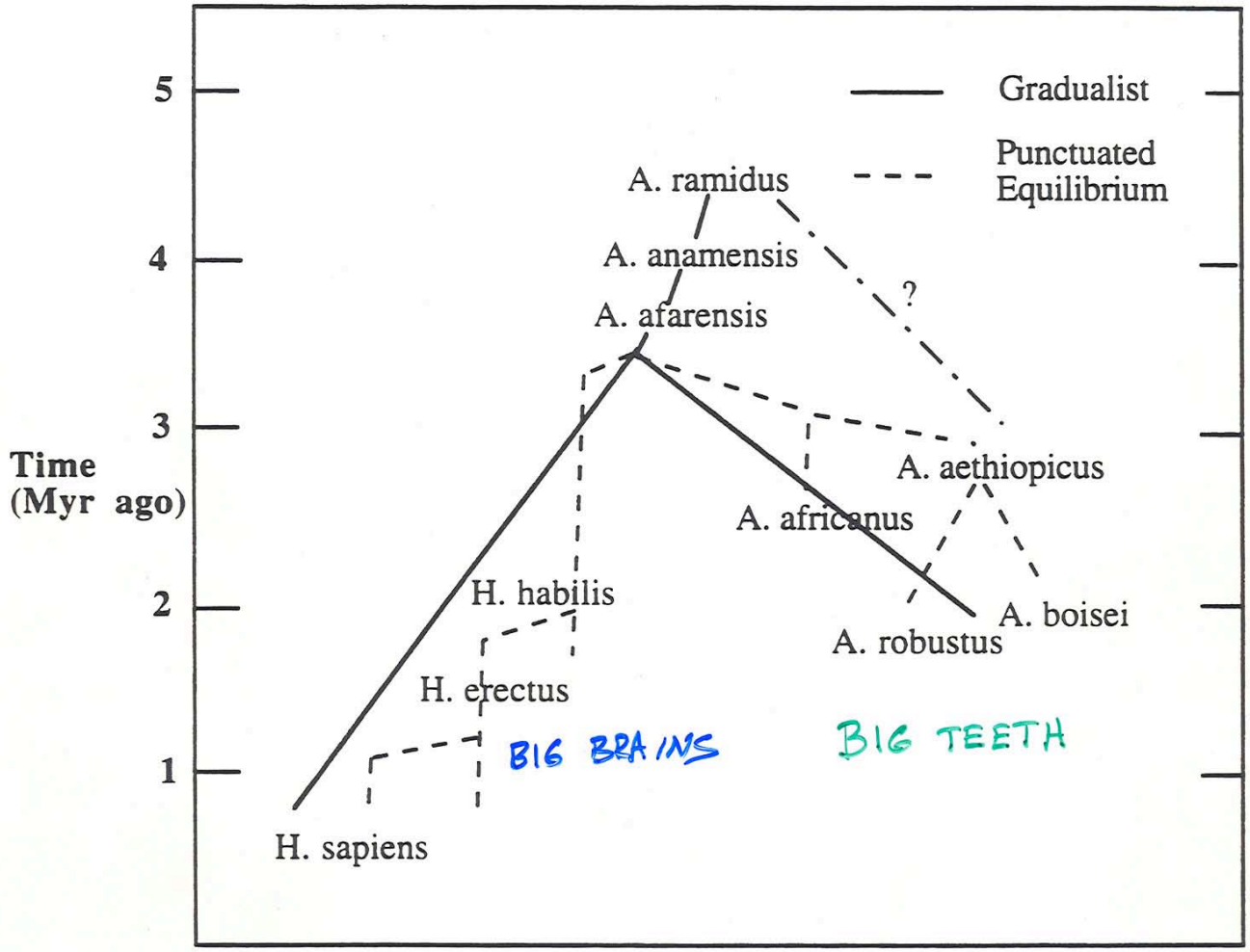

35
30
25
20
15
10
5
Time M yrs ago
Aegyptopithecus
Old World Monkey Ancestor
Gibbon Ancestor
?
?
Dryopithecines
Proconsul
Ramapithecus
Sivapithecus
Gorilla
Chimpanzee
Orangutang
Gibbons
Old World Monkeys
H. sapiens
0
2.5
5
7.5
10
Biochemical Difference (Percent difference in DNA)

# Hominid Evolution

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

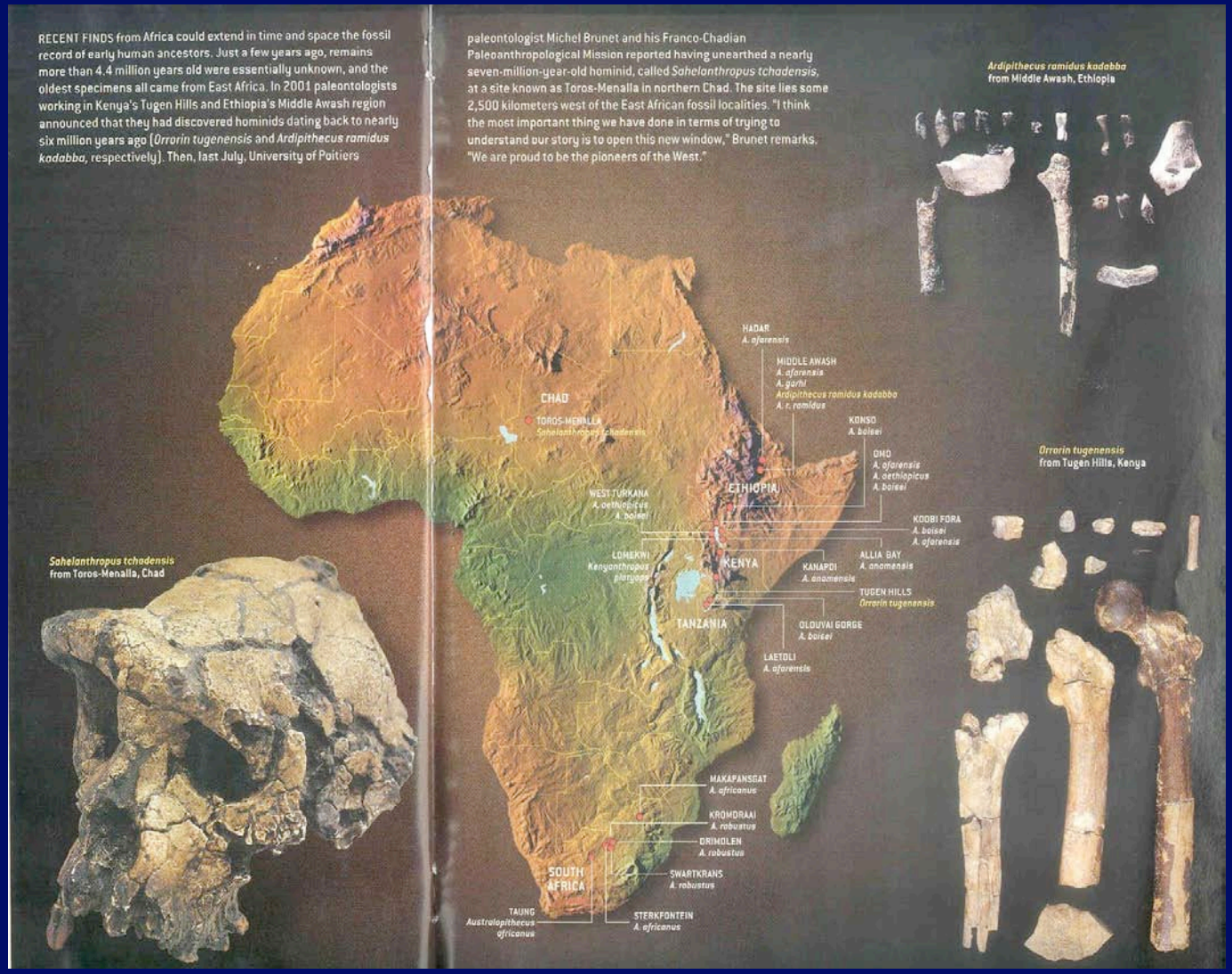
Many variations now known
many species co-existed in Africa
Earlier species show mosaic of human-ape traits

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



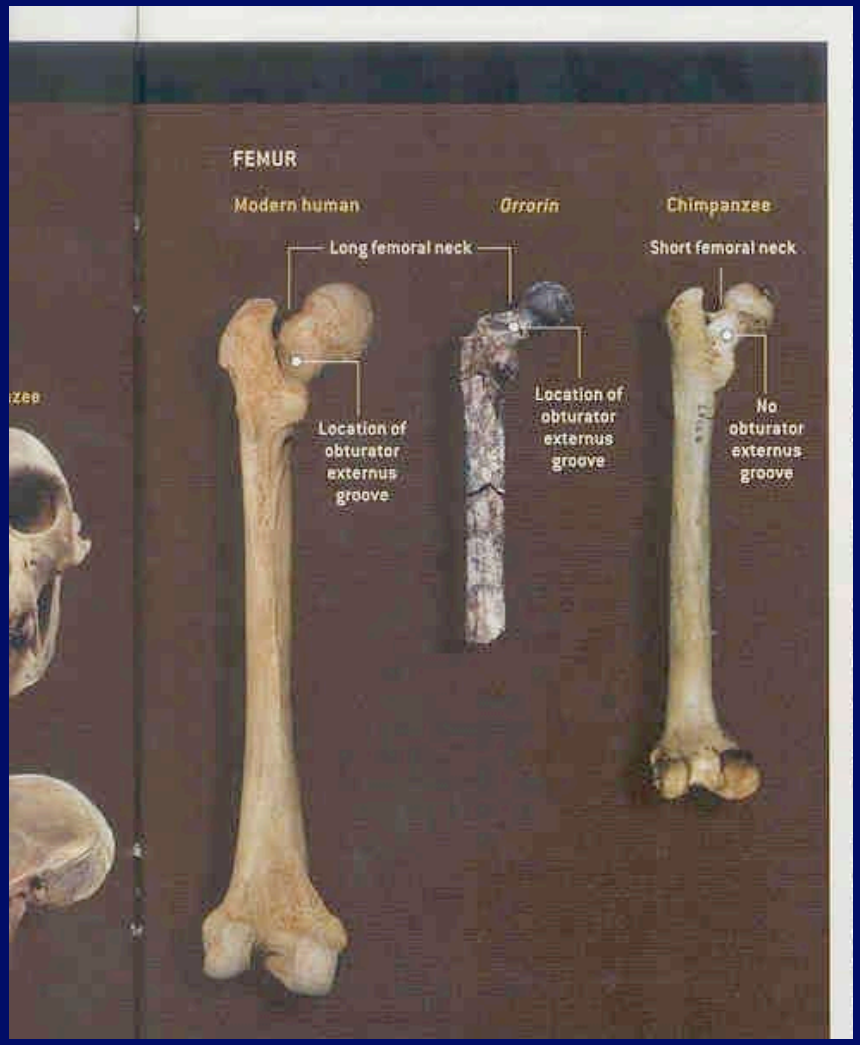

The last 4.5 Myr of hominid evolution are summarized in the accompanying figure. The solid lines in the figure indicate the lines of descent in a gradualist picture, while the dashed lines indicate the picture of punctuated equilibrium.

# Hominids in Africa



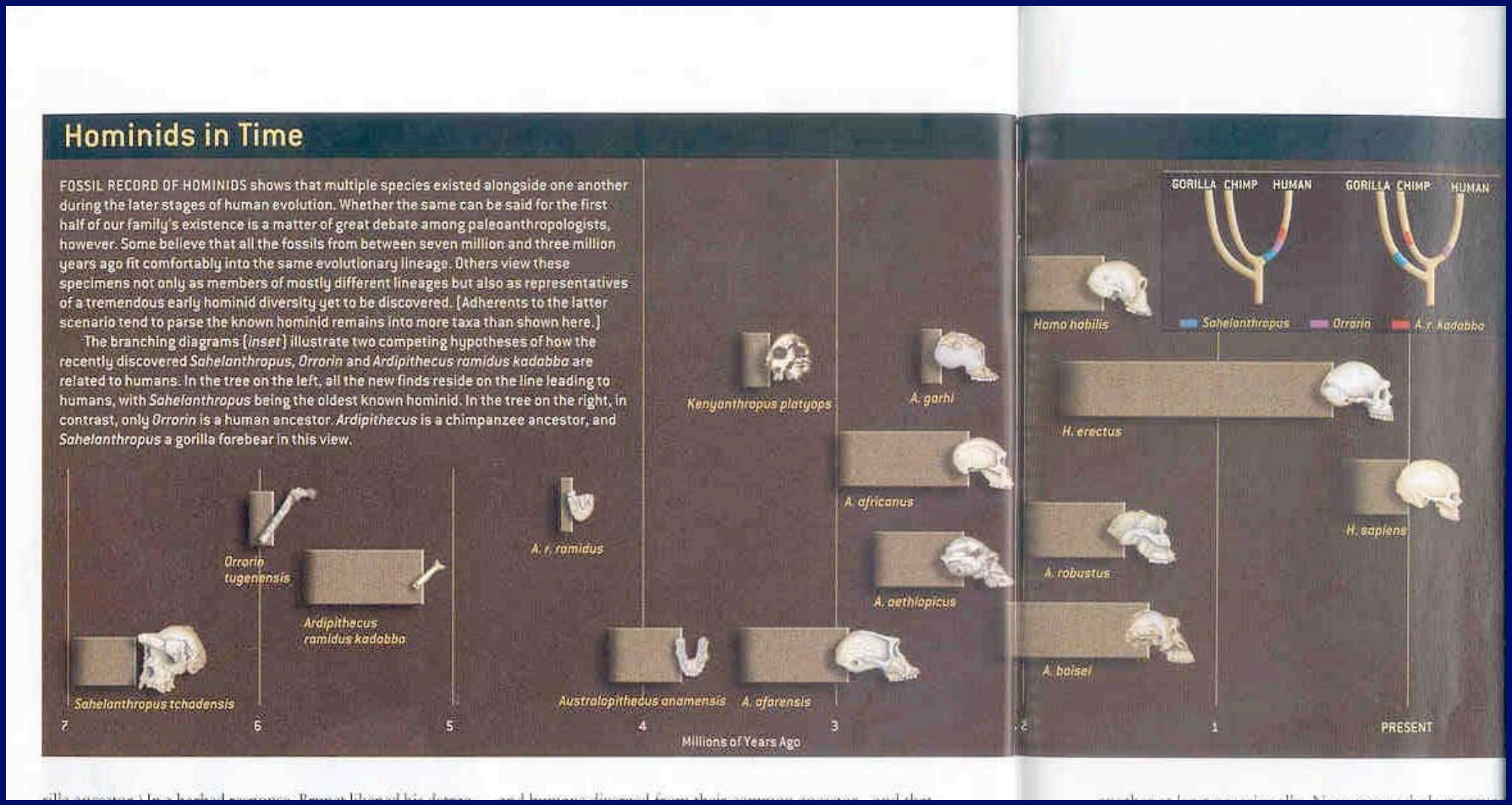

Scientific American
Jan. 2003

# Comparison of Femurs




Femur adapted to bipedality already by 6 Myr ago

# Various Family Trees



# 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

# 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")

# The Last Steps to Modern H. sapiens

## Origin of Modern H. Sapiens

Some 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

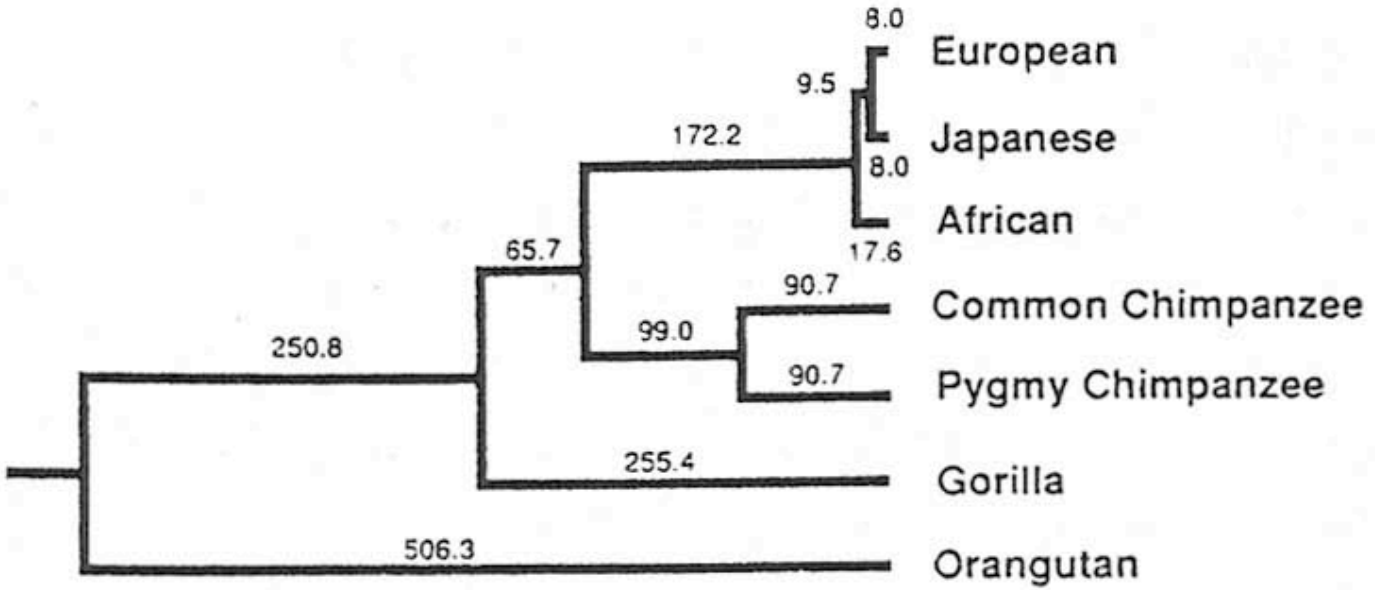
Genetic: humans are **very** homogeneous
greatest diversity is in Africa

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

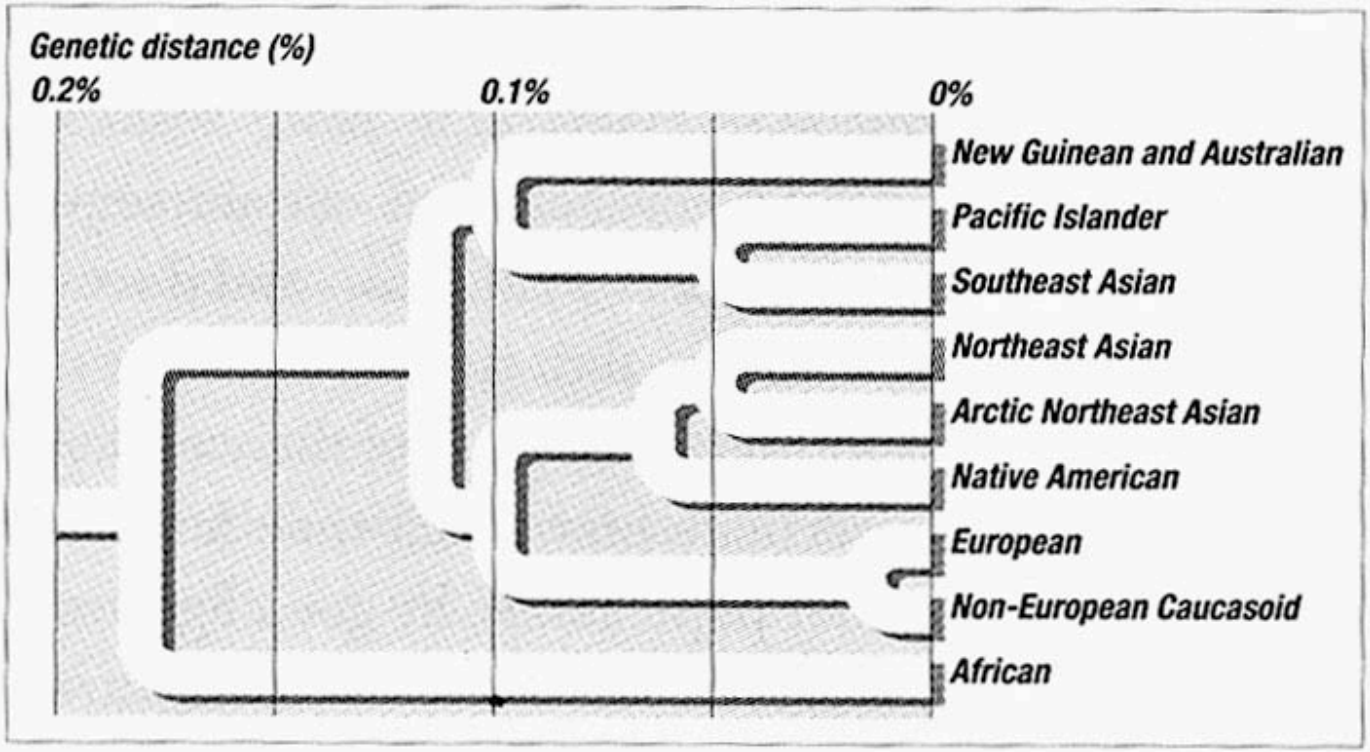
Linguistic: Good correlation of linguistic family tree with genetic one

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

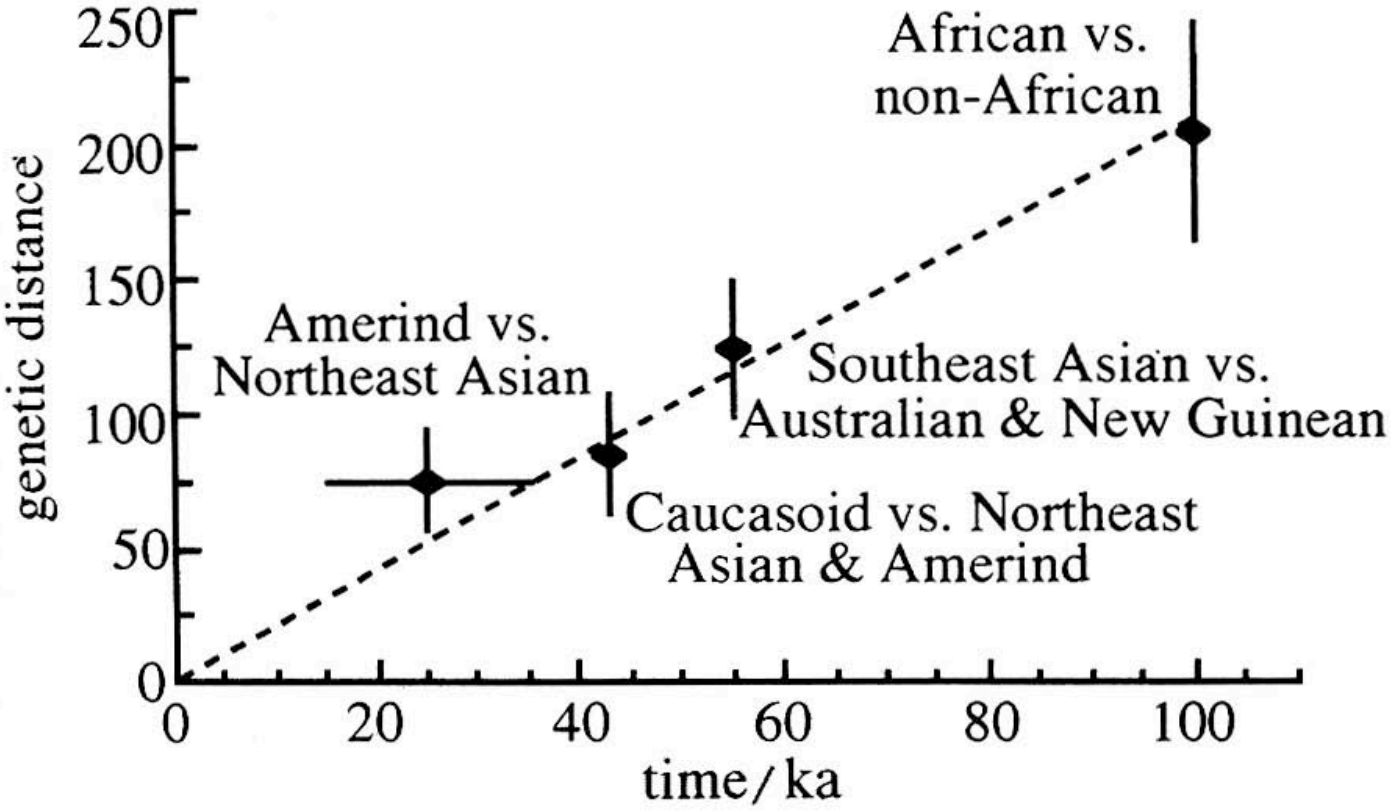
# From Stringer & McKie - *African Exodus*




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.




39 This tree of modern population relationships based on nuclear DNA products is from the work of Cavalli-Sforza and colleagues. The various African populations have been lumped into a single branch for simplicity.




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.

# Update on Genetic Analysis

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 M yr H. erectus

~ 500,000 “neanderthal”

~ 100,000 Modern humans

But genes mixed (interbreeding)

Europeans may have some neanderthal genes (still controversial)

Asians may have some H. erectus genes

“Mostly Out - of - Africa”

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

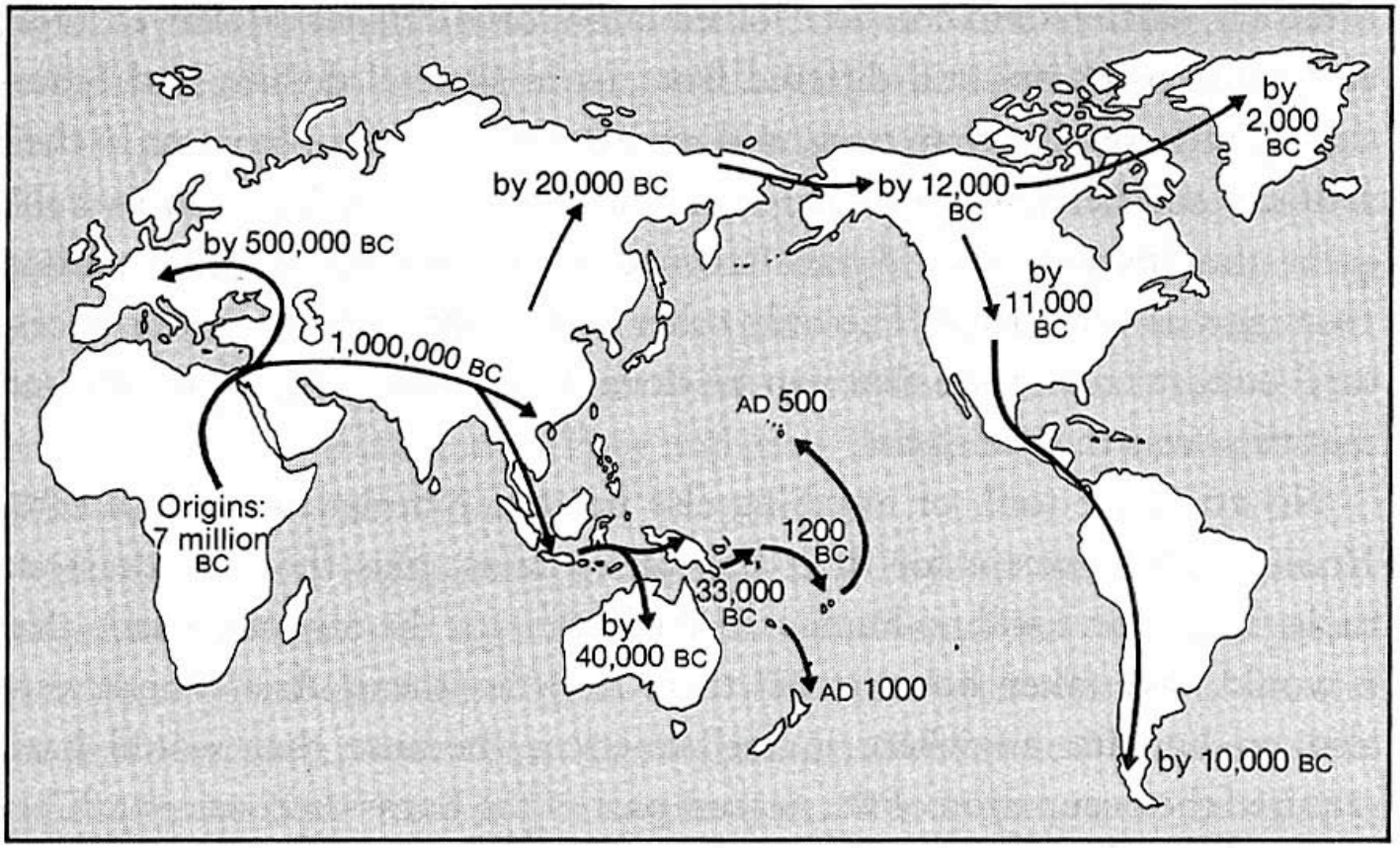
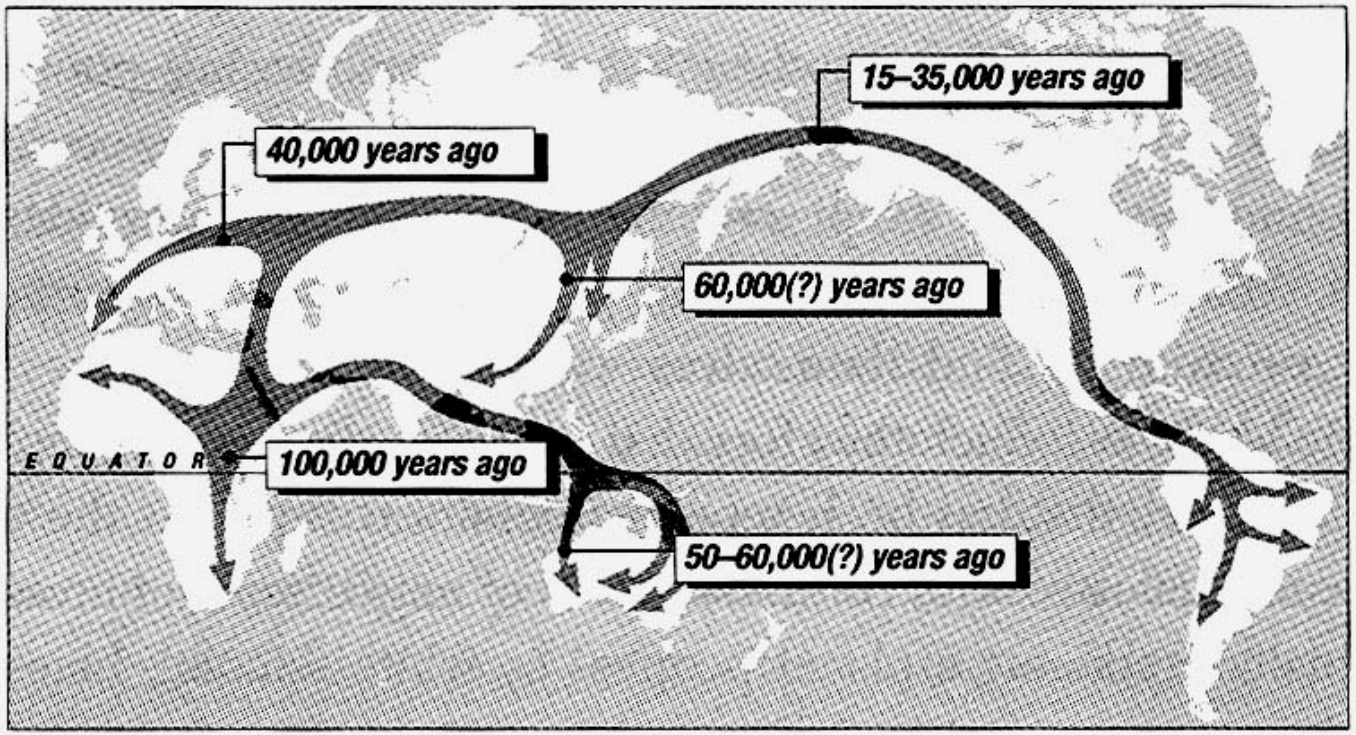



*Figure 1.1. The spread of humans around the world.*

# From Stringer & McKie - *African Exodus*




46 Genes and fossils have been used to reconstruct this map of the spread of *Homo sapiens* over the last 100,000 years.

# 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)

# 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)

4. 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

   Complex life requires more benign conditions
   more stars closer to center of galaxy (stars closer together)

   Supernovae, X-rays, Gamma-rays
   could 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 <u>one</u> are suspect