

The Origin of Intelligence

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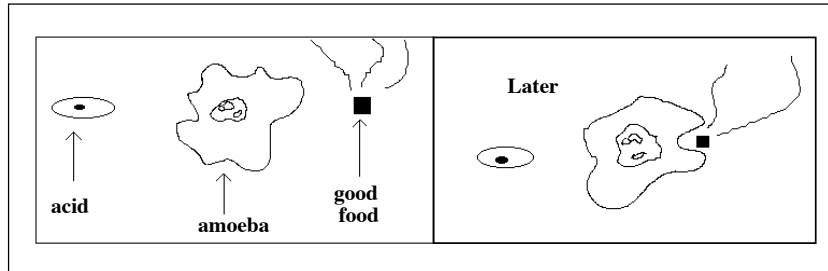
f_i : Fraction of life-bearing planets where
Intelligence develops

What is intelligence?

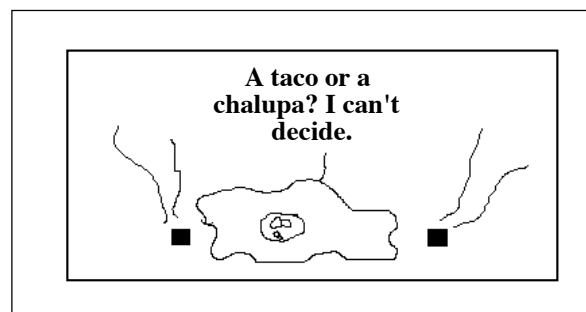
Propose: “The ability to model the world,
including the organism itself”

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

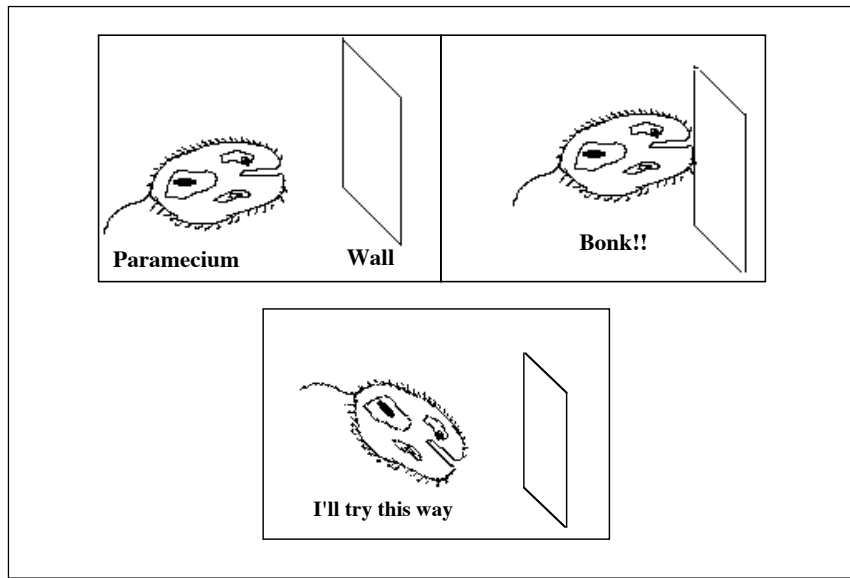
Amoeba intelligence



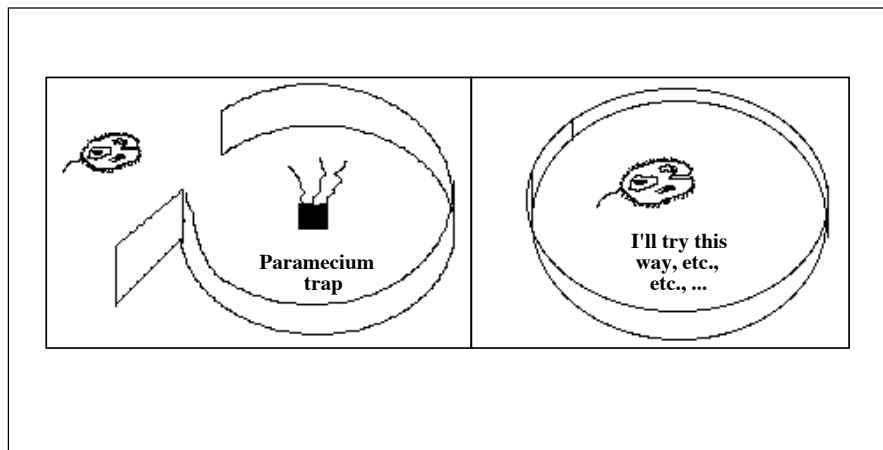
The Amoeba's dilemma



The smarter Paramecium



But not THAT smart...



Information as Measure of Intelligence

Evolution of intelligence \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

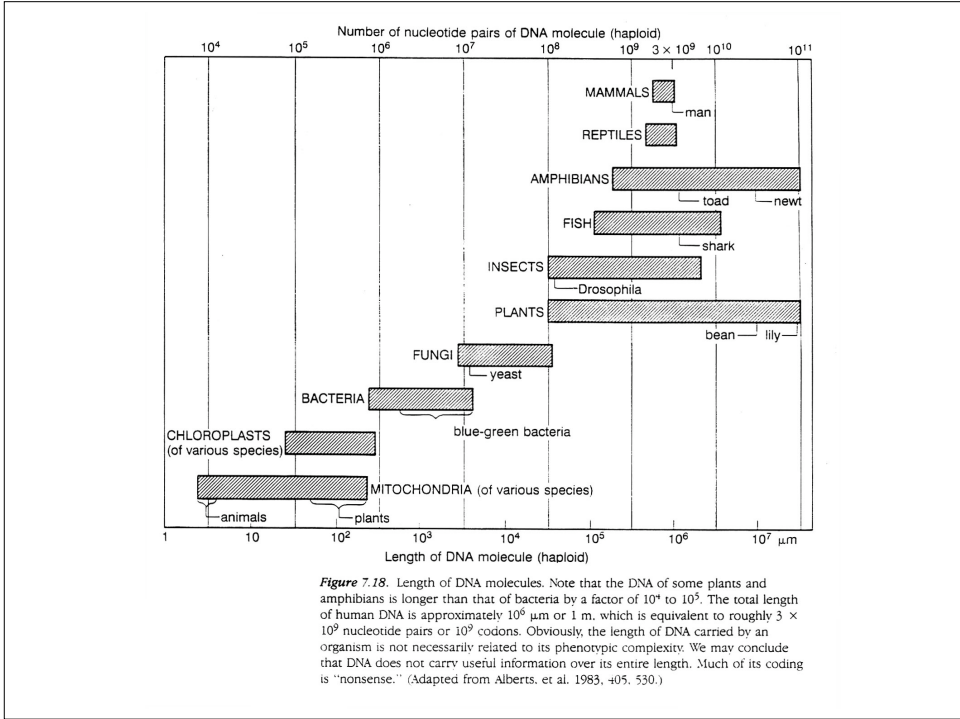
e.g.	<u>Purines</u>	<u>Pyrimidines</u>
	Adenine (A)	Cytosine (C)
	Guanine (G)	Thymine (T)

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

\times 1.2×10^8 bits



Evolution produced Increase in information

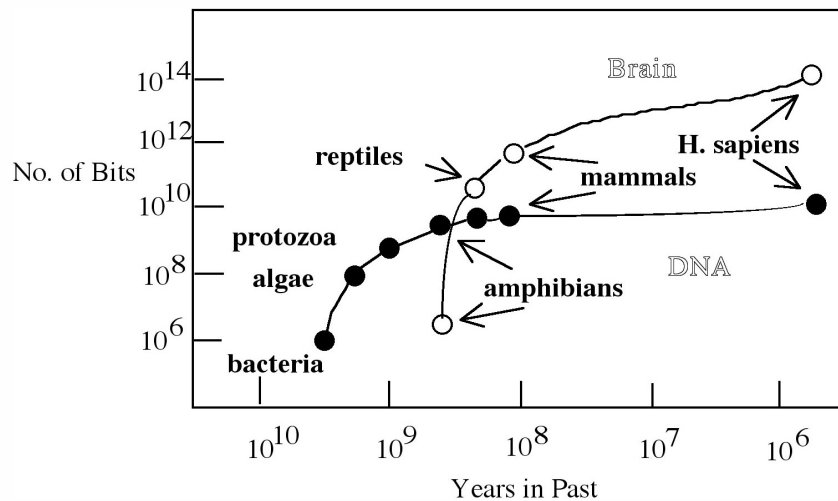
Caveat:
 much of DNA is "non-coding" □ hard to count
 Information stored in DNA limited by fidelity of replication

<u>Organism</u>	<u>Error Rate</u>	<u># of Bits</u>
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

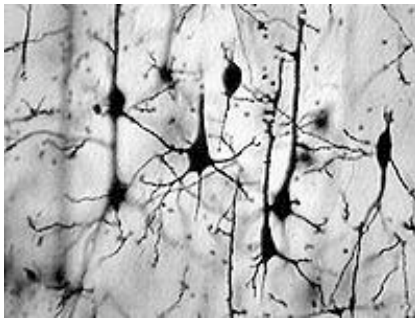
Neurons led to brains

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

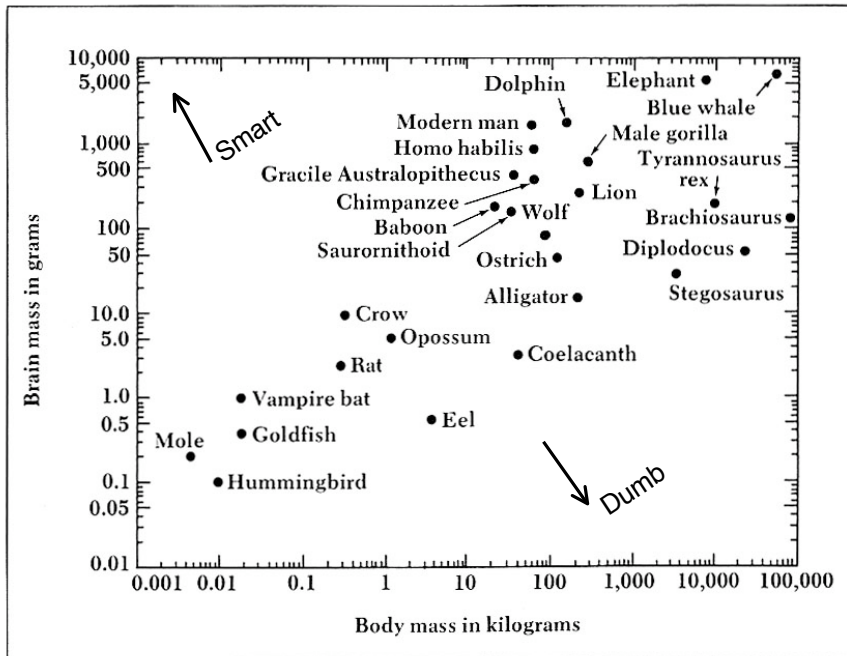
An analog computer □ Hard to count

$\sim 10^{11}$ neurons, 10^{14} synapses

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

Surrogate Measure:

Brain size or Brain mass/body mass



Brain organization

Brain is reprogrammable , unlike genes

□ Individual can learn

Two hemispheres

Many functions parallel, but some specialized

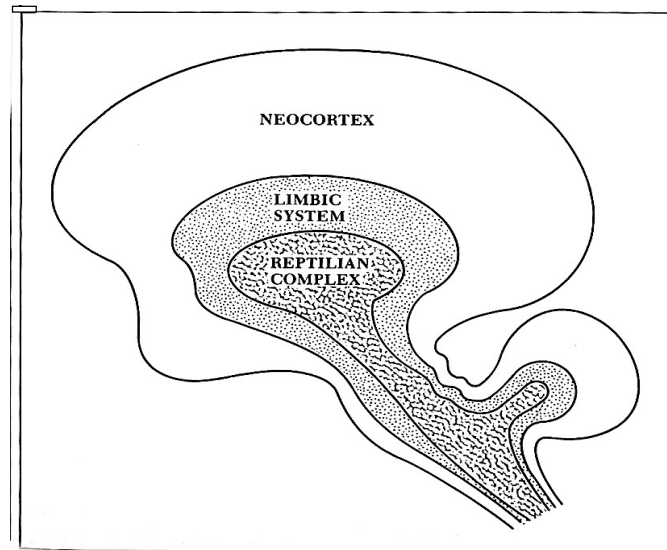
Many ways to divide brain

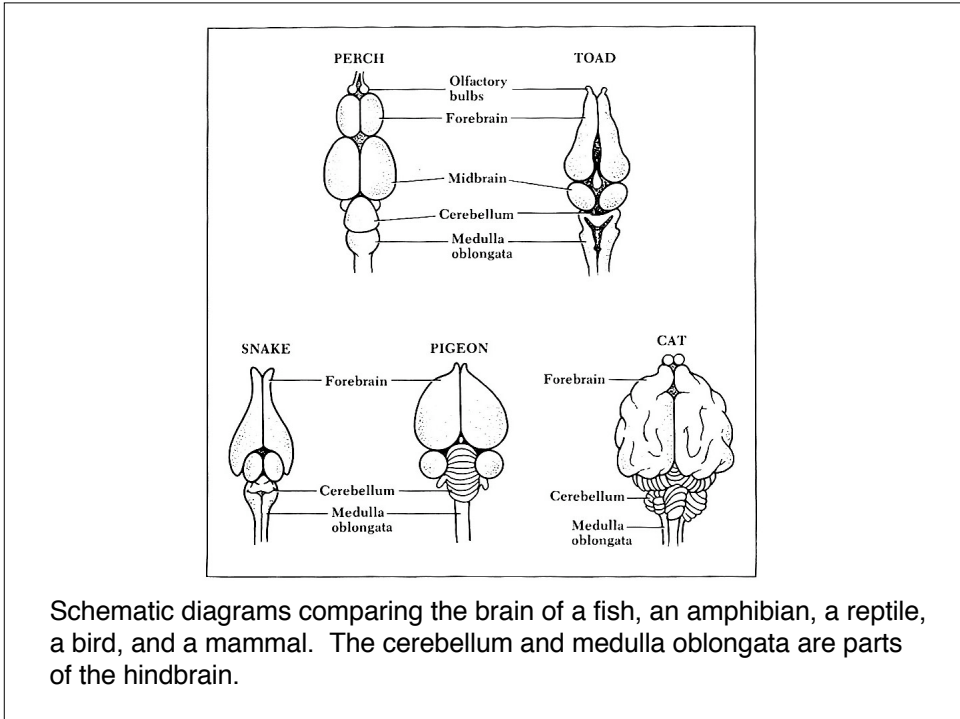
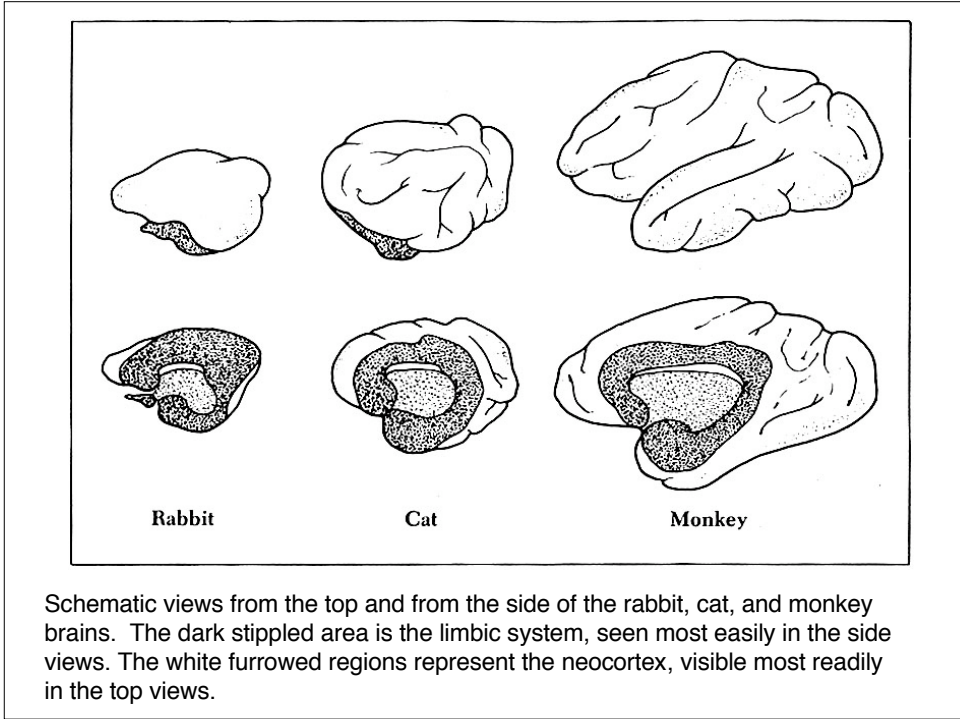
Layered brain: reptilian brain
 limbic system (mammals)
 cortex

Brain size has increased (in some species) with time

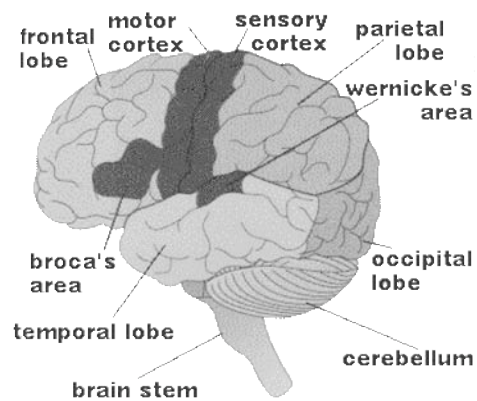
❓ Evolution favors higher intelligence (sometimes)

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





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

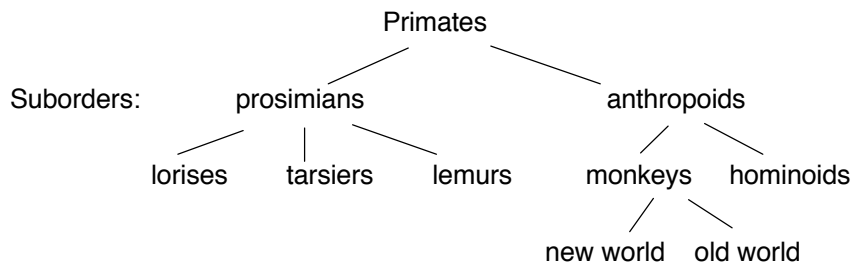
Order: primates - late cretaceous ~ 80Myr ago

Primate Characteristics

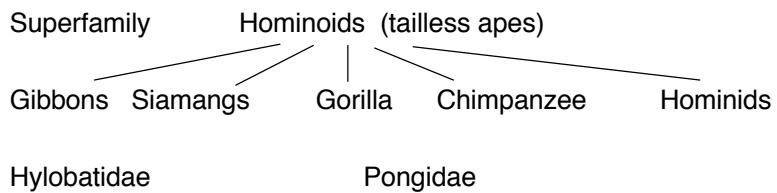
Few anatomical specializations

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.

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

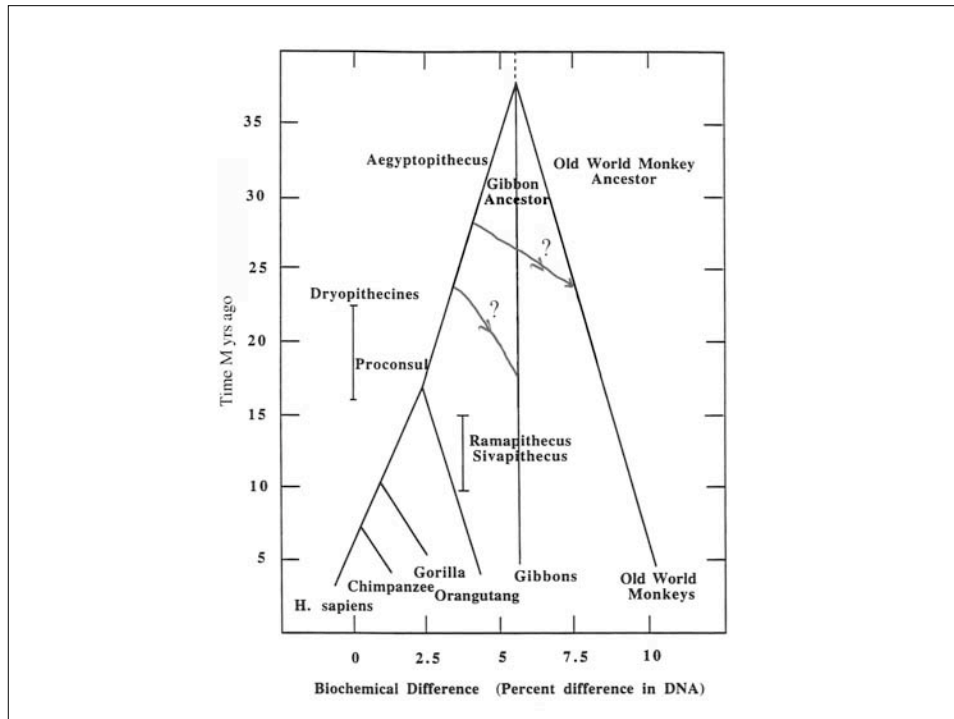
Eocene transition to oligocene ~ 37 Myr ago
cooler, more grasslands

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



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

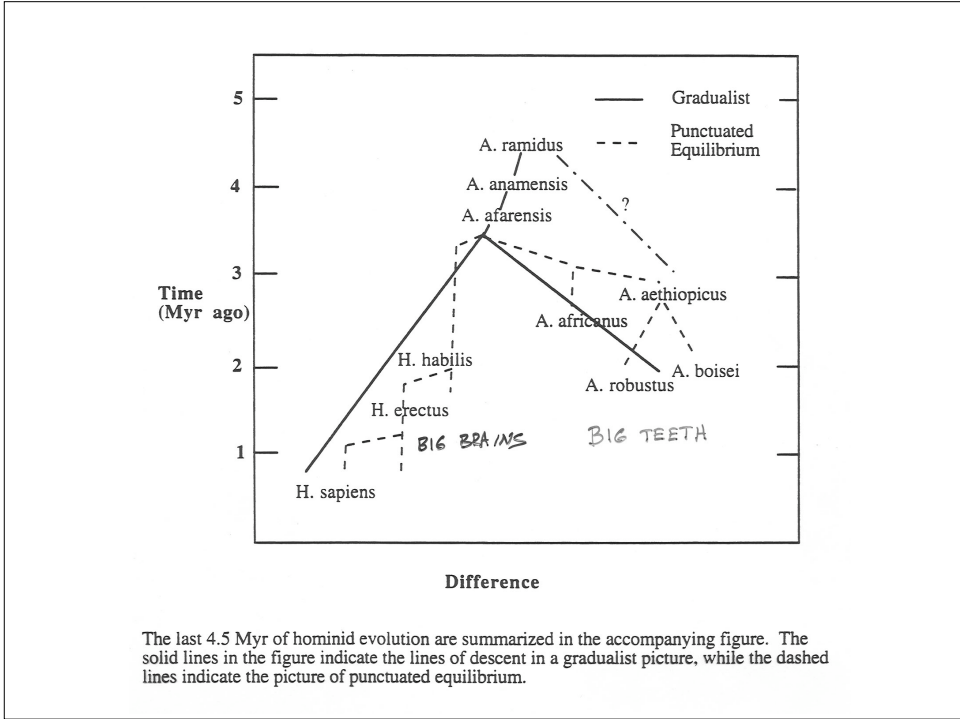
Earlier species show mosaic of human-ape traits

Upright walking preceded brain growth, tool making

May not have arisen on Savanna

Looks like “radiation”: many species arising

All but one extinct now



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, hominids more than 4.0 million years old were essentially unknown, and the oldest specimens all came from East Africa. In 2002 paleontologists working in Kenya's Lugen Hills and Ethiopia's Middle Awash region announced that they had discovered hominids dating back to nearly 5.0 million years ago (*Orrorin tugenensis* and *Ardipithecus kadabba*, respectively). Then, last July, University of Poitiers

paleontologist Michel Brunet and his Franco-Chadian Paleoneurologist Mischa Lepland 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 that time window," Brunet remarks. "We are proud to be the pioneers of the West."

Ardipithecus ramidus skeleton from Middle Awash, Ethiopia

Orrorin tugenensis from Lugen Hills, Kenya

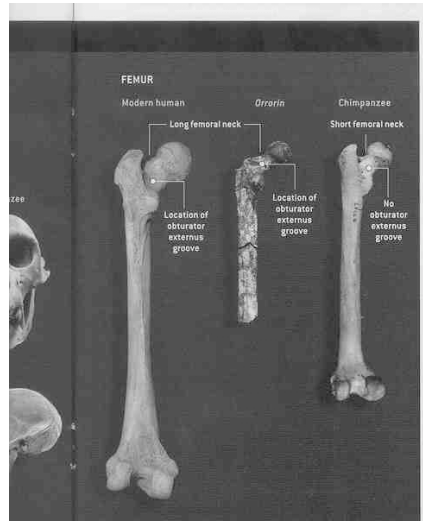
Sahelanthropus tchadensis from Toros-Menalla, Chad

Kenyanthropus from Lugen Hills, Kenya

Orrorin tugenensis from Lugen Hills, Kenya

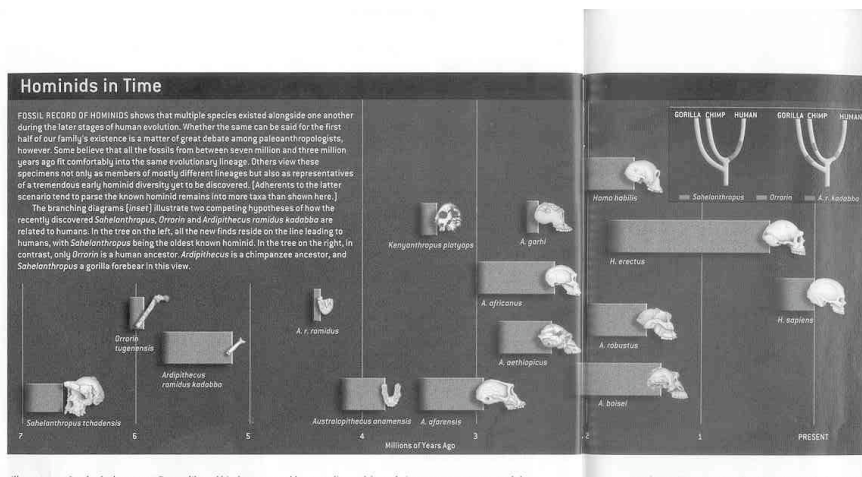
Scientific American
Jan. 2003

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

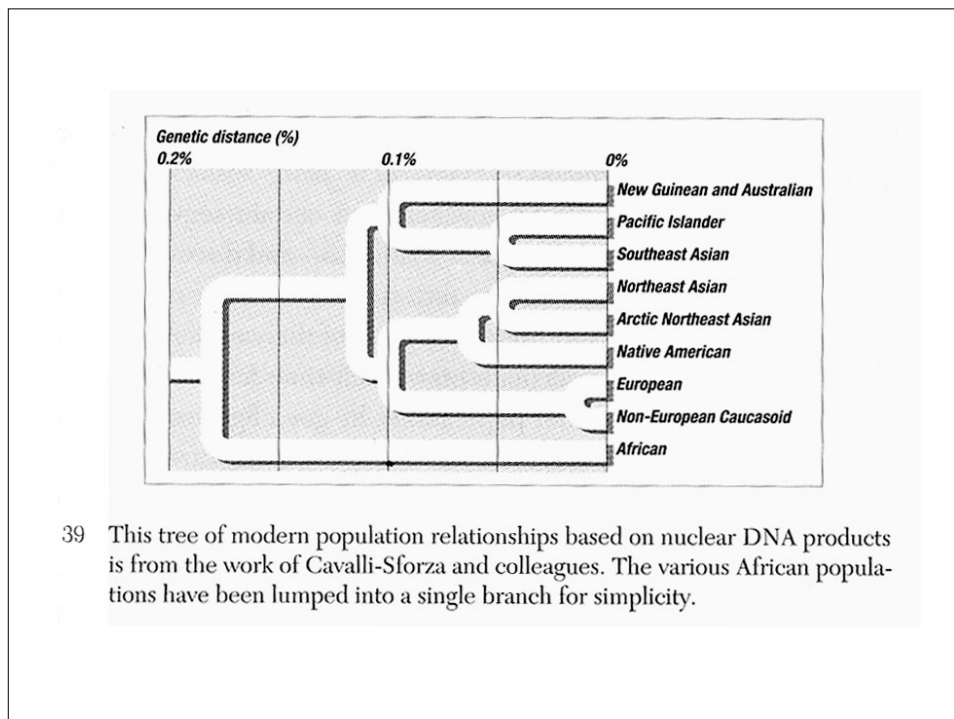
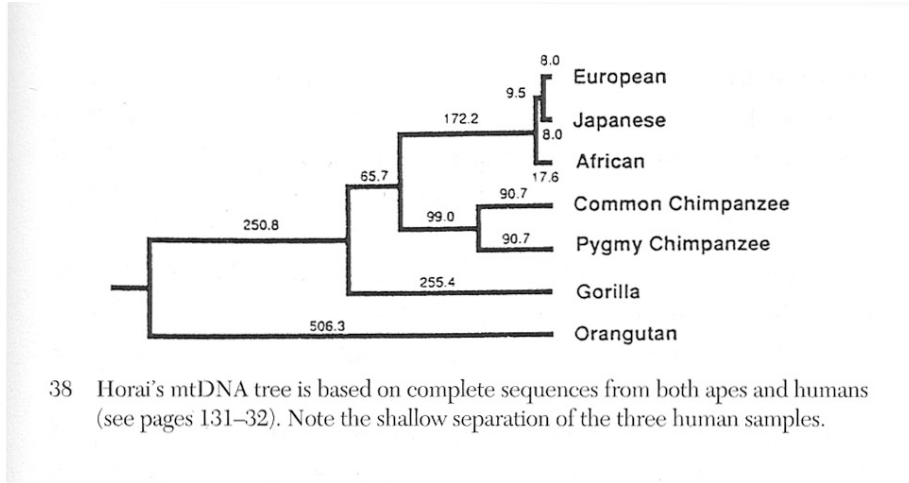
Genetic: humans are **very** homogeneous
greatest diversity is in Africa

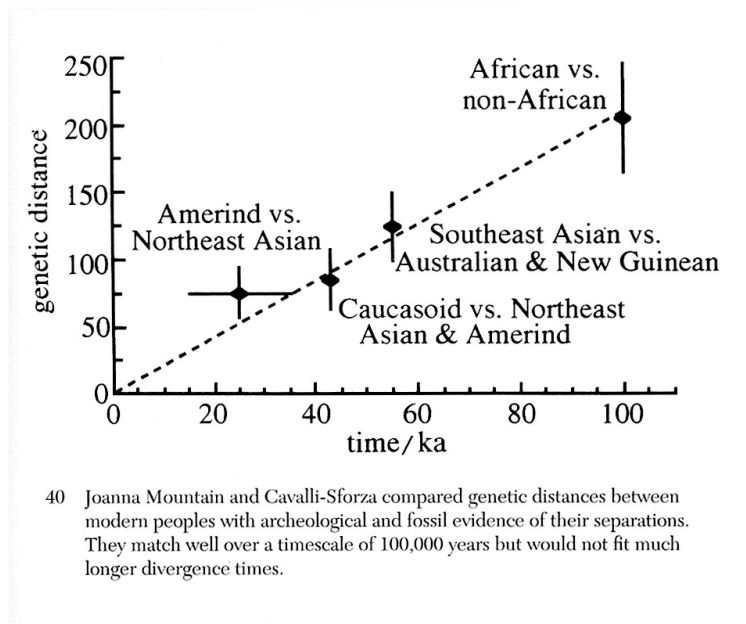
- Evolved in Africa, population bottleneck
a small group left Africa, spread over Earth

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*





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*

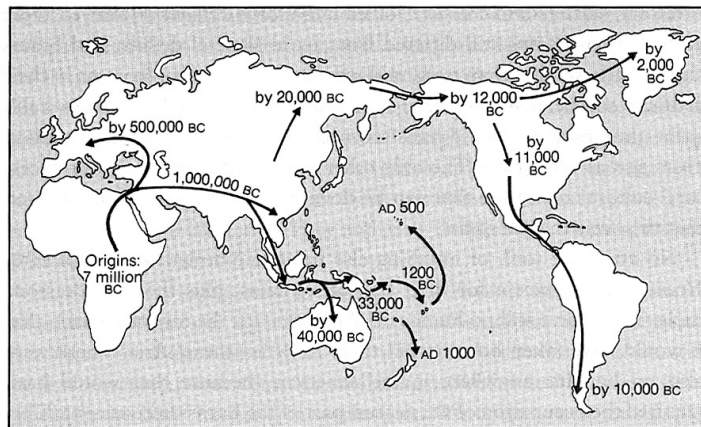
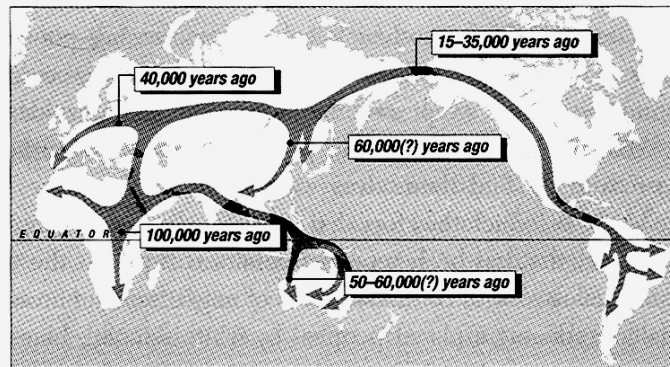


Figure 1.1. The spread of humans around the world.

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 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)

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 one are suspect