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

A taco or a chalupa? I can't decide.
The smarter Paramecium

Paramecium  Wall  Bonk!!

I'll try this way
But not THAT smart...

Paramecium trap

I'll try this way, etc., etc., ...
Information as Measure of Intelligence

Evolution of intelligence $\sim$ 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

<table>
<thead>
<tr>
<th>Unit</th>
<th># of Bits</th>
<th># of Pages</th>
<th># of Books</th>
<th>Notes</th>
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<tbody>
<tr>
<td>1 base</td>
<td>2</td>
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<td></td>
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<tr>
<td>1 codon</td>
<td>6</td>
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<tr>
<td>Virus</td>
<td>(~10^3)</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Bacterium</td>
<td>(10^6)</td>
<td>1000</td>
<td>1000</td>
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<td>Amoeba</td>
<td>(5 \times 10^8)</td>
<td></td>
<td>500</td>
<td>small library</td>
</tr>
<tr>
<td>H. Sapiens*</td>
<td>(6 \times 10^9)</td>
<td></td>
<td></td>
<td>(~2% \text{ codes for proteins})</td>
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</tbody>
</table>

* \(~2\% \text{ codes for proteins}\)

\[ \text{\textbullet \ 1.2 \times 10^8 \text{ bits}} \]
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 $10^9$ 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 Albers, 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

<table>
<thead>
<tr>
<th>Organism</th>
<th>Error Rate</th>
<th># of Bits</th>
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<tr>
<td>Virus</td>
<td>$10^{-3}$</td>
<td>$10^4$</td>
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<td>Bacterium</td>
<td>$10^{-6}$</td>
<td>$10^6 - 10^7$</td>
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<tr>
<td>Eukaryotes</td>
<td>$10^{-9} - 10^{-8}$</td>
<td>$10^8 - 10^{10}$</td>
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</table>

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

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 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.
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

Suborders:
- prosimians
  - lorises
  - tarsiers
- anthropoids
  - lemurs
  - monkeys
    - new world
    - old world
  - hominoids
There are alternative schemes

Superfamily

Hominoids (tailless apes)

Gibbons  Siamangs  Gorilla  Chimpanzee  Hominids

Hylobatidae  Pongidae
“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.
<table>
<thead>
<tr>
<th>Era</th>
<th>Period</th>
<th>Epoch</th>
<th>Time at beginning (Myr ago)</th>
<th>Events, Fossils of Note</th>
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<tbody>
<tr>
<td>Cenozoic</td>
<td>Quaternary</td>
<td>Recent</td>
<td>5000 yrs</td>
<td>Historical Records, Homo sapiens, Homo erectus</td>
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<td>1.8–2.5</td>
<td>Homo habilis</td>
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<td>Australopithecus, Ardipithecus</td>
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<td>Sahelanthropus, Gap</td>
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<td>6–7</td>
<td>Ramapithecus, Dryopithecine Apes</td>
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<td>23–26</td>
<td>Gap</td>
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<td>37–38</td>
<td>Aegyptopithecus</td>
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<td>54</td>
<td>Tarsiers</td>
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<td>Eocene</td>
<td>65</td>
<td>Lemurs, Tree Shrews - Primates</td>
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<td>Paleocene</td>
<td>65</td>
<td>Proliferation of Mammals, Origin of Many Orders</td>
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<tr>
<td>Mesozoic</td>
<td>Cretaceous</td>
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</table>
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
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 paleoanthropologists working in Kenya's Tugen Hills and Ethiopia's Hadar region announced that they had discovered hominids dating back to nearly six million years ago (Ds. in Desebido and Dikika, respectively). Then, in 2003, University of Pittsburgh paleoanthropologist Michel Brunet and his Franco-Chadian Palaeoanthropologic Mission reported finding unearthed a nearly seven-million-year-old hominid, called Sahelanthropus tchadensis, an in-line relative to Oreopithecus, 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 recognize this complexity," Brunet remarks. "We are proud to be the pioneers of the West."

Scientific American
Jan. 2003
Comparison of Femurs

Femur adapted to bipedality already by 6 Myr ago
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 this 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. (Advances in the latter scenario tend to pare the known hominid remains into more taxa than shown here.)

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

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. The 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.
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.
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.
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”
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…
- 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 one are suspect