5 November
2019

EVOLUTION OF LIFE ON EARTH, SENSES AND NEURONS, & INTELLIGENCE

Exam #2 on Thursday in class
Review session tomorrow

1

Exam #2

1 hr 15 min in-class exam, open book and open notes

- Things you should DEFINITELY bring with you:
  - Writing utensil (pencil or pen – blue or black ink)
  - Calculator
- Things you should PROBABLY bring with you:
  - Lecture notes
  - Laptop or tablet (so that you can access the WeBWorK homework problems)

REVIEW SESSION – tomorrow (Wednesday) at 7:45pm in B&L 203H

2

Evolution of life on Earth, Senses and neurons, & Intelligence

The accurate measurement of ages through Earth's history

Phylogeny

The fossil record and the increasing diversity of life: biological evolution

Information, DNA, and phylogeny

On the way to the Cambrian explosion: evolution of senses and neurons

Information, neurons, and phylogeny: setting the table for intelligence

Pre-intelligence summary of facts and theories of biological evolution: Darwin wins

The evolution of intelligence on Earth, aided by happenstance of geology

Meet the hominins

Brains, diet, and toolmaking: going where natural selection fears to tread

4

4

The dating of sedimentary-rock strata

Currently, we have a good way of measuring the ages of

- Igneous rock of just about any age
- Corpses of plants and animals that died within the last 60,000 years.

Unfortunately, fossils are

- not organic: their material has been replaced by inorganic material. So, ^{14}C dating would not work, even if it could reach very old.
- only found in sedimentary rocks. Sedimentary rocks are made of granules of other sorts of rock whose solidification ages bear no natural resemblance to one another.

5

The dating of sedimentary-rock strata

Fortunately, the Earth is volcanic, and there are sheets of sedimentary rock hundreds of miles across that have been horizontal since formation on ancient ocean floors.

- Sedimentary strata are overlain and underlain with igneous rocks whose ages can be measured by radioisotope means (most frequently K-Ar or K-Ca).
- Sediments build from the bottom up, so older sediments were buried by newer ones and now lie at a lower elevation or greater depth. Paleontologists call this the **principle of superposition**.
- Fossil ages can therefore be measured with a few-percent accuracy, and we can construct the **fossil record**: the census of living things through the last few Gyr.

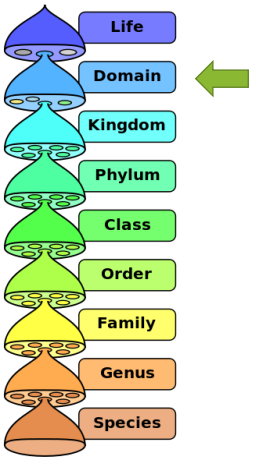
6

The structure of fossils and life forms: phylogeny

To go with our accurate measures of time, we characterize the structure and, nowadays, the **genetic content**, of organisms.

This study is called **phylogeny** and was invented by Carl Linnaeus in the early 1700s.

The broadest classification is the **domain**. It is based on the distinction between cells that have organelles like nuclei, mitochondria, etc. (**eukaryotes**) and those that do not (**prokaryotes**, divided into **eubacteria** and **archaea**).



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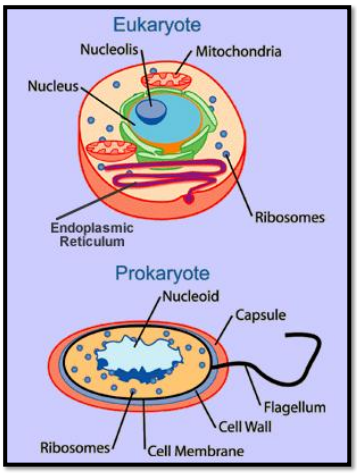
The structure of fossils and life forms: phylogeny

Archaea were first identified among the extremophiles; later, they were found genetically to be much different from eubacteria in their ribosomal RNA. (They still have essentially the same genetic code as other Earthly organisms, though.)

Evolutionary sequence of archaea → eubacteria → eukaryotes seems clear:

- Complexity and diversity increase in this direction
- Some organelles, particularly mitochondria and plastids, look like prokaryotes that assimilated into the structure of eukaryotes



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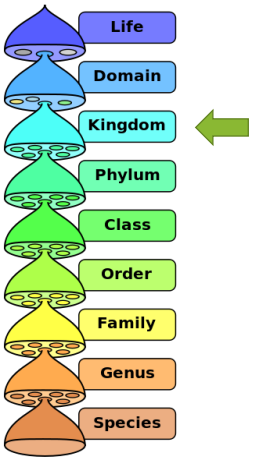
The structure of fossils and life forms: phylogeny

So far, all types can either manufacture their own nutrients out of monomers in the environment (**autotrophs**, the forerunners of plants) or need to eat processed nutrients or other life forms (**heterotrophs**).

The eukaryotes are the most diverse and are thus further sorted into **kingdoms**:

- **Animalia**: multicellular heterotrophs
- **Plantae**: multicellular autotrophs
- **Fungi**: multicellular symbionts
- **Protista**: unicellular eukaryotes



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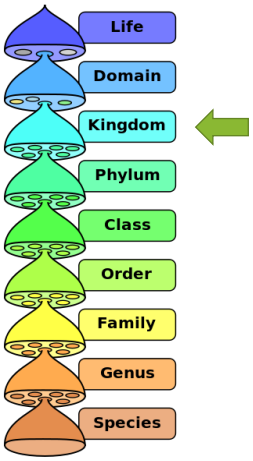
The structure of fossils and life forms: phylogeny

Within kingdoms comes an internal, genetic differentiation: **ploidy**, the number of copies of the nucleic-acid structures each cell contains.

- **Genes**: nucleic acid sequences that code proteins
- **Chromosomes**: structures containing genes
- **Haploids**: Life forms (permanently) containing only one copy of each chromosome
- **Diploids**: Life forms containing two copies of each chromosome. We are diploids.

Importance: this leads to a non-mutation means of having reproduction lead to greater diversity of each multi-ploid life form. We call this, of course, **sexual reproduction**.



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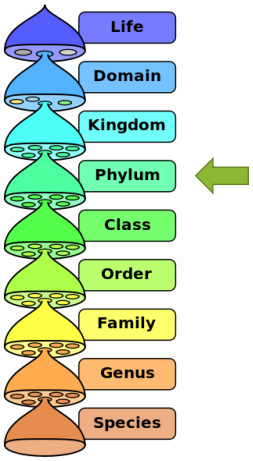
The structure of fossils and life forms: phylogeny

Each kingdom is further sorted into **phyla**.

- For example, the kingdom animalia is divided into 35 different phyla.
- We belong to the phylum chordata, those animals with spinal chords (though not necessarily spines).
- Plants are usually divided into 11 phyla, fungi into 6.
- Phyla first appeared 550 Myr ago: in the Cambrian Explosion, of which the Burgess Shale provides the most examples.



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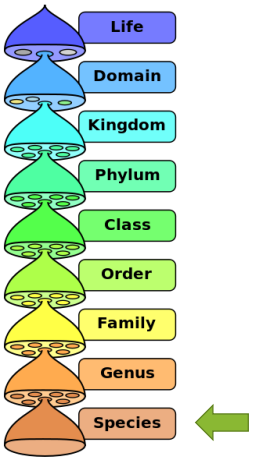
The structure of fossils and life forms: phylogeny

And so on, down to genus and species.
Examples:

Human	Giant sequoia redwood
Eukarya	Eukarya
Animalia	Plantae
Chordata	Pinophyta
Mammalia	Pinopsida
Primatae	Pinales
Hominidae	Cupressaceae
Homo	Sequoiadendron
sapiens	giganteum



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The fossil record

Myr ago	Era	Fossil group	Event
Now	Cenozoic		
	Mesozoic		
		Burgess Shale	
	Paleozoic		Macroscopic life
		Ediacara	
			Snowball Earth
	Precambrian		
1000		Bitter Springs	Worm tracks (?)
			Multicellular algae
		Beck Spring Dolomite	
			Eukaryotes certain
		McArthur Group	Sexual reproduction (?)
2000		Gunflint chert	Eukaryotes possible
	Proterozoic		Oxygen-rich atmosphere
			Snowball Earth
			Formation of continents
3000		Bulawayan	
		Fig Tree	
		Onverwacht	
		Warrawoona	Autotrophs-Stromatolites
	Archean		Life begins (?)
			(Prokaryote heterotrophs)
4000			Formation of oceans
			Bombardment decreases
			Frequent impacts
	Hadean		Formation of Earth
5000			

13

Myr ago	Era	Fossil group	Event
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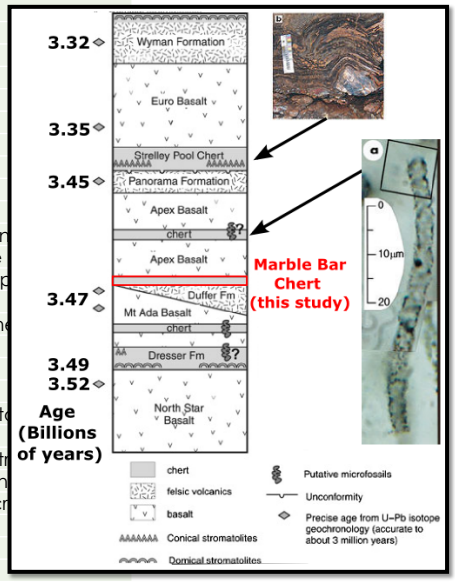

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Myr ago	Era	Fossil group	Event
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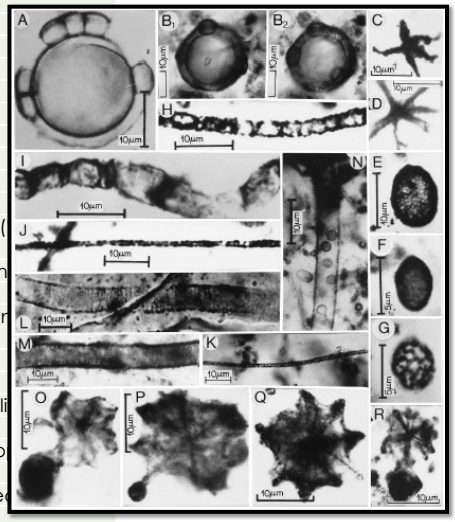

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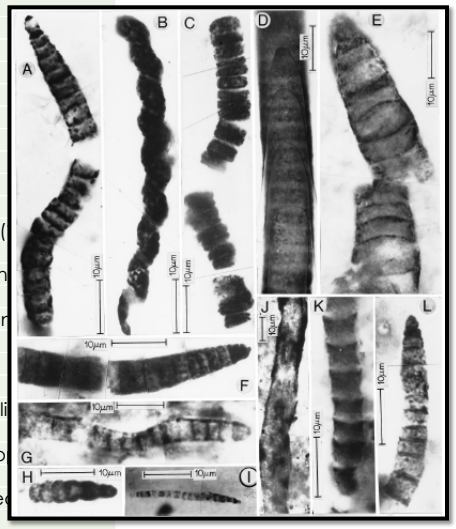

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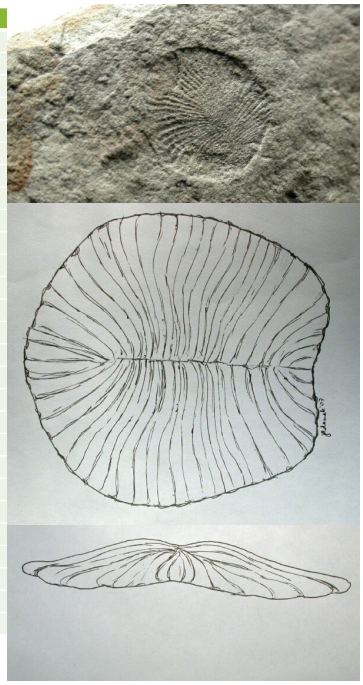

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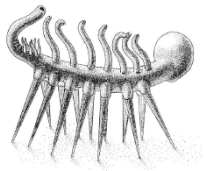
18

The fossil record 0-800 Myr ago: the Cambrian Explosion and its descendants

Era	Period	Myr ago	Life forms	Events
Cenozoic	Quaternary	2	H. sapiens	Ice ages
	Tertiary	65	Primates	Extinction of dinosaurs
Mesozoic	Cretaceous	136	Birds	South Atlantic open to 1900 miles
	Jurassic	190		North Atlantic open to 600 miles
	Triassic	225	Mammals	Continental drift
Paleozoic	Permian	280	Reptiles	Pangaea breaks up
	Carboniferous	345	Amphibians	Formation of coal
	Devonian	395	Insects	
	Silurian	430	Land plants	
	Ordovician	500	Fish (Chordata)	Burgess Shale forms
	Cambrian	543	Trilobites	
Precambrian		545	Small shelly fossils	*Appearance of phyla*
		580	Ediacarans	
		600-680		Snowball Earth episodes
		0		
			Multicellular life	



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The fossil record 0-800 Myr ago: the Cambrian Explosion and its descendants

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	Silurian	430	Land plants	
	Ordovician	500	Fish (Chordata)	Burgess Shale forms
	Cambrian	543	Trilobites	*First good example of classes*
Precambrian		545	Small shelly fossils	
		580	Ediacarans	
		600-80		Snowball Earth episodes
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20

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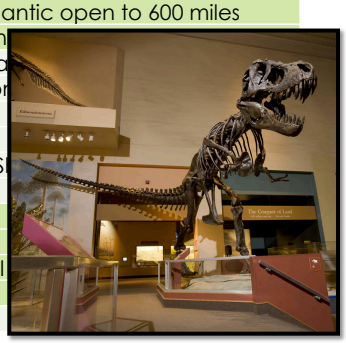

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Summary of fossil record

Cellular life has been around for at least 3 Gyr.

Simple organisms developed first, more complex ones later: prokaryotes, then eukaryotes, then multi-cells.

Deterministic "progress" of families is not observed:

- Many organisms develop and become extinct with no links to successors.
- Some families develop greater diversity, but many stay about the same complexity (e.g. bacteria).

General increase in complexity and diversity of life forms, though:

- Huge animal boom in the Cambrian Explosion.
- Plant boom in the last 150 Myr, driven by flowering plants and insect hosts.

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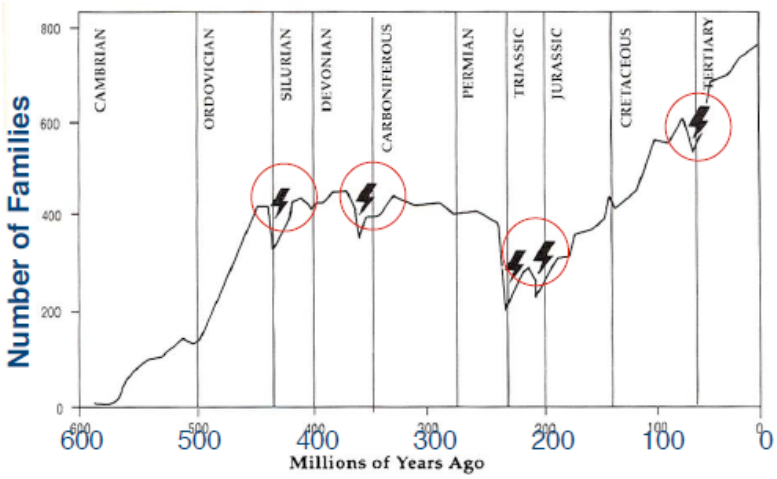
Major extinctions



Diversity rising

"Biological diversity has increased slowly over geological time, with occasional setbacks through mass global extinctions. There have been five such extinctions so far, indicated here by lightning flashes. The data given are for families (groups of related species) of marine organisms. A sixth major decline is now underway as a result of human activity." - E.O. Wilson, *The Diversity of Life*

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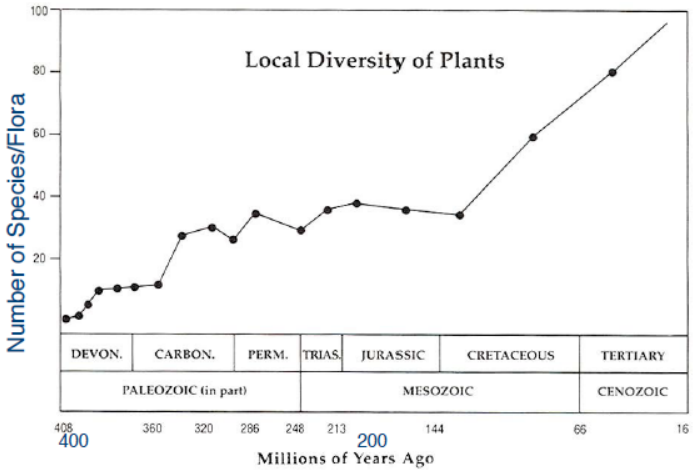

Local diversity of plants

"The average number of plant species found in local floras has risen steadily since the invasion by plants 400 million years ago. The increase reflects a growing complexity in terrestrial ecosystems around the world." - E.O. Wilson, *The Diversity of Life*

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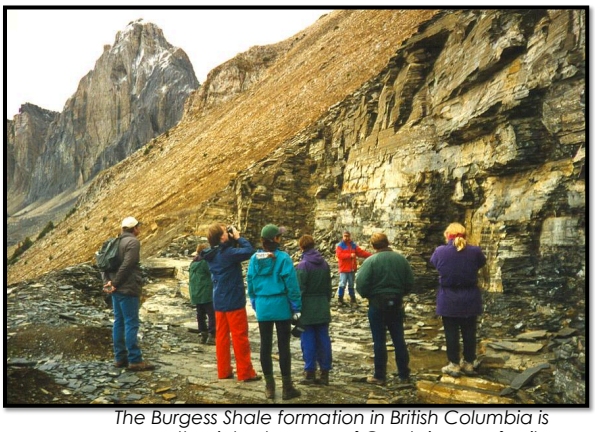
Biological evolution

Features of the fossil record:

- Change of Earth's population with time over billions of years
- Development of greater structural complexity and diversity of fossils as time goes on
- Clear developmental patterns among species within many families as time goes on

These features are all experimental facts. Thus, **biological evolution is also an experimental fact** to go with all the other cosmic evolutions we have found so far.



The Burgess Shale formation in British Columbia is the richest source of Cambrian-era fossils.

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Information, DNA, and phylogeny

The modern ability to determine the sequence of nucleotides in complete **genomes** has added a lot to the classification.

Genetic complexity grows with structural complexity: eubacteria have $\sim 10^3$ genes, single-cell eukaryotes $10^4 - 10^5$.

All organisms possess a lot of non-coding, or **junk**, DNA: stretches of nucleic acid that do not lead to proteins.

Useful to evolutionary biologists:

- Mutations in junk DNA do not affect the organism, allowing us to study the mutation rate separately from the fate of the species.
- In turn, this has allowed estimates of the time scale of DNA evolution.

27

Three fossils of the same species are found. Two have accurate geological ages of 2.0 and 3.0 Myr and differ in junk DNA along a certain stretch by 20 base pairs. The third was found in a 100 Myr-old geological context and differs by 5 base pairs from the older of the first two. How old is the third fossil?

Question!

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Why do you suppose that there is such a big difference in the ages of the geological context among these fossils?

Question!

A. The third one was found in a cave.
B. The third one was found in an ancient lake bed among nothing but sedimentary rock.
C. The third one was found in the ice in Antarctica.
D. The third one was found in a carbonaceous chondrite meteorite.
E. K-Ar dating accuracy is not any better than 100 Myr.

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Question!

Why would this age-dating scheme not work if the base-pair difference were found in non-junk DNA?

A. The fossils would probably be of different species if non-junk DNA differ by this many base pairs.
B. Non-junk DNA never changes.
C. It would still be in disagreement with the geological ages.

30

Information, DNA, and phylogeny

The total information content – the length of DNA – does not connote complexity.

Junk usually dominates the genome!

Unit	Bits	Pages	Books
Base pair	2		
Codon	6		
Virus	10^3	1	
(Eu-) bacterium	10^6	1000	1
Single-cell eukaryote	5×10^8		500
Human	6.4×10^9		6400
Newt	10^{11}		100,000

Only 128 non-junk (2%)

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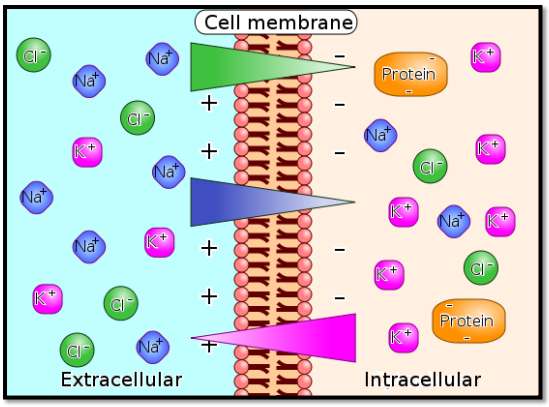
On the way to the Cambrian explosion: evolution of senses and neurons

The fifth part of our provisional definition of life is

- [Living things] exhibit **sensitivity**: they respond to changes in their environment.

Sensation indicates the beginning of neural activity.

- As discussed a couple of weeks ago, cell membranes are made of **polarized** lipid bilayers: the negatively-charged ends of these zwitterions always lie toward the cell's interior, and the positive charges toward the cell's exterior.



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On the way to the Cambrian explosion: evolution of senses and neurons

As a result, there is an **electric voltage** across the membrane, albeit a small one.

This is a result of natural selection: other arrangements of "containers" do not retain the proteins and nucleic acids or allow the transmission of ions and monomers from the outside.

But it has other uses, too, as the **polarization allows the membrane to be distorted or modified by other electrical impulses**. For example,

- Impulses specific to certain large molecules, like nutrients that would save the cell from having to make such molecules
- Impulses passed on from cell to cell in a multicell organism: transmission of **signals** in a rather familiar modern fashion.

This would be very different in life that developed in non-polar solvents!

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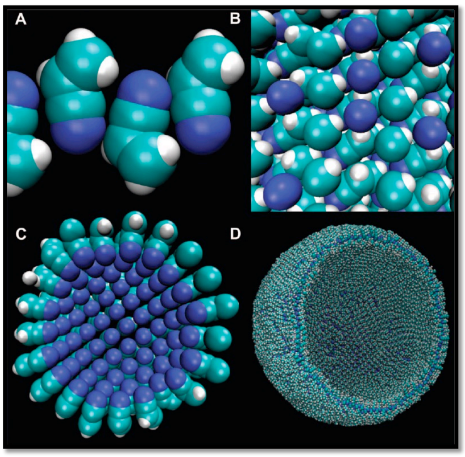
Evolution of senses and neurons with non-polar solvents

In the liquid-methane azotosome models of membranes which we previously discussed, the polar molecules in the membrane line up + to −.

This promotes the passage through the membrane of nonpolar molecules…

…but leaves essentially **zero voltage** across the membrane. So multicellular life in Titan's hydrocarbon lakes would have to have a completely different means of transmitting and receiving sensory signals.



Stevenson, Lunine, & Clancy (2015)

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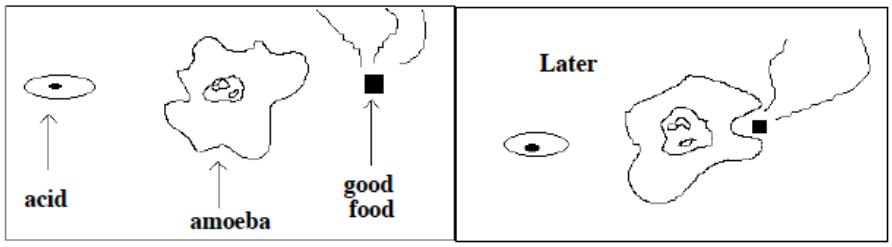
Evolution of senses and neurons

If a certain cell-membrane configuration…

- Which, of course, is coded in the DNA

…is electrically conducive to beneficial electrical distortion that makes it easier for organisms to survive or reproduce, the population of these organisms will dramatically increase. Another example of natural selection.



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Evolution of senses and neurons

Simple example: jellyfish, in which membrane-mediated electrical transmission among the cells around the edges synchronize the movement of these cells, help propel the organism through the water and thereby make more food accessible.

Jellyfish have no brain or memory: this simple nervous system is **autonomic**. Cut a jellyfish in half and the halves will still "swim" in the same fashion.

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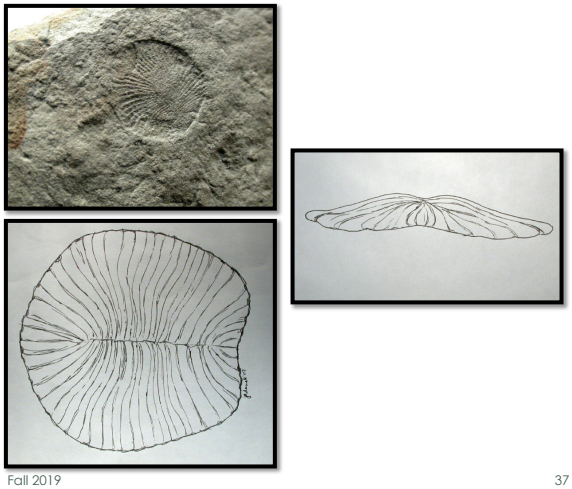
Evolution of senses and neurons

Before the Cambrian Explosion, no organism in the fossil record was any more complex than a jellyfish.

- Like the "Ediacara" organisms of 900–600 Myr ago.

The Cambrian Explosion gave rise to organisms with structures that, in modern organisms, do not correspond to autonomous functions.

The difference is the presence of cells that **store** electrical impulses and can therefore transmit that **memory** among the cells.



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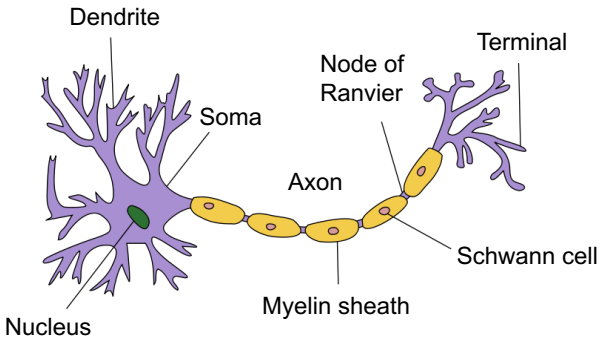
Evolution of senses and neurons

These new, specialized cells remember previous sensations and can compare them (by adding or subtracting voltages) to current sensations. Nowadays, we call them **neurons**. Their advent **apparently coincides with the Cambrian Explosion**.



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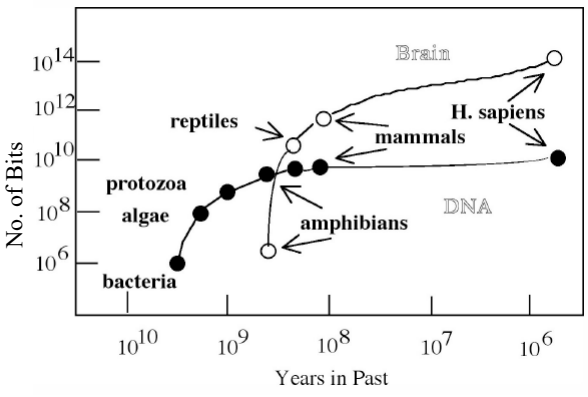
Information, neurons, and phylogeny

Once neurons exist, memory and commanding is possible and would clearly give a species a high propensity to reproduce, survive, and, if necessary, compete for scarce resources.

As it is beneficial, the trait of having increasingly larger memory and commanding capacity will continue to be selected naturally until the memory capacity of neurons far outstrips the storage capacity inherent in the nucleic acids.

The structure of neurons is (still) encoded in the nucleic acids. The nucleic acids serve the same purpose as the boot ROM and BIOS in your computer; the neurons the same purpose as the RAM and hard disk.



Plot of information capacity of DNA in filled circles – including junk – and of nervous system in open circles.

39

Information, neurons, and phylogeny

Information stored in DNA, though it contains the instructions for building a new copy of the organism and may even account for instinctive reactions to stimuli, cannot tell the entire story.

To learn, a life form must have a non-genetic way of storing information, thus to record the unique and random experiences of the individual.

This, of course, is the function of the nervous system in higher animals, exemplified by our brain.

The ultimate product is **intelligence**.

Intelligence can change the rules of evolution when it reaches a certain stage, as there are aspects of intelligence that can be passed to progeny.

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Our observations for the first 13.2 Gyr

1. Evolution of the atomic composition of the Universe and the Galaxy, by explosive and stellar-core nucleosynthesis, producing the relative abundances of the elements
2. Evolution of the structure and lifetimes of stars and their planetary systems
3. Evolution of the molecular composition of the interstellar medium, resulting in prebiotic molecules on habitable planets
4. Evolution of primitive life – RNA World – from prebiotics (speculation, but with strong theoretical and experimental support)
5. Evolution of complex cellular life from primitive life
6. Evolution of organisms from complex cellular life

The first five Evolutions are explained by means which we would not hesitate to call **natural selection**. How about the sixth?

41

Theories of the origin of species

An origin of species in evolution was first suspected in the 1700s, after Linnaean phylogeny had become widespread.

There have been fewer basic scientific theories of the origin of species than you might think. Only two, really:

- **Evolution by adaptation**. Individuals acquire characteristics that help them cope with environment, pass these acquired characteristics on to their progeny.
- **Evolution by natural selection**. A population develops a diversity of traits by a combination of mutation and sexual reproduction. Those traits which are better matched to the environment or its changes will help those with the traits to survive or reproduce, and eventually those traits become the new norm.

Guided evolution **Unguided evolution**

42

Guided evolution

Jean-Baptiste Lamarck (France, 1744–1829) is the leading figure in evolution by adaptation.

- Circumstances force individuals to adapt: to lose characteristics they do not need and to develop useful ones.
- Individuals that succeed have adapted well to the conditions – climate, food supply, etc. – with which they are faced.
- Beneficial adaptations are thereafter inherited: "better" species descend from these individuals.

Today, it is easiest to refute this theory by noting that individuals cannot adapt their DNA, and DNA governs inheritance, but other objections are not difficult to find.

43

True or false: Extinction would represent a failure of Larmarck's theory.

Question!

44

True or false: Modern organisms and the fossil record indicate that more complex, intelligent organisms are more likely to survive.

Question!

45

Unguided evolution

According to Charles **Darwin** (1809 – 1882) and Alfred **Wallace** (1823 – 1923), evolution proceeds by natural selection, as follows:

- There are random, inborn variations among individual life forms of a given type or species. Mutation or sexual reproduction can produce such variations.
- Such inborn variations can (obviously) be inherited.

Today, mutation is understood as either DNA transcription errors or external modification of DNA (e.g. by high-energy radiation).

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Unguided evolution

Most of these variations are neutral or harmful, but occasionally a variation is beneficial, suiting the individual better to its circumstances.

If a beneficial variation makes it easier for an individual to survive or reproduce, the variation will appear in large numbers in a short time compared to the geological timescale.

- Thus *populations* evolve; individuals *develop*.
- Small variations could produce gradual evolution and differentiation of species; even "small" and "gradual" can be geologically fast, and a new species can appear suddenly in the fossil record.

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Unguided evolution

Additional nuances: whether there are chronologies known accurately enough to rule out such **gradualism** is occasionally tested but has not yet succeeded:

- Saltationism (e.g. Thomas Hunt Morgan): substantial mutation leading to a new species in a single generation. Popular in the early 20th century, this is now ruled out by more recent chronology.
- Punctuated equilibrium (e.g. Stephen Jay Gould): environmental pressures on *part* of the population of a species will lead to more rapid selection and development of new species, while the rest of the population is in stasis. This is still under discussion, but it is not that different from gradualism.

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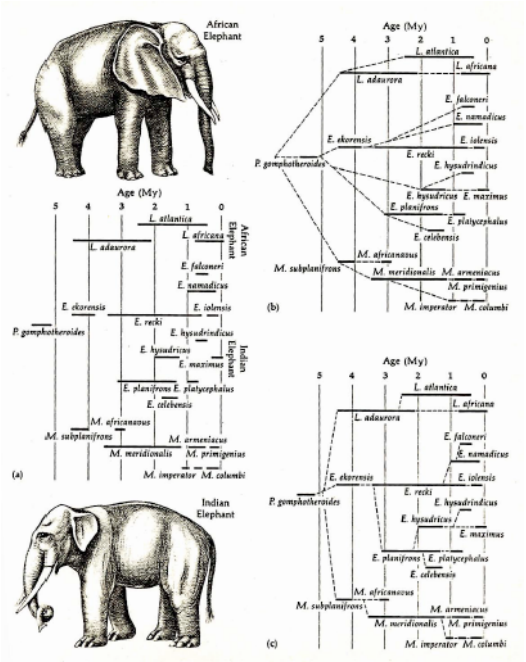

Gradualism v. punctuated equilibrium

Fossil record of elephants, interpreted as gradualism (upper) or punctuated equilibrium (lower). From Gould, *Wonderful Life*.

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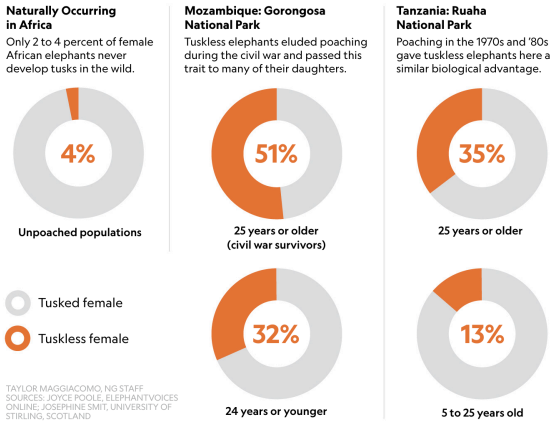
Forced evolution

The process of natural selection can also be affected by a species' habitat.

- A recent study found there are more tuskless elephants in Mozambique than is typical. It has been surmised that the hunting of these creatures for their ivory has preferentially "selected" those without tusks to have a higher survival rate.
- Biologists are unsure what affect this will have on this and other species, since tusks are used to dig for water, debark trees for food, and compete for mates.



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Evolution by natural selection

The theory of evolution by natural selection has been very successful and has, in particular, stood up remarkably well against the findings of molecular biology and genetics.

Consistent with many experiments based on artificial selection (breeding), as Darwin noted.

Seems a natural successor to RNA World, which is the most consistent explanation of the emergence of biomolecules and in which natural selection functions.

Consistent with genetics, including mutation timescales measured from junk-DNA variation.

Consistent with the existence of junk DNA and gene duplication in different species. Other, more "guided" theories of evolution (and creation) are not.

51

True or false: extinction represents a weak point for Darwin's theory, one that the theory does not well explain.

Question!

52

Darwin's view of natural selection is often described as "survival of the fittest" – see the cover of *Origin*. Is this an accurate summary of natural selection?

Question!

A. Yes, as there is always competition for resources.
B. Maybe: introduction of species from harsh environments to hospitable environments usually results in predominance of those species.
C. No. Natural selection works the same no matter what the abundance of resources, as better-suited species would still reproduce more copiously than poorer-suited ones.

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Development of brains & intelligence

Recall that a multi-cell organism cannot reliably modify its DNA in a prescribed fashion in response to neural impulses within every cell.

Therefore, the evolution of neural capacity still has to be facilitated by

- Mutation or sexual reproduction
- The largest gene pool possible
- Natural selection

…and will therefore take a very long time to produce much in the way of capacity for **thinking**.

Fortunately, hundreds of Myrs were available.

Furthermore, the resources from which intelligence could develop were arranged in a rather lucky fashion as a result of plate tectonics.

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Plate tectonics

Even after Earth had cooled enough to permit a continuous solid crust, the mantle has remained either fluid or plastic.

This has permitted long **rifts** to form where the outer part of the mantle is warmest. From these rifts emerges molten rocky material, pushing the edges of the cracks apart at a rate of 1-10 cm per year.

In turn, this creates other cracks: the **plates** of crust material which propagate away from the rifts can break from the rest of the crust.

The far side of the plate from the rifts slides either over or under the neighboring plates.

Plates topped by lower-density rock, being more buoyant, float a bit higher above the mantle; these are **continents**.

The plates made from the rifts are higher-density rock which floats lower; today, these are the **ocean floors**.

55

Supercontinents

When one plate slides underneath (**subducts** beneath) another, its material melts and returns to the mantle.

There is friction in subduction, so the growing ocean plates push the other plates across the surface of the mantle (**tectonic** motion).

At several points in the geological record, particularly vigorous rifts have pushed all the continents into a single mass, called a **supercontinent**.

The first four supercontinents existed 3.1-2.8 Gyr, 2.7-2.5 Gyr, 1.9-1.4 Gyr, and 1.1-0.75 Gyr ago. All of these were barren: no land life had yet evolved.

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Question!

Should all terrestrial planets exhibit tectonic plate activity?

A. No. If they are too small ($\ll 1M_{\oplus}$), their interiors should cool off too fast to have the right sort of mantle.
B. Maybe. Radioactive heating could keep the mantles plastic forever.
C. Yes, which is why there is abundant evidence of volcanism and plate boundaries on Mars, Mercury, and the Moon ($M = 0.1 - 0.01M_{\oplus}$).

57

Concentration of the gene pool on land

The fifth supercontinent, which geologists call **Pangaea**, conveniently appeared about 300 Myr ago during the **Permian era**. This was about 100 Myr after land plants and insects appeared, and around the time that reptiles first appeared.

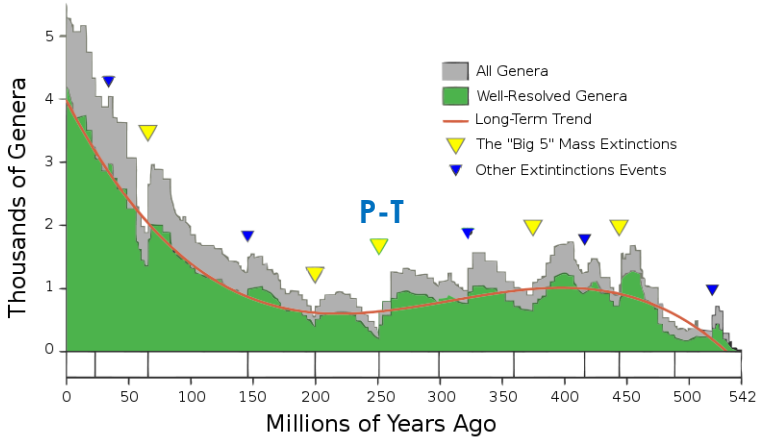
Unlike its immediate predecessors, it stretched nearly from pole to pole, most of it having tropical and temperate climates.

Therefore, all land life – the entire land gene pool – was connected 250 Myr ago.

58

Concentration of the gene pool on land

Then disaster struck – the **Permian-Triassic extinction** (252 Myr ago), during which close to 90% of all living beings died: 60% of all families, 80% of all genera, 96% of all marine species. (We will discuss possible causes for this later in the semester.)

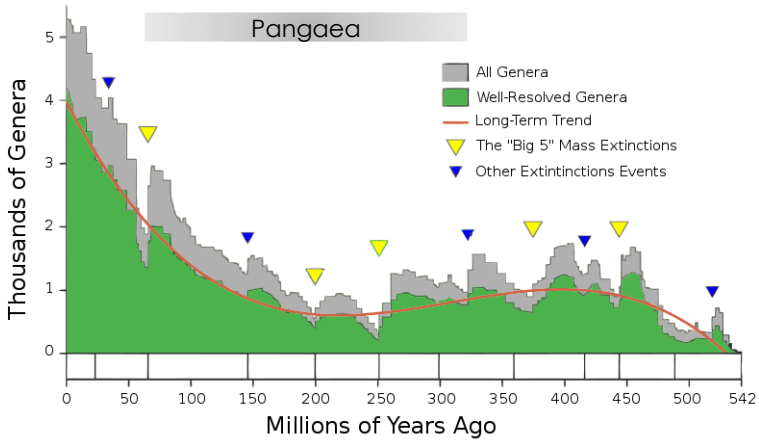


59

Concentration of the gene pool on land

But Pangaea was still connected and remained *largely* so for a long time: all of the land was accessible to all of the species, and the entire gene pool was involved in the recovery.

This promoted genetic diversity, and in particular the evolution of intelligence, much more rapidly than disconnected continents would have, despite two more mass extinctions 200 Myr and 65 Myr ago.



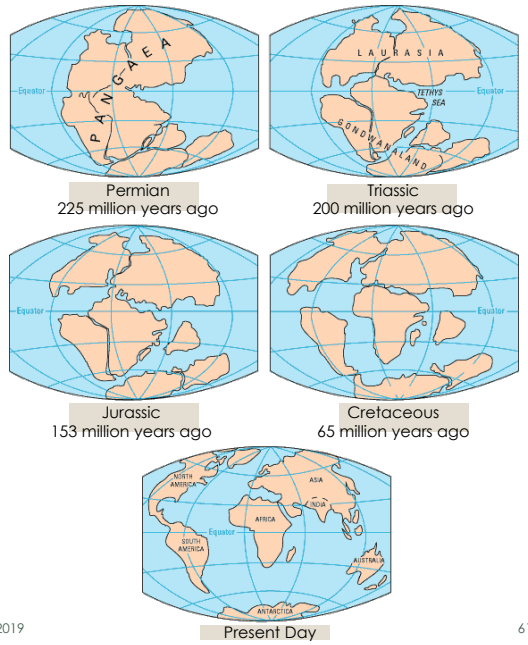
60

Intelligence

Consider mammals, which first appeared 225 Myr ago. By about 175 Myr ago, the most successful species were marsupials, which overspread Pangaea.

The edges of Pangaea began to break off about 160 Myr ago.

The first to go was a plate containing Antarctica, Australia, and India. The former two remain isolated and sparsely populated compared to the rest, and today, marsupials remain the most advanced native animals.



61

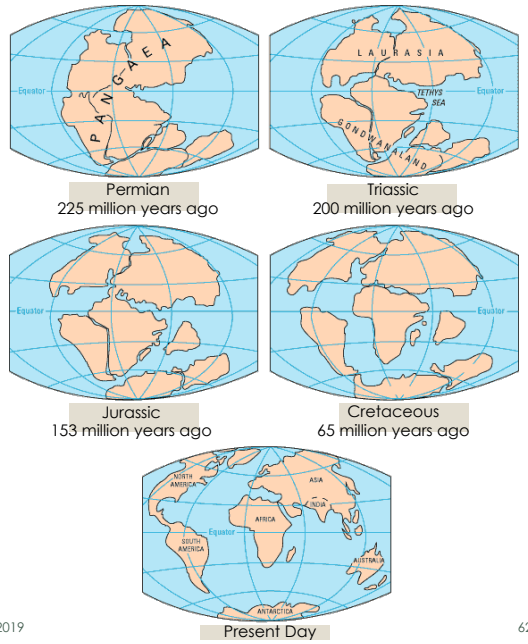
Intelligence

Over the next 50 Myr, placental mammals evolved from the still-large gene pool in the forested areas of Pangaea. The most advanced beings at this time were of the **primate** order: the **prosimian** family, led by the lemur.

Madagascar broke off 110 Myr ago, taking the lemurs along. Lemurs remain the most advanced animals there.

Next to go was South America, about 90 Myr ago.

By then, the lemurs had vanished from Pangaea proper and true **monkeys** existed, which in South America have subsequently evolved into marmosets and spider monkeys.



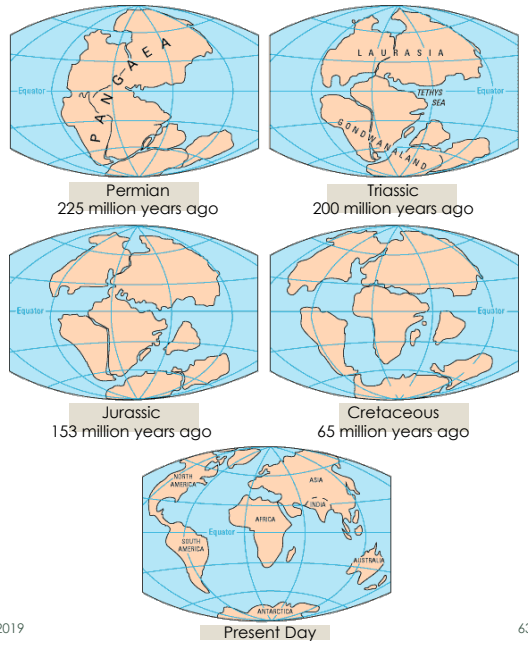
62

Intelligence

A much larger gene pool remained in Africa-Eurasia-North America.

By far, the densest collection of animals of all sorts – the bulk of the gene pool – was the forested, low-altitude parts of the remains of Pangaea, which in turn means Africa.

By about 50 Myr ago, the connections between Africa and the rest became flimsy, due to further rift formation and to periodic desertification of the northern part.



63

Question!

Why did the lemurs vanish in the remains of Pangaea after Madagascar broke off?

A. The population which includes lemurs gradually evolved into monkeys, as beneficial mutations were selected.
B. Monkeys evolved and either ate the lemurs or the resources the lemurs needed to survive.
C. We need to know how long they took to vanish before coming up with an explanation.

64

Intelligence

A few million years ago, the next set of rifts began to develop, splitting Arabia from Africa.

This crack, called the Great Rift, proceeds southwards from the Red Sea into the continent.

It splits around Lake Victoria; the rift itself is occupied by long, very deep lakes like Turkana, Tanganyika, and Nyasa.

65

Intelligence

The rift process also raised the land on either side of the crack to great heights. For example, the Ruwenzori range reaches 5100 m (16,800 ft).

This had a decisive influence on the climate east of the rift.

- Weather comes from the west in this part of the world.
- The new mountains caused most of the rain to fall to the west of their crest, leaving a rain shadow to their east.

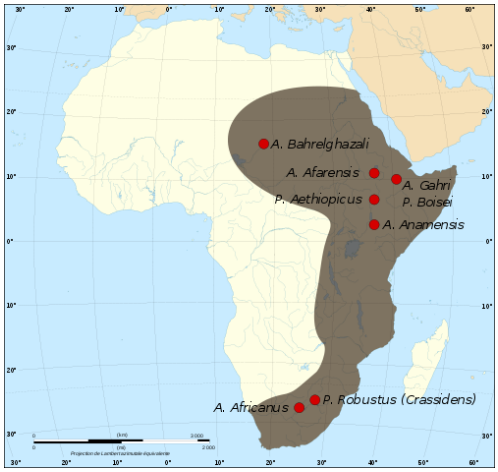
66

Intelligence

By this time, the most advanced animals – large brains, fingered limbs, opposable thumbs – were the **simian-family** tree dwellers of the extensive forests. These were the first of the **hominid** family.

Climate change took place on a time scale faster than the usual migration times, leaving a population of tree-dwellers with very few trees.

To go from tree to tree, it was necessary to cross grassland. The ones who survived were the ones who crossed the fastest, walking on two feet.



Hominid fossil finds

67

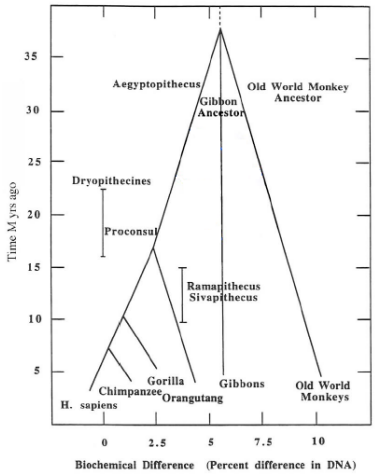
From monkeys to hominins

This left the hands free. Having larger brains, they soon developed other uses for hands.

This selection produced a new subfamily called **hominins**.

Once bipedal hominids (hominins) began to appear in newly-drier East Africa, many mutations were naturally selected which accelerated the differences between them and the apes.

- Distinct process from steady rate of increased difference in junk DNA.
- Most evident in parts of genes called **human accelerated regions** (HARs), of which 49 have been noted.



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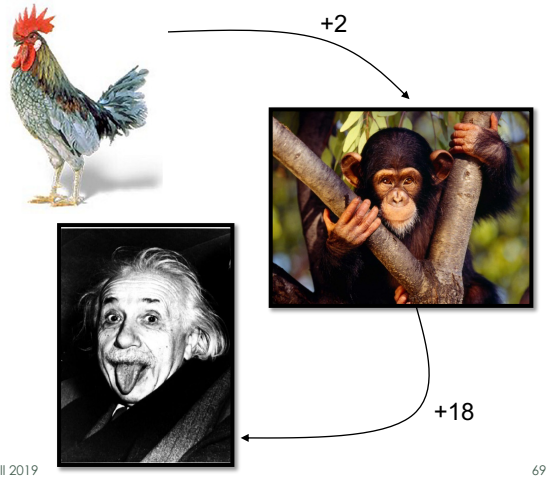
From monkeys to hominins

HARs were discovered in 2006 by Katie Pollard (UCSF) as one of the first huge achievements of the new science of **genomics**.

HAR1, chromosome 20 (non-junk!), for example:

- Present in reptiles onward
- Base-pair difference between chimpanzees and chickens: 2
- Base-pair difference between chimpanzees and humans: 18



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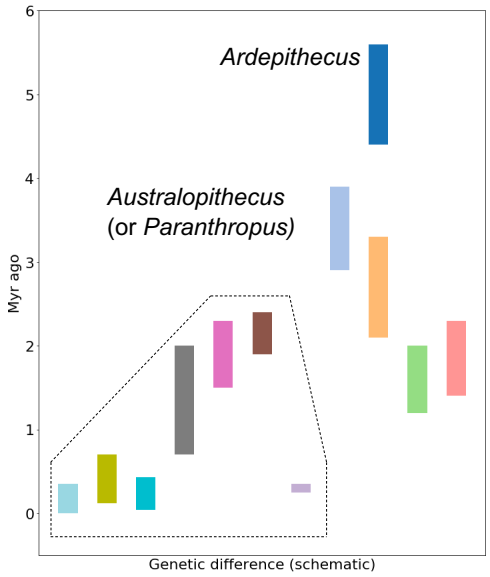
Africa's hominins

All bipedal and tailless

- *Ardepithecus*: several species known mostly by femurs
- *Australopithecus afarensis* (e.g. Lucy), *africanus*, *robustus*, *bosei*. Evolved toward bigger teeth.
- *Homo naledi*, *rudolfensis*, *habilis*, *ergaster/erectus*, *rhodesiensis/heidelbergensis*, *neanderthalensis*, *sapiens*. Evolved toward bigger brains.



70

First of genus *Homo*?

Composite skeleton of *Homo naledi*, and related fossil remains from 15 *H. naledi* individuals found in the Rising Star cave system, Gauteng, South Africa, provisionally dated to 2.5-2.8 Myr ago (Berger et al. 2015, National Geographic).

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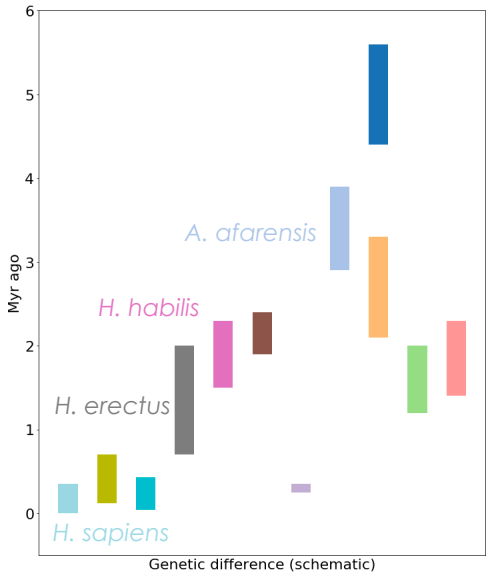
Evolution of diet

As they walked from tree to tree, hominins gradually were selected for eating more than fruit and leaves.

- *A. afarensis*: grasses and meat as well (e.g. Sponheimer & Lee-Thorp 1999)
- *H. habilis*: even more meat
- *H. erectus*: wider variety of meat
- *H. sapiens*: as much meat as they could get



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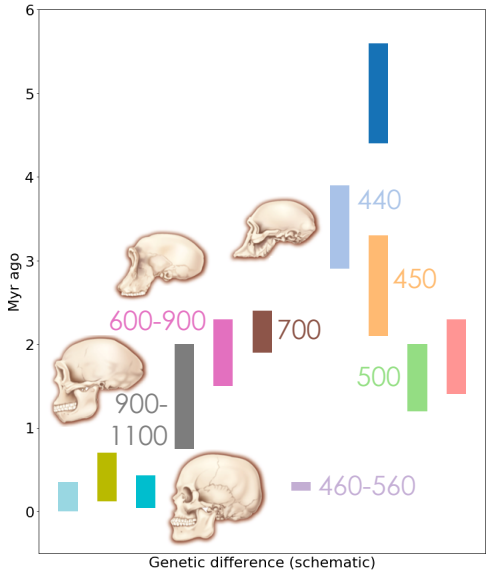
Evolution of brains

Cranial capacity increases dramatically along the *Homo* branch of the hominids.

- *A. afarensis*, at an average of 440 cc, would fit comfortably in the chimpanzee range (300–500 cc).
- Capacity about the same for all post-*erectus* species (except *H. naledi*)



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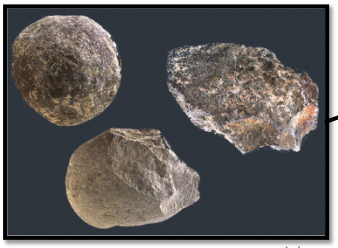
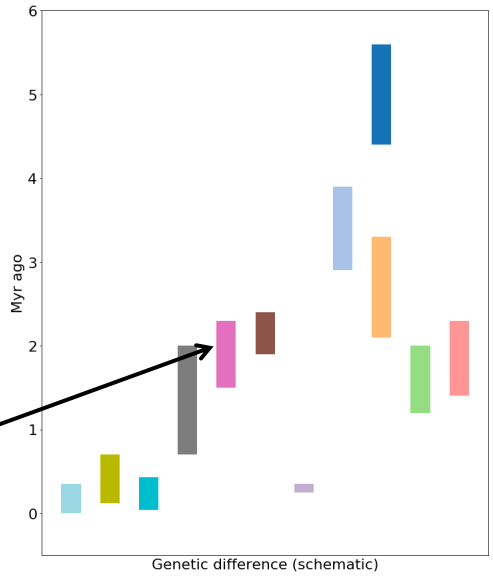
Evolution of tools

The ability to develop tools is the hallmark of intelligence.

H. habilis ("handy man") was the **first hominin to make tools**: stone hand-axes and scrapers that go with scraped animal femurs, both found with *habilis* remains.





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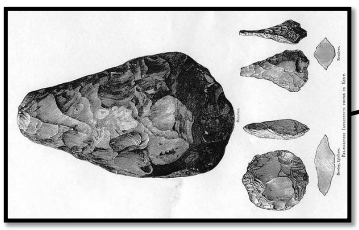
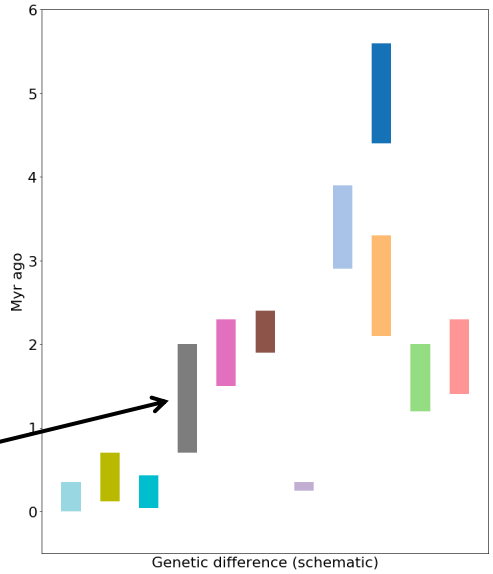
Evolution of tools

H. erectus chipped both sides of the stone, symmetrically, to produce much better hand axes.

This **biface** toolmaking tradition is called **Acheulean**, after finds in the suburb of Amiens (France) from which the tools were first characterized.





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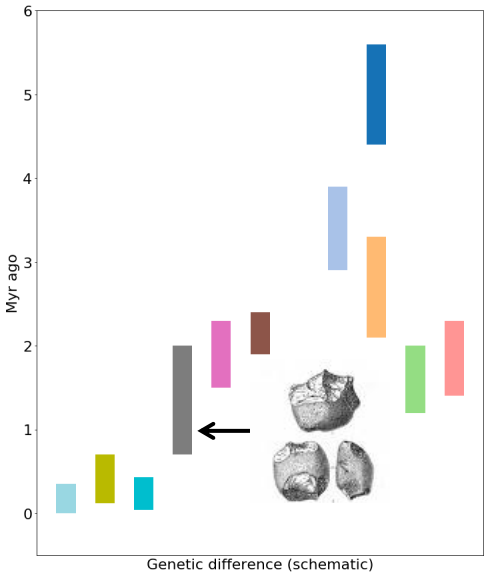
Evolution of tools

Incomplete Acheulean tools show that *H. erectus* were about 85% right-handed, as we are (e.g. Toth 1985, Llaurens et al. 2009).

H. habilis showed no preference for right or left in toolmaking.

Handedness is a sign of **brain lateralization** (hemisphere specialization).

Brain lateralization is closely connected with **speech**. *H. erectus* might, therefore, have invented **language**.



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Of what genus and species is the star of the video clip we saw at the beginning of class?

Question!

A. *A. afarensis*
B. *H. naledi*
C. *H. rudolfensis*
D. *H. habilis*
E. *H. erectus*
F. *H. heidelbergensis*
G. *H. neanderthalensis*

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The end of natural selection for genus *Homo*

There are, of course, indications in non-human animals that non-genetic knowledge is exchanged.

- Some young predators like wolves and lions learn to hunt while belonging to their pack and do not learn how to hunt (while young) if they are raised in captivity.

With the invention of tools and language by *Homo* we have

- A definitive detection of the emergence of intelligence from the natural-selection evolutionary processes
- With the **possibility of passing traits to members of the community whether genetically linked or not**: a change in the rules for subsequent evolution

Next time: f_i