History of Life on Earth-I

Lectures 1-17: From the Origin of Life to Early Mammal Evolution

Instructor: Steve Greenhouse

"Our family doesn't believe in evolution."

About this Course

- I am your instructor:
  - I am not a paleontologist (I'm a recently retired electrical engineer). Paleontology and paleoanthropology are long-time interests of mine.
  - I hope and expect there will be plenty of discussion and questions.
  - So, I won't have all the answers, but I'll try to get them.
  - I apologize in advance for mispronouncing some biological names (e.g., *Archaeopteryx).*
- This course will present evolution from a scientific point of view:
  - It is, after all, a scientific discipline.
  - This course is under the OLLI Science Program, not the Religion Program.

About this Course (cont'd)

- There is a lot of material to cover in 8 sessions:
  - Slides I have generated.
  - There are 17 DVDs from the "Great Courses" available (~30 min each). May only have time for several. These were used to create an outline for the course and are summarized in the slides.
  - A guest lecturer from GMU's biology department, Dr. Karl Fryxell (Week 4).
- I encourage discussion/feedback, but I would prefer to limit discussion of these two topics:
  - Creationism/Intelligent design.
  - The difference between a fact and a theory.
- Next term there will be another course:
  - From Early Primates to Homo Sapiens.
  - 4 sessions, Slides, 7 DVDs available.
  - A guest lecturer from the SI Museum of Natural History's Human Origins Program, Dr. Briana Pobiner.

2 Quotes

- The Last Paragraph of *On the Origin of Species* by Charles Darwin:

  "Thus, from the war of nature, from famine and death, the most exalted object of which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."

- Daniel Dennett, philosopher and cognitive scientist, speaking of *Darwin's Dangerous Idea* (evolution by natural selection):

  "The single best idea anybody ever had."

Course Outline (From the Great Courses)

- Lecture 1 – Macroevolution and Major Transitions
- Lecture 2 – Paleontology and Geologic Time
- Lecture 3 – Single-Celled Life
- Lecture 4 – Metazoans
- Lecture 5 – The Development of Skeletons
- Lecture 6 – The Rise of Vertebrates
- Lecture 7 – Colonization of the Land
- Lecture 8 – Origins of Insects and Powered Flight
- Lecture 9 – Seed Plants and the First Forests
- Lecture 10 – From Fish to 4-Limbed Animals
- Lecture 11 – The Egg Came First: Early Reptile Evolution
- Lecture 12 – The Origins and Successes of the Dinosaurs
- Lecture 13 – Marine and Flying Reptiles
- Lecture 14 – Birds: The Dinosaurs Among Us
- Lecture 15 – The First Flowers and Pollinator Coevolution
- Lecture 16 – Egg to Placenta: Early Mammal Evolution
- Lecture 17 – From Land to Sea: The Evolution of Whales

References

Adams, Fred	Origins of Existence
Asimov, Issac	Beginnings: The Story of Origins
Azimov, Issac	In the Beginning
Darwin, Charles	On the Origin of Species
Dawkins, Richard	Ancestor's Tale, The
Dawkins, Richard	Greatest Show on Earth, The
Dawkins, Richard	River Out of Eden
Dawkins, Richard	Selfish Gene, The
Dennett, Daniel C.	Darwin's Dangerous Idea
Diamond, Jarred	Third Chimpanzee, The
Edey, Maitland & Johanson, Donald	Blueprints: Solving the Mystery of Evolution
Gould, Stephen Jay	Bully for Brontosaurus
Gould, Stephen Jay	Full House
Gould, Stephen Jay	Rocks of Ages
Kingdon, Jonathan	Lowly Origins
Larson, Edward J.	Evolution
Leakey, Richard	Origins Reconsidered
Marks, Jonathan	What It Means to Be 98% Chimpanzee
Sagan, Carl and Druyan, Ann	Shadows of Forgotten Ancestors
Scott, Andrew	Creation of Life, The
Smith, Cameron M. and Sullivan, Charles	Top 10 Myths about Evolution, The
Washburn, S.L. and Moore, R.	Ape into Man: A Study of Human Evolution
Watson, James D.	Double Helix, The
Willis, D.	Hominid Gang, The

Life on Earth

- **Life**: the state of an organized structure characterized by capacity for metabolism, growth, reaction to stimuli, reproduction and, through *natural selection*, adaptation to the environment in successive generations.
- All life on earth, it appears, has a carbon- and water-based cellular form with complex organization and heritable genetic information.
- Opinions differ on whether **viruses** are a form of life or organic structures that interact with living organisms:
  - They have been described as "organisms at the edge of life" in that they possess genes and evolve by natural selection, and reproduce by creating multiple copies of themselves through self-assembly.
  - But, viruses do not have a cellular structure, which is often seen as the basic unit of life, and require a host cell to make new products.

Evolution

- **Evolution** is the process by which all living things have developed from primitive organisms through changes occurring over billions of years.
- Charles Darwin used the term "**descent with modification**" to describe evolution:
  - Darwin's idea is elegant in its simplicity but, in a sense, obvious.
  - At the time, there was little information available to him about genetics and plate tectonics.
- *Natural selection* is the underlying mechanism of evolution.

Evolution (cont'd)

- Evolution is a scientific fact. There are competing theories as to the exact explanatory mechanisms for certain aspects of evolution.
  - The *theory* of gravity may be a good analogy – there is no question in anyone's mind that gravity is a fact, but there may be various theories as to its cause or mechanism.
  - Evolution is not mathematically provable like the Pythagorean theorem, but is provable by the overwhelming weight of evidence for it, the fossil record and molecular biology.
  - And I would add: it is self-evident from a common sense point-of-view, i.e., how could it be otherwise? **(see natural selection example).**
  - I take issue with the term "believing" (or not believing) in evolution; the better term is "accepting" (or not accepting).
    - Science is not a belief system.
    - It is a methodology for arriving at facts about nature.

Evolution (cont'd)

- Evolution has no foreordained purpose or desired goal. Humans (*Homo sapiens*) are not the goal or end result of evolution. In terms of evolutionary success:
  - Humans are (arguably) the most intelligent species yet evolved. Dolphins may be a close second.
  - Insects are the most diverse class of animals.
  - Birds are the most speciose class of tetrapod vertebrates.
  - Bacteria have the greatest biomass.
- Humans are, however, the end result – the last session – of these courses!

Relative Brain-to-Body Mass Ratios

Species	Encephalization quotient (EQ)[1]
Human	7.44[1]
Bottlenose dolphin	5.31[2]
Orca	2.57
Chimpanzee	2.48
Rhesus monkey	2.09
Elephant	1.87
Whale	1.76
Dog	1.17
Cat	1.00
Horse	0.86
Sheep	0.81
Mouse	0.50
Rat	0.40
Rabbit	0.40

Descent with Modification: Darwin's Theory of Natural Selection

Descent with Modification

- Biological evolution is described as **descent with modification** from the original life on earth. Descent with modification refers to the passing on of traits from parent organisms to their offspring. This passing on of traits is known as heredity, and the basic unit of heredity is the gene.
- The passing on of genes is not always exact, parts of the blueprints may be copied incorrectly (*mutation*) or in the case of organisms that undergo sexual reproduction, genes of one parent are combined with the genes of another parent organism.
- Bodies are vessels for genes; their survival and ability to reproduce (replicate their genes) are necessary for species to survive and evolve (*speciate*).
- Individuals that are more fit, better suited for their environment, are more likely to transmit their genes to the next generation than those individuals that are not as well-suited for their environment.

Q1

Descent with Modification (cont'd)

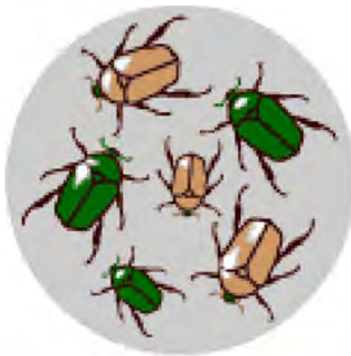
- For this reason, the genes present in a population of organisms are in constant flux due to various forces—natural selection, mutation, genetic drift, migration. Over time, gene frequencies in populations change—evolution takes place.
- There are three basic concepts that are often helpful in clarifying how descent with modification works. These concepts are:
  - genes mutate or are the result of the combination of the genes of the individual's parents (sexual reproduction)
  - individuals are selected*
  - <u>only</u> populations evolve

*The selfish gene theory states genes are selected rather than the individual.

Selection and Adaptation

- **Selection**: A natural or artificial (breeding) process that favors or induces survival and perpetuation of one kind of organism over others that die or fail to produce offspring.
- **Adaptation**: An alteration or adjustment in structure or habits, often hereditary, by which a species or individual improves its condition (its likelihood of survival and reproductive success) in relationship to its environment.

Natural Selection Example



(1 of 4) Variation

There is variation in traits in an (intra-breeding) population of beetles. For example, some beetles are green and some are brown.

(2 of 4) Differential reproduction

Since the environment can't support unlimited population growth, not all individuals get to reproduce to their full potential. In this example, green beetles tend to get eaten by birds and survive to reproduce less often than brown beetles do.

Natural Selection Example (cont'd)

(3 of 4) Heredity
The surviving brown beetles tend to have brown baby beetles because this trait has a genetic basis.

(4 of 4) End result
The more advantageous trait, brown coloration, which allows the beetle to have more offspring, becomes more common in the population. If this process continues, eventually, all individuals in this population will be brown.

Natural Selection Example (cont'd)

- It may eventually become impossible for this population of, now, all brown beetles to mate and produce fertile offspring with other populations of the original green and brown beetles. If this occurs, a new species of beetles has evolved (speciation).
  - The "all brown" and "original" populations must have been *isolated* from each other for many generations to prevent genetic transfer between the two for speciation to occur.
  - If individuals are capable of mating and producing <u>fertile</u> offspring with other individuals (of course, opposite sex), they belong to the same species.
  - An interesting example is horses and donkeys who mate and produce <u>sterile</u> offspring (mules): they are of different species.
- Likewise, the birds who liked to eat the green beetles may eventually evolve to like the more common (readily available) brown beetles. This is how an evolutionary *arms race* gets started. Three types of arms races are:
  - Predator vs prey (above)
  - Parasite vs host
  - Individual vs individual

Myths about Evolution [1]

- Survival of the Fittest:
  - A bumper sticker description of evolution often taken to mean "red of tooth and claw [Tennyson]," a world of savage predation. Fittest in the sense of better adapted to the environment, more likely to survive and reproduce for a myriad of possible reasons.
- It's Just a Theory:
  - *To repeat*: Evolution is a scientific fact. There are competing theories as to the exact explanatory mechanisms for certain aspects of evolution.
- The Ladder of Progress:
  - *To repeat*: It is not true that there is an inevitable progression from lower life-forms leading to humans as the goal of evolution.

[1] Cameron M. Smith and Charles Sullivan, "The 10 Top Myths about Evolution," New York: Prometheus Books, 2007.

Myths about Evolution (cont'd)

- The Missing Link:
  - The idea of a single (sometimes missing) link between species distorts the reality of the continuous nature of evolution. Many transitional forms exist in the fossil record.
- Evolution is Random:
  - *Here I take some issue with the authors*: There *is* randomness in many aspects of evolution. This includes choice of a mate, mutation and combination of genes, and even the environment within which selection takes place (the authors acknowledge the second aspect). Adaptations to the environment are <u>not</u> random. *So, I don't think this is a total myth unless one believes there is no randomness in the universe, that everything is deterministic.*
- People Come from Monkeys:
  - Monkeys and humans share a latest common ancestor (about 30 mya). Great apes and humans share a later common ancestor (about 7-4 mya). So, we are distant "cousins" of great apes, even more distant "cousins" of monkeys. We don't "come from" either.

Myths about Evolution (cont’d)

- Nature’s Perfect Balance:
  - Examination of the fossil record and the causes of the rise and extinction of millions of life-forms over 4 billion years has shown that the patterns of nature aren't the result of an intended plan. They represent the result of chance events that disturb equilibrium and the reorganization of balance by the survivors.*
- Evolution is Immoral:
  - Much of our morality (and immorality) may have evolutionary roots.
  - The attempt to morally justify the policies of social Darwinism (based on “might makes right”) and eugenics misapply our understanding of evolution by assuming:
    - Unfettered competition is natural.
    - Race mixing is biologically harmful.
    - There are inferior races.
    - Because something is natural–even a product of evolution–it must be good.

* It is estimated that 99.9% of all species that have ever existed are now extinct.

Myths about Evolution (cont'd)

- *(My own "myth")* There is no selective advantage to "partial adaptations" such as half an eye or one-tenth of a wing:
  - Actually, there are 2 counter-arguments:
    - An "incompletely" evolved feature <u>can</u> provide a selective advantage, e.g., a simple light sensitive patch of skin may give the animal improved ability to escape predators or to find food; an incomplete wing may allow the animal to start a glide from a tree.
    - The "incomplete" feature may have evolved for a different purpose, e.g., feathers may have originally been used for insulation, not flying: some dinosaurs had feathers but did not fly.

Q2

- *(My own "myth")* The increasing complexity of life seen in evolution violates the 2nd law of thermodynamics (entropy or disorder is non-decreasing with time):
  - Applies to a closed system where no energy or matter can enter or leave. The earth and the ecologies within it are open systems where energy (e.g., sunlight) and matter (e.g., meteorites and atmospheric gases) enter/leave all the time.
  - It is not necessarily correct that complexity has increased. It is obviously true that some life has become more complex; however, the simplest life-form, bacteria, has a larger biomass than all animals and plants.

Myths about Evolution (cont'd)

- Creationism Disproves Evolution:
  - Creationism's argument for a young earth and the Biblical creation story is challenged by the fossil record as well as DNA evidence. Likewise the belief that all living species have existed and remain unchanged since the creation. Noah's flood story is challenged by geology. *Some creationists accept an ancient earth while believing a creator jump-started the process of evolution; this is unchallenged by science.*
- Intelligent Design is Science:
  - Intelligent design is creationism's dressed-up twin. It is inspired by a political agenda and fails to live up to the standards of science. There is no evidence to support the contention that every step of evolution is guided by an "intelligent designer."

Creationism and the Constitution

- *Edwards v. Aguillard*, 482 U.S. 578 (1987) was a legal case about the teaching of creationism that was heard by the Supreme Court of the United States in 1987. The Court ruled 7-2 that a Louisiana law requiring that creation science be taught in public schools, along with evolution, was unconstitutional because the law was specifically intended to advance a particular religion.
- It also held that "teaching a variety of scientific theories about the origins of humankind to school children might be validly done with the clear secular intent of enhancing the effectiveness of science instruction."
- In an op-ed piece in the Washington Post the following day entitled "Good Grief, Scalia," conservative columnist George Will severely criticized the dissenting opinion.

Species

- A species is an <u>entire</u> population of organisms capable of interbreeding *(intrabreeding?)* and producing fertile offspring.
  - This covers most instances, but sometimes similarity of DNA, morphology or ecological niche are used to define a species.
  - This definition applies to sexually reproducing organisms.
  - A 2-part **binomial** name is used for naming organisms *(Genus species),* e.g.,
    - *Homo sapiens*
    - *Boa constrictor*

Species Data

- Estimates of the number of living species vary widely (next 2 slides); one estimate has it at 1.6 million (described and catalogued), another 8.7 million (predicted).
- It is estimated that 99.9%* of all species that have ever existed are now extinct:
  - This would imply several billion species have existed in the 4 billion year history of life on earth.
- Estimates of the average lifespan of species vary even more widely. I have seen numbers ranging from several hundred-thousand to over ten-million years:
  - Mass extinctions seem to occur randomly.

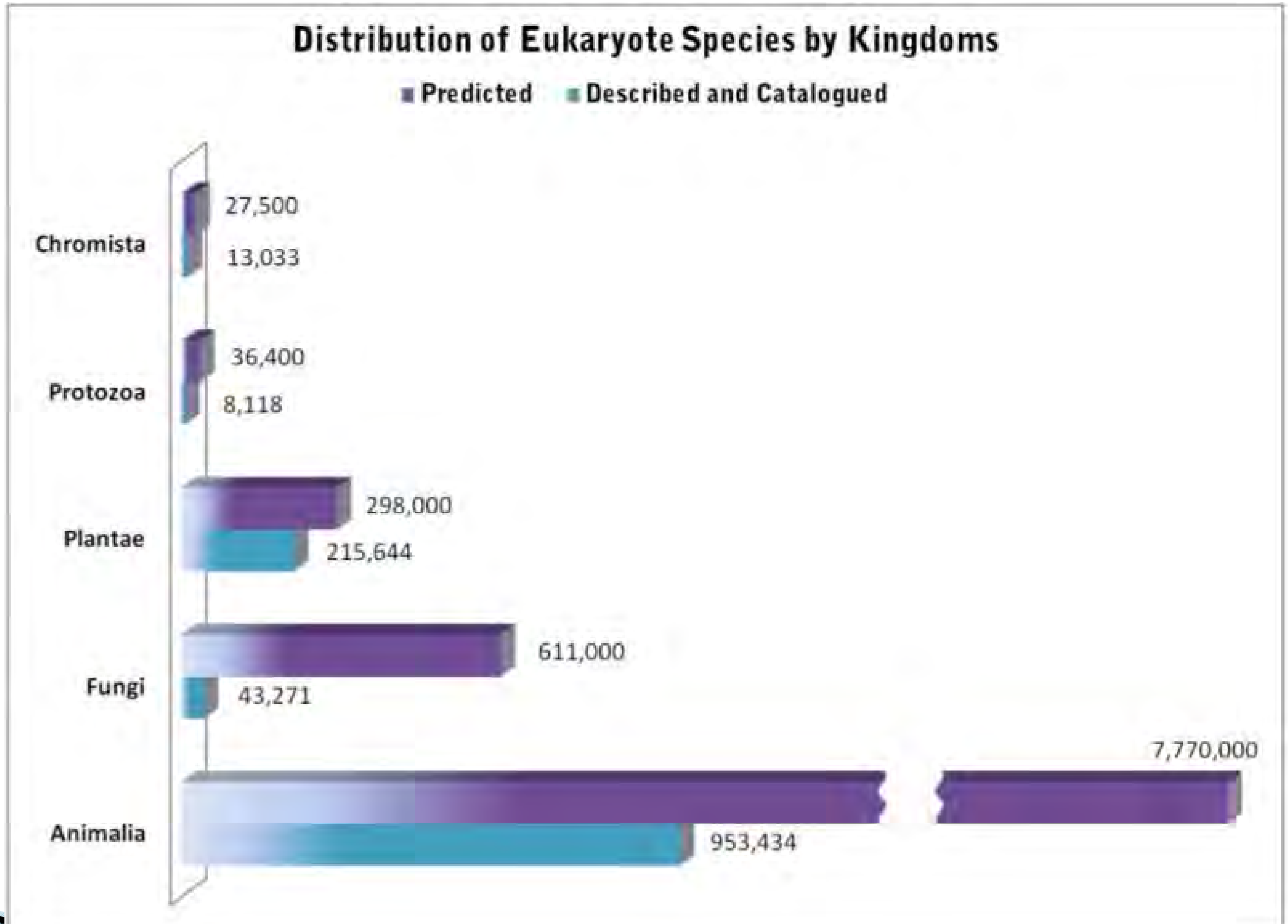
* I have seen 5 9's after the decimal point.

Number of Living Species
(2007 Estimate)

GROUP	NUMBER OF SPECIES
Vertebrates	
Amphibians	6,199
Birds	9,956
Fish	30,000
Mammals	5,416
Reptiles	8,240
Subtotal	59,811
Invertebrates	
Insects	*950,000
Molluscs	81,000
Crustaceans	40,000
Corals	2,175
Others	130,200
Subtotal	1,203,375
Plants	
Mosses	15,000
Ferns and allies	13,025
Gymnosperms	980
Dicotyledons	199,350
Monocotyledons	59,300
Green Algae	3,715
Red Algae	5,956
Subtotal	297,326
Others	
Lichens	10,000
Mushrooms	16,000
Brown Algae	2,849
Subtotal	28,849
Total	1,589,361

*350,000 are beetles

Number of Living Species
(Recent Estimate)



Average Lifespan of Species

Taxonomy	Source of Estimate	Species Average Lifespan years (MYA)
All Invertebrates	Raup (1978)	11
Marine Invertebrates	Valentine (1970)	5-10
Marine Animals	Raup (1991)	4
Marine Animals	Sepkoski (1992)	5
All Fossil Groups	Simpson (1952)	.5-5
Mammals	Martin (1993)	1
Cenozoic Mammals	Raup and Stanley (1978)	1-2
Diatoms	Van Valen	8
Dinoflagelates	Van Valen (1973)	13
Planktonic Foraminifera	Van Valen (1973)	7
Cenozoic Bivalves	Raup and Stanley (1978)	10
Echinoderms	Durham (1970)	6
Silurian Graptolites	Rickards (1977)	2

Sexual and Artificial Selection

- **Sexual selection** is a mode of natural selection in which some individuals outreproduce others of a population because they are better at securing mates. The concept was introduced by Charles Darwin as a significant element of his theory of natural selection. The sexual form of selection
  - "... depends, not on a struggle for existence, but on a struggle between the males for possession of the females; the result is not death to the unsuccessful competitor, but few or no offspring."
  - "... when the males and females of any animal have the same general habits ... but differ in structure, colour, or ornament, such differences have been mainly caused by sexual selection."

  His sexual selection examples include ornate peacock feathers, birds of Paradise, the antlers of stag (male deer), and the manes of lions.
- **Artificial selection** (selective breeding) is the modification of a species by human intervention so that certain desirable traits are represented in successive generations. The different breeds of domestic dogs bred to perform specific tasks and the large ears of maize corn are products of artificial selection.

Homologous Features and Camouflage

- **Homologous features** are similar corresponding features in sometimes very different species. An example: the paired pelvic and pectoral fins of lobe-finned fish are *homologous* for pelvic and pectoral limbs on tetrapods. Homologous traits of organisms are therefore due to descent from a common ancestor.
- **Camouflage.** In nature, every advantage increases an animal's chances of survival, and therefore its chances of reproducing. This simple fact has caused animal species to evolve a number of special adaptations that help them find food and keep them from becoming food. One of the most widespread and varied adaptations is natural camouflage, an animal's ability to hide itself from predator and prey.

The Selfish Gene Theory

- **The Selfish Gene** is a *theory* made popular by Richard Dawkins where altruism exhibited by an individual toward closely related kin increases the likelihood of that individual's genes being passed on to future generations (altruism itself being a genetic trait). Here we have the gene being selected for survival rather than the individual:
  - Individuals are likely to defend or provide for their more closely related kin: first offspring, then immediate family, then tribe, finally nation.
  - The male of a species of spiders is eaten by the female just after impregnating her. He gives his life in exchange for propagating his genome into future generations, the ultimate in altruistic (instinctual) behavior.

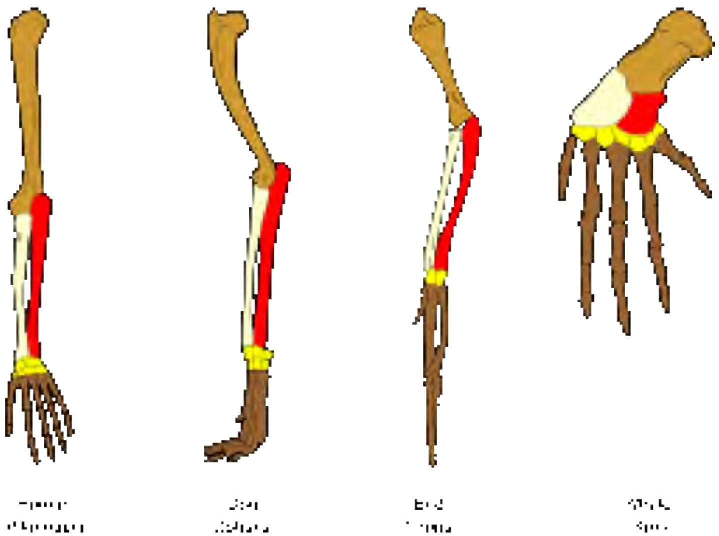
Sexual Selection

Goldie's Bird of Paradise : Ornamented male above; female below.

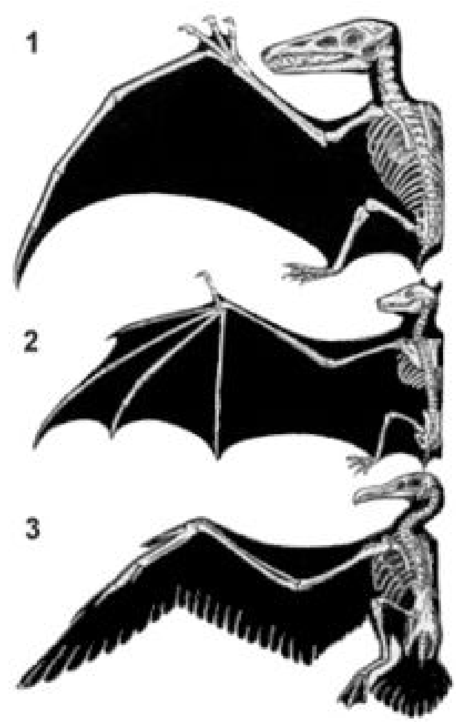
Artificial Selection

Dogs: examples of artificial selection or selective breeding.

Homologous Features



The principle of **homology**: The biological derivation relationship (shown by colors) of the various bones in the forelimbs of four vertebrates is known as homology and was one of Darwin's arguments in favor of evolution.



The wings of **pterosaurs** (1), **bats** (2) and **birds** (3) are analogous as wings, but homologous as forelimbs.

Camouflage

This **toad** is hardly distinguishable from its surroundings.

Heredity *(to repeat)*

- Biological evolution is described as descent with modification from the original life on earth. Descent with modification refers to the passing on of traits from parent organisms to their offspring. This passing on of traits is known as **heredity**, and the basic unit of heredity is the gene.

Heredity

- A **chromosome** is an organized structure of **DNA**, protein and RNA found in the nucleus of *eukaryotic* cells. It is a single piece of coiled, double-stranded DNA containing many **genes**, regulatory elements and other *nucleotide* sequences.
- Chromosomes also contain DNA-bound proteins, which serve to package the DNA and control its functions. They are compacted by a factor of about 10,000 from their uncoiled length. Chromosomal DNA encodes most or all of an organism's genetic information.
- Chromosomes in humans can be divided into two types: **autosomes** and sex chromosomes. Certain genetic traits are linked to a person's sex and are passed on through the sex chromosomes. The autosomes contain the rest of the genetic hereditary information. All act in the same way during cell division.

Heredity (cont'd)

- All "normal" human cells, except reproductive cells, contain 23 pairs (a diploid set) of chromosomes (22 pairs of autosomes and one pair of sex chromosomes), giving a total of 46 per cell. In addition to these, human cells have many hundreds of copies of the mitochondrial genome.
- **Gametes** or reproductive cells (sperm in the male, ovum in the female) contain a haploid set (one copy) of chromosomes each. In contrast to a gamete, the diploid somatic cells of an individual contain one copy of the chromosome set from the sperm and one copy of the chromosome set from the egg; i.e., the cells of the offspring have genes expressing characteristics of both the father and the mother.
- A cell (gamete) that fuses with another reproductive cell of the opposite sex during fertilization forms a **zygote** that develops into a new individual.

Heredity (cont'd)

- An **allele** is one of two or more alternative forms of the same gene or group of genes. Different alleles may result in different observable **phenotypic** traits such as eye color:
  - **Genotype** is an organism's full hereditary information. Phenotype is an organism's actual observed properties, such as morphology, development, or behavior. This distinction is fundamental in the study of inheritance of traits and their evolution.
  - Most multicellular organisms have two sets of chromosomes, i.e., they are *diploid*. These chromosomes are referred to as homologous chromosomes. Diploid organisms have one copy of each gene (and therefore one allele) on each chromosome. If both alleles are the same, they are *homozygotes*. If the alleles are different, they are *heterozygotes*.
  - An offspring inherits one allele for a given trait from each parent, but only one is expressed as the phenotypical trait. If there is a dominant allele, this is the one which is expressed.

Heredity (cont'd)

- In some instances, a trait is the result of *codominant* genes which may be expressed as a "combination" of the two alleles, e.g., red and white resulting in pink.

The complex subject of genetics would be a good course for a future term!

2 Examples of Heredity

(1) Parents: D r D r (2 D's)

Offspring: D D D r D r r r

Result: 75% D 25% r

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(2) Parents: D D r r (1 D, 1 r)

Offspring: D r D r D r D r

Result: 100% D

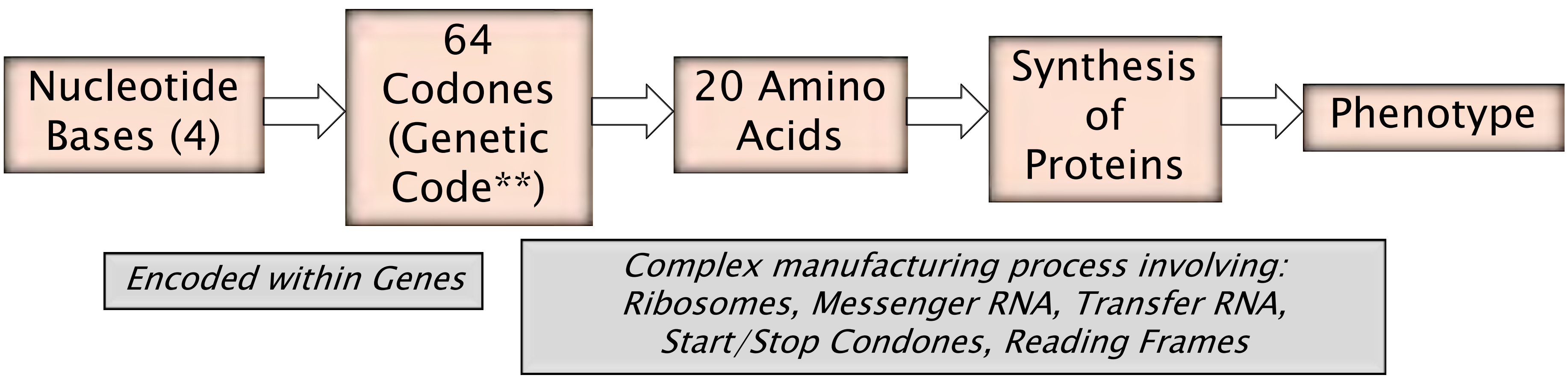
D is the dominant gene/allele, r is the recessive

Total Number of Chromosomes in Some Animals

Species	#	Species	#
Elephants[33]	56	Cow	60
Domestic cat[26]	38	Domestic pig	38
Gorillas, Chimpanzees[32]	48	Domestic sheep	54
Guppy (*poecilia reticulata*)[23]	46	Garden snail[24]	54
Common fruit fly	8	Guinea Pig[22]	64
Donkey	62	Horse	64
Hares[30][31]	48	Human[32]	46
Dog[34]	78	Kingfisher[35]	132
Laboratory mouse[27][28]	40	Laboratory rat[28]	42
Goldfish[36]	100–104	Silkworm[37]	56
Rabbit (*Oryctolagus cuniculus*)[29]	44	Syrian hamster[27]	44
Earthworm (*Octodrilus complanatus*)[25]	36	Tibetan fox	36

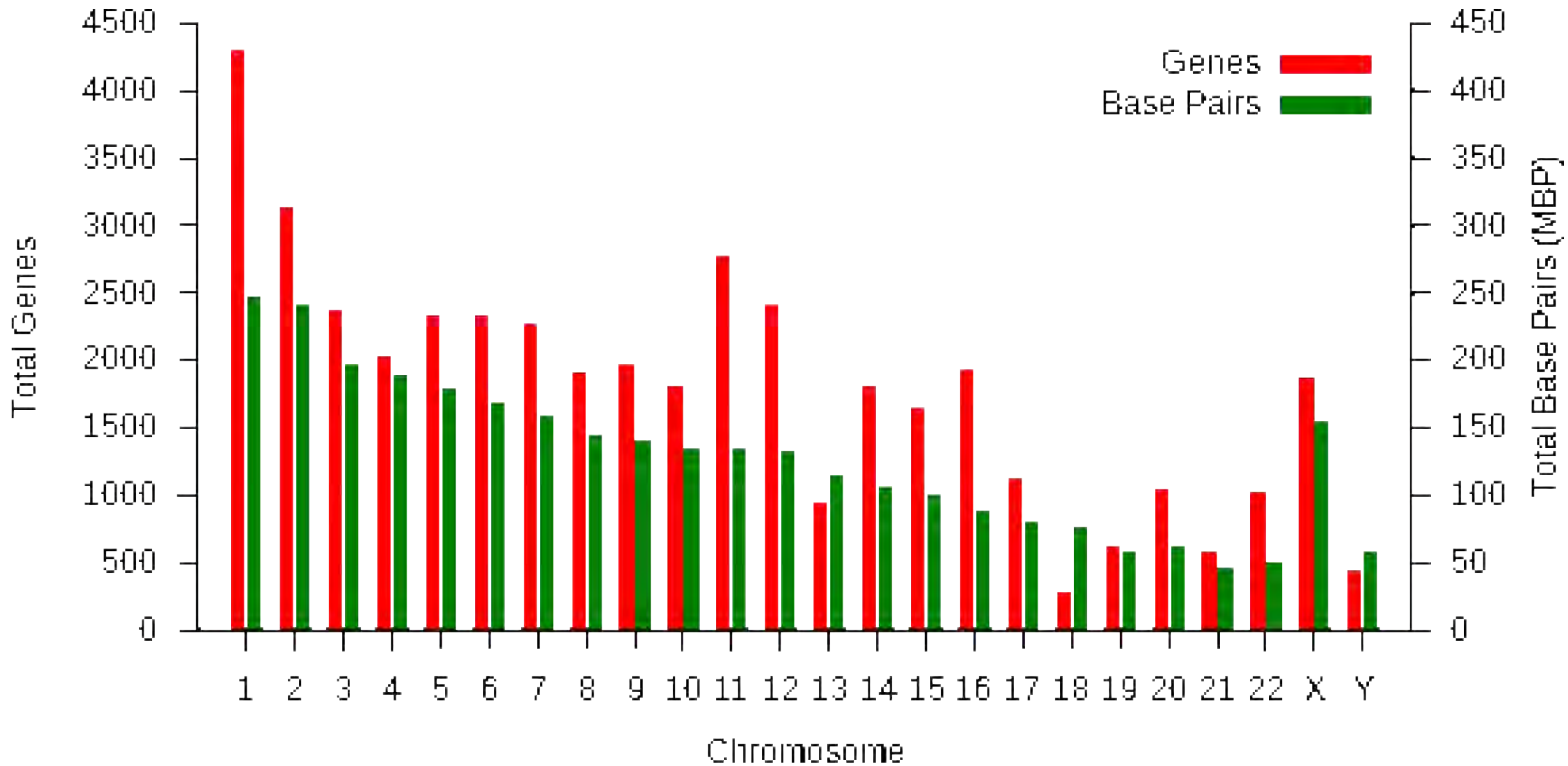
Life is Digital!

	Computers	DNA
Building Blocks	bits: 0,1 (2)	nucleotide bases: A,C,G,T* (4)
Characters	byte (8 bits)	codone (3 nucleotides)
Examples	10110001, 00101100	ACT, CAG
Possible Combinations	2^8 = 256	4^3 = 64
Code for	instructions, data	20 amino acids



*Adenine, cytosine, guanine and thymine.
**The genetic code is highly similar among all organisms.

Human Chromosomes



Estimated number of genes and base pairs (in mega base pairs) on each human chromosome

Myths about Heredity

- Lamarckian Inheritability:
  - Acquired characteristics can be inherited. This discredited theory was believed in Darwin's time and he may have believed it himself. Although some people may be genetically predisposed to tanning from exposure to the sun's ultraviolet rays, the tan itself cannot be passed on even when present at the time of conception (but the predisposition can).
- Blending Inheritance:
  - *(Not to be confused with codominance)* It was also believed in Darwin's time that a phenotypic trait was a blend of the two parents' genes for that trait. E.g., tall and short parents would always produce medium-height children. If this were true, heights would tend toward a sort of "medium average" and very tall or very short individuals would never occur. Darwin found this theory to be incompatible with his observations and with evolution itself.

Why Do Detrimental Genes Persist in a Species' Genome?

- Of course, species can survive with *some* detrimental genes.
- They *do*, however, often cause species to become extinct:
  - This may benefit other species.
  - Doesn't always mean the demise of a gene, it may exist in different species.
- Does matter if the gene acts after the age of reproduction.
- May eventually be filtered out in later generations.
- May also have a positive purpose (e.g., sickle cells in fighting malaria).

Q1

Genetic Differences between Humans and Other Organisms (approx.)

Organism	DNA Difference (%)
Chimpanzee	2
Most Mammals	10
Reptiles	25
Insects	40
Bananas	45
Bacteria	60

Genetic Differences between Humans and Other Primates

Primate	DNA Difference (%)
Other Individual Humans	0.1
Chimpanzee/Bonobo	1.2 [1]
Gorilla	1.6
Orangutan	3.1
Rhesus Monkey	7

[1] Measurement of only substitutions in the base building blocks of those genes that chimpanzees and humans share. Comparison of the entire genome indicates that segments of DNA have been deleted, duplicated over and over, or inserted from one part of the genome into another. When these differences are counted, there is an additional 4 to 5% distinction between the human and chimpanzee genomes.

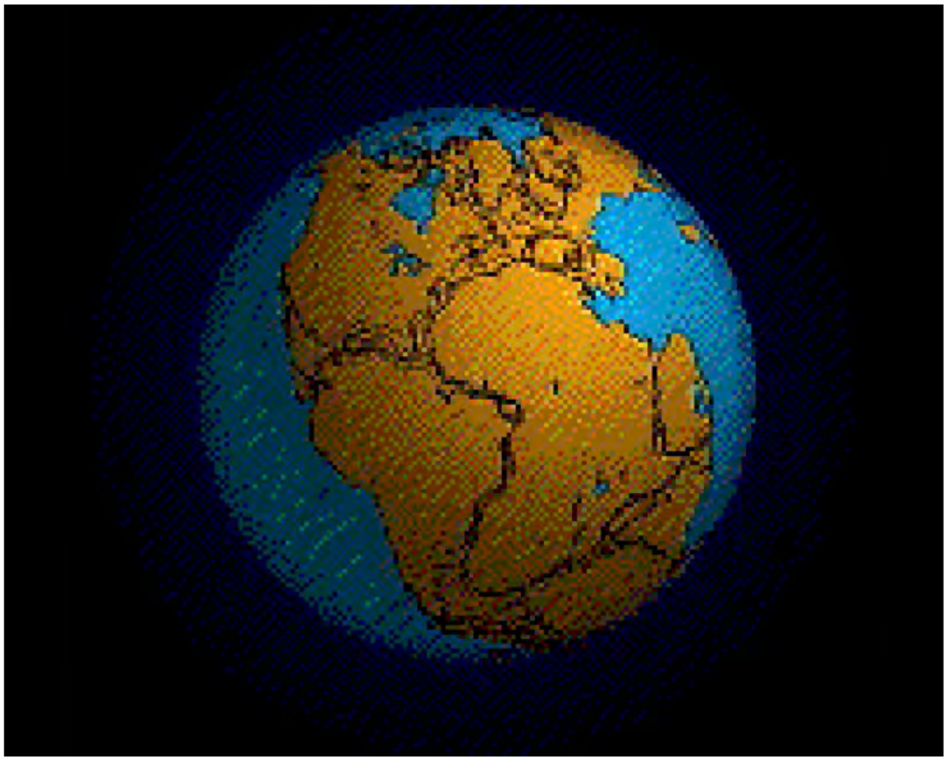
"It's the PERFECT time to move up the evolutionary ladder! The climate is stable, we have no natural predators, and interest rates may never be this low again!"

Lecture 1 – Macroevolution and Major Transitions

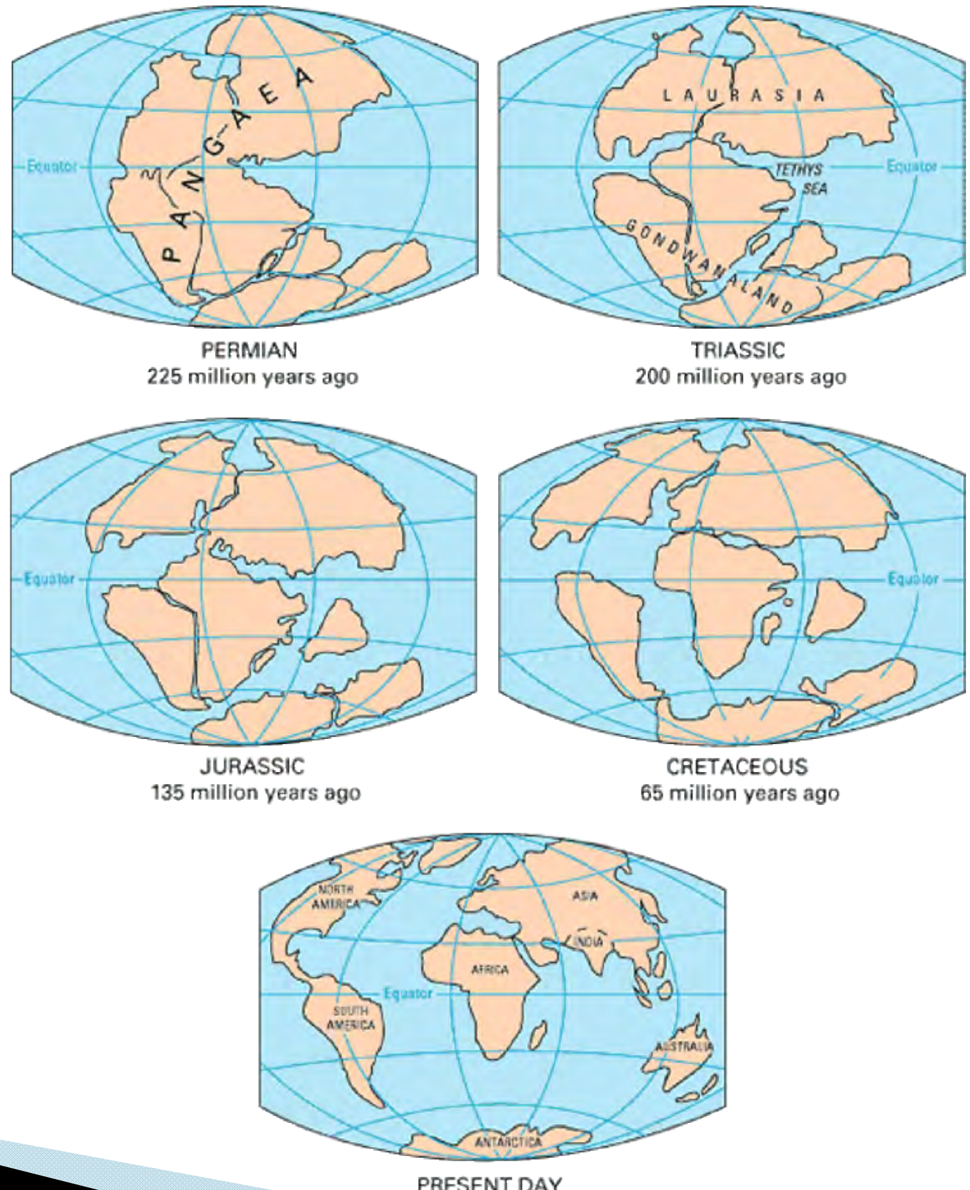
- Evolution means change over time:
  - Macroevolution is the change from one species to another over many generations and often large amounts of time.
  - Microevolution is the change in gene frequency in the gene pool of a species.
- Factors affecting evolution are:
  - geographic isolation
  - continental drift due to plate tectonics
  - genetic drift
  - environmental change
    - climate change
    - oxygen content of the atmosphere
  - mass extinctions
  - predation
  - appearance of plants,

  all allowing natural selection to occur.
- Evolutionary theory draws from the sciences of paleontology, anthropology, geology, developmental biology, genetics and ecology.

Pangea
(Formed ~300 mya, began to break apart ~200 mya)



Gondwana and Laurasia



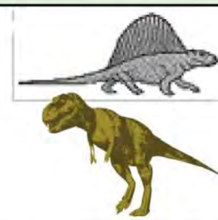
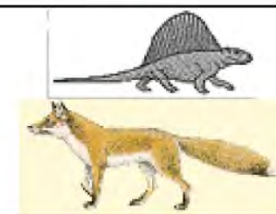
Major Taxonomic Linnaean Ranks
(Intermediate ranks are not shown)

TAXA	HUMAN	OSTRICH
DOMAIN	Eukarya	Eukarya
KINGDOM	Animalia	Animalia
PHYLUM	Chordata	Chordata
CLASS	Mammalia	Aves
ORDER	Primate	Struthioniformes
FAMILY	Hominidae	Struthionidae
GENUS	*Homo*	*Struthio*
SPECIES	*sapien*	*camelus*

Major Taxonomic Linnaean Ranks
(Another example)

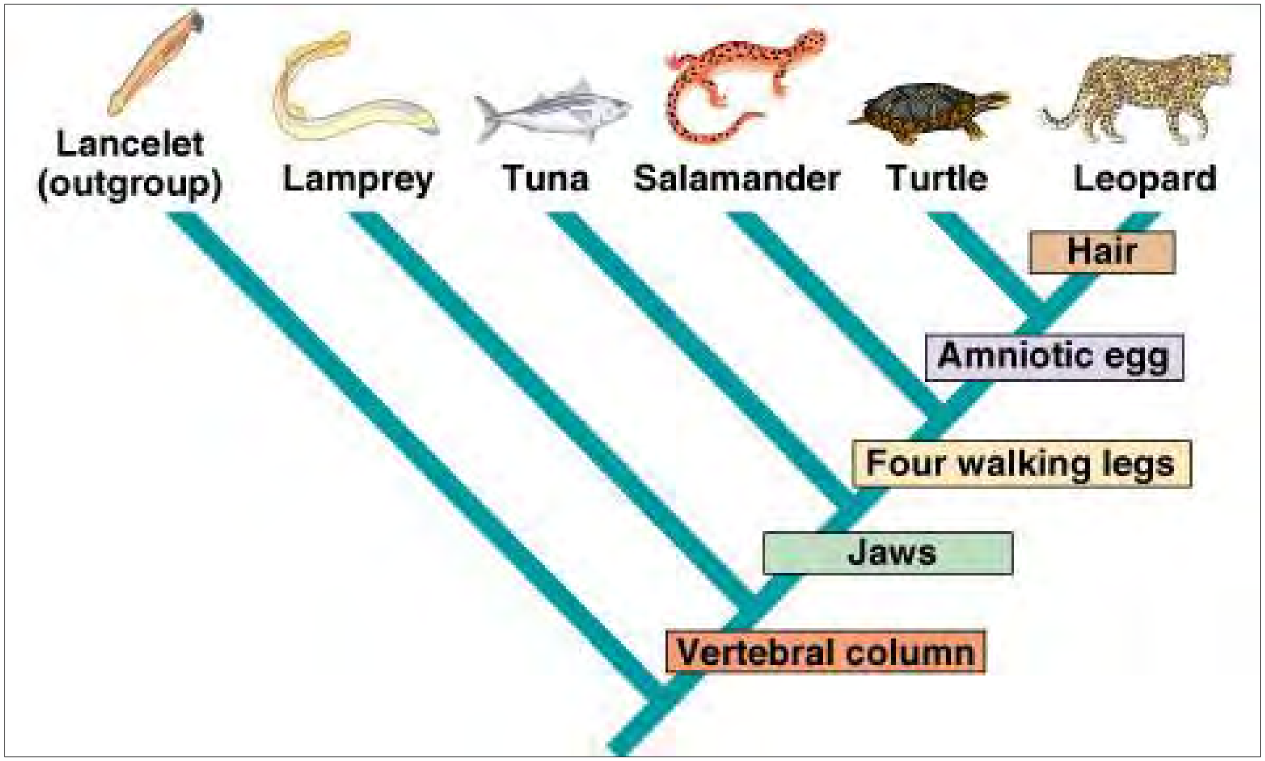
TAXA	Chimpanzee	Southern Leopard Frog	Katydid
Kingdom	Animalia	Animalia	Animalia
Phylum	Chordata	Chordata	Arthropoda
Subphylum	Vertebrata	Vertebrata	Uniramia
Class	Mammalia	Amphibia	Insecta
Order	Primates	Anura	Orthoptera
Family	Hominidae	Ranidae	Tettigoniidae
Genus	*Pan*	*Rana*	*Scudderia*
Species	*troglodytes*	*pipiens*	*furcata*
Scientific Name	*Pan troglodytes*	*Rana pipiens*	*Scudderia furcata*

Cladistic Classification:
A More Modern Ranking System

Linnaean Classification - based on shared traits		Phylogenetic Classification - based on common ancestor	
Class: Reptiles (cold-blooded, scaly, lay eggs)		**Clade: Sauropsids**	
Class: Birds (warm-blooded, feathered, lay eggs)			
Class: Mammals (warm-blooded, furry, live young)		**Clade: Synapsids**	

A **clade** is a group of organisms which includes the most recent common ancestor of all of its members and all of the descendants of that most recent common ancestor.

Cladistic Classification
(Another example)



Humor in Taxonomy

Some whimsical taxonomic names exist….. *Agra vation* is a tropical beetle that was apparently very difficult to collect. Another insect, a true bug, is named *Heerz lukenatcha*. Organisms are sometimes named after people: a louse that lives on owls has been named *Strigiphilus garylarsoni*; a bacterium bears the name *Salmonella mjordan*, named by a microbiologist who is a basketball fan. My advisor named a parasite after his ex-wife. The names of some amphipod crustaceans exceed 40 letters in length, such as *Polichinellobizrrocomic burlescomagicaraneus*.

Lecture 1– Macroevolution and Major Transitions (cont'd)

- Major evolutionary transitions include the development of:
  - Single-cells (prokaryotes and eukaryotes)
  - Multicelled animals (metazoans)
  - Skeletons
  - Life on land
  - Four-legged vertebrates
  - Insects and seed plants
  - Enclosed animal eggs
  - Flowering plants
  - Pollinating insects
  - Mammals
  - Live birth
  - Tree-dwelling primates
  - Humans

Geologic or Deep Time

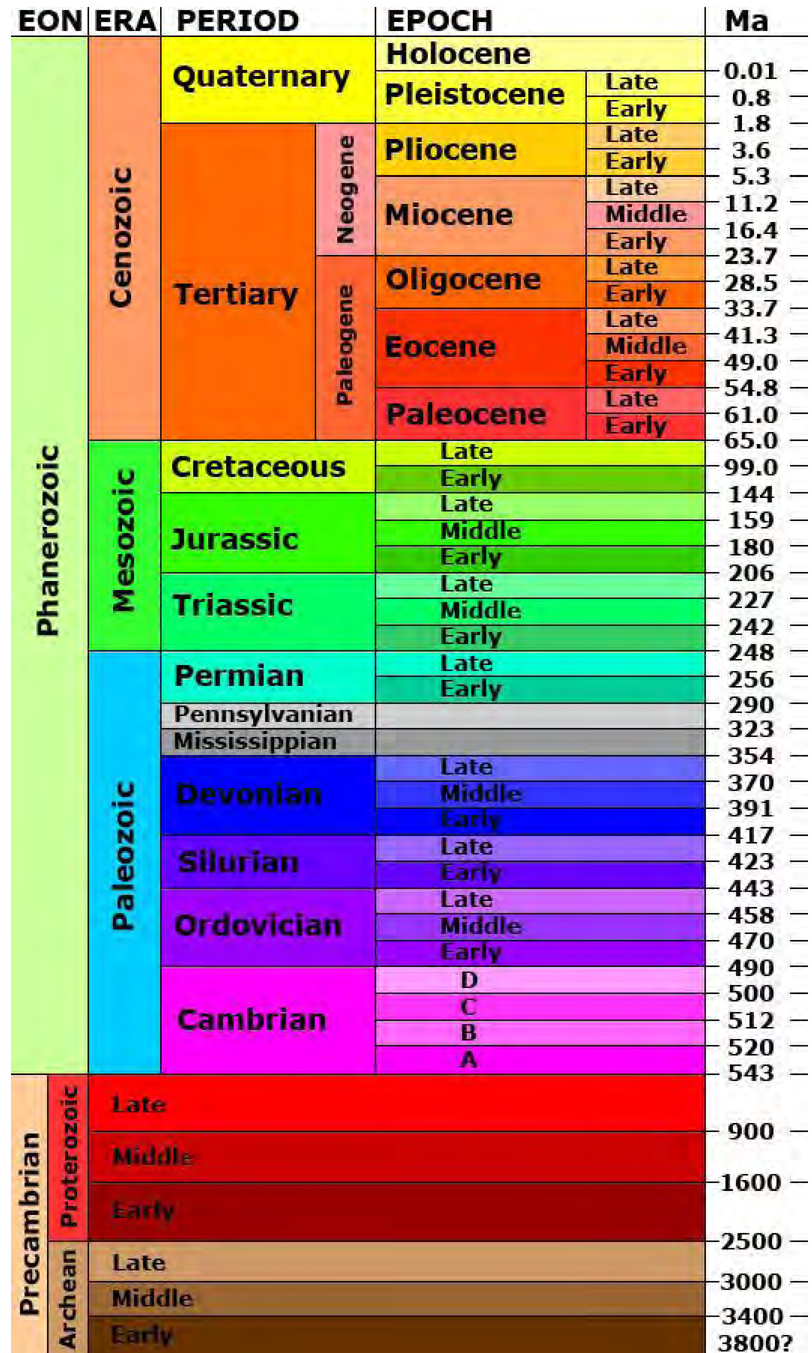
- Evolution has occurred over immense amounts of time from first life on earth to today's magnificent array of life – about 4 billion years.
- We talk about geologic or deep time – as large as 333,000 times the length of human civilization or 200,000,000 human generations.
- While major transitions can take tens or hundreds of millions of years, there are examples of evolutionary change observed in a human lifetime.

Lecture 2- Paleontology and Geologic Time

- Important *spans* of geologic time:
  - *Archean* eon–3.8 to 2.5 bya
    - Continents begin to form and primitive single-celled life evolves.
  - *Proterozoic* eon–2.5 bya to 543 mya
  - *Phanerozoic* eon –543 mya to present
    - *Paleozoic* era–543 to 251 mya
      - Skeletons, invertebrates, vertebrates, first land plants and animals, first forests and flying insects, reptilian eggs, and proto-mammals develop.
    - *Mesozoic* era–251 to 65 mya
      - Dinosaurs and mammals evolve, some reptiles radiate to the sky and sea, birds evolve from early feathered dinosaurs, and flowering plants and pollinating insects coevolve.
    - *Cenozoic* era–65 mya to present
      - Some land mammals radiate back to the sea, primates and then apes evolve, some apes diverge into a lineage which leads to our genus, *Homo*, and our species, *H. sapiens* evolves.
- Lower-level spans are periods, then epochs.
- Boundaries between spans are based on worldwide extinctions and evolutions of species.

The Geologic Time Scale

Time spans are eons, eras, periods and epochs.
Ma = mya.



Important Transitional Events
(some dates are approx or ranges – sources vary)

EVENT	mya	SCALED TO A YEAR
Earth forms	4600	1-Jan
Earliest life appears	4000	17-Feb
Prokaryotes appear	3700	13-Mar
Eukaryotes appear	2700	1-Jun
Simple multicellular organisms evolve	1200	27-Sep
Cambrian "explosion" (Burgess shale fossils)	530	19-Nov
First fish and proto-amphibians appear	500	22-Nov
Earliest arthropods appear	490	23-Nov
Earliest land plants appear	475	24-Nov
Earliest insects and seeds appear	420	28-Nov
Earliest reptiles appear	310	7-Dec
Mammal-like reptiles appear	270	10-Dec
Primitive small mammels appear	200	16-Dec
Earliest birds	150	20-Dec
Extinction of dinosaurs	65	26-Dec
Earliest true primates	55	27-Dec
Anscestors to monkeys and apes appear	32	29-Dec
Earliest great apes	14	30 Dec, 9:20:21 pm
Possible anscestor to apes/humans	12	31 Dec, 1:08:52 am
Earliest hominin	6.5	31 Dec, 11:37:18 am
Australopithecus afarensis (Lucy)	3.2	31 Dec, 5:54:22 pm
First appearance of genus Homo (H. habilis)	2.5	31 Dec, 7:14:21 pm
First anatomically modern humans (Homo sapiens)	0.2	31 Dec, 11:37:09 pm
Behaviorally modern humans appear	0.07	31 Dec, 11:52:00 pm
Human civilization begins	0.012	31 Dec, 11:58:38 pm

Q3

Mass Extinctions

- Mass extinction events are just peaks in the background extinction rate.
- 5 events are usually cited, but there may have been as many as 20. Most occurred during the Phanerozoic eon.
- Periods of high animal diversity give rise to a high extinction rate and low speciation; likewise, periods of low diversity give rise to a low extinction rate and high speciation.
- Extinctions often are caused by an interrelated chain of events, e.g., global warming may cause sea levels to fall stranding marine organisms living near coastlines. Or, an asteroid impact may release aerosols into the atmosphere, obscuring sunlight, killing plant life which rely on photosynthesis, finally starving animals who eat the plants. Ultimately, extinctions are often caused by an interruption of the food chain.

Mass Extinction Events

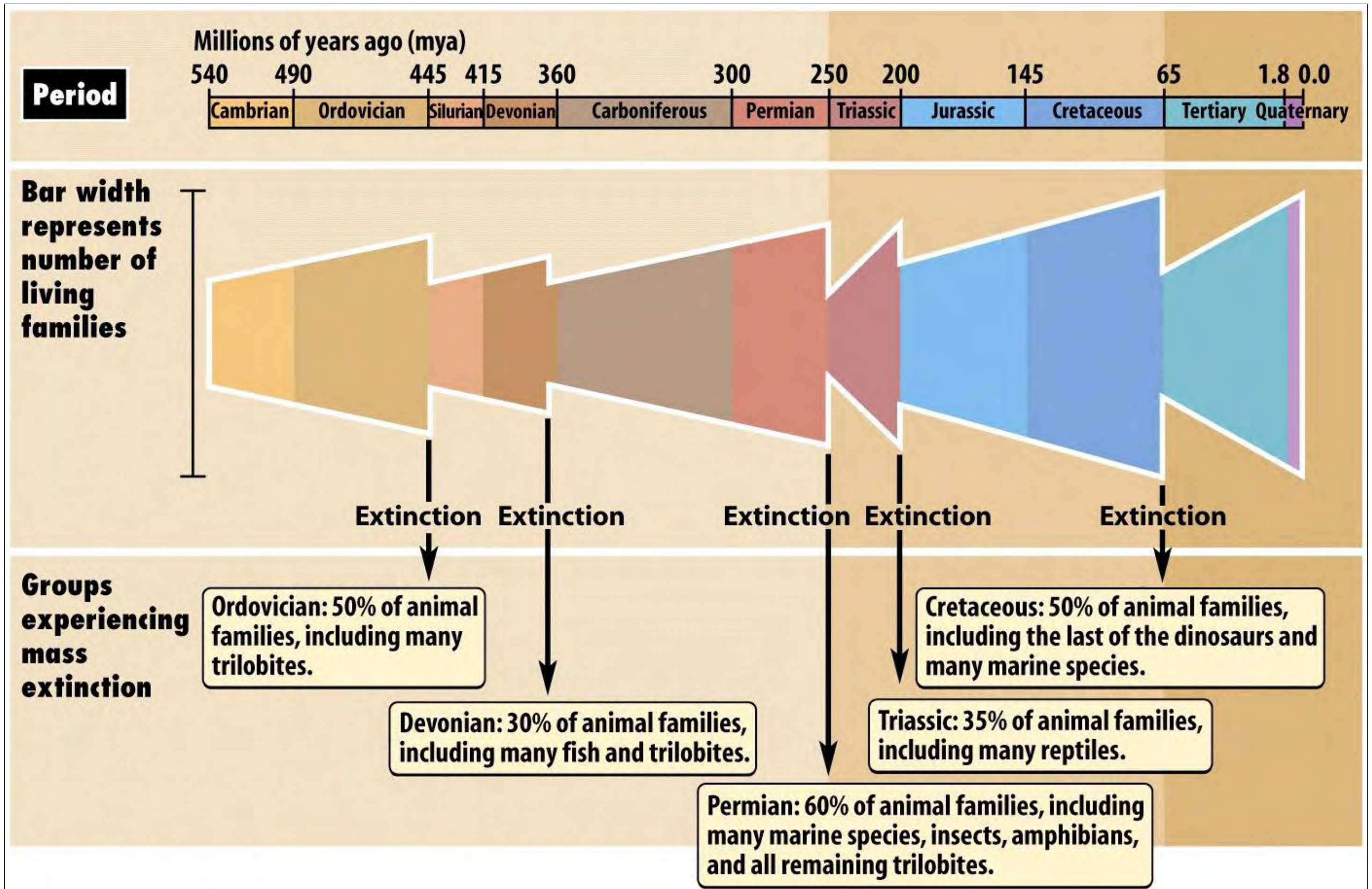


Figure 19-8 Discover Biology 3/e

Causes of Mass Extinctions
(Most Widely Supported Explanations)

- Flood basalt events* (~massive volcanism)
- Sea-level falls*
- Impact events* (an large asteroid impact probably contributed to the end-Cretaceous extinction 65 mya)
- Ocean asteroid impacts (release large quantities of CO_2)
- Sustained and significant global cooling
- Sustained and significant global warming
- Clathrate gun hypothesis (methane eruption)
- Anoxic events (depletion of oceanic oxygen levels)
- Hydrogen sulfide emissions from the seas
- Oceanic overturn (saline gradations upset by ocean circulation changes)
- A nearby nova, supernova or gamma ray burst
- Plate tectonics (movement of the continents can cause or contribute to extinctions in several ways: by initiating or ending ice ages; by changing ocean and wind currents and thus altering climate; by opening seaways or land bridges which expose previously isolated species to competition for which they are poorly adapted)
- Other hypotheses

*Most widely cited explanations

Lecture 2- Paleontology and Geologic Time (cont'd)

- Fossils in vertical sequences of strata (layers of sedimentary rock) show a definite and predictable order. This ordering, known as biological succession, was the result of extinctions and evolution. It enables us to view evolution as a sequential unfolding of transitional events.
- There are 3 categories of fossils:
  - Body fossils, the actual bodily remains of organisms.
  - Trace fossils such as tracks, burrows, teeth marks and feces which show aspects of behavior.
  - Chemical fossils, organic compounds indicating once-living material was present.
- Radiometric age dating confirms the age of ancient rocks and fossils:
  - Dates are discerned from igneous rocks, lava flows and volcanic ash deposits which are interspersed with sedimentary rocks that bear fossils.
  - Radiometric age dating relies on the fact that radioactive elements decay at constant rates.
  - Rates of decay are derived from the ratio of a parent (unstable) isotope's to a daughter (stable) isotope's weights.
  - When this ratio reaches one-half, the elapsed time is called the isotope's half-life.
  - Elapsed times (age of fossil) can be mathematically derived from other measured ratios of the isotopes' weights.

Radiometric Dating
Time scales useful in dating fossils

Unstable Isotope (Parent)	Decays to (Daughter)	Half-life (myrs)
Uranium-238	Lead-206	4500
Potassium-40	Argon-40	1260
Uranium-235	Lead-207	704
Samarium-147	Neodymium-143	108
Iodine-129	Xenon-129	17
Aluminum-26	Magnesium-26	0.74
Carbon-14	Nitrogen-14	0.00573

Other Dating Techniques

- Biochronology:
  - Since animal species change over time, the fauna can be arranged from younger to older. At some sites, animal fossils can be dated precisely by one of these other methods. For sites that cannot be readily dated, the animal species found there can be compared to well-dated species from other sites. In this way, sites that do not have radioactive or other materials for dating can be given a reliable age estimate.
- Molecular clock:
  - Compares the amount of genetic difference between living organisms and computes an age based on well-tested rates of genetic mutation over time. Since genetic material (like DNA) decays rapidly, the molecular clock method can't date very old fossils. It's mainly useful for figuring out how long ago living species or populations shared a common ancestor, based on their DNA.
- Paleomagnetism:
  - Compares the direction of the magnetic particles in layers of sediment to the known worldwide shifts in Earth's magnetic field, which have well-established dates using other dating methods.
- Thermo-luminescence:
  - Measures the number of electrons that get absorbed or trapped within a rock or tooth over time. *(Not clear how this technique is used.)*

The Origin of Life

- *(Speculation)* Today's life originated about 4 billion years ago (bya) when organic compounds were impacted by energy *(lightning?)* in a reducing (little or no free oxygen) atmosphere:
  - This resulted in a self-replicating molecule, perhaps *RNA*.*
  - It only happened once.

Q1

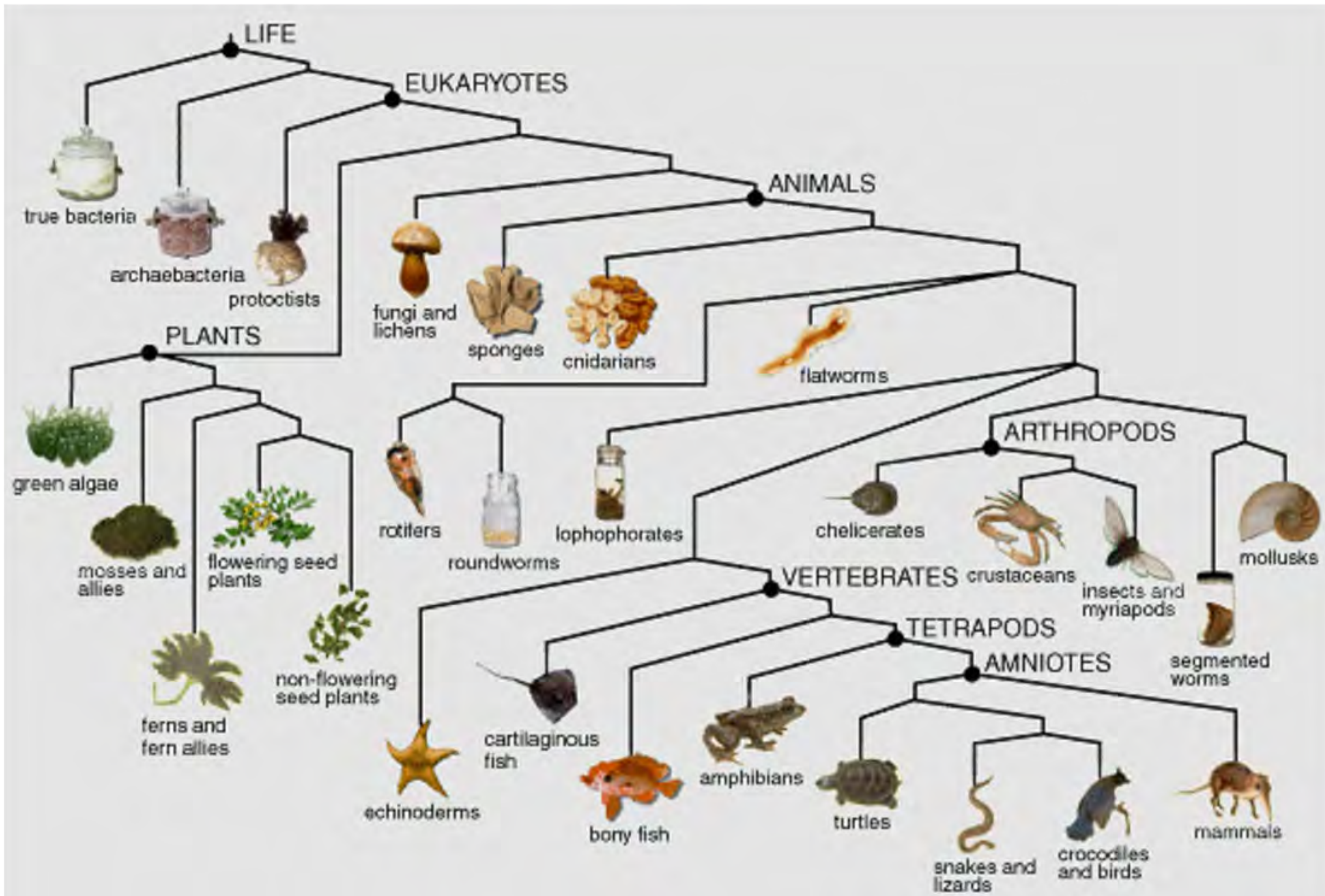
- Although scientists have not succeeded in creating life from organic molecules in the laboratory, they have reproduced many of the intermediate steps:
  - In the famous Miller-Urey experiment (1953), a spark was ignited into organic gases producing over 20 amino acids.

*Some researchers believe cells which had membranes holding lipids acting as catalysts preceded RNA.

The Origin of Life (cont'd)

- All living things, and all organisms that have ever lived for which we have evidence, are descendents of this first persistent life. It is known as the Last Universal Common Ancestor (LUCA):
  - Any two living organisms have a last (most recent) common ancestor. E.g., humans and chimpanzees diverged about 7 mya from a common ancestor, a hominid, which looked more like a modern ape than a human.
- The environment 4 bya was vastly different than today:
  - No continents.
  - Reducing atmosphere.
  - Volcanoes, earthquakes, meteorite impacts were frequent.

Cladogram Showing Common Ancestry of All Life



The Earliest Life

- Earth was able to support life only after the planet had cooled enough for a rocky crust to solidify:
  - Once that happened, water vapor from volcanoes condensed in the atmosphere, fell as rain, and collected on the Earth’s surface.
  - Besides water vapor, volcanoes also produced gases rich in the basic ingredients of life: carbon, hydrogen, oxygen, and nitrogen. Toxic gases such as ammonia and methane were common. Earth's early atmosphere consisted entirely of these volcanic gases, and there was no or little free oxygen.
  - In the primordial “soup” of the early seas, organic molecules concentrated, formed more complex molecules, and became simple primordial life. This occurred between about 4 and 3.7 bya.

Q1

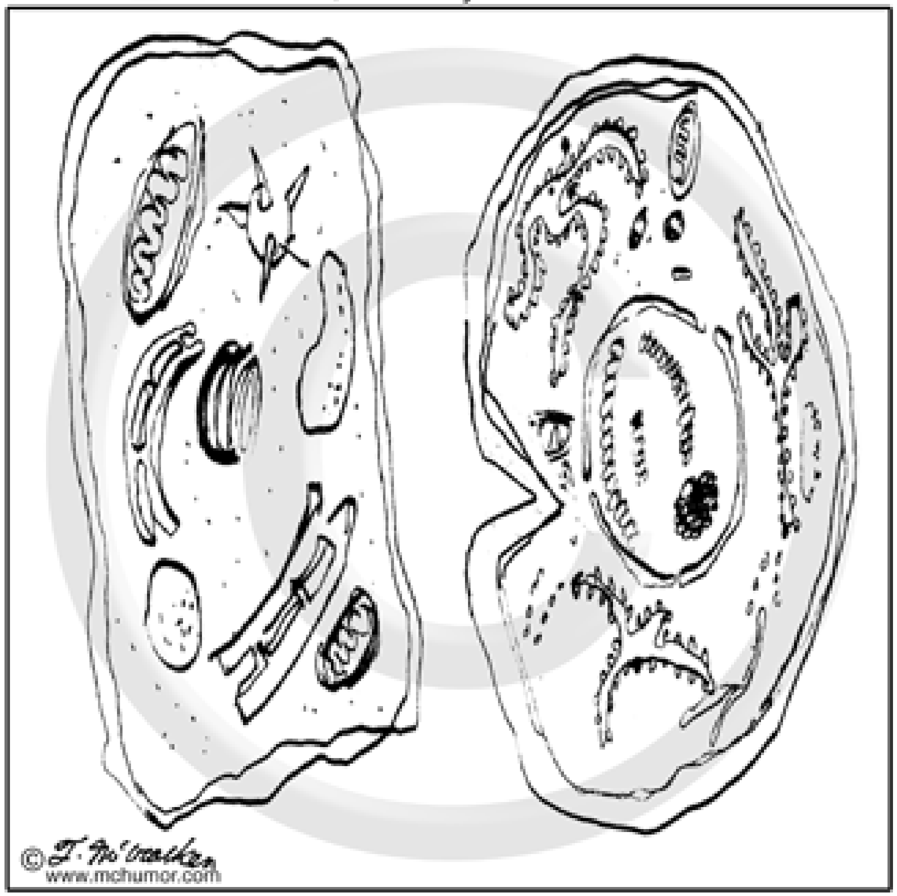
The Earliest Life (cont'd)

- Studies of genetic material indicate that a living group of single-celled organisms called Archaea may share many features with early life on Earth:
  - Many Archaea (extremophiles) now live in hot springs, deep-sea vents, saline water, and other harsh environments.
  - If the first organisms resembled modern Archaea, they also may have lived in such places, but **direct evidence for early life is controversial** because it is difficult to distinguish between complex inorganic structures and simple biological ones in the geologic record.
- The transition from complex organic molecules to living cells could have occurred in several environments:
  - Small, warm ponds are one possibility, but recent work has suggested that deep-sea hydrothermal vents may have been the cradle of Earth's life. These environments contain the chemicals and the source of energy needed to synthesize more complex organic structures.

Topics for Discussion – 1

- Is "descent with modification" different than "natural selection?" If so, how? Just what is modified?
- Are mutations necessary for speciation to occur or is the genetic variation among individuals within a species sufficient?
- Did life on earth originate only once and, if so, how do we know this?
- Describe life before prokaryotes.
- Why do detrimental genes such as genes that cause disease persist in a species' genome?
- How did blue eyes and light skin evolve in northern regions when it is well known that humans migrated from Africa where both alleles (dominant and recessive) were undoubtedly for dark eyes and skin?

MCHUMOR.com by T. McCracken



"I've willed my body to science when I die."

Single-Celled Life – Definitions

- **organelle**– specialized subunit; is to a cell as an organ is to a body.
- **chloroplasts**– trap energy from sunlight (photosynthesis); comes from cyanobacteria.
- **mitochondria**– produces energy from the oxidation of glucose; comes from protobacteria.
- **cytoplasm**– gel-like substance enclosed within cell membrane; contains cell contents except the nucleus in eukaryotes.

no. of cells in the human body = 10–50 trillion

no. of bacteria in the human body = 10 x no. of cells = 1–3 percent of body mass

Lecture 3 – Single-Celled Life

- *Prokaryotic* cells:
  - Evolved about 3.7 bya.
  - Small, lack a nucleus so their chromosomes are scattered throughout the cell, lack organelles with membranes.
  - Reproduce asexually by binary fission which is a replicative process:
    - Cell division by mitosis:
      - Each daughter cell ends up with two complete sets of chromosomes.
    - Also, horizontal gene transfer (the transference of DNA between two cells, as in bacterial conjugation) and mutations (DNA copying errors) occur, processes which are not replicative.
  - Includes bacteria and archaea:
    - Bacteria acquire resistance to anti-bacterial drugs via mutations and horizontal gene transfer (non-replicative).
  - 1-10 um in diameter.

Lecture 3 – Single-Celled Life (cont'd)

- *Eukaryotic* cells:
  - Evolved about 2.7 bya from prokaryotes.
  - Larger, have a definite nucleus containing chromosomes, have complex organelles such as mitochondria and chloroplasts.
  - Reproduce sexually:
    - Cell division by meiosis (non-replicative):
      - Each daughter cell ends up with one set of chromosomes.
    - Meiosis evolved about 1.4 bya, 1.3 by after eukaryotes which were originally asexual.
  - Includes:
    - Chromista– eukaryotes with chloroplasts.
    - Protozoa– originally one-celled animals which have motion (somewhat outdated):
      - Amoebae are protozoa without a definite shape.
      - Paramecia are a genus of protozoa (ciliate phylum) which live in water.
    - Algae– Photosynthesize; can be one-celled or larger.
  - 0.1–1 mm in diameter.
  - Organelles of eukaryotes were once free-living bacteria "taken inside" the eukaryotic cell.

Lecture 3 – Single-Celled Life (cont'd)

- Multiple prokaryotic cells fused to form eukaryotic cells (=*endosymbiosis*).
- *Stromatolites* are trace fossils of prokaryotes:
  - Formed by colonies of cynobacteria.
  - Chemical markers also show the presence of former life.
  - Precambrian fossils (>543 mya) are rare due to plate tectonics, weathering, etc.
- Genetic variability in eukaryotes due to sexual reproduction enabled them to better adapt to changing environments (survive) and eventually evolve into muticellular organisms– the first animals (metazoans).
- The evolution of eukaryotes from prokaryotes literally changed the world enabling later evolution to multicellular organisms:
  - Photosynthesis from algae increased the oxygen content of the atmosphere and oceans.
  - Fungi filled a niche as decomposers in marine environments.

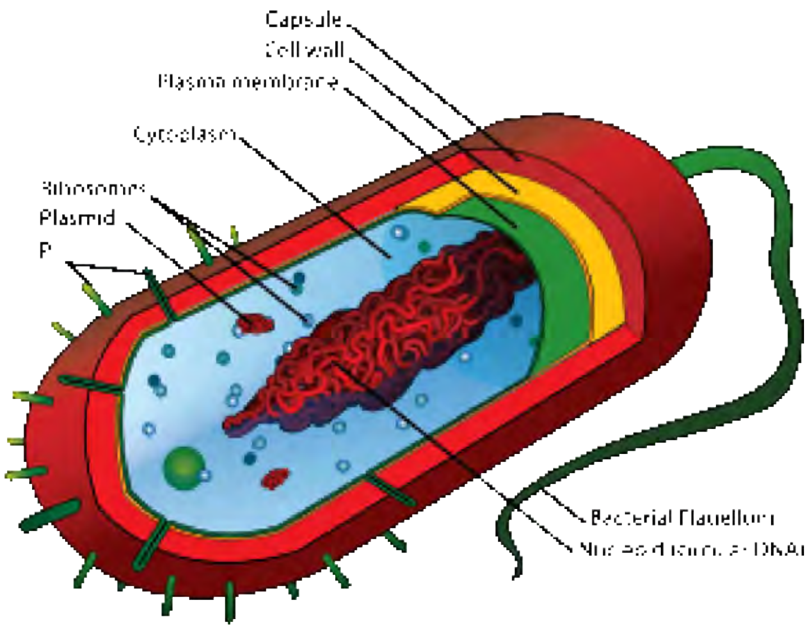
Mutation Rates

- The mutation rate of an organism is an *evolved* characteristic and is strongly influenced by the genetics of each organism, in addition to strong influence from the environment.
- Mutation rates differ between species and even between different regions of the genome of a single species.
- Mutations in non-coding DNA tend to accumulate at a faster rate than mutations in DNA that is actively in use in the organism (gene expression).
- A region which mutates at predictable rate is a candidate for use as a molecular clock:
  - If the rate of neutral mutations in a sequence is assumed to be constant and if most differences between species are neutral rather than adaptive, then the number of differences between two different species can be used to estimate how long ago the two species diverged.

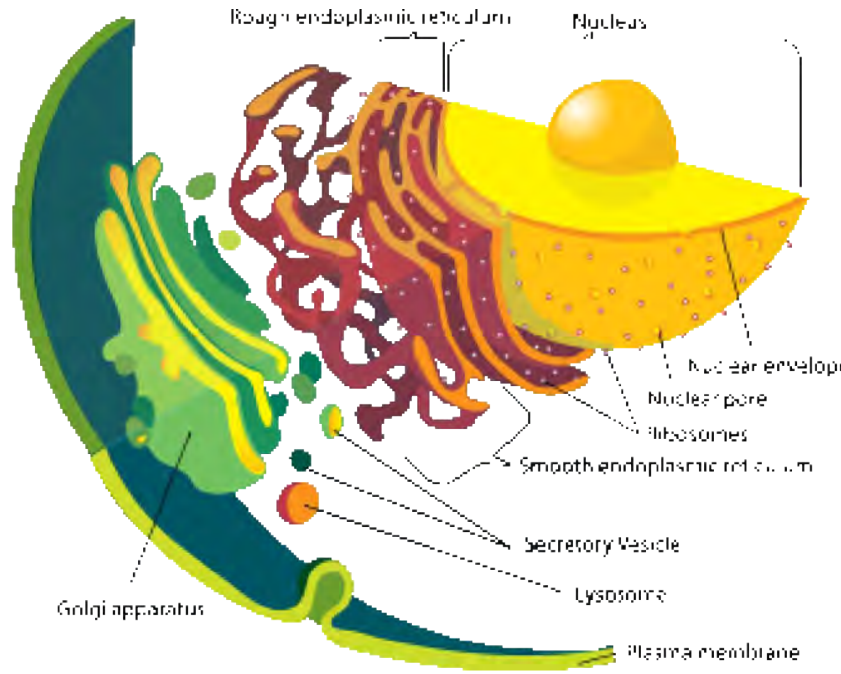
Mutation Rates (cont'd)

- In general, the mutation rate in unicellular eukaryotes and bacteria is ~0.003 mutations per genome per generation.
- The human mutation rate is higher in the male germ line (sperm) than the female (ova), but estimates of the exact rate have varied by an order of magnitude or more:
  - Human mitochondrial DNA has been estimated to have mutation rates of $\sim 3 \times 10^{-5}$ per base per 20 year generation.
  - These rates are considered to be significantly higher than rates of human genomic mutation at $\sim 2.5 \times 10^{-8}$ per base per generation.
  - Using data available from whole genome sequencing, the human genome mutation rate is similarly estimated to be $\sim 1.1 \times 10^{-8}$ per site per generation.

Single-Celled Organisms



Cell structure of a **bacterium**, a member of one of the two domains of **prokaryotic** life.



Detail of the endomembrane system of the **eukaryotic** cell and its components.

Archaea (Prokaryotes)

Archaea were first found in extreme environments, such as volcanic hot springs. Pictured here is Grand Prismatic Spring of Yellowstone National Park.

The **ARMAN** are a new group of **archaea** recently discovered in acid mine drainage.

Examples of extremophiles

Stromatolites (Prokaryotes)

Stromatolites are layered accretionary structures formed in shallow water by the trapping, binding and cementation of sedimentary grains by biofilms of microorganisms, especially cyanobacteria (commonly known as blue-green algae). Stromatolites provide some of the most ancient records of life on Earth by fossil remains which date back more than 3.5 billion years.

Lecture 4 – Metazoans

- Single-celled eukaryotes (=*protozoans*) evolved into multicellular eukaryotes called metazoans between 1 bya and 600 mya.
- These were the first animals, believed to be quite similar to today's sponges.
- Molecular clocks rely on regularly occurring genetic mutations over time:
  - So genetic distance between two organisms corresponds to the elapsed time since they diverged from each other.
  - This is how it was determined metazoans diverged from single-celled eukaryotes about 1 bya.

Lecture 4 – Metazoans (cont'd)

- Metazoans are divided into 2 groups based on symmetry:
  - *Radiatra* display radial symmetry such as sponges and jellyfish.
  - *Bilateria* display bilateral symmetry such as humans.
- Body and trace fossils of metazoans were found in Precambrian deposits from 580–550 mya:
  - They had stiff, tough exteriors but lacked shells.
  - Horizontal burrows, surface trails and scrape marks indicate some had an ability to move and an internal musculature.
  - They lived in shallow marine environments.
  - They grazed on algal mats or other organic material.

Metazoans

Vernanimalcula quizhouena is a fossil believed by some to represent the earliest known member of the **Bilateria.**

The sponge: the earliest metazoa, a member of the **Radiatra.**

Lecture 5 – The Development of Skeletons

- Cambrian fossils (545–505 mya) show a profusion of both soft-bodied and hard-bodied organisms
  - The hard-bodied have tissues into which minerals (often calcite) precipitated from the surrounding environment. This process is called *biomineralization*.
  - The most common example of this is seen in molluscan shells.
  - This led to the development of spikes and plates for protection from predators and both exoskeletons (in arthropods) and endoskeletons.
  - Most soft-bodied animals do not have a skeleton, but some do.
- An arms race ensues when prey evolves due to selection pressure from predators and, then, the reverse occurs. This resulted in coevolution of both beginning in the Cambrian period.
- The development of predators and true coral reefs were both important results of biomineralization establishing the foundation of marine ecosystems.

Skeletal Invertebrates

The fossil coral *Cladocora* from the Pliocene. It has an exoskeleton made from a calcium compound.

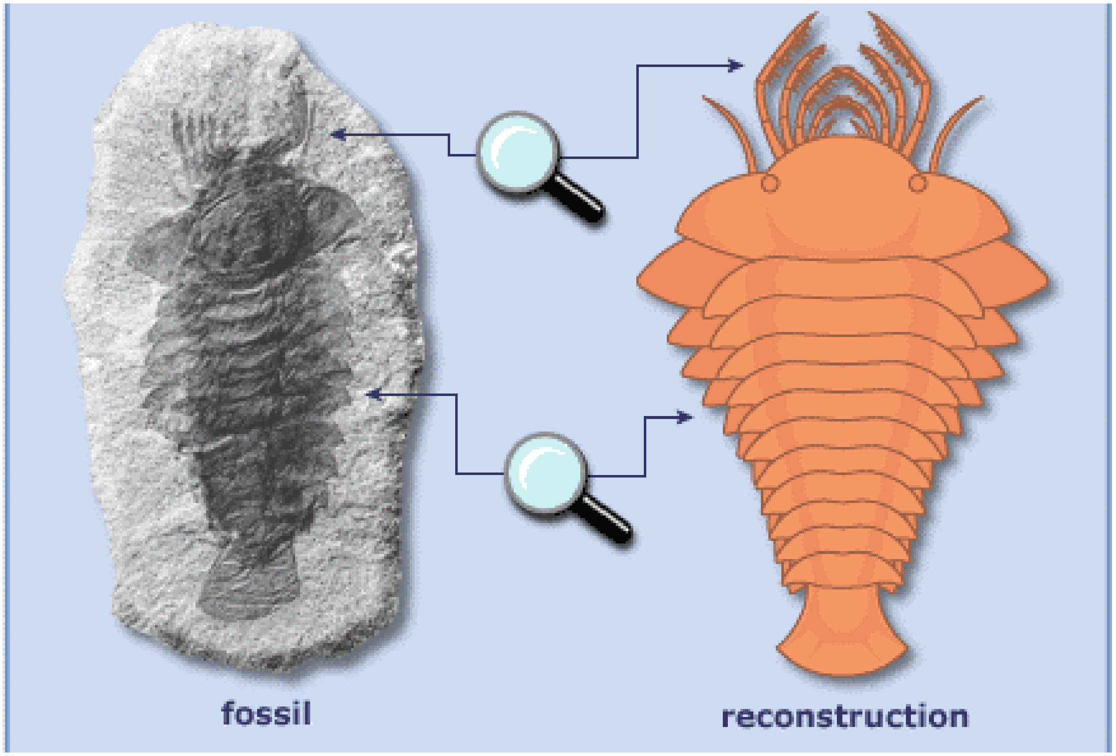
Pacific sea nettle is a jellyfish, the oldest multi-organ animal. It has a hydrostatic exoskeleton, a fluid-filled cavity surrounded by muscles which produces motion and alters the body shape.

Examples of skeletal invertebrates over 500 million years old

The Cambrian "Explosion"

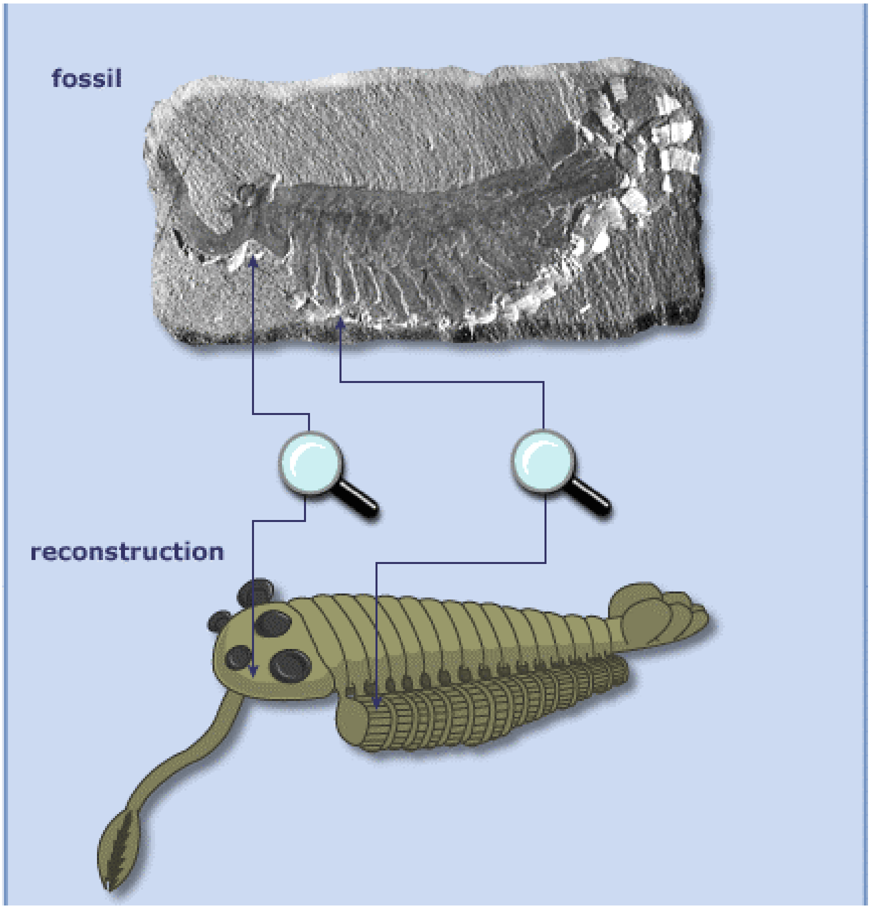
- A plethora of animals dated to about 542-500 mya "suddenly" appeared in the fossil record:
  - All major phyla are represented.
  - Before about 580 mya, most organisms were single-celled, sometimes organized into colonies.
- The most famous site for these fossils of "weird" yet often complex organisms is know as the Burgess Shale in British Columbia, Canada dated at 505 mya:
  - It contained rare imprints of soft parts (legs, antennae).
- This "sudden" appearance supports the controversial "punctuated equilibrium" *theory* of Stephen Jay Gould and Niles Eldredge:
  - Long periods of evolutionary stasis punctuated by relatively sudden change (appearance of new life-forms).
- Many were arthropods and *echinoderms* (e.g., starfish), but all other major phyla were represented. *Trilobites* were:
  - Diverse marine arthropods that lived from 520-250 mya.
  - One of the most successful early animals lasting 270 my.
  - The most diverse extinct organism ever found (17,000 species).
  - They ranged in length from 0.04 to 28 in. (most common 1.2 to 3.9 in.).
  - They finally disappeared during the end-Permian mass extinction.

Cambrian Fauna



Sanctacaris was probably a *chelicerate*, the arthropod group that includes spiders, scorpions, and horseshoe crabs. This group got its start in the Precambrian seas, invaded the land more than 400 million years ago, and still thrives today.

Cambrian Fauna



Opabinia was not an arthropod – it lacked the namesake trait of arthropods: jointed legs. It made the largest single contribution to modern interest in the Cambrian explosion. Note: 5 eyes and a hose-like snout.

Trilobites

Trilobites *(Kainops invius)*

Cheirurus sp., middle Ordovician age

Redlichida, such as this *Paradoxides*, may represent the ancestral trilobites

Phacopid trilobite, Devonian age

Vertebrates – Definitions

- Chordates form a phylum of creatures that are based on a bilateral body plan, and is defined by having at some stage in their lives all of the following:
  - A **notochord**, a fairly stiff rod of cartilage that extends along the inside of the body. Among the vertebrate sub-group of chordates the notochord develops into the spine, and in wholly aquatic species this helps the animal to swim by flexing its tail.
  - A dorsal **neural tube**. In fish and other vertebrates this develops into the spinal chord, the main communications trunk of the nervous system.
  - **Pharyngeal gill slits**. The pharynx is the part of the throat immediately behind the mouth. In fish the slits are modified to form gills, but in some other chordates they are part of a filter-feeding system that extracts particles of food from the water in which the animals live. In mammals, associated pharyngeal gill arches became jaws, inner ear bones and other parts.

Lecture 6 – The Rise of Vertebrates

- Also during the Cambrian, some invertebrate animals evolved into animals with primitive backbones, leading to the first *chordates* and vertebrates (the subphylum):
  - An example of an early chordate was the eel-like *conodont*.
- Chordates have pharyngeal gill slits and a *notochord* running the length of the body to support its dorsally located nerve chord.
- All vertebrates are chordates as are some invertebrates.
- Vertebrates are placed in a group called *Craniata*:
  - Craniates are chordates with skulls; most are vertebrates.
  - Hagfish are craniates, but are not considered vertebrates – the only known animal having a skull without a spine. They are usually classified as chordates.
  - Most modern vertebrates are descended from jawed fish.

Lecture 6 – The Rise of Vertebrates (cont'd)

- Molecular clock data suggest the divergence of non-chordates from chordates and invertebrates from vertebrates happened in the late Proterozoic eon, between 800 and 750 mya. No fossils evidencing this have been found, however.
- The importance of the transition from invertebrates to vertebrates is vast; vertebrates changed the world, occupying every environmental niche and they include most fish, all amphibians, reptiles, birds and mammals.

Living Invertebrates
(these are not chordates)

Protozoa, which are 1-celled animals.

Annelids are most worms. It is a separate phylum.

Mollusks, the largest invertebrate and marine phylum with 85K extant species. Mollusks include: bivalves (oysters, clams, mussels), gastropods (snails, slugs), and squid, octopi and cuttlefish which are the most neurologically advanced invertebrates.

Echinoderms (starfish shown) have a radial body plan.

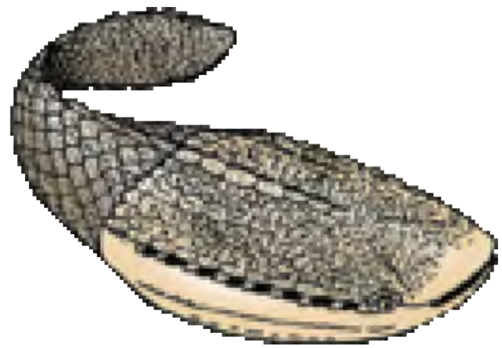
The Rise of Vertebrates

A Pacific hagfish, an example of a craniate but not considered a vertebrate. The jawless hagfish is a living fossil which has not essentially changed for 300 million years. It ranges from 1.6" to 50" in length (20" average).

Dunkleosteus was a gigantic, 33 ft-long, 3.6 ton prehistoric fish about 400 mya. It had a primitive jaw structure and may be ancestral to modern vertebrates.

The Rise of Vertebrates

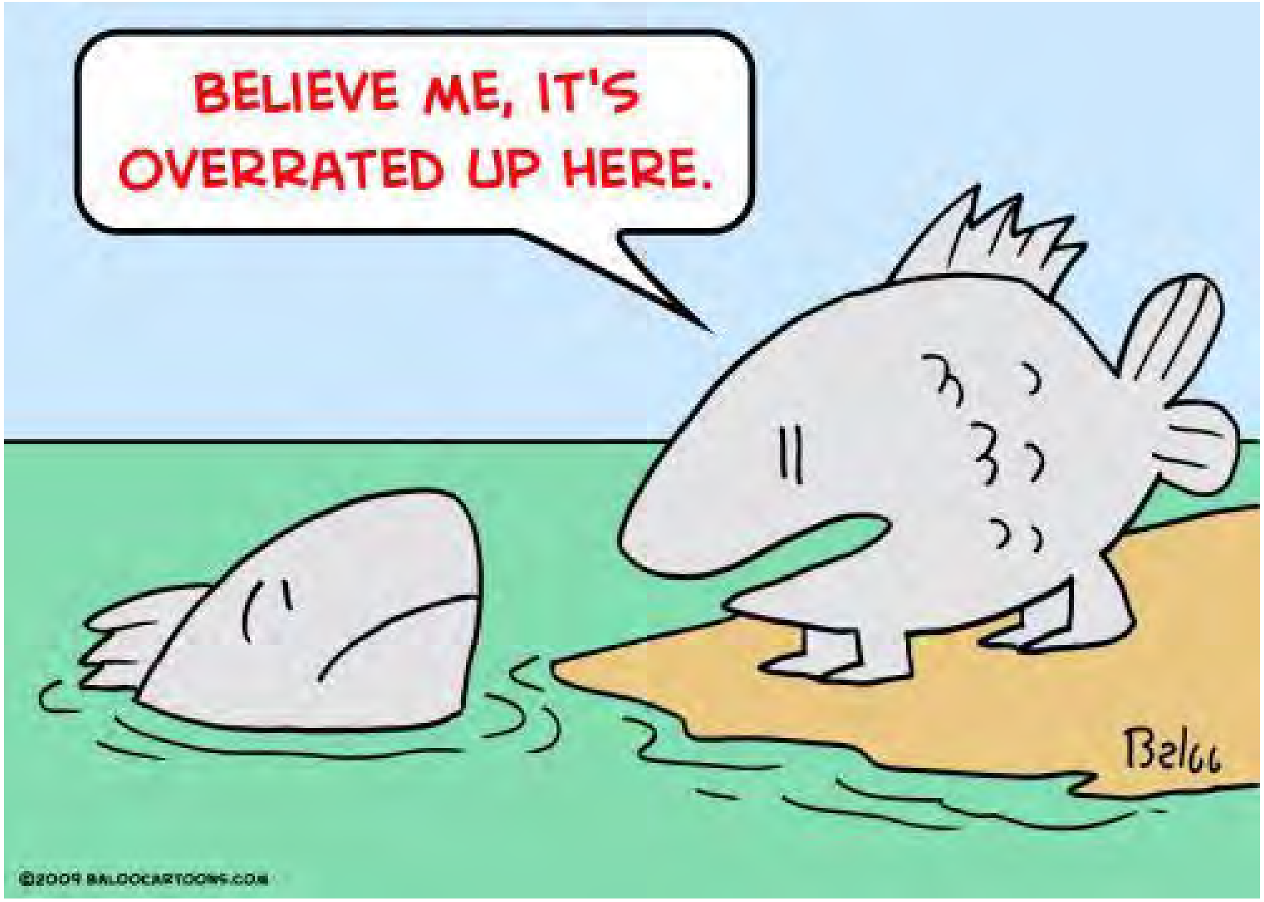
Conodonts (extinct) resembled primitive jawless eels.



Ostracoderms (extinct) were armored jawless fish.

Placoderms (extinct) were armored jawed fish. It is ancestral to modern vertebrates.

A modern jawless (vertebrate!) fish, the lamprey, attached to a modern jawed fish.


BELIEVE ME, IT'S OVERRATED UP HERE.
Baloo
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Lecture 7 – Colonization of the Land

- Sea animals need the following to make the jump to terrestrial environments:
  - Ability to prevent dehydration
  - Ability to tolerate temperature extremes
  - Ability to stand up because of greater gravitational challenges
  - Ability to spread gametes and reproduce
- In the early Cambrian world (about 540 mya):
  - The land was barren, with eroded sediment rather than soil.
  - The atmosphere was about 15% oxygen, opposed to the current 21%.
- Some sea life adapted to terrestrial environments in the early Paleozoic era (500 to 400 mya):
  - These organisms lived first in all water environments, then a combination of in water and on land, finally some totally on land.

Lecture 7 – Colonization of the Land (cont'd)

- A major glaciation* occurred during this period which lowered sea levels and exposed more land for organisms living in formerly shallow marine areas. These emergent areas already had colonies of bacteria and archaeans to provide food for the newcomers.
- Freshwater algae and fungi made the transition from water to land about 475–425 mya.
- Land plants probably descended from multicellular algae.
- Arthropods (an invertebrate phylum) were probably the first animals to make the transition because of their tough exoskeletons. Arthropods:
  - Have an exoskeleton, a segmented body and jointed appendages.
  - Developed internal respiratory structures.
  - May have lived on land before the advent of land plants.
  - Include crustaceans, arachnids and insects.

*A glaciation is an interval of time (thousands of years) within an ice age that is marked by colder temperatures and glacier advances.

Lecture 7 – Colonization of the Land (cont'd)
(Arthropod Characteristics)

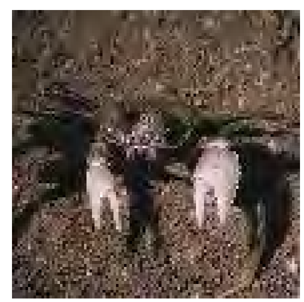
- Insects:
  - 6 legs
  - 1.4-1.8 million species
  - Exoskeleton material is often a polymer called chitin
- Arachnids:
  - 8 legs
  - 100,000 species
  - Exoskeleton material is often a polymer called chitin
- Crustaceans:
  - 2-parted limbs
  - 67,000 species
  - Exoskeleton is made by biomineralizing calcium carbonate
  - Larval differences with other arthropods exist
- Other arthropod classes are millipedes, centipedes, and some others

Arthropods (Invertebrates)

Extinct and living arthropods

Insect

Arachnid



Crustacean

Lecture 8 – Origins of Insects and Powered Flight

- Insects represent one of the greatest evolutionary success stories. Their high reproduction rates and huge number of offspring assure high genetic variability in a population of a species resulting in rapid responses to selection pressures.
  - Insects are arthropods with segmented bodies, 6 jointed legs, an exoskeleton, 2 antennae and compound eyes.
- The oldest fossil insect is from the early Devonian period (about 400 mya). It was land-dwelling and related to winged insects.
- A species of dragonflies which lived 300 mya had a wingspan of 2.5 ft.

Lecture 8 – Origins of Insects and Powered Flight (cont'd)

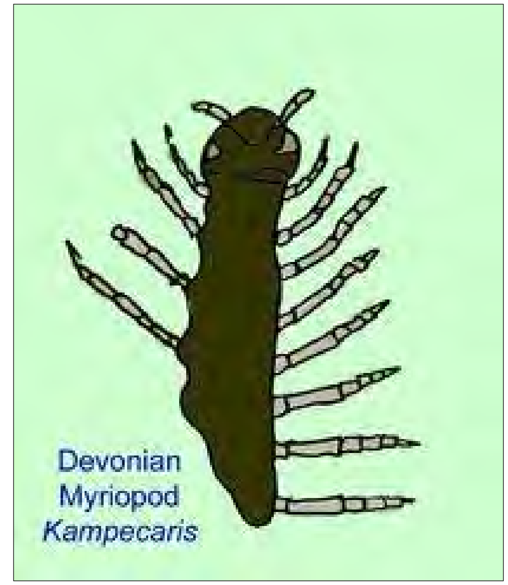
- There are about 30 orders of insects.
- Orders of winged insects include:
  - Mayflies
  - Dragonflies and damselflies
  - Cockroaches and mantises
  - Flies and mosquitoes
  - Beetles
  - Wasps, bees and ants
  - Termites
- Two theories for the origin of flight are surface-skimming and gliding.
- The discovery of *Hox* genes* informed our knowledge of how appendages on segments along the body axis evolved.
- The pollination services provided by flying insects made possible the evolution of flowering plants, forests and, later, primates who live in trees.

*A group of related genes that control the body plan of the embryo along the anterior-posterior (head-tail) axis. After the embryonic segments have formed, the Hox proteins determine the type of structures (e.g. legs, antennae, and wings in insects) that will form on a given segment.

Insects (Arthropods)

Clockwise from top left: dancefly, long-nosed weevil, mole cricket, German wasp, emperor gum moth, assassin bug.

Evolution has produced astonishing variety in insects. Pictured are some of the possible shapes of antennae.



An early arthropod (extinct), believed ancestral to millipedes (an arthropod, but not really an an insect).

Lecture 9 – Seed Plants and the First Forests

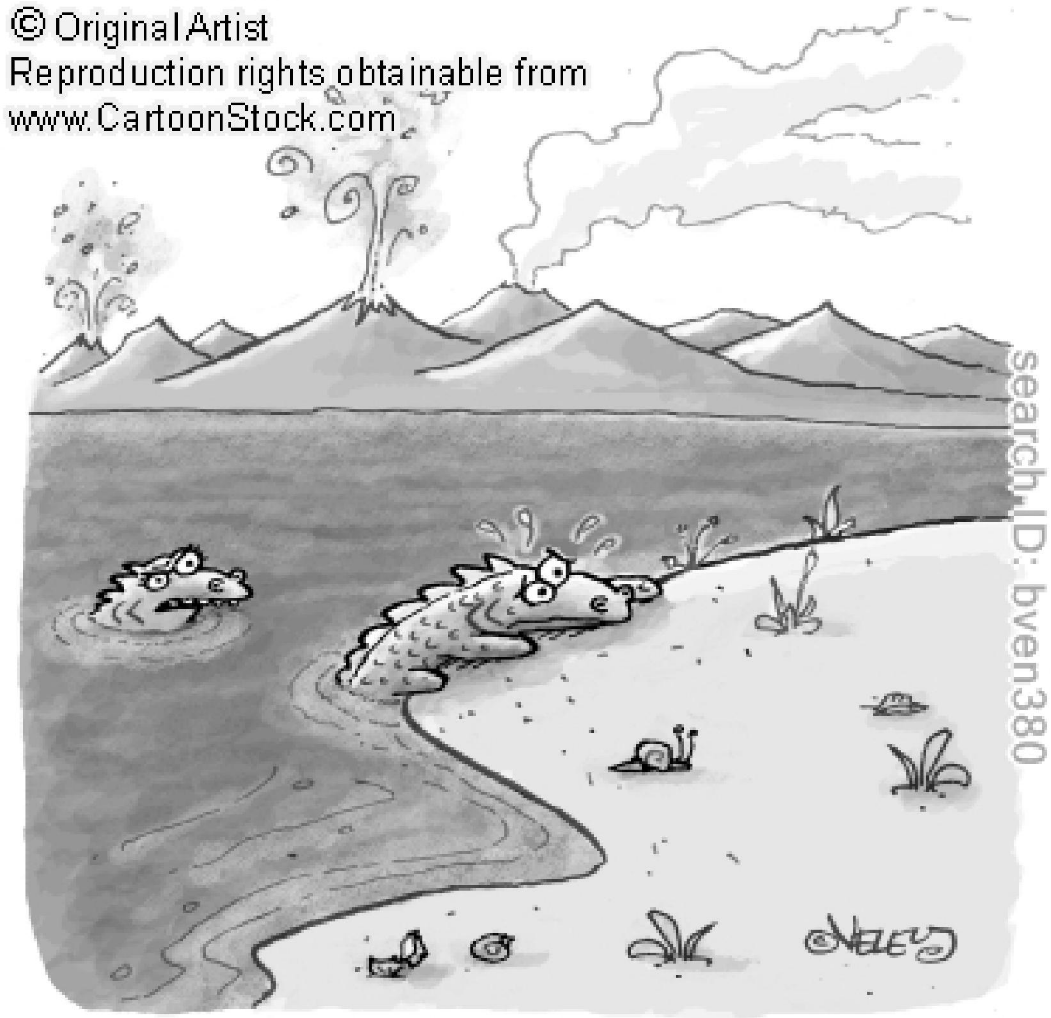
- Fern-like spore*-bearing plants evolved close to 420 mya and were common during the Devonian period (416-359 mya) and probably formed the first forests. Some specimens were 100 ft. tall with 3-ft. wide trunks.
- By 310 mya, extensive forests composed of spore- and seed-bearing plants grew in swampy environments. These vascular** plants formed the vast coal swamps of the Carboniferous period.
- The selective advantage of greater heights was competition for sunlight needed for photosynthesis. As taller and taller trees evolved, they created shade allowing shorter plants selected for shade tolerance.

*Spores are asexual units of reproduction. Spore bearers include mosses and green algae.

**Vascular tissues distribute resources such as water throughout the plant enabling it to grow much larger than non-vascular plants.

Lecture 9 – Seed Plants and the First Forests (cont'd)

- The most important trait that evolved in vascular plants from spore-bearers was the ability to form seeds. The seed-bearers developed:
  - A seed coat for protection against desiccation.
  - Nutrients within the seeds.
  - An embryonic or potential new plant that uses the nutrients to grow.
- The strategy of using spores for reproduction depends on luck (wind conditions, etc.) for fertilization to occur. Seed plants depend on internal fertilization (sexual).
- Seeds (vascular plants) allowed land plants to adapt to drier conditions; they no longer needed to grow near water sources.
- Forests changed terrestrial ecosystems: altering landscapes, increasing the oxygen content and decreasing the carbon dioxide content of the atmosphere, and altering the weather. Forest canopies gave vertebrate animals new opportunities to leave the water and start moving around on land.



"It may be evolution to you, but I call it 'avoidance of intimacy issues!'"

Fish

- The evolution of fish is not studied as a single group – it is not an evolutionary transition. Fish are not a clade – they have a latest common ancestor, but some of the descendants of that common ancestor are not fish, they are tetrapods.
  - The latest common ancestor of fish is thought to be similar to the coral-like sea squirt (tunicate) whose larval stage persisted to adulthood.
- A fish is any member of a paraphyletic* group of organisms that consist of all gill-bearing aquatic craniates that lack limbs with digits.
  - All fish are of the chordate phylum.
  - Most are vertebrates, but some early fish were not (e.g., hagfish, lancelets).
  - Jawed fish are ancestral to all other vertebrates (tetrapods) and modern ones are vertebrates.
  - Lampreys are a jawless vertebrate!
  - Conodonts may be primitive fish.

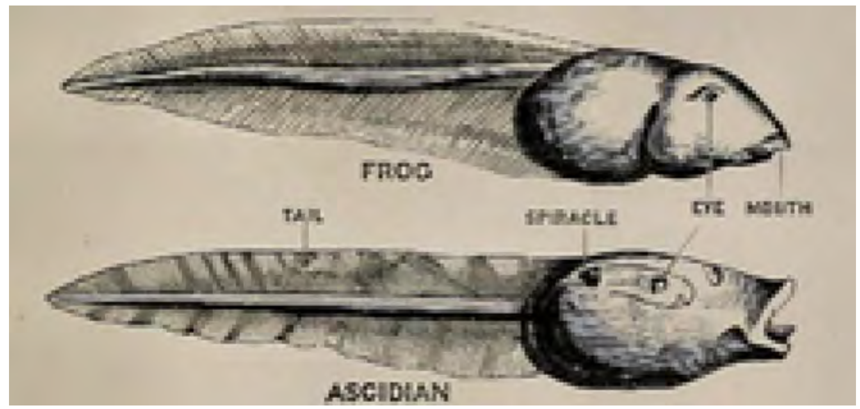
  * Not monophyletic (clade)

Fish (cont'd)

- Fish are the most speciose vertebrate animal with 28K known extant species of which 27K are bony fish.
- There are 5 classes of fish:
  - Jawless fish incl. hagfish, lampreys and extinct varieties
  - Cartilaginous fish incl. sharks and rays
  - Armored fish incl. extinct varieties
  - Spiny sharks (all extinct?)
  - Bony fish incl. ray-finned and fleshy finned which incl. **lobe-finned fish** (ancestral to all tetrapods)

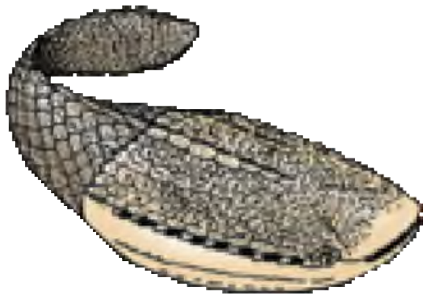
Sea Squirt

Sea tulips, adult tunicates



Comparison of frog tadpole (above) and tunicate tadpole (below)

The 5 Classes of Fish



Ostracoderms (extinct) were armored **jawless** fish.

Megalodon is an extinct species of shark that lived about 28 to 1.5 mya. It is a **cartilaginous** fish.

Placoderms (extinct) were **armored** jawed fish.

Spiny sharks (extinct) were the earliest known jawed fish.

Guiyu oneiros, the earliest known **bony** fish, lived during the Late Silurian, 419 million years ago). It has the combination of both ray-finned and lobe-finned features.

Lecture 10 – From Fish to 4-Limbed Animals

- The transition from lobe-finned fish to four-legged vertebrates (*tetrapods)* took place in the Devonian-Carboniferous periods (roughly 400-300 mya):
  - The Devonian is known as the "age of fish."
  - This was the second colonization of land, the first was by arthropods about 100 my earlier.
  - Tetrapods are of the phylum, chordate and the subphylum, vertebrate. Tetrapods consist of 5 classes:
    - Amphibians
    - Reptiles
    - Dinosaurs
    - Birds
    - Mammals
- Lobe-finned fish:
  - Have four thick, stubby fins.
  - Some have lungs.
  - Survivors today include coelacanths and lungfish.
- Lungs allowed them to stay out of the water for extended periods of time.

Lecture 10 – From Fish to 4-Limbed Animals (cont'd)

- The paired pelvic and pectoral fins of lobe-finned fish are *homologous* for pelvic and pectoral fins (limbs) on tetrapods. To support the greater weight in locomotion on land, vertebrates (tetrapods) leaving the water:
  - Developed lengthened limbs with stronger joints between bones and stronger muscles.
  - Evolved added structural support in their skeletons.
  - Developed a neck to enable the head to move more freely to facilitate walking and predation.
- Body fossils of lobe-finned fish show many transitional traits to tetrapods:
  - The pectoral fin has most homologous bones of a tetrapod "arm/hand."
  - One fossil shows a flat head and body with eyes on top of the skull, ear notches, shoulders disconnected from the skull, and probably both lungs and gills.
  - Another fossil shows 6 or 7 digits in the feet.
- Enclosed eggs and other adaptations, along with the growth of forests, allowed certain lineages of tetrapods to become reptiles during the Carboniferous period (about 320 mya).

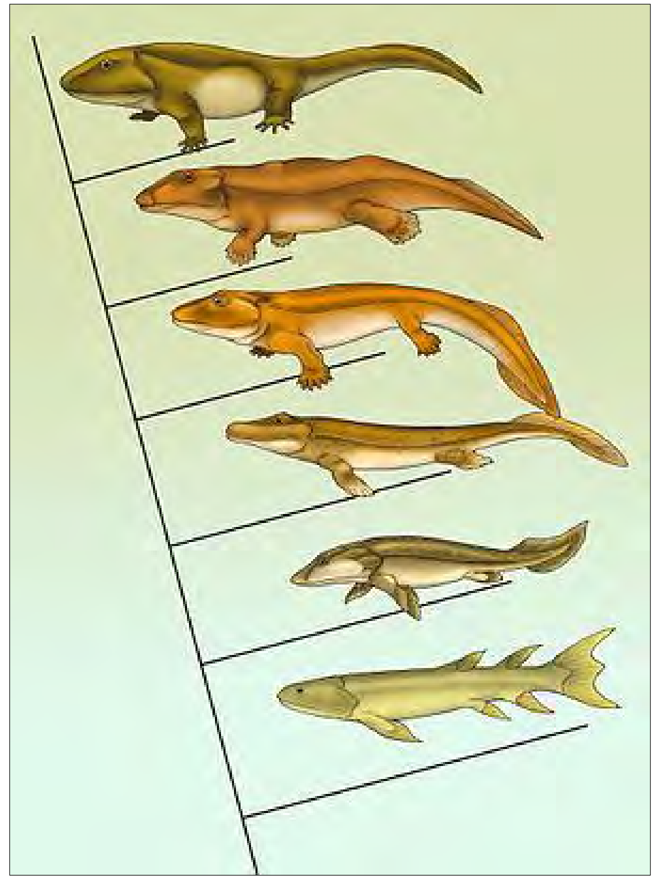
Lobe-finned Fish

South American Lungfish: If you look carefully, you can see the four slender "fins" of this fish, which are homologous to the four legs of terrestrial vertebrates (tetrapods).

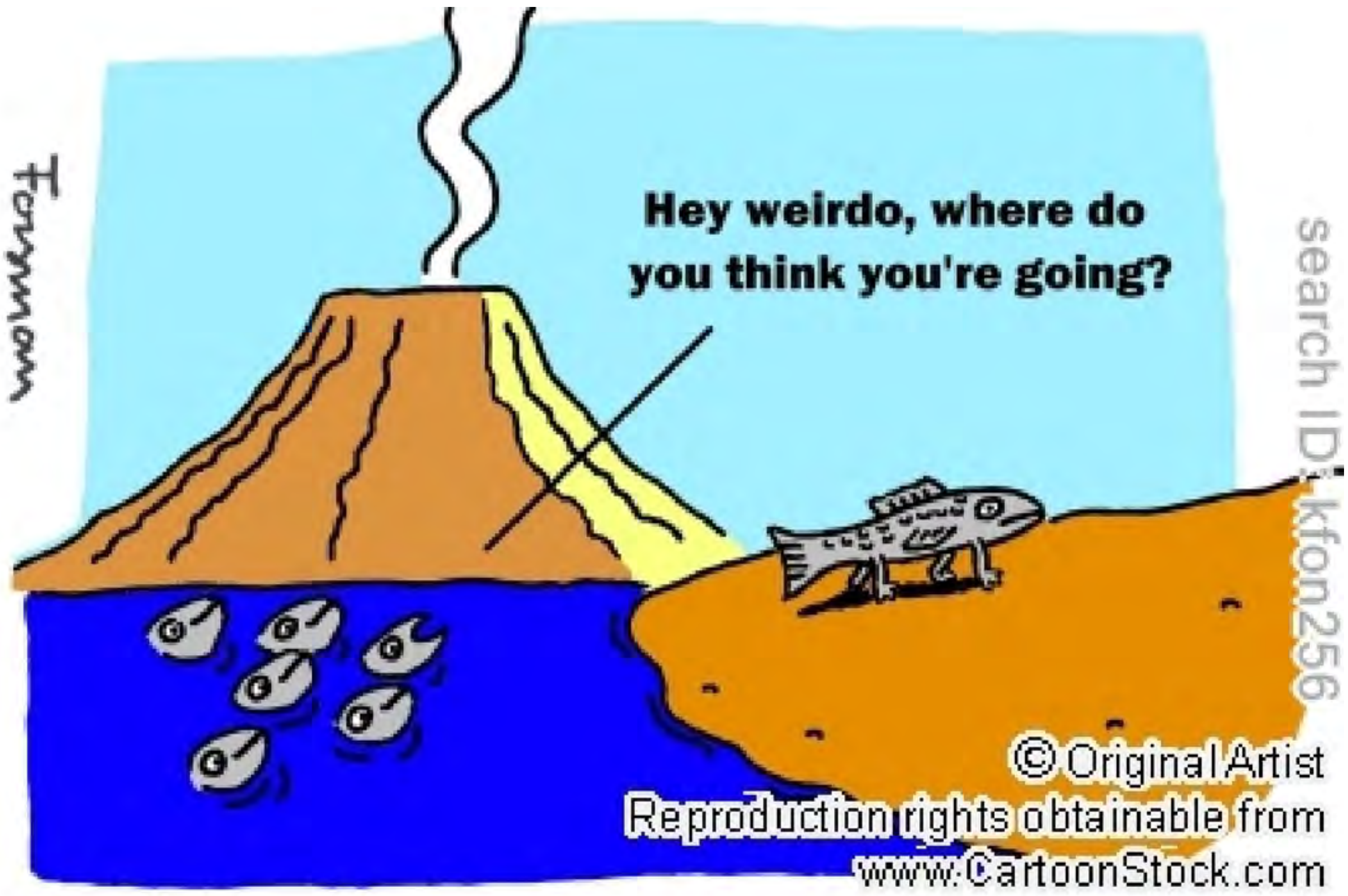
The primitive-looking **coelacanth** (pronounced SEEL-uh-kanth) was thought to have gone extinct with the dinosaurs 65 million years ago.

Evolution of Tetrapods

Ichthyostega (lived about 365 mya) once stood alone as the transitional fossil between fish and tetrapods, combining a fishlike tail and gills with an amphibian skull and limbs.



A cladogram of the evolution of tetrapods showing some of the best-known transitional fossils. It starts with Eusthenopteron at the bottom, indisputably still a fish, through Panderichthys, Tiktaalik, Acanthostega and **Ichthyostega** to Pederpes at the top, indisputably a tetrapod.


Hey weirdo, where do you think you're going?
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Lecture 11 – The Egg Came First: Early Reptile Evolution

- A fossil of the earliest known reptile was found inside a fossil tree and dated to 310 mya.
- The most basic differences between amphibians and reptiles are ecological, not anatomical:
  - Amphibians have external fertilization and depend on water environments their entire lives.
  - Amphibians are the ancestors of all *amniotes*.
  - Reptiles have internal fertilization and lay their eggs and live in a wide range of environments.
- The group amniota are tetrapods with internal fertilization classified by the number of holes (temporal fenestrae) on the sides of their skulls:
  - *Diapsids* have two on each side and are within the clade *Sauropsida* and includes dinosaurs, lizards, snakes, alligators, and birds;
  - *Synapsids* (another clade, *Synapsida)* have one and are represented by all modern mammals and all mammal-like reptiles;
  - *Anapsids* have none and are also within Sauropsida and includes turtles.
  - Members of a clade share a common ancestor.

Q2

Lecture 11 – The Egg Came First: Early Reptile Evolution (cont'd)

- Reptile and amphibian skulls differ, especially the jaw. The reptilian jaw is stronger because of greater biting strength required by its diet. Other differences in the reptilian skeleton are due to it spending most of its life on land.
- Most reptiles lay amniotic (=*cleidoic*) eggs which are enclosed by a tough, leathery shell.
- A transitional fossil between amphibians and reptiles shows 5 digits on all feet and limbs that seem adapted for life on land:
  - 5 digits on both fore and hind feet is typical of reptiles except snakes.
  - Amniote trace fossils from the late Carboniferous show impressions of hard claws, 5 digits and evidence of scales and a less sprawling gate (than amphibians).
  - Most amphibians (except caecilians) have 4 digits on their fore feet and 5 on their hind feet. Caecilians have none.

Lecture 11 – The Egg Came First: Early Reptile Evolution (cont'd)

- Other differences between reptiles and amphibians:
  - Amphibians lay many eggs which are then fertilized by the male. Reptiles lay relatively few eggs (already fertilized) and then care for the eggs and hatchlings. This may have led to live birth in mammals and the way their young are nurtured as well as many behavioral innovations.
  - Reptile eggs are enclosed in a tough, leathery shell which can be eaten by predators. The embryo grows in the amniotic fluid in the egg; hence, the name amniota. (Dinosaurs were the first tetrapod to lay mineralized eggs (calcite) which were difficult to eat.)
  - Amphibians have a larval stage (tadpoles in frogs). For reptiles, all embryonic development is in the egg so the hatchling is a miniature adult.
  - Amphibians must live near water their whole lives while many reptiles live entirely on land.

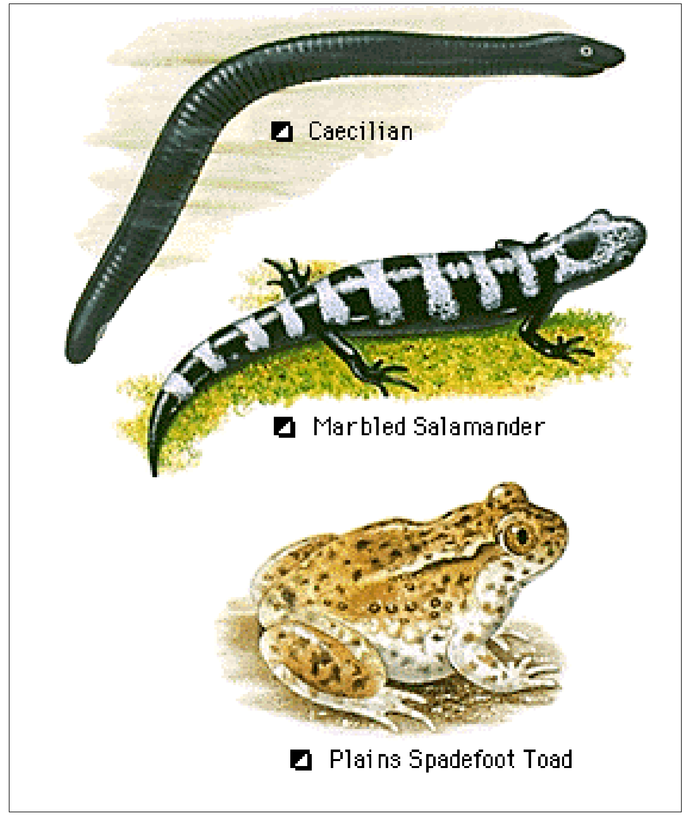
Lecture 11 – The Egg Came First: Early Reptile Evolution (cont'd)

- Which came first, the chicken or the egg?
  - First enclosed eggs appeared about 310 mya
  - First birds appeared about 160 mya
  - Chickens appeared maybe 10 mya

- So, eggs came first by about 300 million years!

Amphibians

Triadobatrachus massinoti, a proto-frog from the Early Triassic of Madagascar.



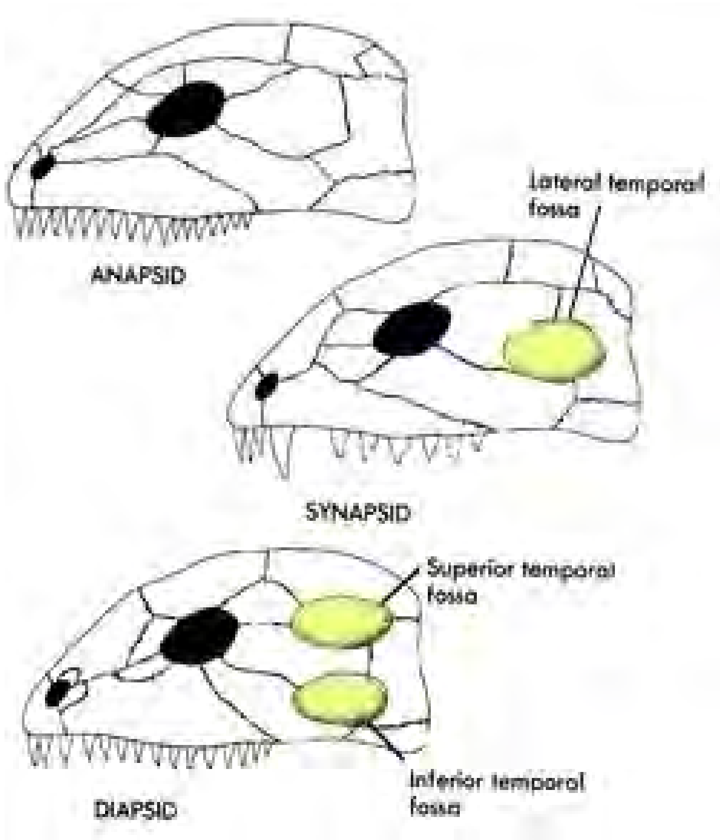
Living amphibian groups are caecilians, salamanders and newts, and frogs and toads. The total number of known amphibian species is approximately 7,000 of which nearly 90% are frogs.

Amniota

Anapsids
Vertebrates that possess skulls with no major fenestrae. Turtles are anapsids.

Synapsids
Vertebrates that possess skulls with one major fenestra in the region of the temporal bone. Mammals are synapsids.

Diapsids
Vertebrates that possess skulls with two major fenestrae. Snakes, lizards, crocodilians, birds, and dinosaurs are diapsids.



Topics for Discussion – 2

- What good is "half an eye" or "one-tenth of a wing?"
- What is the meaning of "*ontogeny* recapitulates *phylogeny*?" Is it true?
  - Embryonic development imitates the evolutionary history of a species.
- Were amphibians the first *tetrapods*? What are the major animal groups descended from *amniota*? Group them according to the number of holes they have in the sides of their skulls (temporal fenestrae). What are these holes for?

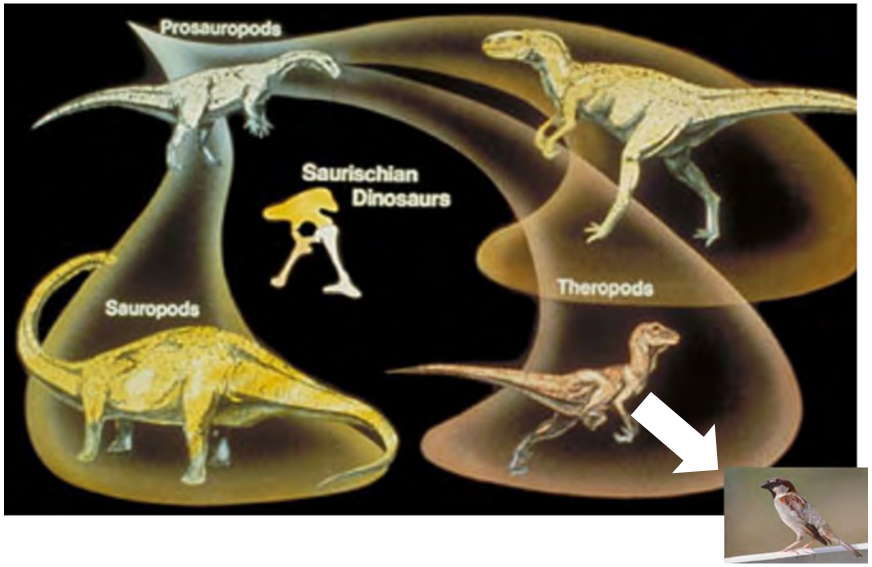
Lecture 12 – The Origins and Successes of the Dinosaurs

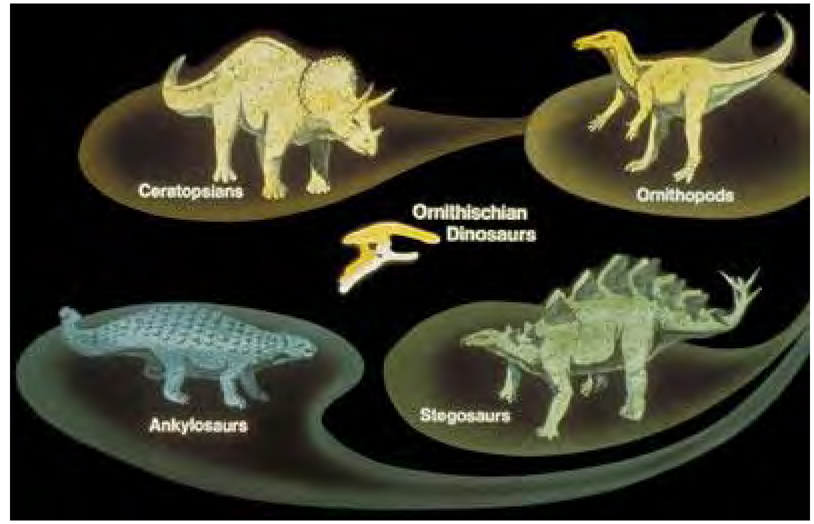
- In the early to middle Triassic period (about 250–230 mya), one lineage of diapsids began evolving into the first dinosaurs. They were small, crow- to human-sized.
  - Dinosaur means "terrible lizard," but they are not lizards, they are a distinct group of diapsid reptiles.
  - Dinosaurs are the "icons of paleontology."
- A ball-and-socket hip arrangement evolved in dinosaurs which enabled them to walk upright or erect. (Upright walking or bipedal locomotion evolved convergently in hominids including humans, as well as in other mammals, dinosauromorphs and birds.):
  - Dinosaurs have 3 digits on their hind feet upon which they walk.
  - They walk with their legs close together like a tightrope walker.
  - This arrangement enables fast running and efficient respiration.
- A split between *saurischian* (lizard hip), which includes *theropods*, and *ornithischian* (bird hip), which includes *ornithopods*, dinosaur clades happened about 235 mya. Both clades are *archosaurs* which are diapsid reptiles. Flightless theropods are ancestral to birds.
- The archosaurs included *dinosauromorphs* (precursors to true dinosaurs) and some other large animals which went extinct by the end of the Triassic, as well as crocodilians.

Lecture 12 – The Origins and Successes of the Dinosaurs (cont'd)

- Environmental conditions favored the evolution of huge dinosaurs, the largest land-dwelling carnivores and herbivores of all time, which dominated the Mesozoic landscape (251–65 mya).
  - The Mesozoic era is known as the "age of dinosaurs," as well as the "age of reptiles."
- At the end of the Triassic period (200 mya), a mass extinction took place opening up ecological niches for dinosaurs to thrive.
- For the remainder of the Mesozoic era, dinosaurs occupied every major terrestrial habitat–underground, on the ground, and in the trees, until the famous Cretaceous mass extinction (65 mya) wiped out most dinosaurs and many other animals.
- Dinosaurs did not really go extinct 65 mya; they are with us today as birds which are descendants of early, feathered dinosaurs (theropods).

The 2 Dinosaur Clades





The **saurischian**, or "lizard-hipped" dinosaurs, like all other tetrapods, had hips composed of three elements: the *ilium* (top bone), *ischium* (middle), and *pubis* (bottom). What distinguishes saurischians (among other major characteristics; including a grasping hand, asymmetrical fingers, and a long, mobile neck) is the pubis that points downward and forward at an angle to the ischium.

All **ornithischians** are united by a pubis pointing backward, running parallel with the ischium. The name "Ornithischia" means "bird-hipped," and birds also have hips in which the pubis points backwards. However, birds are more closely related to the Saurischia.

Lecture 13 – Marine and Flying Reptiles

- *Pterosaurs*:
  - Evolutionary cousins and contemporaries of dinosaurs in the Mesozoic era. Much before birds, many varieties filled the skies.
  - First vertebrates with powered flight.
  - Developed hair-like projections on the skin.
  - May have developed warm-bloodedness (*endothermy*) independently of mammals.
  - Some had wingspans up to 36 ft.
- *Plesiosaurs*:
  - Marine reptiles from the Mesozoic.
  - Their fins looked much like the hands and feet of their land-dwelling ancestors; they were active swimmers.
  - Were some of the largest predators of the Mesozoic seas with lengths reaching 30 ft.
- *Ichthyosaurs*:
  - Another marine reptile from the Mesozoic.
  - Had limbs modified into flippers.
  - Developed the largest eyes of any vertebrate, one-foot in diameter.
  - Had live births, the first amniote to do so.

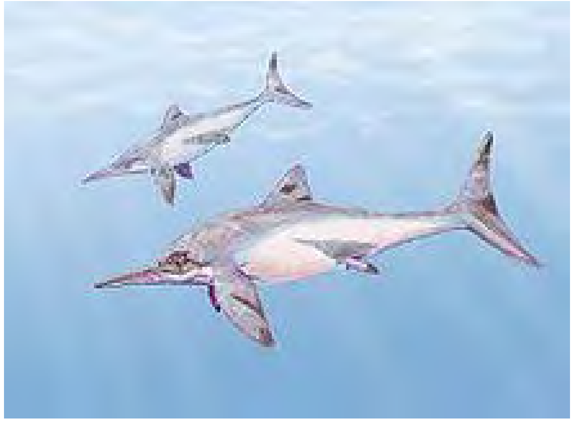
Lecture 13 – Marine and Flying Reptiles

- Other marine reptiles from the Cretaceous period were:
  - *Mososaurs* reaching lengths of 55 ft.
  - Snakes.
  - Sea turtles.
- In addition to the dinosaurs, pterosaurs, mososaurs and many other animals were wiped out by the mass extinction at the end of the Cretaceous period. Only small animals with burrowing abilities survived.

Marine and Flying Reptiles

Fossil trackways show that *pterosaurs* like *Quetzalcoatlus northropi* were quadrupeds. The famous pterodactyls were a pterosaur genus, not a dinosaur.

Plesiosaurus was a genus of large marine sauropterygian reptile that lived during the early part of the Jurassic period.



Ichthyosaurs were giant marine reptiles that resembled dolphins (mammals), a textbook case of convergent evolution*. Ichthyosaurs thrived during much of the Mesozoic era; based on fossil evidence, they first appeared approximately 245 mya and disappeared about 90 mya.

*The independent evolution of similar features in species of different lineages. Flying insects, birds, bats and pterosaurs all evolved powered flight independently. They have "converged" on this useful trait.

Lecture 14 – Birds: The Dinosaurs Among Us

- Birds almost certainly descended from small, flightless theropod dinosaurs in the middle to late Jurassic period (165–155 mya):
  - So birds coexisted with the other dinosaurs for over 90 million years.
  - Birds are diapsids, archosaurs, and a sister group to crocodilians.
  - Bird phylum: chordate, subphylum: vertebrate, class: aves.
- The famous fossil *Archaeopteryx*, an almost perfect blend of dinosaur and bird, is about 150–145 my old. It has:
  - Feathers.
  - 21–22 vertebrae (its tail was too long for a bird, but short for a theropod).
  - A wishbone (as do all birds, but few theropods).
  - Teeth in both jaws (most modern birds do not have teeth).
  - Bird vs. reptile brains:
    - Both have the reptilian brain (basal ganglia), but birds have:
    - A larger cerebral hemisphere and cerebellum,
    - An expansion of the forebrain and the optic lobe required for visual processing 3-dimensional inputs,
    - A smaller olfactory bulb (smell not as important).

Lecture 14 – Birds: The Dinosaurs Among Us (cont'd)

- Birds have the following adaptations for flight:
  - Feathers.
  - A reduction in the size and number of vertebrae in their tails.
  - Forelimbs that have changed in length.
  - Three forward-pointing digits on their feet.
- Birds have one digit on their feet pointing backward which is an adaptation for perching on tree branches.
- Quills and feathers, which are modified scales, first evolved on theropods before flighted birds evolved. They probably developed to provide insulation.
- Three hypotheses for the evolution of flight are:
  - Fast-running theropods simply "took off" to escape predators and catch prey.
  - Theropods were tree climbers that evolved flight first by gliding, then by flapping their arms.
  - Flight assisted running – this combines the first two and is supported by experiments done on living birds.

Theropod Dinosaurs

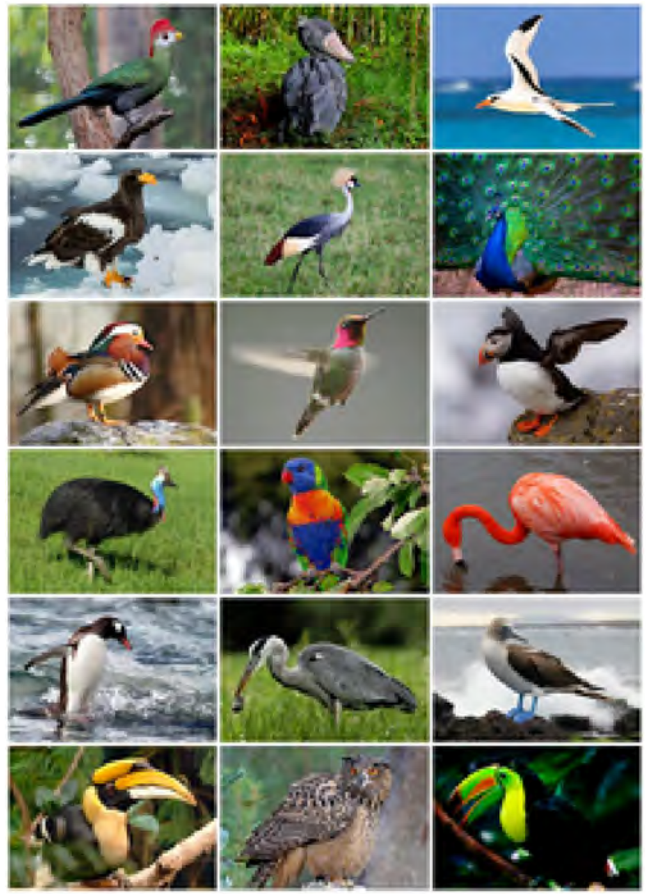
Coelurosauria, a small **theropod**, which includes such famous creatures as *Velociraptor* (shown grasping *Protoceratops*, a ceratopsian dinosaur), is an ancestor of our feathered friends the birds. Recent studies have agreed that *T. Rex* and the tyrannosaurs belong with the coelurosaurs, not with the carnosaurs as was originally believed. Such is the ever-changing nature of theropod phylogeny; new finds and analyses are frequently overturning old ideas. This area of dinosaur paleontology is in a major state of flux.

Archaeopteryx is a clear candidate for a transitional fossil between dinosaurs and birds. It was up to 20 in. in length, about the size of a raven.

Artist's rendition Of Archaeopteryx.

Extinct and Living Birds

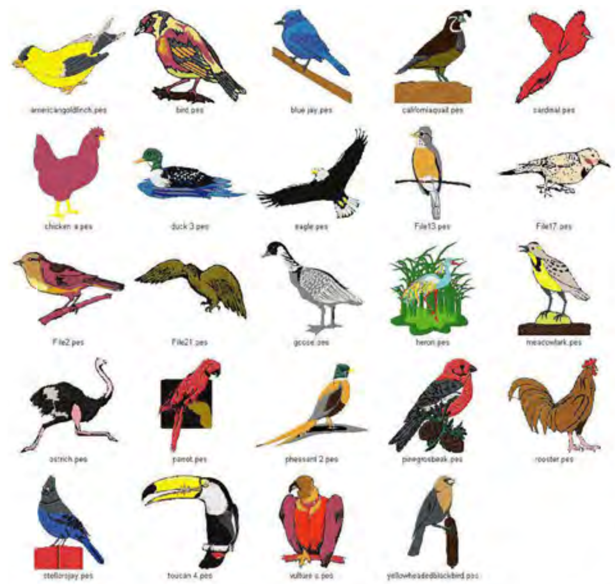
Confuciusornis sanctus fossil, a Cretaceous bird from China, 125-120 mya. It is the oldest known bird to have a beak.



18 orders of birds shown. There are about 32 orders.

Feeding adaptations in beaks. Darwin found beak-determining finch species on various Galapagos islands.

Modern Birds



Birds are feathered, winged, bipedal, endothermic, egg-laying, vertebrate animals. With around 10,000 living species, they are the most speciose class of tetrapod vertebrates.

Lecture 15 – The First Flowers and Pollinator Coevolution

- Flowering plants (*angiosperms*) originated about 130 mya, 200 my after the first non-flowering plants:
  - They account for about 250,000 species, 80% of all land plants.
  - They reproduce using pollen which contains the male gametes. The pollen must be transported to the female parts (ovules) of the same species. If fertilization occurs, seeds are produced and fruits grow to surround the seeds.
  - The origins and diversification of pollinating birds overlapped with the first flowering plants. This was quickly followed by the origins and explosive diversification of many pollinating insects. Even some mammals aid in pollination.
- Flowering plants offer these animals pollen, nectar and fruit to entice them to aid in their reproduction. Insects are attracted to plants as sites for reproduction, as shelter from predators, and as food. Many insects have evolved camouflage to fit in with the visual appearance of plants:
  - Nectar represents a blatant adaptation of plants for attracting insects.
  - Nectar supplies pollinators energy so they can fly from flower to flower.

Lecture 15 – The First Flowers and Pollinator Coevolution (cont'd)

- Flowering plants survived the Cretaceous mass extinction partly because they had undergone over 60 my of adaptive radiation. They also benefited from their mutual alliances with the small terrestrial animals that also survived.
- The important pollinators of today that coevolved with early flowering plants include:
  - Wasps and bees
  - Butterflies and moths
  - Beetles
  - Ants
  - Hummingbirds
  - Bats
  - Honey possums
  - Lemurs (primate precursors)

Lecture 16 – Egg to Placenta: Early Mammal Evolution

- Mammal-like reptiles arose from synapsid reptiles in the Permian period, 290–250 mya. This was about the same time and for some of the same reasons as the rise of the dinosaurs.
- Synapsids (1 temporal fenestra) were the ruling reptiles of the Permian until an end-mass extinction. Among the survivors were a group called *therapsids* that show a number of traits associated with mammals including:
  - Differentiated teeth.
  - Stronger jaws for chewing.
  - Modification of the jaw bones for better hearing.
  - An upright posture.
  - No continuous replacement of teeth enabling suckling of the young and better occlusion.
  - Secondary palate (esophagus and bronchial tube) enabling eating and breathing at the same time.

Lecture 16 – Egg to Placenta: Early Mammal Evolution (cont'd)

- Mammals have several bones that reflect an evolutionary connection to their more reptilian ancestors. For example, two reptilian jaw bones moved up to the inner ear.
- Characteristics of true mammals include:
  - Hair.
  - Mammary glands.
  - Large brains compared to their body sizes.
  - Long care for their offspring.
  - Some grow to extremely large sizes.
- As synapsids went from a sprawling posture associated with reptiles to a more upright one, their:
  - Limbs lengthened.
  - Tails shortened.
  - Hipbones got smaller.
- These shifts reflect the energy demands of increased brain size, metabolism and activity, all associated with endothermy (warm-bloodiness: body temperature kept above ambient).

Lecture 16 – Egg to Placenta: Early Mammal Evolution (cont'd)

- There are 3 modern types of mammals:
  - Monotremes, which are egg-laying:
    - These are really reptile-like mammals.
  - Marsupials, which have live birth, but their embryos are nurtured in a pouch for a lengthy period.
  - Eutherians, which are placental mammals.
    - Placental mammals diverged from marsupials in the late Jurrasic period.
    - The monotreme lineage's divergence appears to be not as well understood, but is believed to have occurred earlier; they were the first mammals.
- Monotreme means one orifice; they have a *cloaca* used for defecation, urination and reproduction.
  - Marsupials (and birds and reptiles) have two openings; they separate out the reproductive function.
  - Placental mammals have three openings.
- Monotremes do not have nipples; the female excretes her milk directly from the skin.
- Only one modern marsupial lives in North America, the opossum. Several live in South America, most in the Australia/New Guinea/Tasmania region.
- There are two living monotreme genera, both live in Australia/New Guinea:
  - Platypus: the male excretes venom from a spur on its legs.
  - Echidna (spiny anteater) with 4 species.

Lecture 16 – Egg to Placenta: Early Mammal Evolution (cont'd)

- The mammalian brain:
  - Mammals have a complex (6-layer) neocortex involved with sensory perception, motor commands, spatial reasoning and, in humans, conscious thought and language:
    - Other vertebrates have none or a primitive one.
    - The neocortex is the outer "rind" of the brain and is the latest to evolve.
  - Primates and large mammals have deep grooves and folds which greatly increase the neocortex's effective surface area allowing a much larger surface area than would otherwise fit in the same size skull (this facilitates live birth):
    - Small mammals have a smooth neocortex.
  - In humans, 90% of the cerebral cortex is neocortex:
    - The ratio of neocortex size-to-rest of brain size is thought to be related to social behaviors.

Mammal-like Reptiles

Archaeothyris, one of the oldest synapsids found, a proto-mammal. Dated at 323-299 mya.

Sphenacodon was a carnivorous pelycosaur that was closely related to Dimetrodon and the therapsids in the late Carboniferous-early Permian.

Cynognathus was the largest predatory cynodont of the Triassic, also a surviving therapsid. The Triassic-Jurrasic extinction 200 mya wiped out all large therapsids. The remaining mesozoic synapsids were shrew-to-badger size.

Lystrosaurus was the most common therapsid shortly after the Permian-Triassic extinction event, 250 mya which wiped out most of the therapsids. The remaining ones then thrived in the Triassic.

Synapsids becoming more mammalian, clockwise from upper left

Marsupials and Monotremes

Virginia opossum, the only North American **marsupial.**

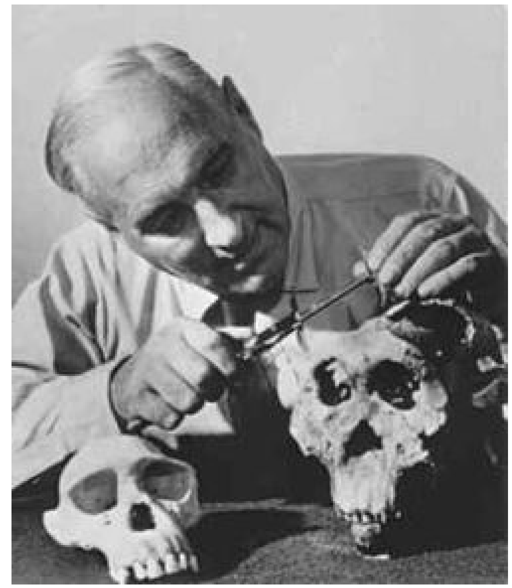
Thylacine (*Thylacinus cynocephalus*), an extinct carnivorous marsupial found in Tasmania until the 1930's.

Platypus, a **monotreme.**

Echidna, another monotreme.

Extinct and Modern Eutherians
(Placental Mammals)

Life restoration of *Juramaia sinensis,* dated from 166 mya. It shows the divergence of placental mammals from marsupials in the late Jurrasic.



Louis Leakey examining skulls from Olduvai Gorge, living and extinct **placental mammals.** He discovered Homo erectus and other Homo fossils in East Africa.

Bat

Black rat

Lecture 17 – From Land to Sea: The Evolution of Whales

- After the end-Cretaceous mass extinction, mammals began to fill ecological niches left by dinosaurs and other large animals.
- Perhaps the most surprising example was the radiation of mammals back to the oceans and the evolution of whales.
- Whales descended from even-toed, hoofed mammals who lived on the land (*artiodactyls*):
  - The closest living artiodactyls to whales are hippopotamuses.
  - Whales diverged from their artiodactyl ancestors about 60 mya.
  - Evidence that reveals the evolutionary origins of whales includes:
    - Hind limbs and hipbones are greatly reduced but still present.
    - Whales have homologous bones in their front flippers which match those in the forelimbs of other mammals.
    - Whales swim in an up-and-down motion which mimics the same spinal flexion as running in mammals (fish swim in a side-to-side motion).

Lecture 17 – From Land to Sea: The Evolution of Whales (cont'd)

- Whale is the common name for various marine mammals of the order *Cetacea*.
- The blue whale evolved to become the largest animal of all time, measuring 100 ft. long and weighing 165 tons.
- Dolphins (which are whales) have been selected for larger brain sizes. They can:
  - Use complicated auditory communications.
  - Recognize themselves in mirrors as individuals.
  - Practice social interaction and cooperation.
- It is believed that larger brains and corresponding higher intelligence coevolved convergently in both whales and primates.

Course Summary

- Background:
  - Life, Evolution, Decent with Modification, Natural Selection Example
  - Myths about Evolution
  - Selection and Adaptation, Species Data, Sexual and Artificial Selection, Homologous Features and Camouflage, The Selfish Gene Theory,
  - Macro- and Microevolution, Continental Drift, Ranking Systems, Geologic Time, Mass Extinctions, Fossils and Fossil Dating

- Evolutionary Transitions:
  - Original Life, Early Life, Prokaryotes, Eukaryotes
  - Metazoans, Skeletons, The Cambrian Explosion

Course Summary (cont'd)

- Vertebrates, Arthropods, Powered Flight, Seed Plants and Forests
- Fish, Tetrapods, Amniotes, Dinosaurs, Flying and Marine Reptiles
- Birds, Flowers and Pollinators, Mammals, Whales

- Next Term:
  - Prosimians
  - Monkeys
  - Apes
  - Hominids
  - Hominins
  - The Genus Homo
  - Homo Sapiens