***Evidence of Evolution***

The Nobel Prize winning scientist Linus Pauling aptly described science as the search for truth.  Science does this by continuously comparing its theories objectively with evidence in the natural world.  When theories no longer conform to the evidence, they are modified or rejected in favor of new theories that do conform.  In other words, science constantly tries to prove its assumptions to be false and rejects implausible explanations.  In this way, scientific knowledge and understanding grow over time.  Religious explanations for the order of things are not science because they are based primarily on faith and do not subject themselves to be objectively falsified.  Because of this fundamental difference in the approach to understanding our natural world, the U.S. Supreme Court in effect decided in 1987 that the Biblically based "creation science" is not a science and cannot be taught as such in public schools as an alternative or in addition to the mainstream evolutionary theory of the biological sciences.  However, religious creation stories and the idea of "intelligent design" can be taught in philosophy, religion, or history courses.  Religion and Science provide different approaches to knowledge.  It is important to understand both.

**What Is Evolution?**

Biological evolution is genetic change in a population from one generation to another.  The speed and direction of change is variable with different species lines and at different times.  Continuous evolution over many generations can result in the development of new varieties and species.  Likewise, failure to evolve in response to environmental changes can, and often does, lead to extinction.

When scientists speak of evolution as a theory they do not mean that it is a mere speculation.  It is a theory in the same sense as the propositions that the earth is round rather than flat or that our bodies are made of atoms are theories.  Most people would consider such fundamental theories to be sufficiently tested by empirical evidence to conclude that they are indeed facts.  As a result of the massive amount of evidence for biological evolution accumulated over the last two centuries, we can safely conclude that evolution has occurred and continues to occur.  All life forms, including humans, evolved from earlier species, and all still living species of organisms continue to evolve today.  They are not unchanging end-products.

For those who have difficulty in accepting evolution because of what they perceive as contradictions with their fundamental religious beliefs, it may be useful to distinguish the ultimate origin of life from its later evolution.  Many, if not most, biological scientists accept that primordial life on earth began as a result of chance natural occurrences 3.5-4 billion years ago.  However, it is not necessary to believe in that view in order to accept that living creatures evolved by natural means after the origin of the first life.  Charles Darwin modified his religious beliefs, as did many others, as a result of the discovery of convincing proof of evolution.  Darwin's religious faith was also severely challenged by the death of his 10 year old daughter Annie in 1851.  Apparently, he came to believe that his God created the order of the universe including the rules of nature that result in biological evolution.  His famous book, *On the Origin of Species*, was not a denial of his God's existence.  However, he did reject a literal interpretation of the Judeo-Christian Bible.  His religious beliefs were probably very similar to those who advocate "theistic evolution" today.

We now understand that there are a number of different natural processes that can cause evolution to occur.  These are presented in a later tutorial of this series ([*Modern Theories of Evolution*](http://anthro.palomar.edu/synthetic/default.htm)).

**How Do We Know That Evolution Has Occurred?**

The evidence for evolution has primarily come from four sources:

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| 1. | the fossil record of change in earlier species |
| 2. | the chemical and anatomical similarities of related life forms |
| 3. | the geographic distribution of related species |
| 4. | the recorded genetic changes in living organisms over many generations |

**The Fossil Record**

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|  | illustration of geological strata containing an evolutionary sequence of fossils from 570 to 2 million years ago |
| Geological strata containing an  evolutionary sequence of fossils |

Remains of animals and plants found in [sedimentary](http://anthro.palomar.edu/evolve/glossary.htm#sedimentary_rock) rock deposits give us an indisputable record of past changes through vast periods of time.  This evidence attests to the fact that there has been a tremendous variety of living things.  Some extinct species had traits that were transitional between major groups of organisms.  Their existence confirms that species are not fixed but can evolve into other species over time.

The evidence also shows that what have appeared to be gaps in the fossil record are due to incomplete data collection.  The more that we learn about the evolution of specific species lines, the more that these so-called gaps or "missing links in the chain of evolution" are filled with transitional fossil specimens.  One of the first of these gaps to be filled was between small bipedal dinosaurs and birds.  Just two years after Darwin published *On the Origin of Species*, a 150-145 million year old fossil of *Archaeopteryx* was found in southern Germany.  It had jaws with teeth and a long bony tail like dinosaurs, broad wings and feathers like birds, and skeletal features of both.  This discovery verified the assumption that birds had reptilian ancestors.

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| http://anthro.palomar.edu/evolve/images/Archaeoptryx_1.jpg |  | http://anthro.palomar.edu/evolve/images/Archaeoptryx_2.jpg |  | http://anthro.palomar.edu/evolve/images/Archaeoptryx_3.gif |
| *Archaeopteryx* fossil |  | *Archaeopteryx* recreation |  | *Archaeopteryx t*ail feathers |

Since the discovery of *Archaeopteryx*, there have been many other crucial evolutionary gaps filled in the fossil record.  Perhaps, the most important one, from our human perspective, was that between apes and our own species.  Since the 1920's, there have been literally hundreds of well-dated intermediate fossils found in Africa that were transitional species leading from apes to humans over the last 6-7 million years.  This evidence is presented in the last 3 tutorials of this series.

The fossil record also provides abundant evidence that the complex animals and plants of today were preceded by earlier simple ones.  In addition, it shows that multicelled organisms evolved only after the first single-celled ones.  This fits the predictions of evolutionary theory.

**Chemical and Anatomical Similarities**

Living things on earth are fundamentally similar in the way that their basic anatomical structures develop and in their chemical compositions.  No matter whether they are simple single-celled protozoa or highly complex organisms with billions of cells, they all begin as single cells that reproduce themselves by similar division processes.  After a limited life span, they also all grow old and die.

All living things on earth share the ability to create complex molecules out of carbon and a few other elements.  In fact, 99% of the proteins, carbohydrates, fats, and other molecules of living things are made from only 6 of the 92 most common elements.  This is not a mere coincidence.

All plants and animals receive their specific characteristics from their parents by inheriting particular combinations of genes.  Molecular biologists have discovered that genes are, in fact, segments of [DNA](http://anthro.palomar.edu/evolve/glossary.htm#DNA) molecules in our cells.

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| simplified drawing of a section of a DNA molecule |
| section of a DNA molecule |

These segments of DNA contain chemically coded recipes for creating proteins by linking together particular [amino acids](http://anthro.palomar.edu/evolve/glossary.htm#amino_acid) in specific sequences.

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| schematic drawing of a section of a protein molecule showing amino acid components |
| simple protein molecule |

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|  | drawing of the bones in a human arm--humerous in the upper arm, radius and ulna in the lower arm, and numerous bones in the wrist and hand |
| Human arm bones (typical vertebrate pattern) |

All of the tens of thousands of types of proteins in living things are made of only 20 kinds of amino acids.  Despite the great diversity of life on our planet, the simple language of the DNA code is the same for all living things.  This is evidence of the fundamental molecular unity of life.

In addition to molecular similarities, most living things are alike in that they either get the energy needed for growth, repair, and reproduction directly from sunlight, by [photosynthesis](http://anthro.palomar.edu/evolve/glossary.htm#photosynthesis) , or they get it indirectly by consuming green plants and other organisms that eat plants.

Many groups of species share the same types of body structures because they inherited them from a common ancestor that had them.  This is the case with the [vertebrates](http://anthro.palomar.edu/evolve/glossary.htm#vertebrates) , which are the animals that have internal skeletons.  The arms of humans, the forelegs of dogs and cats, the wings of birds, and the flippers of whales and seals all have the same types of bones (humerus, radius, and ulna) because they have retained these traits of their shared common ancient vertebrate ancestor.

All of these major chemical and anatomical similarities between living things can be most logically accounted for by assuming that they either share a common ancestry or they came into existence as a result of similar natural processes.  These facts make it difficult to accept a theory of special and independent creation of different species.

**Geographic Distribution of Related Species**

Another clue to patterns of past evolution is found in the natural geographic distribution of related species.  It is clear that major isolated land areas and island groups often evolved their own distinct plant and animal communities.  For instance, before humans arrived 60-40,000 years ago, Australia had more than 100 species of kangaroos, koalas, and other [marsupials](http://anthro.palomar.edu/evolve/glossary.htm#marsupial) but none of the more advanced terrestrial [placental mammals](http://anthro.palomar.edu/evolve/glossary.htm#placental_mammals) such as dogs, cats, bears, horses.  Land mammals were entirely absent from the even more isolated islands that make up Hawaii and New Zealand.  Each of these places had a great number of plant, insect, and bird species that were found nowhere else in the world.  The most likely explanation for the existence of Australia's, New Zealand's, and Hawaii's mostly unique biotic environments is that the life forms in these areas have been evolving in isolation from the rest of the world for millions of years.

**Genetic Changes Over Generations**

The earth's environments are constantly changing, usually in subtle and complex ways.  When the changes are so great as to go beyond what most members of a population of organisms can tolerate, widespread death occurs.  As Charles Darwin observed, however, not all individuals always perish.  Fortunately, natural populations have genetic diversity.  Those individuals whose characteristics allow them to survive an environmental crisis likely will be the only ones able to reproduce.  Subsequently, their traits will be more common in the next generation--evolution of the population will have occurred.

This process of natural selection resulting in evolution can be easily demonstrated over a 24 hour period in a laboratory petri dish of bacteria living in a nutrient medium.  When a lethal dose of antibiotic is added, there will be a mass die-off.  However, a few of the bacteria usually are immune and survive.  The next generation is mostly immune because they have inherited immunity from the survivors.  That is the case with the purple bacteria in the Petri dishes shown below--the bacteria population has evolved.

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| Evolution of antibiotic resistant bacteria |
| illustration of  an experiment showing the evolution of antibiotic resistent bacteria as a result of an antibiotic killing off non-resistant ones and those then reproducing to become a large population that is genetically different from the parent population |

This same phenomenon of bacteria evolution speeded up by human actions occurs in our own bodies at times when an antibiotic drug is unable to completely eliminate a bacterial infection.  That is the reason that medical doctors are sometimes hesitant to recommend an antibiotic for their patients and insist that the full dosage be used even if the symptoms of illness go away.  They do not want to allow any potentially antibiotic resistant bacteria to survive.

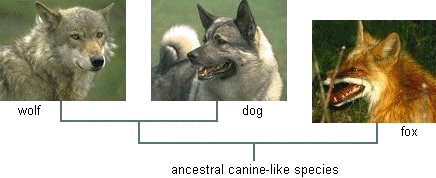
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| **photo of a pure bred dog variety--a cocker spaniel** |
| Dog variety resulting from selective breeding over many generations |

People have developed many new varieties of plants and animals by selective breeding.  This process is similar to the bacteria experiment described above.  Selection of specimens to breed based on particular traits is, in effect, changing the environment for the population.  Those individuals lacking the desirable characteristics are not allowed to breed.  Therefore, the following generations more commonly have the desired traits.

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|  | closeup photo of an insect--a small wasp |
|  | Insect with a high reproductive potential |

Species that mature and reproduce large numbers in a short amount of time have a potential for very fast evolutionary changes.   Insects and microorganisms often evolve at such rapid rates that our actions to combat them quickly lose their effectiveness.  We must constantly develop new pesticides, antibiotics, and other measures in an ever escalating biological arms race with these creatures.   Unfortunately, there are a few kinds of insects and microbes that are now significantly or completely resistant to our counter measures, and some of these species are responsible for devastating crop losses and deadly diseases.

If evolution has occurred, there should be many anatomical similarities among varieties and species that have diverged from a common ancestor.  Those species with the most recent common ancestor should share the most traits.  For instance, the many anatomical similarities of wolves, dogs, and other members of the genus *Canis* are due to the fact that they are descended from the same ancient canine species and still share 99.8% of their genes.  Wolves and dogs also share similarities with foxes, indicating a slightly more distant ancestor with them.



Given the abundant evidence supporting the theory of biological evolution, it is highly probable that evolution has occurred and is still occurring today.  However, there remains speculation in regards to the specific evolutionary path of some species lines and the relative importance of the different natural processes responsible for their evolution.  These issues will be discussed more fully in later tutorials of this series.

Much has been added to our understanding of the nature of evolution since the 19th century.  It is now known that there are six different processes that can operate independently or in consort to bring about evolution.  The understanding of these processes has become the basis for an overall [synthetic theory of evolution](http://anthro.palomar.edu/evolve/glossary.htm#synthetic_theory_of_evolution) [click this icon to hear the preceding term pronounced](http://anthro.palomar.edu/evolve/sounds/synthetic_theory_of_evolution.mp3).  This theory encompasses multiple causes, including Charles Darwin's concept of natural selection, Gregor Mendel's experimental results concerning [genetic](http://anthro.palomar.edu/evolve/glossary.htm#genetics) inheritance, as well as a number of crucial 20th century discoveries.  The synthetic theory of evolution will be revisited with more detail in the [6th tutorial](http://anthro.palomar.edu/synthetic/default.htm) of this biological anthropology series.

**The Public Perception of Evolution in the United States**

Biological evolution is far from being universally accepted by Americans.  Annual national polls carried out since the mid 1980's by the Center for Biomedical Communication at Northwestern University School of Medicine indicate that the percentage of Americans who accept evolution has dropped from 45% to 40%.  Curiously, the number who reject evolution have also dropped from 48% to 39% over the same time period.  Those who are uncertain about whether evolution occurs or not have increased from 7% to 21%.  While it is encouraging that fewer people are now hostile to the idea of biological evolution, the U.S. still has a higher percentage of its population who hold this view than 33 of the 34 European nations and Japan.  This is very likely a consequence of the relative emphasis placed on teaching science in public schools in the different countries.  In addition, anti-evolution sentiment is far stronger in American national politics.

For the vast majority of biologists, the debate over whether evolution occurs took place in the 19th century and has long been settled--evolution won.  The noted environmental biologist Theodosius Dobzhansky summed it up in 1973 by saying "nothing in biology makes sense except in the light of evolution".

***NOTE:   Some critics have said that the kinds of rapid evolutionary changes in insects and bacteria referred to above are not good evidence of the process of natural evolution because they occur as a result of human interference.  However, there is abundant evidence of rapid evolution occurring today independent of people.  An example was described by Cristina Sandoval in the May 23, 2002 issue of Nature.  A species of insect called the "walking stick" (Timena cristinae) found in the Santa Ynez Mountains of California now exists in two distinct varieties or forms that are in the process of evolving into two separate species by adapting to different environments.  The insect forms differ in terms of genetically determined color patterns--one is striped and the other is not.  The striped ones hide from predators on the striped chamise plant, while the unstriped ones hide on the unstriped blue lilac plant.  Those that have inherited the appropriate camouflaging color pattern for their chosen environment survive the onslaught of lizards and birds.  In this case, the natural predators, rather than humans, are the driving forces of natural selection.  Mating experiments show that each variety of "walking stick" prefers to mate only with others having the same color pattern.  This breeding isolation is leading to the evolution of two distinct species.***