

Alles Introductory Biology: Illustrated Lecture Presentations

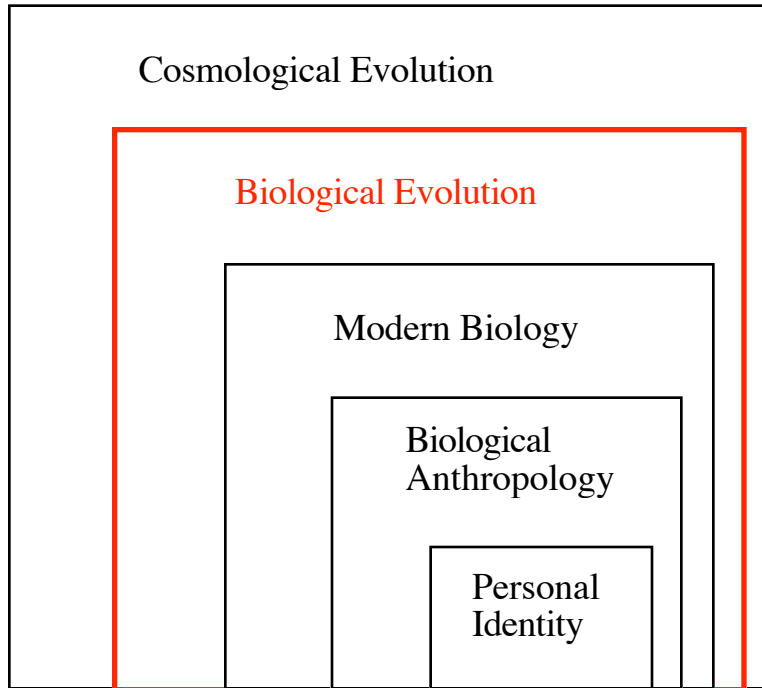
Instructor David L. Alles

Western Washington University

Part Two: The Conceptual Framework of Biology

Biological Evolution

Increasingly Inclusive Concepts in Science



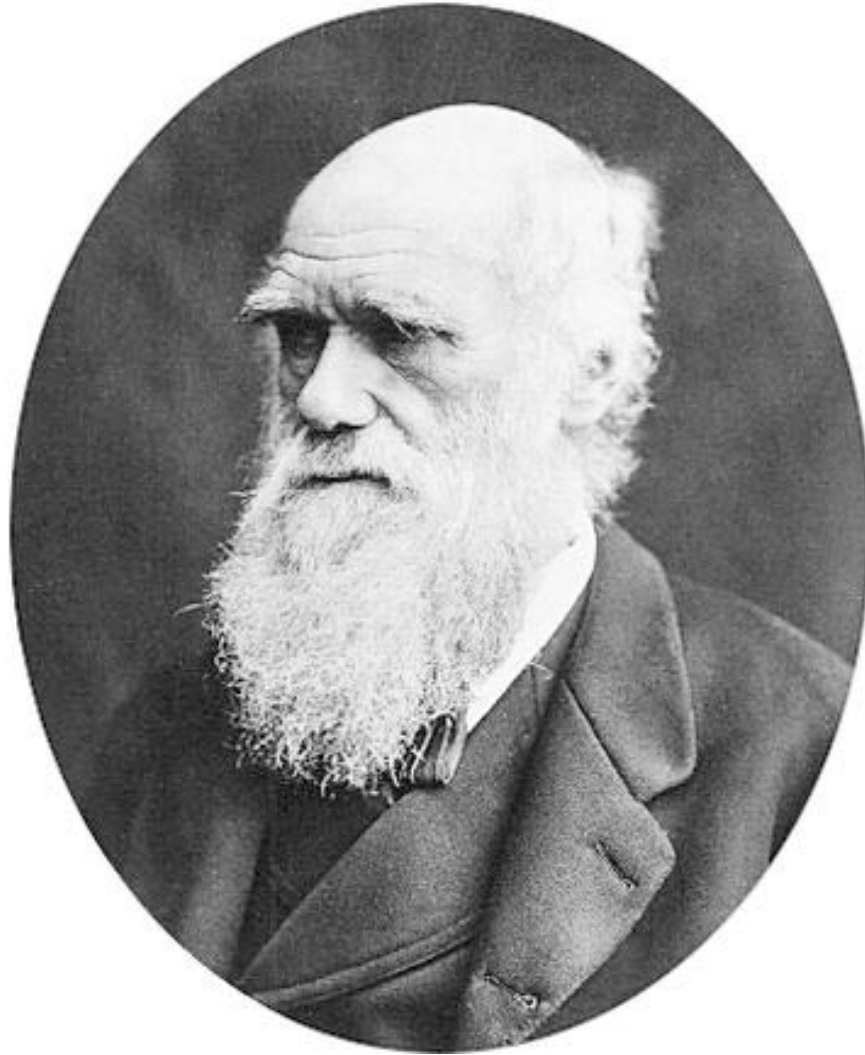
Biological evolution is more inclusive than modern biology because it includes a large part of modern geology. The history of life on Earth and the geological history of the Earth are intimately tied together.



Charles Darwin in 1854

“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.”

This quote is the last line from the book *On the Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life* written by Charles Darwin and published in 1859.



Charles Darwin in 1878

“Never in the field of scientific endeavor can so great a theory [evolution by natural selection] have been misunderstood by so many with so little reason.” (Gould 1977; Ridley 1995)

Darwin's Five Theories

(after Ernst Mayr 1982, 505)

- 1) Evolution as Historical Fact—the mutability of species or evolution as such.
- 2) Common Descent—all organisms have descended from common ancestors by a continuous process of branching speciation.
- 3) Gradualism—the mode of evolutionary change is gradual—gradual changes within a population as opposed to sudden changes between generations.
- 4) Speciation—the process of multiplication of species.
- 5) Natural Selection—the mechanism of evolutionary change.

• **Point:** Evolutionary theory is not just one scientific theory and involves much more than what most people think.

Questions

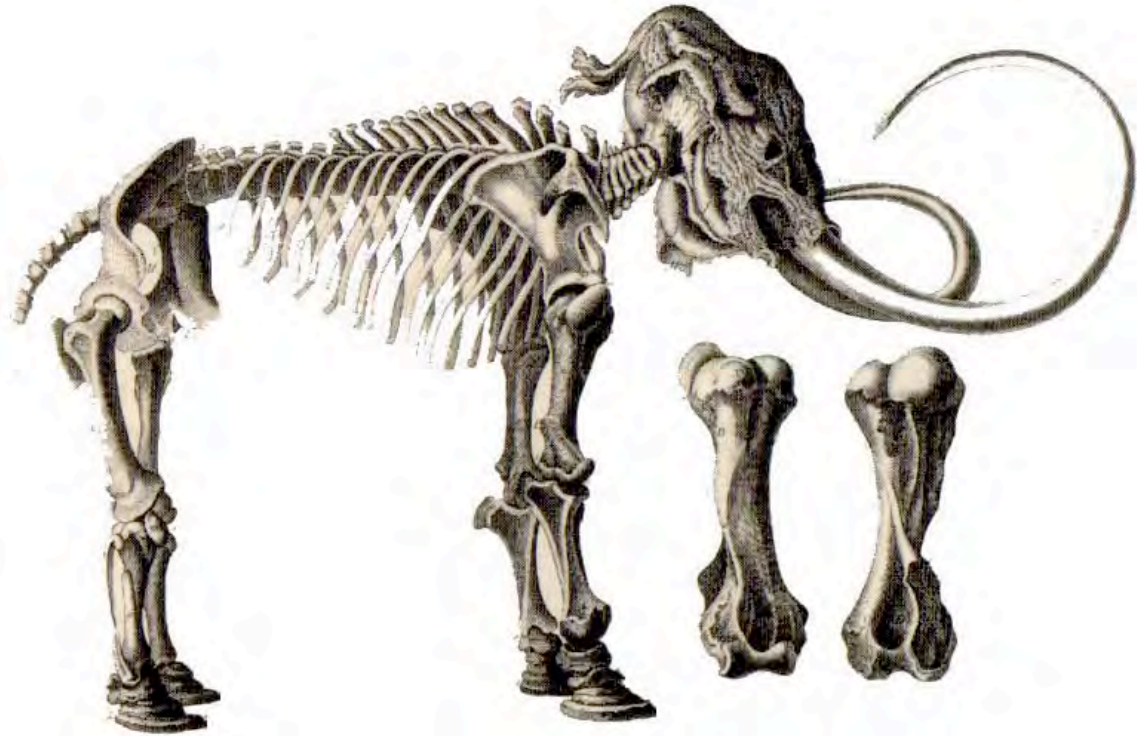
- **How did the species of plants and animals we see today originate?**
- **Have each of these life-forms remained the same since they originated?**
- **Has the number and types of species remained the same through time?**



Columbia Mammoths on the Great Plains of North America 11,000 y.a.

The story of the mammoths provides a case study by which we can answer the last two questions. The answer to the first question had to wait for Charles Darwin. An average Columbian mammoth stood over 12 feet tall at the shoulder and weighed over 10,000 pounds.

Painting by Karen Carr



The first complete skeleton of a mammoth to be displayed to the public, called the Adams mammoth and now identified as a woolly mammoth, was mounted for display in St. Petersburg in 1808. Over 16 ft long and 10 ft tall, with curving tusks 10 ft long, it was a male which had died at about the age of 45 years. Samples of its skin and hair were sent to many European and American museums including the Paris museum of natural history.

(Drawing from the book *Mammoths* by Lister and Bahn, 1994)



Georges Cuvier (1769-1832)

The location of the Adams mammoth find and the animal's tooth structure led Georges Cuvier of the Paris museum of natural history to his pioneering conclusion that it was a cold-adapted, **extinct local species** of proboscidean, the family to which all elephants, mammoths, and mastodons belong. This was the first conclusive study that established the extinction of a species as a fact.

With Cuvier's conclusive study showing that woolly mammoths were extinct, it became scientifically impossible to maintain that the number and types of species had remained the same throughout time. And with his demonstration of the close relationship between mammoths and modern elephants, it appeared that they must have had a common ancestor at some time in the past. This makes it improbable that these life-forms had remained the same since their origin.

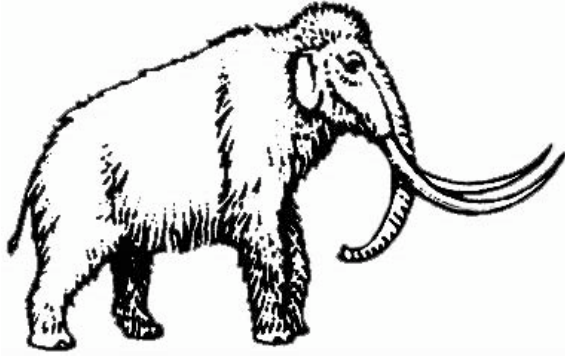
Web Reference

<http://www.ucmp.berkeley.edu/history/cuvier.html>

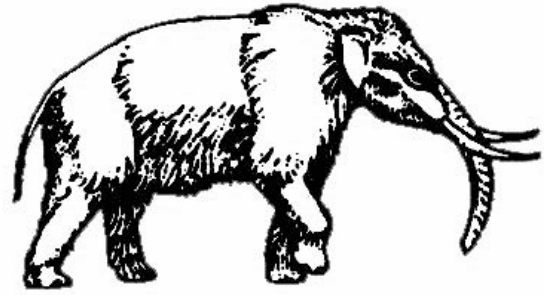


During the last Ice Age in northern Europe woolly mammoths migrated between winter and summer ranges.

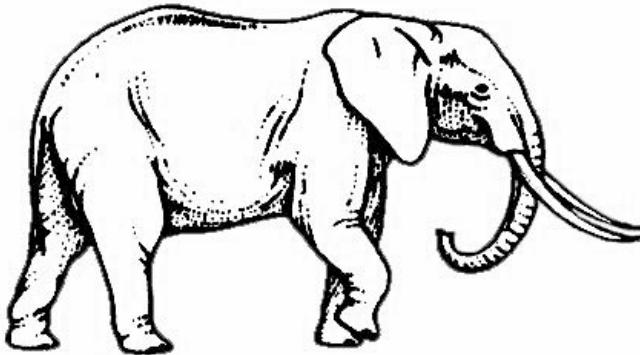
Image courtesy of the BBC



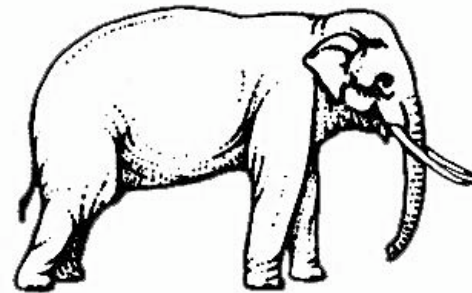
Woolly Mammoth



American Mastodon



African Elephant



Indian Elephant

Mammoths, mastodons, and modern elephants roamed the Earth at the same time only 11,000 years ago. Mammoths are closely related to elephants, especially to the Indian elephant. Mammoths differed from mastodons, which were smaller, standing 8 to 10 feet tall at the shoulder and weighing four to six tons. But the key difference was the shape of their teeth and thus their diet. Mammoths had flat teeth with ridges for grinding grasses, while mastodons had cones on their teeth that enabled them to feed off shrubs and trees.



Extinct Columbia Mammoth of North America

At some locations in North America mammoth fossil are extremely abundant. Two of the best sites are at the Hot Springs mammoth site in South Dakota, and the La Brea tar pits in downtown Los Angeles. The La Brea tar pits have yielded 17 proboscideans, including Columbia mammoths and mastodons mainly from one pit.

Web Reference

<http://www.tarpits.org/education/guide/index.html>



Mammoth Skull unearthed at Hot Springs, South Dakota

About 26,000 years ago a deep, water-filled sink hole in southwestern South Dakota proved deadly for numerous mammoths. The sink was a highly mineralized hot spring. Presumably, the steep, slick sides of the sink caused unfortunate animals to slip in, with no way out. After eventually drowning, the animals would sink to the pool's bottom, soft parts would decay, and the remaining bones were wonderfully preserved in the hot mineral water.

The site was discovered in 1974. Many of the fossils have been left in place for display where they were uncovered and a building has been built over them to protect them. The picture above and the following two are from the site.



Below the skull are the remains of another individual that died earlier including vertebra, ribs and tusks. Altogether, the fossils of 49 Columbia mammoths and 3 woolly mammoths have been found at the Hot Springs mammoth site in South Dakota.



Above is a mammoth tooth still imbedded in the jaw. Note the coarse ridges for grinding grasses.

Evolution as Historical Fact

“For biologists of today, evolution is no longer a hypothesis but simply a fact, documented by the changes in the gene pools of species from generation to generation and by the changes in the fossil biota in accurately dated geological strata. Current resistance is limited entirely to opponents with religious commitments.”—Mayr, 1982

Evolution by Common Descent

The Weak Version

“all organisms have descended from common ancestors by a continuous process of branching speciation.”—Mayr, 1982

The Strong Version

The strong version of Darwin’s theory views life at the molecular, genetic level from the perspective of non-linear thermodynamic systems. It is from this perspective that the conclusion is derived that life is “a single, ongoing, genetically controlled chemical chain reaction.”

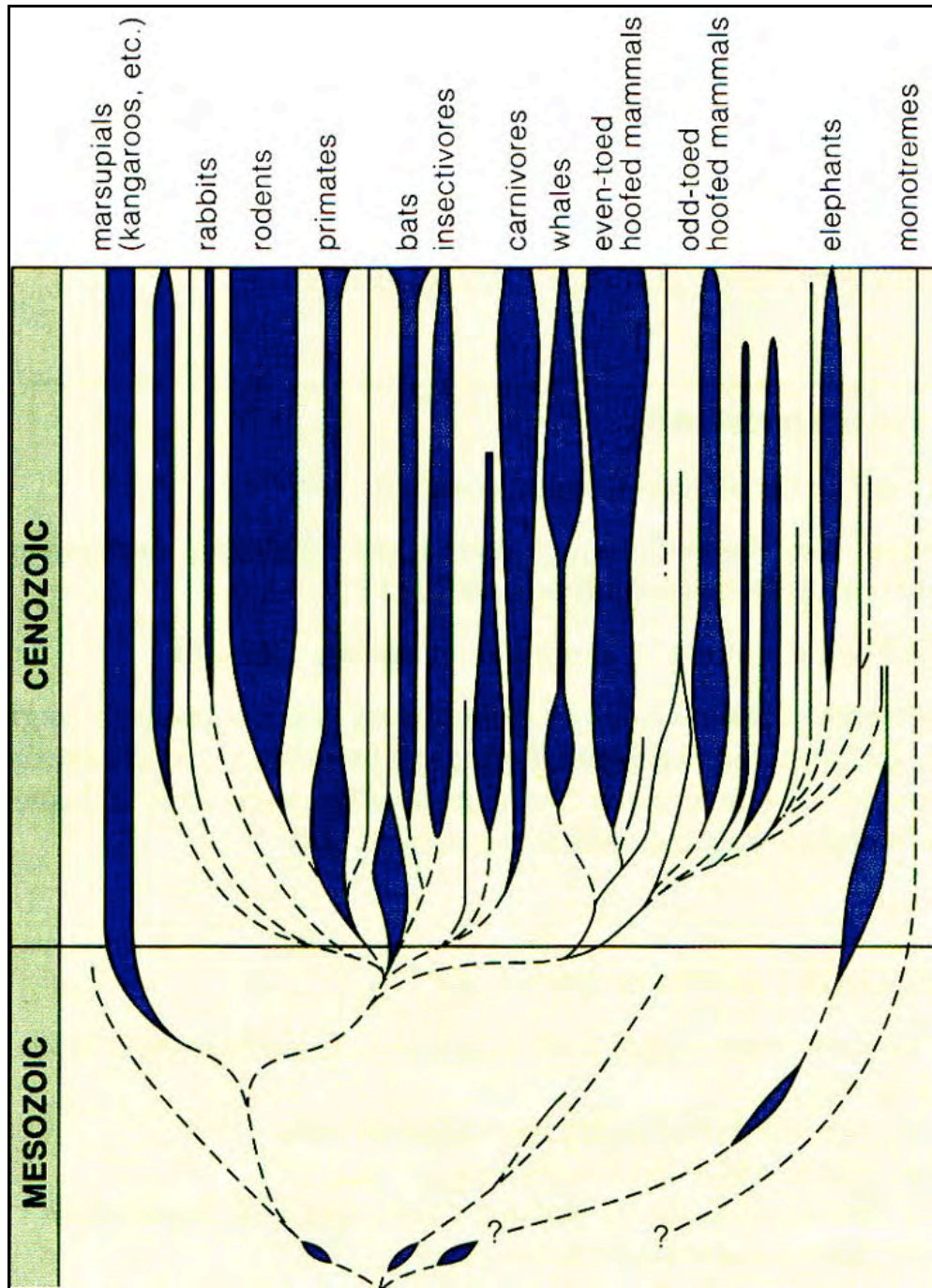
- **Note:** “branching” speciation is allopatric speciation, i.e. parent species “branch” off geographically and give rise to daughter species where both species survive at least for a time.

Gradualism: The Tempo and Mode of Evolution

The Tempo of Evolutionary Change

The rate of evolutionary change in populations of organisms has varied greatly over geological time. This is the **tempo** of evolutionary change and is related to the multiplication of species. It now appears to be true that this tempo consists of long periods of little change called stasis that are punctuated by rapid (rapid in terms of geological time) periods of evolution.

This is punctuated equilibrium.

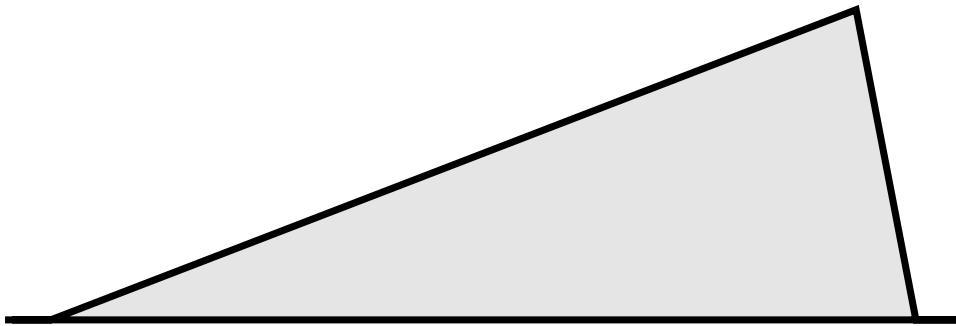


The Adaptive Radiation of Mammals

The Mode of Evolutionary Change

The **mode** of evolutionary change by slight variations caused by small mutations is always a gradual process. “It is the slow, cumulative, one-step-at-a-time, non-random survival of random variants.” —Dawkins, 1996

This is expressed in Richard Dawkins’ metaphor of Mount Improbable.



The Metaphor of Mount Improbable

Speciation

Allopatric or Phylogenetic or both?

“A new species develops if a population which has become geographically isolated from its parental species acquires during this period of isolation characters which promote or guarantee reproductive isolation when the external barriers break down.”
—Mayr, 1982

Points:

- **Allopatric speciation is speciation that takes place in geographic space.**
- **Phylogenetic speciation is speciation that takes place through time.**
- **Both, however, must occur to produce a new species.**

A Note on Terminology

Cladogenesis: Evolution in which a daughter species splits off from a population of the older species, after which both the old and the young species coexist together. Notice that this allows a descendant to coexist with its ancestor. Cladogenesis is the type of evolutionary change that occurs in allopatric speciation.

Anagenesis: Evolution in which an older species, as a whole, changes into a new descendent species, such that the ancestor is transformed into the descendant. Anagenesis is the type of evolutionary change that occurs in phylogenetic speciation.

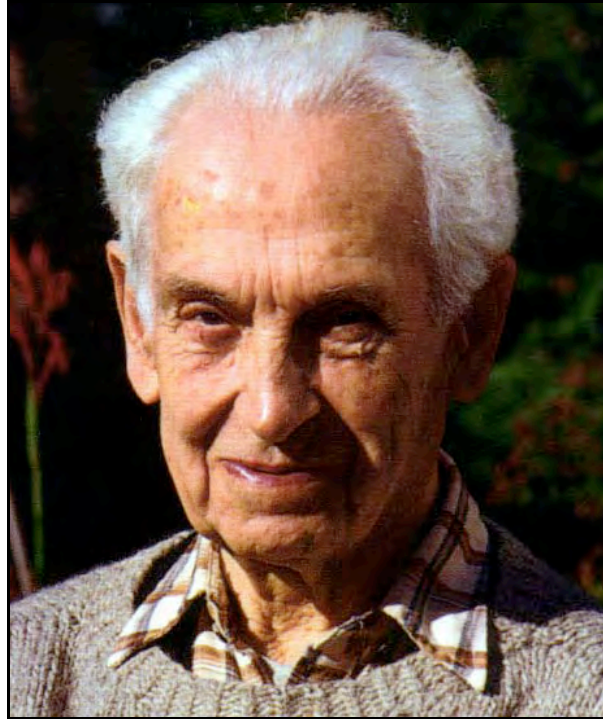
Population Thinking

Ernst Mayr has shown that, in order to understand evolution by natural selection, we must look to the nature of populations and not of individuals.

- **Individual organisms do not evolve; only populations of interbreeding organisms evolve.**

- **Only populations have continuity through time; individual organisms are temporary.**

It was also Ernst Mayr who set population thinking in opposition to Platonic essentialism (see essays on the Medieval worldview) to help us understand the difference between evolutionary thinking and the antiquated notion of the fixity of species. Essentialism held that each species had a fixed spiritual essence or ideal form and that any variation was, therefore, a corrupt deviation from this pure form.



Ernst Mayr (1905-2005)

Ernst Mayr was one of the 20th century's leading biologists. His work contributed to the conceptual revolution that led to the synthesis of Mendelian genetics and Darwinian evolution. Mayr was Emeritus Professor of Zoology at Harvard University until his death. This photograph was taken for the publication of his book *This is Biology* in 1997, which he wrote at age ninety-two. In 2001, he published a new book, *What Evolution Is*, at age ninety-six. He died in 2005 at the age of one hundred.

Web Reference

http://www.edge.org/3rd_culture/bios/mayr.html

Natural Fecundity

“There is no exception to the rule that every organic being naturally increases at so high a rate, that if not destroyed, the Earth would soon be covered by the progeny of a single pair.”

Charles Darwin from *On the Origin of Species*, page 64

Natural Selection

- **Over Production** (caused by Natural Fecundity)
coupled to
 - **Variation** that can be Inherited
leads to
 - **Differential Reproductive Success**
which leads to
- **Evolutionary Adaptation** to Changing Local Environments
(after Gould, 1977)

Points:

- 1) Natural selection is a dynamic process and not a person or a thing.
- 2) It is reasonable to equate natural selection to circumstances.
- 3) Natural selection only operates in the present, i.e. it is only the circumstances of the present that count in the process.
- 4) Present **circumstances** (natural selection) operating on individuals results in **changing** (evolving) populations.

Restated in other words, evolution by natural selection is a
nature algorithm.

Defining a Natural Algorithm

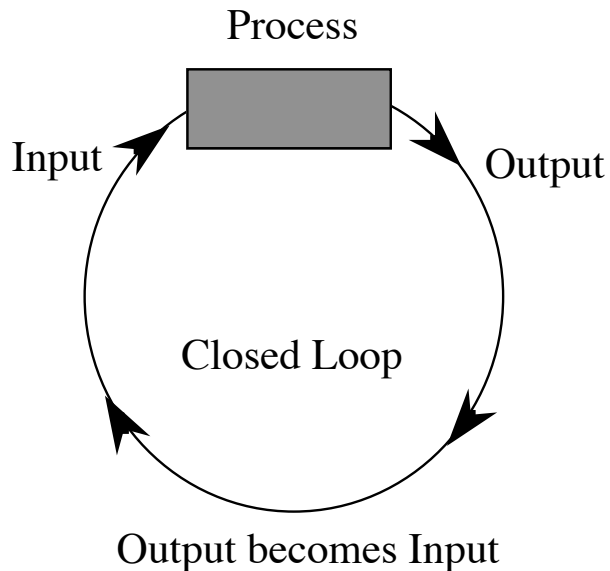
Using Daniel Dennett's definition from his book *Darwin's Dangerous Idea* (1995, 50-51) an algorithm has:

- 1) **substrate neutrality**: The power of the process is due to its *logical* structure, not the properties of the materials involved in its particular occurrence.
- 2) **underlying mindlessness**: Although the overall organization of the process may yield brilliant results, each constituent step, as well as the transition between steps, is utterly simple.
- 3) **guaranteed results**: Whatever it is that an algorithm does, it always does it. If it occurs without misstep, an algorithm is a foolproof recipe.

This does not mean that an algorithm must always produce the same result. Algorithms of natural processes always operate on a unique set of initial conditions, that, in turn, produce historically contingent outcomes. What evolutionary algorithms are a foolproof recipe for is cumulative change, where each outcome of the algorithmic process operating on an historical system is different from the last. What is guaranteed is change itself.

What Dennett doesn't clarify until later in his book is that, as it concerns evolution in natural systems, we are talking about *natural* algorithms—algorithmic processes in nature that have the above characteristics but do not have an end directed goal. They exist and operate but they are not algorithms for producing particular outcomes. They have no teleological purpose, no "final cause". This is Aristotle's fourth division of causality, and it is final not in the temporal sense of coming last, but in the Latin meaning of ultimate purpose. Natural algorithms are distinct from *constructed* algorithms—algorithms that have been created by humans to produce particular outcomes as in mathematics and computers.

Cause and Effect in a Closed System



The natural algorithm of evolution by natural selection is a process that operates on the closed historical system of genetics and reproduction of life on Earth. Using the figure above the “process” of evolution works on the gene pool of every population of organisms and results in the “output” of a unique gene pool every generation in the population. This then is the only gene pool (the input) available to produce the next generation.

The only way to stop this process would be to insure that there was absolutely no genetic change, no random mutations in DNA, no differential reproduction, nothing throughout the entire history of the population. Every generation’s gene pool would have to be genetically identical to the last one, and given the nature of genetics and reproduction, this is clearly impossible.

For more on the nature of evolution go to:
<http://fire.biol.wvu.edu/trent/alles/ABTpaperthree.pdf>

Adaptations

Evolution by natural selection does not lead to optimal adaptations. It produces only historically constrained answers to past environmental challenges. What worked in the past was cobbled together from what was genetically available then and has no guarantee of working in the future. Evolutionary adaptations are always a gamble that future conditions will be similar to the past. If the environment changes a highly specialized adaptation may suddenly become useless if not a liability.

- **In reality the only “adaptation” natural selection “selects” is reproductive success.**

Point: The point is that natural selection allows only what “works” to continue into the next generation, but the measure of every adaptation is in how it works to enhance reproductive success. Reproductive success is, therefore, the measure of every adaptation.

References for Biological Evolution

- Darwin, C. (1859). *On the Origin of Species (1st edition facsimile 1964)*. Cambridge, MA: Harvard University Press.
- Dawkins, R. (1996). *Climbing Mount Improbable*. New York: Norton.
- Dennett, D. C. (1995). *Darwin's Dangerous Idea: Evolution and the Meanings of Life*. New York: Simon & Schuster.
- Gould, S. J. (1977). *Ever Since Darwin*. New York: Norton.
- Lister, A., & Bahn, P. (1994). *Mammoths*. New York: MacMillan.
- Mayr, E. (1982). *The Growth of Biological Thought: Diversity, Evolution, and Inheritance*. Cambridge, MA: Harvard University Press.
- Mayr, E. (1997). *This is Biology*. Cambridge, MA: Belnap / Harvard.
- Mayr, E. (2001). *What Evolution Is*. New York: Basic Books.
- Ridley, M. (1995). Here, there, everywhere. *Nature*, 375(June 8), 457-458.

Return to Alles Biology 101 Illustrated Lectures
http://fire.biol.wvu.edu/trent/alles/101Lectures_Index.html

Return to Alles Biology Homepage
<http://fire.biol.wvu.edu/trent/alles/index.html>