Biology

ORIGIN AND EVOLUTION OF LIFE

Chapter

Life is defined as "The arrangement of the atoms in the most vital parts of an organism and the interplay of these arrangements differ in a fundamental way from all those arrangements of atoms which physicist and chemists have hitherto made the object of their experimental and theoretical research." The history of life can be conceptualized as the history of variant chemical structures harvesting energy to create ever more complex replicates of similar forms. All species of living organisms, including bacteria and chimpanzees, evolved at some point from a different species. Evolution is a gradual and ongoing process. The theory of evolution is the unifying theory of biology. Evolution by natural selection describes a mechanism for the change of species over time . Well before Darwin began to explore the concept of evolution, the idea that species change over time had already been suggested and debated. The view that species are static and unchanging was grounded in the writings of Plato, yet there were also ancient Greeks who expressed ideas about evolution. During the eighteenth century, ideas about the evolution of animals were reintroduced by the naturalist Georges-Louis Leclerc Comte de Buffon who observed that various geographic regions have different plant and animal populations, even when the environments are similar. It was also accepted that there are extinct species. Thus there were many sceintific and non- scientific theories put forward, namely:

1. Special creation: Life-forms may have been put on earth by supernatural or divine forces. It was put forward by Father Suarez, a spanish monk.

2. Extraterrestrial origin: Life may not have originated on earth at all; instead, life may have infected earth from some other planet. The theory of panspermia proposes that meteors or cosmic dust may have carried significant amounts of complex organic molecules to earth, kicking off the evolution of life. Hundreds of thousands of meteorites and comets are known to have slammed into the early earth, and recent findings suggest that at least some may have carried organic materials. It is still believed to be true by some scientists like Wickramsinghe, Francis Crick and Leslie Orgel.

3. Spontaneous origin: Life may have evolved from inanimate matter, as associations among molecules became more and more complex. In this view, the force leading to life was selection. As changes in molecules increased their stability and caused them to persist longer, these molecules could initiate more and more complex associations, culminating in the evolution of cells.

4. Biogenesis: Francesco Redi and Louis Pasteur laid the foundation for the Theory of Biogenesis, which propounded that living organisms arise from pre- existing ones and not from non- living matter.

5. Chemosynthetic theory or Chemogeny: This theory proposed that first form of life originated from inorganic chemical elements by formative action of some external physical force viz. lightening or cosmic rays etc. It was put forward by A I Oparin and J B S Haldane and the experimental evidence was provided by Stanley Millar and Harold Urey.

6. Natural Selection: This theory stated that all organisms are products of evolution adapted to their environment. During this time, a Scottish naturalist named James Hutton proposed that geological change occurs gradually by the accumulation of small changes over long periods of time. This theory contrasted with the predominant view of the time that the geology of the planet is a consequence of catastrophic events that occurred during a relatively brief past.

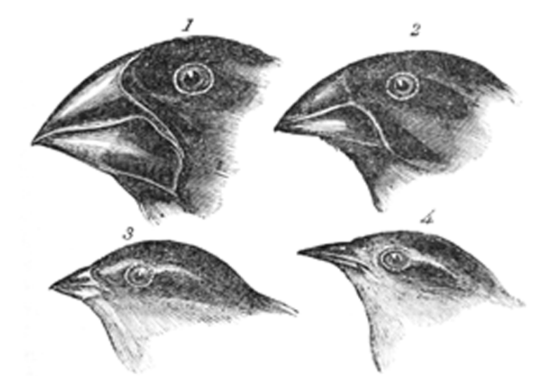
During the nineteenth century, Hutton's views were popularized by the geologist Charles Lyell, who was a friend of Charles Darwin. Lyell's ideas, in turn, influenced Darwin's concept of evolution. The greater age of the earth proposed by Lyell supported the gradual evolution that Darwin proposed, and the slow process of geological change provided an analogy for the gradual change in species. In the early nineteenth century, Jean-Baptiste Lamarck published a book that detailed a different mechanism for evolutionary change. This mechanism is now referred to as an inheritance of acquired characteristics. This idea states that modifications in an individual are caused by its environment, or the use or disuse of a structure during its lifetime, and that these changes can be inherited by its offspring, bringing about change in a species. While this mechanism for evolutionary change was discredited, Lamarck's ideas were an important influence on the concept of evolution.

CHARLES DARWIN AND NATURAL SELECTION

In the mid-nineteenth century, the mechanism for evolution was independently conceived of and described by two naturalists: Charles Darwin and Alfred Russel Wallace. Darwin visited the Galápagos Islands west of Ecuador. On these islands, Darwin observed that species of organisms on different islands were clearly similar, yet had distinct differences.

Beak Shape Among Finch Species

Darwin observed that beak shape varies among finch species. He postulated that the beak of an ancestral species had adapted over time to equip the finches to acquire different food sources.



1. Geospiza magnirostris 2. Geospiza fortis
3. Geospiza parvula 4. Certhidea olivacea

Finches from Galapagos Archipelago

Natural Selection

Wallace and Darwin observed similar patterns in other organisms and independently developed the same explanation for how and why such changes could take place. Darwin called this mechanism natural selection. Natural selection, also known as "survival of the fittest," is the more prolific reproduction of individuals with favorable traits that survive environmental change because of those traits. Natural selection, Darwin argued, was an inevitable outcome of three principles that operated in nature. First, most characteristics of organisms are inherited, or passed from parent to offspring, although how traits were inherited was unknown. Second, more offspring are produced than are able to survive. The capacity for reproduction in all organisms outstrips the availability of resources to support their numbers. Thus, there is competition for those resources in each generation. Both Darwin and Wallace were influenced by an essay written by economist Thomas Malthus who discussed this principle in relation to human populations. Third, Darwin and Wallace reasoned that offspring with the inherited characteristics that allow them to best compete for limited resources will survive and have more offspring than those individuals with variations that are less able to compete. Because characteristics are inherited, these traits will be better represented in the next generation. This will lead to change in populations over successive generations in a process that Darwin called descent with modification. Ultimately, natural selection leads to greater adaptation of the population to its local environment; it is the only mechanism known for adaptive evolution. Darwin reasoned that offspring with inherited characteristics that allow them to best compete for limited resources will survive and have more offspring than those individuals with variations that are less able to compete. Because characteristics are inherited, these traits will be better represented in the next generation. This will lead to change in populations over generations in a process that Darwin called "descent with modification," or evolution.

PROCESSES AND PATTERNS OF EVOLUTION

Variation

Natural selection can only take place if there is variation, or differences, among individuals in a population. Importantly, these differences must have some genetic basis; otherwise, the selection will not lead to change in the next generation. This is critical because variation among individuals can be caused by non-genetic reasons, such as an individual being taller due to better nutrition rather than different genes. Genetic diversity within a population comes from two main mechanisms: mutation and sexual reproduction. Mutation, a change in the DNA sequence, is the ultimate source of new alleles, or new genetic variation in any population. The genetic changes caused by mutation can have one of three outcomes:

- Many mutations will have no effect on the fitness of the phenotype; these are called neutral mutations.
- A mutation may affect the phenotype of the organism in a way that gives it reduced fitness (a lower likelihood of survival or fewer offspring).
- A mutation may produce a phenotype with a beneficial effect on fitness. Different mutations will have a range of effects on the fitness of an organism that expresses them in their phenotype, from a small effect to a great effect.

Sexual reproduction also leads to genetic diversity: when two parents reproduce, unique combinations of alleles assemble to produce the unique genotypes and thus phenotypes in each of the offspring. However, sexual reproduction cannot lead to new genes, but rather provides a new combination of genes in a given individual.

Adaptations

A heritable trait that aids the survival and reproduction of an organism in its present environment is called an adaptation. E.g. The cheetahs' fast speed is an adaptation for catching prey. Whether or not a trait is favourable depends on the environmental conditions at the time. The same traits are not always selected because environmental conditions can change. The evolution of species has resulted in enormous variation in form and function. Sometimes, evolution gives rise to groups of organisms that become tremendously different from each other. When two species evolve in diverse directions from a common point, it is called divergent evolution. Such divergent evolution can be seen in the forms of the reproductive organs of flowering plants which share the same basic anatomies; however, they can look very different as a result of selection in different physical environments and adaptation to different kinds of pollinators .

EVIDENCES OF EVOLUTION

The evidence for evolution is compelling and extensive. Looking at every level of organization in living systems, biologists see the signature of past and present evolution.

Fossils provide solid evidence that organisms from the past are not the same as those found today; they show a progression of evolution. Scientists calculate the age of fossils and categorize them to determine when the organisms lived relative to each other. The resulting fossil record tells the story of the past and shows the evolution of form over millions of years. Over time, evolution led to changes in the shapes and sizes of these bones in different species, but they have maintained the same overall layout. Scientists call these synonymous parts homologous structures.

Anatomy, Some structures exist in organisms that have no apparent function at all, appearing to be residual parts from a common ancestor. These unused structures (such as wings on flightless birds, leaves on some cacti, and hind leg bones in whales) are vestigial.

The examples of human vestigiality are numerous, including the anatomical (such as the human appendix, tailbone, wisdom teeth, and inside corner of the eye), the behavioral (goose bumps and palmar grasp reflex), sensory (decreased olfaction), and molecular (noncoding DNA).

Embryology, the study of the development of the anatomy of an organism to its adult form, provides evidence for evolution as embryo formation in widely-divergent groups of organisms tends to be conserved. Structures that are absent in the adults of some groups often appear in their embryonic forms, disappearing by the time the adult or juvenile form is reached. For example, all vertebrate embryos, including humans, exhibit gill slits and tails at some point in their early development. These disappear in the adults of terrestrial groups, but are maintained in adults of aquatic groups, such as fish and some amphibians. Great ape embryos, including humans, have a tail structure during their development that is lost by birth.

ADAPTATIONS

Biogeography

The geographic distribution of organisms on the planet follows patterns that are best explained by evolution in conjunction with the movement of tectonic plates over geological time. Broad groups that evolved before the breakup of the supercontinent Pangaea (about 200 million years ago) are distributed worldwide. Groups that evolved since the breakup appear uniquely in regions of the planet, such as the unique flora and fauna of northern continents that formed from the supercontinent Laurasia compared to that of the southern continents that formed from the supercontinent Gondwana. The marsupials of Australia, the finches on the Galápagos, and many species on the Hawaiian Islands are all unique to their one point of origin, yet they display distant relationships to ancestral species on mainlands.

Speciation

Given the extraordinary diversity of life on the planet, there must be mechanisms for speciation: the formation of two species from one original species. Darwin envisioned that as one species changes over time, it branches repeatedly to form more than one new species as long as the population survives or until the organism becomes extinct.

For speciation to occur, two new populations must be formed from one original population; they must evolve in such a way that it becomes impossible for individuals from the two new populations to interbreed. Biologists have proposed mechanisms by which this could occur that fall into two broad categories:

Allopatric speciation (allo- = "other"; -patric = "homeland")

It involves geographic separation of populations from a parent species and subsequent evolution. When a population is geographically continuous, the allele frequencies among its members are similar; however, when a population becomes separated, the allele frequencies between the two groups can begin to vary. If the separation between groups continues for a long period of time, the differences between their alleles can become more and more pronounced due to differences in climate, predation, food sources, and other factors, eventually leading to the formation of a new species. Geographic separation between populations can occur in many ways; the severity of the separation depends on the travel capabilities of the species. Allopatric speciation events can occur either by dispersal, when a few members of a species move to a new geographical area, or by vicariance, when a natural situation, such as the formation of a river or valley, physically divide organisms.

When a population disperses throughout an area, into new, different and often isolated habitats, multiple speciation events can occur in which the single original species gives rise to many new species; this phenomenon is called adaptive radiation.The Hawaiian honeycreeper illustrates one example of adaptive radiation. From a single species, called the founder species, numerous species have evolved .

Adaptive Radiation

The honeycreeper birds illustrate adaptive radiation. From one original species of bird, multiple others evolved, each with its own distinctive characteristics.

In Hawaiian honeycreepers, the response to natural selection based on specific food sources in each new habitat led to the evolution of a different beak suited to the specific food source. The seed-eating birds have a thicker, stronger beak which is suited to break hard nuts. The nectar-eating birds have long beaks to dip into flowers to reach the nectar. The insect-eating birds have beaks like swords, appropriate for stabbing and impaling insects.

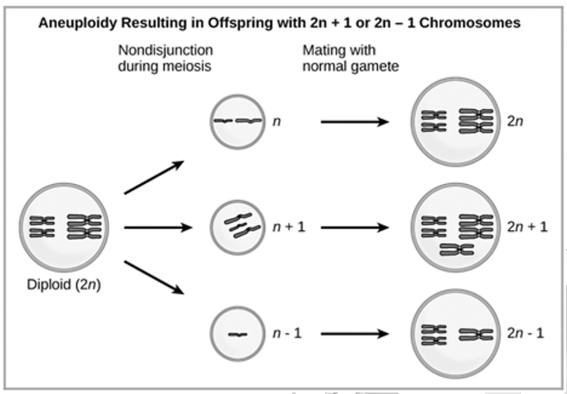
Sympatric Speciation

It involves speciation occurring within a parent species remaining in one location. Sympatric speciation can occur when one individual develops an abnormal number of chromosomes, either extra chromosomes (polyploidy) or fewer, such that viable interbreeding can no longer occur.

Once a species develops an abnormal number of chromosomes, it can then only interbreed with members of the population that have the same abnormal number, which can lead to the development of a new species.

The prefix "sym" means same, so "sympatric" means "same homeland" in contrast to "allopatric" meaning "other homeland." A number of mechanisms for sympatric speciation have been proposed and studied.

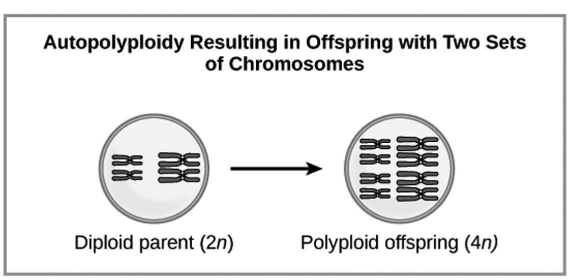
One form of sympatric speciation can begin with a serious chromosomal error during cell division. In a normal cell division event, chromosomes replicate, pair up, and then separate so that each new cell has the same number of chromosomes. However, sometimes the pairs separate and the end cell product has too many or too few individual chromosomes in a condition called aneuploidy.



Aneuploidy results when the gametes have too many or too few chromosomes due to nondisjunction during meiosis. In the example shown here, the resulting offspring will have 2n+1 or 2n-1 chromosomes.

Polyploidy is a condition in which a cell or organism has an extra set, or sets, of chromosomes.

Scientists have identified two main types of polyploidy that can lead to reproductive isolation, or the inability to interbreed with normal individuals, of an individual in the polyploidy state. In some cases, a polyploid individual will have two or more complete sets of chromosomes from its own species in a condition called **autopolyploidy** . The prefix "auto-" means "self," so the term means multiple chromosomes from one's own species. Polyploidy results from an error in meiosis in



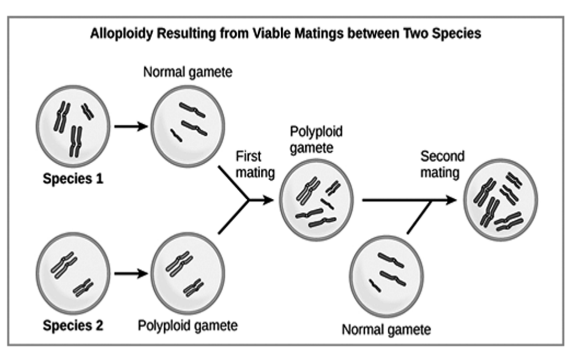
which all of the chromosomes move into one cell instead of separating.

Autopolyploidy results when meiosis is not followed by cytokinesis.

For example, if a plant species with 2n = 6 produces autopolyploid gametes that are also diploid (2n = 6, when they should be n = 3), the gametes now have twice as many chromosomes as they should have. These new gametes will be incompatible with the normal gametes produced by this plant species. However, they could either self-pollinate or reproduce with other autopolyploid plants with gametes having the same diploid number. In this way, sympatric speciation can occur quickly by forming offspring with 4n: a tetraploid. These individuals would immediately be able to reproduce only with those of this new kind and not those of the ancestral species.

The other form of polyploidy occurs when individuals of two different species reproduce to form a viable offspring called an allopolyploid. The prefix "allo-" means "other" (recall from allopatric). Therefore, an allopolyploid occurs when gametes from two different species combine . Notice how it takes two generations, or two reproductive acts, before the viable fertile hybrid results.

Alloploidy results when two species mate to produce viable offspring. In the example shown, a normal gamete from one species fuses with a polyploidy gamete from another.



Two matings are necessary to produce viable offspring. The cultivated forms of wheat, cotton, and tobacco plants are all allopolyploids. Although polyploidy occurs occasionally in animals, it takes place most commonly in plants. (Animals with any of the types of chromosomal aberrations described here are unlikely to survive and produce normal offspring.)

Reproductive Isolation

Given enough time, the genetic and phenotypic divergence between populations will affect characters that influence reproduction: if individuals of the two populations were to be brought together, mating would be improbable, but if mating did occur, offspring would be non-viable or infertile. Many types of diverging characters may affect reproductive isolation, the ability to interbreed, of the two populations. Reproductive isolation is a collection of mechanisms, behaviours, and physiological processes that prevent the members of two different species that cross or mate from producing offspring, or which ensure that any offspring that may be produced is not fertile.

PHYLOGENY

Phylogenetic Relationships

Phylogeny describes the relationships of an organism, such as the relationship with its ancestors and the species it is most closely related. Phylogenetic relationships provide information on shared ancestry but not necessarily on how organisms are similar or different. The use of advanced genomic analysis has allowed us to establish phylogenetic trees, which map the relationship between species at a genetic and molecular level. The ability to use these technologies has established previously unknown relationships and has contributed to a more complex evolutionary history. These technologies have established genomic similarities between distant species by establishing genetic distances . In addition, the mechanisms by which genomic similarities between distant species occur can include horizontal gene transfer.

Evolution of Population

According to evolutionary theory, every organism from humans to beetles to plants to bacteria share a common ancestor. Millions of years of evolutionary pressure caused some organisms to died while others survived, leaving earth with the diverse life forms we have today. Within this diversity is unity; for example, all organisms are composed of cells and use DNA. The theory of evolution gives us a unifying theory to explain the similarities and differences within life's organisms and processes.

Evolution on earth

Evolution has resulted in living things that may be single-celled or complex, multicellular organisms. They may be plants, animals, fungi, bacteria, or archaea. This diversity results from evolution.

Genetic Variation in Populations

A population is a group of individuals that can all interbreed, often distinguished as a species. Because these individuals can share genes and pass on combinations of genes to the next generation, the collection of these genes is called a gene pool. The process of evolution occurs only in populations and not in individuals. A single individual cannot evolve alone; evolution is the process of changing the gene frequencies within a gene pool. Five forces can cause genetic variation and evolution in a population: mutations, natural selection, genetic drift, genetic hitchhiking, and gene flow.

Mutations

It is a change in the genetic code. Mutations occur spontaneously, but not all mutations are heritable, they are passed down to offspring only if the mutations occur in the gametes. These heritable mutations are responsible for the rise of new traits in a population.

Just as mutations cause new traits in a population, natural selection acts on the frequency of those traits. Because there are more organisms than resources, all organisms are in a constant struggle for existence. In natural selection, those individuals with superior traits will be able to produce more offspring. The more offspring an organism can produce, the higher its fitness. As novel traits and behaviours arise from mutation, natural selection perpetuates the traits that confer a benefit. As mutations create variation, natural selection affects the frequency of that trait in a population. Mutations that confer a benefit (such as running faster or digesting food more efficiently) can help that organism survive and reproduce, carrying the mutation to the next generation.

Genetic Drift

When selective forces are absent or relatively weak, gene frequencies tend to “drift” due to random events. This drift halts when the variation of the gene becomes “fixed” by either disappearing from the population or replacing the other variations completely. Even in the absence of selective forces, genetic drift can cause two separate populations that began with the same genetic structure to drift apart into two divergent populations.

Gene Fixation

In this simulation, there is fixation in the blue gene variation within five generations. Images these dots are beetles and some of them are destroyed by a wildfire. As the surviving population changes over time, some traits (red) may be completely eliminated from the population, leaving only the beetles with other traits (blue).

Genetic Hitchhiking

When recombination occurs during sexual reproduction, genes are usually shuffled so that each parent gives its offspring a random assortment of its genetic variation. However, genes that are close together on the same chromosome are often assorted together. Therefore, the frequency of a gene may increase in a population through genetic hitchhiking if its proximal genes confer a benefit.

Gene Flow

Gene flow is the exchange of genes between populations or between species.If the gene pools between two populations are different, the exchange of genes can introduce variation that is advantageous or disadvantageous to one of the populations. If advantageous, this gene variation may replace all the other variations until the entire population exhibits that trait.

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