ENTRI

Evolutionary Biology

- ❖ An outline of evolutionary theories
  - ➢ Evolutionary theories take the long -term look at the emergence of the human species
  - ➢ According to this perspective ,humans of today carry with them genetically guided characteristics passed from generation to generation that have contributed to survival and reproductive success
  - ➢ Evolutionary theory highlights the adaptive value of within - species variability
  - ➢ Optimal biological and behavioural strategies differ depending on the nature of the environmental context as well as the characteristics of the organism such as age ,sex ,health or physical size
  - ➢ The evolutionary theory framework covers applications of natural selection to the ecological behavior of individuals and groups or populations ,including the demographic and social epidemiology of pathogenic disease.
- ❖ **Darwinism**
  - ➢ Charles Darwin was a British naturalist who proposed the theory of biological evolution by natural selection.
  - ➢ Darwin defined evolution as **"descent with modification,"** the idea that species change over time, give rise to new species, and share a common ancestor.
  - ➢ The mechanism that Darwin proposed for evolution is natural selection. Because resources are limited in nature, organisms with heritable traits that favor survival and reproduction will tend to leave more offspring than their peers, causing the traits to increase in frequency over generations.

- ➢ Natural selection causes populations to become adapted, or increasingly well-suited, to their environments over time. Natural selection depends on the environment and requires existing heritable variation in a group.
- ➢ The basic idea of biological evolution is that populations and species of organisms change over time. Today, when we think of evolution, we are likely to link this idea with one specific person: the British naturalist Charles Darwin.
- ➢ In the 1850s, Darwin wrote an influential and controversial book called On **the Origin of Species.** In it, he proposed that species evolve (or, as he put it, undergo **"descent with modification"**), and that all living things can trace their descent to a common ancestor
- ➢ Darwin also suggested a mechanism for evolution: natural selection, in which heritable traits that help organisms survive and reproduce become more common in a population over time.

❖ **Influences on Darwin**

- ➢ **Darwin and the voyage of the Beagle**
- ➢ Darwin's seminal book, **On the Origin of Species**, set forth his ideas about evolution and natural selection. These ideas were largely based on direct observations from Darwin's travels around the globe. From 1831 to 1836, he was part of a survey expedition carried out by the ship **HMS Beagle,** which included stops in South America, Australia, and the southern tip of Africa. At each of the expedition's stops, Darwin had the opportunity to study and catalog the local plants and animals.

- Over the course of his travels, Darwin began to see intriguing patterns in the distribution and features of organisms. We can see some of the most important patterns Darwin noticed in distribution of organisms by looking at his observations of the Galápagos Islands off the coast of Ecuador.
- Darwin found that nearby islands in the Galápagos had similar but nonidentical species of finches living on them. Moreover, he noted that each finch species was well-suited for its environment and role. For instance, species that ate large seeds tended to have large, tough beaks, while those that ate insects had thin, sharp beaks. Finally, he observed that the finches (and other animals) found on the Galápagos Islands were similar to species on the nearby mainland of Ecuador, but different from those found elsewhere in the world
- Darwin didn't figure all of this out on his trip. In fact, he didn't even realize all the finches were related but distinct species until he showed his specimens to a skilled ornithologist (bird biologist) years later cubed Gradually, however, he came up with an idea that could explain the pattern of related but different finches.
- According to Darwin's idea, this pattern would make sense if the Galápagos Islands had long ago been populated by birds from the neighboring mainland. On each island, the finches might have gradually adapted to local conditions (over many generations and long periods of time). This process could have led to the formation of one or more distinct species on each island
- If this idea was correct, though, why was it correct? What mechanism could explain how each finch population had

acquired adaptations, or features that made it well-suited to its immediate environment? During his voyage, and in the years after, Darwin developed and refined a set of ideas that could explain the patterns he had observed during his voyage. In his book, On the Origin of Species, Darwin outlined his two key ideas: evolution and natural selection.

❖ **1.Evolution**

- ➢ Darwin proposed that species can change over time, that new species come from preexisting species, and that all species share a common ancestor. In this model, each species has its own unique set of heritable (genetic) differences from the common ancestor, which have accumulated gradually over very long time periods. Repeated branching events, in which new species split off from a common ancestor, produce a multi-level **"tree"** that links all living organisms.
- ➢ Darwin referred to this process, in which groups of organisms change in their heritable traits over generations, as "**descent with modification.**" Today, we call it evolution. Darwin's sketch above illustrates his idea, showing how one species can branch into two over time, and how this process can repeat multiple times in the **"family tree"** of a group of related species.

❖ **2.Natural Selection**

- ➢ Importantly, Darwin didn't just propose that organisms evolved. If that had been the beginning and end of his theory, he wouldn't be in as many textbooks as he is today! Instead, Darwin also proposed a mechanism for evolution: natural selection. This mechanism was elegant and logical, and it explained how populations could evolve (undergo descent with modification) in such a way that they became better suited to their environments over time

- ➢ Darwin's concept of natural selection was based on several key observations:
- ➢ Traits are often heritable. In living organisms, many characteristics are inherited, or passed from parent to offspring. (Darwin knew this was the case, even though he did not know that traits were inherited by genes.)
- ➢ More offspring are produced than can survive. Organisms are capable of producing more offspring than their environments can support. Thus, there is competition for limited resources in each generation.
- ➢ Offspring vary in their heritable traits. The offspring in any generation will be slightly different from one another in their traits (color, size, shape, etc.), and many of these features will be heritable

❖ **Based on these simple observations, Darwin concluded the followin**g:

- ➢ In a population, some individuals will have inherited traits that help them survive and reproduce (given the conditions of the environment, such as the predators and food sources present). The individuals with the helpful traits will leave more offspring in the next generation than their peers, since the traits make them more effective at surviving and reproducing.
- ➢ Because the helpful traits are heritable, and because organisms with these traits leave more offspring, the traits will tend to become more common (present in a larger fraction of the population) in the next generation.
- ➢ Over generations, the population will become adapted to its environment (as individuals with traits helpful in that environment have consistently greater reproductive success than their peers).

➢ Darwin's model of evolution by natural selection allowed him to explain the patterns he had seen during his travels. For instance, if the Galápagos finch species shared a common ancestor, it made sense that they should broadly resemble one another (and mainland finches, who likely shared that common ancestor). If groups of finches had been isolated on separate islands for many generations, however, each group would have been exposed to a different environment in which different heritable traits might have been favored, such as different sizes and shapes of beaks for using different food sources. These factors could have led to the formation of distinct species on each island.

❖ **Example of how natural selection can work**

➢ To make natural selection more concrete, let's consider a simplified, hypothetical example. In this example, a group of mice with heritable variation in fur color (black vs. tan) has just moved into a new area where the rocks are black. This environment features hawks, which like to eat mice and can see the tan ones more easily than the black ones against the black rock.

➢ Because the hawks can see and catch the tan mice more easily, a relatively large fraction of the tan mice are eaten, while a much smaller fraction of the black mice are eaten. If we look at the ratio of black mice to tan mice in the surviving (**"not-eaten"**) group, it will be higher than in the starting population

➢ Fur color is a heritable trait (one that can be passed from parent to child). So, the increased fraction of black mice in the surviving group means an increased fraction of black baby mice in the next generation. After several generations of selection, the population might be made up almost entirely of black mice. This change in the heritable features of the population is an example of evolution.

❖ **Lamarckism**

- Lamarckism is the first theory of evolution, which was proposed by Jean Baptiste de Lamarck (1744-1829), a French biologist. Although the outline of the theory was brought to notice in 1801, but his famous book **“Philo-sophic Zoologies”** was published in 1809, in which he discussed his theory in detail. Lamarck coined the terms **“invertebrates” and “Annelida”**. The term **“Biology”** was given by Lamarck and Treviranus (1802).

❖ **Lamarck’s Propositions:**

- Lamarckism includes four main propo-sitions.
- **(i) Internal Vital Force:**
- All the living things and their component parts are continually increased due to internal vital force. Lamarck.
- **(ii) Effect of Environment and New Needs:**
- Environment influences all types of organisms. A change in environment brings about changes in organ-isms. It gives rise to new needs. New needs or desires produce new structures and change habits of the organisms. Doctrine of desires is called appetency.
- **(iii) Use and Disuse of Organs:**
- If an organ is constantly used it would be better developed whereas disuse of the organ results in its degeneration.
- **(iv) Inheritance of Acquired Characters:**
- Whatever an individual acquires (to pos-sess) characters in its lifetime due to internal vital force, effect of environment, new needs and use and disuse of organs, they are inherited (transmitted) to the next generations. The process continues. After several generations, the variations accumulate up to such an extent that they give rise to new species.
- **Examples in Support of Lamarckism:**

- Lamarck explained his theory by giving the following examples.
- **(i)Evolution of Giraffe**
- The ancestors of giraffes were bearing a small neck and fore-limbs and were like horses. But as they were living in places with no surface vegetation, they had to stretch their neck and fore-limbs to take the leaves for food, which resulted in the slight elongation of these parts. Whatever they acquired in one generation was transmitted to the next generation with the result that a race of long necked and long four-limbed animals was developed.
- **ii) Webbed Toes of Aquatic Birds:**
- Aquatic birds like ducks have evolved from their terrestrial ancestors.
- **(iii) Disappearance of Limbs in Snakes:**
- The snakes have evolved from lizard-like ancestors which had two pairs of limbs.
- **(iv) Flat Fishes:**
- They are flat and bear both the eyes on one side and live at the bottom of the water. During the embryonic stage their eyes are present laterally, one eye on either side. The body of these fishes is not flat at this stage but later on both the eyes are shifted to one side and the body becomes flat to withstand the pressure of water.
- **(v) Flightless Birds:**
- The ancestors of these birds (e.g., Ostrich) were capable of flying, but due to some environmental factors they had plenty of food and were well protected. So they did not use their wings and that is why the latter became vestigial.
- **(vi) Retractile Claws of Carnivorous Mammals**
- The ancestors of carnivorous mammals such as lions, tigers etc. had ordinary claws for tearing the flesh of their prey. As the latter

gained in running, the carnivorous mammals also had to run fast for which claws were a hindrance. The animals, therefore, developed retractile claws.

- **(vii) Deer**
- The ancestors of deer did not have so much speed in running, but as they needed protection from other animals of that time they started running, due to which present speed was achieved by the deer.
- **(viii) Cave Dwellers:**
- The ancestors of cave dwellers had normal eye sight. On account of living under continuous dark conditions, the animal lost their power to see.
- **(ix) Emergent Hydrophytes**
- The effect of environment and inheritance of acquired characters is clearly seen in emergent hydrophytes like **Ranunculus aquatilis.** Here the submerged leaves are dissected while the emerged ones are simply lobed. When the plant is grown out of water, all the leaves are un-dissected. In the submerged environment all the leaves are dissected.
- **Criticism of Lamarckism:**
- (Evidences against the Inheritance of Acquired Characters):
- The first proposition of the theory does not have any ground because there is no vital force in organisms which increases their body parts. As regards the second proposition, the environment can affect the animal but it is doubtful that a new need forms new structures. The third proposition, the use and disuse of the organs is correct up to some extent. The fourth proposition regarding the inheritance of acquired characters is disputed.

- Mendel’s Laws of Inheritance and Weismann’s Theory of Continuity of Germplasm (1892) discarded Lamarck’s concept of inheritance of acquired characters.
- (i) Theory of Continuity of Germplasm. August Weismann (1834-1914), a German biologist, was the main opposer of the inheritance-of acquired characters. He put forward the theory of continuity of germplasm. According to Weismann, the characters influencing the germ cells are only inherited. There is a continuity of germplasm (protoplasm of germ cells) but the somato-plasm (protoplasm of somatic cells) is not transmitted to the next generation hence it does not carry characters to the next generation. Weismann cut off the tails of rats for as many as 22 generations and allowed them to breed, but tailless rats were never born
- (ii) Boring of pinna (external ear) and nose of Indian women is never inherited to the next generations.
- (iii) The wrestler’s powerful muscles are not transmitted to the offspring.
- (iv) European ladies wear tight waist garments in order to keep their waist slender but their offspring at the time of birth have normal waists.
- (v) Chinese women used to wear iron shoes in order to have small feet, but their children at the time of birth always have normal feet.
- (vi) Circumcision of penis is in Jews and Muslims but it is not inherited to the next generation.
- (vii) Dull progeny of Nobel Prize winners cannot be explained by Lamarckism.
- **Evidences in Favor of the Inheritance of Acquired Characters:**
- **(i) Formation of Germ Cells from Somatic Cells**:

- In certain cases somatic cells can produce the germ cells, which is against Weismann's theory of continuity of germ-plasm. This occurs in vegetative propagation in plants and regeneration in animals.
- **(ii) Effect of Environment directly on Germ Cells:**
- Tower exposed the young de-veloping Potato Beetles to extremes of temperature and humidity at the time of the development of their reproductive organs. This did not produce any change in the beetles themselves. Their offspring, however, had color variations, which were passed on to the succeeding generations. Tower's observations indicate direct effect of environment on germ cells.
- (**iii) Effect of Radiation:**
- Exposure of organisms to high energy radiations (ultra-violet rays, X-rays, gamma rays, etc.) or feeding them with mutagenic chemicals, produces sudden inheritable variations or mutations. For example, Auerbach et al obtained a number of mutations and chromosome aberrations in Drosophila with the help of mustard gas.
- **(iv) Agar:**
- Agar reared water fleas in a culture of green flagellates and found that some abnormalities were developed in their structures. The parthenogenetic eggs of such individu-als when kept in ordinary water and allowed to hatch produced individuals with the same abnormalities.
- **(v) Effect of Chemicals:**
- There is no isolation of somatic and germ cells. Rather one part of the body affects other parts of the body through chemicals called **hormones.** Change in the secretion of hormones results in the change of different parts of the body.

- **(vi)Guyar and Smith:**
- Guyar and Smith took the solution of the eye lens of rabbit and inoculated the same into fowl. The fowl's serum containing antibodies was injected into pregnant rabbits. Some of the offspring were found to have malformed or degenerate eyes.
- **(viii) Effect of Change of Environment:**
- Radish is a two-year crop in cold countries but completes its growth in one year in tropical areas. Similarly, deciduous European Peach becomes evergreen in India
- **Neo-Lamarckism:**
- Modified form of Lamarckism is called Neo-Lamarckism (neo = new).
- **Neo-Lamarckism proposes that**
- (i) Environment does influence an organism and change its heredity.
- (ii) At least some of the variations acquired by an individual can be passed on to the offspring.
- (iii) Internal vital force and appetite do not play any role in evolution.
- iv) Only those variations are passed on to the offspring which also affect germ cells or where somatic cells give rise to germ cells.
- Evidences in favor of the inheritance of acquired characters support the Neo-Lamarckism

- **Modern Synthetic Theory of Evolution**
    - The Modern Synthetic Theory of Evolution (also called Modern Synthesis) merges the concept of Darwinian evolution with Mendelian genetics, resulting in a unified theory of evolution. This theory is also referred to as the Neo-Darwinian theory and was introduced by a number of

evolutionary biologists such as T. Dobzhansky, J.B.S. Haldane, R.A. Fisher, Sewall Wright, G.L. Stebbins, Ernst Mayr.

- ➢ It describes the evolution of life in terms of genetic changes occurring in the population that leads to the formation of new species. It also describes the genetic population or Mendelian population, gene pool and gene frequency. The major concepts coming under this theory include genetic variations, reproductive and geographical isolation and natural selection.
- ➢ The Modern Synthetic Theory of Evolution showed a number of changes as to how the evolution and the process of evolution are conceived. The theory gave a new definition of evolution as **“the changes occurring in the allele frequencies within the populations, ”** which emphasizes the genetic basis of evolution.

❖ **Factors of Modern Synthetic Theory of Evolution**

- ➢ The factors that contribute to the change in allele frequency of a population are as follows:
- ➢ **Genetic Recombination**
- ➢ Recombination is a process where new combinations of alleles are formed. The genetic recombination occurs during sexual reproduc-tion at the time of gamete formation. There occurs an exchange of genetic material between non-sister chromatids during meiosis that is called crossing over. It leads to recombination and is one of the causes of genetic variability present within a population.
- ➢ **Mutation**
- ➢ Mutations are the sudden inheritable changes that occur in the gene and have a certain phenotypic effect. Chromosomal

mutations may be due to change in the genes or chromosome structure or number, e.g. deletion, inversion, duplication, translocation, aneuploidy, polyploidy, etc. Mutation produces a variety of changes that may be harmful. Many of the mutant forms of genes are recessive and are expressed only in the homozygous condition. Advantageous mutations may be selected by natural selection and gradual small changes accumulate over time. These mutations cause variation in a population.

- **Genetic Drift and Gene Flow**
- Any change in the gene/allele frequency of a population due to sudden, random changes, is referred to as genetic drift. It occurs due to chance events. Genetic drift is more prominent in a small population. Gene flow is due to the immigration or emigration of individuals from one population to another. If the migration occurs multiple times it leads to gene flow and changes the allele/gene frequency of the populations.
- **Natural selection**
- Organisms that are better adapted to the environment are selected by nature. Natural selection produces a change in the frequency of the genes from one generation to the other favoring the differential form of reproduction.
- **Isolation**
- It is one of the significant factors responsible for the synthetic theory of evolution. The isolation helps in preventing the interbreeding of related organisms which is a reproductive form of isolation.

- ➢ In addition to these factors, other factors such as hybridization between two species increases the genetic variability of the popu-lation.

❖ **Origin of Higher Categories**

➢ **Punctuated Equilibrium**

➢ Punctuated equilibrium is a theory that states that evolution occurs primarily through short bursts of intense speciation, followed by lengthy periods of stasis or equilibrium. The model postulates that nearly 99% of a species' time on earth is spent in stasis, and change happens very quickly.

➢ So, if a species appears in fossil records for about 10 million years, it is likely that speciation occurred over the span of fewer than 100,000 years. Once complete, however, the model suggests that there is little morphological change after the speciation event. The species will then maintain a period of stability, called stasis, for a long period of time.

➢ The theory also provides a reasonable explanation for the absence of intermediate forms in fossil records, where new species seem to appear from ancestral forms abruptly and ultimately disappear without experiencing any apparent morphological change during their existence.

➢ While this was a shift from the idea that all new species arose due to continuous, gradual and incremental changes, the founders of this theory have also conceded that other modes of evolution could co-exist. The opposite theory is gradualism, which suggests that change occurs consistently, over long periods of time.

➢ **Punctuated Equilibrium Examples**

➢ Support for punctuated equilibrium is seen in fossil records. The impact of reproductive isolation has been observed by biologists, systematists, and taxonomists across the world. Given the fact that this is a theory of evolution, its predictions cannot be directly tested.

- While the fossil record can provide support for the theory, some indications need to arise from the living world. For example, animals living in similar environments which experience reproductive isolation must become incapable of interbreeding, indicating the emergence of a new species. This has been observed several times.
- **Reproductive Isolation among Kingfishers**
- The study of kingfishers in Papua New Guinea showed the deep impact of reproductive isolation on speciation. There are three subspecies that reside on the mainland. Here, the environment can vary wildly from humid, dense rain forest to monsoon forests with extended dry seasons. These subspecies can not only interbreed but are nearly indistinguishable from each other.
- However, on islands a few hundred kilometers away, even when the environment is similar to the nearest part of the mainland, the kingfishers are markedly different. More species have been found on these smaller islands than on the mainland. Similar observations have been made for birds and reptiles and invertebrates across the world, where geographical separation has led to the emergence of new species, while large continuous tracts with varying conditions maintain homogeneous populations. This evidence supports the punctuated equilibrium theory.
- **Land Snails of Bermuda**
- About 300,000 years ago, Poecilozonites bermudensis, an air-breathing land snail, colonized the island of Bermuda. The snail might have been carried on driftwood from North America. The

fossils of these snails constitute the large majority of Bermuda's land fossils.

- Until recently, one species continued to survive on the island. The earliest populations of this snail had two stocks, with distinct color banding patterns. When these became extinct, a derivative from a peripheral population that was evolving on a separate island became dominant. Fossil samples taken from six different geological times and from various geographical locations points to the repeated evolution of species from peripherally isolated populations that ultimately led to the formation of the land snail that remained morphologically static until it was observed in the 1950s.
- **Features of Punctuated Equilibrium**
- One of the cornerstones of this hypothesis is that reproductive isolation is necessary for the formation of new species. This implies that the fossil record at any one place is unlikely to record the process of speciation because new species can evolve only from small, isolated populations. Therefore, variations will be seen only in fossils of the same age arising from different geographical locations.
- **Rapid Morphological Changes**
- Punctuated equilibrium postulates that genetic and morphological changes that bestow a survival advantage will be amplified quickly in small populations. The rapid pace of evolution in these isolated groups is also stated as the reason why there is no fossil record of evolution, and new species seem to appear abruptly.
- It also predicts that while intermediates will be rare in the evolution of single species, they will be seen among larger groups. For example, while Australopithecus afarensis, is the precursor of modern humans, there are no fossils showing a gradual change in

the cranial capacity or body size of the Australopithecus. However, there are other species such as Homo habilis and Homo erectus that show the transition from Australopithecus towards a modern man in terms of cranial capacity and body size.

- **Periods of Stasis**
- Another important feature of this hypothesis is the explanation given for extended periods of stasis. It implies that the average morphology of a species is under a homogenizing influence. Interbreeding populations appear static. This is due to the fact that small changes within a large population become diluted and homogenized.
- A number of explanations have been given for this phenomenon observed in the fossil record. These include the effect of gene flow, assertions that the morphology of a species is under 'homeostatic' pressure, and koinophilia or the rejection of mates with unusual attributes.
- **Gradualism vs Punctuated Equilibrium**
- Punctuated equilibrium is pitted against phyletic gradualism. These competing theories of evolution both hypothesize about the rate of emergence of new species. Gradualism places importance on the slow appearance of new characters in interbreeding subspecies that, over time, lead to the evolution of a new species from ancestral forms.
- Fossils seem to appear suddenly throughout history. Punctuated equilibrium tries to explain these fossil **'gaps'** or the absence of intermediate forms, by stating that they exist for very short periods of time when speciation occurs intensely in an isolated population.
- The criticism of punctuated equilibrium focuses on the possibility that fossil records may simply be incomplete. Intermediate forms

may be found in regions where fossils are abundant and well-preserved. In addition, critics point to the fact that there is no evidence that an external homogenizing influence keeps interbreeding populations in stasis.

❖ **Macro Evolution**

➢ Macroevolution generally refers to evolution above the species level. So instead of focusing on an individual beetle species, a macroevolutionary lens might require that we zoom out on the tree of life, to assess the diversity of the entire beetle clade and its position on the tree.

➢ Macroevolution encompasses the grandest trends and transformations in evolution, such as the origin of mammals and the radiation of flowering plants. Macroevolutionary patterns are generally what we see when we look at the large-scale history of life.

➢ It is not necessarily easy to **"see"** macroevolutionary history; there are no firsthand accounts to be read. Instead, we reconstruct the history of life using all available evidence: geology, fossils, and living organisms.

➢ Once we've figured out what evolutionary events have taken place, we try to figure out how they happened. Just as in microevolution, basic evolutionary mechanisms like mutation, migration, genetic drift, and natural selection are at work and can help explain many large-scale patterns in the history of life.

➢ The basic evolutionary mechanisms — **mutation, migration, genetic drift, and natural selection** — can produce major evolutionary change if given enough time.

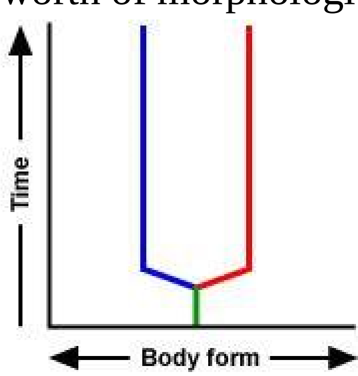
➢ A process like mutation might seem too small-scale to influence a pattern as amazing as the beetle radiation, or as large as the difference between dogs and pine trees, but it's not. Life on Earth has been accumulating mutations and passing them through the filter of natural selection for 3.8 billion years — more than enough time for evolutionary processes to produce its grand history.

❖ **Patterns in macroevolution**

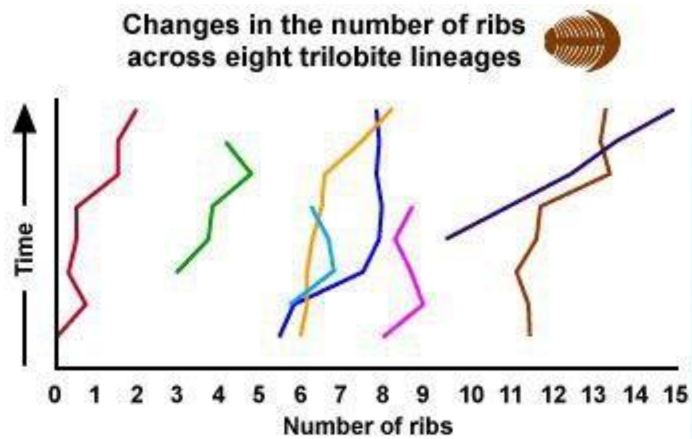
➢ You can think of patterns as **"what happened when."** All of the changes, diversifications, and extinctions that happened over the course of life's history are the patterns of macroevolution.

➢ However, beyond the details of individual past events — such as, when the beetle radiation began or what the first flowers looked like — biologists are interested in general patterns that recur across the tree of life:

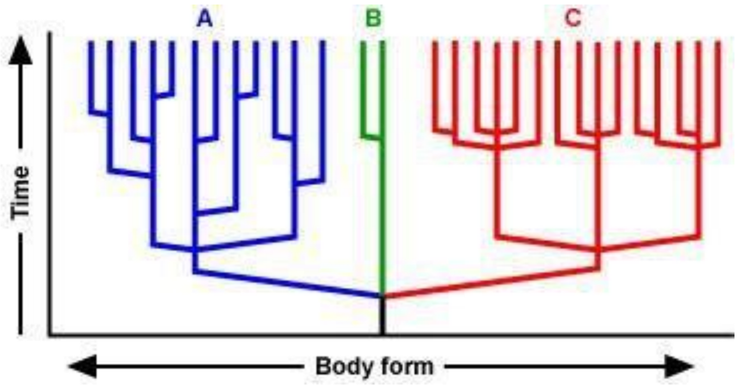
➢ **Stasis:** Many lineages on the tree of life exhibit stasis, which just means that they don't change much for a long time, as shown in the figure to the right. In fact, some lineages have changed so little for such a long time that they are often called living fossils. Coelacanths comprise a fish lineage that branched off of the tree near the base of the vertebrate clade. Until 1938, scientists thought that coelacanths went extinct 80 million years ago. But in 1938, scientists discovered a living coelacanth from a population in the Indian Ocean that looked very similar to its fossil ancestors. Hence, the coelacanth lineage exhibits about 80 million years' worth of morphological stasis.

➢ 

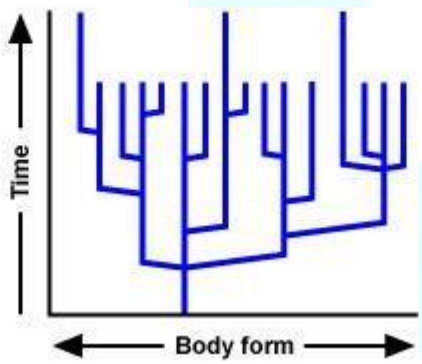
➢ **Character change:** Lineages can change quickly or slowly. Character change can happen in a single direction, such as evolving additional segments, or it can reverse itself by gaining and then losing segments. Changes can occur within a single lineage or across several lineages. In the figure to the right, lineage A changes rapidly but in no particular direction. Lineage B shows slower, directional change. Trilobites, animals in the same clade as modern insects and crustaceans, lived over 300 million years ago.

➢ 

➢ **Lineage-splitting (or speciation)**: Patterns of lineage-splitting can be identified by constructing and examining a phylogeny. The phylogeny might reveal that a particular lineage has undergone unusually frequent lineage-splitting, generating a "bushy" tuft of branches on the tree (Clade A, below). It might reveal that a lineage has an unusually low rate of lineage-splitting, represented by a long branch with very few twigs coming off (Clade B, below). Or it might reveal that several lineages experienced a burst of lineage-splitting at the same time (Clade C, below).

➢ 

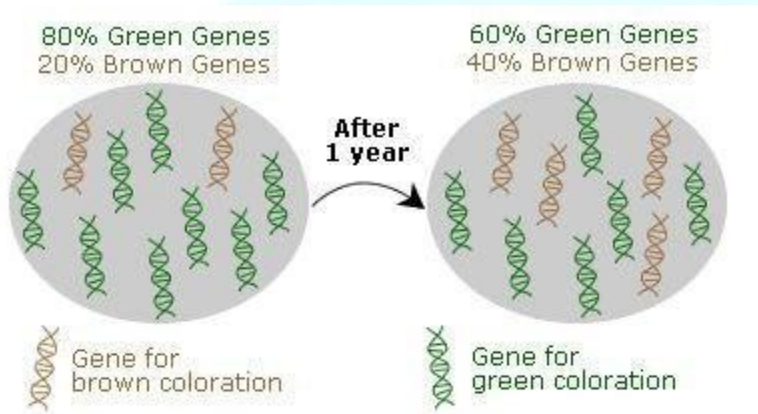
➢ **Extinction:** Extinction is extremely important in the history of life. It can be a frequent or rare event within a lineage, or it can occur simultaneously across many lineages (mass extinction). Every lineage has some chance of becoming extinct, and overwhelmingly, species have ended up in the losing slots on this roulette wheel: over 99% of the species that have ever lived on Earth have gone extinct. In this diagram, a mass extinction cuts short the lifetimes of many species, and only three survive.

➢ 

❖ **Micro Evolution**

➢ Microevolution is evolution on a small scale — within a single population. That means narrowing our focus to one branch of the tree of life.

➢ If you could zoom in on one branch of the tree of life scale — the insects, for example — you would see another phylogeny relating all the different insect lineages. If you continue to zoom in, selecting the branch representing beetles, you would see another phylogeny relating different beetle species. You could continue zooming in until you saw the relationships between beetle population

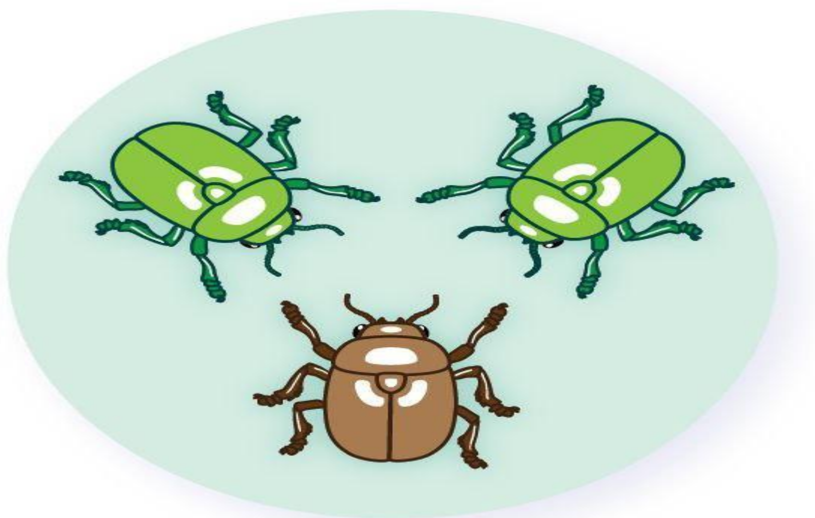
- We've defined microevolution as a change in gene frequency in a population and a population as a group of organisms that share a common gene pool — like all the individuals of one beetle species living on a particular mountaintop.
- Imagine that you go to the mountaintop this year, sample these beetles, and determine that 80% of the genes in the population are for green coloration and 20% of them are for brown coloration. You go back the next year, repeat the procedure, and find a new ratio: 60% green genes to 40% brown genes
- 

❖ Mechanisms of microevolution

- There are a few basic ways in which microevolutionary change happens. Mutation, migration, genetic drift, and natural selection are all processes that can directly affect gene frequencies in a population.
- Imagine that you observe an increase in the frequency of brown coloration genes and a decrease in the frequency of green coloration genes in a beetle population. Any combination of the mechanisms of microevolution might be responsible for the

pattern, and part of the scientist's job is to figure out which of these mechanisms caused the change:

- **Mutation**
- Some **"green genes"** randomly mutated to **"brown genes"** (although since any particular mutation is rare, this process alone cannot account for a big change in allele frequency over one generation).



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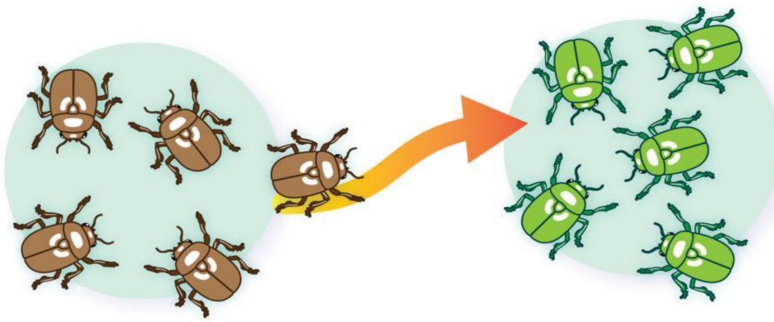
- **Migration (or gene flow)**
- Some beetles with brown genes immigrated from another population, or some beetles carrying green genes emigrated.



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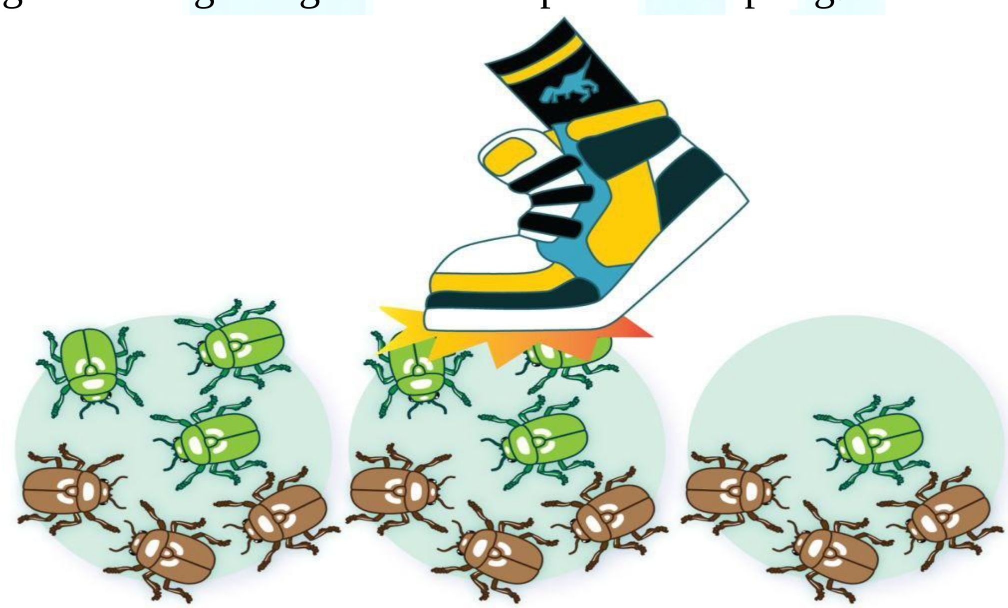
➢ **Genetic drift**

➢ When the beetles reproduced, just by random luck more brown genes than green genes ended up in the offspring.



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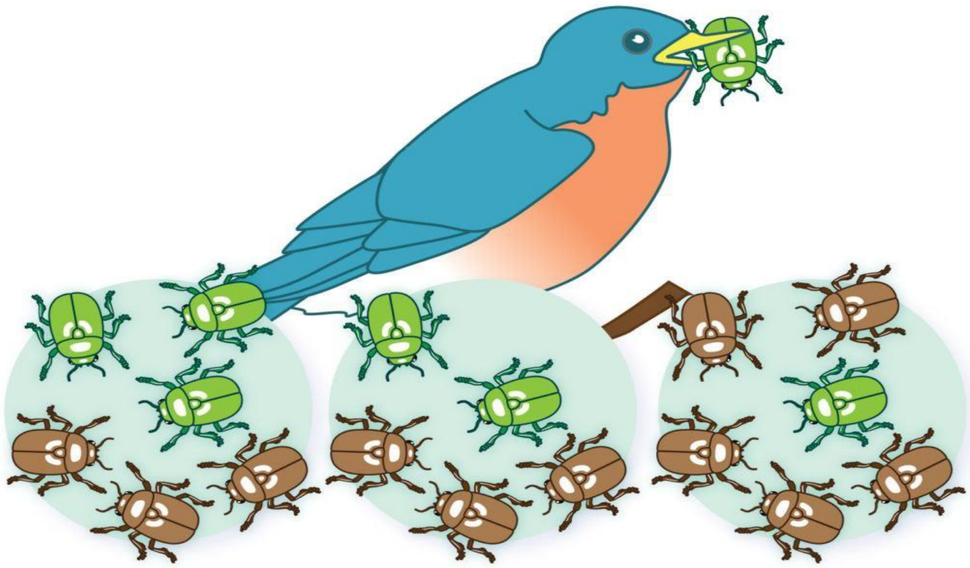
➢ **Natural selection**

➢ Beetles with brown genes escaped predation and survived to reproduce more frequently than beetles with green genes, so that more brown genes got into the next generation.



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❖ **CO -Evolution**

➢ coevolution, the process of reciprocal evolutionary change that occurs between pairs of species or among groups of species as they interact with one another. The activity of each species that participates in the interaction applies selection pressure on the others. In a predator-prey interaction, for example, the emergence of faster prey may select against individuals in the predatory species who are unable to keep pace. Thus, only fast individuals or those with adaptations allowing them to capture prey using other means will pass their genes to the next generation. Coevolution is one of the primary methods by which biological communities are organized. It can lead to very specialized relationships between species, such as those between pollinator and plant, between predator and prey, and between parasite and host. It may also foster the evolution of new species in cases where individual populations of interacting species separate themselves from their greater metapopulations for long periods of time.

- How an interaction coevolves between species depends not only on the current genetic makeup of the species involved but also on new mutations that arise, the population characteristics of each species, and the community context in which the interaction takes place. Under some ecological conditions (such as in some predator-prey interactions or between competitors for a resource), an antagonistic interaction between two species can coevolve to enhance the antagonism; the species **“build up”** methods of defense and attack, much like an evolutionary arms race. Under other ecological conditions (such as in certain parasite-host interactions), however, the antagonism may be lessened
- Coevolution does not necessarily require the presence of antagonism. The interactions or characteristics within groups of unrelated species may converge to allow individual species to exploit valuable resources or enjoy increased protection. Once an interaction evolves between two species, other species within the community may develop traits akin to those integral to the interaction, whereby new species enter into the interaction. This type of convergence of species has occurred commonly in the evolution of mutualistic interactions, including those between pollinators (such as bees) and plants and those between vertebrates (such as birds and bats) and fruits.
- Some of the species drawn into mutualistic interactions become co-mutualists, contributing as well as benefiting from the relationship, whereas others become cheaters that only exploit the relationship. In many interactions between bee pollinators and

plants, bees collect the nectar from the reproductive parts of the plant and are often dusted with pollen in the process

- When the bees fly to another plant of the same species, they may fertilize the plant by depositing pollen on the plant's stigma. In contrast, some bumblebees, such as those of Bombus terrestris, obtain nectar from the plant without picking up or dropping off pollen. They cheat by cutting through other parts of the plant instead of entering the flower.
- In other cases, the behavior or appearance of several species may converge to enhance their mutual protection . For example, several species of heliconidae butterflies that are distasteful to predators have evolved to resemble one another. In addition, one species may evolve to mimic the behavior or appearance of another to garner some of the same protections enjoyed by the model species .This evolutionary strategy has been successful for nonvenomous snakes, such as the scarlet king snake (Lampropeltis triangulum elapsoides), whose coloration closely resembles that of coral snakes, which can deliver a poisonous bite.
- Coevolution is a complex process that occurs on many levels. It may appear in situations where one species interacts closely with several others, such as the interaction between European cuckoos (Cuculus canorus) and the other species whose nests they parasitize; it may involve many species, as in relationships between fruit-bearing plants and birds; or it may take place in some subgroups of species but not others (see geographic mosaic theory of coevolution). It is important to note that human activities often disrupt the process of coevolution by changing the nature and the extent of the interactions between coevolving species. Some examples of harmful human activities include habitat fragmentation, increased hunting pressure, favoritism of one

species over another, and the introduction of exotic species into ecosystems that are ill-equipped to handle them

❖ **Founder Principle**

➢ founder principle, in genetics, the principle whereby a daughter population or migrant population may differ in genetic composition from its parent population because the founders of the daughter population were not a representative sample of the parent population. For example, if only blue-eyed inhabitants of a town whose residents included brown-eyed people decided to found a new town, their descendants would all be blue-eyed.

➢ **Founder Effect Definition**

➢ The founder effect is a phenomenon that occurs when a small group of individuals becomes isolated from a larger population. Regardless of what the original population looked like, the new population will resemble only the individuals that founded the smaller, distinct population. The founder effect is due to the randomness that accompanies selecting a small group from a larger population. The smaller the population, the higher the chance that the small population does not represent the larger population. See the graphic below. If the few organisms that migrate or get separated from the parent population do not carry the same frequency of alleles as the main population, the resulting founder effect will cause the population that separated to become genetically distinct from the original population. This may lead to a new subspecies of organisms, or even entirely new species given enough time.

➢ The founder effect can take place due to many different circumstances. The founder effect can be due to geographic isolation, when a small population of individuals migrates to a new area. In this case, the distance or obstacles between the two populations make interbreeding impossible, and the new populations become genetically distinct over time. In another scenario, a mutation may cause a population of organisms to become reproductively isolated from the parent foundation. Without the ability to interbreed with the larger population, the small population becomes distinct. If successful it will grow into a new species. Mutations and random allele changes in small populations are collectively known as **genetic drift**, and the founder effect is a piece of genetic drift.

❖ **Examples of the Founder Effect**

➢ **Genetic Diseases in Humans**

➢ Many genetic diseases are increasing in prevalence in human population due in part to the founder effect. Small populations of humans are either forcibly separated, or leave the larger genetic pool by choice. An example of the founder effect in this context is the higher incidence of fumarase deficiency in a population of members of a fundamentalist church. Practices of the church included endogamy, or marrying within the religion, and polygyny or the practice of taking several wives. What the founders of the religion did not know was that they carried a severely detrimental allele. The allele created a form of fumarase that did not function.

➢ This enzyme is needed to produce energy in the mitochondria. Without functional mitochondria, nearly all the cells in the body are affected. Children that receive a non-functional allele from both parents are severely disabled, with both developmental abnormalities and mental retardation. The founder effect has caused the population that practices this religion to experience a much higher incidence of this specific genetic condition.

➢ **Small Islands**

- Ecologists have been studying small islands for a long time, as the populations between small islands often display remarkable diversity. The Galapagos finches, for example, represent several species of finch that all resemble a mainland finch, with various modifications.
- The theory remains that the population on the islands is under the influence of the founder effect. It is hypothesized that small colonies of finches were established on each island when storms would carry them far away from the coastline. Due to the small number of finches that arrived at each island, each population only had certain alleles from the parent population. Over time, the populations varied greatly, both in their size and the roles they filled within the ecosystem. Similar examples have been noted in amphibians, reptiles, and mammals. The founder effect is a well-known cause of differentiation between populations that span a great distance. This is known as the serial founder effect, if the individual populations spread over a geographic distance do not interbreed.

❖ **C-Value paradox**

- The C value paradox is that the amount of **DNA** in a haploid genome (**the 1C valu**e) does not seem to correspond strongly to the complexity of an organism, and 1C values can be extremely variable. Some salamanders have more than 30 times the amount of DNA per cell as humans, and within genera such as the sunflowers, Helianthus, some species have 1C values four times greater than others. Much DNA in the cell is present as repetitive sequences of varying lengths, often intermediate repeat sequences which are mostly selfish elements. Over 50% of the maize genome probably consists of retroelements.

- A strong correlation between the C value and nuclear size, cell size, and cell cycle time has led some to suggest that selection on these factors maintains a C value which is more or less optimal for the organism. According to this hypothesis, the organism requires a certain amount of DNA, which could consist of any sequence. Selfish DNA is particularly good at competing for this **'resource,'** hence its presence in the genome. The organism can regulate the C value, for example, by deleting stretches of sequence in heterochromatic regions. The organism thus has the final say in the C value, and selfish DNA does not explain the paradox.
- The opposing argument is that selfish DNA can increase the C value to well above that which is best for the organism: conflict between selfish elements and the rest of the genome results in different C values depending on which is winning. Under this view, selfish DNA can explain much of the paradox.
- One factor suggesting that organisms have ultimate control over their genome size is the presence of genomes which contain mostly coding DNA, but have no major reason to prevent the build-up of selfish genetic elements. Although bacterial genomes have little surplus DNA, this can be explained by strong selection for rapid replication. Organelle genomes are similarly economical, but this may be due to competition among themselves for representation in the cell or in the gametes. Indeed, petite mutants of yeast contain defective mitochondria which are successful due to their increased replication rate, but do not provide a respiratory function (they have been suggested as selfish DNA in their own right). Since the methods by which selection acts on increased genome size are still a topic of debate, it seems likely that the issue will remain controversial.

❖ **Molecular Clock**

- molecular clock measures the constant rate of change in an organism's genome (DNA or protein sequences of a specific gene) over time. This constant rate of change occurs randomly among different species of organisms such as animals, plants, fungi, and viruses. By measuring these changes, scientists can then create phylogenetic trees representing a species that evolved or diverged from another long ago.
- When an organism inherits genetic material from the previous generation, the change occurs steadily, and the genes are said to be neutral. They are neither disadvantageous nor advantageous, meaning they do not inhibit natural selection or fitness but are rather due to genetic drift. Different genes containing different nucleotide substitutions are studied to determine the rate at which the sequences of the genes have been evolving. This occurrence happens over a timeframe of millions of years as the genes are passed down and altered from one generation to the next
- The molecular clock measures the number of random mutations of an organism's gene (DNA or protein sequences) at a relatively constant rate over a specific timeframe. It is calibrated with fossil records and geological timescales. It measures how long-ago different organisms were on Earth and when the divergence of a new species (animal, plant, virus, fungi) happened
- The molecular clock was discovered by chemist Linus Pauling and biologist Emile Zuckerkandl in 1962. During this time, the exploration of protein sequences was readily available. Linus and Emile found several differences in the amino acid (building blocks of proteins) sequences in hemoglobin proteins across different mammalian species. The study's outcome was that the rate of substitution in the protein sequences was similar to that of the time of divergence from a common ancestor. Molecular clocks came in

hand when fossil records fell short. They helped estimate important times in evolutionary events, such as the divergence of species or dating back species without a fossil record.

- **How does the Molecular Clock Work?**
- Molecular clocks are helpful by showing the linear relationship between the genetic distance and time since a species has diverged from another, which usually dates back further than the fossil record. This divergence essentially shows how many mutations are present in a population during a specific time frame, which correlates with the timescale of Earth and fossil records (present or not). Molecular clocks thus create a bigger and clearer picture to traceback these mutations and determine the dates of divergence.
- When looking at the difference in base pairs of two DNA sequences (**AAA changes to AAG**), the mutations over the years can be 1 of 2 things.
- They are either fixed into a population where the gene is passed on from generation to generation or lost due to genetic drift. Thus, the change in the nucleotide sequences **AAA to AAG** is either fixed (passed on) or not. When the gene is passed on time and time again, scientists can then, at a later stage, deduce the percentage of the difference between the DNA sequences being studied. Scientists can then conclude whether a specific gene they are looking at is mutating at a relatively constant low rate or constant fast rate. Each gene acts as a separate clock, and each clock ticks at different rates. Thousands of genes and proteins within each organism evolve at different rates. However, they all represent the same evolutionary events.
- If you analyze the DNA of a specific gene in two related species (**C and D)** and find that 2000 mutations are different between them, you can trace back the date. By knowing the mutation rate,

say 1000 new mutations every one million years (0,001 mutations per year), one can then divide the number of mutations by the mutation rate to determine the timeframe:

➢ 2000 mutations divided by 0.001 mutations per year = 2 million years oldThus, one will find that species C and D diverged from a common ancestor around 2 million years ago.

➢ When the clock for a particular gene or protein is calibrated against an event on the fossil record or geological time scale, then the actual date when all other events occurred can be determined as well. This process happens by examining the protein or gene substitution rate along the phylogenetic tree.

➢ **Molecular Clock Example**

➢ Suppose the rate of evolution of a gene or protein is relative to the evolutionary change along lineages of different species. In that case, the DNA and proteins of those organisms act as the molecular clock. The protein sequence can then be used to reconstruct the time at which each branch diverged off a common ancestor.

➢ For example: take three different proteins (**Cytochrome c, Hemoglobin, and Fibrinopeptide**) that evolve at different rates to each other but independently evolve at a constant pace.

➢ **Uses of the Molecular Clock**

➢ Molecular clocks are **'calibrated'** against evolutionary events that are known from the fossil record. But, from these known events and rates of genomic change, we can estimate relative dates of evolutionary events that aren't already documented in the fossil record. For example, if you know that a change occurs every 700,000 years, and you can identify 42 changes overall, then you have determined that the two species diverged about 600,000 years ago.

- ➢ Molecular clock analysis can be used to create evolutionary timelines for organisms that don't have much of a footprint in the fossil record. Many plants, fungi, and soft-bodied animals don't leave behind fossils because they don't have the hard body parts to do so. Molecular clocks to the rescue! For these guys, we can use the molecular clocks of organisms that do leave behind fossils and make inferences about their genomic changes based on those that have given us a good record.
- ➢ Molecular clocks can be useful not only for identifying when living organisms diverged over time but also viruses such as HIV. Working backwards using a molecular clock, scientists have been able to identify when HIV first jumped to humans, which was back in the 1930s.

❖ **Cytochrome c**

- ➢ Cytochrome c is one of the mitochondrial proteins that is released into the cytosol when the cell is activated by an apoptotic stimulus.

- ➢ In the cytosol, cytochrome c engages the apoptotic protease activating factor-1 **(APAF1**), and forms the apoptosome, which activates caspase-9.
- ➢ The release of cytochrome c has been suggested to occur in two phases: mobilization from the mitochondrial intermembrane space and translocation through the outer mitochondrial membrane.The mechanisms of cytochrome c release are controversial. Whether the permeabilization of the outer or the inner membrane is responsible for the downstream events is one of the debated topics. Most evidence supports a model in which the outer membrane is permeabilized without inner membrane events.

- ➢ The release of cytochrome c and cytochrome-c-mediated apoptosis are controlled by multiple layers of regulation, with the most prominent players being members of the **B-cell lymphoma protein-2 (BCL2)** family.
- ➢ Cytochrome c is primarily known for its function in the mitochondria as a key participant in the life-supporting function of **ATP synthesis.** However, when a cell receives an apoptotic stimulus, cytochrome c is released into the cytosol and triggers programmed cell death through apoptosis. The release of cytochrome c and cytochrome-c-mediated apoptosis are controlled by multiple layers of regulation, the most prominent players being members of the B-cell lymphoma protein-2 (BCL2) family. As well as its role in canonical intrinsic apoptosis, cytochrome c amplifies signals that are generated by other apoptotic pathways and participates in certain non-apoptotic functions.

❖ **Hameoglobin**

- ➢ Haemoglobin is a type of globular protein present in red blood cells (RBCs), which transports oxygen in our body through blood. It is a tetrameric protein and contains the heme prosthetic group attached to each subunit. It is a respiratory pigment and helps in transporting oxygen as oxyhaemoglobin from the lungs to different parts of the body. Some amount of carbon dioxide is also transported back via hemoglobin as carbaminohemoglobin.
- ➢ Other oxygen binding proteins are myoglobin in muscles, **haemocyanin in arthropods** and **molluscs, leghaemoglobin in legumes,** etc.
- ➢ Hemoglobin A present in humans is coded by **HBA1, HBA2** and **HBB genes**. The sequence of amino acids in polypeptide chains of Hb varies in different species.

- Heme part of Hb is synthesized in mitochondria and cytoplasm of immature RBCs. Globin protein is synthesized in the cytoplasm by ribosomes. Even after losing nucleus in mature mammalian RBCs, the residual **rRNA** continues to synthesize **Hb** until the reticulocytes enter the vasculature.
- The hemoglobin level is measured in g/dL of the blood. In a healthy individual, the level ranges from 12 to 20 g/dL. Generally Hb level in males is greater compared to females. The normal level in males is 13.5 to 17.5 g/dL and in females, it is 12 to 15.5 g/dL.
- **Hemoglobin Structure**
- Max Perutz described the molecular structure of hemoglobin in 1959. Hemoglobin is a tetrameric protein. The main type of hemoglobin in adults is made up of two subunits each of '$\boldsymbol{\alpha}$' and '**β**' polypeptide chains. Each polypeptide chain is linked to a heme prosthetic group.
- **$\boldsymbol{\alpha}$ subunit** – It is made up of alpha polypeptide chain having 141 amino acid residues.
- **β subunit** – It is made up of beta polypeptide chain having 146 amino acid residues.
- Heme group – It is an iron-containing prosthetic group, which is attached to each polypeptide chain. It contains iron in the center of the porphyrin ring.
- In the quaternary structure, there is a strong interaction between $\boldsymbol{\alpha}$ and **β** subunits. On mild treatment with urea, hemoglobin partially dissociates but $\boldsymbol{\alpha}$**β** dimers remain intact. The subunits are bound together by mostly hydrophobic interactions, hydrogen bonding and a few ion pairs or salt bridges.
- In infants, there are 2 alpha and 2 gamma chains, which get replaced by beta chains.

- ➢ Hemoglobin is present in two conformations, i.e. R state and T state. Oxygen has more affinity to **R state** and deoxyhaemoglobin is primarily present in **T state**.
- ➢ **Hemoglobin Function**
- ➢ The main function of Hb is to carry and transport oxygen to various tissues. The binding of oxygen to Hb is cooperative binding. The binding and release of oxygen from Hb in the lungs and tissues respectively is due to the transition between low oxygen affinity T state (Tense) and high oxygen affinity R state (Relaxed).
- ➢ **Transport of oxygen**
- ➢ The affinity of oxygen to Hb is affected by pH, 2,3 BPG (2,3-Bisphosphoglyceric acid). Low pH, high BPG and CO_2 present in tissues favor T-state and oxygen are released, whereas R-state is favored in the alveoli due to high pH, low CO_2 and BPG concentration, which leads to the binding of oxygen to Hb.
- ➢ Binding of oxygen is also regulated by the partial pressure of oxygen. In the lungs where pO_2 is high, oxygen binds with Hb and in tissues, where pO_2 is low, oxygen is released.Every 100 ml of oxygenated blood carries 5 ml of O_2 to the tissues.
- ➢ Binding of the first oxygen molecule to the heme unit of one subunit of the deoxyhaemoglobin (T-state) causes conformational changes leading to an increase in the affinity, thereby the second molecule binds more rapidly. The binding of the fourth molecule occurs, when it is already in the R state. The binding of oxygen to Hb shows a sigmoid curve.
- ➢ This type of binding is known as allosteric binding, where binding at one site affects the affinities of the remaining binding sites.

- The pulse oximeter measures the amount of oxygen present in the blood. It is used to diagnose **hypoxia**. It is based on the fact that **oxyhemoglobin** and **deoxyhemoglobin** have different absorption spectra. This is a major tool that doctors are using to check the oxygen saturation level of COVID-19 patients and also in those who are at risk.
- **Transport of Carbon dioxide**
- Around 20-25% of CO2 is transported bound to hemoglobin as carbaminohemoglobin. In tissues where pCO2 is more and pO2 is less, binding of carbon dioxide is favored and in the alveoli dissociation of carbaminohemoglobin takes place due to high pO2 and low pCO2. Rest of the CO2 is transported as bicarbonate, which is facilitated by an enzyme called carbonic anhydrase.
- Every 100 ml of deoxygenated blood carries 4 ml of CO2 to the alveoli.
- Hemoglobin also transports nitric oxide bound to the globin protein. It binds to the thiol groups present in the globin chains.
- Carbon monoxide can also bind to hemoglobin and forms the carboxyhemoglobin complex. Haemoglobin has 250 times higher affinity for carbon monoxide than oxygen. So even the slightest concentration of CO can affect the binding of oxygen. So, inspiring air rich in CO can cause headache, nausea or even unconsciousness. It can block 20% of active binding sites of oxygen in heavy smokers.
- **Diseases related to Hemoglobin**
- There can be various reasons for hemoglobin deficiency. Hemoglobin deficiency leads to the lower oxygen-carrying capacity of the blood. It can be due to nutritional deficiency, cancer, kidney failure or any genetic defects.

- Higher than normal hemoglobin level is associated with various heart and pulmonary diseases.
- **Sickle cell anemia** – It is due to a defect in the hemoglobin gene. There is a single nucleotide or point mutation in the β globin chain. **'GAG'** gets converted into **'GTG'** leading to the replacement of glutamic acid by valine at the 6th position.
- **Thalassemia** – It is caused due to less production of hemoglobin. There are two types of thalassemia, **α-thalassemia** and **β-thalassemia.** It is also caused due to defective genes and severity depends on how many genes are missing or defective.
- Hemoglobin level is commonly used as a diagnostic tool. The **HbA1c level,** i.e. glycosylated Hb or Hb linked with sugar is a marker for average glucose level in the blood of a diabetic patient.
- To sum up, hemoglobin is an essential pigment, which is required for oxygen transport and to carry out normal body functions.

❖ **Histones**

- A histone is a protein that provides structural support for a chromosome. Each chromosome contains a long molecule of DNA, which must fit into the cell nucleus. To do that, the DNA wraps around complexes of histone proteins, giving the chromosome a more compact shape. Histones also play a role in the regulation of gene expression.
- Histones are proteins that are critical in the packing of DNA into the cell and into chromatin and chromosomes. They're also very important for regulation of genes. We used to think that histones acted essentially as DNA suitcases to sort of hold the DNA, but it was very clear that histones are regulated and have a lot to do with when genes are turned on and turned off. You can think about them as a regulated suitcase that determines when the suitcase is

opened and a gene gets out. So they turn out to have very important functions, not only structurally, but also in the regulation of gene function in expression.

- A histone is a protein that provides structural support for a chromosome. Each chromosome contains a long molecule of DNA, which must fit into the cell nucleus. To do that, the DNA wraps around complexes of histone proteins, giving the chromosome a more compact shape.
- Histones are the proteins promoting the DNA packaging into chromatin fibers. Histone proteins are positively charged possessing several arginine and lysine amino acids binding to the negatively charged DNA. There are two types of Histones:
- **Core Histones**
- **Linker Histones**
- **H2A, H2B, H3 and H4** are the core histones. **Two H3, H4** dimers and **two H2A, H2B** dimers form an octamer.
- Linker histones lock the DNA in place onto the nucleosome and can be removed for transcription.
- Histones can be modified to change the amount of packaging a DNA does. The addition of the methyl group increases the hydrophobicity of histones. This results in tight DNA packaging.
- Acetylation and phosphorylation make the DNA more negatively charged and loosens the DNA packaging.
- Enzymes that add methyl groups to histones are called **histone methyltransferases**.
- The enzymes that add acetyl groups to the histones are called **histone acetyltransferases**
- while the ones that remove the histones are called **histone deacetylases**.