Evolution: The Modern Synthesis

Evolution

Biological Evolution refers to the changes in the properties of populations of organisms over many generations. This means that species are not fixed or immutable but can change over time. The descendants of a particular type of organism may be members of a radically different species. Indeed the descendents of an organism may over many generations become numerous different species. For example, there is good evidence that all the present bird species are descended from one or a few types of dinosaur. Hence evolution is sometimes said to be “descent with modification”.

In the specific sense of biological evolution an individual organism can not evolve; only populations of organisms evolve. Also the traits that evolve must be heritable by the offspring from the parent(s).

Natural Selection

Darwin proposed a specific mechanism for biological evolution which he named Natural Selection. (Darwin did not claim that it was the only mechanism – just the most important one.)

In the Origin of Species, he notes that animal breeders select for certain traits and breed only those animals with the desired traits. Over time the properties of the population of these animals change. This can be seen in the wide variety of physical traits that pigeons and dogs (to follow Darwin) of different breeds exhibit. Yet all pigeon breeds are descended from the common rock-pigeon and all dog breeds are most likely descended from the gray wolf.

Now the different dog breeds are not different species, as evidenced by the large number of mixed breed puppies for sale, nor are the different pigeon breeds. Nevertheless Darwin saw in the malleability of traits in dogs and pigeons under the hands of the breeder a clue to the development of species. If the selection for traits continued over a much longer time (i.e. many more generations) the divergence of characters in the breeds could become so great as to create distinct populations that were incapable of interbreeding – in other words, different species.

But who or what plays the role of the breeder? Darwin’s answer was nature. The natural environment (including other living things) acts as the breeder determining who will live or, more importantly, breed. In most natural populations more offspring are born than can be supported by the local environment. The offspring vary slightly in their characteristics with some better adapted to survive and mate under the natural conditions. The attributes of these organisms will be preferentially passed down to the next generation. As a result these features will become more prevalent in later generations and given many generations the characteristics of the population may change significantly.
Natural selection does not just work between the organisms and the physical environment. The organisms compete with other species. In addition, members of the population compete amongst themselves for survival and reproductive success. Sexual selection, where organisms compete for mates, can play a powerful role in evolution as characteristics that have no intrinsic survival benefit but increase the chance of mating will be “selected” as well. (The peacock’s tail is an example of a trait that has no survival benefit but does increase the chance of mating as the male peacock uses it to attract females.)

**Genetics and Evolution**

Darwin could not answer two important questions in his theory. How does variation arise in species and how are characteristics inherited? Today we know that the answer to both these questions lies in the field of genetics. This combination of modern genetics and evolutionary theory is known as the Modern Synthesis and forms the basis for mainstream evolutionary biology.

*A quick review of genetics*

Gegor Mendel developed a model of inheritance based on factors or *genes*. The characteristics of an organism were determined by a set of genes that were transmitted unmodified from the parents to the offspring. In the simplest model each characteristic of the organism is determined by a pair of genes. Each of the parents contribute one gene to the pair.

A commonly used example is eyecolor. Let’s imagine a family in which the mother has brown eyes and the father has blue eyes. There are three children: Hugo, Karl and Erich. Hugo and Erich have blue eyes but Karl has brown eyes. The mother’s pair of eyecolor genes are blue/blue. The father’s pair is blue/brown. As each of the children receive one of the pair of genes from each parent they can have either blue/blue, (a blue gene from each) or blue/brown (a blue gene from the mother and a brown gene from the father.) Hugo and Eric have two blue eyecolor genes and hence exhibit blue eyes. The brown-eyed boy, (Karl) will have one blue and one brown gene.

The eyecolor example illustrates a number of features. One concept in genetics is that genes for a trait come in a number of forms or *alleles*. The gene for blue eyecolor is one of the alleles of the gene for eyecolor. Another important idea is that of *dominant* and *recessive* alleles. If an organism has two different alleles for a trait then the characteristic is determined by the dominant allele. In the eyecolor example the dominant allele is brown and the recessive allele is blue. Karl has a brown and a blue allele so he has the trait associated with the dominant allele (i.e. brown eyes). Hugo and Eric have two identical alleles and take on that trait (i.e. blue eyes).

Of course, nothing is ever that simple and biologists have learned that genes seldom determine a single trait but can act on a number of characteristics. In addition many
characteristics are determined by a number of genes acting together. One obvious consequence is that the simple dominant and recessive model is seldom as clear as in our eyecolor example. (In fact even eyecolor isn’t really as simple as our model.) Finally the genes not only interact with each other but with the environment. This makes the connection between an organism’s set of genes, or *genotype*, and the organism’s set of characteristics, or *phenotype*, very complex.

The genes are located inside the nucleus of the cells of most organisms. (The exceptions are viruses and some bacteria and algae.) The genes are located on bodies called *chromosomes* that reside inside the cell nucleus. In most cases of cell division the chromosomes are duplicated so that each new cell has the same set of chromosomes as the original. However in the creation of the sex cells the number of chromosomes is only half that of the original cell. When a sperm and egg cell combines the two “halves” make a complete set of chromosomes in the fertilized egg.

This has important consequences for our picture of genetic inheritance. The genes are transmitted to the offspring not independently but in combinations of genes on the chromosomes. The likelihood of receiving certain sets of alleles from a parent would be greater than other sets. The sets of genes are not perfectly correlated as it is possible for chromosomes to break and reform in certain ways during division.

The chromosomes are made of a long-chain molecule called deoxyribonucleic acid or DNA. This molecule is made from a pair of long sugar-phosphate chains wrapped around each other in the famous double helix shape. The amino acid base pairs that make up the long chains are connected by hydrogen bonds like the rungs on a spiraling ladder. These base pairs match-up with each other in specific ways and the order of the base pairs contains the genetic information. The order of the base pairs codes for the proteins and enzymes that construct and maintain living organisms.

DNA is also able to replicate itself which makes possible the replication of the chromosomes and hence cells and organisms.

*Darwin’s Questions*

With an understanding of the genetics we are now able to answer the two questions that Darwin could not: How are characteristics inherited? How does variation in the population of species arise?

The answer to the first question we now know. Characteristics are inherited via the genes located on the chromosomes in the sex cells of the parents. The second question has two answers. Some variation comes from the shuffling of the parental genes in the creation of the genotype of the offspring. But this does not create new alleles. To see how these arise requires a deeper look at the process of DNA and chromosomal replication.

When DNA replicates there is always the possibility of an error in copying. This error may be caused by environmental effects such as radiation or chemical *mutagens*. It may
also arise spontaneously due to the complexity of the chemical processes. If there is an
change in the order of base pairs (either by substitution of one base pair for another or the
elimination or addition of base pairs) the “genetic code” will be altered. The new mutant
allele created may have little or no impact on the organism or it may have large and far-
reaching effects depending on specific mutation and how it interacts with the rest of the
genotype and the environment.

By the constant creation of new alleles and the incessant reshuffling of alleles in the
population the raw material of variation is provided. Natural selection acts upon this
variation increasing or decreasing the prevalence of specific alleles in the population over
successive generations. This is the method by which “endless forms most beautiful and
most wonderful have been, and are being, evolved.”

Resources

There are numerous resources on the basic concepts in modern evolutionary theory. The
www contains a number of useful sites. Below are some of the best of the web.

The Talk Origins Archive FAQs:
The talk.origins Usenet newsgroup has been debating the evolution/creationism issue
since the earliest days of the internet. An excellent series of FAQs have been developed
that cover every aspect of the debate including a number of excellent discussion s of
evolutionary theory.
www.talkorigins.org/origins/faqs-mustread.html

BBC Education Evolution:
This site contains the complete text of Origins as well as a good biographical material on
Darwin. Particularly insightful is the Steven Rose essay on the use and misuse of the
evolutionary metaphors.
www.bbc.co.uk/education/darwin/index.shtml

PBS Evolution:
A companion to the PBS video series this site is full of excellent audiovisual resources as
well as some fine essays.
www.pbs.org/wgbh/evolution/