BIOL2007
MENDELIAN GENETICS AND EVOLUTION

Part 1 = review historical background/milestones of evolutionary biology. Part 2 = examine a simple model as an illustrative example. Evolutionary biology aims to understand the factors that shape the diversity of life. Evolutionary processes occurring rapidly within populations are called microevolution. Processes occurring on a longer timescale to generate diversity in the fossil record and in the relationships of living species are called macroevolution. Note three striking aspects of evolution: **1)** Focus of selection is not survival but reproductive success (see e.g. of sexual cannibalism). **2)** Strong selection may produce rapid evolution in large populations (e.g. guppies) **3)** Organisms are mosaics of parts with different ages.

Darwin's theory of natural selection
*Observations **1)** Variation, in the form of individual differences, exists in every species, **2)** All organisms produce more offspring than survive to reproductive age. Conclusions* **1)** A competition for survival causes the elimination of many individuals, **2)** The characteristics of the surviving individuals are passed onto future generations.

Darwin's '*The Origin of Species*' was a triumph, but it was not without problems. In general, biologists accepted the concept of evolution: species were not fixed in form and were not separately created. However, Darwin lacked a satisfactory explanation of the scientific basis of the concepts of **variation and inheritance**. In Darwin's theory, the evolution of characters takes place gradually and each successive stage has to be advantageous for it to be favoured by natural selection.

Many biologists argued that this was difficult to imagine for the evolution of an organ such as the wing of a bird. The idea was that while a fully formed wing might be advantageous for a bird, the first stage or proto-wing might not be. One solution was to invoke some kind of "**directed variation**" or "**directed mutation**" model (e.g. **Lamarckian** inheritance). Darwin preferred a theory of inheritance which he called "**The provisional hypothesis of pangenesis**". This theory accepted that acquired characters could be inherited and in addition had a lot in common with earlier "blending" theories of inheritance in which offspring blend their attributes (*see later*).

The key issue was the relative importance of natural selection and the inheritance of acquired characteristics. **Weismann** (1880s) combined theoretical argument and empirical results to demonstrate that acquired characteristics are not inherited. He proposed (correctly) that cells which form the germ line and eventually the gametes are set aside from the rest of the body (somatic cells) early in development. So the inheritance of acquired characters is impossible. Some evidence came from crude experiments over many generations involving the removal of tails from mice prior to their breeding. A de-tailed mouse never produced a tailless mouse.

Breakthrough in 1900: three botanists replicated **Mendel**'s results (obtained 30 years earlier) for seed characters of pea plants. Looked at characters that were distinct e. g. round or wrinkled seeds between which were no intermediate forms. From controlled breeding experiments, Mendel postulated "particulate" or "atomistic" theory of inheritance: **1)** there

are “particles” of inheritance, **2)** these particles are present in pairs in the breeding adults, **3)** these particles separate during the formation of gametes, so that each gamete contains only one form of each pair, **4)** these particles have alternative dominant and recessive forms.

These particles were termed genes by Johannsen. Following Mendel, early 20th century geneticists studied the inheritance of phenotypic characters. Fundamentals of the Mendelian approach are now known to be true. Much work towards the end of the 19th century focused on the behaviour of chromosomes during cell division and it was logical to assume that the gene was a real physical presence embodied within the chromosome. *As you know, subsequent research to test this hypothesis culminated in the recognition that genes are sequences of DNA. Now we know the structure and mechanisms of DNA in detail and also that information in the genotype is, in general,* ***conserved from one generation to the next.*** *This fits with the findings of Mendelian genetics where* ***genes retain their identity through succeeding generations****.*

Contrast the basics of blending inheritance (see **overhead**). Imagine that there is a factor *A* that causes its carriers to grow up black in colour and another factor *a* that causes carriers to grow up white. Also suppose that individuals carry two copies of each factor. In the parental generation, offspring of a cross between the two phenotypes inherit factors *A* & *a*. Under blending heredity, the factors blend in those *Aa* offspring and they produce a new factor *A’* causing carriers to appear gray.

What happens in the next, F2, generation? With blending, AN INDIVIDUAL DOES NOT PASS ON THE SAME FACTORS/GENES AS IT INHERITED. Individuals of the *Aa* type will only produce gametes of the new A’ type causing gray coloration. So in the F2 generation, a cross between two gray individuals will produce solely gray progeny.

So the population has become homogeneous. The difficulty in proposing this mechanism as an explanation of evolution is that natural selection can have no effect on such a population (because it requires variation) and furthermore any newly arising variations will be lost by a similar process of homogenisation.

Now consider Mendelian heredity, using the same example. In the parental generation we have black and white phenotypes who are homozygous for factors *A* and *a* respectively. Their gametes combine in the F1 generation to produce phenotypes that are heterozygous. To keep things simple let’s assume that there is no dominance in the system. In other words, the heterozygous phenotype is mid-way between the two homozygous phenotypes. So the *Aa* phenotype will appear gray in colour.

So at this stage the 2 modes of heredity, although different in underlying mechanism, have similar outcomes. But this changes in the F2 generation. The gray heterozygote passes on ‘**intact’** to its offspring the *A* and *a* genes that it inherited from its father and mother. Therefore in a cross between two gray heterozygotes genes will segregate to yield 3 possible combinations of genes, *AA*, *aa* & *Aa*. These F2 progeny will appear black, white & gray.

Crucial difference is that under Mendelism, different genes are preserved over the generations whereas with blending, the genes that an individual inherits from its parents are physically

lost as the two parental sets are blended together. With Mendelism, it is possible for parental PHENOTYPES to be merged in the offspring - in our example this happens in the F1 progeny (because the heterozygote is intermediate between the two homozygotes). But we see from the segregation in the F2 that the ***underlying genes have been preserved.***

Mendel's particulate theory complemented Darwin's theory because it preserves genetic variation over the generations. The consequence of this for natural selection is that potentially favourable genes can persist in a population and become established. They will not be removed by a process of dilution. The so-called problem of blending inheritance doesn't exist; recombination among loci can amplify variation and new stable variants can arise by mutation.

Note that there are many 'complications' for the basic Mendelian model. Genes can have more than one effect on the phenotype ('pleiotropy'): a particular phenotype may often result from the expression of several genes (a 'polygenic' character): genes do not work in isolation and the expression of an allele or alleles at a locus may be affected by other alleles at other loci ('epistasis'): phenotypic characters are affected by the interaction between genes and their environment during the process of development. You will learn more about these phenomena in the rest of this course.

The fact that Mendel's work powerfully supported Darwin's theory wasn't realised immediately. In fact in the early years of the 20th century, the re-discovery of Mendel's work boosted the reputations of biologists who opposed Darwin's theory of natural selection. These *Mendelians* (**De Vries**, **Bateson**), worked on the inheritance of large-scale differences between individuals. These traits segregated in breeding tests in Mendelian fashion and showed a clear particulate pattern of inheritance. De Vries, Bateson and others concluded that evolution proceeded in big jumps, via macromutations, and that species arose in one or a few steps as discrete mutations. If species can arise purely by mutation, their origin does not require natural selection and so they dismissed Darwin's key principles of natural selection and gradual change.

This was disputed by the *Biometricians* (**Galton**, **Pearson**, **Weldon**). Their focus was on small rather than large differences between individuals. They developed statistical techniques to describe how distributions of traits within populations changed from parental to offspring generations. Galton *et al* concluded that evolution proceeded via steady shifts of populations and saw no need to invoke macromutational events to explain phenotypic novelty.

These two groups couldn't resolve their differences for a considerable period. Modern evolutionary theory came into being between the 1920s and 1950s with contributions from many fields, genetics, paleontology, systematics and classification. These melded to produce the **Neo-Darwinian Theory** – reconciling Darwin's theory with the facts of genetics. This is often referred to as **The Modern Synthesis**. This synthesis resolved the debate between the Mendelians and the Biometricians. Many contributed but the 3 most significant intellects were Ronald Fisher, J.B.S. Haldane and Sewall Wright. They worked on the mathematical theory that lay behind the Modern Synthesis.

Fisher demonstrated that the results known to the biometricians (looking at small differences between individuals) could be derived from Mendelian principles. Together with **Haldane** he compared changes in frequencies of different genes if those genes had very slight variation in their response to natural selection. **Wright** developed a comprehensive theory that investigated the consequences not only of selection but also of the effects of chance events. Taken together, their work demonstrated that natural selection could work with the kinds of variation that is seen in natural populations and the laws of Mendelian inheritance. Neo-Darwinism is now widely accepted. Many of the concepts and principles that we'll describe in the rest of this course will rely upon the foundations built by these individuals. However, we hope to explain how the main ideas of the modern synthesis are developing in current research in a number of widely separated areas.

Now let's review briefly a simple model in evolutionary biology which will be familiar to many of you. This model lies at the heart of the genetical theory of evolution. We can use it in order to understand the general approach to solving more complex problems. The model is the **HARDY-WEINBERG THEOREM**.

*The relevant background on the comprehensive **handout** given out at this lecture. Read this to refresh your memory on the fundamentals of this model. **Do not assume that you can remember the details from any previous exposure to the Hardy-Weinberg theorem.***

The theory of population genetics at one locus is mainly concerned with understanding two closely connected variables. These are **allele frequency** and **genotype frequency**. The **handout** shows how to calculate these quantities for a simple example of 1 locus with 2 alleles and describes the assumptions and the conclusions of the model.

Illustrative Example:

The Hardy-Weinberg equation is useful because it allows us to **predict** the expected ratio of genotypes from known allele frequencies when a population is at Hardy-Weinberg equilibrium. In fact, genotype frequencies in some populations in **nature** may be close to the theoretical expectation of the Hardy-Weinberg ratio.

Example of scarlet tiger moth *Panaxia dominula*.. Real data from 1971. These moths were classified for one character, the **degree of spotting on the wings**. There were three categories; 1) with white spotting, 2) with much reduced spotting, 3) with an intermediate degree of spotting. Please go through the calculations (**handout**) to ensure that you understand how to perform the chi-square test to determine whether phenotypes are in 'HW' proportions.

Remember that the importance of the Hardy-Weinberg theorem is not as an empirical prediction. The interest is that as evolutionary biologists we can ask whether a **real population deviates** from the Hardy-Weinberg equilibrium? If we find that it does, then the interest is in finding out why this is the case. It suggests that something else is going on such as **selection or non-random mating** and this would merit further research.

In other parts of this course, we'll look at more complex examples of significant deviations from the Hardy-Weinberg equilibrium and we'll examine the reasons for those deviations.