# The Individual and the Biological Hierarchy[1]

**Biology 114**
**Conservation Biology**

## Individuals and the Concepts of Phenotype and Genotype

In one sense, organisms can be seen as a sort of duality. There is the **genotype** – the set of inherited instructions on how to construct and (largely) operate the organism and then the result of this construction and operation – the phenotype. The **phenotype** of an organism includes all of its measurable internal and external structures and processes. It also includes externally directed processes such as its behavior and the artifacts (results) of its behavior[2].

Phenotypes vary between individuals and within the same individual over time. Biological individuals are never absolutely identical nor is an individual identical over time. Compare this with the situation in chemistry. If I consider molecules of diatomic oxygen ($O_2$) where both atoms are isotope 16, then every one of these oxygen molecules is for all intents and purposes identical. Sure, there may be slight differences in energy states, but any one of these molecules can be put into essentially identical states with others. There is no variation that begins to approach the magnitude of what is seen in biological systems. The same is largely true of any chemical species (again ignoring the chance of different isotopes being used in different molecules). **Variation is the result of the incredible complexity of even the simplest biological entities**.

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| Many would say that the central role of biology is to understand the source, production, maintenance and meaning of variation. |

When we see variation, we see evidence on the phenotypic level for possible genetic differences. We see differences that may well affect the ability of an organism to reproduce and may have important implications for evolution.

## More About the Phenotype: The Notions of Form and Function

A central theme of biology is the intimate association of the phenotype's **structure or form** and its **functions and activities**.

- **Form** refers to the shape and physical properties of some structure, whether it is a molecule, collection of large molecules, cell, limb or even the results of behavior (e.g., a nest). Put another way, when biologists talk about form, they talk about some material facet of the organism's phenotype – internal or external to the individual.
- **Function** refers to the *use of forms* -- what does a particular bone do (usually many things!), how does a particular behavior serve the

individual that displays the behavior, *etc*. As with mechanical devices, for a particular function, certain shapes are better than others, others are more or less equivalent or offer other possibilities.

Clearly form and function are intimately inter-related and it is the role of much of biology to study these relationships.

**Above the Individual -- Biological Populations**

A **population** is a collection of individuals, usually ones that are relatively similar in terms of genes. Perhaps the most important biological population is called the **deme** – it is a collection of individuals found in a particular location who are capable of reproducing with each other (species after often defined as consisting of one or more demes). Since **phenotypic variation** – the lack of identity between individuals -- is a central fact of biology, then, **descriptions of populations such as demes require a statistical approach**. These statistics (called descriptive statistics) s are essentially a formalized way of summarizing the aggregate characteristics of the members of a group. They are separate from those mentioned previously when we discussed hypothesis testing (those types of statistics are called inferential statistics).

**Changes that Occur In the Lifetime of an Individual vs. Those that Occur Over the Lifetime of a Population**

Phenotypic changes that occur within one individual over time are referred to as **ontogenetic** (from the word ontogeny) – another term is **developmental**. On the other hand, if differences occur over several generations to members of a population at comparable ages, and if these differences are due to changes in the frequencies of genes in this population, then we say that these are **evolutionary** changes. So, evolution is a population phenomenon characterized by changes in the genetic makeup of the group over generational time whilst ontogenetic changes occur within individuals and are not accompanied by changes in the genes the individual carries (although they are related to changes in something called gene expression – we'll cover this later this semester).

**The Biological Hierarchy of Complexity**

Humans love to categorize things (i.e., we love to make inductive generalizations). We find it useful to take objects and assign them to one group or another based on some sort of shared properties. Groups are to some degree the product of the mind and they are not necessarily perfect reflections of nature. For these man-made groupings to be useful in a practical sense, they need to be defined by meaningful differences and similarities.

We humans engage in group-making behavior every time we see something new. This includes things that we can sense without aids -- such as new types of animals, plants or rocks or new assemblages of the same and likewise, it applies to things that are totally new to us because we have extended out senses. Thus, with the invention of the microscope we see cells for the first time and begin to group them; and a similar process happens with telescopes and the discovery of nebulae, galaxies and far more exotic objects.

It seems that we next cannot resist the notion of grouping these groups according to similarity. One of the most common and useful ways of doing this is as a **hierarchy** – an arrangement where **the members of different "levels" become increasingly more inclusive**. Hierarchy based on size is the best example of this. In size hierarchy, groupings are arranged from smallest to large and generally at the same time from simplest to the most complex. Thus, the nature is divided by scientists into a hierarchy starting with subatomic particles, *e.g.*, quarks (or perhaps "strings"), to the universe as a whole (the cosmos). Biologists study a limited portion of this spectrum: their interest begins with macromolecules and ends with ecosystems. Study of each level of this hierarchy is accomplished by specialists who have mastered certain tools that have proven to be most appropriate to a particular level.

| Level | Specialization |
|---|---|
| Macromolecule | biochemistry, biophysics |
| Cell | cytology, cell biology |
| Tissue | histology, physiology, structural biology |
| Organ | physiology |
| Organ System | physiology, endocrinology |
| Organism | physiology, ethology (behavior) |
| Population | evolution, ecology |
| Community | community ecology (*e.g.* marine biology) |
| Ecosystem | limnology, oceanography |

As you might suspect, given the complexity of life, not all biological specializations can be so conveniently ordered because their subject matter encompasses more than one structural level. **Genetics**, which explores the question of the hereditary basis of life, can be approached from the level of macromolecules (molecular genetics which studies the hereditary material itself - DNA), from the level of the individual (Mendelian genetics which studies the rules governing the transmission of traits from parent to offspring) and from the population level (population genetics which studies the amount of genetic variation in and between populations and serves as the basis for the study of evolution).

**Reductionism, Holism and the Biological Hierarchy**

The fact that nature can be usefully viewed as a hierarchy has more significance than simply providing a classification scheme for arranging biological specializations. It has given rise to a philosophical debate among scientists known as **holism** (or **antireductionism**) versus **reductionism**.

- **Holists** view each level as unique and ruled by processes that cannot be understood from a study of its component parts. In its most radical form holists believe that the whole is greater than the sum of its parts, because new properties **emerge** at each level. A less radical version of holism posits that complexity produces many possible interactions and it is not easy to predict which will dominate at higher levels of organization based on knowledge of simpler, less inclusive levels. Thus, knowledge of the property of cells found in a mammal could not be used to readily predict how a mammal regulates its temperature.

**The Relationship Between Holism and Emergence**
Note that the notion of holism is closely allied with a belief in emergence. **Holism** is simply the notion that some factors are best understood a particular level of complexity and not from its atoms (see reductionism below) and **emergence** goes along with this and states that some properties appear at higher levels of organization that were not evident at simpler levels.

- **Reductionists** take a different view of structural levels from holists. They argue that each level can be fully understood by analyzing its "atoms" or parts. For reductionists, **the whole is nothing but the sum of its parts**.

Reductionism is a basic strategy of scientists who attempt to explain nature in the simplest way possible and with the fewest laws or generalizations needed to achieve this task. The ideal reductionist goal is to explain the universe by means of a single equation that integrates the four known forces of nature (electromagnetism, weak nuclear force, strong nuclear force and gravity). As regards biology, the reductionist position would be that all of biology could be reduced to the laws of physics and chemistry; biology would then be the study of a subset of natural phenomena circumscribed by the limits of chemistry and physics, and biological laws could be written in terms of physiochemical laws.

Holists categorically deny this possibility and argue that the findings of biology, although describable to some extent in terms of physiochemical process, deal with a level of complexity that is a consequence of the interaction of its parts and so cannot be understood simply from analysis of its parts alone. During the history of life and its constituent parts, the phenomenon of **emergence** occurs whereby novelty is introduced through the interaction of parts. Emergence can be seen in both phylogeny (e.g., the origin of birds and their unique structural feature - feathers) and ontogeny (e.g., the development of organs from undifferentiated tissue).

### Study Questions/Things to Remember

1. Terms:

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| Genotype | Phenotype | Population |
| Deme | Ontogeny (& ontogenetic) | Holism |
| Reductionism | Emergence | |

2. Know the biological hierarchy and understand its purpose and limitations (both of these will become more apparent over the semester). You need not know the names of biological specialties that focus on various parts of the hierarchy.
3. Compare and contrast the reductionist and holist paradigms. Why did I call them paradigms?
4. Be able to distinguish between holism and emergence (related but not identical concepts). You may want to consult a reliable external sauce such as Wikipedia to learn more.
5. What is the relationship between form and function? Use an example of artificial objects with which you are familiar.