Scientific Method and Data Analysis

The Scientific Method

The process of "doing science" is usually carried out in a more or less formalized way. A scientist that is in possession of a certain amount of knowledge about a system adds to that knowledge through a procedure known as the "scientific method". Preliminary observations suggest a question. For example, you might observe that most of the squirrels you have ever seen have bushy tails. This suggests the following question: What is the evolutionary advantage of having a bushy tail? (Or, put another way, why does natural selection apparently favor squirrels with bushy tails?) You, the scientist, now formulate some tentative answers to this question; these speculative answers are known as hypotheses. Some hypotheses might be: 1) squirrels with such tails stay warmer (perhaps with their tails wrapped around themselves) and thus survive better in cold weather, or 2) tails act as balancing organs, and squirrels with such tails are less likely to die or be injured by falling out of trees. Countless other hypotheses are possible. The next step is to test each hypothesis to determine its validity. The idea is to try to refute each of your hypotheses, one by one; the one or ones that you are not able to reject are then tentatively accepted as perhaps correct. (Notice how different this is from the popular notion that scientists set out to "prove" hypotheses. In what ways is the former procedure more rigorous?)

Initial hypotheses are usually phrased in rather general terms, and are not directly testable. The next step, then, is to take each of your hypotheses and formulate testable predictions that are logical outcomes of the hypothesis. These predictions allow you to formulate testable hypotheses, usually designed to be mutually exclusive, termed a "null hypothesis" (H_0) and an "alternative hypothesis" (H_A). Expanding on the squirrel example, we could examine the first hypothesis (bushy tails are for warmth) and generate some predictions. If bushy tails help squirrel survival by keeping them warm, we should expect squirrels from colder climates to have bushier tails than squirrels from warmer climates. We could state null and alternative hypotheses as follows:

H_0: There is **no difference** between the tails of squirrels from Fargo, North Dakota and Houston, Texas in terms of tail bushiness.

H_A: There **are differences** between the tails of squirrels from North Dakota and Texas: squirrels from North Dakota have thicker tail fur.

Notice that the "null hypothesis", H_0, is always the hypothesis of "no differences". Whenever possible, H_A should predict the direction of the difference, rather than simply the existence of a difference, because it gives greater statistical power. If the evidence allows you to *reject* H_0, then you tenatively *accept* H_A. If you can accept H_A, this lends support to the idea that bushy tails evolved for warmth. (However, there are many others differences between the environments of North Dakota and Texas that could also act as important selective factors. Even if there is a difference, you have not proven *why* that difference exists.)

You can lend additional support to the "warmth" hypothesis by testing *more* predictions generated by it. You could do an experiment. Suppose you have a group of squirrels, and shave the fur from the tails of half of them, then expose them to cold conditions. If the tails contribute warmth, the furred animals should be able to maintain higher body temperatures than shaved animals. Your null and alternative hypotheses would be as follows:

H_0: There is **no difference** in body temperature between squirrels with shaved tails and squirrels with bushy tails.

H_A: There **are body temperature differences** between the two groups: squirrels with shaved tails will have lower body temperature.

If you can reject this null hypothesis, you can feel more confident that the "warmth" hypothesis may be correct. You can never be completely certain that the differences are not due to sheer coincidence, but you *can* make a statement about the *probability* that the alternative hypothesis is correct. This is where statistics play an important role; statistics allow scientists to establish levels of certainty for particular outcomes.

To review the process again: First, observations are made. They suggest a question that is tentatively answered in the form of one or more general hypotheses. Each hypothesis is used to generate testable predictions, which are stated in the form of mutually exclusive null and alternative hypotheses. The test is performed, and the results assessed, to determine whether they warrant rejection of the null hypothesis. Tests can be either experimental (i.e., they can involve some manipulation of the system, such as shaving the squirrels' tails), or they can be observational (i.e., they can require the gathering of additional field data, such as measuring fur thickness in North Dakota and Texas).

Both methods have advantages and disadvantages. The experimental approach involves establishing two situations that differ with respect to only a single factor or variable. The two situations are referred to as the experimental group and the control group. While other variables can be carefully controlled in an experiment, the situation may consequently be very unrealistic. The metabolism of squirrels may be different in the lab from what it is in the field. An observational test, on the other hand, while much more realistic, may be less conclusive, because it is harder to control competing variables. How many ways do Texas and North Dakota differ from one another besides temperature? The choice of which kind of test to perform depends on factors such as feasibility and personal philosophy.

Although it is not reviewed in this handout, which was developed for another class, questions about adaptation can also be addressed by the comparative method.