Do the traits of organisms provide evidence for evolution?

Consider two hypotheses about where Earth's organisms came from.

The first hypothesis is from John Ray, an influential British naturalist of the 17th century. Ray believed that all species were independently created:

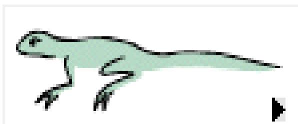
> "A species is never born from the seed of another species."

The second hypothesis is from Charles Darwin, who published *On The Origin of Species* in 1859. Darwin believed that all species were derived, by descent with modification, from a single common ancestor:

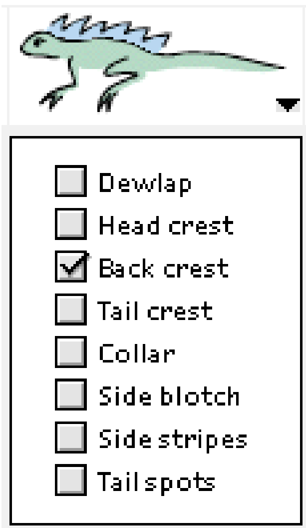
> "...all the organic beings which have ever lived on this earth have descended from some one primordial form..."

This tutorial will let you explore some potential consequences of these two hypotheses. First, you will independently design several lizard species. Then, you will guide the evolution, by descent with modification, of several more. In each case, you will examine the pattern of similarities and differences among the lizards you have created.

Designer lizards



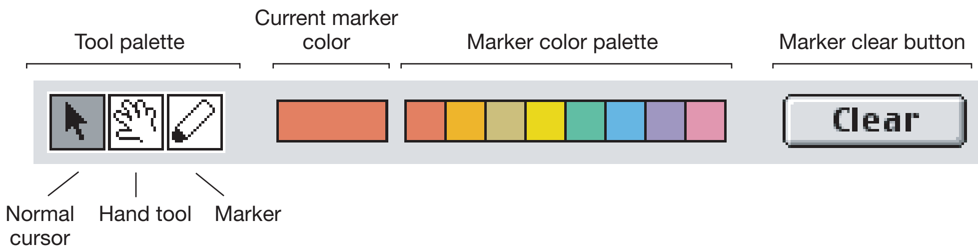
Launch the application PhyloStrat. The first thing you will see is an advertisement for my book. You can click on it to make it go away, or you can wait a few seconds for it to go away on its own. After the ad disappears, you should see a window titled Designer Lizards. Lined up near the top are seven lizards, each of which looks like the one at left.



Note the small black triangle just below each lizard's tail. Click on this triangle. It will change orientation to point downward, and reveal a menu of traits you can bestow on the lizard.If you click the Back Crest box, for example, a check mark appears in the box and a crest appears along the lizard's back. If you change your mind about giving this lizard a back crest, you can click on the box again. Both the check mark and the crest itself will disappear.

Your task now is to design seven lizards, by adding traits to each of the lizards in the window. You can give any lizard any combination of traits you like, but do give each lizard at least two or three traits. That will make your next task more interesting and instructive.

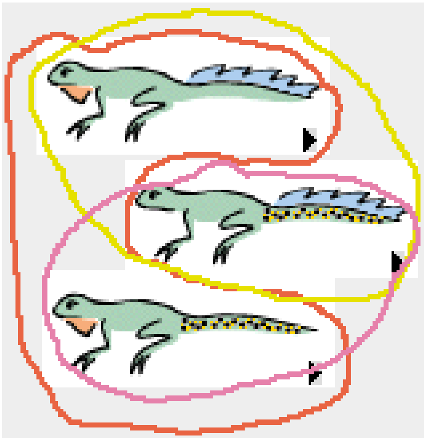
After you have designed your seven lizards, look near the bottom of the window and notice the array of tools you can use:



Try the hand tool first. When you click on the hand tool, the mouse cursor becomes a hand. You can use the hand to move your lizards around in the window. Just place the hand over the lizard you want to move, hold the mouse button down, and drag the lizard to its new location.

Now try the marker tool. When you click on the marker tool, the cursor becomes a marker. Pick a color from the marker color palette (by clicking on it), then use the marker to draw in the window. Place the marker anywhere in the window, hold the mouse button town, and drag. The marker will draw a line (or squiggle) in the color you have chosen. Play with the marker a bit to get the feel of it, then erase your scribbles by clicking on the marker clear button.

Now that you know how to use the tools, here is your task. Move the seven lizards you have designed around in the window to organize them. Try to arrange them so that the lizards with dewlaps are near each other. And so that the lizards with head crests are near each other. And so that the lizards with back crests are near each other, and so on. It



may take some experimentation to arrive at a reasonable arrangement. Do not worry about making the arrangement perfect.

Now use the marker to draw a red circle that surrounds all the lizards with dewlaps. Next draw an orange circle that surrounds all the lizards with head crests. Then draw a tan circle around all the lizards with back crests. Continue with different colored circles for tail crests, collars, side blotches, side stripes, and tail spots. An example with just three lizards is shown at left.

Consider how your different groups of lizards are related to each other. Are the groups organized in some way? Are the lizards with collars, for example, a subset of the lizards with side stripes? Or do the groups intersect willy-nilly? Do the lizards with back crests, for example, overlap–but only partially–the lizards with side blotches?

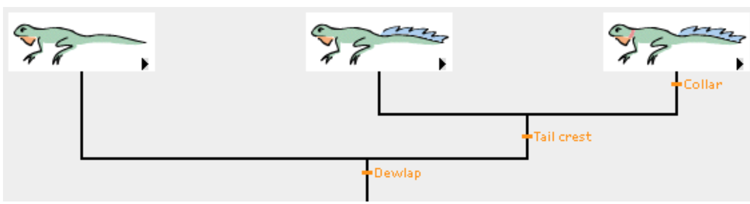
Evolving lizards

Leave the Designer Lizards window open, so you that later you can go back and look at your work again. Under the Window menu select Evolving Lizards. This will open a new window, with just one lizard sitting near the bottom. Click the Run button at the bottom right. When you do so, the lizard will slowly move up the window, dragging a black line behind it. Note that you can pause at any time by clicking the same button, now labelled Pause, again. Click the pause button now.

While the simulation is paused, give the lizard a trait, just like you did in the Designer Lizards window. Now run the simulation again. Note that a label has appeared on the line below the lizard, marking the time at which the first trait, a dewlap perhaps, appeared.

Now, while the simulation is running, click directly on the lizard itself. It will become two lizards, each representing a different species. And the line it was dragging will split as well. Note that both lizard species have inherited dewlaps (or whatever trait you chose) from their common ancestor, and that you can trace their evolutionary history by following the branching lines up from the bottom of the window.

Pause the simulation and give one of the lizard species a new trait. Note that, as before, the time at which the trait appeared is automatically marked on the evolutionary tree. Now run the simulation, let a bit of time go by, and click on one of your lizards to cause another speciation event. Let some more time pass, then pause the simulation and give one of your lizards another new trait. At this point, your evolutionary tree might look something like this:



This tree shows that the common ancestor of all three lizard species had a dewlap. The common ancestor split into two daughter species, and the daughter on the right evolved a tail crest. The tail crested species then split, and one of its daughters evolved a collar.

Continue letting your own lizards evolve, occasionally adding new traits and occasionally causing species to split, until you have seven species and have used up all of the traits. (You will notice that this simulation will let each trait evolve only once, and will not let traits disappear. A question worth pondering is what complications would arise later in our analysis if, as in the real world, traits sometimes *did* evolve in more than one lineage, and sometimes *did* disappear.)

After you have guided the evolution of seven lizard species, use the marker tool to circle groups of lizards sharing traits–just like you did with the lizards you designed before. Draw a red circle that surrounds all the lizards with dewlaps, an orange circle that surrounds all the lizards with head crests, and so on.

Again consider how your different groups of lizards are related to each other. Are the groups organized in some way? Or do the groups intersect willy-nilly?

Designer lizards versus evolved lizards

Switch back and forth between your designer lizards and your evolved lizards. You can do this by clicking on the windows themselves, or by selecting them under the Windows menu.

Is there a difference in the way the groups of lizards with different traits are related to each other when the lizards were independently designed versus when they evolved by descent with modification from a common ancestor? It is possible, if you are a designer with a highly organized mind, that your designer lizard groups are as fully organized as your evolved lizard groups. I am betting, however, that you will notice a way in which your evolved lizard groups are more organized than your designer lizard groups. Try to describe the nature of this organization in your own words. We will discuss it in class.

If you want to try again with either the designer lizards or the evolving lizards, you can reset either window by choosing the Reset command under the File menu.

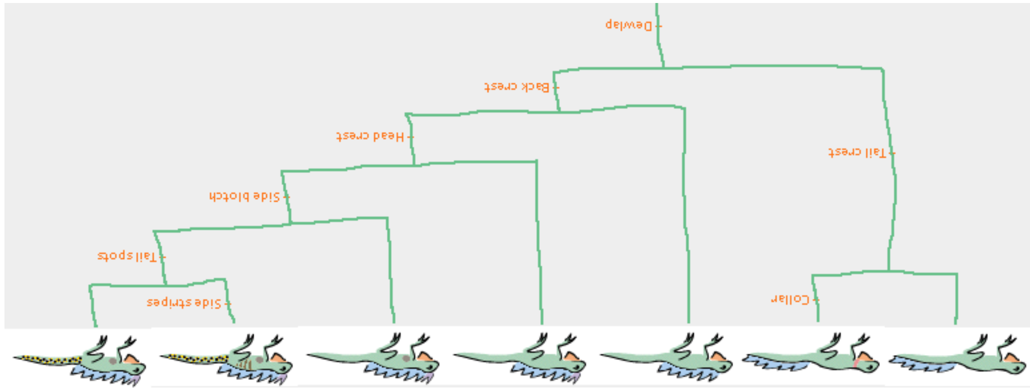
A challenge

To explore the consequences of Darwin's hypothesis in more detail, and to test your own understanding of descent with modification, go to the Windows menu in PhyloStrat and select Challenge. The Challenge window presents these seven lizards:

These lizards evolved by descent with modification from a common ancestor. In other words, I made them in the Evolving Lizards window. They are the seven species that were present at the branch tips at the end of the simulation. Except that I have rearranged them on the screen to present them in random order.

Your challenge is to reconstruct their evolutionary history. You can use the hand tool rearrange the lizards. You can use the marker tool to draw the evolutionary tree. And you can use the hand tool to drag the trait labels up from the bottom of the window to mark the appearance of the traits on the tree you have drawn. When you are done, you should have a tree that looks like it was created in the Evolving Lizards window. In fact, another way to solve the challenge would be to use the Evolving Lizards window to recreate the evolutionary history of these lizards.

The solution appears on the next page, but don't look at it until you've tried to figure it out on your own.

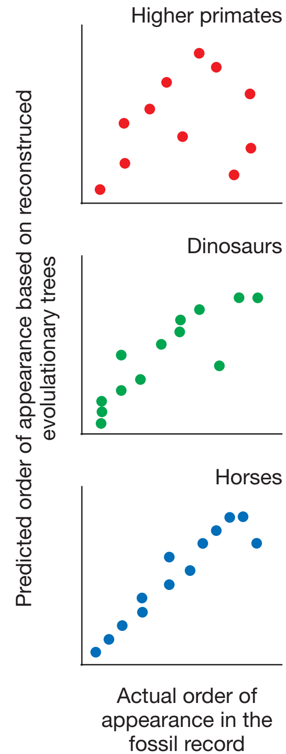


The solution to the challenge is shown above. When comparing my solution to yours, note that there are different ways to draw this tree that still show the same evolutionary history. For example, in my solution tail crests evolved on the left branch, and back crests on the right branch. But the same history would be captured by a tree in which back crests evolved on the left and tail crests on the right.

A test of Darwin's hypothesis

If you successfully completed the challenge, you have learned how to reconstruct evolutionary history from the traits shared among extant organisms. Reconstructing history from traits, in turn, provides a way to test Darwin's hypothesis that today's organisms arose through descent with modification from common ancestors. That is because the reconstructed evolutionary tree allows us to predict the order in which traits should appear in the fossil record. The solution to the challenge, for example, predicts that dewlaps should appear in the fossil record first, then back crests, then head crests, then side blotches (if we can see them in fossils), then tail spots, and finally side stripes. This test, which involves checking the correspondence between evolutionary trees, or phylogenies, and the fossil record, or stratigraphic data, is what gives the application PhyloStrat its name.

Mark Norell and Michael Novacek (1992) performed this kind of test using data from real organisms. For a variety of animal groups, they prepared scatter plots showing the predicted order of trait appearance based on reconstructed evolutionary trees versus the actual order of trait appearance in the fossil record. If the predictions match the fossil record perfectly, then the points in the scatter plots will fall on a diagonal line rising from lower left to upper right. In some cases, such as the higher primates shown at right, top, the predictions based on reconstructed trees are not especially good. In most cases, however, like the dinosaurs and horses shown at center and bottom right, the predictions match the fossil record well. Norell and Nocacek concluded that predictions based on reconstructed evolutionary trees are generally consistent with the fossil record. This is evidence in favor of Darwin's theory. For other examples see Benton and Hitchin (1997) and Benton (1998).



Literature cited

Benton, Michael J. 1998. Molecular and Morphological Phylogenies of Mammals: Congruence with Stratigraphic Data. Molecular Phylogenetics and Evolution 9: 398–407.

Benton, Michael J. and Rebecca Hitchin. 1997. Congruence between phylogenetic and stratigraphic data on the history of life. Proceedings of the Royal Society of London, B 264: 885-890.

Norell, Mark A., and Michael J. Novacek. 1992. The fossil record and evolution: Comparing cladistic and paleontologic evidence for vertebrate history. Science 255: 1690-1693.