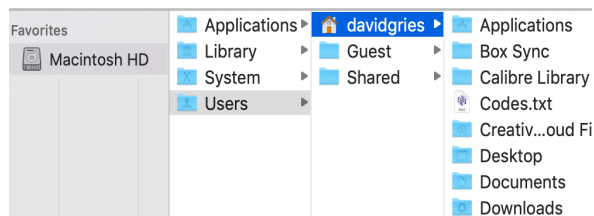


Examples of Trees

Trees are used in many areas of CS —compilers, databases, operating systems, for example. They are also used outside computer science. We give some examples.

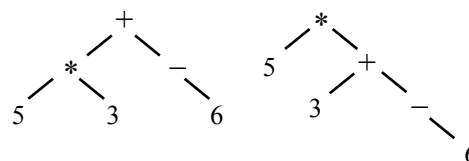
Hard drives

The hard drive on your computer is organized as a tree. The tree to the right shows part of the hard drive on David Gries's laptop. The root, *Macintosh HD*, is the main directory on the hard drive. It has four children. Child *Users* has been selected, so its children are shown (but not the children of its siblings). Node *davidgries* has been selected, so some of its children (but not the children of its siblings) are shown. Only one leaf, file *Codes.txt*, is shown, but of course there are many more.



Arithmetic expressions

Arithmetic expressions are often represented as trees. To the right, we show the tree representation of the expression $5 * 3 + -6$. The root is the last operation to be performed, $+$. Its left subtree is the tree for its left operand, $5 * 3$, and its right subtree is the tree for its right operand, -6 . The second tree to the right is for the expression $5 * (3 + -6)$. As you can see, parentheses are not needed in the tree representation of an expression.



HTML tree

HTML is the language in which webpages are written. To the far right is a file containing HTML source for a webpage. To its left is what that HTML page looks like when seen in a browser like Safari or Chrome.

A simple web page

[Cornell CS web](#)

A list

- A. coffee
- B. tea

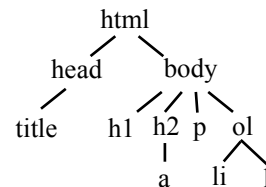
In HTML, formatting is indicated using *tags*, which generally come in pairs: an opening tag like `<head>` and a closing tag like `</head>`. Tags can be nested, and that is where the concept of a tree comes in. Generally, whenever one sees nesting, trees are implicitly involved. Here are what the less obvious tags mean:

- `h1`: header 1
- `h2`: header 2
- `p`: paragraph
- `ol`: ordered list
- `li`: item in a list
- `a`: anchor —contains a URL (web address)

To the right, we show the tree structure for the html tag on this webpage. When a browser displays this page, it traverses the tree to determine where and how to place text, images, and other items.

If you have never seen HTML before, you now have learned a little bit about what the source of a webpage looks like and how a browser works to display a page.

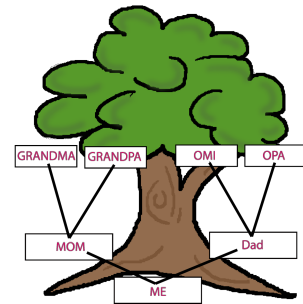
```
<!DOCTYPE HTML PUBLIC "-//W3C//DTD
HTML 4.01//EN"
"http://www.w3.org/TR/html4/strict.dtd">
<html>
<head>
  <title>demo</title>
</head>
<body>
<h1>A simple web page</h1>
<h2><a href="http://www.cs.cornell.edu/">
Cornell CS web</a></h2>
<p>A list</p>
<ol type="A">
  <li>coffee</li>
  <li>tea</li>
</ol>
</body>
</html>
```



Family trees

Family trees are sometimes drawn as shown to the right, showing the ancestors of a person. ME is the root, and branches (lines) are drawn to the MOM and DAD, and from them to their parents (OMI and OPA are German terms for grandmother and grandfather). Computer scientists would draw this tree upside down, with ME at the top.

MY FAMILY TREE

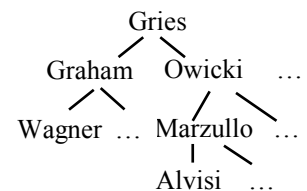


Of course, such family “trees” are not always trees as we define them in computer science, because of divorces, remarriages and the like. In one of his books, Mark Twain proved that it was possible for a person to be their own grandfather, which led Dwight Latham and Moe Jaffe to write a song titled “I’m My Own Grand-Paw” — see https://en.wikipedia.org/wiki/I%27m_My_Own_Grandpa.

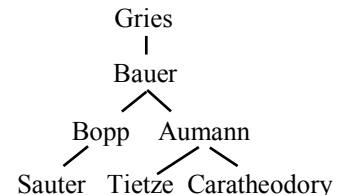
Wikipedia (https://en.wikipedia.org/wiki/Family_tree) tells us that the longest known family tree is that of the Chinese philosopher and educator Confucius; it spans 80 generations and includes more than 2 million members.

PhD genealogy

The website <https://genealogy.math.ndsu.nodak.edu> maintains a database of PhDs in math and computer science. As of 1 Jan 2019, it had almost 237,000 entries. For each person, it shows their one or two advisors and their advisees. To the right is part of the tree of Gries and his descendents — for example, Susan Graham and Susan Owicki were two of his 21 PhD advisees. The dots ... represent more advisees (children).



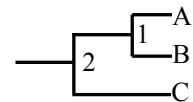
When drawing a tree of descendents, there can be any number of children. On the other hand, on this website, a PhD can have at most two advisors, so if we draw a tree of advisors, or ancestors, we get a tree in which each node has at most two children, as illustrated to the right.



These trees can be quite large. For example, Gries has over 190 ancestors on this website. To construct the full tree by hand is an arduous, error-prone task. Instead, we wrote a program that reads html files from the website and constructs the tree. This requires knowing (1) how to read websites in Java and (2) how to write a recursive procedure to traverse a tree.

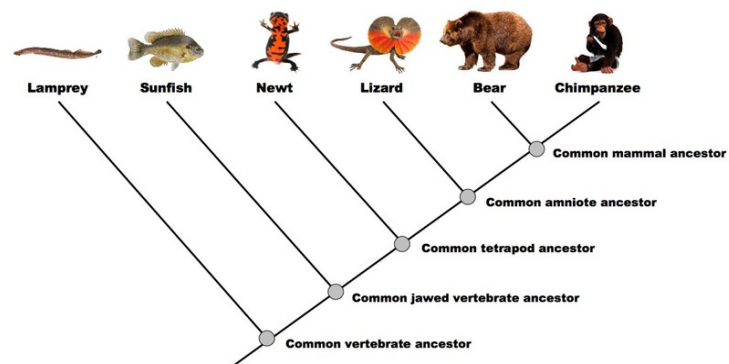
Phylogenetic trees

Phylogeny is the study of the evolution of genetically related groups of organisms, and *Phylogenetic trees* are used to represent hypotheses on how different species evolved from common ancestors. People in this field draw trees slightly differently than we do in CS. In the tree to the right, the leaves (A, B, C), are species. This tree indicates that A and B evolved from common ancestor 1 and that, earlier in history, C and 1 evolved from common ancestor 2.



The phylogenetic tree shown to the right¹ has the same form as the one above but its root is at the bottom instead of to the left. Search the web and you can find many example of such phylogenetic trees.

Charles Darwin, in his *On the Origin of Species* (1859), said “The affinities of all the beings of the same class have sometimes been represented by a great tree. I believe this simile largely speaks the truth.”



¹ Taken from https://zimdarsgen564s14.weebly.com/uploads/2/6/0/7/26071264/8898816_orig.jpeg?341