Computational Structures in Data Science

Data Structures:
Trees

Week 6, Summer 2024. 7/24 (Wed)

Lecture 20

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Announcements

- Reminder: Climate and culture in the classroom are important.
  - https://eecs.link/climate EECS Climate Form
  - [CDSS / Data Science](https://eecs.link/climate) climate form
  - You are free to use either or both forms.
- Midterm Grading is in progress
  - MT Grades will be released by Mon 7/29 (hopefully sooner)

Learning Objectives

- Trees can be seen as a general version of linked lists
- Trees have a value, and are connected to "sub-trees" called branches
- We can often use recursion to process all items in a tree
  - We typically have recursion inside a loop over all the tree's branches
  - This is called "Depth First Search"

Why Use Trees?

- **Trees** represent lots of natural structures

  - A boss who has employees report to them

  - Courses which belong to departments, and departments which colleges in a University

  - Anything with a hierarchy, really.

    - A family tree

    - Biological taxonomies (Kingdom, Phylum....)

    - Files and Folders

  - A game board, which representers as series of potential moves, one after the next.

    - E.g. Given Move 1, link the next possible moves, which link the next set of possible moves

Recall: Tree Recursion

List all items on your hard disk
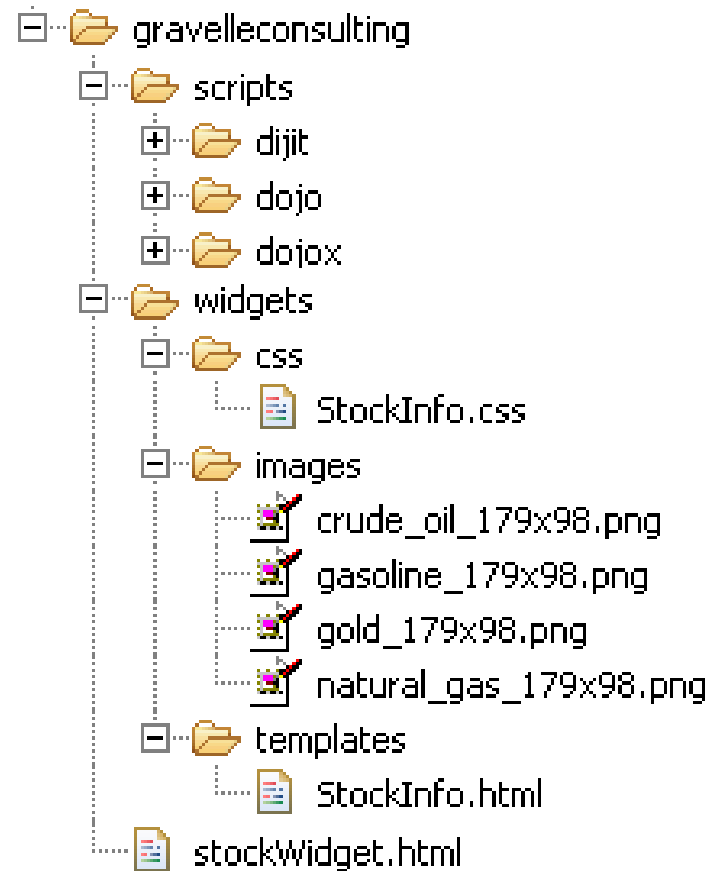
- Files
- Folders contain
  - Files
  - Folders

```
def
process_directory(directory
):
    for item in directory:
        if is_file(item):

process_file(item)
        else:

process_directory(item)
```

Review: Linked Lists

- A Recursive List, sometimes called a "rlist"

- Linked lists contain other linked lists

- A series of items with two pieces:

  - A value, usually called `"first"`

  - A "pointer" to the `rest` of the items in the list.

- We'll use a very small Python class "Link" to model this.
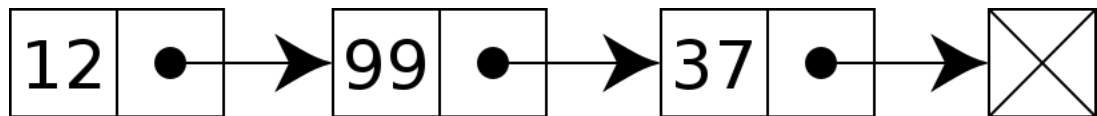
What is a tree?

- **What is a tree?** (in CS...)

  - A *data structure* -- an organization of objects in a particular format.

  - In this case, Objects which have one or more *children*

- Almost like a linked list!

  - What if a linked list could have multiple "rest" elements

- We call these children elements *branches*.
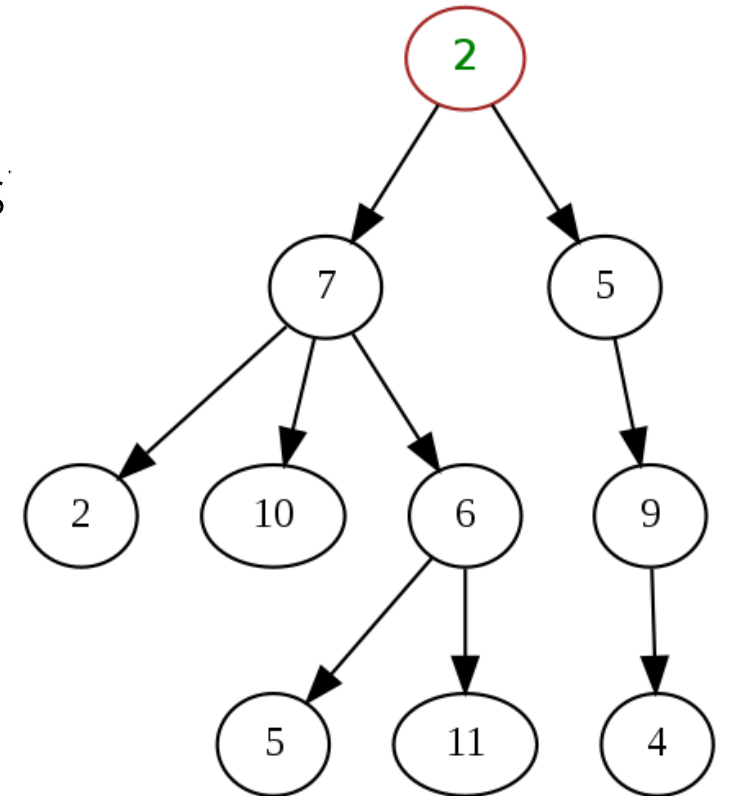
Trees are Recursive

- Another recursive data structure!
  - We can keep practicing recursion and working with classes
  - Computer science really likes recursion. ☺
- Recall: *tree recursion* from before the midterm...
  - **Tree recursion exists independently of tree data structures!**
  - However, tree recursion is a common technique for processing data in trees.
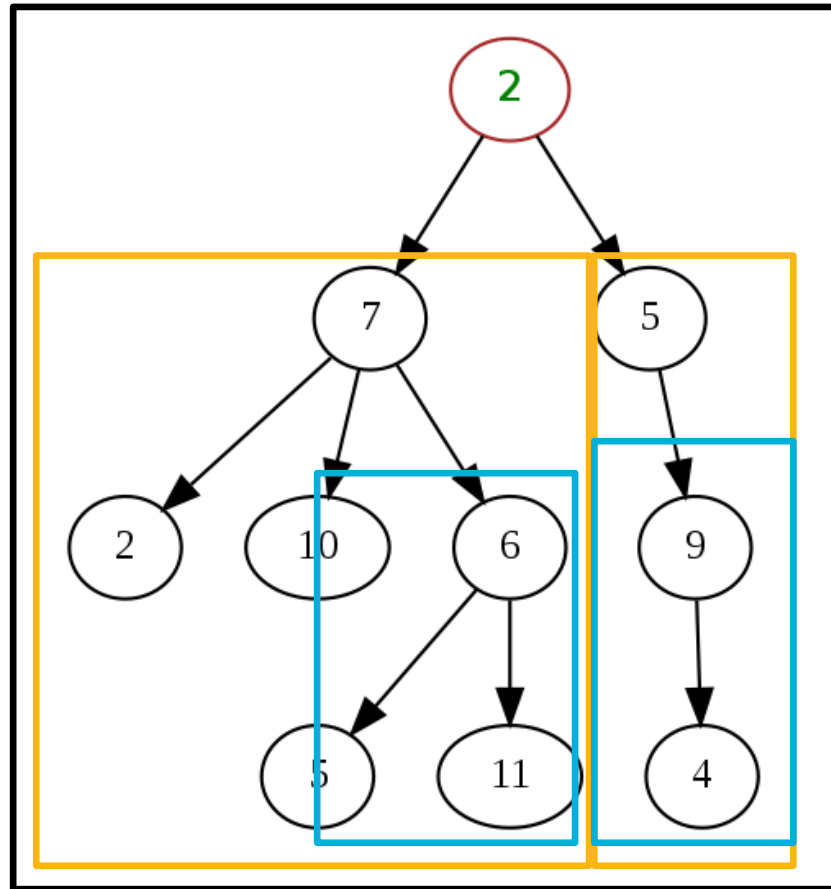- Each branch is also its own Tree.

How many trees are there?
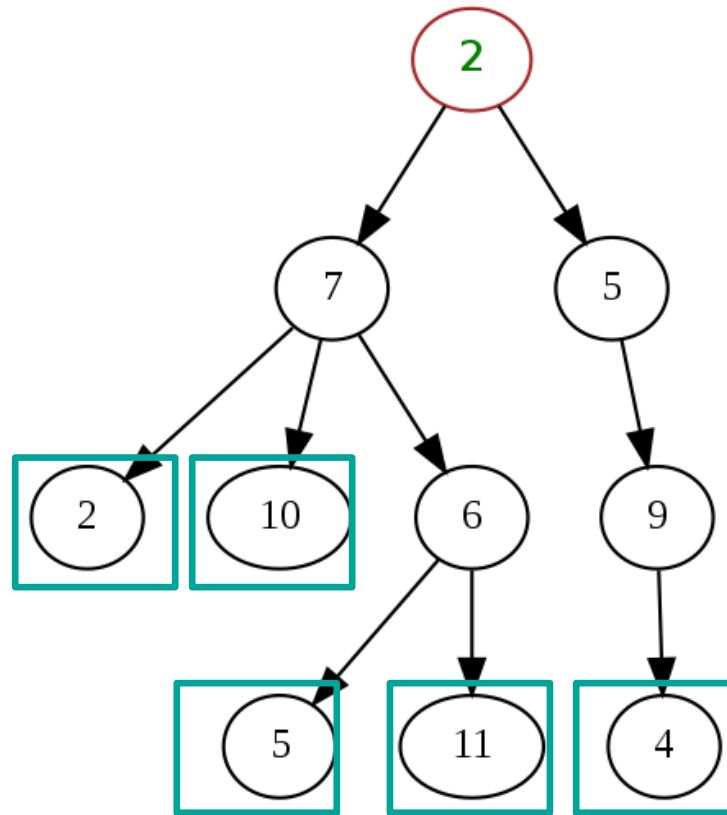
- Mostly a rhetorical question...
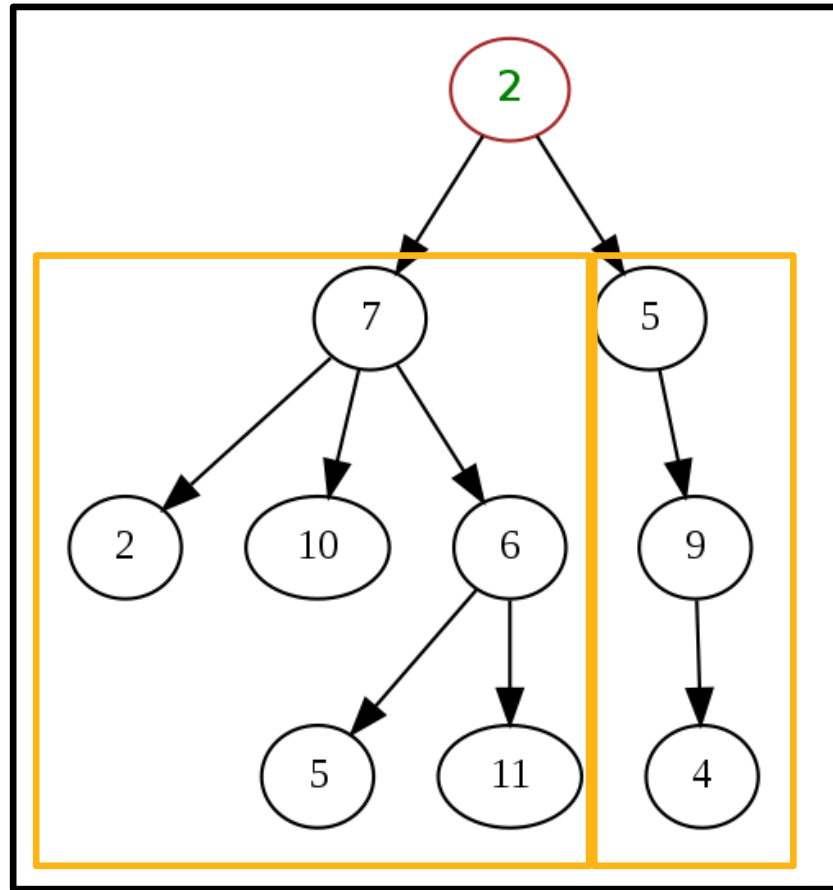
How many trees are there?

- Mostly a rhetorical question...

How many trees are there?

- Leaf notes are the elements with no branches
- They are *also* a Tree – this will make our recursive code simpler. ☺

Trees are common in Computer Science

- We shown trees showing numbers *for simplicity.*
  - In practice, the value of each tree element varies a lot!
  - In can be a person, a course, any kind of object.
- Trees give us awesome approaches for "divide and conquer"
  - Used in every computer to speed up searching for files (Binary search!)
  - Used for modeling decision systems in AI programs
  - Used for modelling the potential moves in a game.
- Trees are a simplified form of a *graph*, a tool which can help us model just about anything.
  - Graphs are a (relatively) important topic in CS61B

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Trees: Code Overview

(Go Inspect the ipynb)

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What's a tree? (C88C-style)

- A tree is a list of trees!

- Each tree has a node, with a value.

- Each node has `branches` which are itself, trees.

  - There can be zero or many branches

- There is always 1 "root" node

Our Simple Tree Class: A couple new methods!

```python
class Tree:
    def __init__(self, value, branches=()):
        self.value = value
        for branch in branches:
            assert isinstance(branch, Tree)
        self.branches = list(branches)
    def __repr__(self):
        branches_str = ''
        if self.branches:
            branches_str = ', ' + repr(self.branches)
        return f'Tree({self.value}{braches_str})'
    def is_leaf(self):
        return not self.branches
    def add_branch(self, tree):
        assert isinstance(tree, Tree), "Each branch of a Tree must be an instance of a Tree"
        self.branches.append(tree)
```

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Trees:
Practice With Recursion:
`traverse_recursive`

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Trees:
Counting Each Node

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How do we count nodes?

- The "root" or top of the tree is one node.
  - (We assume we can't have a tree of 0 nodes!)
- For each subtree we... Count the nodes!
  - Doesn't this sound like recursion?
- Hard Part: How do we group the results of recursion?
- Remember our recursive algorithm:
  - Base case
  - Recursive Case:
    - Divide
    - Invoke
    - Combine

```python
def count_nodes(t):
    """The number of leaves in tree.

    >>> count_nodes(fib_tree(5))
    8
    """
    if t.is_leaf():
        return 1
    else:
        return 1 + sum(map(count_nodes, t.branches))
```

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Trees:
Practice With Recursion:
`print_tree`

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Searching Trees: Two Strategies

- The searching we have been doing today is called "Depth First Search", or DFS.
- Recursion makes the algorithm very nice.
  - First: we deal with our current item, then we get to the branches.
  - We always make a recursive call on the first branch
  - We continue recursing until there are no more branches
  - Then the function executes, and we go back "up" a level and check out the next branch.
  - We sometimes say: "popping up the stack".
  - The *stack* is the "stack of function calls" the computer uses to keep track of how things work, and you'll learn about this in CS61B.

Searching a Tree by level: Breadth First Search

- What if I want to check out all the values of my branches before making a recursive call?

- What if we said, you just can't use recursion. (Sometimes, CS instructors do weird things like that…)

- This is used in practice for lots of cool things:

  - Shortest path between two items (more of a graph and not a tree, usually). Google Maps uses it for routing and the algorithms that power the internet use it.