Computational Structures in Data Science

Trees:
Introduction

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Introductions

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Learning Objectives

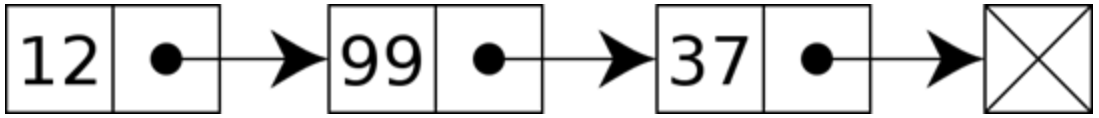
- Trees can be seen as a general version of linked lists
- Trees have a value, and are connected to ‘sub-trees’ called branches
- We can often use recursion to process all items in a tree
  - We typically have recursion inside a loop over all the tree's branches
  - This is called ‘Depth First Search’

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 belong to colleges in a University
  - Anything with a hierarchy, really:
    - A family tree
    - Biological taxonomies (Kingdom, Phylum….)
    - Files and Folders

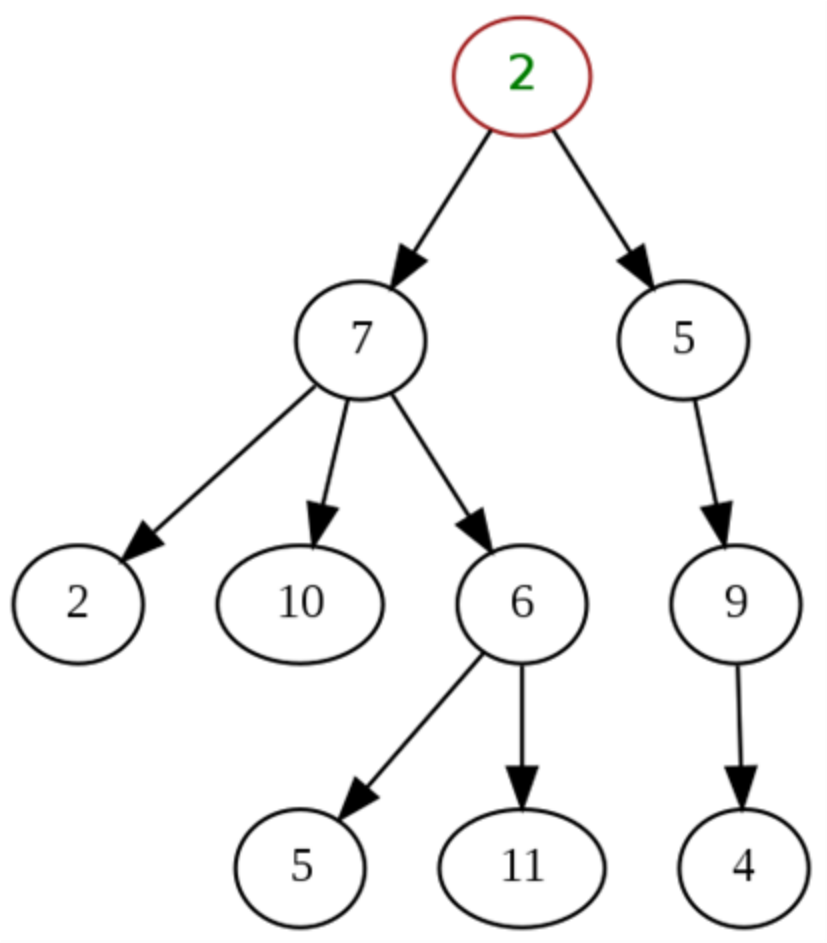
Review: Linked Lists

- A Recursive List is sometimes called an '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?

- A recursive data structure
  - Almost like a linked list!
- What if a linked list could have multiple "rest" elements?
- We call these ‘branches’
- **Each branch is also its own Tree**



Trees are common in Computer Science

- 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
- Another recursive data structure!
  - We can keep practicing recursion and working with classes
  - Computer science really likes recursion ☺
- 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 a data structures class

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Trees: Code Overview

(Go Inspect the ipynb)

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What's a tree? (C88C-style)

- A tree object consists of a value and a list of branches
- Each value inside the list of branches is itself a tree object
  - There can be zero branches or multiple branches
- There is always 1 'root' node

Our Simple Tree Class: A couple new methods!

```
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:
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

Define count_nodes

```
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:
Advanced Topics: Searching

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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 easy.
  - 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 a data structures class

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.

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Thank you!

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Extra Credit ☺

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