Taking Stock: Where Are We?
- Stack
- Queue
- Vector
- string
- PriorityQueue
- Map
- Set
- Lexicon
- Stack
- Queue
- Vector
- string
- PriorityQueue
- Map
- Set
- Lexicon

Could do this with a dynamic array (in class) or a linked list (exercise to the reader).
Could do this with a linked list (in class) or as a dynamic array (exercise to the reader).
Almost always backed by dynamic arrays.
✓ Stack
✓ Queue
✓ Vector
✓ string
✓ PriorityQueue
☐ Map
☐ Set
☐ Lexicon

As a binary heap on top of a dynamic array
(Assignment 5!)
✓ Stack
✓ Queue
✓ Vector
✓ string
✓ PriorityQueue
☐ Map
☐ Set
☐ Lexicon
Implementing Nonlinear Containers
What is the average cost of looking up an element in this list?

Answer: $O(n)$.

*Intuition:* Most elements are far from the front.
Can you chain a bunch of objects together so that most of them are near the front?
An Interactive Analogy
Take a deep breath.
And exhale.
Feel nicely oxygenated?
Your lungs have about 500 million alveoli... yet the path to each one is short.
**Key Idea:** Most elements in a tree are near the *root* (top) of the tree.
Harnessing this Insight
How do we know to go this way to get 109?
How do we know to go this way to get 108?
**Goal:** Store elements in a tree structure where there’s an easy way to find them.
Elements less than 106 go here... 

... and elements greater than 106 go here.
Elements less than 106 go here...

... and elements greater than 106 go here.
There are 13 nodes in this tree…

... yet the path to each one is short.
How can we check if 108 is in this tree?
How can we check if 108 is in this tree?
How can we check if 108 is in this tree?
How can we check if 108 is in this tree?
How can we check if 108 is in this tree?
How can we check if 108 is in this tree?
How can we check if 108 is in this tree?
How can we check if 108 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
How can we check if 83 is in this tree?
Binary Search Trees

• The data structure we have just seen is called a **binary search tree** (or **BST**).
• The tree consists of a number of **nodes**, each of which stores a value and has zero, one, or two **children**.
• All values in a node’s left subtree are **smaller** than the node’s value, and all values in a node’s right subtree are **greater** than the node’s value.
A Binary Search Tree Is Either...

an empty tree, represented by

`nullptr`
A Binary Search Tree Is Either...

- an empty tree, represented by `nullptr`, or...
- a single node, whose left subtree is a BST of smaller values...
- and whose right subtree is a BST of larger values.
Binary Search Tree Nodes

```c
struct Node {
    Type value;
    Node* left;  // Smaller values
    Node* right; // Bigger values
};
```

Kinda like a linked list, but with two pointers instead of just one!
Searching Trees
A Binary Search Tree Is Either...

an empty tree, represented by

nullptr
A Binary Search Tree Is Either...

an empty tree, represented by

nullptr

If you're looking for something in an empty BST, it's not there! Sorry.
A Binary Search Tree Is Either…

an empty tree, represented by `nullptr`, or…

… a single node, whose left subtree is a BST of smaller values …

… and whose right subtree is a BST of larger values.
Good exercise:
Rewrite this function iteratively!
Walking Trees
Print all the values in a BST, in sorted order.
A Binary Search Tree Is Either...

an empty tree, represented by `nullptr`, or...

... a single node, whose left subtree is a BST of smaller values ...

... and whose right subtree is a BST of larger values.
Print all values smaller than 106...

... then 106...

... then all values larger than 106.
Inorder Traversals

• The particular recursive pattern we just saw is called an *inorder traversal* of a binary tree.

• Specifically:
  • Recursively visit all the nodes in the left subtree.
  • Visit the node itself.
  • Recursively visit all the nodes in the right subtree.
Challenge problem:
Rewrite this function iteratively!
Time-Out for Announcements!
WiCS Speed Mentoring Night

network with grad students + learn about their research!

who  Grad students sharing their research!
date + time  FEB 26 @ 6-7 PM
location  Gates 219

For more details, check out the Facebook event.
Assignment 5

- Assignment 5 (*Data Sagas*) is due on Wednesday at the start of class.
  - Have questions? Stop by the LaIR (for coding questions) or CLaIR (for conceptual questions!)
  - Recommendation: aim to complete the first three parts of this assignment by Monday.
Back to our regularly scheduled programming...
Adding to Trees

Thanks, WikiHow!
Let's insert 147 into this tree.
Let's insert 147 into this tree.
Let's insert 147 into this tree.
Let’s insert 147 into this tree.
Let's insert 147 into this tree.
Let's insert 147 into this tree.
Let's insert 147 into this tree.
Let’s insert 147 into this tree.
How do you add 221 into this tree?
Let's Code it Up!
A Binary Search Tree Is Either...

- an empty tree, represented by
  `nullptr`
A Binary Search Tree Is Either...

an empty tree, represented by
nullptr
A Binary Search Tree Is Either...

- an empty tree, represented by `nullptr`, or...

- a single node, whose left subtree is a BST of smaller values...

...and whose right subtree is a BST of larger values.
Your Action Items

- **Keep working on Assignment 5.**
  - Aim to complete multiway merge, lower bound search, and heap priority queue by Monday.

- **Read Chapter 16 of the textbook.**
  - There’s a bunch of BST topics in there, along with a different intuition for how they work.
Next Time

- **More BST Fun**
  - Some other cool tricks and techniques!
- **Custom Types in Sets**
  - Resolving a longstanding issue.