



Big O and Data Structures

Web Development Boot Camp
Lesson 22.3



Outline



Project Check-In



Computer Science Context



Big O Notation



Data Structures



Arrays



Hash Tables



Stacks/Queues



Sets



Linked Lists



Binary Trees & Binary Search Trees



Dictionaries



Graphs

Project Check-In

Project Status

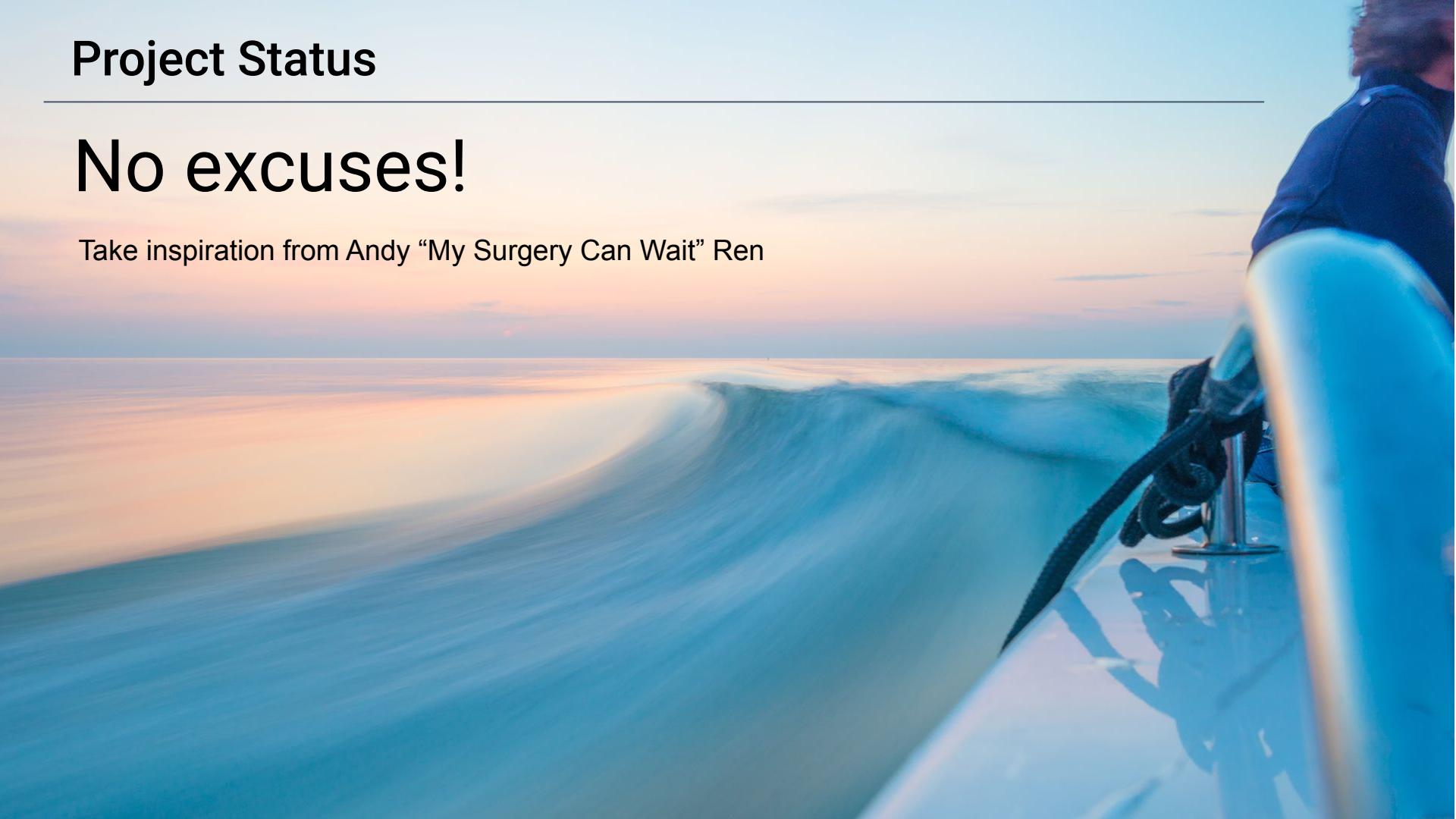
Smooth sailing?



Project Status

No excuses!

Take inspiration from Andy “My Surgery Can Wait” Ren



Project Check-In: Deliverable #1 is Due by the End of Today's Class

Please send the following to your Instructor and TAs:



Overview of intended application (has anything changed?)



MVP Features (placeholders/stubs are fine for now)



Breakdown of group member roles and who has-done/will-do what



Overview of your project management strategy

Submit by the end of the day!



Computer Science Context



Welcome to...
Computer Science Fundamentals!

Remember...

Computer science fundamentals



Fundamentals aren't the “easy” computer science stuff.



Rather, they are the fundamental concepts that underlie all of the work we've been doing to date.



The biggest takeaway is to understand that there are different tools to increase computational efficiency.

Fundamentals

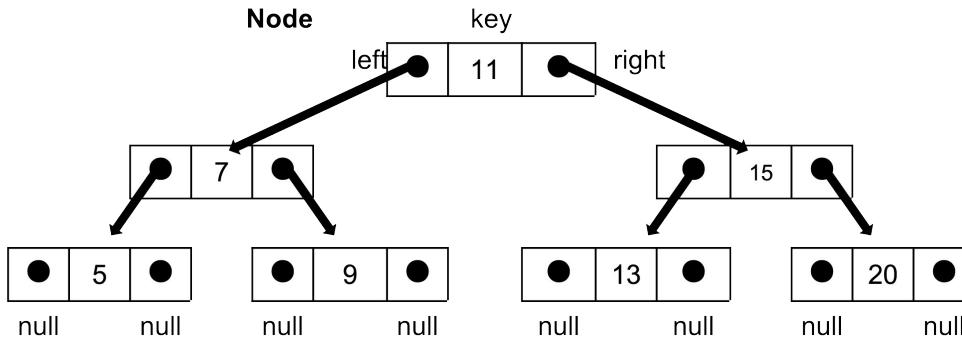
Remember this stuff? Yeah, me neither.

Stokes Theorem

$$\oint_C \vec{F} \cdot d\vec{r} = \iint_S \text{curl } \vec{F} \cdot d\vec{A}$$


S smooth oriented surface
C piecewise smooth oriented boundary
 \vec{F} smooth vectorfield defined on S and C.

It Gets Hairy and Scary



```

function divideBy2(decNumber) {
  var remStack = new Stack(),
      rem,
      binaryString = '';

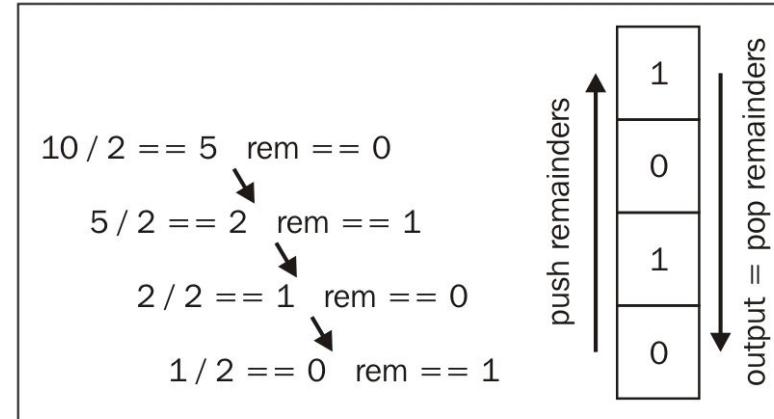
  while (decNumber > 0){ //1
    rem = Math.floor(decNumber % 2); //2
    remStack.push(rem); //3
    decNumber = Math.floor(decNumber / 2); //4
  }

  while (!remStack.isEmpty()){ //5
    binaryString += remStack.pop().toString();
  }

  return binaryString;
}
  
```

```

var fromVertex = myVertices[0]; //9
for (var i=1; i<myVertices.length; i++){ //10
  var toVertex = myVertices[i], //11
  path = new Stack(); //12
  for (var v=toVertex; v!=fromVertex;
  v=shortestPathA.predecessors[v]) { //13
    path.push(v); //14
  }
  path.push(fromVertex); //15
  var s = path.pop(); //16
  while (!path.isEmpty()): //17
    s += ' - ' + path.pop(); //18
  }
  console.log(s); //19
}
  
```





Be Wary of Imposter Syndrome

Don't let the hard stuff scare you.

Why Cover This?

01

These concepts sometimes appear in coding interviews.

02

When inheriting large codebases, you might be tasked to optimize code efficiency.

03

The computational challenges in this lesson force you to deepen your understanding.

Bottom Line

My goal is to give you the terminology and the concepts.



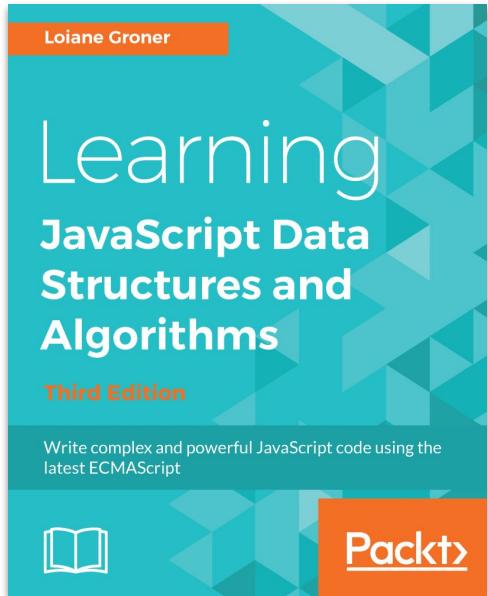
I want to give you enough insight so you can understand the context of interview questions that come your way.



And to encourage those of you who are into math to take a second look!

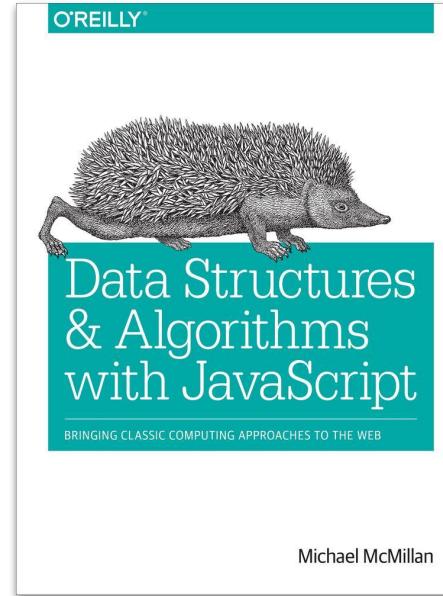
Going Deep

For those who dare dive deeper



Learning JavaScript Data Structures and Algorithms—Third Edition
by **Loiane Groner**

Publisher: Packt Publishing
Release Date: April 2018



Data Structures and Algorithms with JavaScript
by **Michael McMillan**
Publisher: O'Reilly Media, Inc.
Release Date: March 2014

Efficiency

What does “Efficient” Mean?

We talk a lot about efficiency. But what exactly does “efficient” mean?



Fewer Steps = Faster Code
Number of Steps ~ Efficiency

(Kinda, not always!)

More Steps = Less Efficient
Fewer Steps = More Efficient

(Again, kinda, not always!)

What's a Step?



A step is an instruction to the computer.



All computations boil down to a handful of basic steps.



Arithmetic (+, *, etc.)



Assignment (`var x = 42;`)



Boolean tests (`x === 42`)



Reading from memory



Writing from memory

What's a Step?

Each of these counts as a step.



What's a Step?

Fewer steps = faster code

(Wait for the caveat...)

Beware of...

Transpiling

Hidden Steps

Poor memory utilization

Pop Quiz (!)



Which function is more efficient?



Which has fewer instructions?

```
function list_items (list) {
  for (var i = 0; i < list.length; i += 1) {
    // Log each item in the array
    console.log(list[i]);
  }
}

function head (list) {
  // Return first item of a list
  return list[0];
}
```



Count the instructions!

Count Instructions

head = 1 instruction

Count Instructions

list_items = n instructions

...

(n = list.length)

The Verdict

head is more efficient.

The Verdict

But `list_items` isn't bad.

Time Complexity

Quantifying Efficiency

head always executes one instruction...

Quantifying Efficiency

...no matter how long the array is.

Quantifying Efficiency

head takes the same amount of time on any input

```
// Three elements...
var names = ['Gogol', 'Pushkin', 'Dostoevsky'];

// One thousand elements...
var huge_array = generate_array(1000);

// ...But these statements take
// the same amount of time.
console.log( head(names) );
console.log( head(huge_array) );
```

Quantifying Efficiency

`list_items` needs n instructions

Quantifying Efficiency

One `console.log` per item:

```
function list_items (list) {  
    for (var i = 0; i < list.length; i += 1) {  
        // Log each item in the array  
        console.log(list[i]);  
    }  
}
```

Quantifying Efficiency

console.log is fast...

Quantifying Efficiency

...but not free.

Quantifying Efficiency

Longer arrays = more time

Quantifying Efficiency

Double array length = Double time

Triple array length = Triple time

Quantifying Efficiency

In other words...

Quantifying Efficiency

The running time of `head` and
`list_items` scale differently.



Time complexity =
the rate at which algorithm
slows as input **grows**.

Quantifying Efficiency

head is always one instruction.



Running time **does not** slow
for larger inputs.

Quantifying Efficiency

In other words...

Quantifying Efficiency

The running time of **head**
is **constant**.

Quantifying Efficiency

list_items takes n instructions



Running time
depends on array.

Quantifying Efficiency

Double array length,
double time,
etc...

Quantifying Efficiency

Running time **increases linearly** with array length.

Big O Notation

Big O



Big O Notation lets us describe how running time scales when we increase the input size (n).



It is denoted with a big O and the growth factor in parentheses.

Examples:



`head ~ O(1)` Grows like “1” (i.e., running time never grows)



`list_items ~ O(n)` Grows like “ n ” (i.e., gets bigger as n gets bigger)

Big O

There are other Big O “classes.”

Big O

```
function findDuplicates (list) {
  var duplicates = [];

  for (var i = 0; i < list.length; i += 1) {
    var current = list[i];

    for (var j = 0; j < list.length; j += 1) {
      if (j === i)
        continue;
      else if (current === list[j] && !duplicates.includes(list[j]))
        duplicates.push(current);
    }
  }

  return duplicates;
}
```

n steps for each of the n items in list (!)

Big O

$2x$ length = $4x$ time

$3x$ length = $9x$ time

nx length = n^2 time

Big O

Running time grows
as **square** of input.

Big O

find_duplicates ~ $O(n^2)$

“**Quadratic** time complexity”



Big O:
MAJOR INSIGHT!

Big O

2 nested

for

loops $\sim O(n^2)$



NOT COINCIDENCE!

Big O

3 nested for loops $\sim O(n^3)$

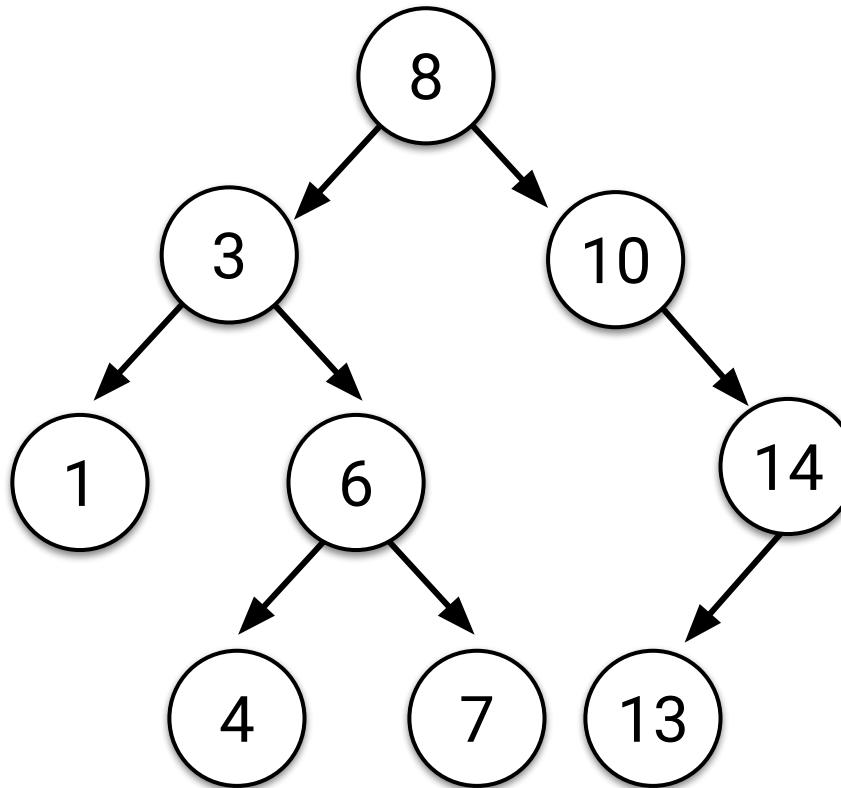
Etc.



Big O:
One More...

Big O

How fast is binary search?



Big O

Is it...



$O(1)$



$O(n)$



$O(n^2)$



Something else?

Big O

Something else? Why?!



Activity:

Binary search this array by hand, for 3, then 9.
Count the steps.

```
// Ready for binary search!
var sorted = [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10];
```



Activity:

Binary search this array by hand, for 3, then 9.
Count the steps.

```
// Ready for binary search!
var sorted = [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10];
```

Answer: 3 Steps



Big O

Add the digits 11–20. Repeat.

Big O

Add the digits 11–20. Repeat.

Answer: 4 Steps (!)



Much faster than linear.

Big O

$(\text{input size})^2 \sim 2x$ running time

$(\text{input size})^3 \sim 3x$ running time

Etc.

Big O

This is called $O(\lg n)$.

Big O

$\lg n$ = how many times do I divide n
by 2 to get to 1?

Logarithm Example

What is $\lg 8$?

Logarithm Example

$$8 / 2 = 4 \text{ (1)}$$

$$4 / 2 = 2 \text{ (2)}$$

$$2 / 2 = 1 \text{ (3)}$$

Logarithm Example

$$\lg 8 = 3$$

But if this is confusing...

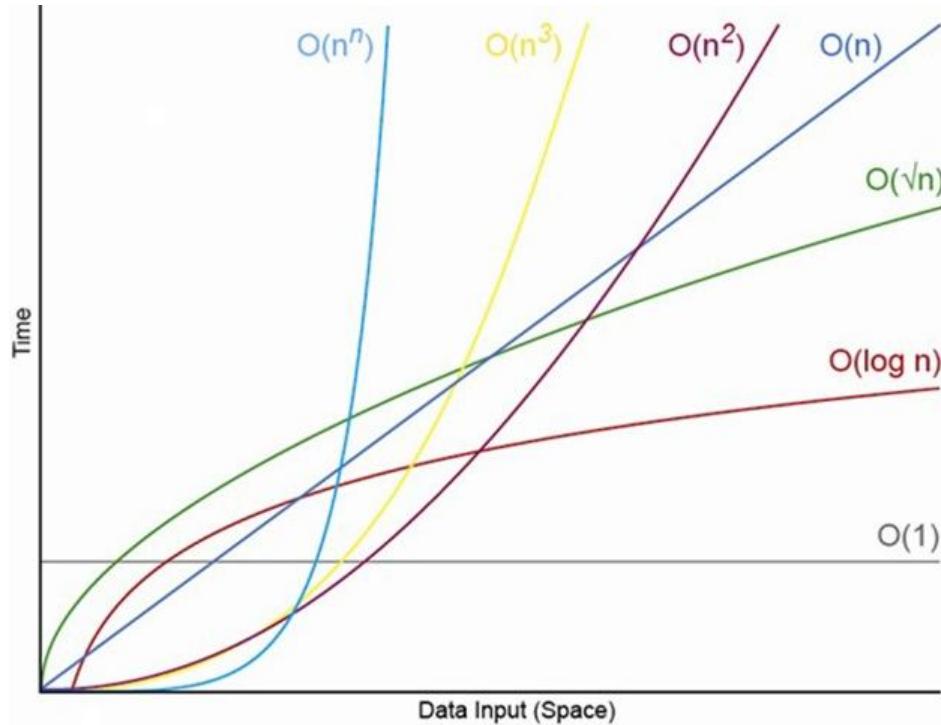
Logarithm Example

Don't worry about it.

Big O Review

<code>head</code> ~ $O(1)$	Grows like "1" (i.e., 2x input size -> 1x running time)
<code>list_items</code> ~ $O(n)$	Grows like " n " (i.e., 2x input size -> 2x running time)
<code>find_duplicates</code> ~ $O(n^2)$	Grows like " n^2 " (i.e., 2x input size -> 4x running time)
<code>binary_search</code> ~ $O(\lg n)$	Grows like " $\lg n$ " (i.e., (input size) 2 -> 2x running time)

Big O Comparisons



Javascript

Javascript

- Javascript is **single-threaded**
 - Javascript is a single threaded language. This means it has one call stack and one memory heap. As expected, it executes code in order and must finish executing a piece of code before moving onto the next.
- What is a “thread”?
 - A thread in computer science is short for a thread of execution. Threads are a way for a program to divide (termed “split”) itself into two or more simultaneously (or pseudo-simultaneously) running tasks
- Don’t let the asynchronous AJAX calls fool you!
 - Javascript is fairly quick, most of all the Javascript executes THEN your promises/callbacks are fair game
- The V8 runtime *may* be using multi-threading behind the scenes, that doesn’t mean that Javascript is multithreaded

Javascript

- Javascript is...
 - Loosely typed, you don't need to specify a variable type
 - Garbage collected, you don't have to worry about freeing up memory
 - Interpreted, not compiled, so a Javascript file is all you need and at runtime that Javascript file is executed
 - Don't confused "compiling" with "transpiling" which is what React and the bundler do behind the scenes
 - Prototype-based, not class-based or object-oriented
 - Javascript "classes" are transpiled to constructor functions behind the scenes
- jQuery, React, Handlebar, Bootstrap...
 - Are not "languages"
 - They are frameworks

Data Structures

Data Structures? (Tricky Question)

What is a data structure?
(And what is an example?)



Data Structures? (Tricky Question)

Before we answer that...

Code = Data. Data Is Saved.

Code that we write gets saved in memory.

```
var name = Ahmed
```

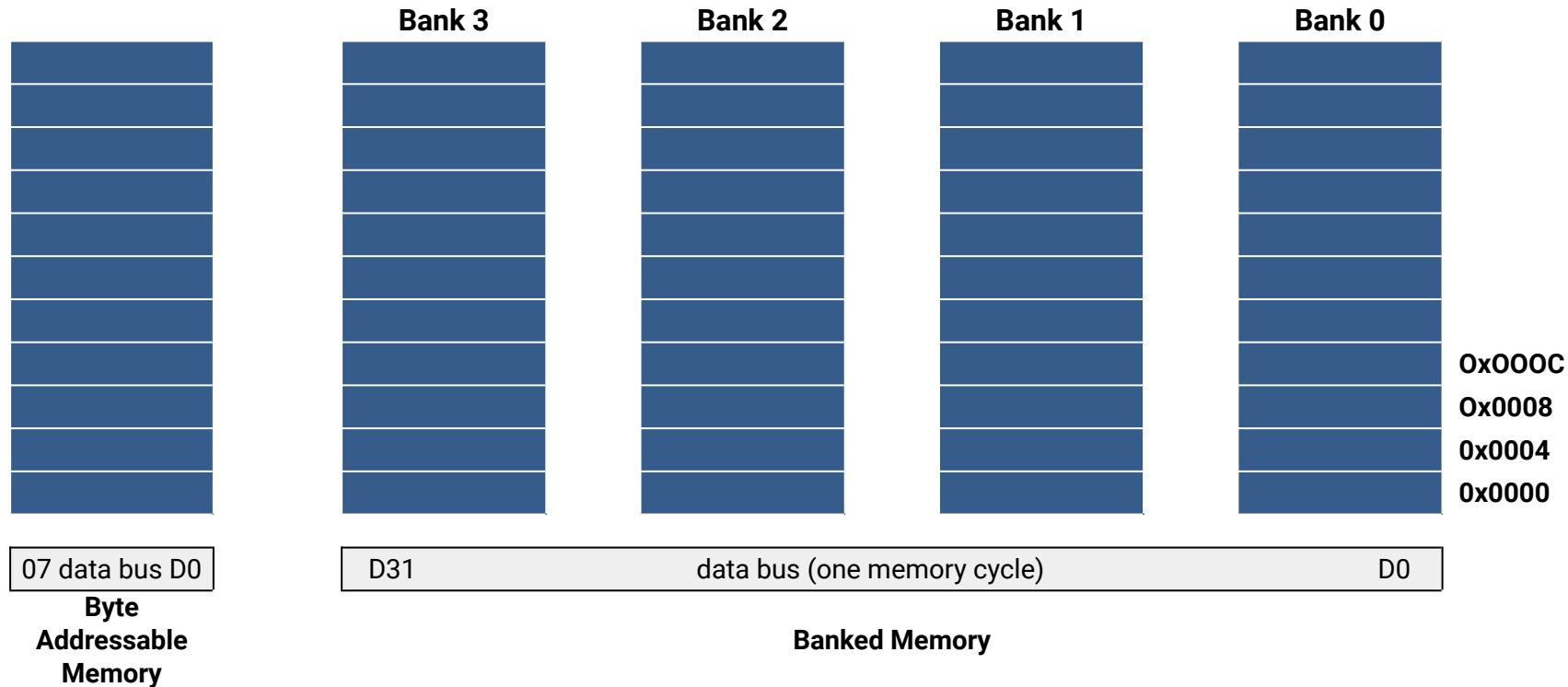
```
var age = 82
```

```
var isCool = true
```



Different Ways to Save

Memory can be visualized as slots. Data is then allotted to these slots.



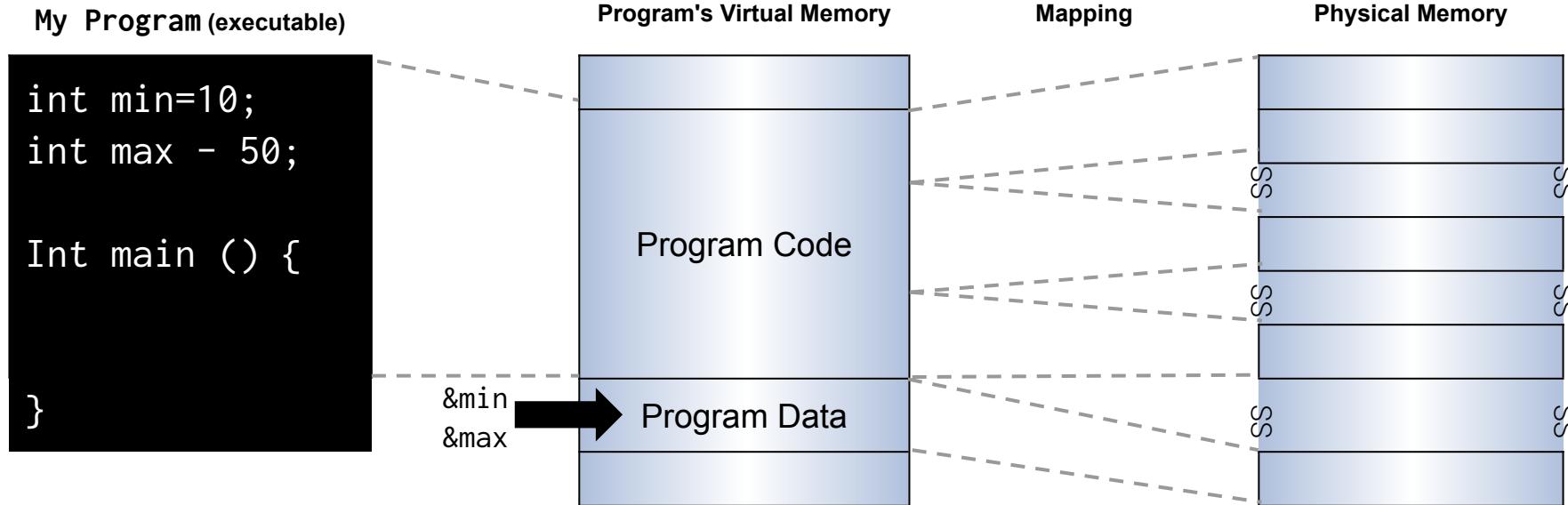
Memory on My Mind



Our code as a whole takes some of these slots of memory.

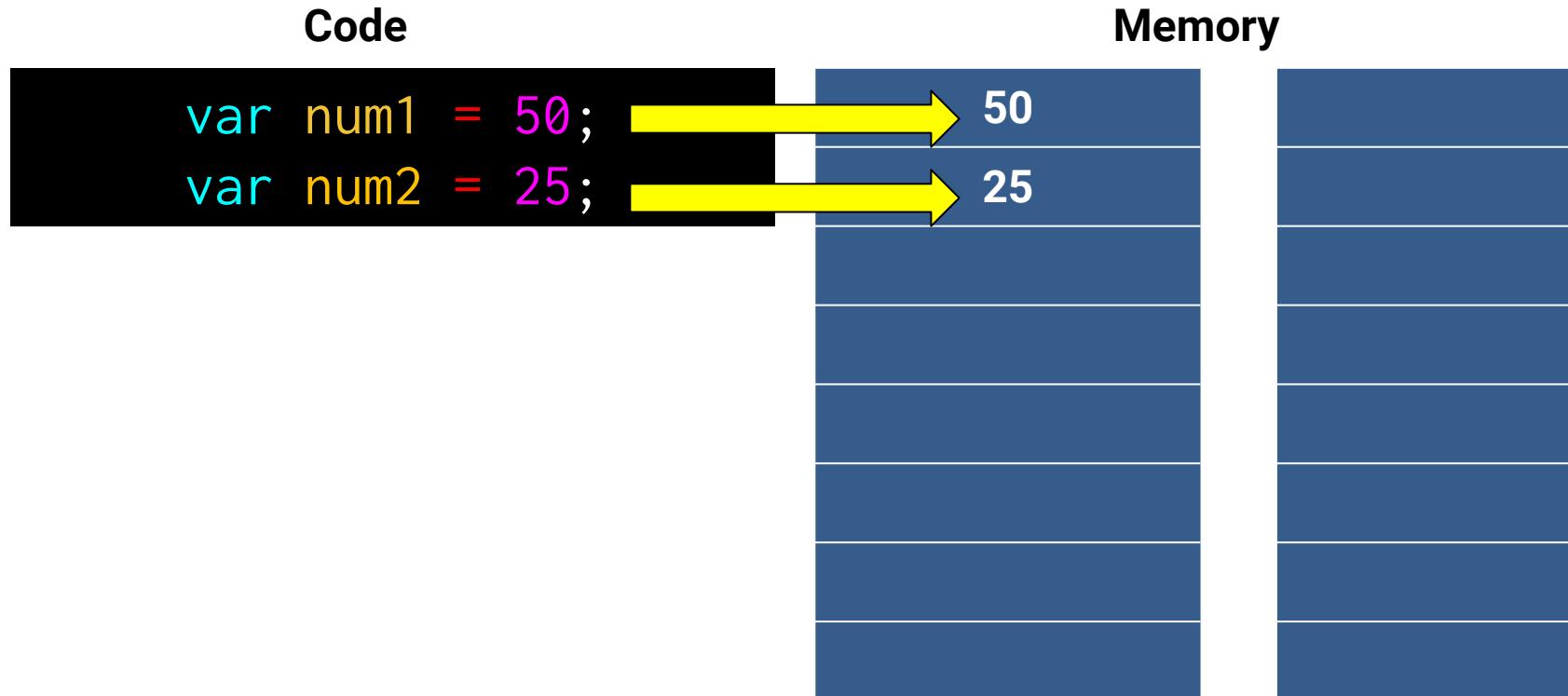


Our variable data itself also takes slots of memory.



Saving to Memory

Each time we declare or instantiate a variable, we are **saving** that data to memory.



Retrieving from Memory

When we reference these variables in our code, we are **retrieving** the data from memory.

Code

```
var num1 = 50;  
var num2 = 25;
```

Memory

50
25

```
console.log(num1 + num2);
```

Growing Data = Growing Problem

As applications grow and we begin to incorporate larger quantities of information with inter-relationships.

These simple operations of saving, retrieving, etc.

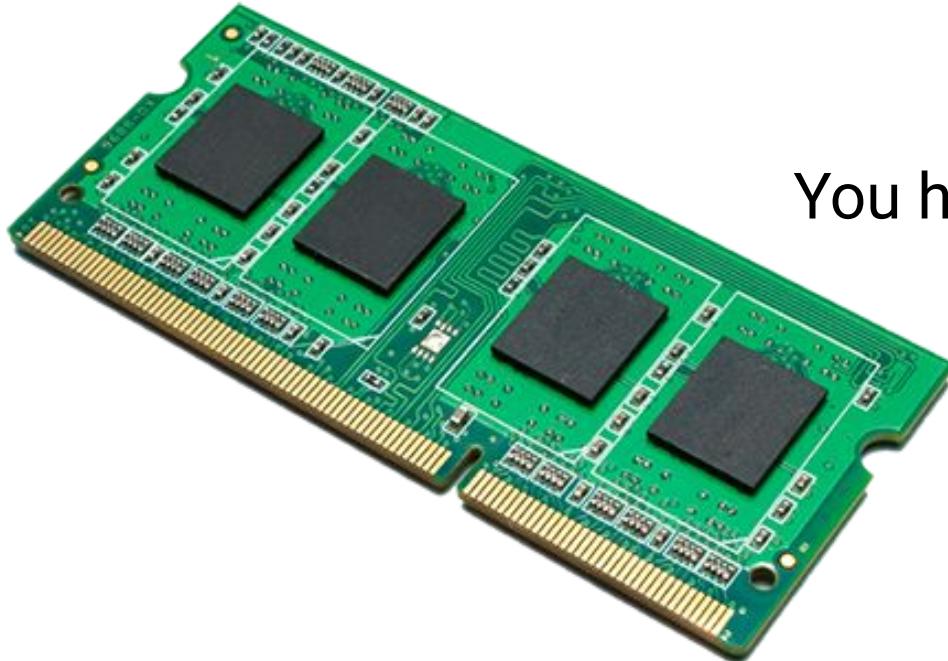
Become a lot more intensive (both time-wise and CPU-processing-wise).



Don't let the simplicity fool you!

Building Devices

Devices inherently have limited memory because of space requirements—making efficiency decisions critical.



You have 1 MB. Use it wisely!

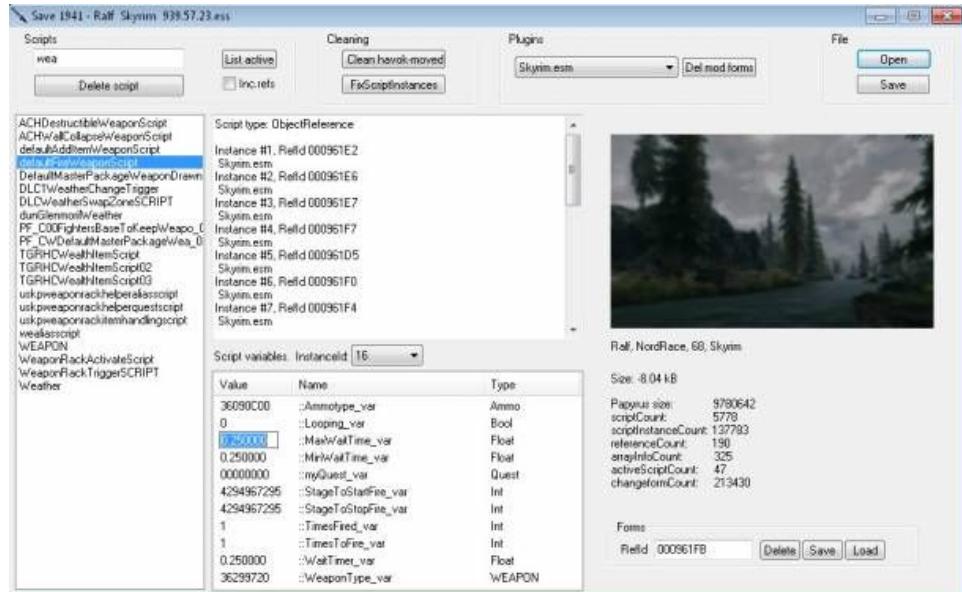
Memory Wizards

- The original Super Mario Brothers was only 32 kilobytes
- They saved memory by doing clever things, for instance the clouds and the bushes are the same sprite with different colors



Memory Wizards

- Skyrim state was revolutionary
- Drop a sweetroll in the middle of Whiterun and you can come back to it...a year later!
- Location, rotation, all the stats of the item are saved as bits



Retrieving from Memory

Even simple objects require memory to keep track of numerous relationships.

Code

```
var pet = {  
    type: "Mammal",  
    animal: "Cat"  
    name: "Sammy",  
    age: 24  
}
```

Memory





What is a
data structure?



A way of storing data
so that it can be used
efficiently by the
computer or browser.



What is a
data structure?



They are built upon
simpler primitive data
types (like variables)



What is a
data structure?



It is non-opinionated, in
the sense that it is only
responsible for holding
the data.

Data Structures?

Example Data Structure: Arrays

```
var favFoods ["Pickles", "Onions", "Carrots"]
```

Arrays

Arrays!



Arrays are the simplest data structure.



JavaScript includes it natively.



In most languages, arrays do not allow mixing of types.



In most languages, arrays are not extendable. (They are fixed sizes.)

averageTemp

31.9	35.3	42.4	42.4	60.8	...
[0]	[1]	[2]	[3]	[4]	

```
var averageTemp = [];
averageTemp[0] = 31.9;
averageTemp[1] = 35.3;
averageTemp[2] = 42.4;
averageTemp[3] = 52;
averageTemp[4] = 60.8;
```

Arrays in JavaScript



In most languages (non-JavaScript), arrays are **immutable**—meaning that upon declaration, the length of the array is fixed.



With JavaScript, we can easily add elements using the `.push()` method.



`.push` adds elements to which side of the array?

31.9	35.3	42.4	42.4	60.8
[0]	[1]	[2]	[3]	[4]

Arrays in JavaScript



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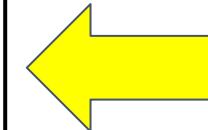


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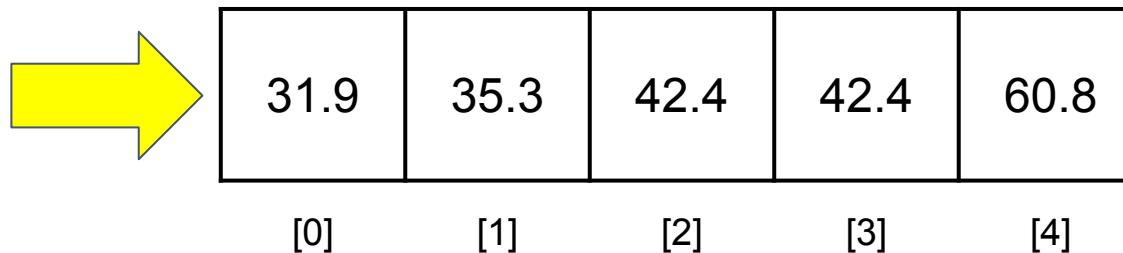
31.9	35.3	42.4	42.4	60.8
[0]	[1]	[2]	[3]	[4]



Arrays in JavaScript



How can we add an element to the **beginning** of the array?



How would you solve this without a built-in Array method?

Arrays in JavaScript

Unshift method:

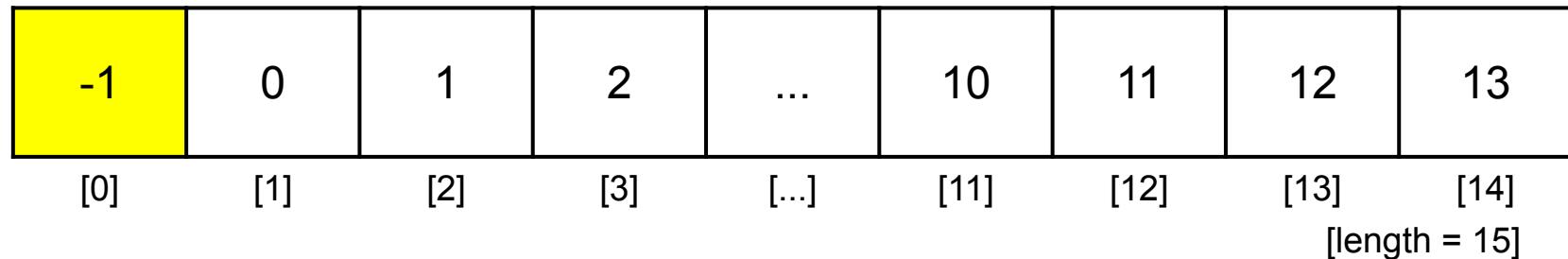
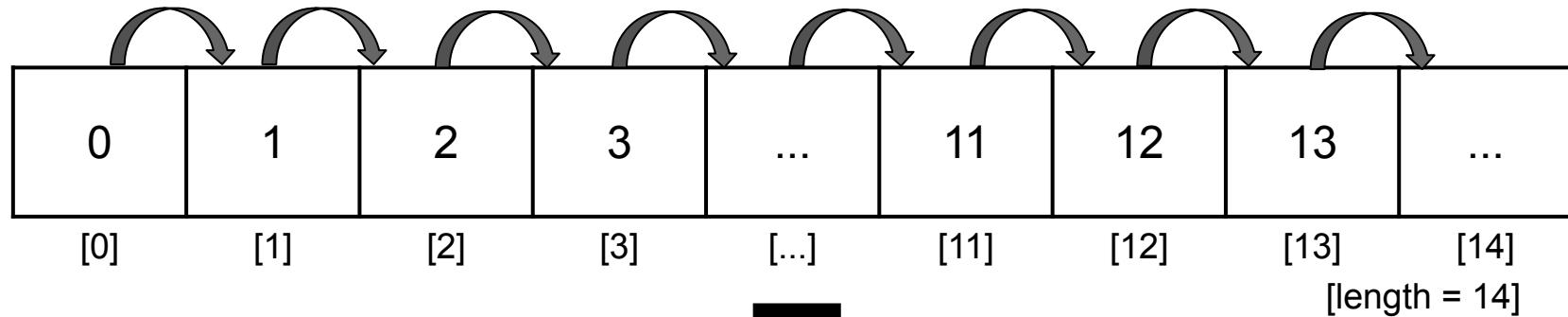
```
myArray.unshift(-1);
```

What's really happening:

```
for (var i=myArray.length; i>=0; i--){
    myArray[i] = myArray[i-1];
}
myArray[0] = -1;
```

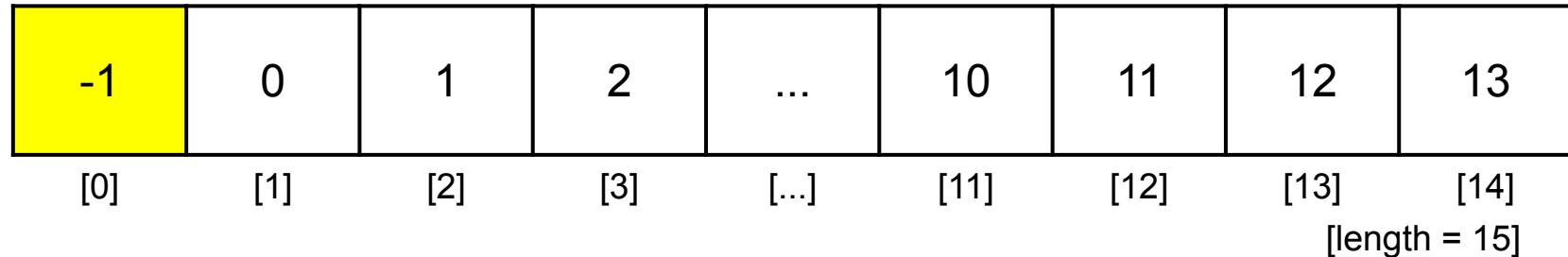
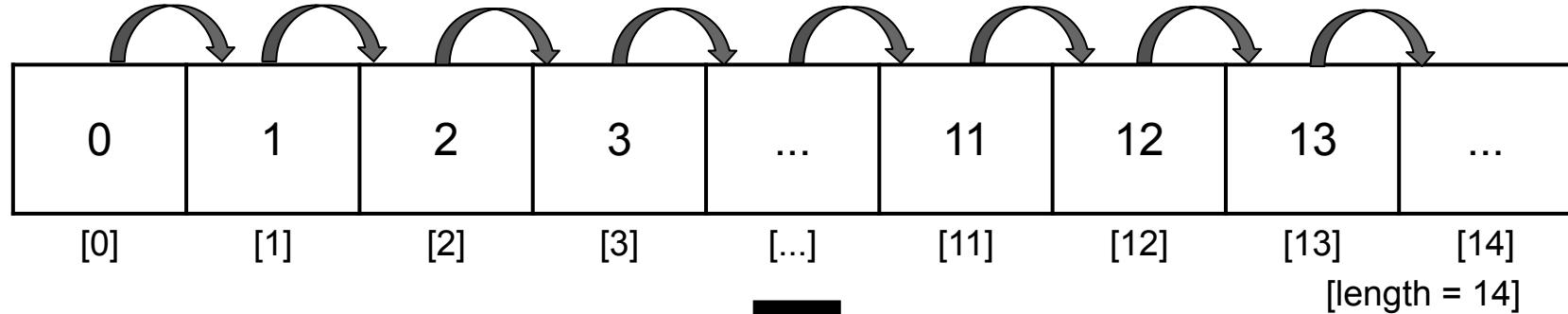
Arrays in JavaScript

An inefficiency emerges!



Arrays in JavaScript

An inefficiency emerges! We'll come back to this.



Stacks/Queues



Data Structures = Abstractions

Going forward, treat each of the following data structures as concepts. These are paradigmatic ways of organizing data that are commonly seen in code.

Stacks

Stacks are another common data structure.



They are similar to arrays in that they are a sequenced order of numbers.



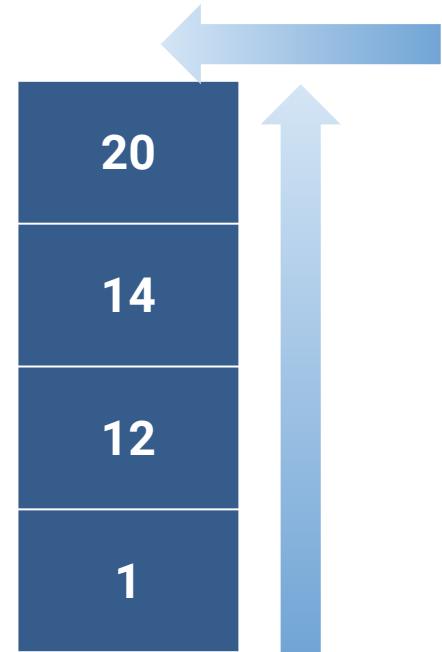
The difference is they **only allow access to the top element**.



These data structures obey “**LIFO**” (**Last-in-first-out**). This means that new elements are placed at the top and removed from the top.



Stacks are an **abstraction** of how data can be arranged.



Stacks

Stacks are another common data structure.



They are similar to arrays in that they are a sequenced order of numbers.



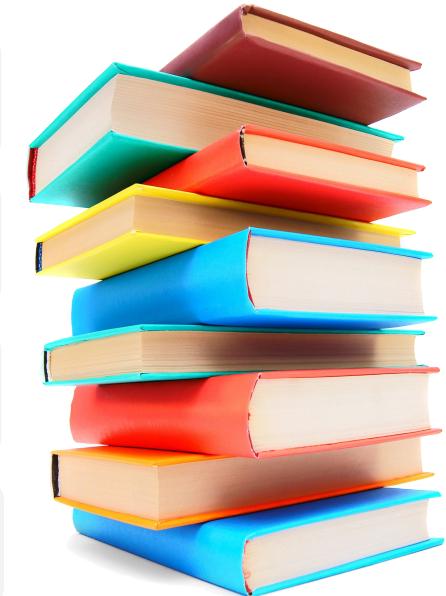
The difference is they **only allow access to the top element**.



These data structures obey “**LIFO**” (**last in, first out**). This means that new elements are placed at the top and removed from the top.

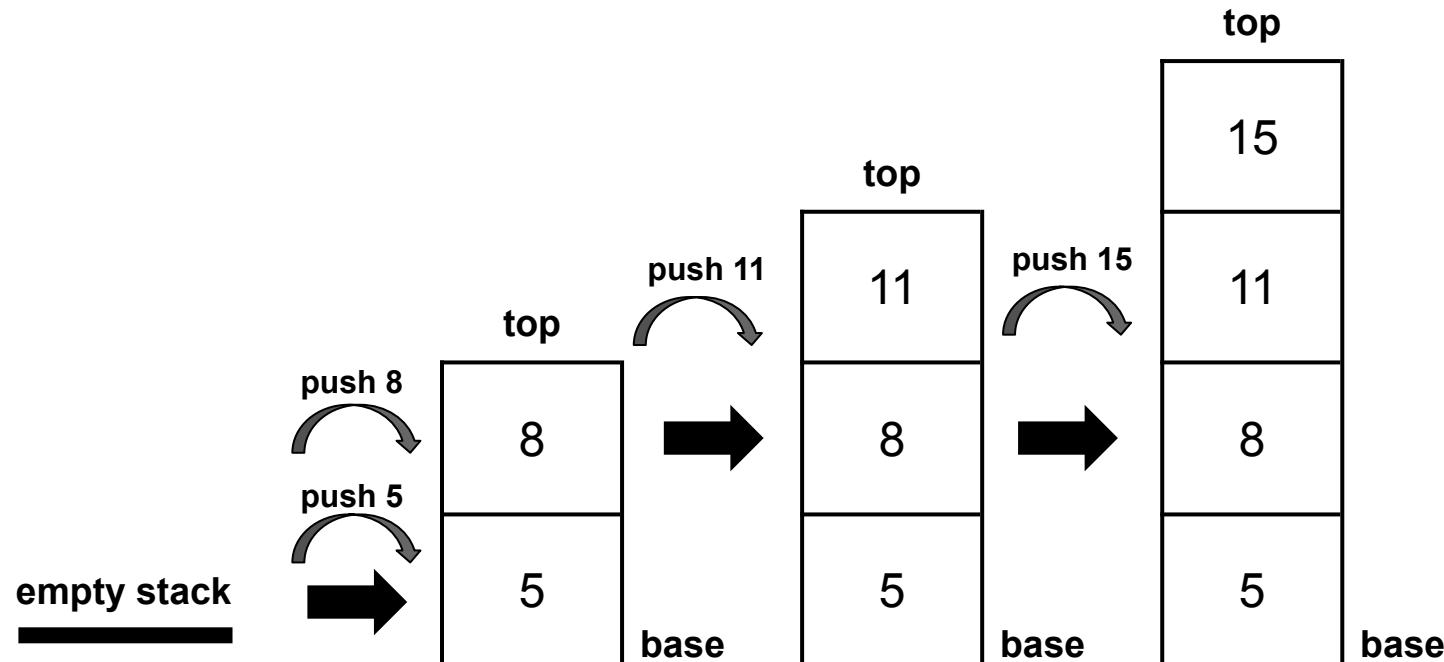


Stacks are an **abstraction** of how data can be arranged.



Stacks

Last in First Out: Items added to the top. Removed from the top



Stacks: In Code

“Stacks” aren’t supported natively in JavaScript.

To utilize this structure, one needs to create the class themselves.

Once you’ve created a class you can create and utilize these structures in your code.

```
class Stack {  
  constructor () {  
    this.items = [];  
  }  
  
  // Push, Pop, Peek  
  push(element){  
    this.items.push(element);  
  }  
  
  pop(element){  
    this.items.pop();  
  }  
  
  peek(){  
    return this.items[this.items.length-1];  
  }  
  
  isEmpty(){  
    return this.items.length;  
  }  
  
  clear(){  
    this.items = [];  
  }  
}
```

```
// Creates an instance of the Stack  
var newStack = new Stack()  
  
// Starts running methods  
newStack.push(1);  
newStack.push(2);  
newStack.push(4);  
  
console.log(newStack.peek());
```

Queue

Queues are another common data structure.



They are similar to arrays in that they are a sequenced order of numbers.



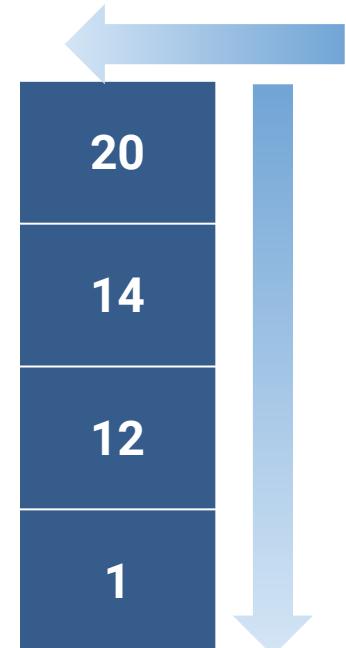
The difference is they **only allow access to the first element**.



These data structures obey **FIFO (first in, first out)**. This means that new elements are placed at the “back” but that the “first” element is removed from the front.



Queues are an **abstraction** of how data can be arranged.



Queue

Queues are best remembered as similar to a movie queue.
The first one in line is the first one to enter (or exit).



Queue: In Code

“Queues” aren’t supported natively in JavaScript.

Again, this means we need to create our own.

Queues provide two common methods: **enqueue** and **dequeue**.

```
// Creates the Queue Class for use later
class Queue {

  constructor() {
    this.items = [];
  }

  // Push, Pop, Peek
  enqueue(element) {
    this.items.push(element);
  }

  dequeue() {
    this.items.shift();
  }

  get first() {
    return this.items[0];
  }

  isEmpty() {
    return this.items.length === 0;
  }

  size() {
    return this.items.length;
  }
}
```

```
// Creates an instance of the Queue
var newQueue = new Queue();

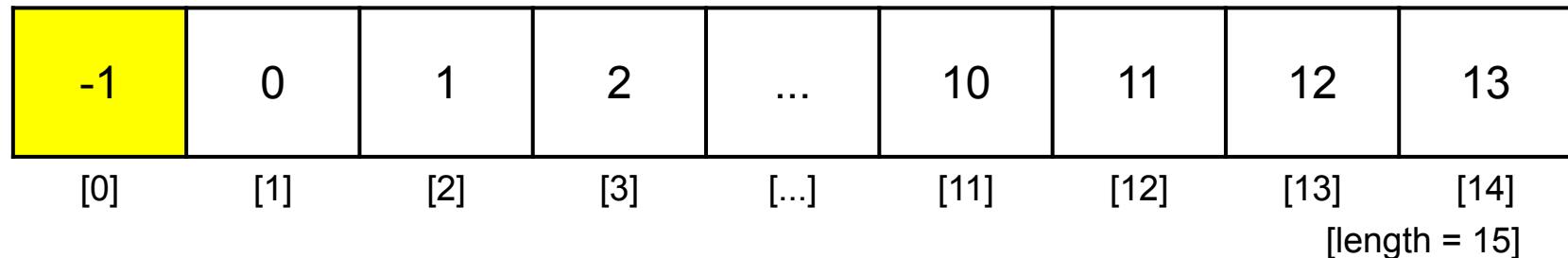
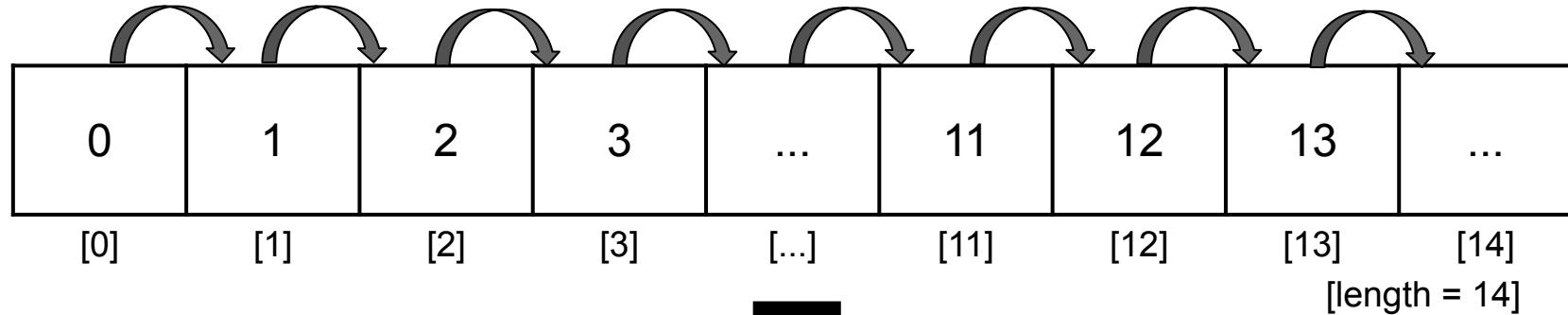
// Starts running methods
newQueue.enqueue("Ahmed");
newQueue.enqueue("Roger");
newQueue.enqueue("John");

console.log(newQueue.first);
```

Linked Lists

Arrays in JavaScript

An inefficiency emerges! We'll come back to this.



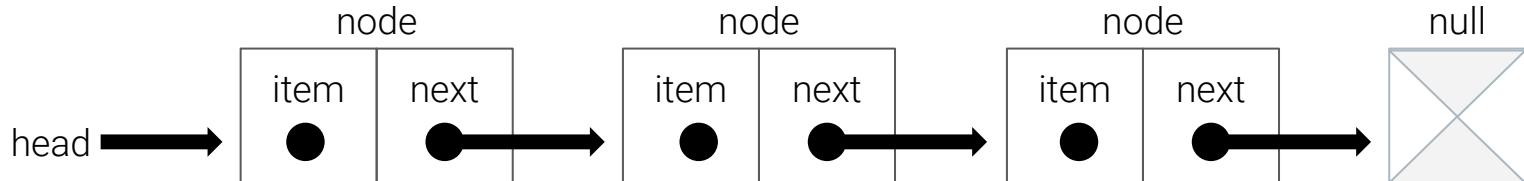
Linked Lists

Linked lists are data structures in which each element of the list is sequentially joined to the next element.

The major difference is that the list elements are not stored **contiguously** in memory (i.e., they fall in different memory slots).

These linked lists keep track of the position of elements using **pointers**, which explicitly point to the “connected item.”

Each element (called a **node**) tracks both the item’s and the next item’s position.



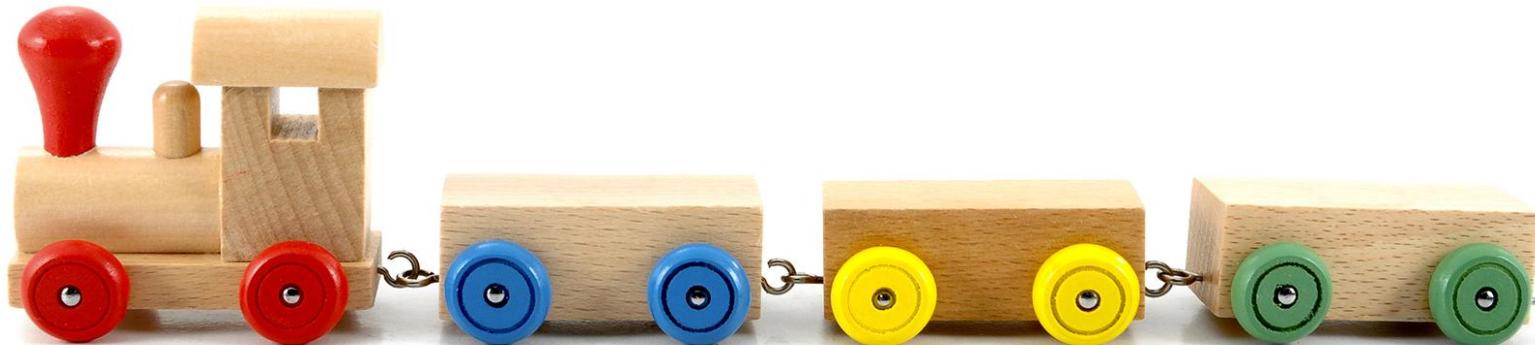
Linked Lists



Linked lists are like trains.



Each car in the train not only knows its own position but it also knows the position of the car in front of it.



Linked List: In Code

JS does not include linked lists natively, but when you need one, plenty of implementations are available online.

```
1  class Node {
2    constructor(data, next) {
3      this.data = data;
4      this.next = next;
5    }
6
7    getData() {
8      return this.data;
9    }
10
11   setData(data) {
12     this.data = data;
13   }
14
15   getNext() {
16     return this.next;
17   }
18
19   setNext(next) {
20     this.next = next;
21   }
22 }
23
24 class LinkedList {
25   constructor(dataArray) {
26     this.first = new Node();
27
28     var counter = 0;
29     if (dataArray) {
30       var actual = this.first;
31       for (var data of dataArray) {
32         var newNode = new Node(data);
33         actual.setNext(newNode);
```

Pulse Check

You Be the Teacher

To the person next to you, explain each of the following concepts:



What is a data structure?



What does FIFO and LIFO stand for and mean?



What is a stack?



What is a queue?



What is a linked list?



How are they each different from arrays?



What is one disadvantage of an array?



Most important question: why are we doing all this again?

Dictionaries (Maps)

Dictionaries (Maps): Actually Useful

Dictionaries are an incredibly important data structure. In fact, they address a common situation you've faced in this class.



How would you print all the pet names?

```
var myPets = {  
    cat: "Mr. Hyena",  
    lizard: "Mr. Big Big",  
    goat: "Wolf Who Ate Wall Street",  
    pigeon: "Joan"  
}
```

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```

Arrays don't solve the problem either:

```
var myPetAnimals = ["cat", "lizard", "goat", "pigeon"]  
var myPetNames = ["Mr. Hyena", "Mr. Big Big", "Wolf Who Ate Wall Street", "Joan"]
```

Dictionaries (Maps): Actually Useful

The solution is to use a dictionary (map).



In a way, dictionaries are like a hybrid of objects and arrays.



They can be iterated over like arrays.



They have key, value pairs like objects.



They're included in JavaScript ES6.

```
var map = new Map();

map.set("cat", "Mr. Hyena");
map.set("lizard", "Mr. Big Big");
map.set("goat", "Wolf Who Ate Wall Street");
map.set("pigeon", "Joan");

console.log(map.keys());
console.log(map.values());
console.log(map.get("pigeon"));
```



BIG DEAL!

Learn More About Dictionaries (Maps) in JS:

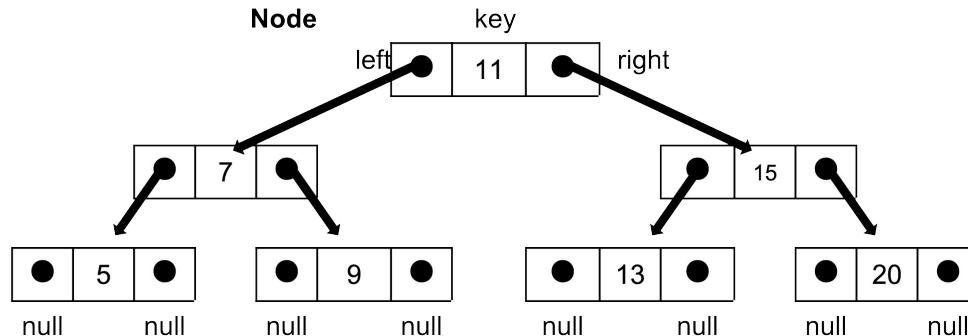
developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Map

Trees

Trees

Trees are a favorite data structure for computer scientists

- Trees are a non-sequential data structure made of parent-child relationships.
- The top node of a tree is the root.
- Trees have internal nodes and external nodes.
- Each node has ancestors and descendants.



Kind of like a linkedlist

Binary Trees

Binary Trees / Binary Search Trees (BST) are particularly useful



In a binary tree, nodes have two children at most: one on the left and the right.

In a Binary Search Tree:



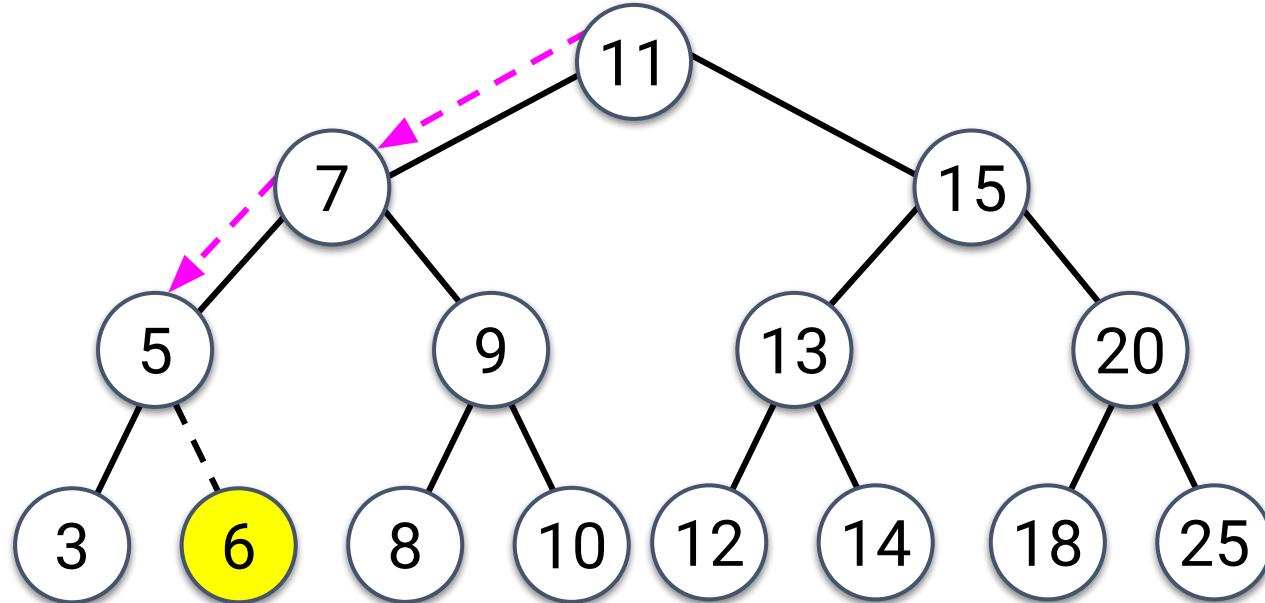
Left-hand side is lesser number; right-hand side is the larger



Paradigm makes it easy to insert, search, and delete from tree

Binary Trees

Binary search trees are extremely efficient for searching.

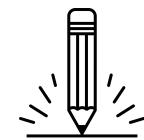
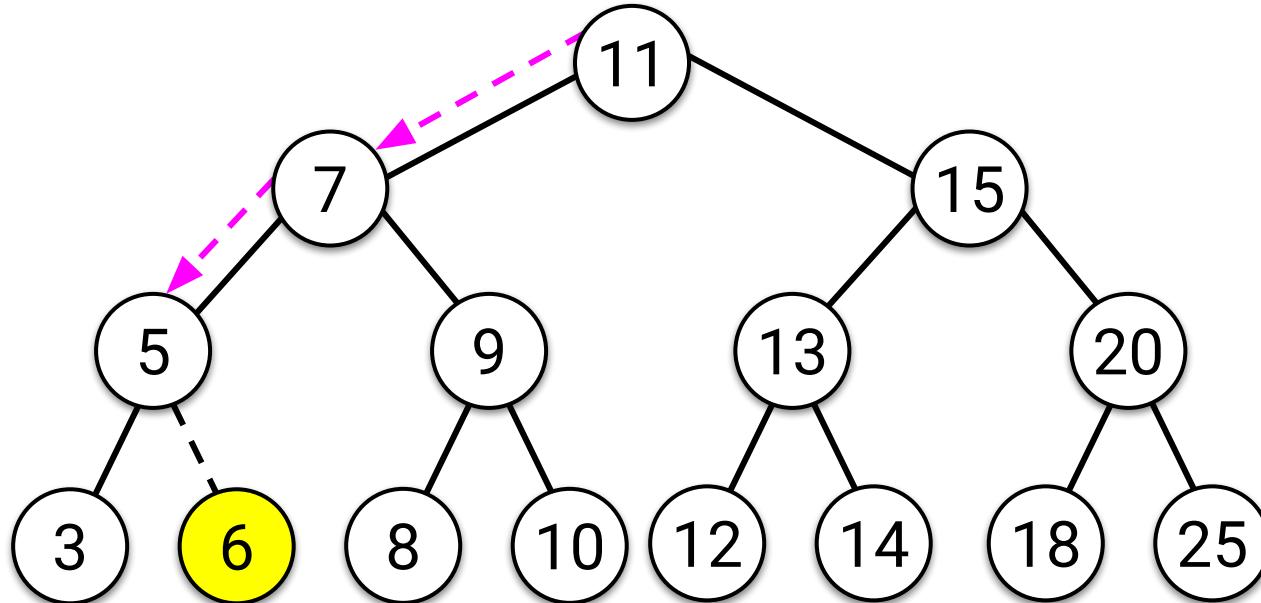


Binary Search Trees

npmjs.com/package/binary-search-tree

Activity: Let's Build This!

Take a few moments to build a binary search tree with those around you.
As a suggestion, implement the following tree.
Then run a search for any number in the tree.



Graphs

Graphs

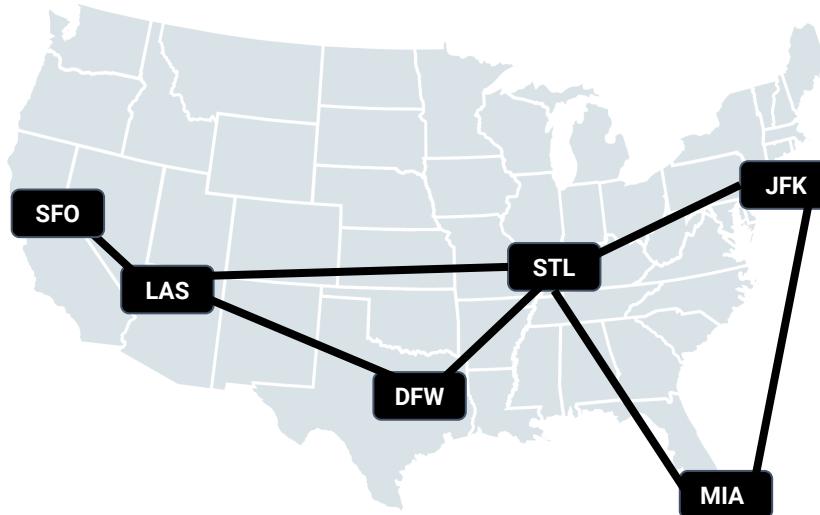
Graphs are extremely powerful and increasingly common structures.



Graphs are abstract models of a network structure. They are a set of nodes (or vertices) connected by edges.



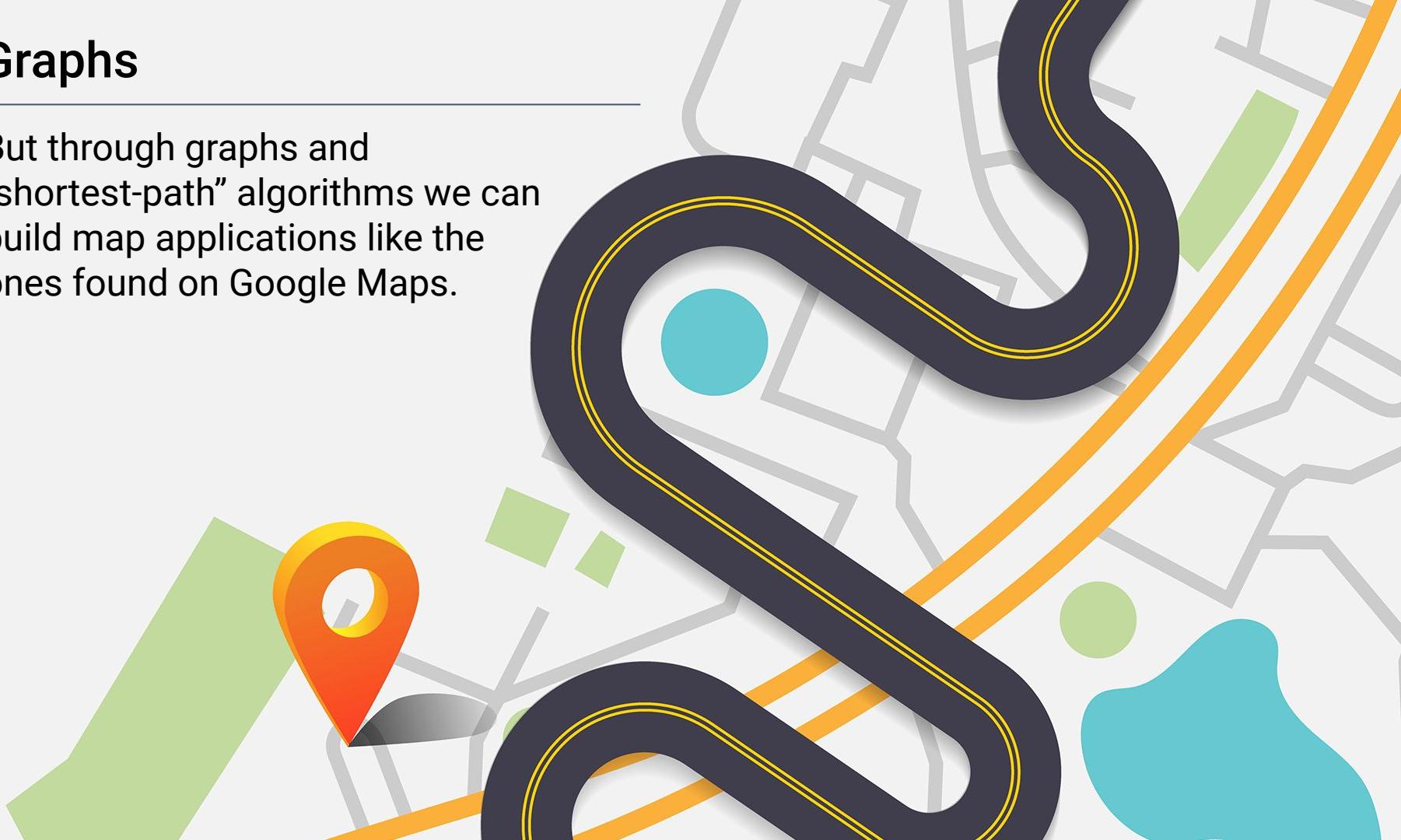
They are the essence of social networks and geographic maps.



The math gets ridiculously scary with this stuff.

Graphs

But through graphs and “shortest-path” algorithms we can build map applications like the ones found on Google Maps.



Back to Projects!

Questions?