CompSci – Data Structures

The Coding Bootcamp | July 8, 2017

Outline

- Project Check-In
- Computer Science Context
- Big O Notation
- Data Structures
  - Arrays
  - Stacks / Queues
  - Linked Lists
  - Dictionaries
  - Hash Tables
  - Sets
  - Binary Trees and Binary Search Trees
  - Graphs

Project Check-In

Project Status?

Smooooooth Sailing?

Project Check-In

Remember!

Deliverable #2 is due today by the end of class.

Please send the following to your Instructor + TAs:

- Prototype of application key features

Submit by the end of the day (9:00 PM)!

Computer Science Context

Welcome To…

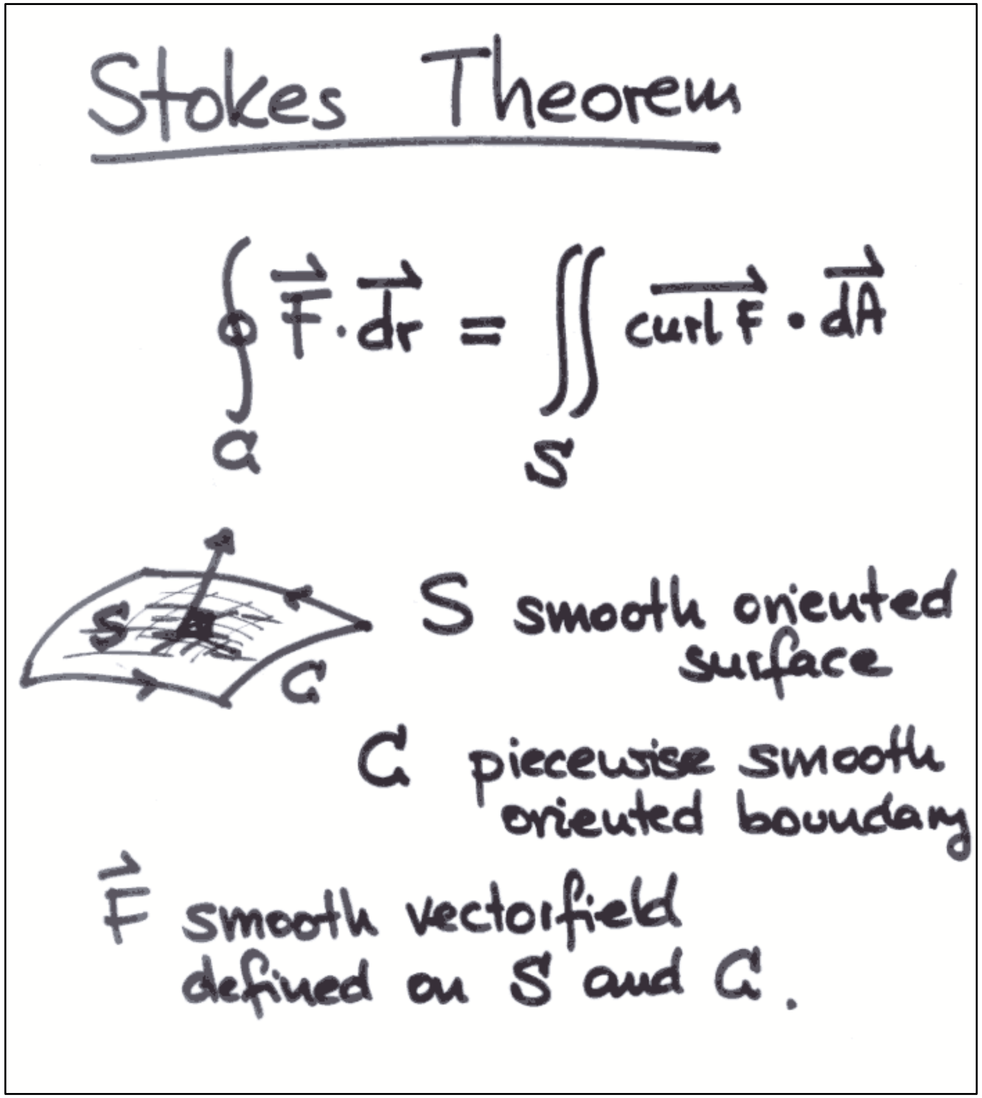
“Computer Science Fundamentals”

Remember…

Computer Science "Fundamentals"

- Isn't about "easy" computer science stuff.
- Rather, it's about 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.

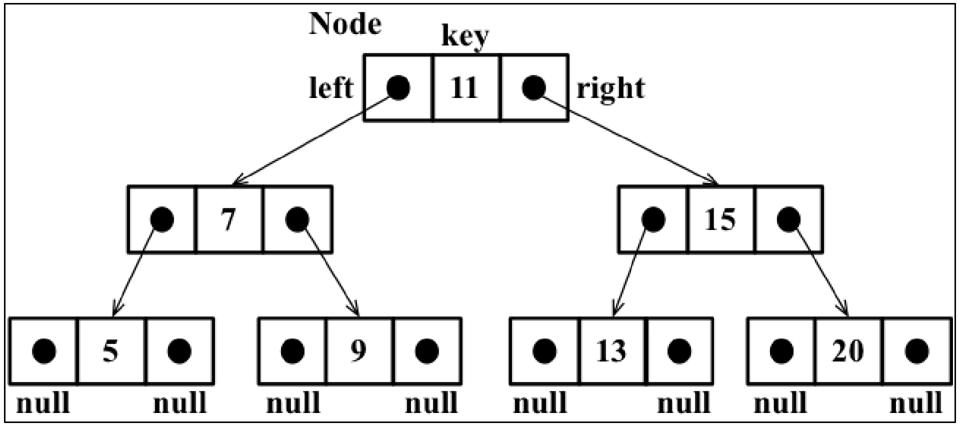
“Fundamentals”



Remember this stuff?

Yeah. Me neither.

It gets hairy… and scary.




```
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}
}
```

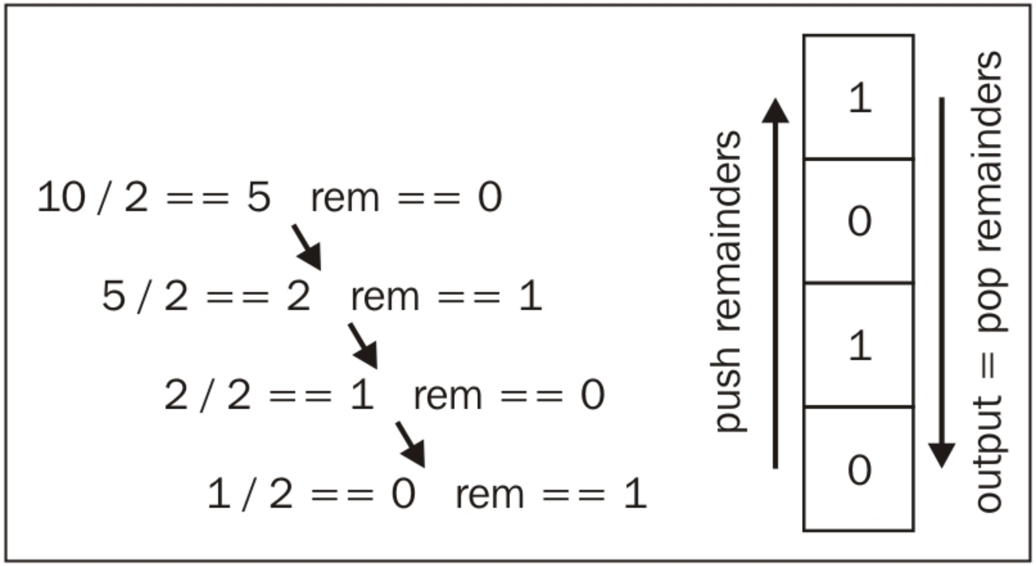
```
function divideBy2(decNumber){

  var remStack = new Stack(),
  rem,
  binaryString = '';

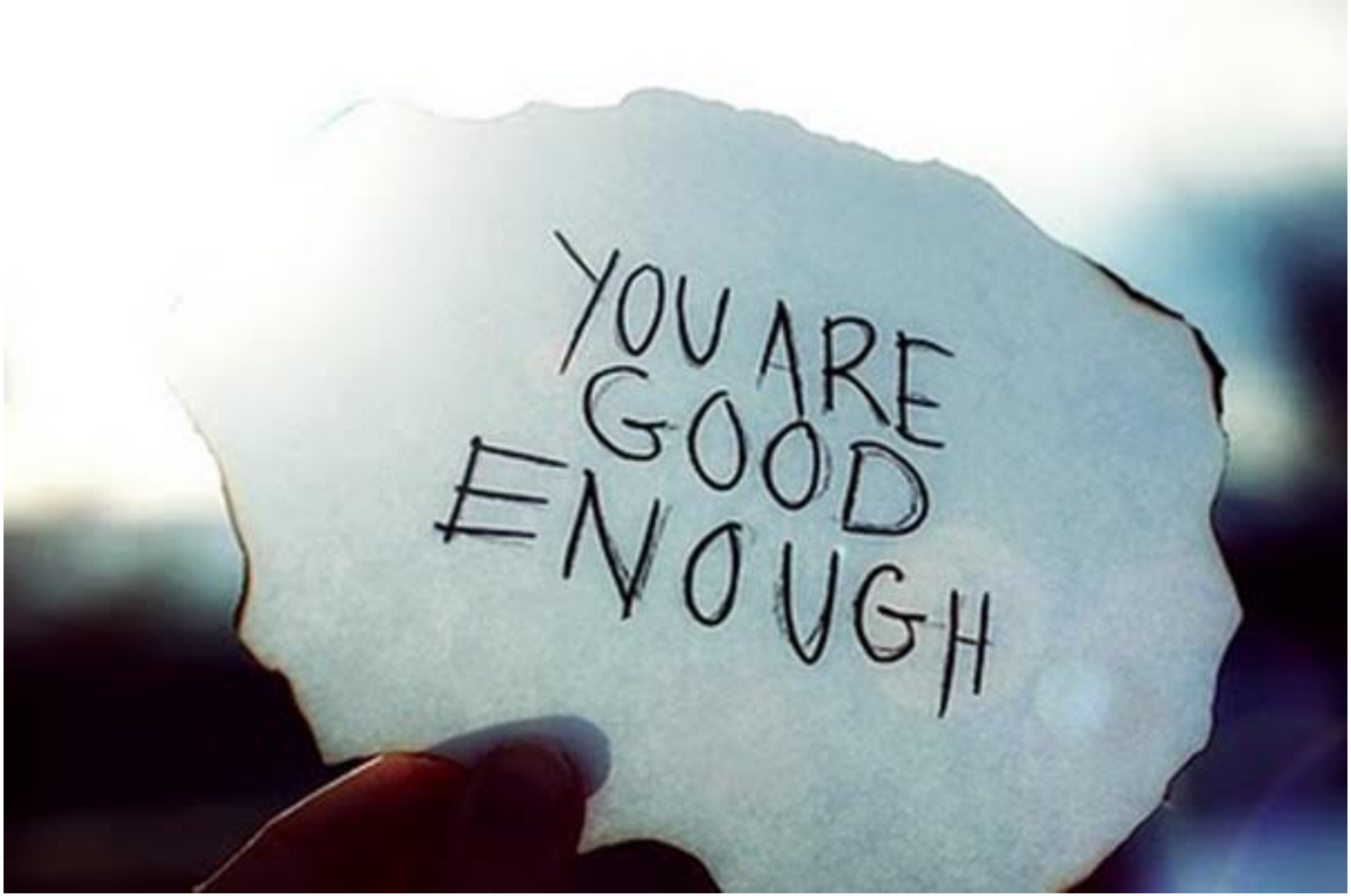
  while (decNumber > 0){ //{1}
    rem = Math.floor(decNumber % 2); //{2}
    remStack.push(rem); //{3}
    decNumber = Math.floor(decNumber / 2); //{4}
  }

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

  return binaryString;
}
```



Be Wary of Imposter Syndrome!



Don’t let the hard stuff scare you…

Why Cover This?

1. These concepts sometimes appear in **coding interviews**

2. When inheriting large code-bases you may be tasked to “**optimize” code efficiency.**

3. The computational challenges here forces you to **deepen your understanding**.

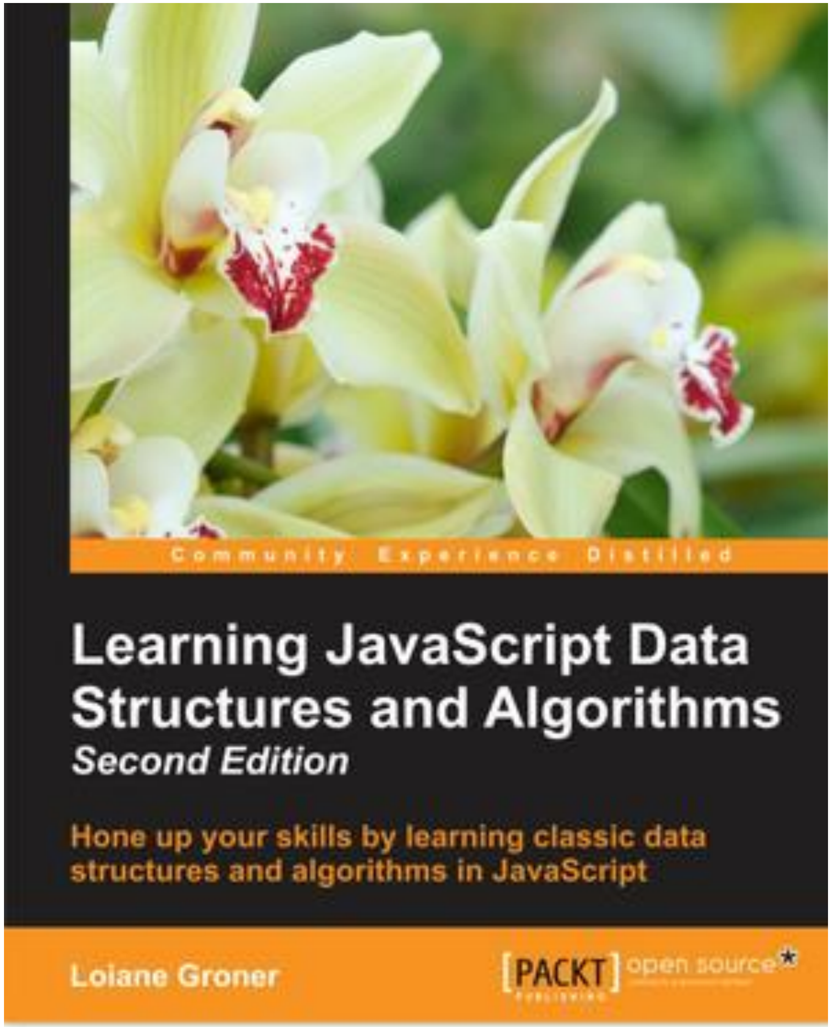
Bottom Line

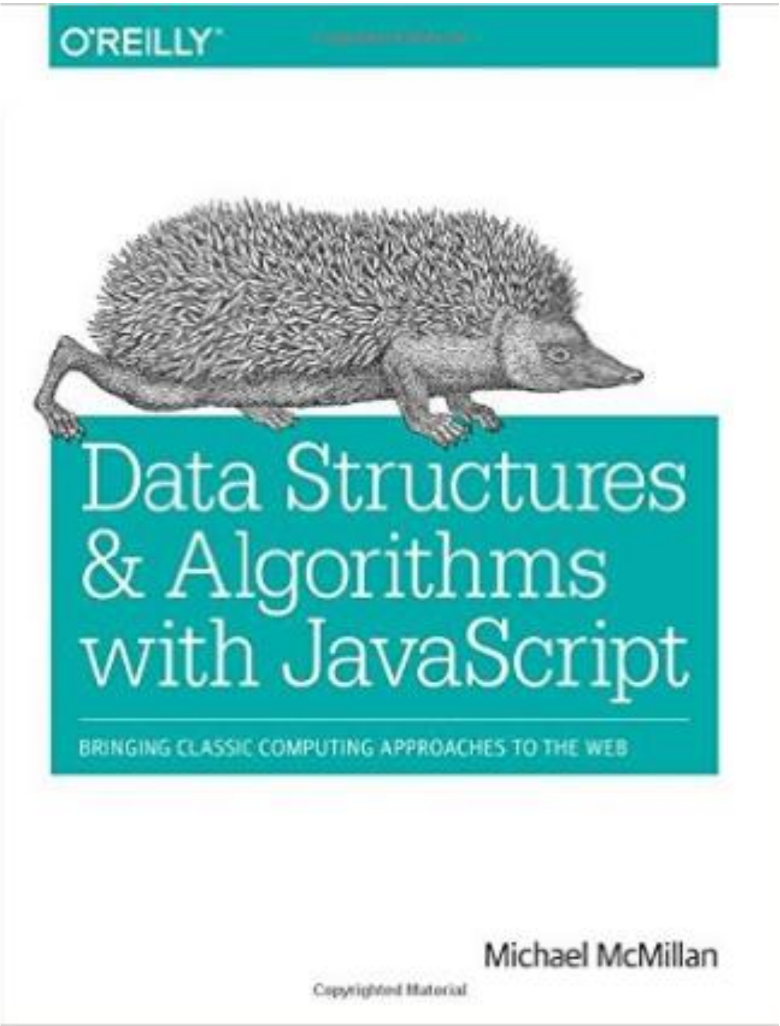
My goal is to give you the <u>terminology</u> and the <u>concepts.</u>

Enough insight that you can understand the context of interview questions that come your way.

And… to encourage those of you into math to take a second look.

Going Deep





For those that dare dive deeper.

Efficiency

What does “efficient” mean?

We talk a lot about “efficiency”.

What does “efficient” mean?

But…

What does “efficient” mean?

What, *exactly*, does “**efficient**” mean?

Fewer Steps = Faster Code

Number of steps ~ Efficiency

Fewer Steps = Faster Code

More steps = Less Efficient

Fewer Steps = More Efficent

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

Pop Quiz (!)

Which function is more efficient?

```
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];
}
```

(Which has fewer instructions?)

Count Instructions

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_names` isn't bad…

Time Complexity

Quantifying Efficiency

`head` ***always*** executes one instruction…

Quantifying Efficiency

…No matter how long our array is

Quantifying Efficiency

```
// 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) );
```

`head` takes same amount of time on **any** input

Quantifying Efficiency

`list_items` needs `n` instructions

Quantifying Efficiency

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

One `console.log` **per item**

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

In other words…

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

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

Time complexity = Rate at which algorithm **slows** as input **grows**

Quantifying Efficiency

`head` is **always** one instruction

Quantifying Efficiency

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

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 **increase 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*)

- 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

There are other Big O “classes”

Big O

```
function find_duplicates (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

Running time grows as *square* of input

`find_duplicates` ~ $O(n^2)$

"***Quadratic*** time complexity"

<u>MAJOR INSIGHT</u>

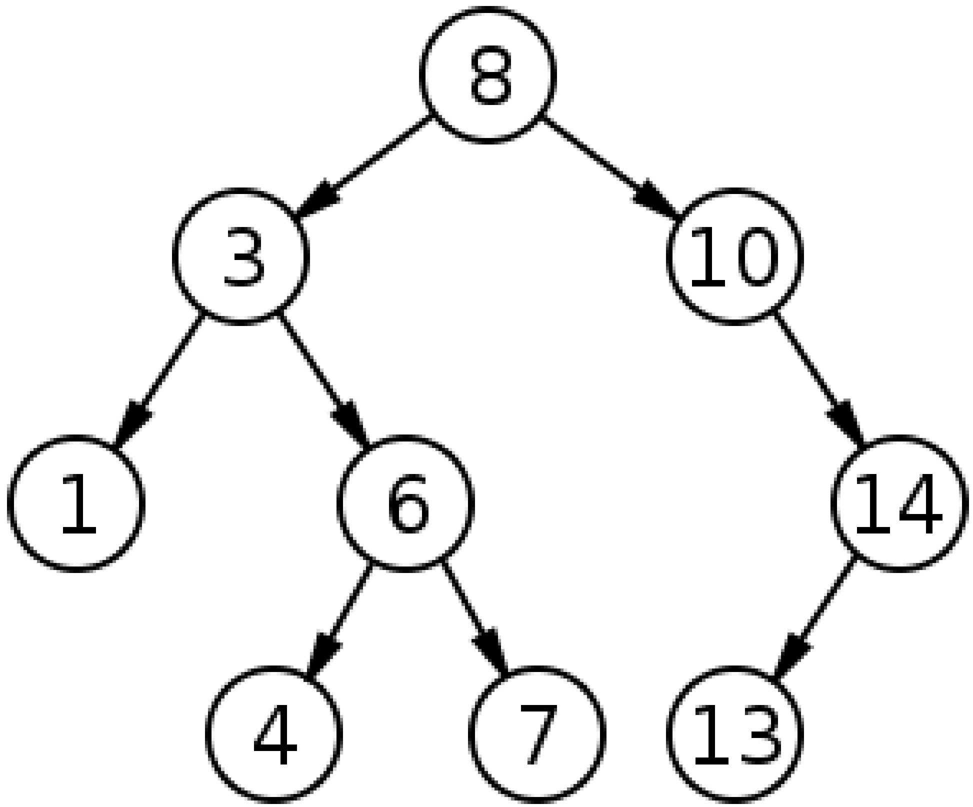
2 nested `for` loops ~ $O(n^2)$

NOT COINCIDENCE!

3 nested `for` loops ~ O(n^3)

Etc.

One more…



How fast is binary search?

Is it…

- $O(1)$
- $O(n)$
- $O(n^2)$
- Something else?...

Something else.

Why?

Exercise

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

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

Count the steps.

Big O

3 steps.

Add the digits 11-20. Repeat.

4 steps (!)

<u>Much</u> faster than linear.

(input size)^2 ~ 2x running time

(input size)^3 ~ 3x running time

Etc.

This is called O(lg n).

lg n = how many times do I divide n by two to get to 1?

Logarithm Example

What is lg 8?

Logarithm Example

8 / 2 = 4 (1)
4 / 2 = 2 (2)
2 / 2 = 1 (**3**)

Logarithm Example

$$\lg 8 = 3$$

But if this is confusing…

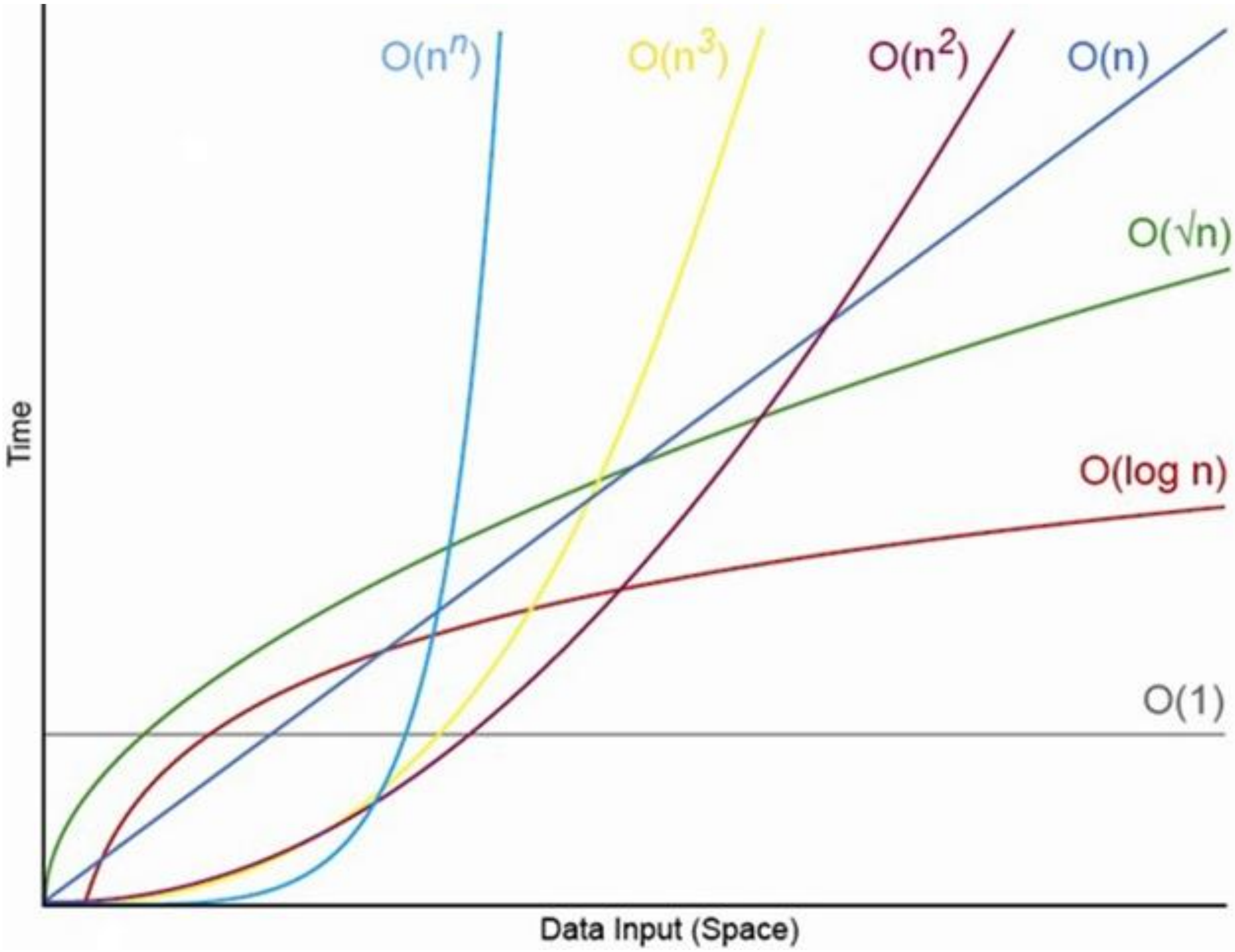
Logarithm Example

Don't worry about it.

Big O Review

- `head` ~ O(1)
  - Grows like "1"—i.e., 2x input size -> 1x running time
- `list_items` ~ O(n)
  - Grows like "n"—i.e., 2x input size -> 2x running time
- `find_duplicates` ~ O(n^2)
  - Grows like "n^2"—i.e., 2x input size -> 4x running time
- `binary_search` ~ O(lg n)
  - Grows like "lg n"—i.e, $(\text{input size})^2$ -> 2x running time

Big O Comparisons



Data Structures

Data Structures? (Tricky Question)

What is a data structure?

(And what is an example?)

Data Structures? (Tricky Question)

Before we answer that…

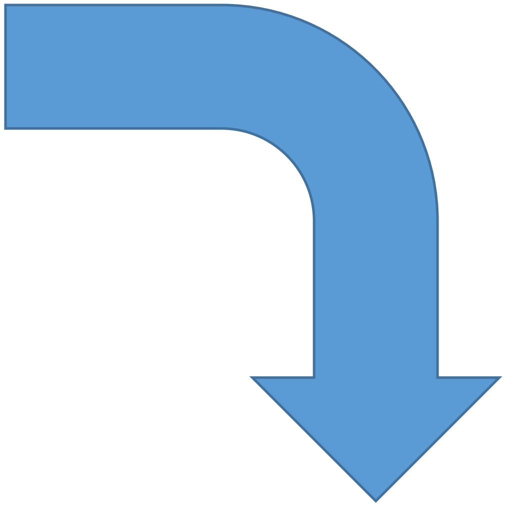
Code = Data. Data is Saved.

Code we write…

```
var name = Ahmed
```

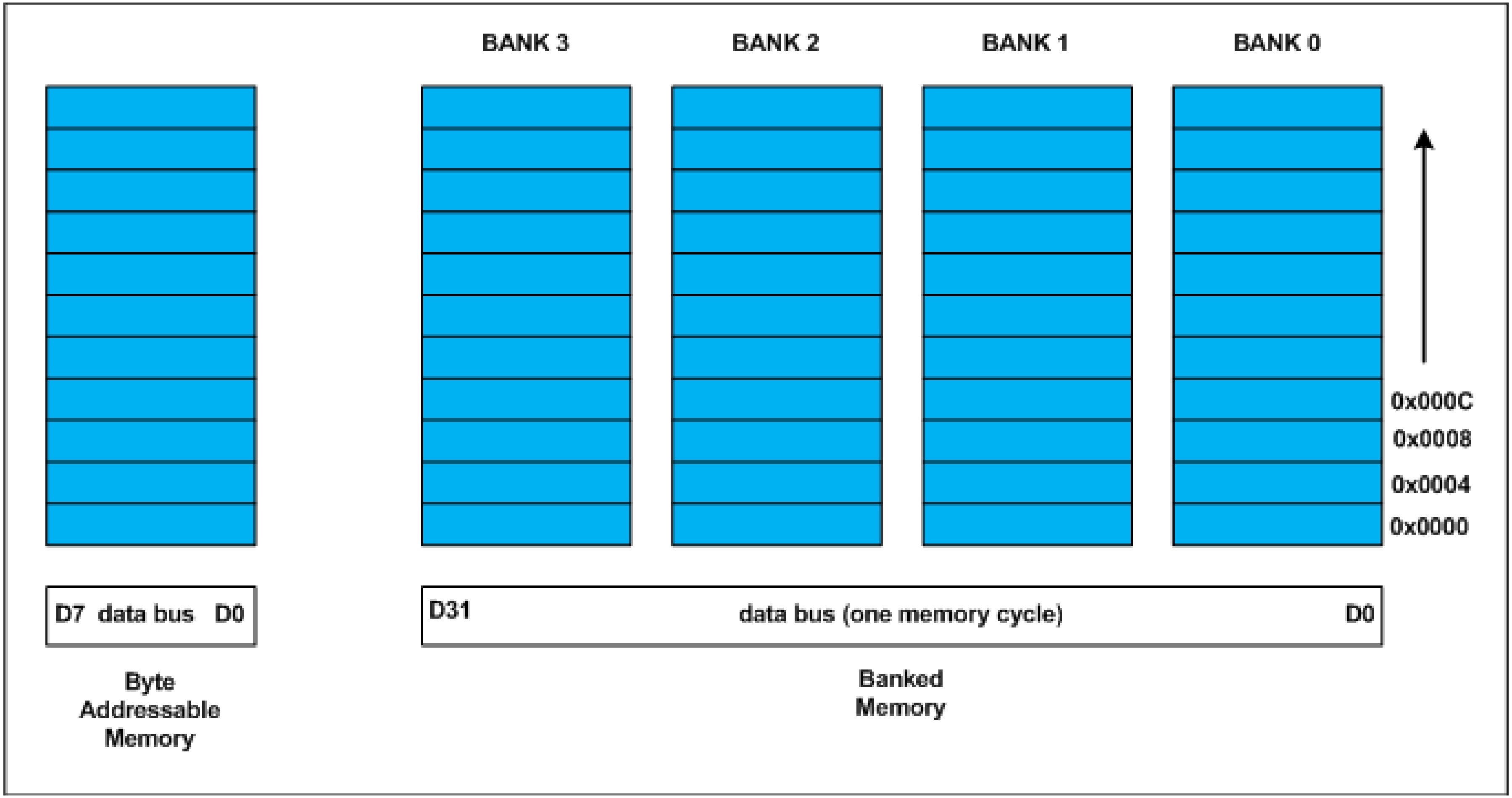
```
var age = 82
```

```
var isCool = true
```



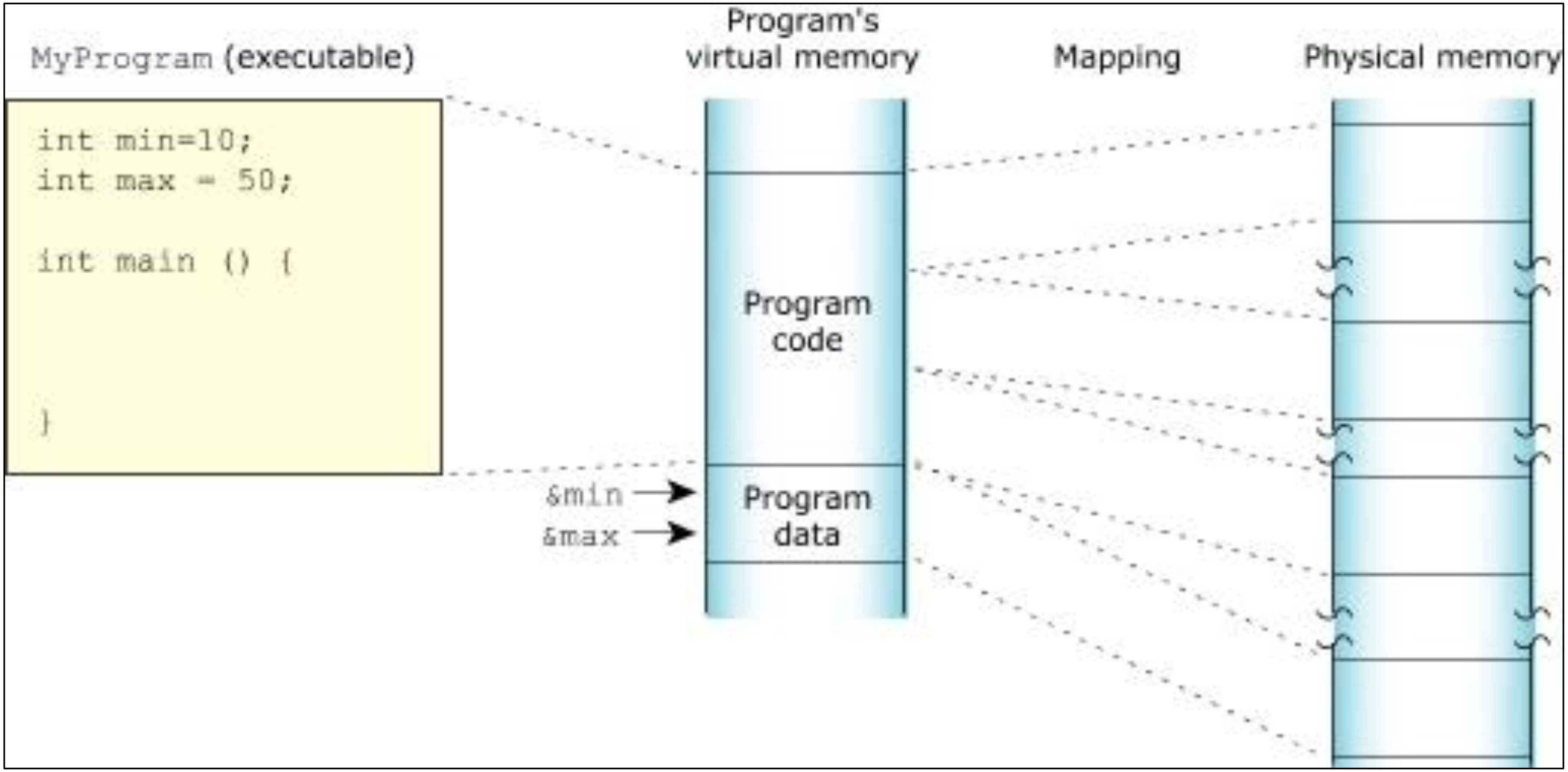
Gets saved in memory…

Different Ways to Save…



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

Memory on My Mind



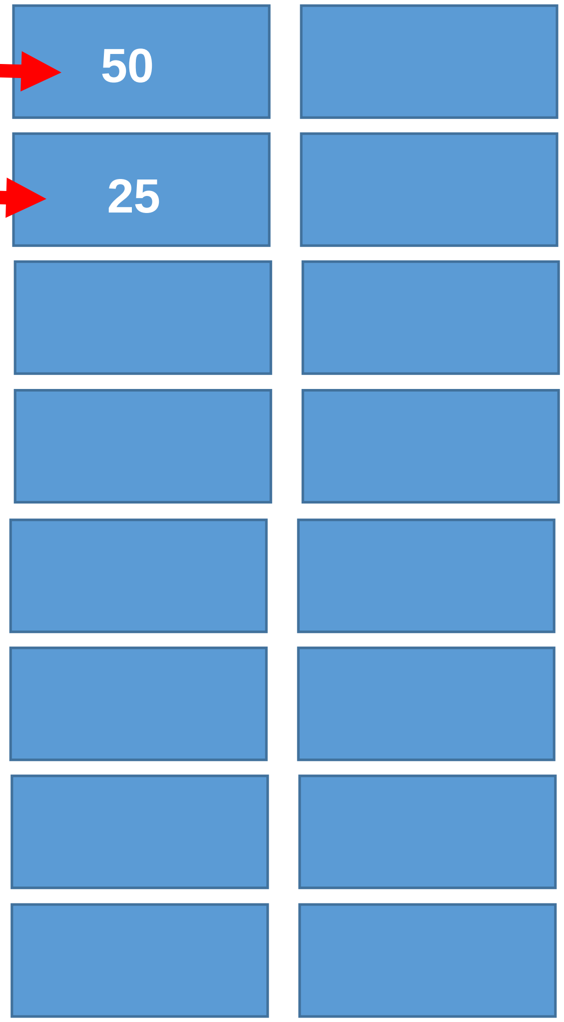
- Our code as a whole takes some of these slots of memory.
- Our variable data itself also takes slots of memory.

Saving to Memory…

Code

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

Memory



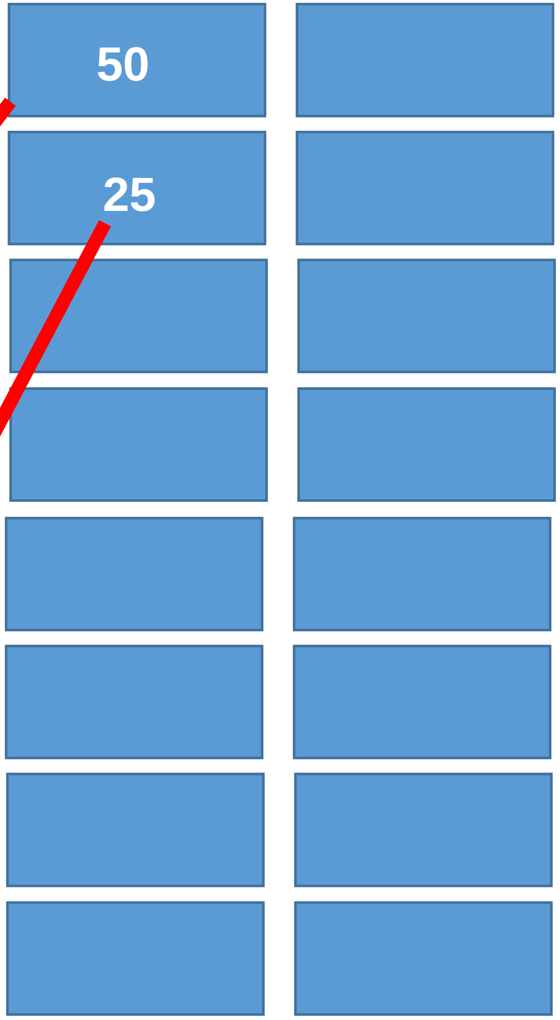
Each time we declare or instantiate a variable, we are **saving** that data to memory.

Retrieving from Memory…

Code

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

Memory



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

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

Growing Data = Growing Problem

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

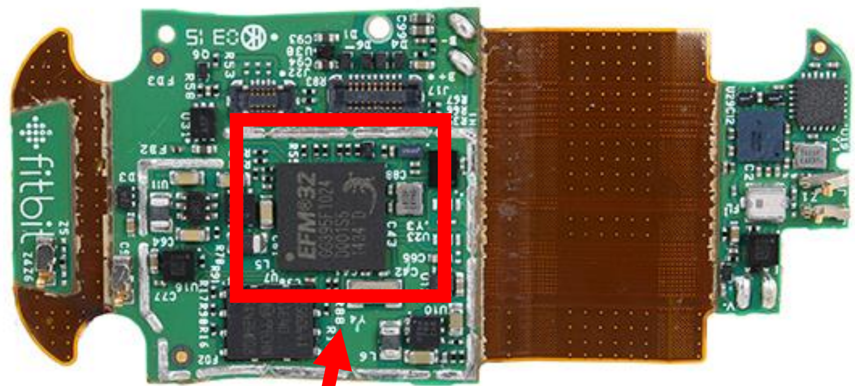
- These simple operations of saving, retrieving, etc.

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

- ***Don’t let the simplicity fool you!***

Building Devices

<u>Fitbit Surge</u>



You have 1 MB. Use it wisely

<u>Devices inherently have limited memory because of space requirements – making efficiency decisions critical</u>

Retrieving from Memory…

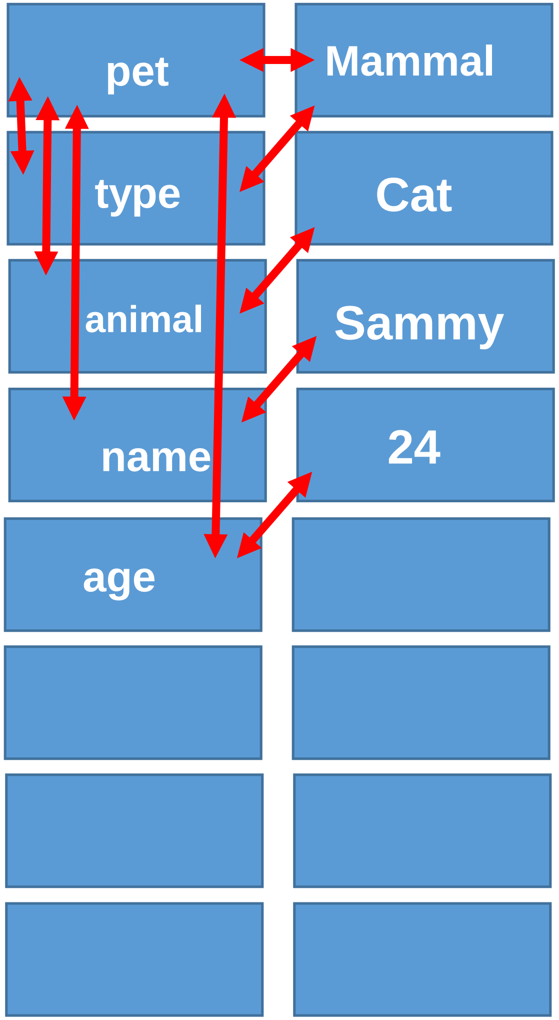
Code

```
var pet = {

    type: "Mammal",
    animal: "Cat"
    name: "Sammy",
    age: 24
}
```

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

Memory



What is a data structure?

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

<u>What is a data structure?</u>

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

What is a data structure?

They are non-opinionated, in the sense, that they are just responsible for holding the data.

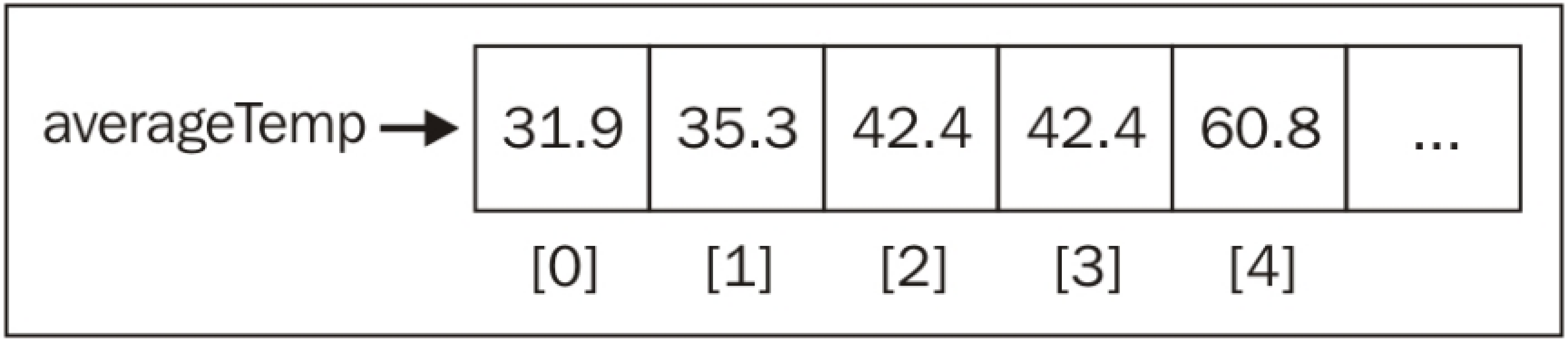
Example Data Structure:

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)

```
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().**

<u>Question for You</u>

.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

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

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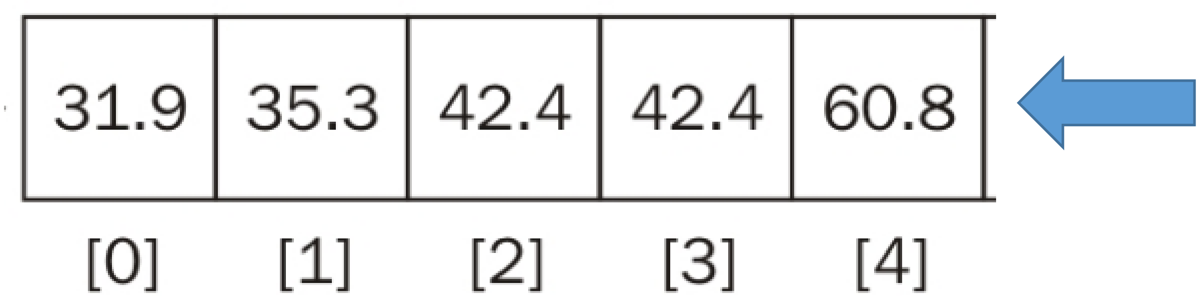
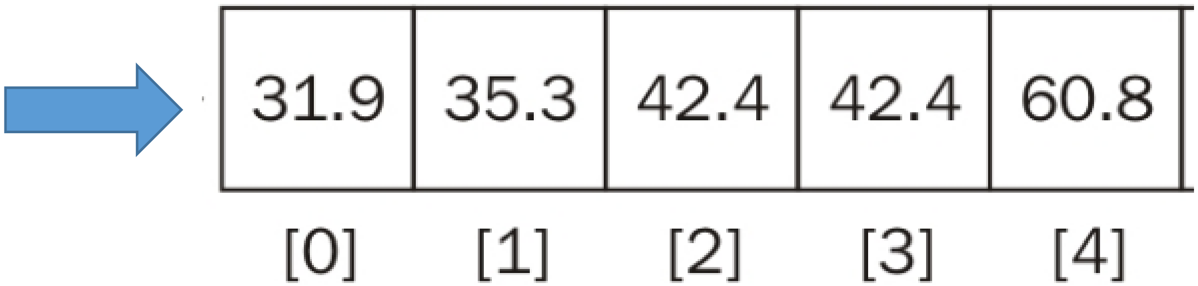


2nd Question for You

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



If you finish early, implement it yourself.

(i.e. Don’t use the in-built method).

Arrays in Javascript

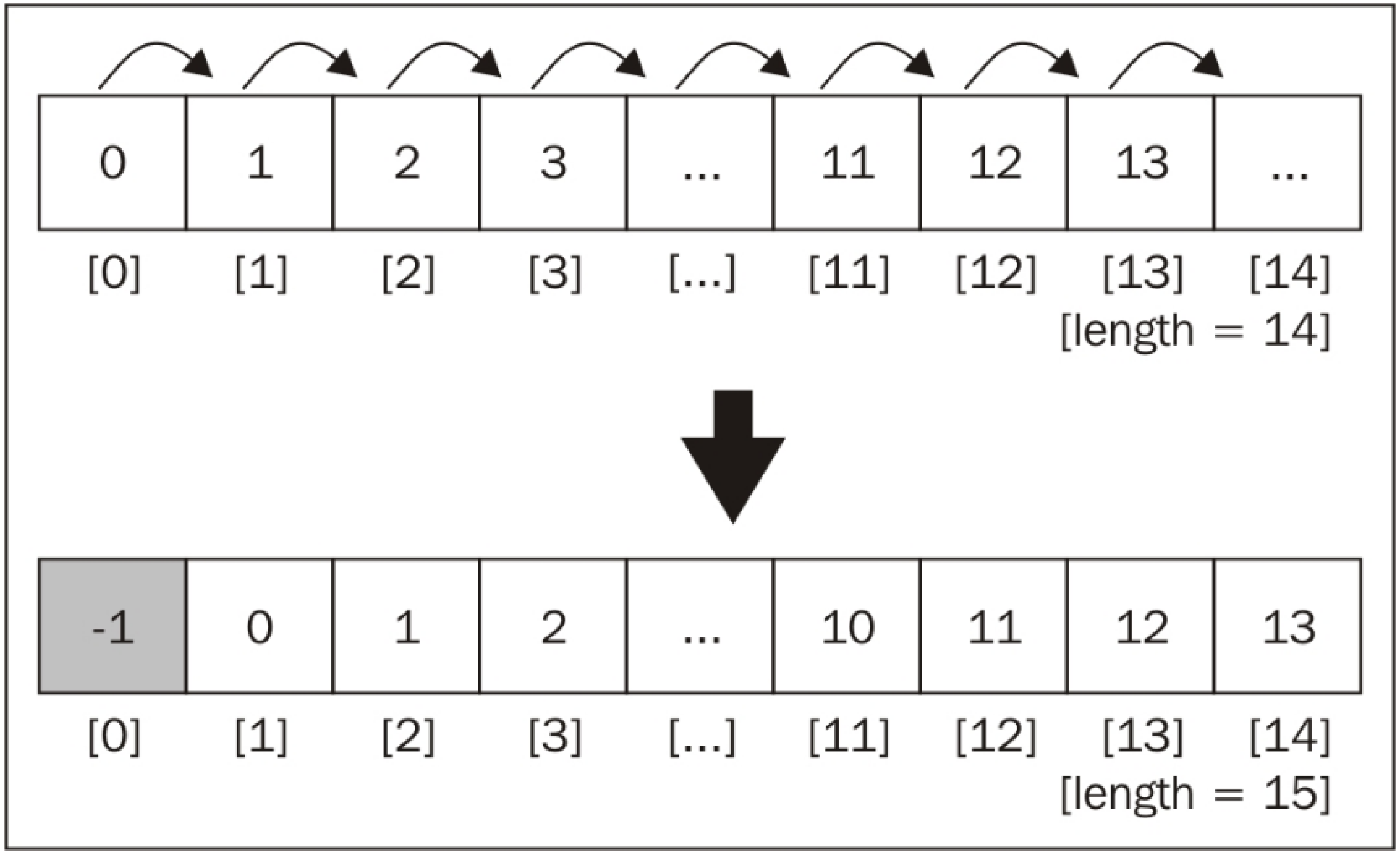
Unshift Method

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

What's really happening…

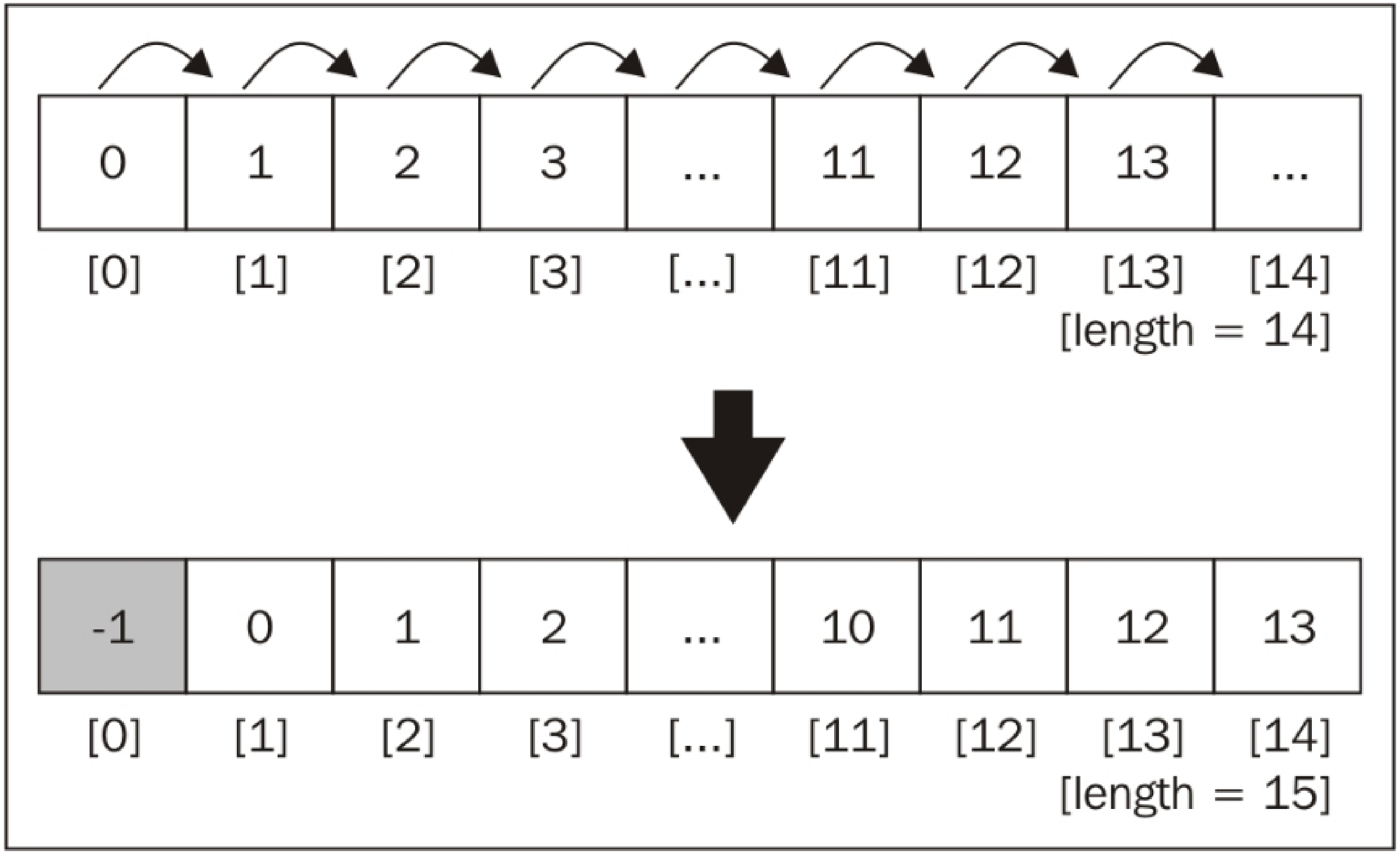
```
for (var i=myArray.length; i>=0; i--){
  myArray[i] = myArray[i-1];
}
myArray[0] = -1;
```

An inefficiency emerges!



An inefficiency emerges!

We'll come back to this.



Stacks / Queues

Going forward, treat each of the following data structures as <u>concepts.</u>

These are paradigmatic ways of organizing data that are commonly seen in code.

Stacks

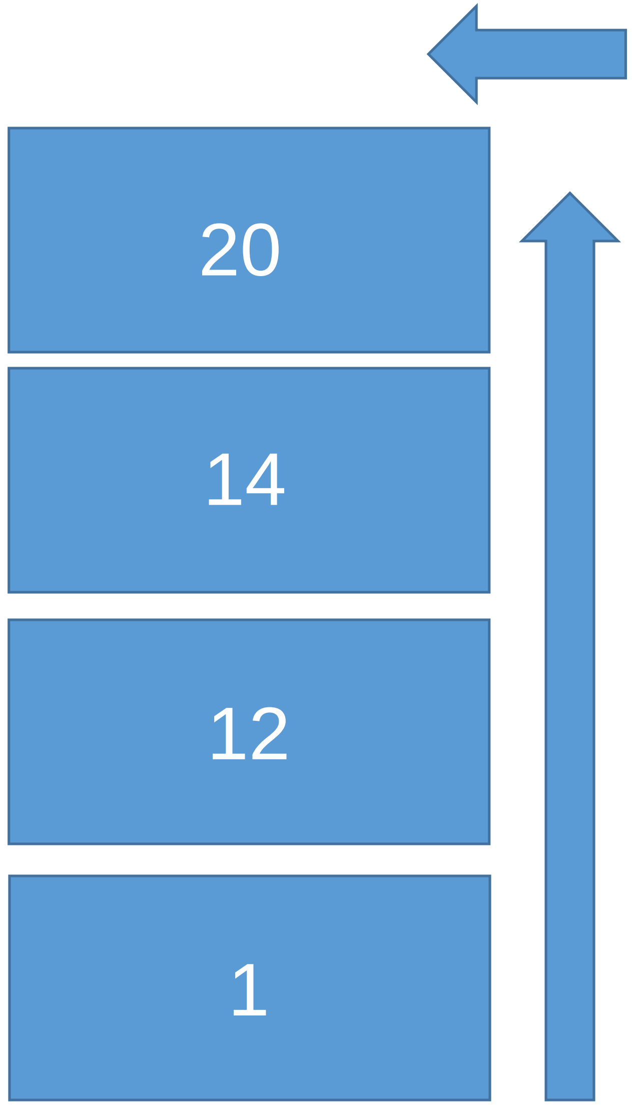
Stacks are another common data structure.

- 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** for how data can be arranged.*



Stacks

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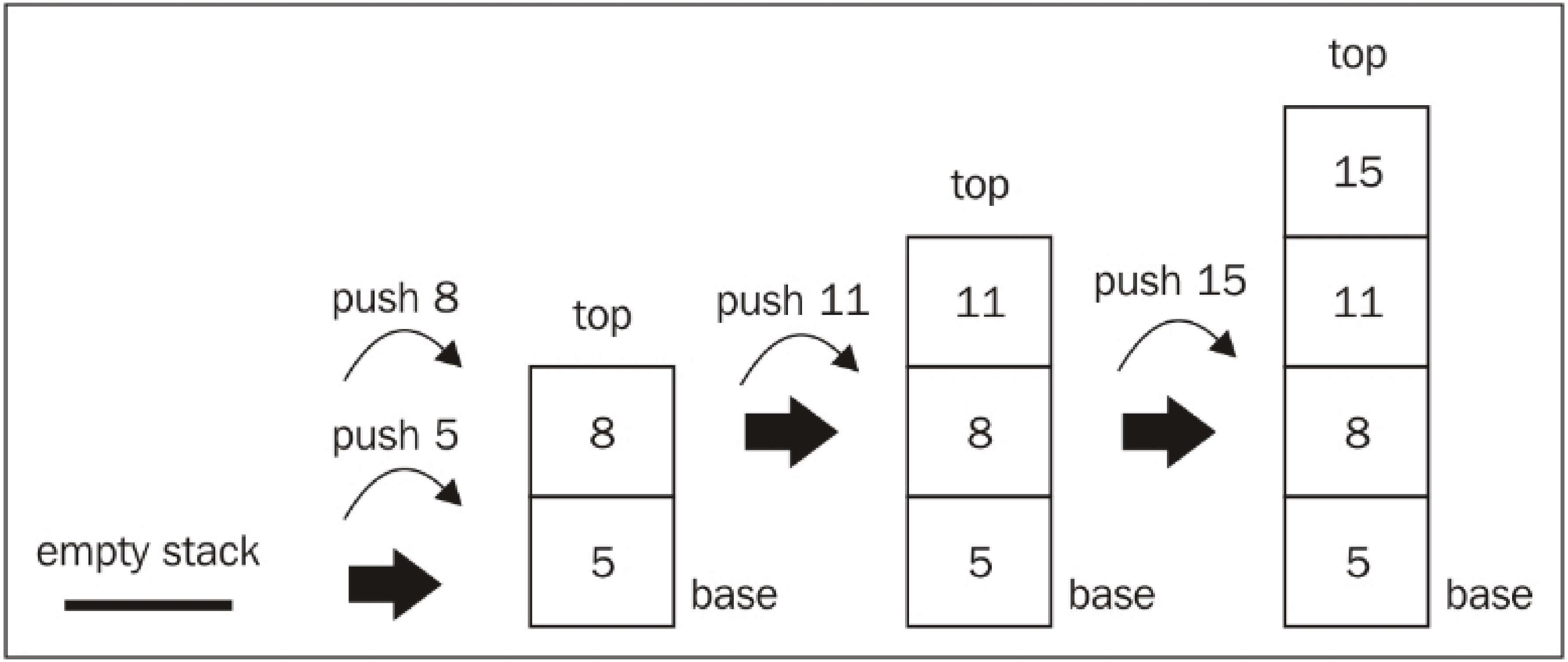
- These data structures obey **<u>"LIFO" (Last-in-first-out)</u>.** This means that new elements are placed at the top and removed from the top.
- <u>*Stacks are an **abstraction** for how data can be arranged.*</u>

Stacks



Last in First Out:

Items added to the top. Removed from the top

Stacks – In 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 = [];
  }

}
```

- “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.

```
// Creates an instance of the Stack
var newStack = new Stack()

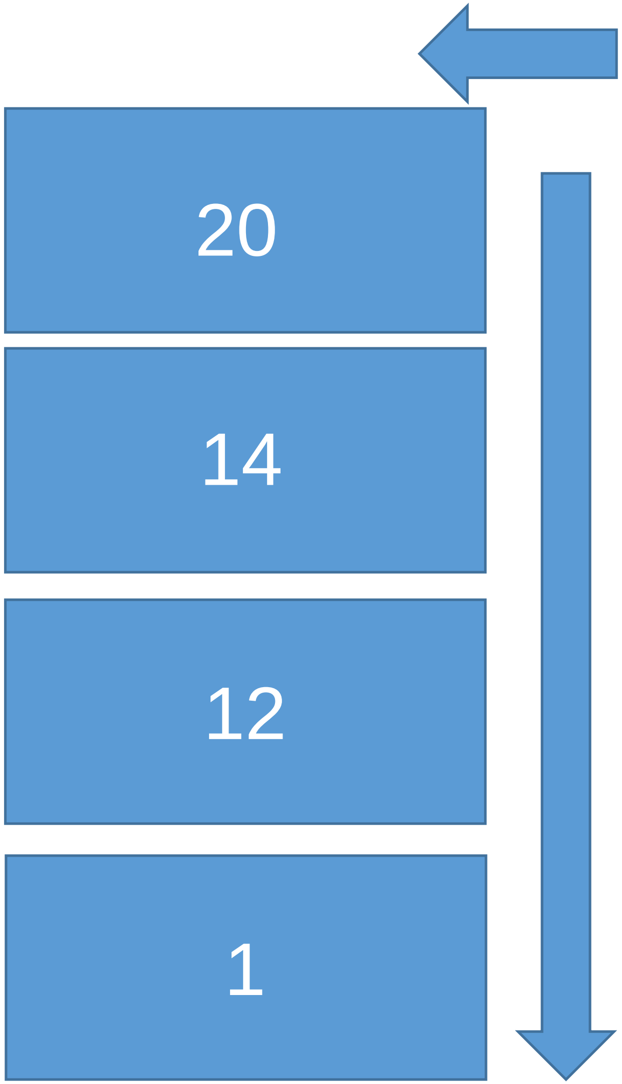
// Starts running methods
newStack.push(1);
newStack.push(2);
newStack.push(4);

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.
- *Queue are an **abstraction** for 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

```
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 = [];
  }

}
```

- "Queues" aren't supported natively in Javascript.
- Again, this means we need to create our own for use.
- Queues provide two common methods: **enqueue** and **dequeue**.

```
// Creates an instance of the Stack
var newStack = new Stack()

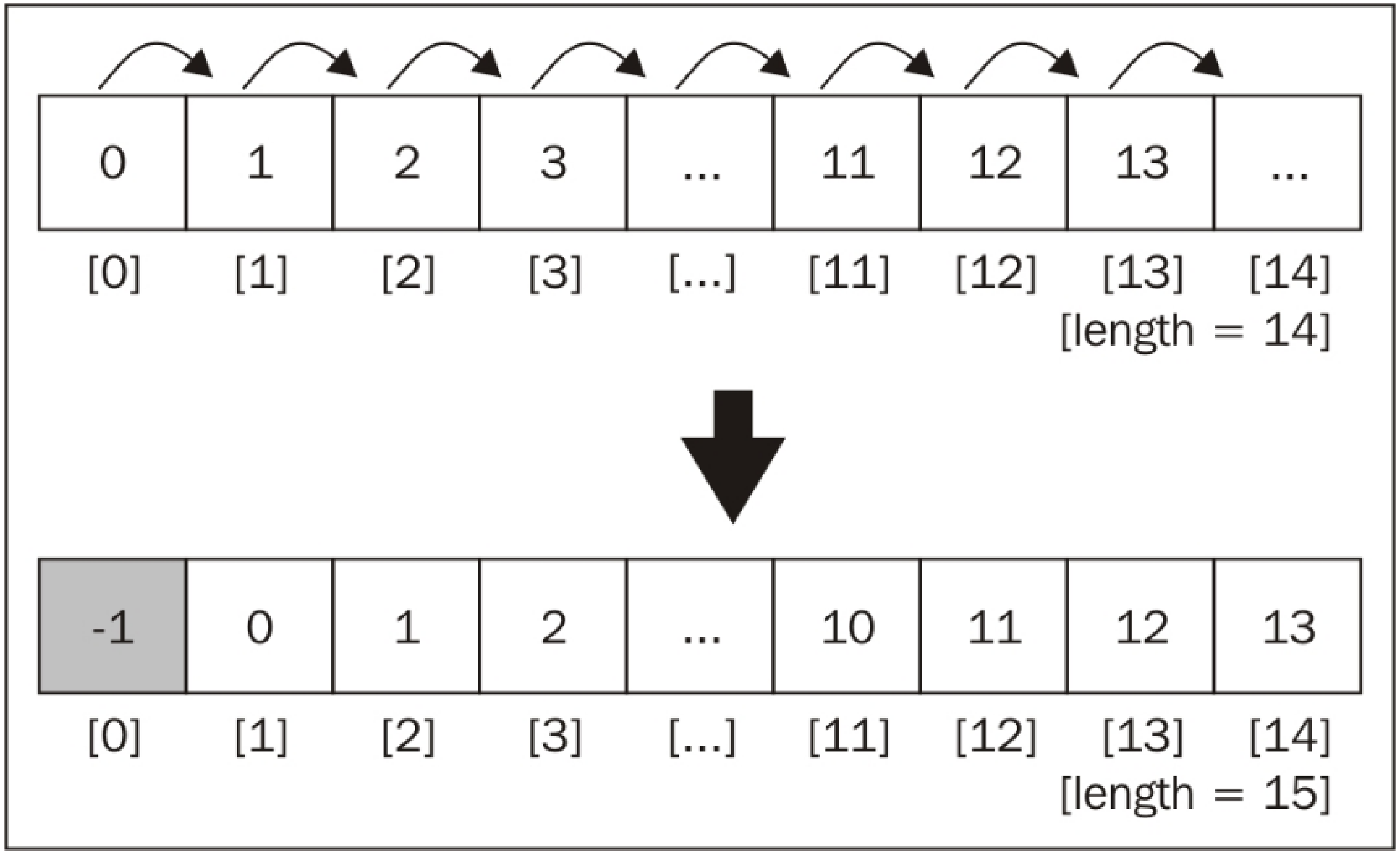
// Starts running methods
newStack.push(1);
newStack.push(2);
newStack.push(4);

console.log(newStack.peek());
```

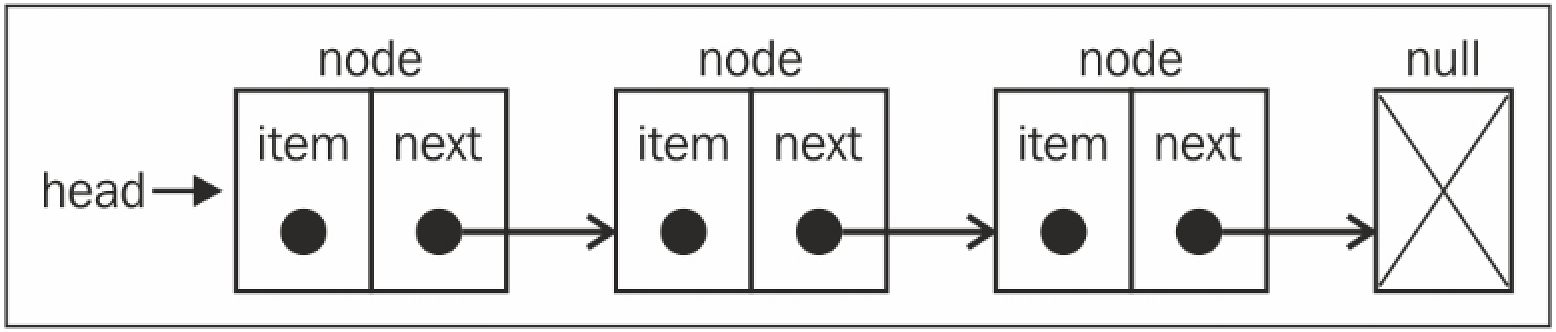
Linked Lists

An inefficiency emerges!

We’ll come back to this.



Linked List



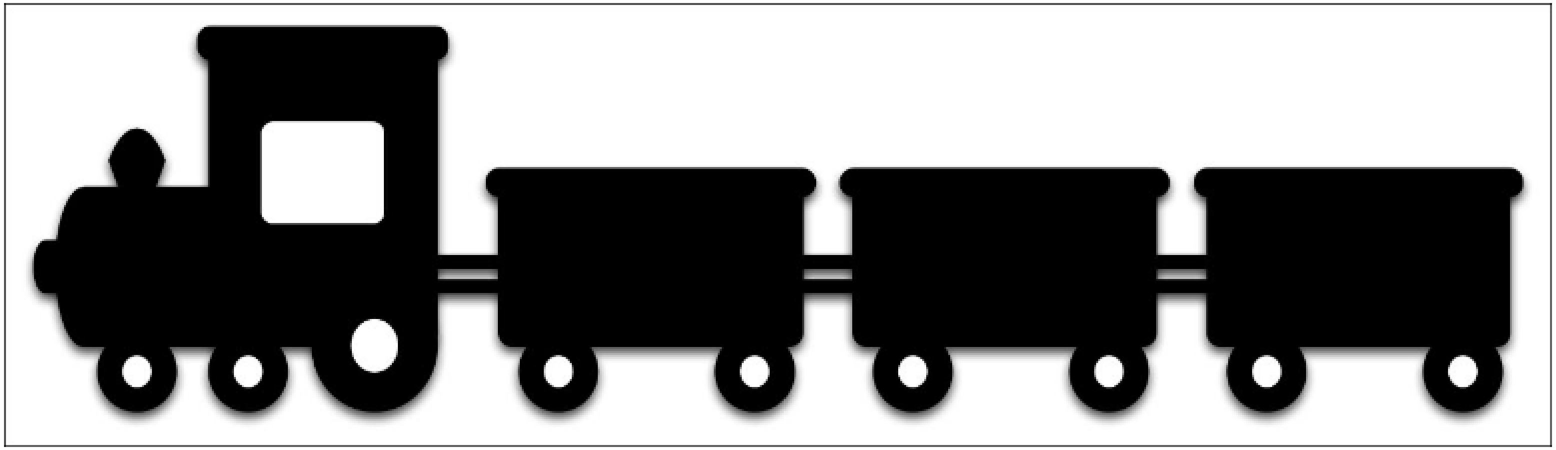
- **Linked Lists** are data structures in which each element of the list is sequentially joined to the next element.

- 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 nodes)** track both the item and the "next item's" position.

Linked List



- **Linked Lists** are like trains.

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

Linked List – In Code

```
class Node {
  constructor(data, next) {
    this.data = data;
    this.next = next;
  }

  getData() {
    return this.data;
  }

  setData(data) {
    this.data = data;
  }

  getNext() {
    return this.next;
  }

  setNext(next) {
    this.next = next;
  }
}

class LinkedList {
  constructor(dataArray) {
    this.first = new Node();

    var counter = 0;
    if (dataArray) {
      var actual = this.first;
      for (var data of dataArray) {
        var newNode = new Node(data);
        actual.setNext(newNode);
```

- JS does not include Linked Lists natively
- But when you need one…
- Plenty of implementations are available online.
- http://codepen.io/gben/pen/ZGLava

For the Lazy… (Myself included)

linkedlist public

Array like linked list with iterator

LinkedList is a data structure which implements an array friendly interface

Class Methods

```
LinkedList.prototype.push(data)
LinkedList.prototype.pop()
LinkedList.prototype.unshift(data)
LinkedList.prototype.shift()
LinkedList.prototype.next()
LinkedList.prototype.unshiftCurrent()
LinkedList.prototype.removeCurrent()
LinkedList.prototype.resetCursor()
```

What happens when npr
together to share with or

`npm install li`

how? learn more

kilianc published 4

Pulse Check…

You Be the Teacher

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

1. What is a data structure?
2. What does FIFO and LIFO stand for and mean?
3. What is a Stack?
4. What is a Queue?
5. What is a Linked List?
6. How are they each different from arrays?
7. What is one disadvantage of an array?
8. 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.

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

How would you print all the pet names?

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}
```

How would you print all the pet names?

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 serve as a hybrid between objects and arrays.
- They can be iterated over like arrays.
- They have key, value pairs like objects.
- Aaaand, it’s included in the latest version of 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!

Dictionaries (Maps) **** (Actually Useful) ****

Learn more about Dictionaries (Maps) in JS:

Map

SEE ALSO

Standard built-in objects

`Map`

- Properties
  - `Map.prototype`
  - `Map.prototype.size`
  - `Map.prototype[@@toStringTag]`
  - `get Map[@@species]`
- Methods
  - `Map.prototype.clear()`
  - `Map.prototype.delete()`

The **`Map`** object is a simple key/value map. Any value (both objects and primitive values) may be used as either a key or a value.

Syntax

```
new Map([iterable])
```

Parameters

`iterable`

Iterable is an Array or other iterable object whose elements are key-value pairs (2-element Arrays). Each key-value pair is added to the new Map. `null` is treated as `undefined`.

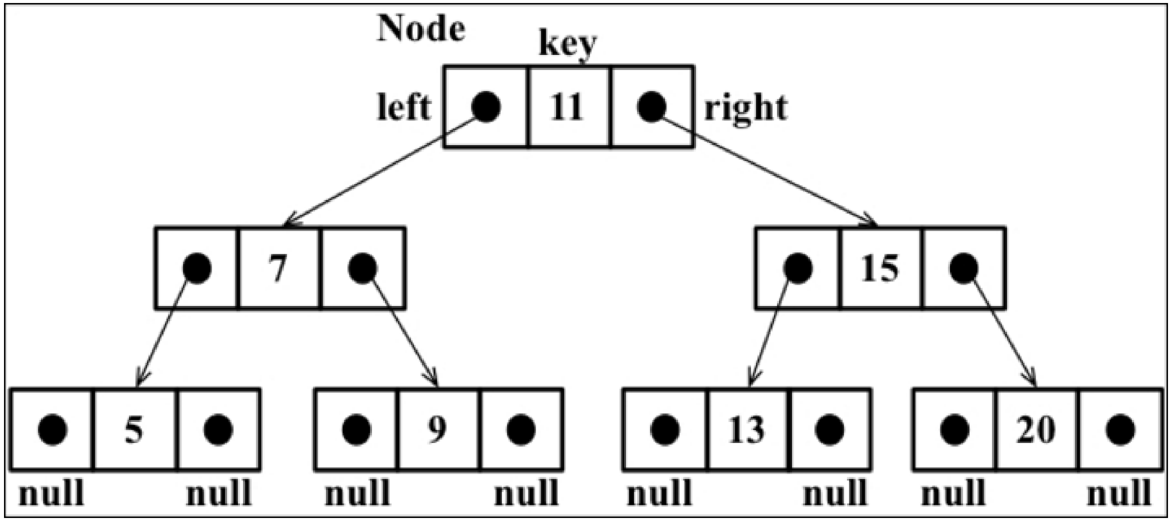
https://developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Map

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

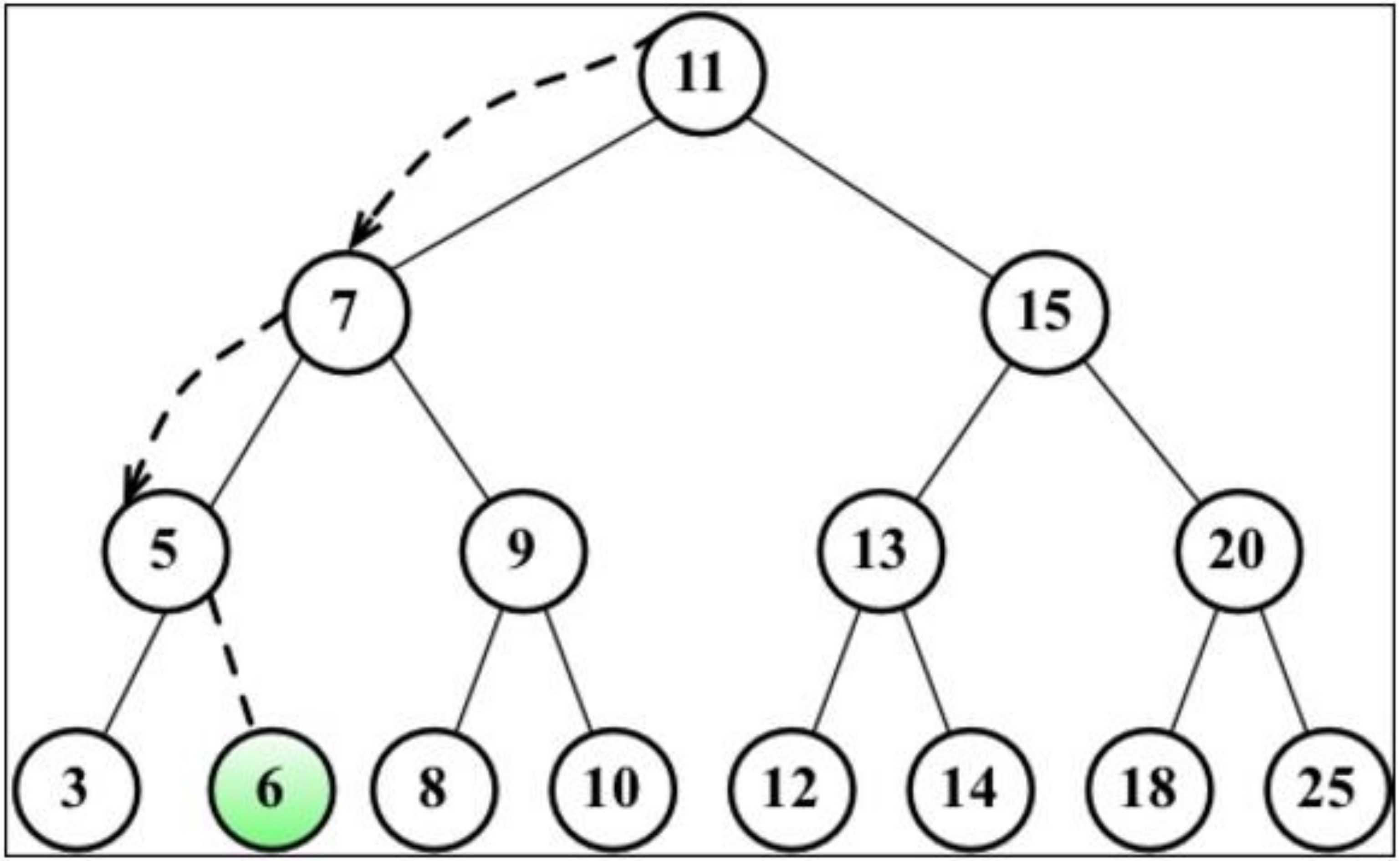
- In a **Binary Tree**, nodes have **two children** at most. One on left and on right.

- 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

binary-search-tree public

Different binary search tree implementations, including a self-balancing one (AVL)

Binary search trees for Node.js

Two implementations of binary search tree: basic and AVL (a kind of self-balancing binmary search tree). I wrote this module primarily to store indexes for NeDB (a javascript dependency-less database).

Installation and tests

Package name is `binary-search-tree`.

```
npm install binary-search-tree --save

make test
```

Usage

The API mainly provides 3 functions: `insert`, `search` and `delete`. If you do not create a unique-type binary search tree, you can store multiple pieces of data for the same key. Doing so with a unique-type BST will result in an error being thrown. Data is always returned as an array, and you can delete all data relating to a given key, or just one piece of data.

`npm i binary-search-tree`

how? learn more

louischatriot published 4 months ago

0.2.6 is the latest of 15 releases

github.com/louischatriot/node-binary-search-tree

MIT

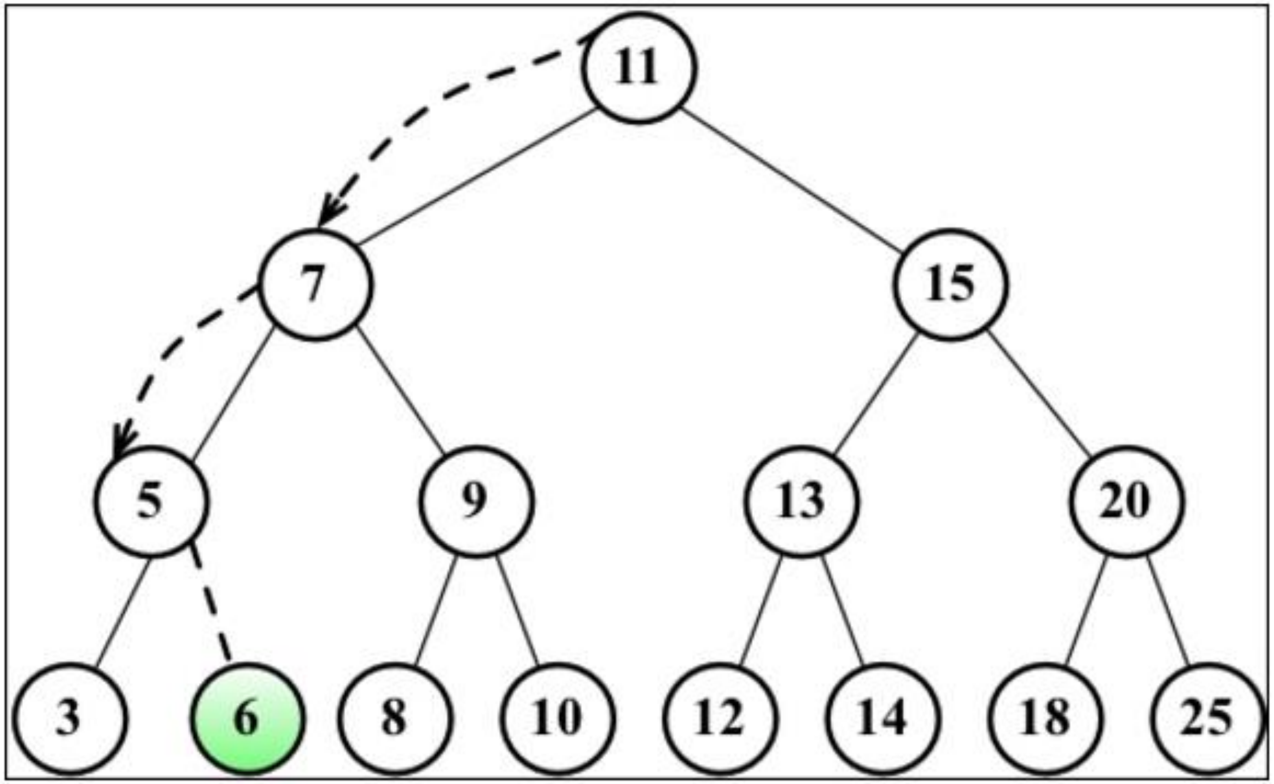
Collaborators

https://www.npmjs.com/package/binary-search-tree

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.



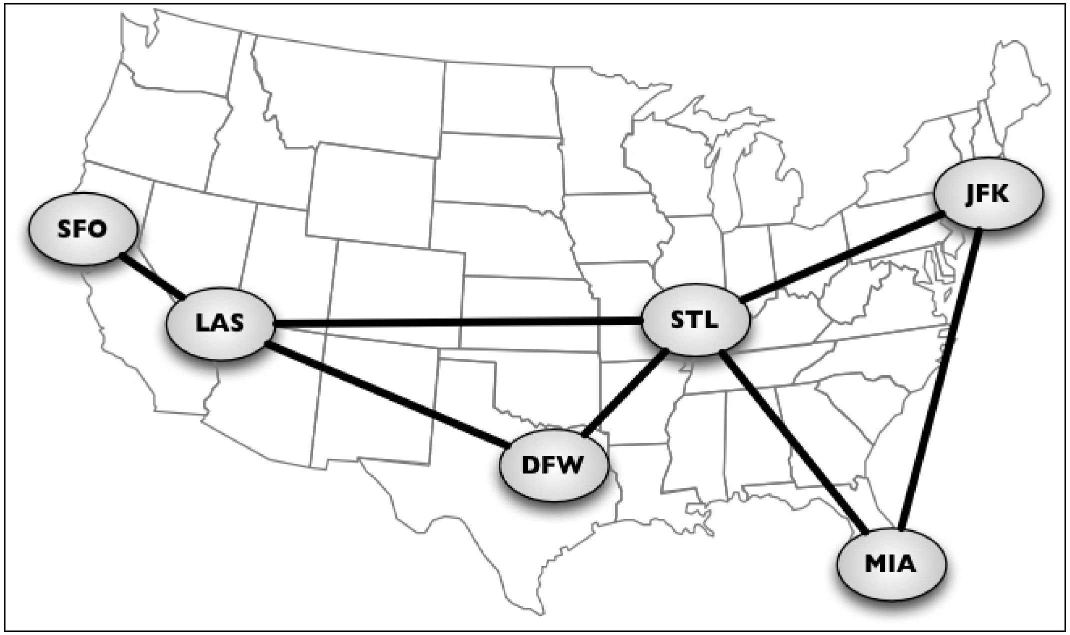
Graphs

Graphs

<u>Graphs are extremely powerful and increasingly common structures.</u>

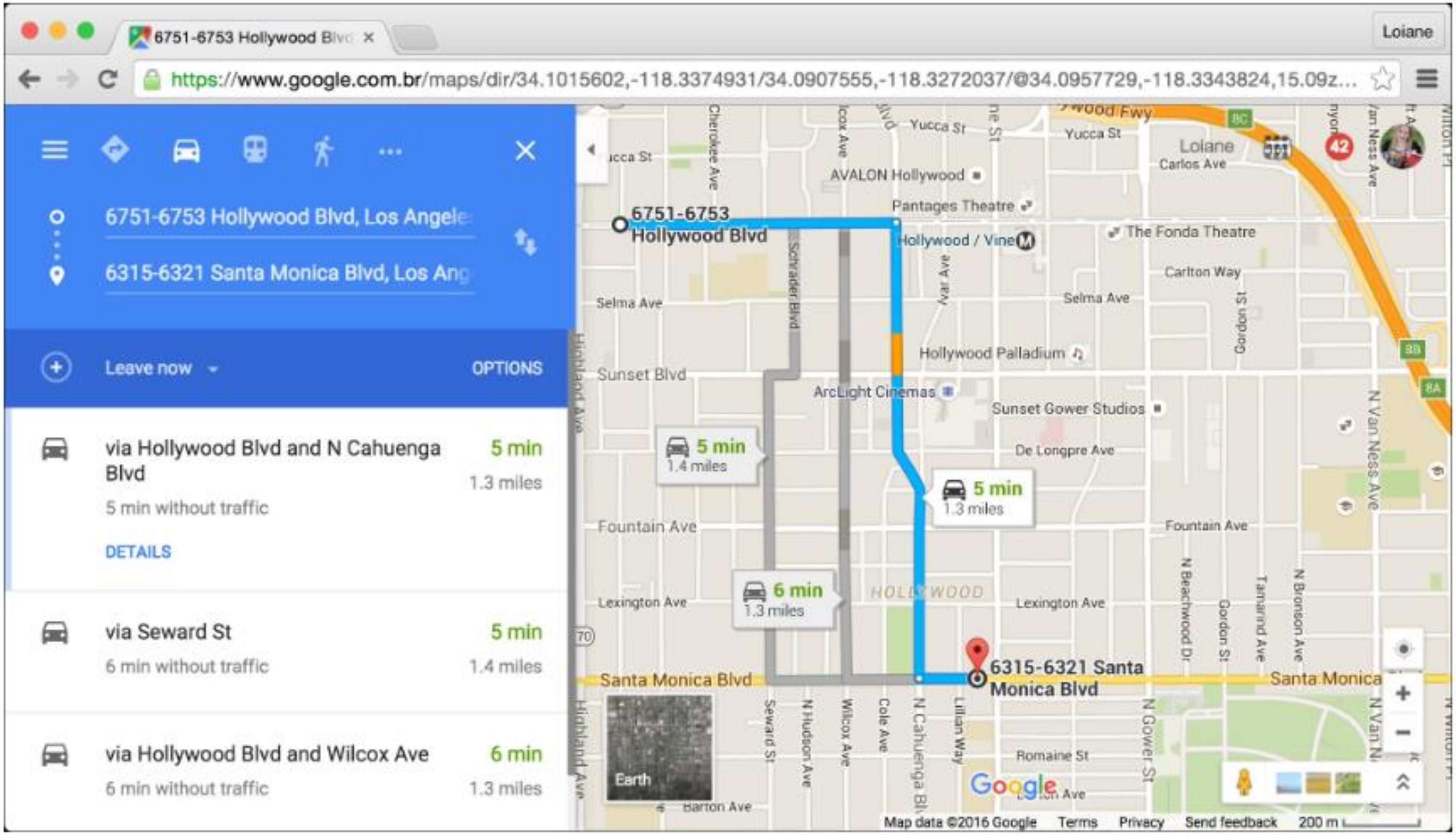
- Graphs are abstract models of a network structure. They are a set of **nodes (or vertices)** connected by **edges.**

- 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