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
  - Stacks/Queues
  - Linked Lists
  - Dictionaries
  - Hash Tables
  - Sets
  - Binary Trees & Binary Search Trees
  - Graphs

Project Check-In

Project Status

Smooth sailing?

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
- Detailed screen-by-screen UI layouts with annotations
- Breakdown of group member roles
- Screenshot of project management tool

Submit by the end of the day!

Computer Science Context

Welcome to…
Computer Science Fundamentals!

Remember...

Computer science fundamentals

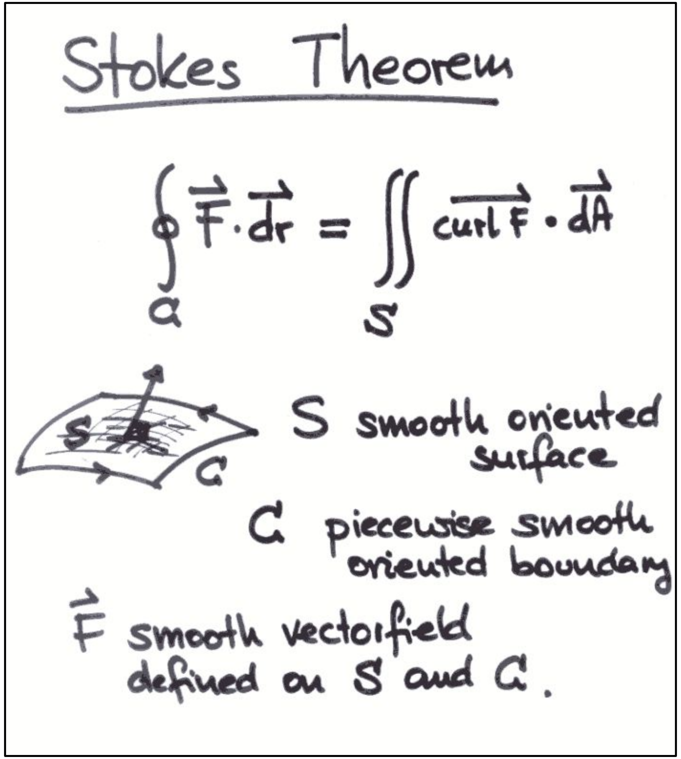
Fundamentals aren't the "easy" computer science stuff.

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

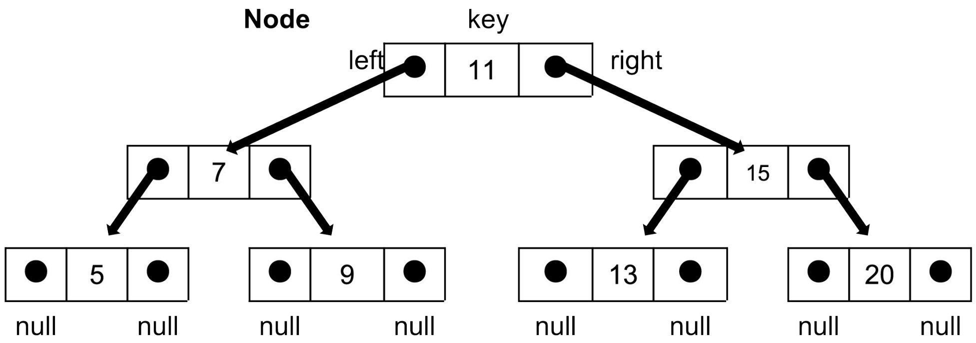
The biggest takeaway is to understand that there are different tools to increase computational efficiency.

Fundamentals

Remember this stuff? Yeah, me neither.



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}
}
```

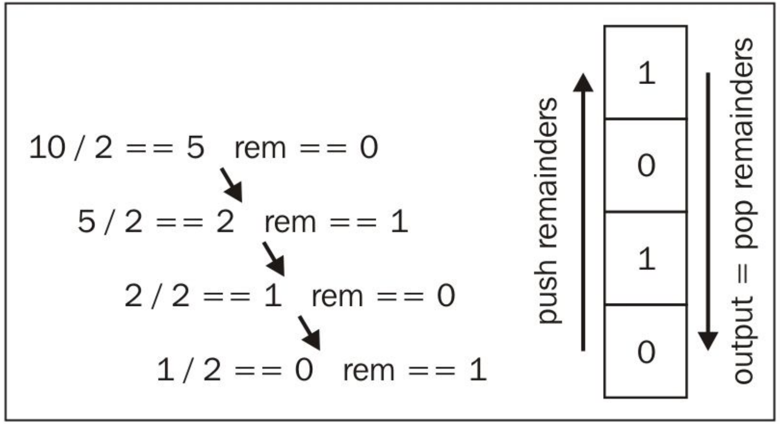
```
function divideBy2(decNumber){

  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?

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

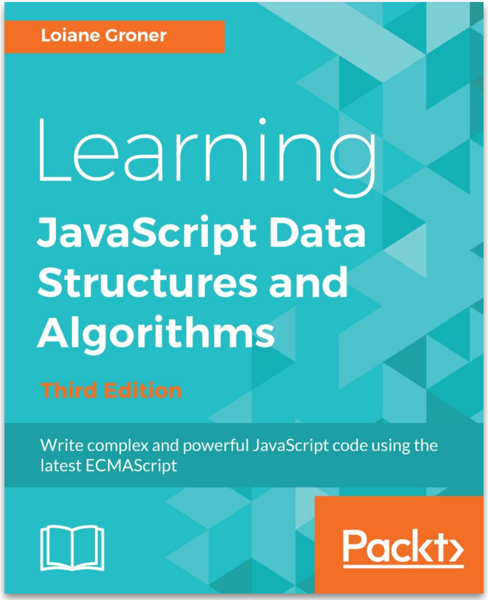
My goal is to give you the terminology and the concepts.

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

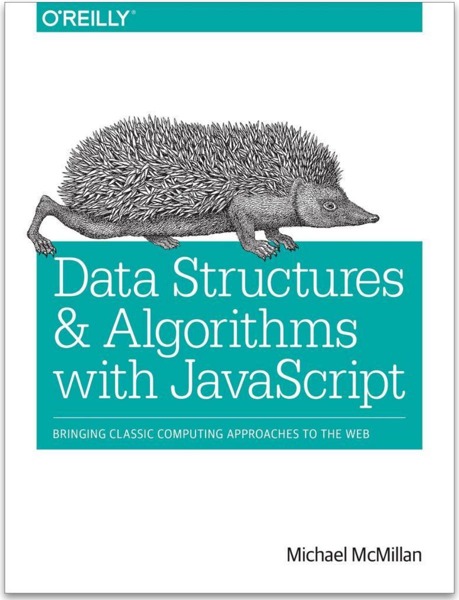
And to encourage those of you who are into math to take a second look!

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

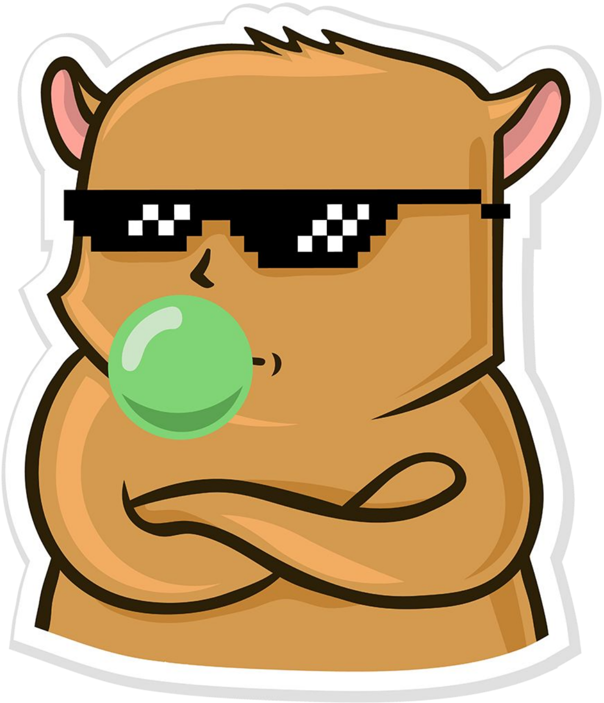


Data Structures and Algorithms with JavaScript
by Michael McMillan
Publisher: O'Reilly Media, Inc.
Release Date: March 2014

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

More Steps = Less Efficient

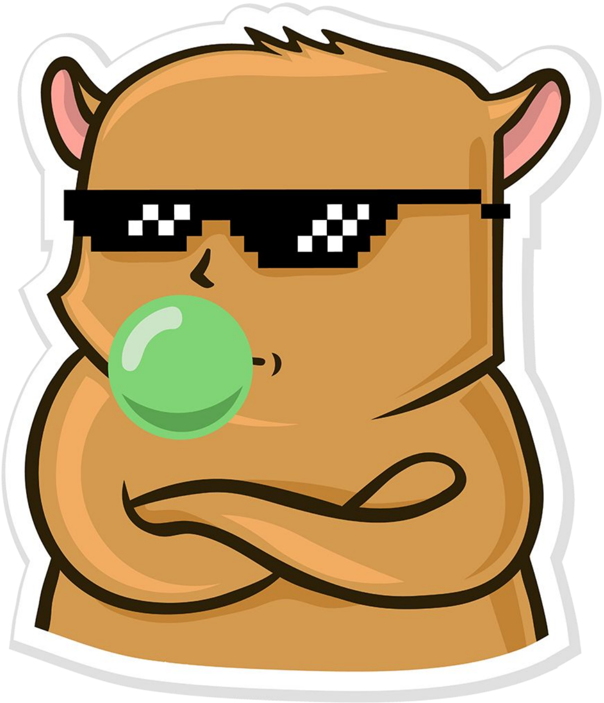
Fewer Steps = More Efficient

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?

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 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

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 ~ $O(n^2)$

NOT COINCIDENCE!

Big O

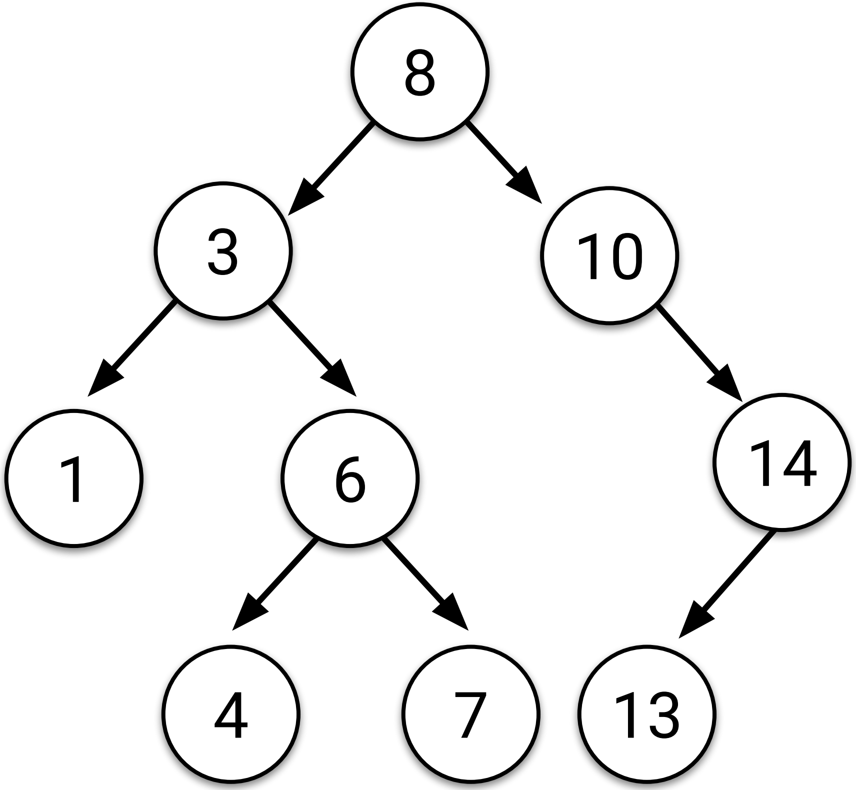
3 nested for loops ~ $O(n^3)$

Etc.

Big O:
One More…

Big O

How fast is binary search?



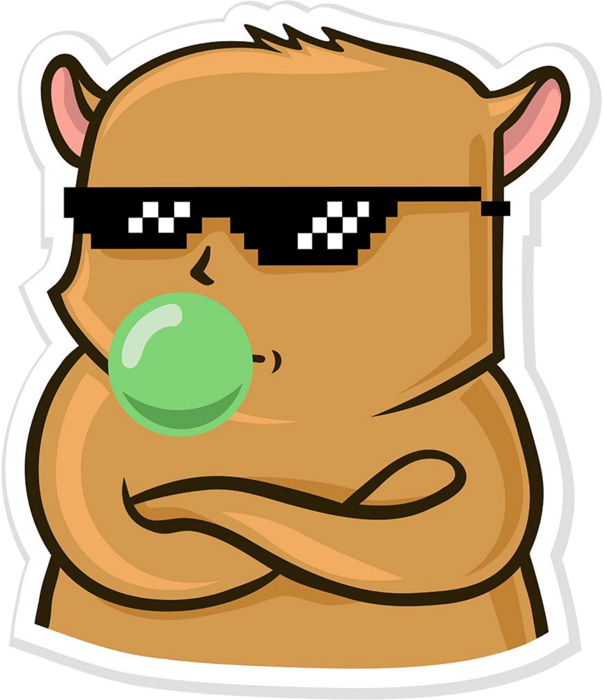
Big O

Is it…

- O(1)
- O(n)
- O(n2)
- 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

Add the digits 11–20. Repeat.

Add the digits 11–20. Repeat.

Answer: 4 Steps (!)

Much faster than linear.

Big O

$(\text{input size})^2 \sim 2\text{x running time}$
$(\text{input size})^3 \sim 3\text{x running time}$

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 (1)

4 / 2 = 2 (2)

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

Logarithm Example

$$\lg 8 = 3$$

But if this is confusing…

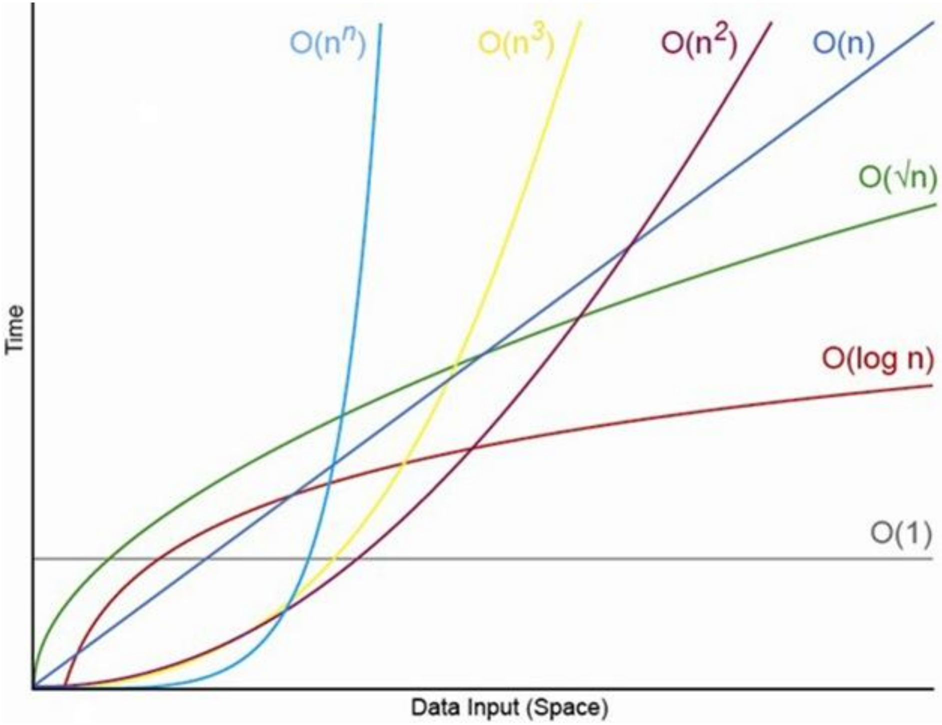
Logarithm Example

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)

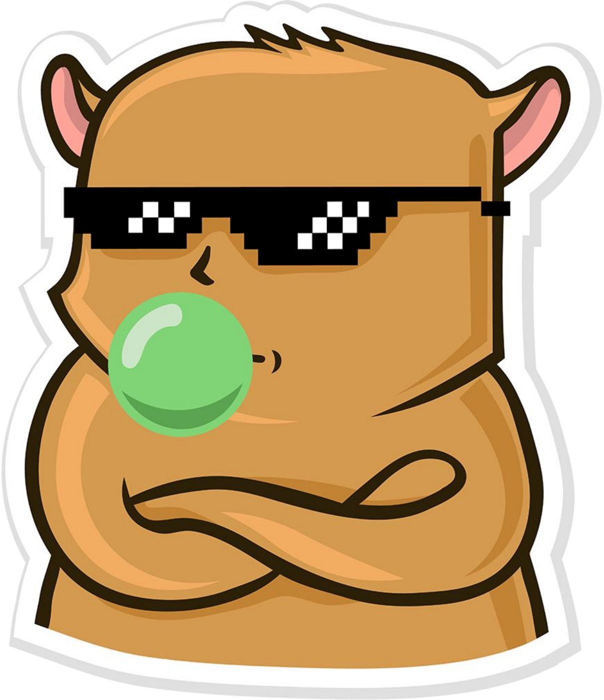
Big O Comparisons



Data Structures

Data Structures? (Tricky Question)

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



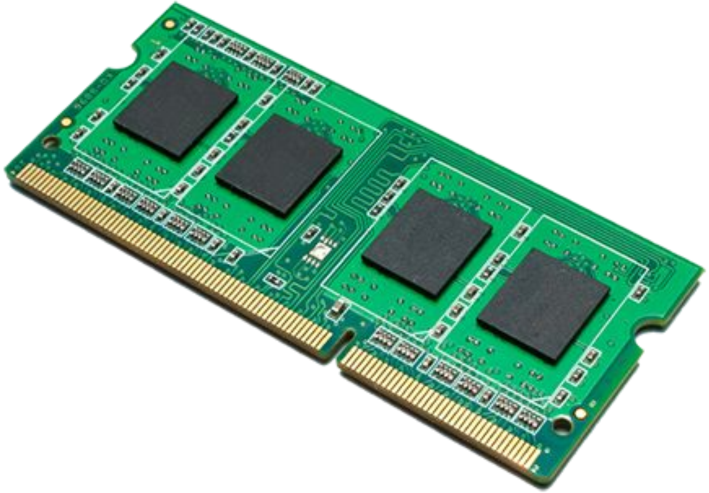
Data Structures? (Tricky Question)

Before we answer that…

Code = Data. Data Is Saved.

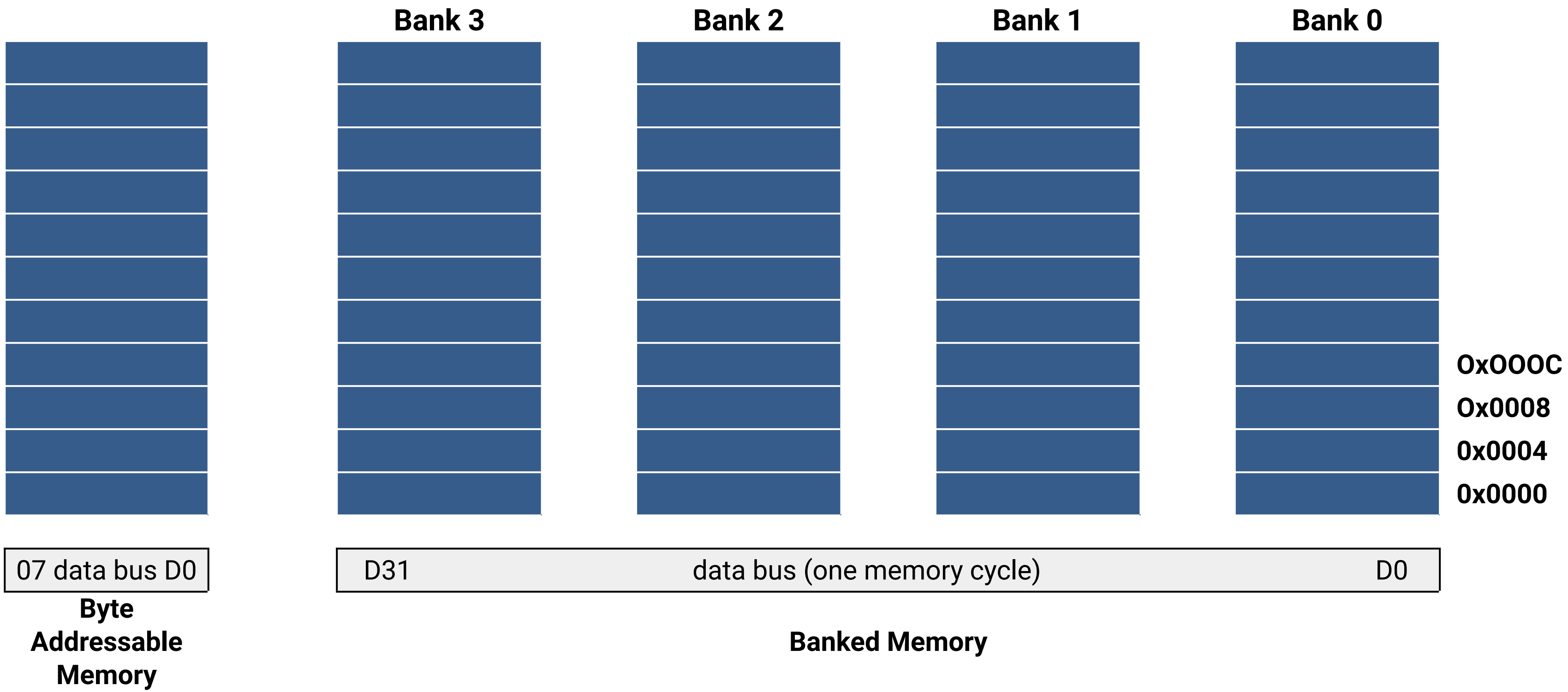
Code that we write gets saved in memory.

```
var name = Ahmed
var age = 82
var isCool = true
```



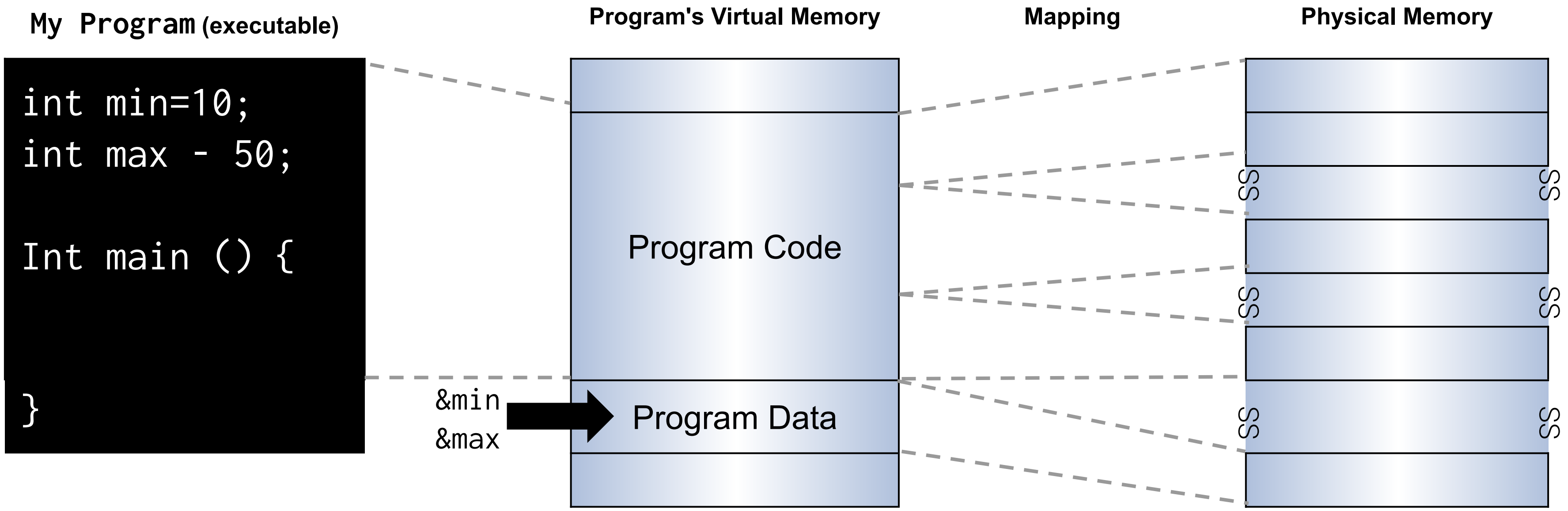
Different Ways to Save

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.



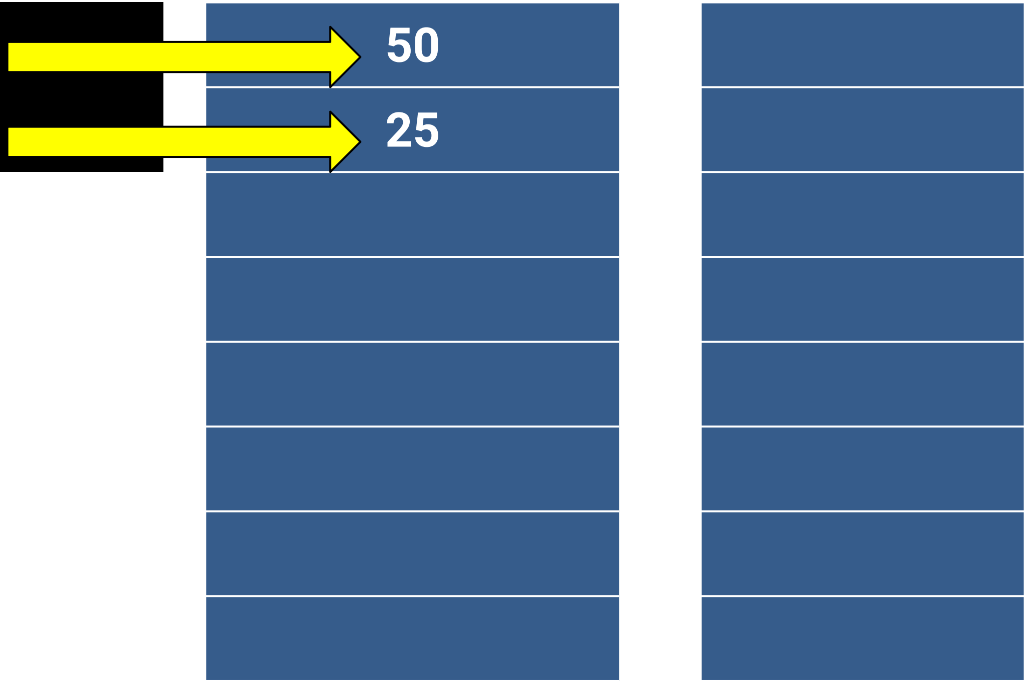
Saving to Memory

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

Code

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

Memory



Retrieving from Memory

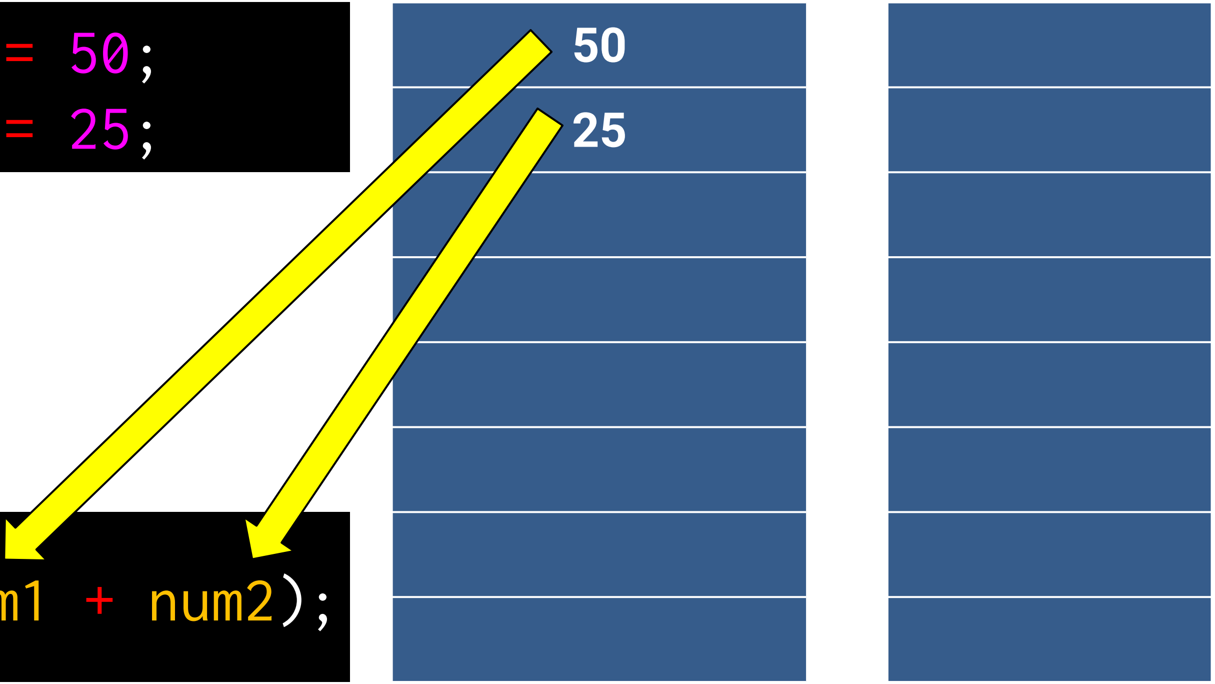
When we reference these variables in our code, we are **retrieving** the data from memory.

Code

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

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

Memory



Growing Data = Growing Problem

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

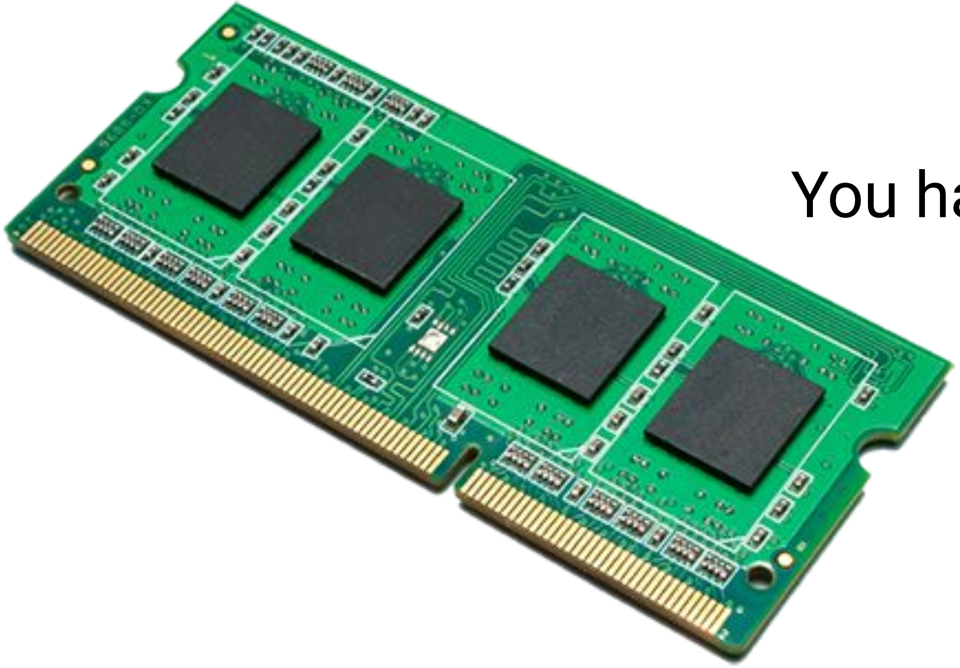
These simple operations of saving, retrieving, etc.

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!

Retrieving from Memory

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

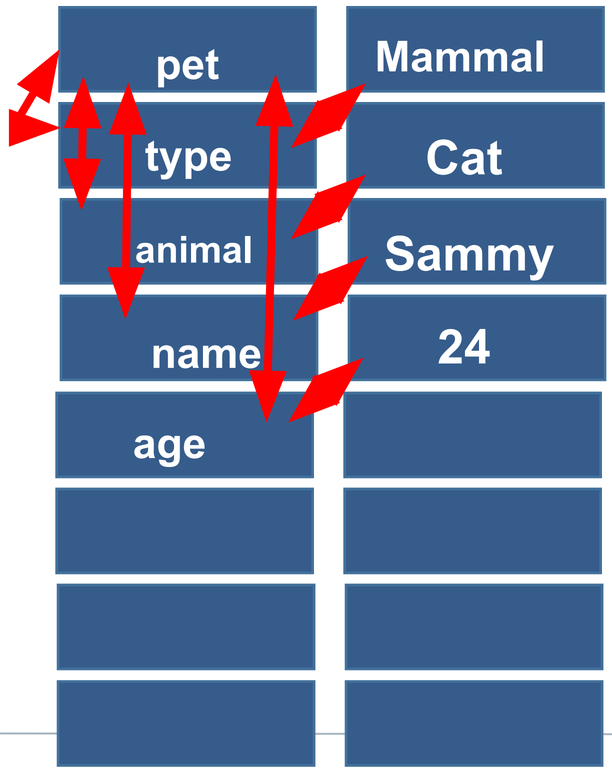
Code

```
var pet = {

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

}
```

Memory



Q

What is a
data structure?

A

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

Q

What is a
data structure?

A

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

Q

What is a **data structure**?

A

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.

Q

`.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.

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

Q

`.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

Q

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

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

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

Arrays in JavaScript

Unshift method:

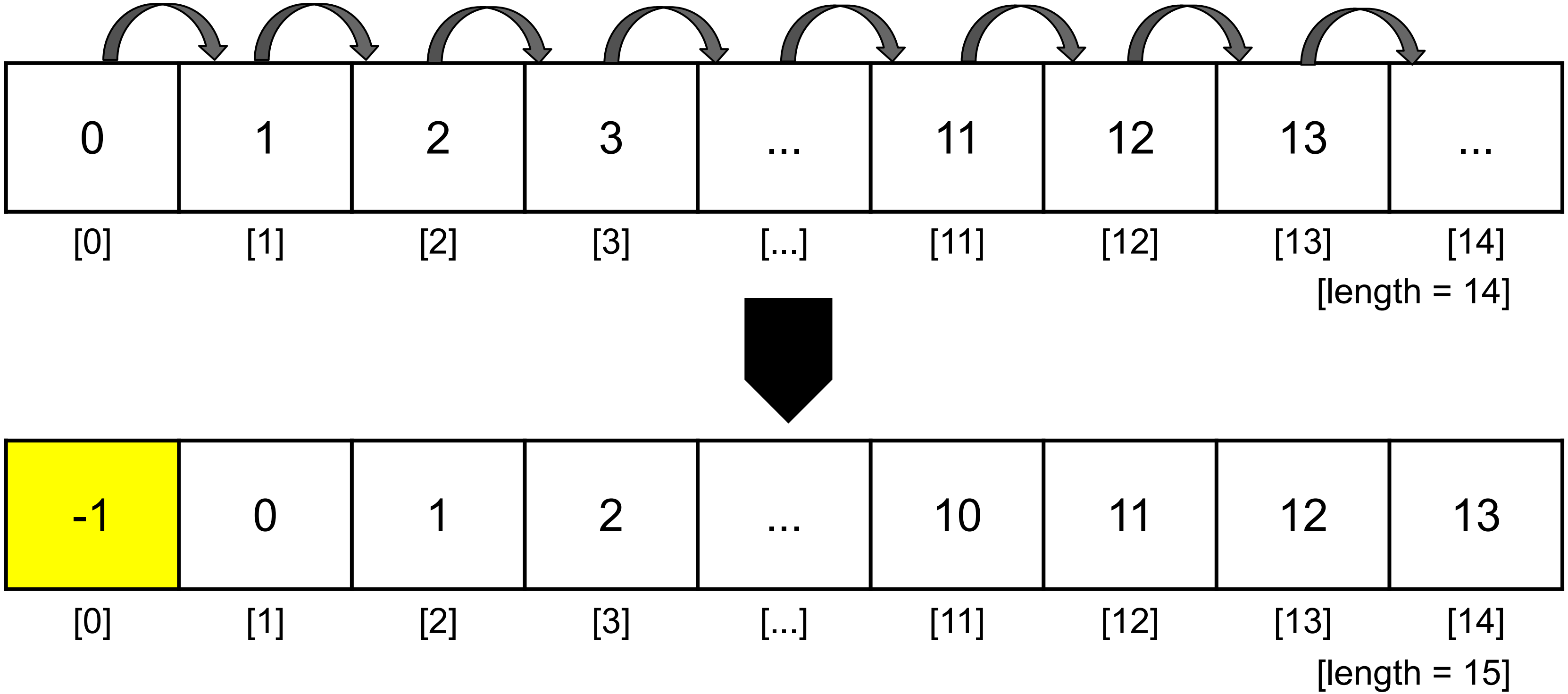
```
myArray.unshift(-1);
```

What's really happening:

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

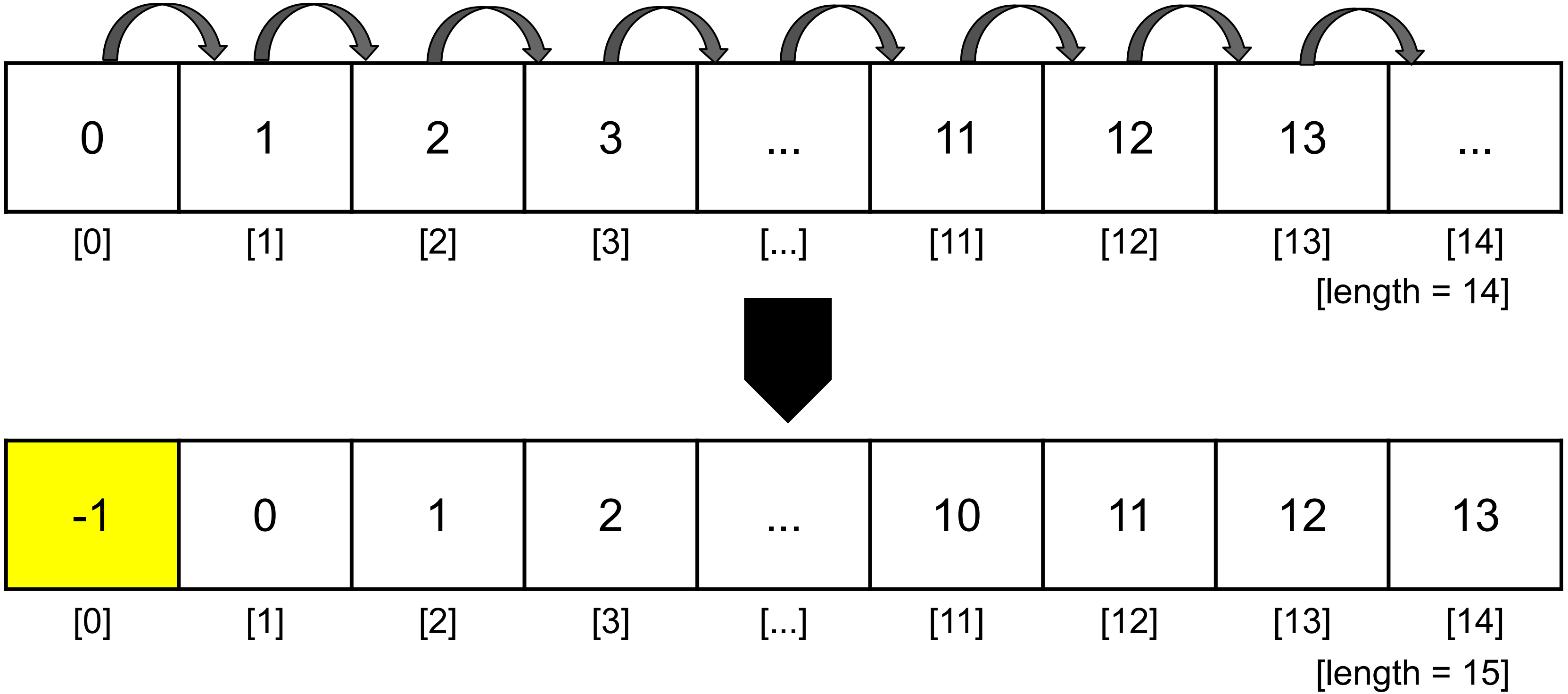
Arrays in JavaScript

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

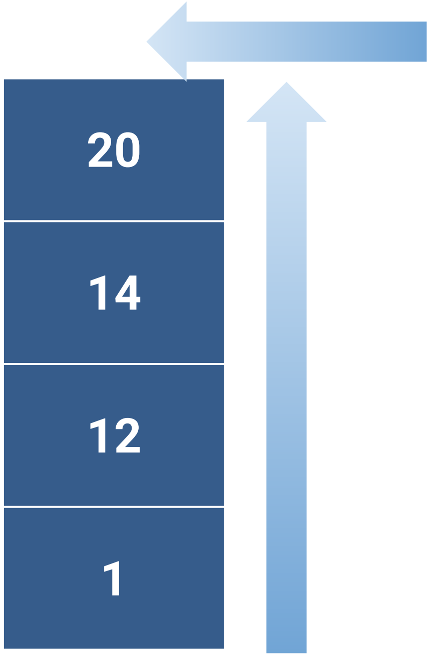
Stacks are another common data structure.

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.

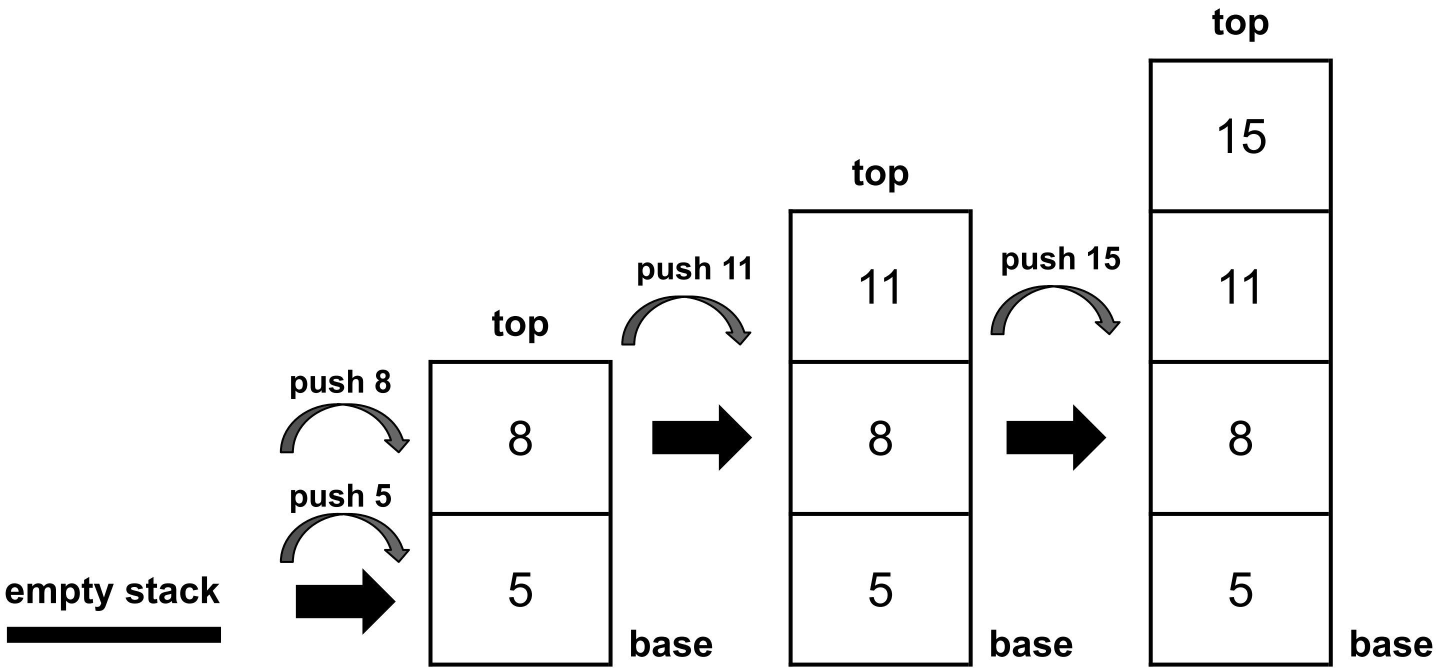
The difference is that they **only allow access to the top element.**

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

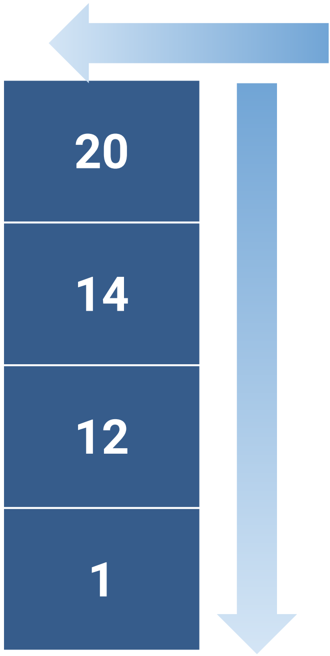
Queues are another common data structure.

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.

```javascript
// 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;
  }

}
```

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

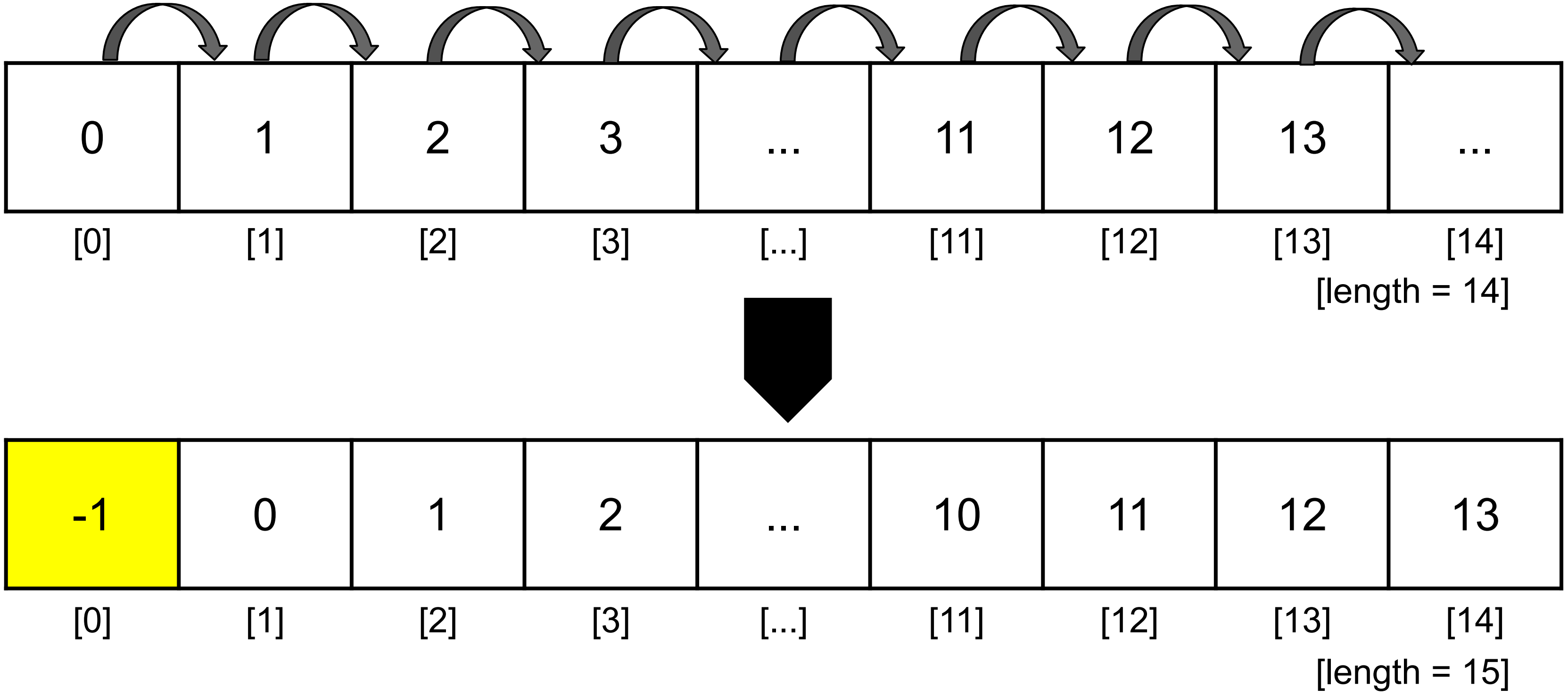
// Starts running methods
newQueue.enqueue("Ahmed");
newQueue.enqueue("Roger");
newQueue.enqueue("John");

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

Linked Lists

Arrays in JavaScript

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



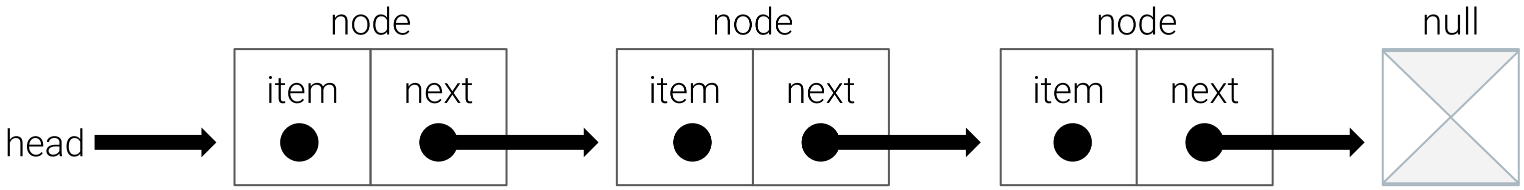
Linked Lists

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."

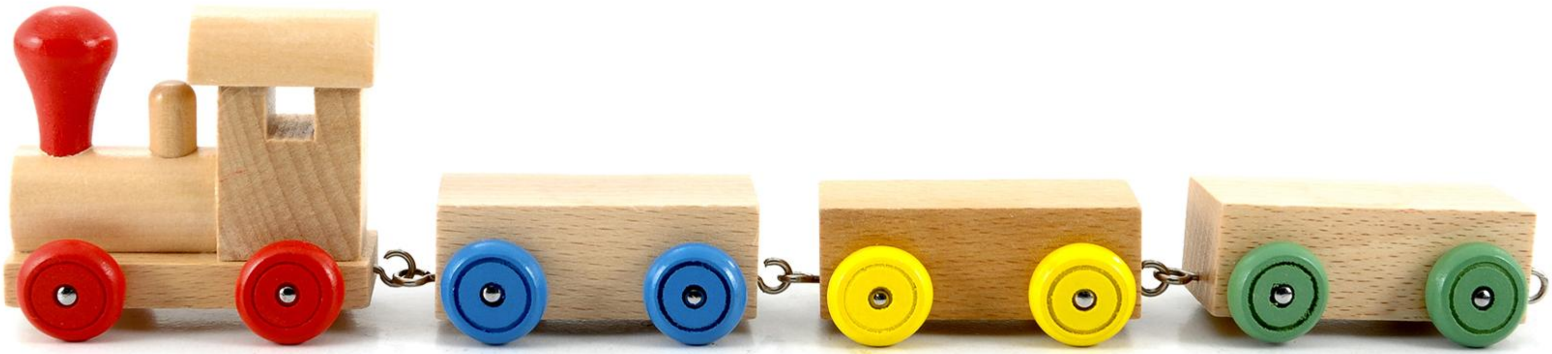
Each element (called a **node**) tracks both the item's and the next item's position.



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.

```
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);
```

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.

Q

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:

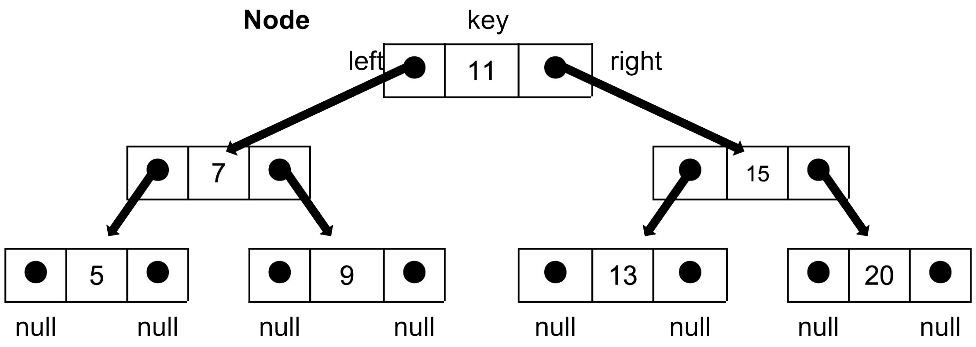
developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Map

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

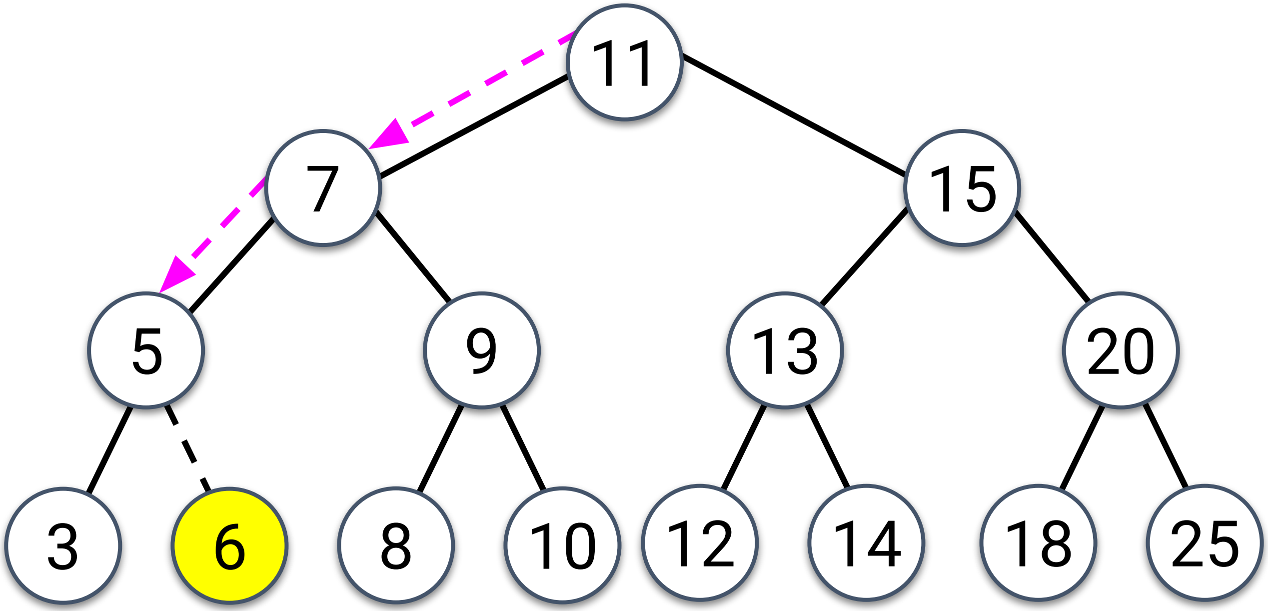
- In a binary tree, nodes have two children at most: one on the left and the right.

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.

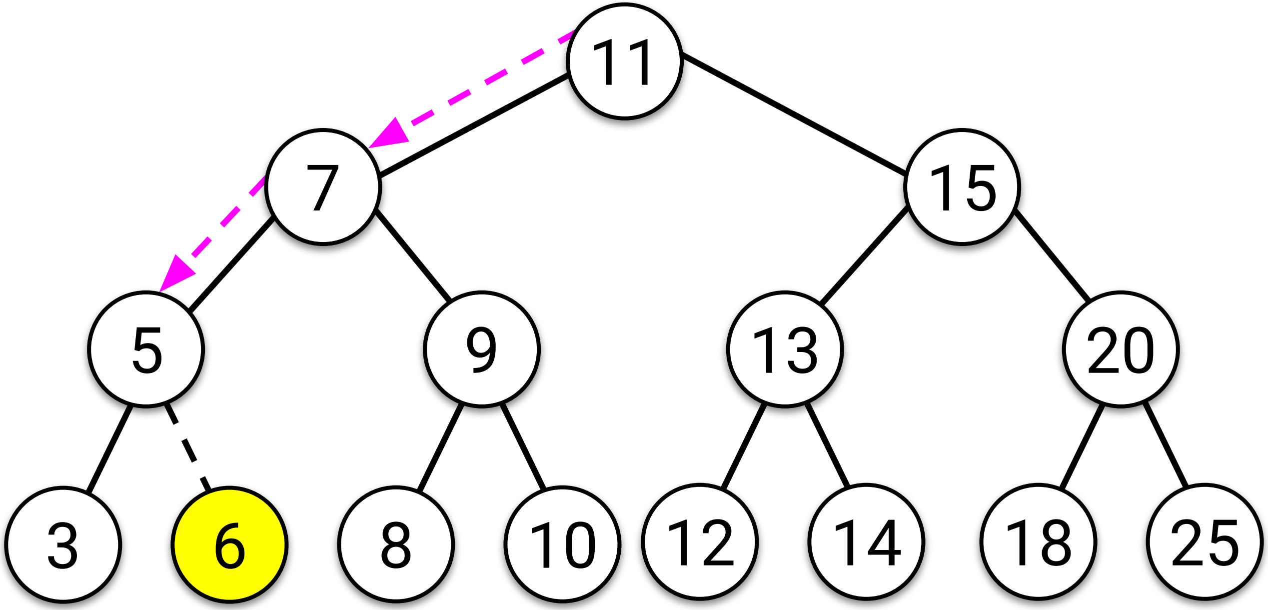


Binary Search Trees

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.

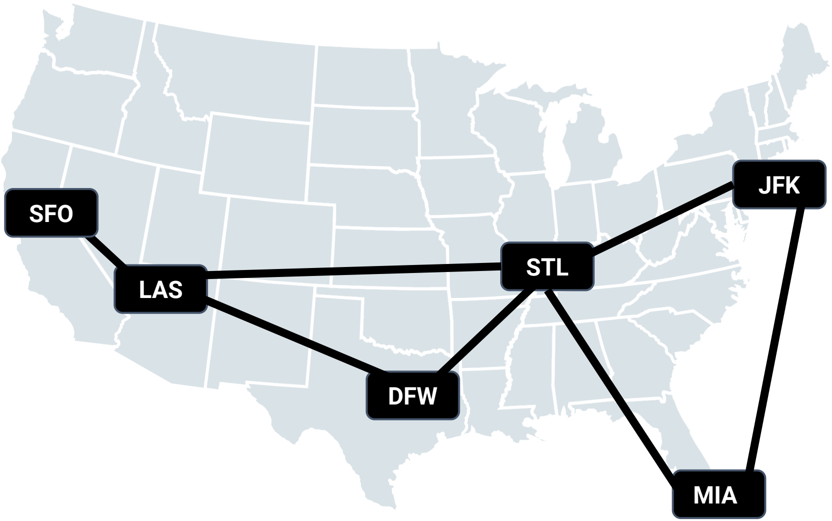


Graphs

Graphs

Graphs are extremely powerful and increasingly common structures.

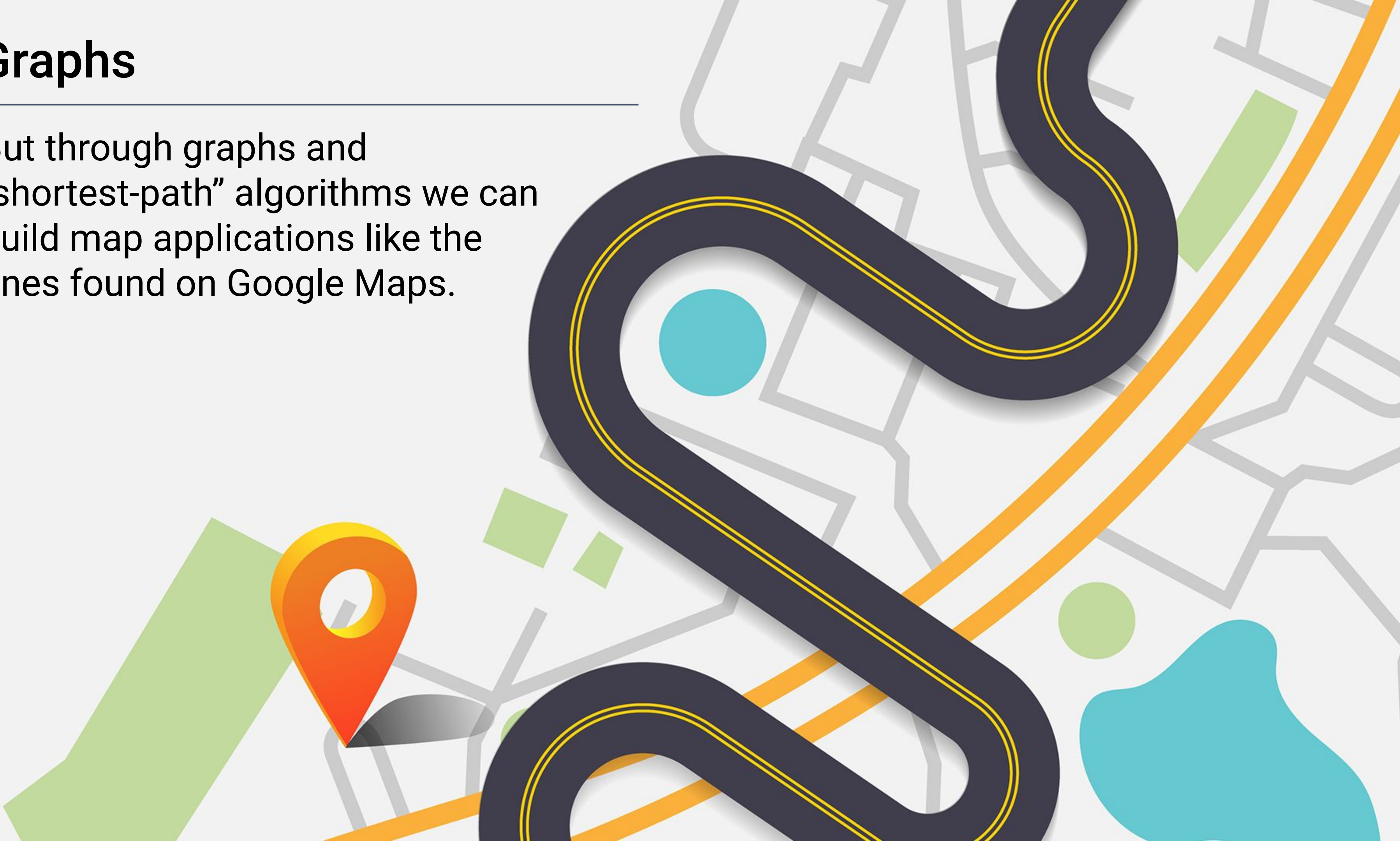
- Graphs are abstract models of a network structure. They are a set of nodes (or vertices) connected by edges.
- They are the essence of social networks and geographic maps.



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?