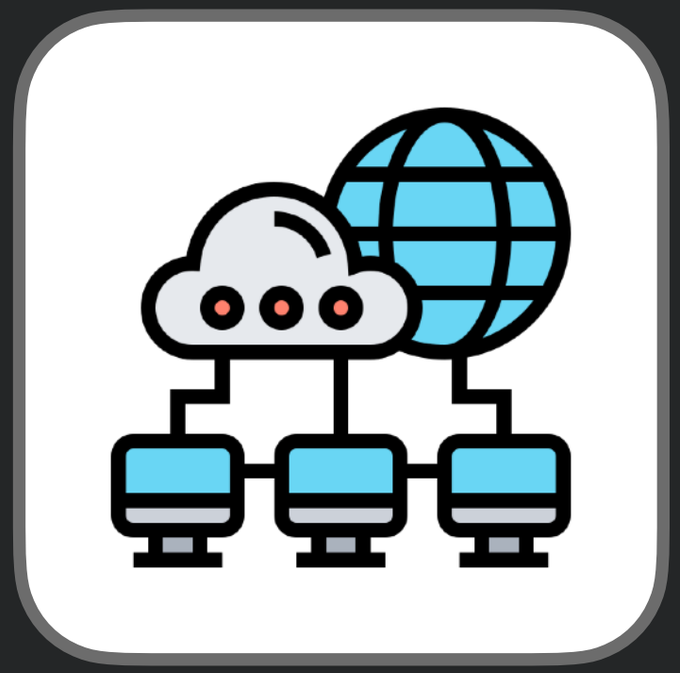
SWE 432 -Web Application Development

Spring 2023

George Mason University

Dr. Kevin Moran

Week 3: Asynchronous Programming I



Administrivia

- *HW Assignment 1* - Due Today Before Class
- *HW Assignment 2* - Out on Thursday, will discuss next class
- *Quiz #2:* Discussion

Quiz #2 Review

Given the code snippet below, write code that will log myProp to the console.

```
var object = {
foo: 'bar',
age: 42,
baz: {myProp: 12} }
```

```
console.log(“MyProp: " + object.baz.myProp)
```

Output: “MyProp: 12”

Quiz #2 Review

Given the code snippet below, using a template literal to access the value of the first (zeroth) element, print the message “Population of ”, and log the name and population of each element.

```
let cities =
[{name: 'Fairfax', population: 24574},
{name: 'Arlington', population: 396394},
{name: 'Centreville', population: 71135}];
```

```
console.log(`Population of ${cities[0].name}: ${cities[0].population}`);
```

output: “Population of Fairfax: 24574”

Quiz #2 Review

What is the output of the code snippet listed below?

```
function makeAdder(x) {
return function(y) {
return x + y;
};
}

var add5 = makeAdder(5);
var add10 = makeAdder(10);

console.log(add5(2));
console.log(add10(2));
```

Output: “7
12”

Review: Closures

- Closures are expressions that work with variables in a specific context
- Closures contain a function, and its needed state
  - Closure is a stack frame that is allocated when a function starts executing and not freed after the function returns
- That state just refers to that state by name (sees updates)

```
var x = 1;
function f() {
    var y = 2;
    return function() {
        console.log(x + y);
        y++;
    };
}
var g = f();
g();          // 1+2 is 3
g();          // 1+3 is 4
```

This function attaches itself to x and y so that it can continue to access them.

It “**closes up**” those references

Closures

```
var x = 1;
function f() {
    var y = 2;
    return function() {
        console.log(x + y);
        y++;
    };
}
var g = f();
g();          // 1+2 is 3
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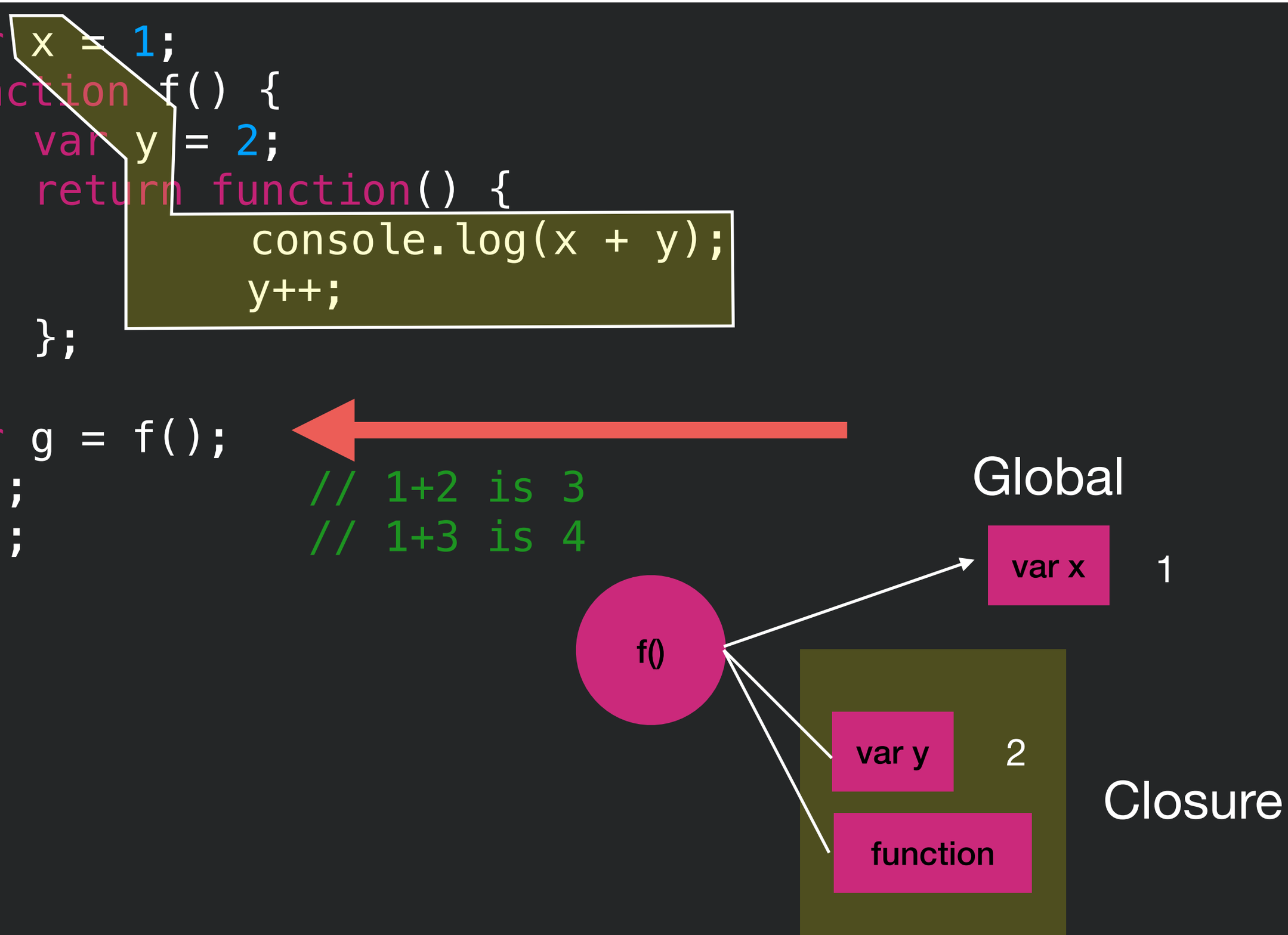

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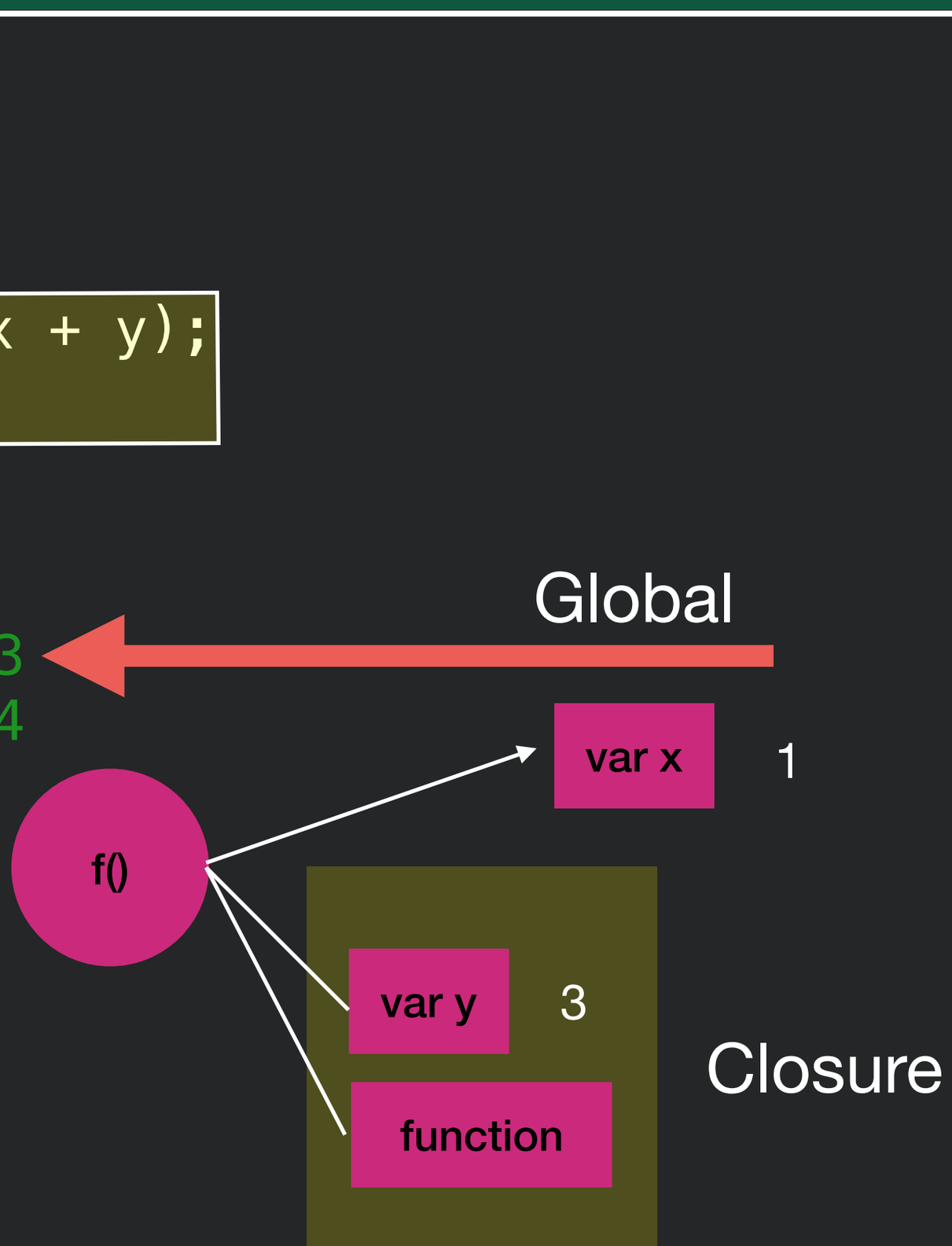

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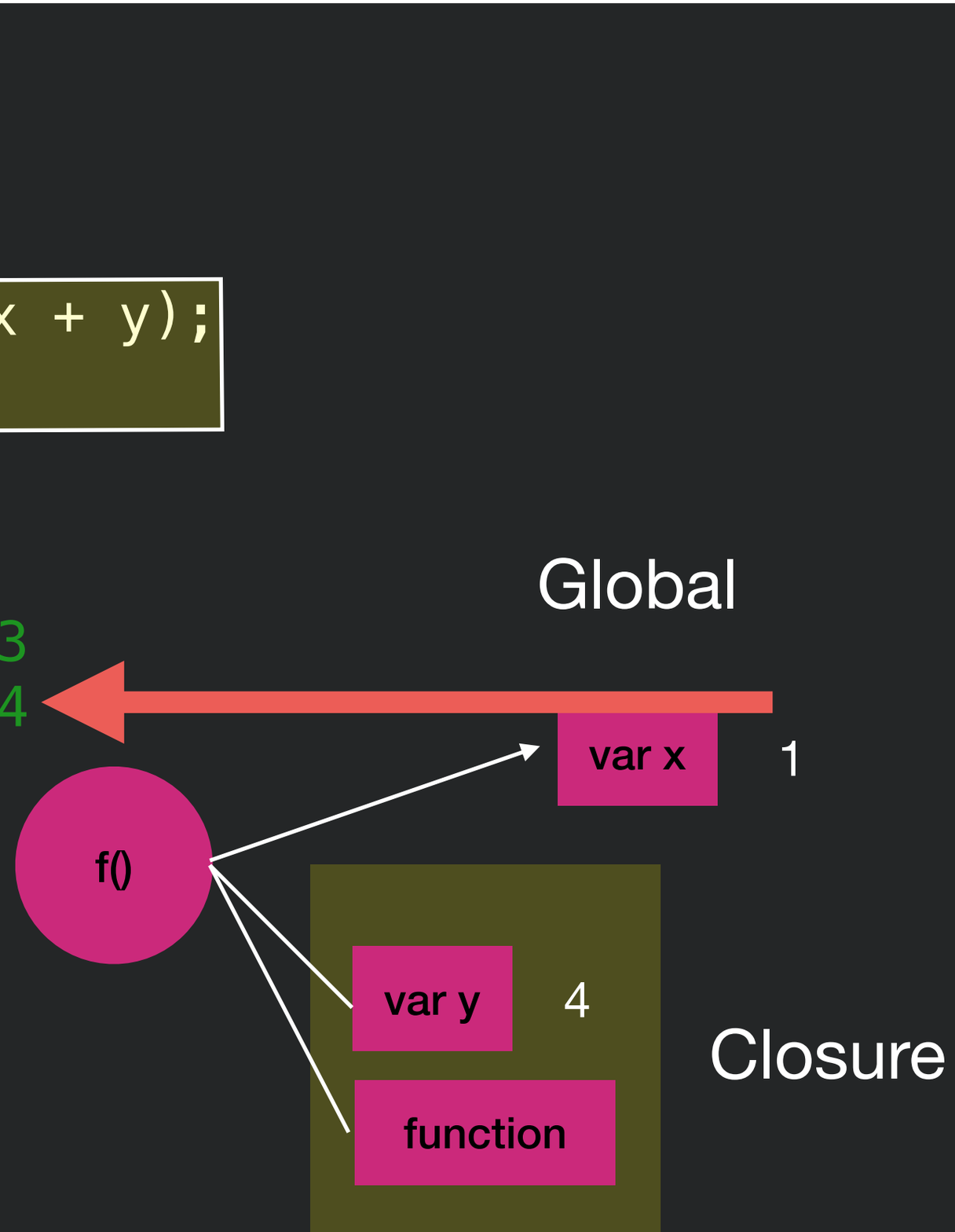


Class Overview

Class Overview

- *Part 1 - Asynchronous Programming I:*

  Communicating between web app components

- *Part 2 - Asynchronous Programming II:*

  More communication strategies

Asynchronous Programming I

Lecture 1

- What is asynchronous programming?
- What are threads?
- Writing asynchronous code

For further reading:

- **Using Promises:** https://developer.mozilla.org/en-US/docs/Web/JavaScript/Guide/Using_promises
- **Node.js event loop:** https://nodejs.org/en/docs/guides/event-loop-timers-and-nexttick/

Why Asynchronous?

- Maintain an interactive application while still doing stuff
  - Processing data
  - Communicating with remote hosts
  - Timers that countdown while our app is running
- Anytime that an app is doing more than one thing at a time, it is asynchronous

What is a thread?

Program execution: a series of sequential method calls (★s)

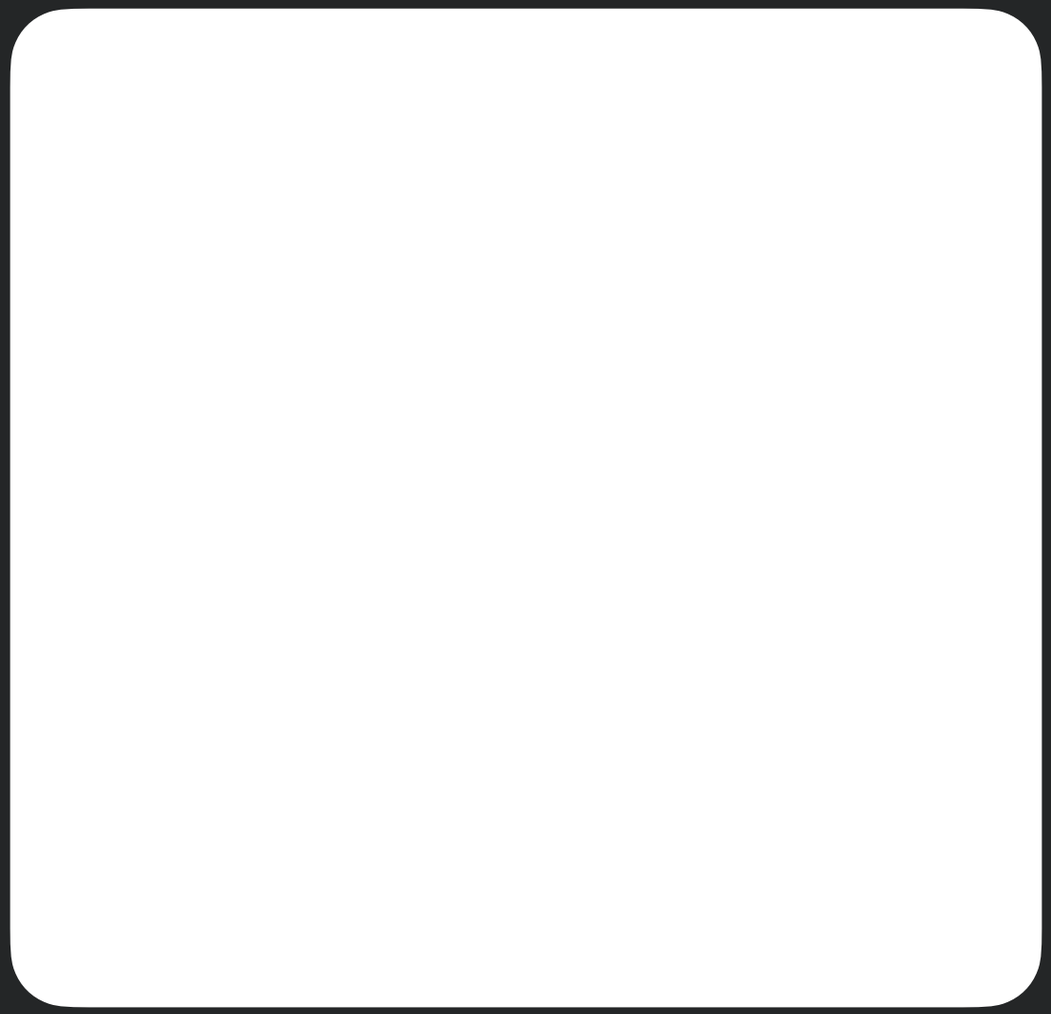
App Starts

App Ends

What is a Thread?

Program execution: a series of sequential method calls (★s)

App Starts

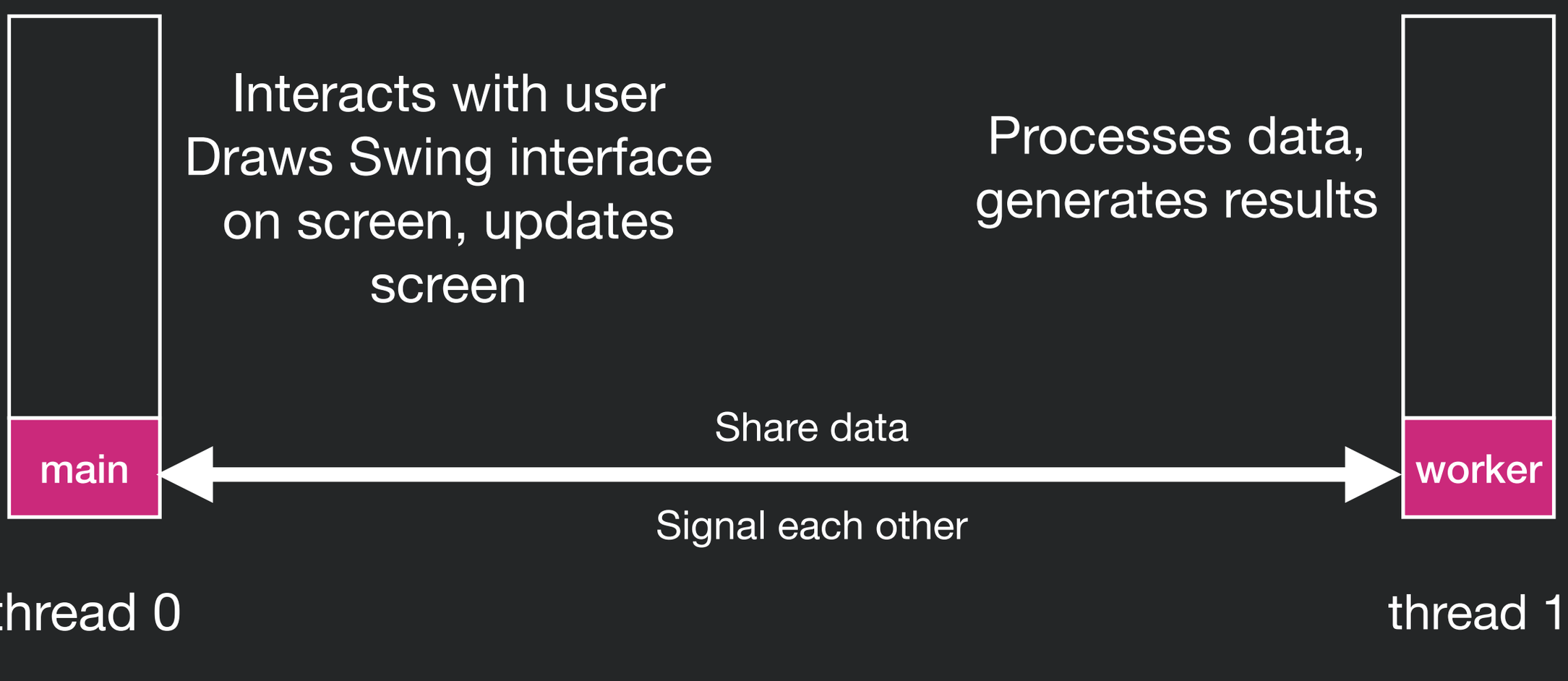


App Ends

Multiple threads can run at once -> allows for asynchronous code

Multi-Threading in Java

- Multi-Threading allows us to do more than one thing at a time
- Physically, through multiple cores and/or OS scheduler
- Example: Process data while interacting with user



Woes of Multi-Threading

```
public static int v;
public static void thread1()
{
   v = 4;
   System.out.println(v);
}
```

```
public static void thread2()
{
   v = 2;
}
```

This is a data race: the `println` in thread1 might see either 2 OR 4

Thread 1	Thread 2
Write V = 4	
	Write V = 2
Read V (2)	

Thread 1	Thread 2
	Write V = 2
Write V = 4	
Read V (4)	

Multi-Threading in JS

```
var request = require('request');
request('http://www.google.com', function (error, response,
body) {
    console.log("Heard back from Google!");
});
console.log("Made request");
```

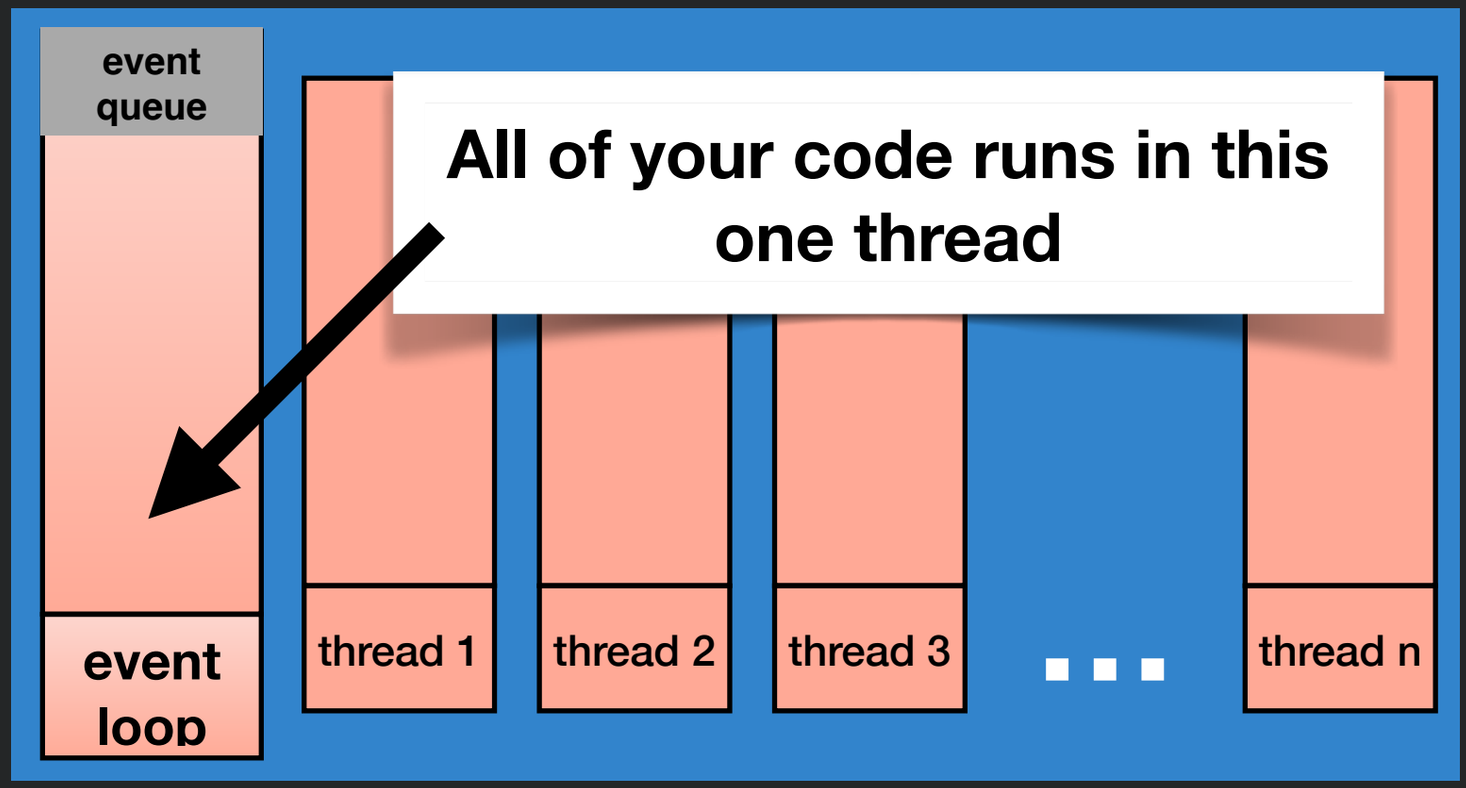
Output:

Made request
Heard back from Google!

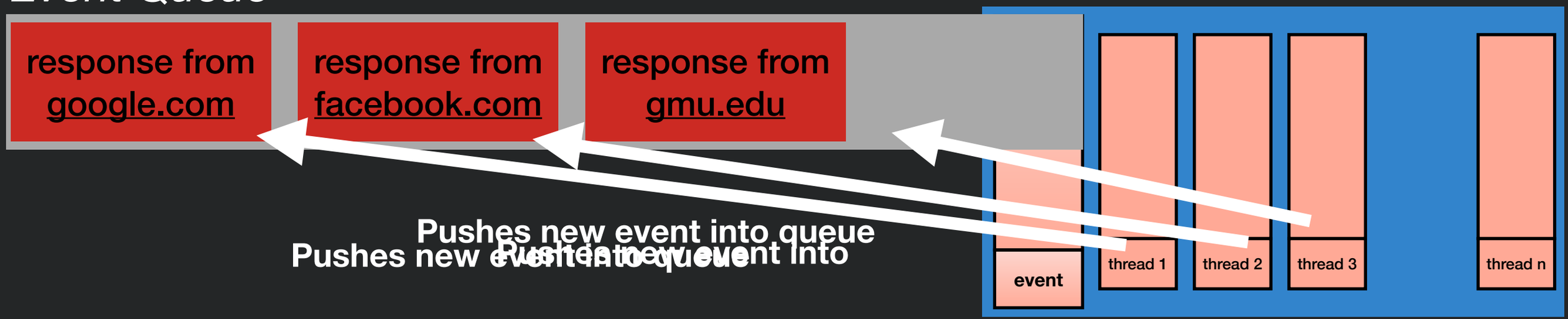
Request is an ***asynchronous call***

Multi-Threading in JS

- Everything you write will run in a single thread* (event loop)
- Since you are not sharing data between threads, races don't happen as easily
- Inside of JS engine: many threads
- Event loop processes events, and calls your callbacks



The Event Loop



Event Being Processed:

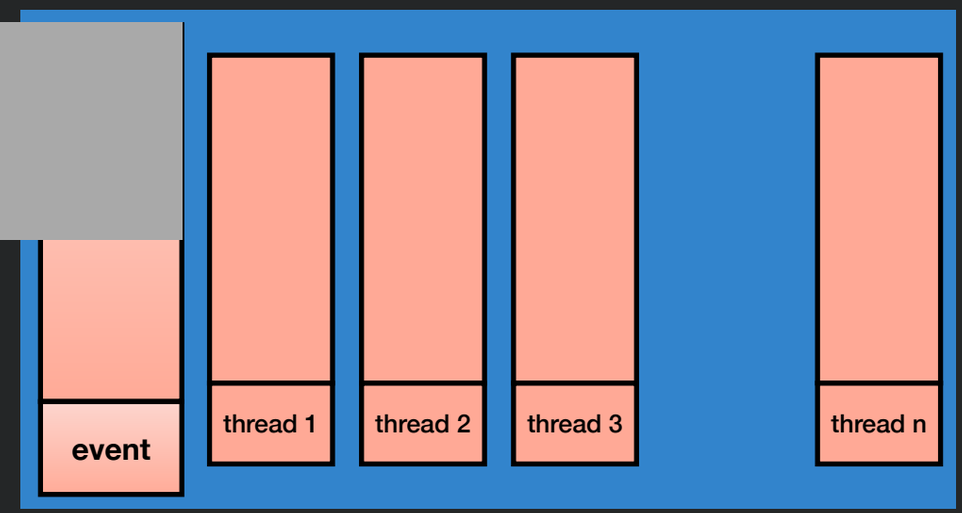
JS Engine

The Event Loop

Event Queue

response from facebook.com

response from gmu.edu



Event Being Processed:

response from google.com

JS Engine

Are there any listeners registered for this event?

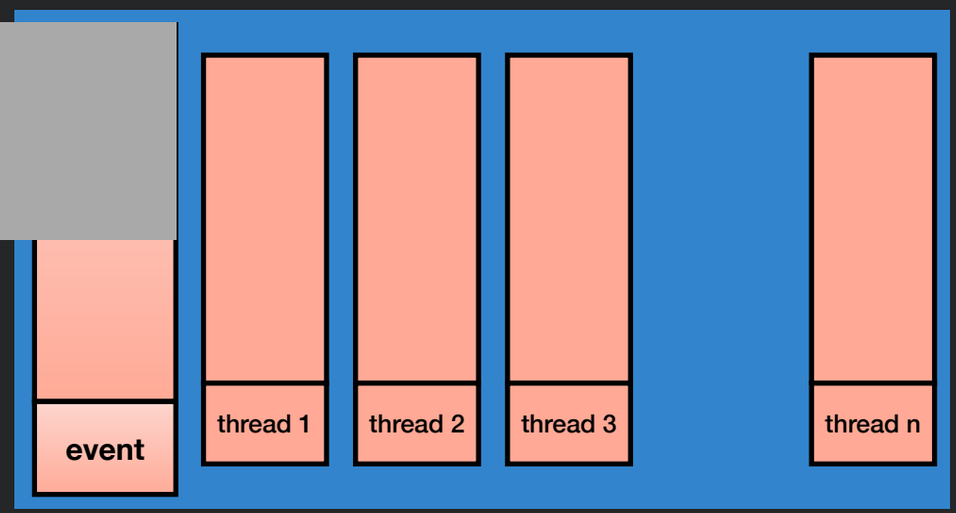
If so, call listener with event

After the listener is finished, repeat

The Event Loop

Event Queue

response from gmu.edu



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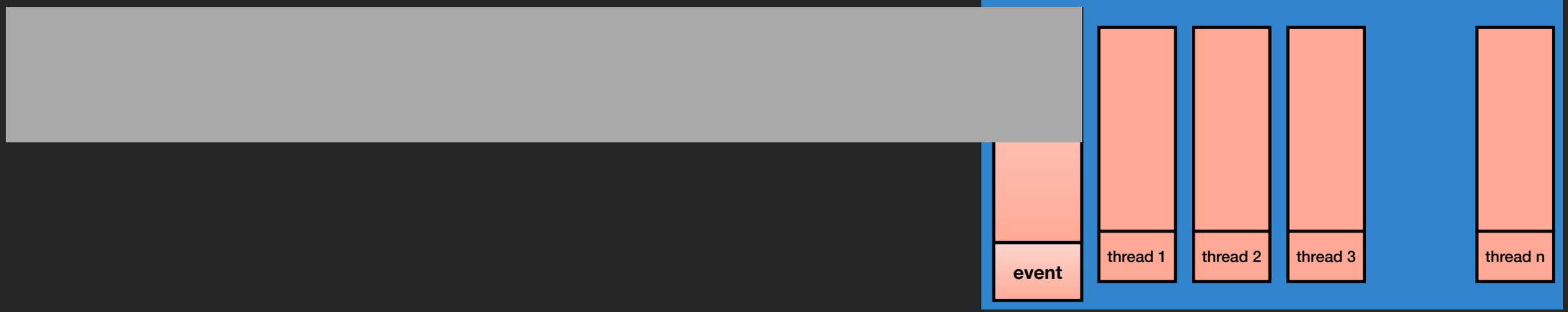


Event Being Processed:

response from gmu.edu

JS Engine

Are there any listeners registered for this event?

If so, call listener with event

After the listener is finished, repeat

The Event Loop

- Remember that JS is **event-driven**

```
var request = require('request');
request('http://www.google.com', function (error, response, body) {
    console.log("Heard back from Google!");
});
console.log("Made request");
```

- Event loop is responsible for dispatching events when they occur
- Main thread for event loop:

```
while(queue.waitForMessage()){
  queue.processNextMessage();
}
```

How do you write a "good" event handler?

- Run-to-completion
  - The JS engine will not handle the next event until your event handler finishes

- ***Good news:*** no other code will run until you finish (no worries about other threads overwriting your data)

- ***Bad/OK news:*** Event handlers must not block
  - Blocking -> Stall/wait for input (e.g. alert(), non-async network requests)
  - If you *must* do something that takes a long time (e.g. computation), split it up into multiple events

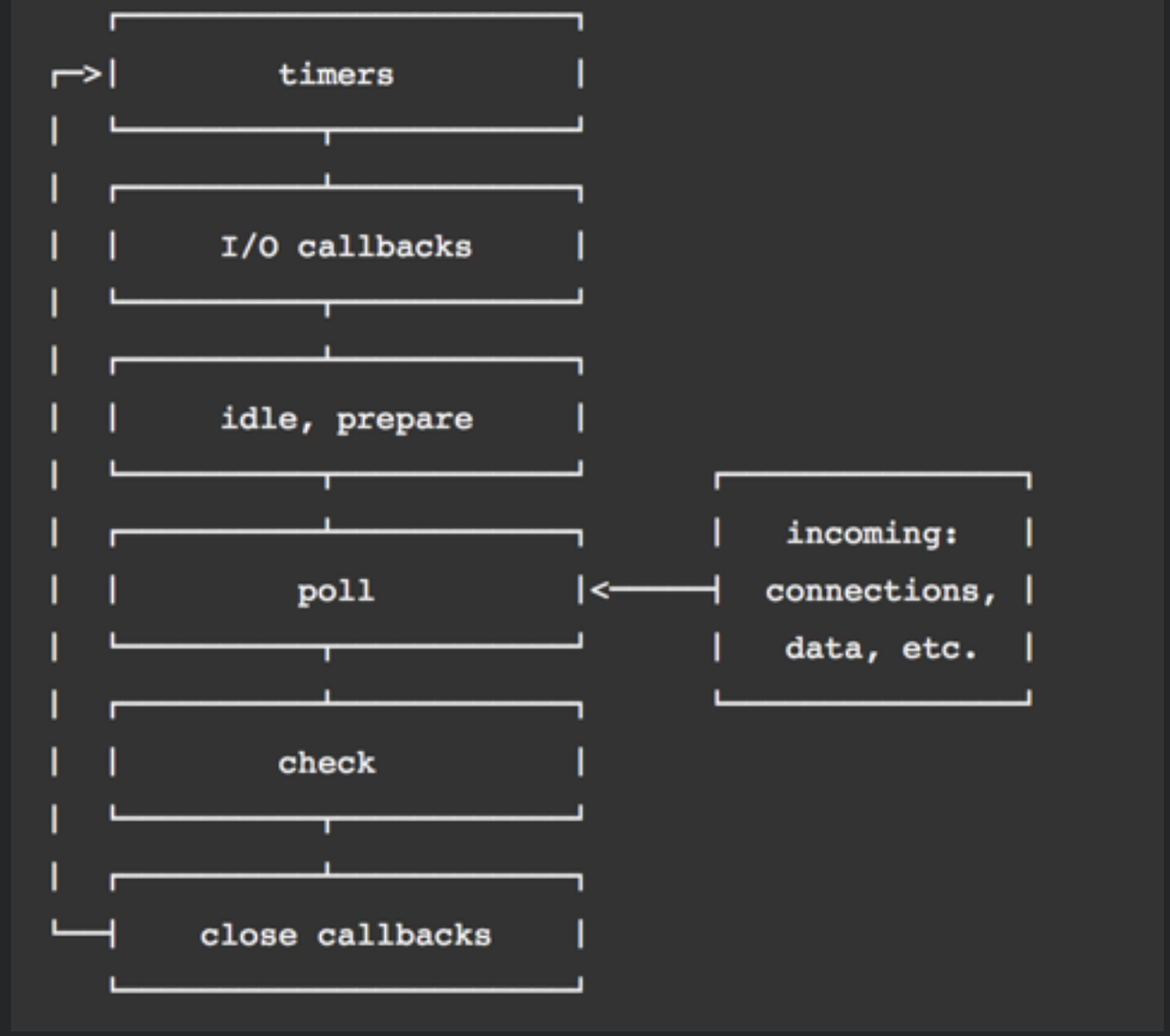
More Properties of Good Handlers

- Remember that event events are processed in the order they are received
- Events might arrive in unexpected order
- Handlers should check the current state of the app to see if they are still relevant

Prioritizing Events in `node.js`

- Some events are more important than others
- Keep separate queues for each event "phase"
- Process all events in each phase before moving to next

First



Last

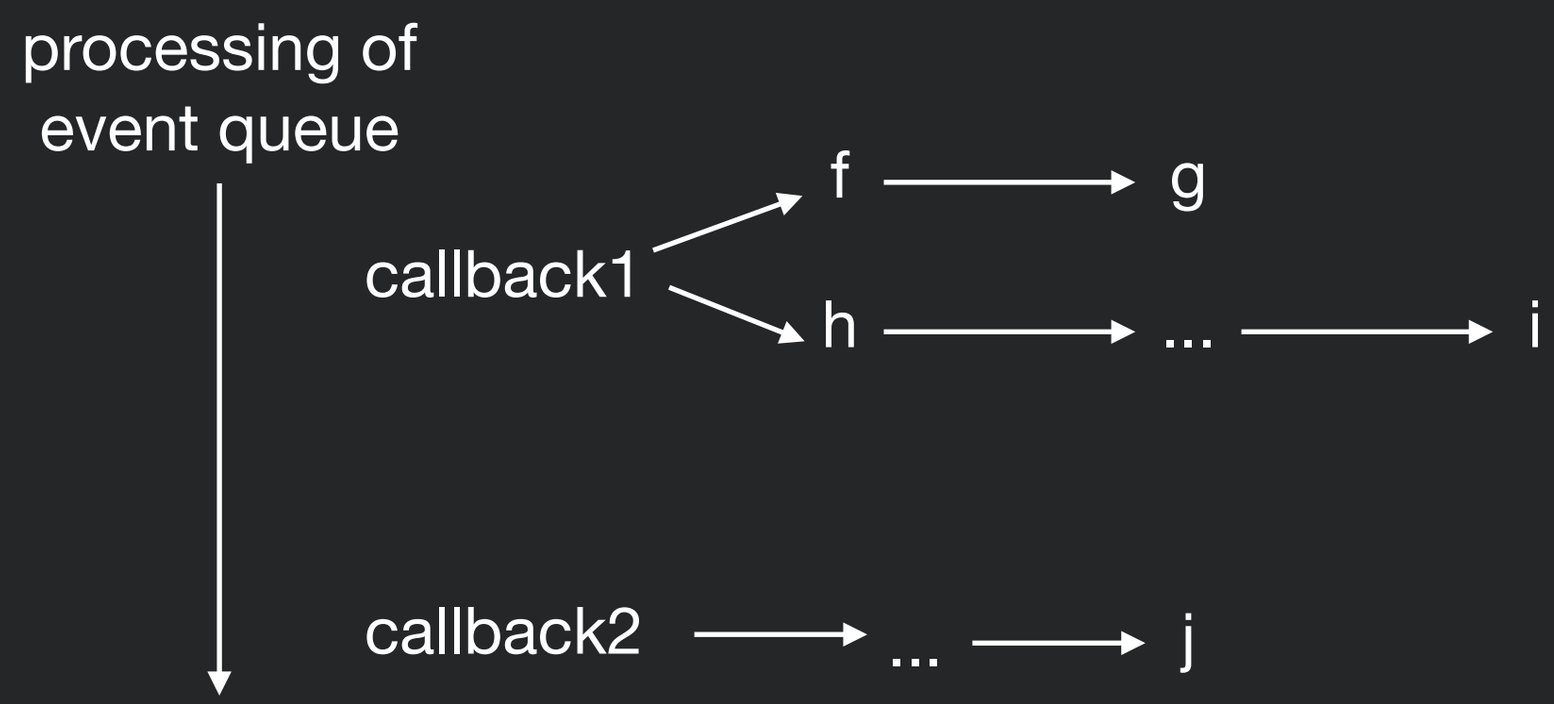
https://nodejs.org/en/docs/guides/event-loop-timers-and-nexttick/

Benefits vs. Explicit Threading (Java)

- Writing your own threads is ***difficult*** to reason about and get right:
  - When threads share data, need to ensure they correctly ***synchronize*** on it to avoid race conditions
- Main downside to events:
  - Can not have slow event handlers
  - Can still have races, although easier to reason about

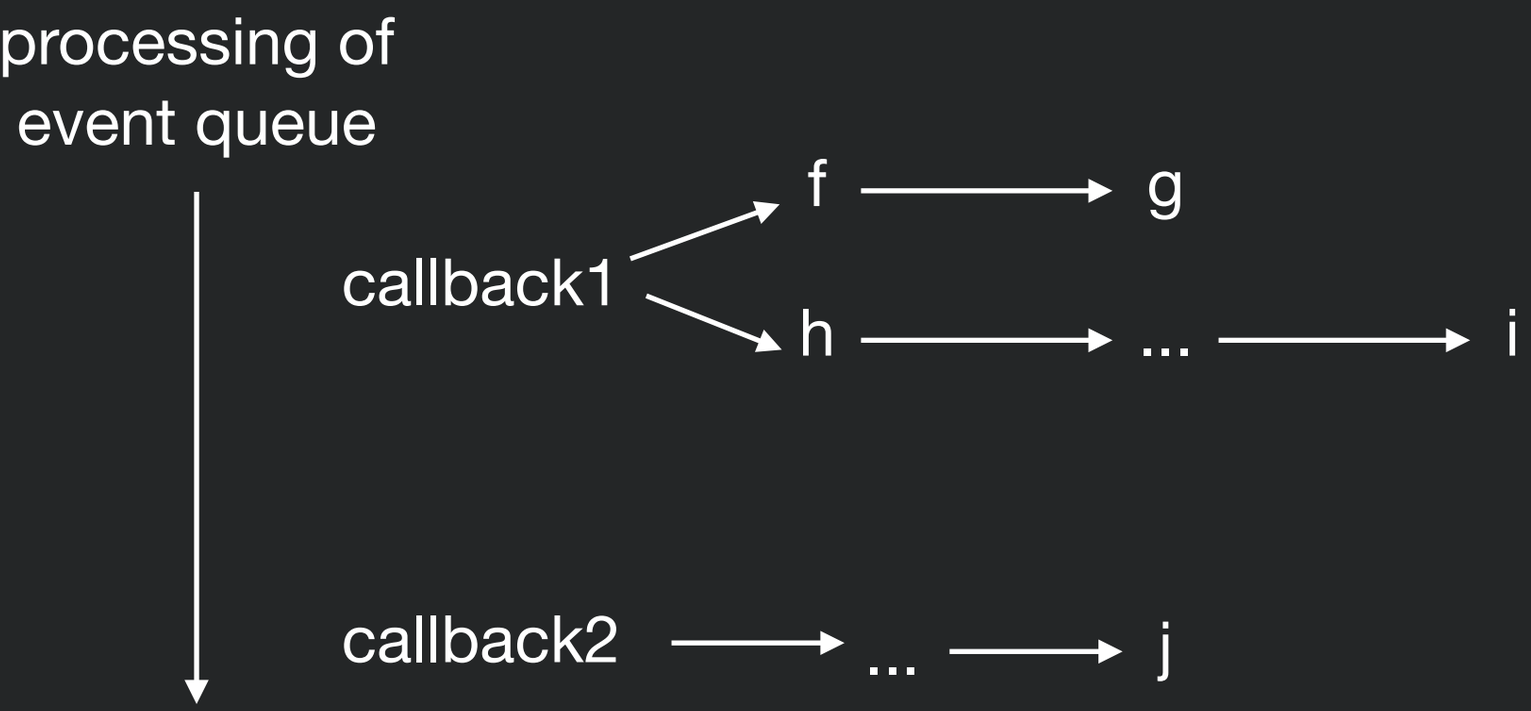
Run-to-Completion Semantics

- Run-to-completion
  - The function handling an event and the functions that it (transitively) synchronously calls will keep executing until the function finishes.
  - The JS engine will not handle the next event until the event handler finishes.



Implications of Run-to-Completion

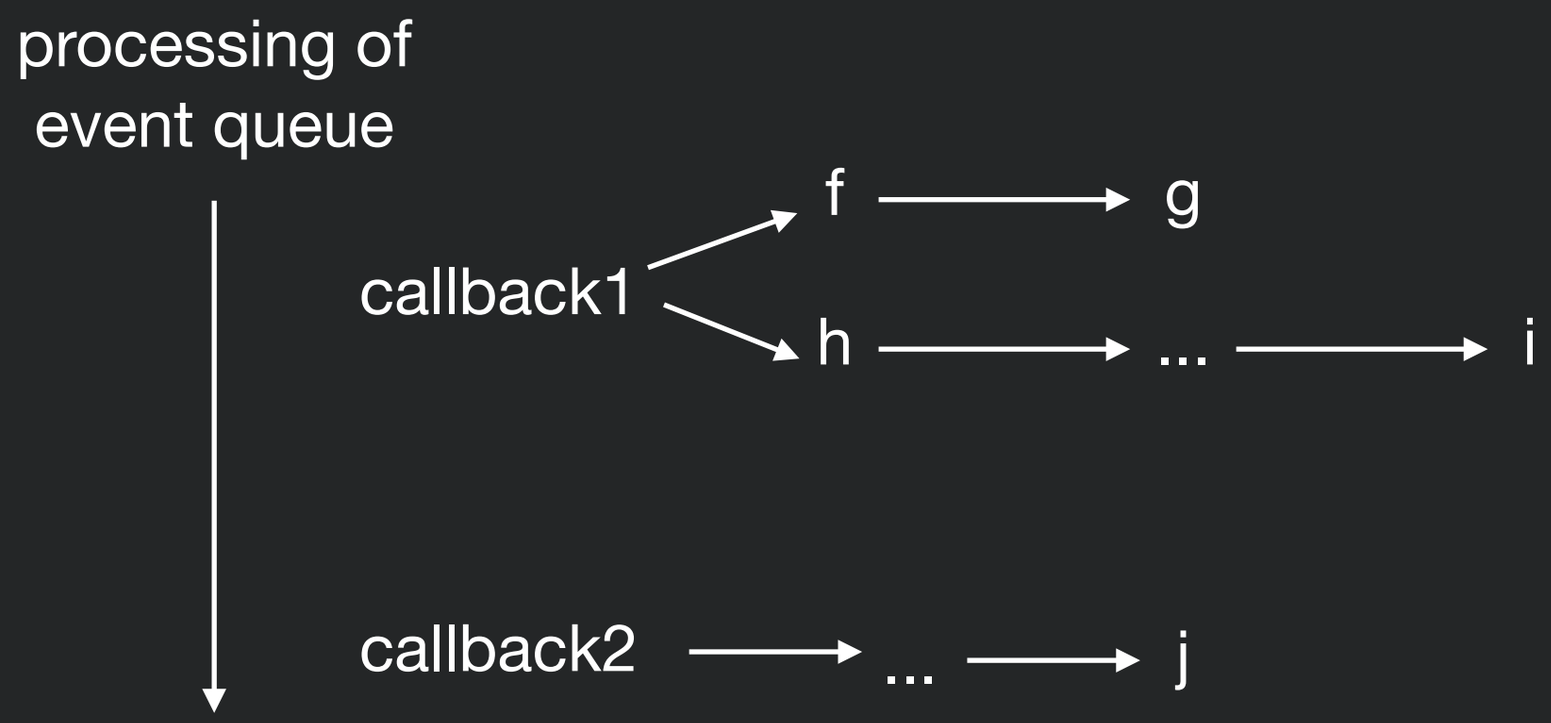
- Good news: no other code will run until you finish (no worries about other threads overwriting your data)



`j` will not execute until after `i`

Implications of Run-to-Completion

- Bad/OK news: Nothing else will happen until event handler returns
  - Event handlers should never block (e.g., wait for input) --> all callbacks waiting for network response or user input are **always** asynchronous
  - Event handlers shouldn't take a long time either



`j` will not execute until `i` finishes

Decomposing a long-running computation

- If you ***must*** do something that takes a long time (e.g. computation), split it into multiple events
  - `doSomeWork();`
  - ... [let event loop process other events]..
  - `continueDoingMoreWork();`
  - ...

Dangers of Decomposition

- Application state may ***change*** before event occurs
  - Other event handlers may be interleaved and occur before event occurs and mutate the same application state
  - --> Need to check that update still makes sense

- Application state may be in ***inconsistent*** state until event occurs
- leaving data in inconsistent state...
- Loading some data from API, but not all of it...

When good requests go bad

- It can be tricky to keep track of the status of our asynchronous requests: what happens if they cause an error?
- Most async functions let you register a second callback to be used in case of errors
- Example:

```
myAPI.request('value', function(foundValue){
    //found some data
}, function(error){
     //something went wrong
});
```

- You *must* check for errors and fail gracefully

Sequencing events

- We'd like a better way to sequence events.
- Goals:
  - Clearly distinguish ***synchronous*** from ***asynchronous*** function calls.
  - Enable computation to occur only ***after*** some event has happened, without adding an additional nesting level each time (no pyramid of doom).
  - Make it possible to handle ***errors***, including for multiple related async requests.
  - Make it possible to ***wait*** for multiple async calls to finish before proceeding.

Sequencing events with Promises

- Promises are a ***wrapper*** around async callbacks
- Promises represents ***how*** to get a value
- Then you tell the promise what to do ***when*** it gets it
- Promises organize many steps that need to happen in order, with each step happening asynchronously
- At any point a promise is either:
  - Unresolved
  - Succeeds
  - Fails

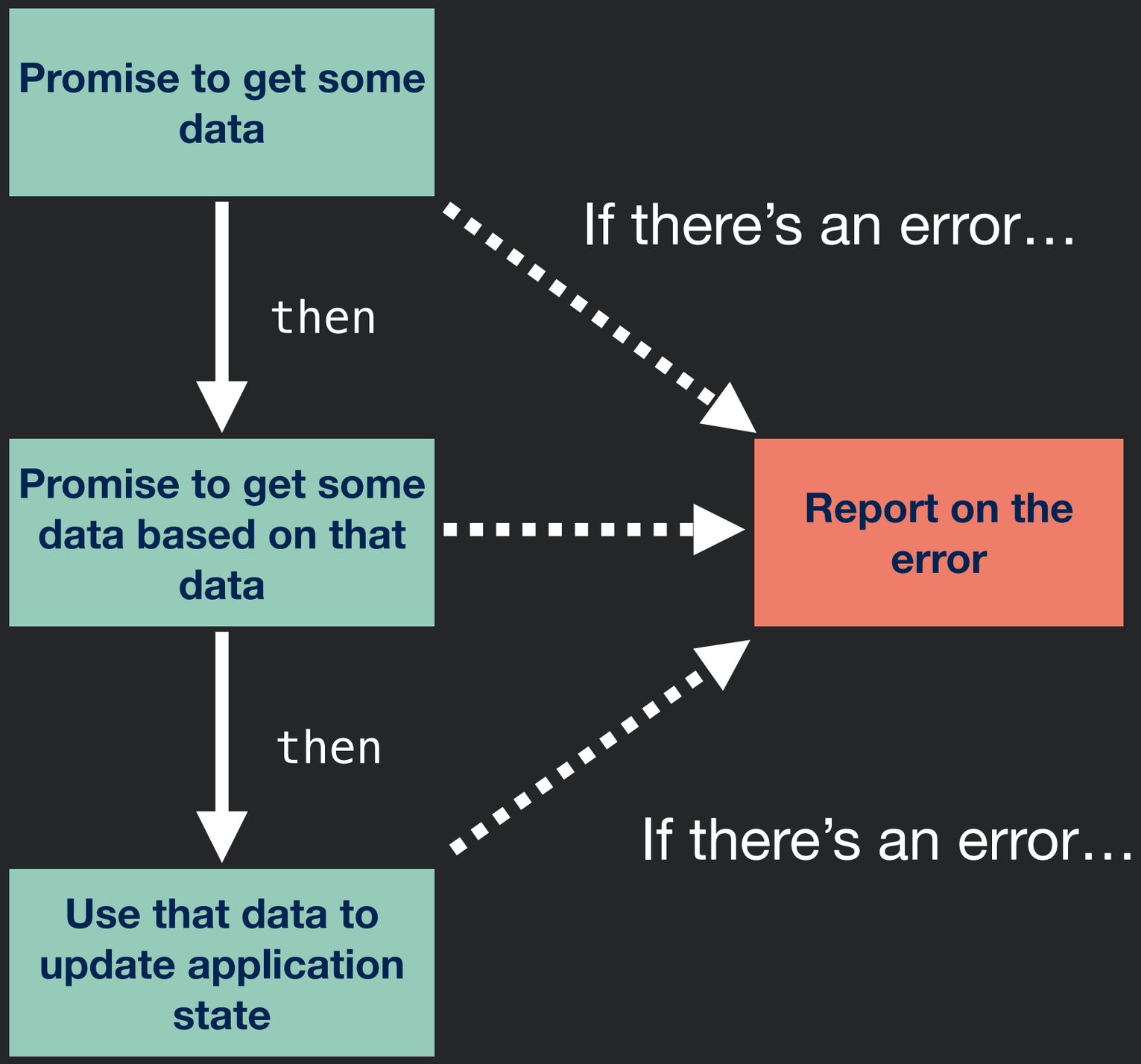
Using a Promise

- Declare what you want to do when your promise is completed (`then`), or if there's an error (`catch`)

```
fetch('https://github.com/')
    .then(function(res) {
        return res.text();
    });
```

```
fetch('http://domain.invalid/')
    .catch(function(err) {
        console.log(err);
    });
```

Promise One Thing Then Another



Chaining Promises

```
myPromise.then(function(resultOfPromise){
    //Do something, maybe asynchronously
    return theResultOfThisStep;
})
.then(function(resultOfStep1){
    //Do something, maybe asynchronously
    return theResultOfStep2;
})
.then(function(resultOfStep2){
    //Do something, maybe asynchronously
    return theResultOfStep3;
})
.then(function(resultOfStep3){
    //Do something, maybe asynchronously
    return theResultOfStep4;
})
.catch(function(error){

});
```

Writing a Promise

- Most often, Promises will be generated by an API function (e.g., `fetch`) and returned to you.
- But you can also create your own Promise.

```
var p = new Promise(function(resolve, reject) {
    if (/* condition */) {
        resolve(/* value */);  // fulfilled successfully
    }
    else {
        reject(/* reason */);  // error, rejected
    }
});
```

Example: Writing a Promise

- loadImage returns a promise to load a given image

```
function loadImage(url){
    return new Promise(function(resolve, reject) {
        var img  = new Image();
        img.src = url;
        img.onload = function(){
            resolve(img);
        }
        img.onerror = function(e){
            reject(e);
        }
    });
}
```

Once the image is loaded, we'll resolve the promise

If the image has an error, the promise is rejected

Writing a Promise

- Basic syntax:
  - do something (possibly asynchronous)
  - when you get the result, call resolve() and pass the final result
  - In case of error, call reject()

```
var p = new Promise( function(resolve,reject){
    // do something, who knows how long it will take?
    if(everythingIsOK)
    {
        resolve(stateIWantToSave);
    }
    else
        reject(Error("Some error happened"));
} );
```

Promises in Action

- Firebase example: get some value from the database, then push some new value to the database, then print out “OK”

```
todosRef.child(keyToGet).once('value')
    .then(function(foundTodo){
        return foundTodo.val().text;
    })
    .then(function(theText){
        todosRef.push({'text' : "Seriously: " + theText});
    })
    .then(function(){
        console.log("OK!");
    })
    .catch(function(error){
        //something went wrong
    });
```

Do this

Then, do this

Then do this

And if you ever had an error, do this

Testing Promises

```
function getUserName(userID) {
    return request-promise('/users/' + userID).then(user => user.name);
}

it('works with promi', () => {
expect(user.getUserN (4).toEqual('Mark'));
});
```

```
it('works with promises', () => {
    expect.assertions(1);
return user.getUserName(4).then(data => expect(data).toEqual('Mark'));
});

it('works with resolves', () => {
    expect.assertions(1);
return expect(user.getUserName(5)).resolves.toEqual('Paul');
});
```

https://jestjs.io/docs/en/tutorial-async

Asynchronous Programming II

Review: Asynchronous

- Synchronous:
  - Make a function call
  - When function call returns, the work is done
- Asynchronous:
  - Make a function call
  - Function returns immediately, before completing work!

Review: Asynchronous

- How we do multiple things at a time in JS
- NodeJS magically handles these asynchronous things in the background
- Really important when doing file/network input/output

Review: Run-to-completion semantics

- Run-to-completion
  - The function handling an event and the functions that it (transitively) synchronously calls will keep executing until the function finishes.
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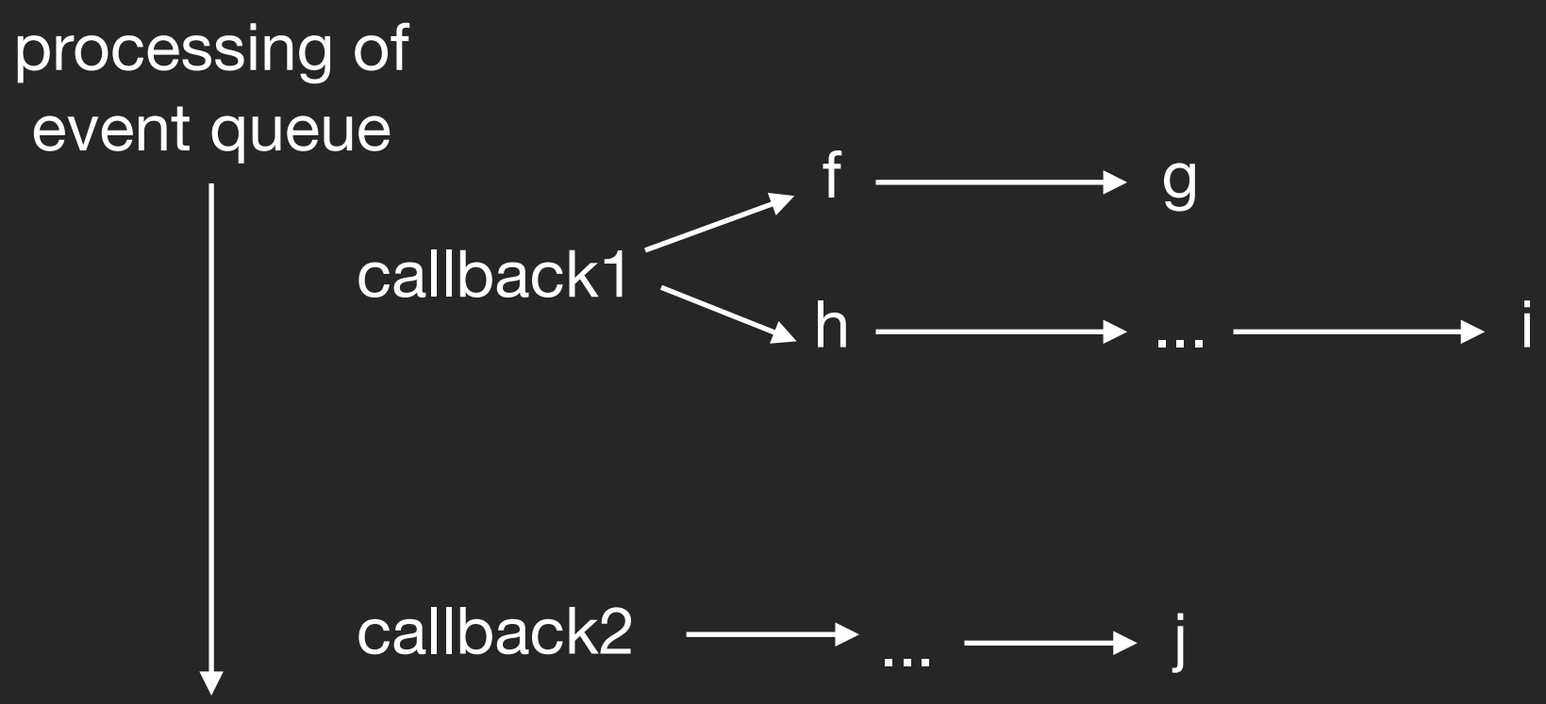

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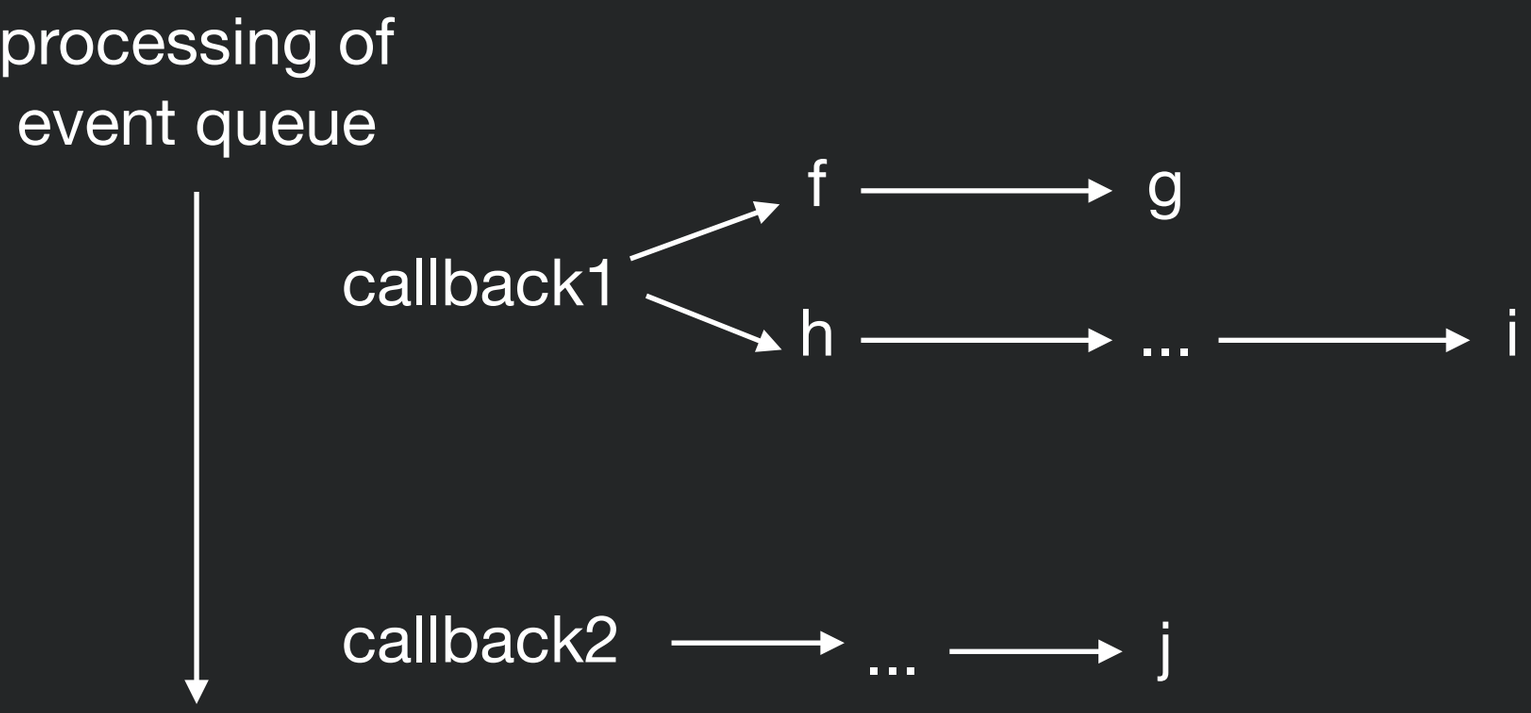

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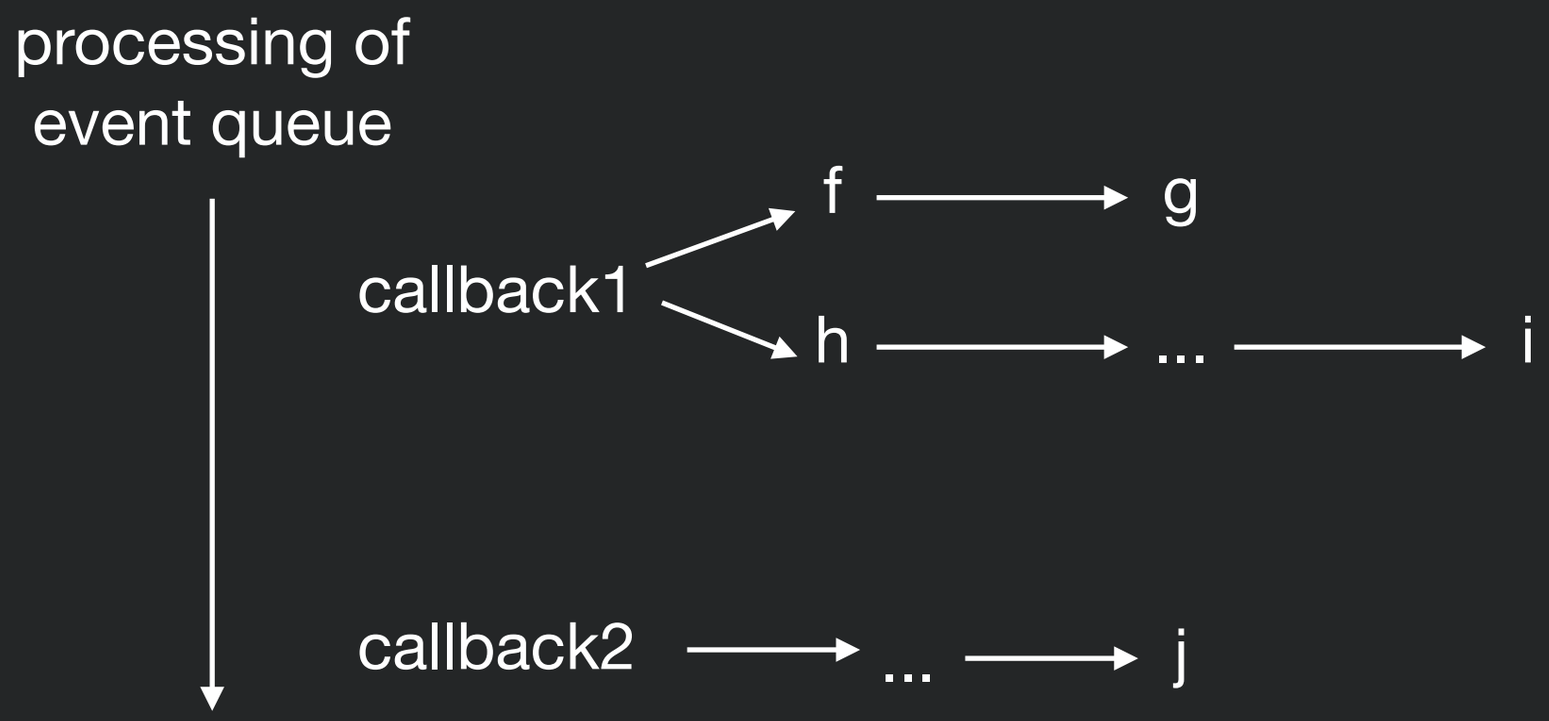

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})
.then(function(resultOfStep2){
    //Do something, maybe asynchronously
    return theResultOfStep3;
})
.then(function(resultOfStep3){
    //Do something, maybe asynchronously
    return theResultOfStep4;
})
.catch(function(error){

});
```

Current Lecture

- Async/await
- Programming activity

Promising many things

- Can also specify that *many* things should be done, and then something else
- Example: load a whole bunch of images at once:

```
Promise
  .all([loadImage("GMURGB.jpg"), loadImage(“CS.jpg")])
  .then(function (imgArray) {
        imgArray.forEach(img => {document.body.appendChild(img)})
    })
  .catch(function (e) {
    console.log("Oops");
    console.log(e);
  });
```

Async Programming Example

1 second each

Go get a data item	Go get a data item	Go get a data item	Go get a data item	Go get a data item
Go get a data item	Go get a data item	Go get a data item	Go get a data item	Go get a data item

2 seconds each

thenCombine

Group all Cal updates

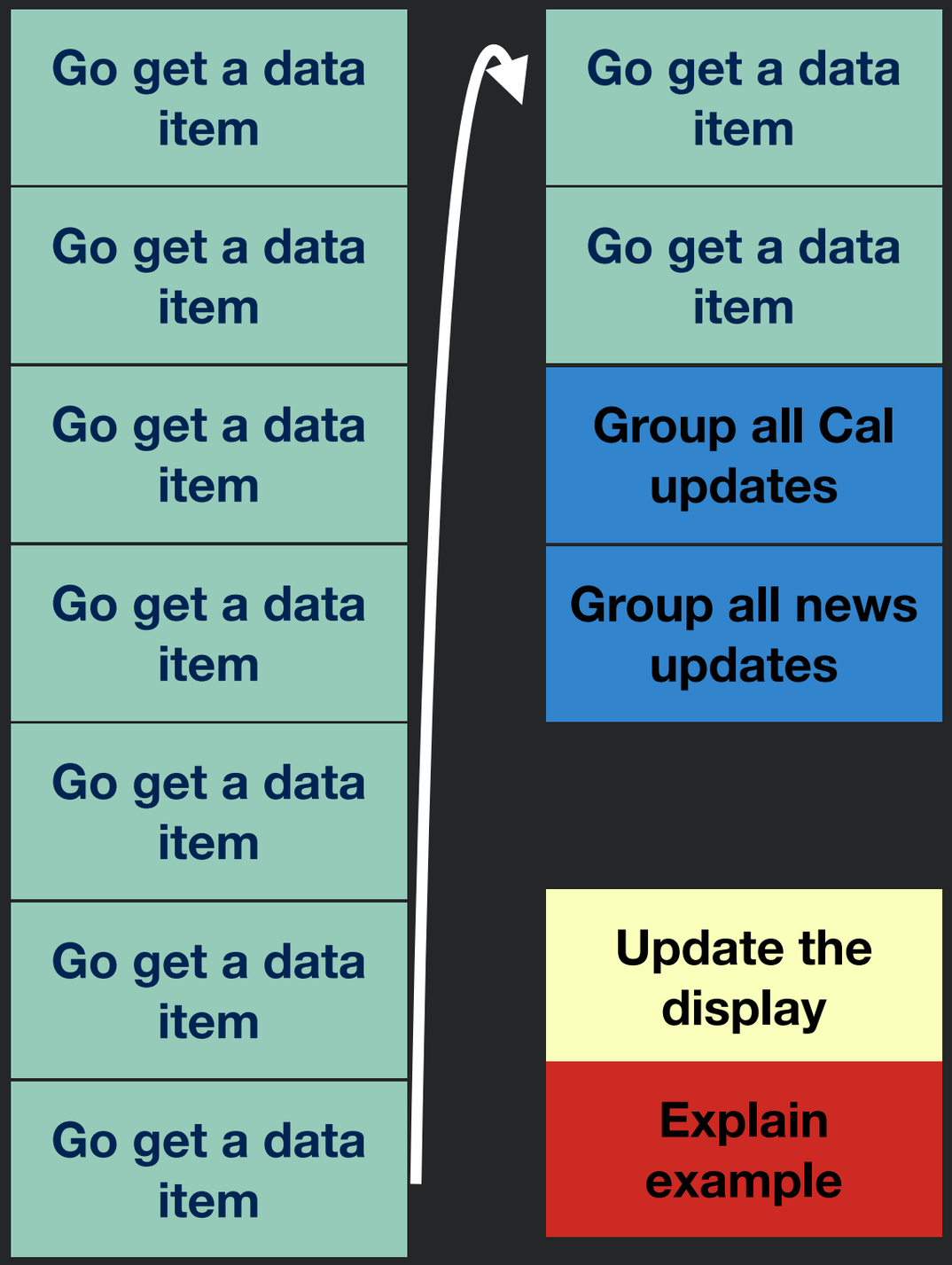
Group all news updates

when done

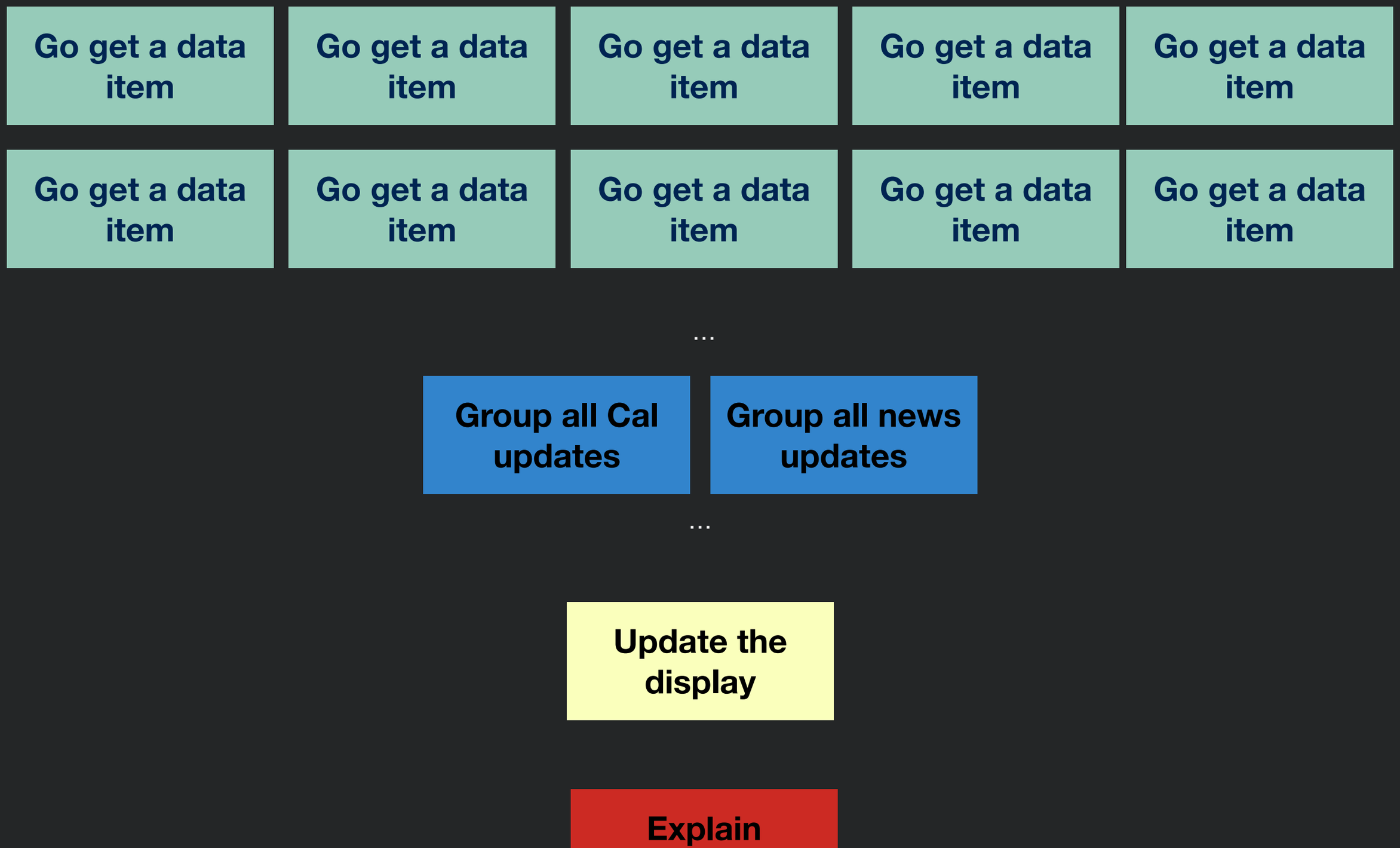
Update display

Explain example

Synchronous Version



Asynchronous Version



Sync Programming Example

```
let lib = require("./lib.js");

let thingsToFetch = ['t1','t2','t3','s1','s2',
's3','m1','m2','m3','t4'];
let stuff = [];
for(let thingToGet of thingsToFetch)
{
    stuff.push(lib.getSync(thingToGet));
    console.log("Got a thing");
}
//Got all my stuff
let ts = lib.groupSync(stuff,"t");
console.log("Grouped");
let ms = lib.groupSync(stuff,"m");
console.log("Grouped");
let ss = lib.groupSync(stuff,"s");
console.log("Grouped");

console.log("Done");
```

```
node v12.16.1
```

Async Programming Example (Callbacks, No Parallelism)

```
let lib = require("./lib.js");

let thingsToFetch = ['t1', 't2', 't3', 's1', 's2', 's3', 'm1', 'm2', 'm3', 't4'];
let stuff = [];
let ts, ms, ss;
let outstandingStuffToGet = thingsToFetch.length;

lib.getASync(thingsToFetch[0],(v)=>{
    stuff.push(v);
    console.log("Got a thing")
    lib.getASync(thingsToFetch[1],(v)=>{
        stuff.push(v);
        console.log("Got a thing")
        lib.getASync(thingsToFetch[2],(v)=>{
            stuff.push(v);
            console.log("Got a thing")
            lib.getASync(thingsToFetch[3],(v)=>{
                stuff.push(v);
                console.log("Got a thing")
                lib.getASync(thingsToFetch[4],(v)=>{
                    stuff.push(v);
                    console.log("Got a thing")
                    lib.getASync(thingsToFetch[5],(v)=>{
                        stuff.push(v);
                        console.log("Got a thing")
                        lib.getASync(thingsToFetch[6],(v)=>{
                            stuff.push(v);
                            console.log("Got a thing")
                            lib.getASync(thingsToFetch[7],(v)=>{
                                stuff.push(v);
                                console.log("Got a thing")
                                lib.getASync(thingsToFetch[8],(v)=>{
                                    stuff.push(v);
                                    console.log("Got a thing")
                                    lib.getASync(thingsToFetch[9],(v)=>{
                                        stuff.push(v);
                                        console.log("Got a thing")
                                        lib.groupAsync(stuff, "t", (t) => {
                                            ts = t;
                                            console.log("Grouped");
                                            lib.groupAsync(stuff, "m", (m) => {
                                                ss = s;
                                                console.log("Grouped");
```

```
node v12.16.1
```

Async Programming Example (Callbacks)

```
let lib = require("./lib.js");

let thingsToFetch = ['t1', 't2', 't3', 's1', 's2', 's3', 'm1', 'm2', 'm3', 't4'];
let stuff = [];
let ts, ms, ss;
let outstandingStuffToGet = thingsToFetch.length;
for (let thingToGet of thingsToFetch) {
    lib.getASync(thingToGet, (v) => {
        stuff.push(v);
        console.log("Got a thing")
        outstandingStuffToGet--;
        if (outstandingStuffToGet == 0) {
            let groupsOfStuffTogetStill = 3;
            lib.groupAsync(stuff, "t", (t) => {
                ts = t;
                console.log("Grouped");
                groupsOfStuffTogetStill--;
                if (groupsOfStuffTogetStill == 0)
                    console.log("Done");

            });
            lib.groupAsync(stuff, "m", (m) => {
                ms = m;
                console.log("Grouped");
                groupsOfStuffTogetStill--;
                if (groupsOfStuffTogetStill == 0)
                    console.log("Done");
            });
            lib.groupAsync(stuff, "s", (s) => {
                ss = s;
                console.log("Grouped");
                groupsOfStuffTogetStill--;
                if (groupsOfStuffTogetStill == 0)
                    console.log("Done");
            })
        }
    });
}
```

```
node v12.16.1
```

Async Programming Example (Promises, No Parallelism)

```
let lib = require("./lib.js");

let thingsToFetch = ['t1', 't2', 't3', 's1', 's2', 's3', 'm1', 'm2', 'm3', 't4'];
let stuff = [];
let ts, ms, ss;
let outstandingStuffToGet = thingsToFetch.length;
lib.getPromise(thingsToFetch[0]).then(
    (v)=>{
        stuff.push(v);
        console.log("Got a thing");
        return lib.getPromise(thingsToFetch[1]);
    }
).then(
     (v)=>{
        stuff.push(v);
        console.log("Got a thing");
        return lib.getPromise(thingsToFetch[1]);
    }
).then(
    (v)=>{
        stuff.push(v);
        console.log("Got a thing");
        return lib.getPromise(thingsToFetch[1]);
    }
).then(
    (v)=>{
        stuff.push(v);
        console.log("Got a thing");
        return lib.getPromise(thingsToFetch[2]);
    }
).then(
    (v)=>{
        stuff.push(v);
        console.log("Got a thing");
        return lib.getPromise(thingsToFetch[3]);
    }
).then(
    (v)=>{
        stuff.push(v);
        console.log("Got a thing");
        return lib.getPromise(thingsToFetch[4]);
```

```
node v12.16.1
```

Async Programming Example (Promises, Parallel)

```
let lib = require("./lib.js");

let thingsToFetch = ['t1', 't2', 't3', 's1', 's2', 's3',
'm1', 'm2', 'm3', 't4'];
let stuff = [];
let ts, ms, ss;

let promises = [];
for (let thingToGet of thingsToFetch) {
    promises.push(lib.getPromise(thingToGet));
}
Promise.all(promises).then((data) => {
    console.log("Got all things");
    stuff = data;
    return Promise.all([
            lib.groupPromise(stuff, "t"),
            lib.groupPromise(stuff, "m"),
            lib.groupPromise(stuff, "s")
        ]
    )
}).then((groups) => {
    console.log("Got all groups");
    ts = groups[0];
    ms = groups[1];
    ss = groups[2];
    console.log("Done");
});
```

```
node v12.16.1
```

Problems with Promises

```
const makeRequest = () => {
    try {
        return promise1()
            .then(value1 => {
                // do something
            }).catch(err => {
                //This is the only way to catch async errors
                console.log(err);
            })
    }catch(ex){
        //Will never catch async errors!!
    }
}
```

Async/Await

- The latest and greatest way to work with async functions
- A programming pattern that tries to make async code look more synchronous
- Just “await” something to happen before proceeding
- https://javascript.info/async-await

Async keyword

- Denotes a function that can block and resume execution later

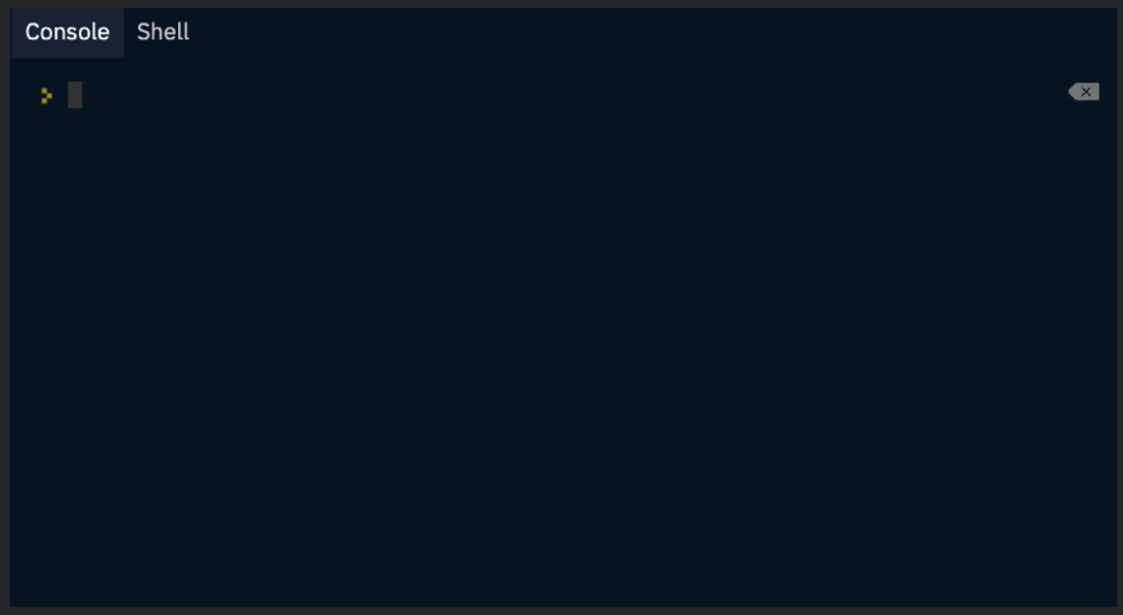
```
async function hello() { return "Hello" };
hello();
```

- Automatically turns the return type into a Promise

Async/Await Example

```
function resolveAfter2Seconds() {
    return new Promise(resolve => {
        setTimeout(() => {
            resolve('resolved');
        }, 2000);
    });
}

async function asyncCall() {
    console.log('calling');
    var result = await
resolveAfter2Seconds();
    console.log(result);
    // expected output: 'resolved'
}
```



https://replit.com/@kmoran/async-ex#script.js

Async/Await -> Synchronous

```
let lib = require("./lib.js");

async function getAndGroupStuff() {
    let thingsToFetch = ['t1', 't2', 't3', 's1', 's2',
‘s3’, 'm1', 'm2', 'm3', 't4'];
    let stuff = [];
    let ts, ms, ss;

    let promises = [];
    for (let thingToGet of thingsToFetch) {
        stuff.push(await lib.getPromise(thingToGet));
        console.log("Got a thing");
    }
    ts = await lib.groupPromise(stuff,"t");
    console.log("Made a group");
    ms = await lib.groupPromise(stuff,"m");
    console.log("Made a group");
    ss = await lib.groupPromise(stuff,"s");
    console.log("Made a group");
    console.log("Done");
}

getAndGroupStuff();
```

```
node v12.16.1
```

Async/Await

- Rules of the road:
  - You can only call **await** from a function that is **async**
  - You can only **await** on functions that return a **Promise**
- Beware: await makes your code synchronous!

```
async function getAndGroupStuff() {
...
    ts = await lib.groupPromise(stuff,"t");
...
}
```

Async/Await Activity

Rewrite this code so that all of the things are fetched (in parallel) and then all of the groups are collected using async/await

```
let lib = require("./lib.js");

async function getAndGroupStuff() {
    let thingsToFetch = ['t1', 't2', 't3', 's1', 's2', 's3', 'm1', 'm2', 'm3', 't4'];
    let stuff = [];
    let ts, ms, ss;

    let promises = [];
    for (let thingToGet of thingsToFetch) {
        stuff.push(await lib.getPromise(thingToGet));
        console.log("Got a thing");
    }
    ts = await lib.groupPromise(stuff,"t");
    console.log("Made a group");
    ms = await lib.groupPromise(stuff,"m");
    console.log("Made a group");
    ss = await lib.groupPromise(stuff,"s");
    console.log("Made a group");
    console.log("Done");
}

getAndGroupStuff();
```

https://replit.com/@kmoran/SWE-Week-3-Activity#index.js

I will also post to Ed right now!

Acknowledgements

Slides adapted from Dr. Thomas LaToza's SWE 432 course