

Asynchronous JS

SWE 432, Fall 2019

Web Application Development

Today

- 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/>

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)

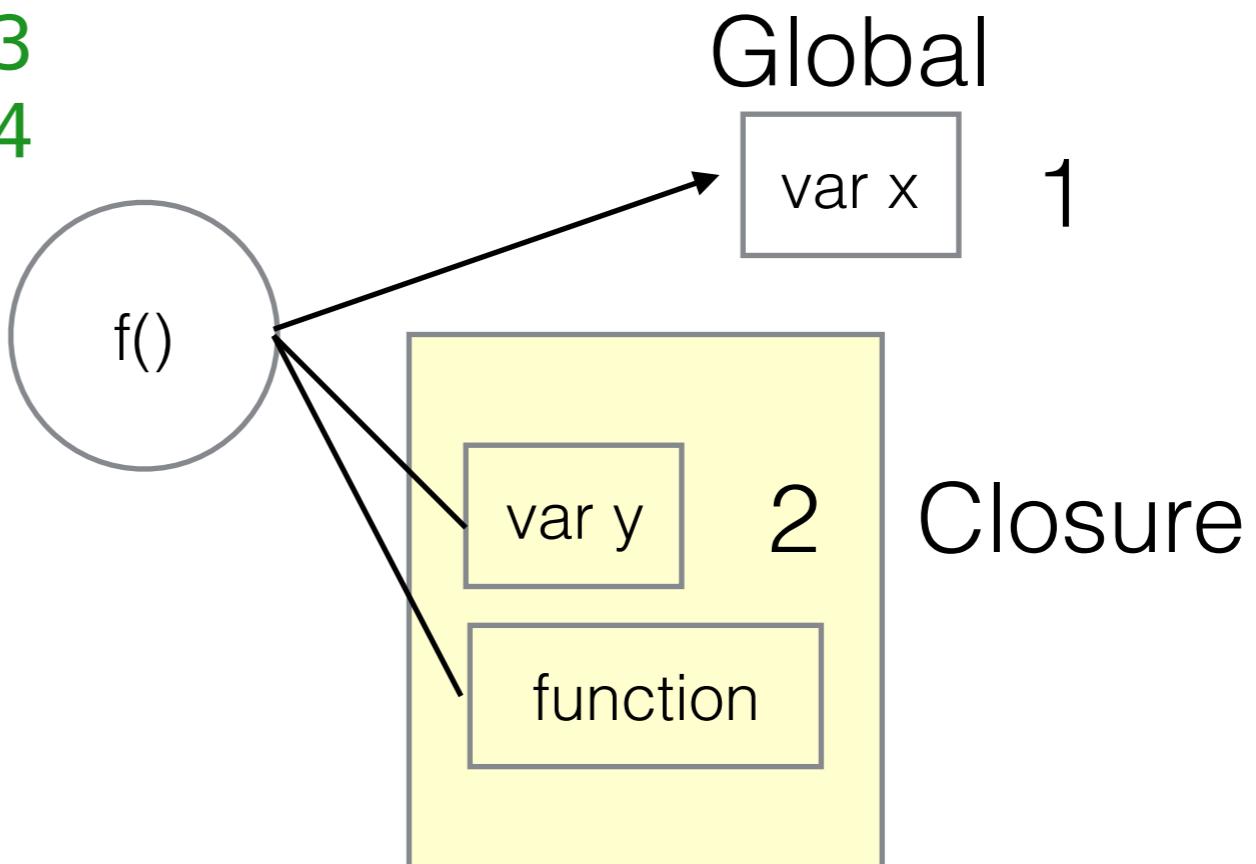
```
var x = 1;
function f() {
  var y = 2;
  return function() {
    console.log(x + y)
    y++;
  };
}
var g = f();
g();           // 1+2 is 3
g();           // 1+3 is 4
```

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

It “**closes up**” those references

Review: Closures

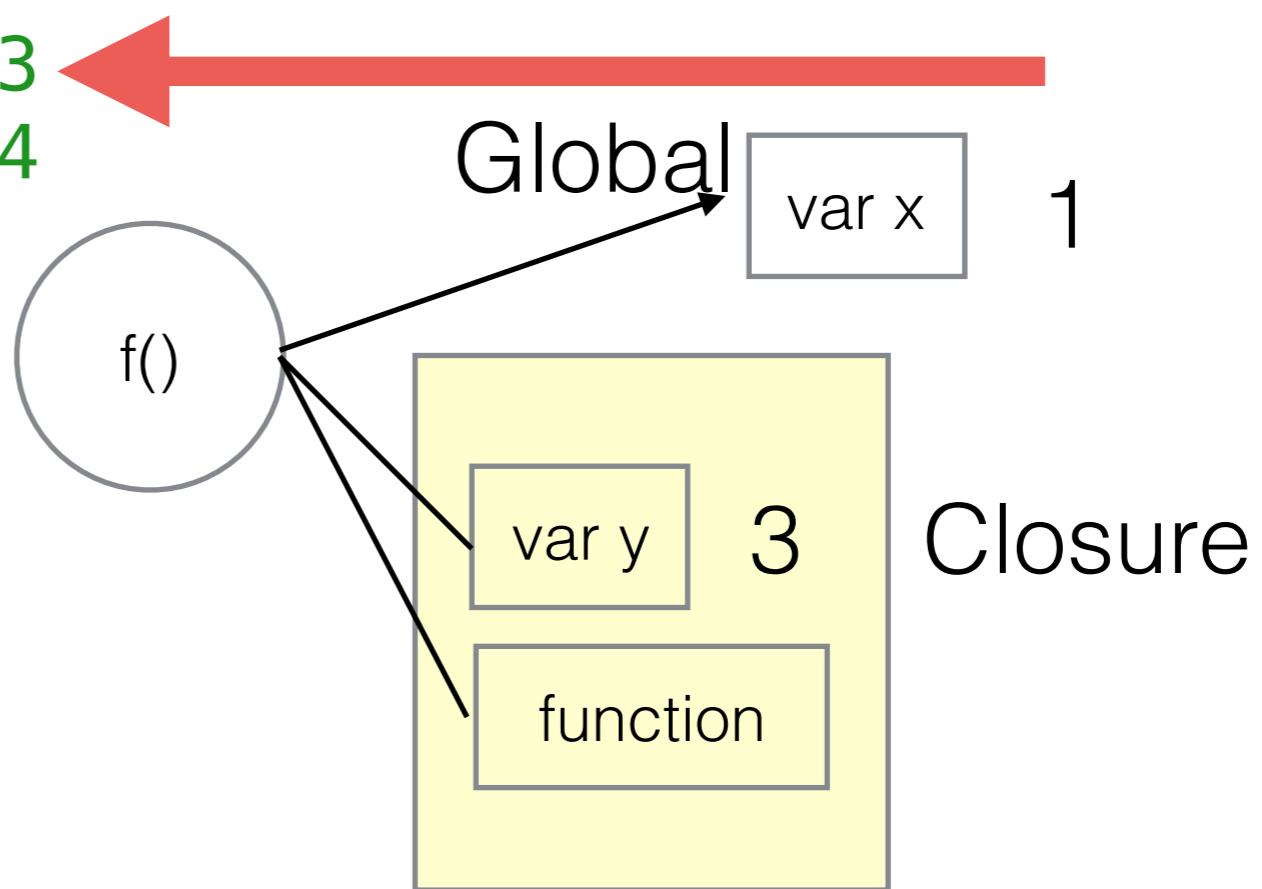
```
var x = 1;  
function f() {  
  var y = 2;  
  return function() {  
    console.log(x + y);  
    y++;  
  };  
}  
var g = f();  
g(); // 1+2 is 3  
g(); // 1+3 is 4
```



Review: Closures

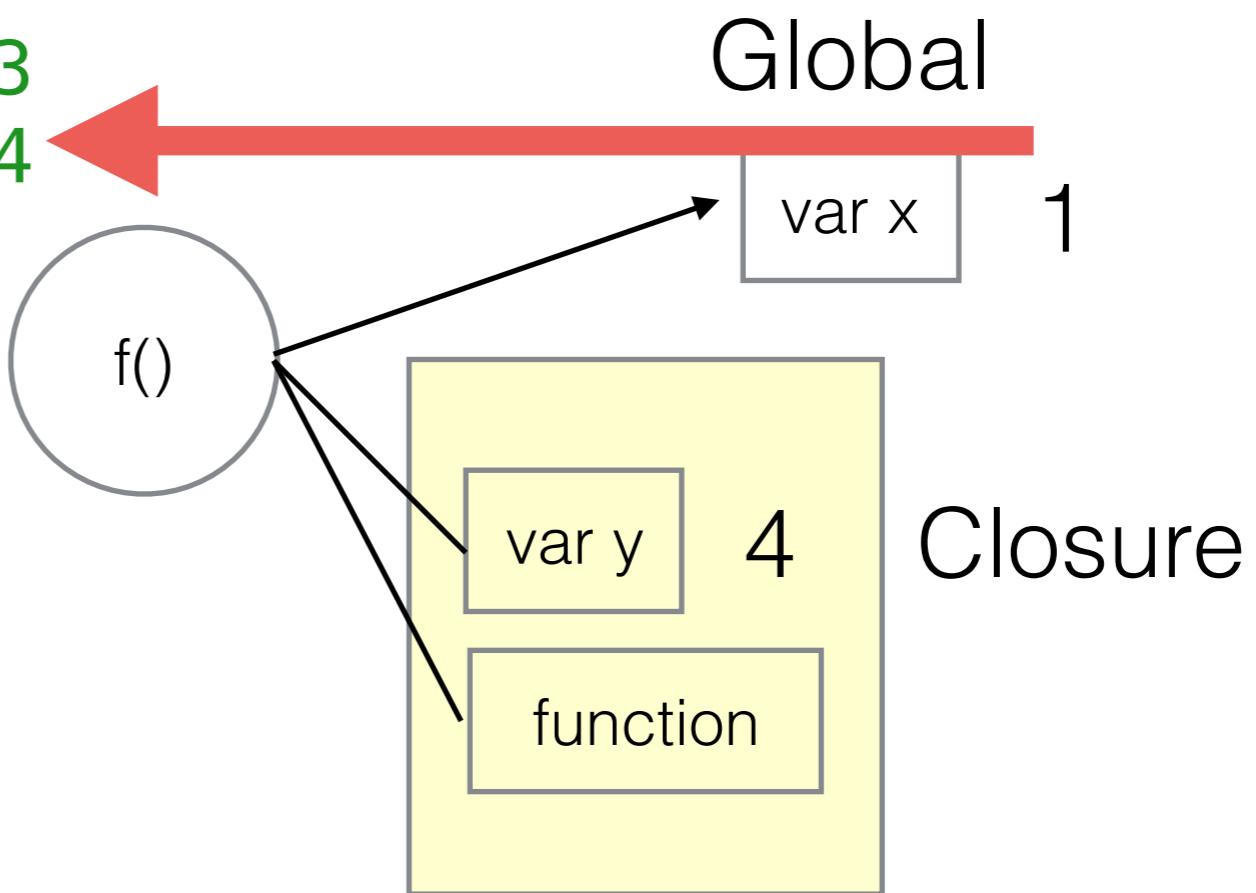
```
var x = 1;  
function f() {  
  var y = 2;  
  return function() {  
    console.log(x + y);  
    y++;  
  };  
};
```

```
var g = f();  
g();           // 1+2 is 3  
g();           // 1+3 is 4
```



Review: Closures

```
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
```



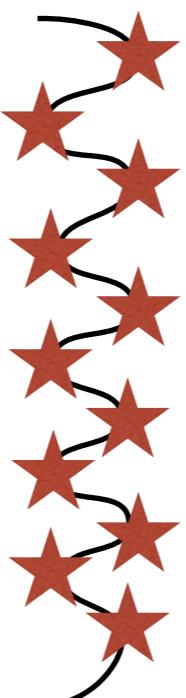
Why Asynchronous?

- 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)

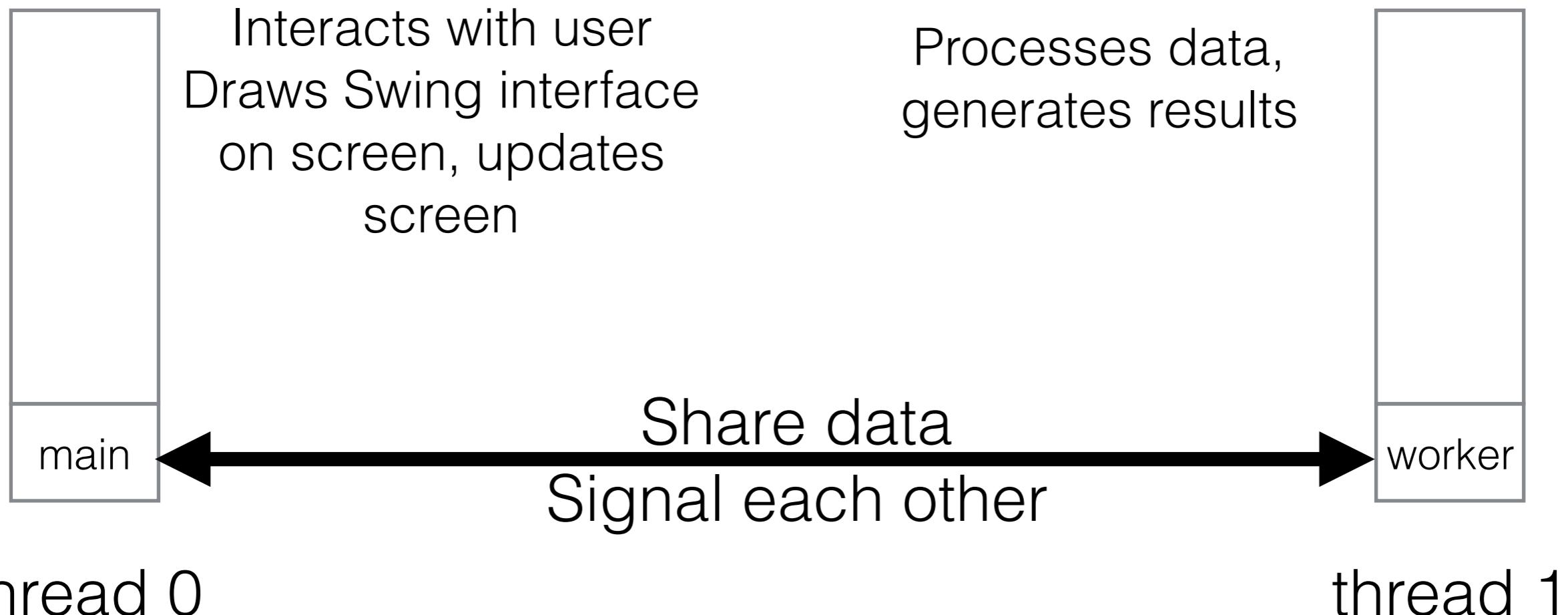
App Starts

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

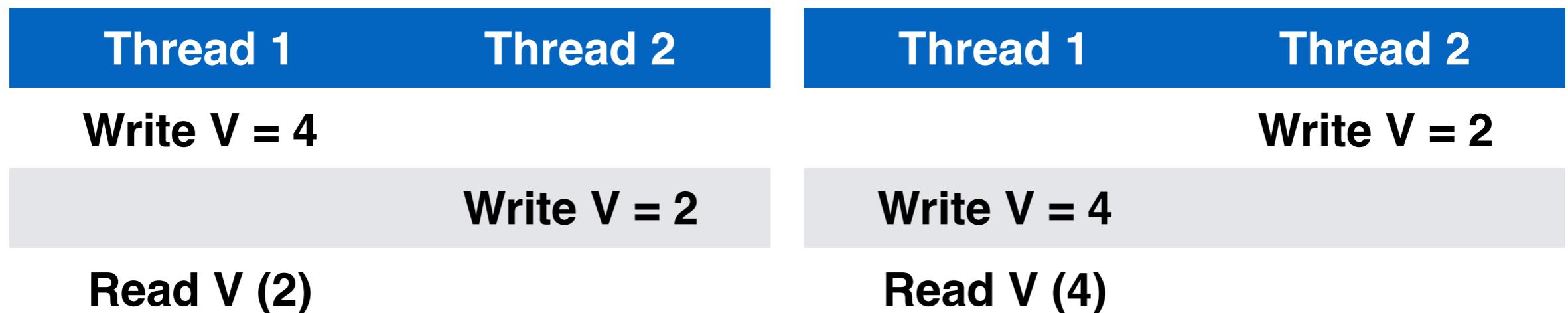


Woes of Multi-Threading

```
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



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");
```

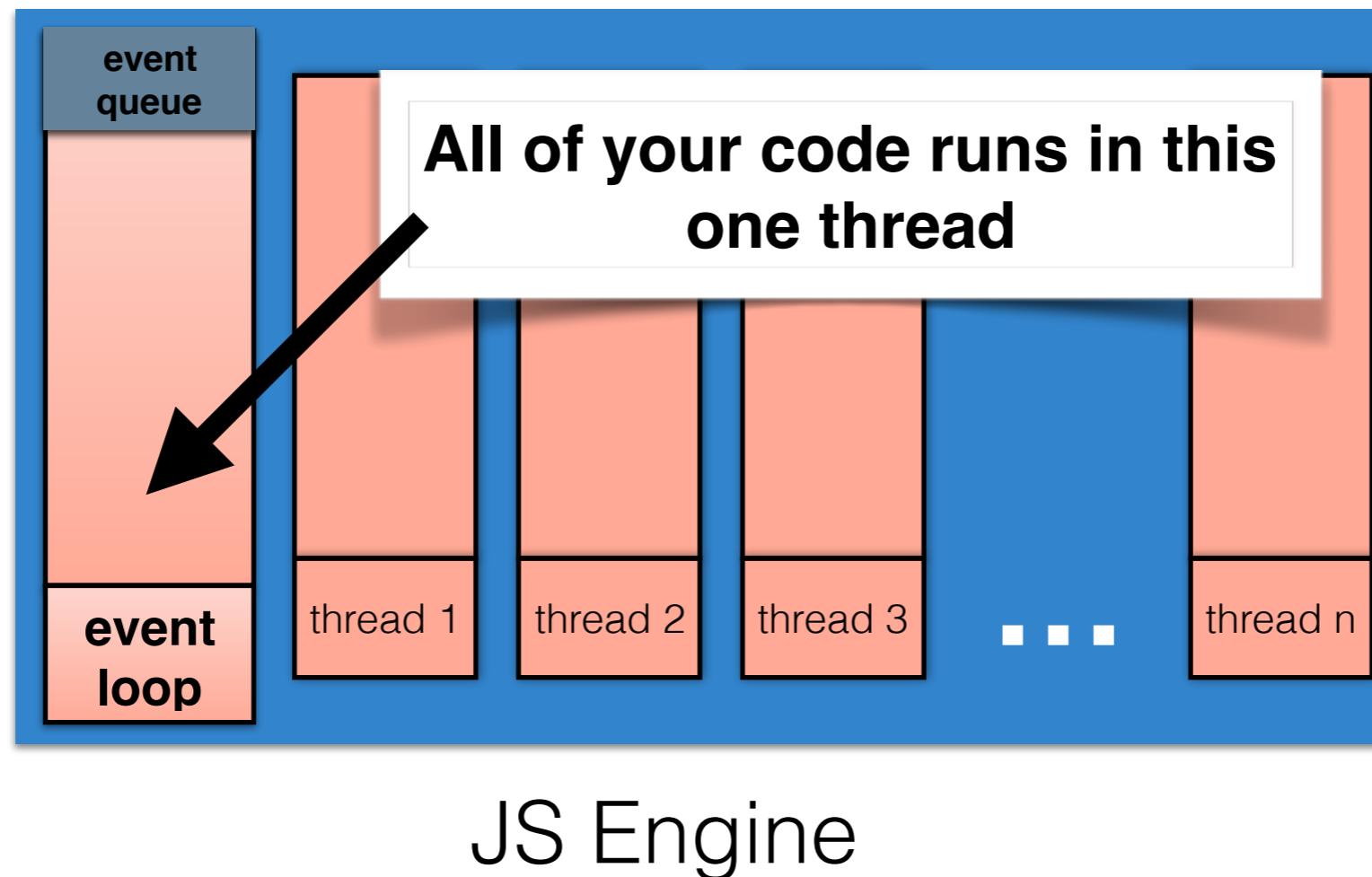
Output:

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



JS Engine

The Event Loop

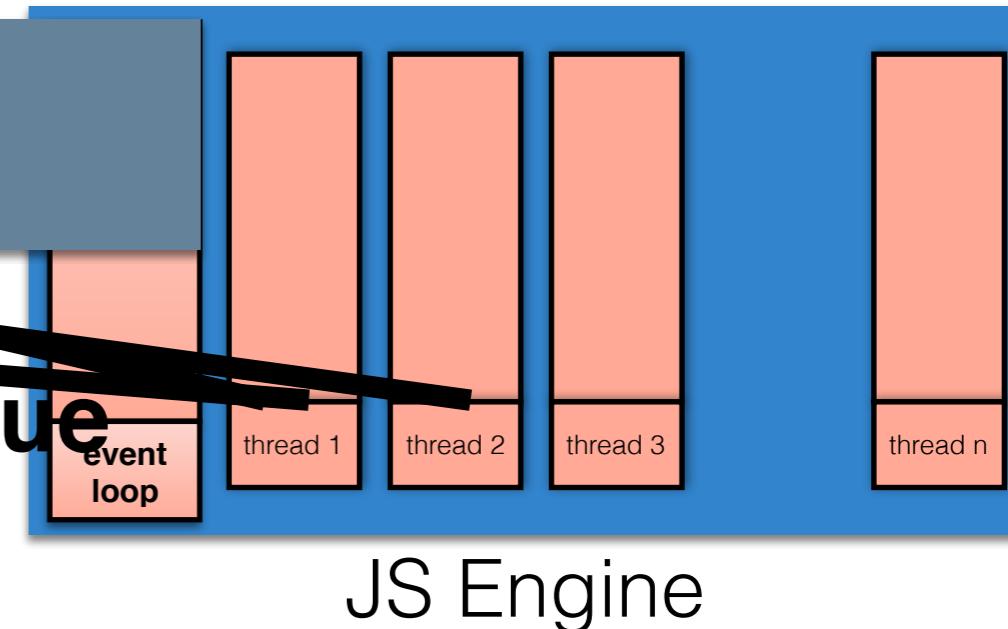
Event Queue

response from
google.com

response from
facebook.com

response from
gmu.edu

Process these events in the event queue



JS Engine

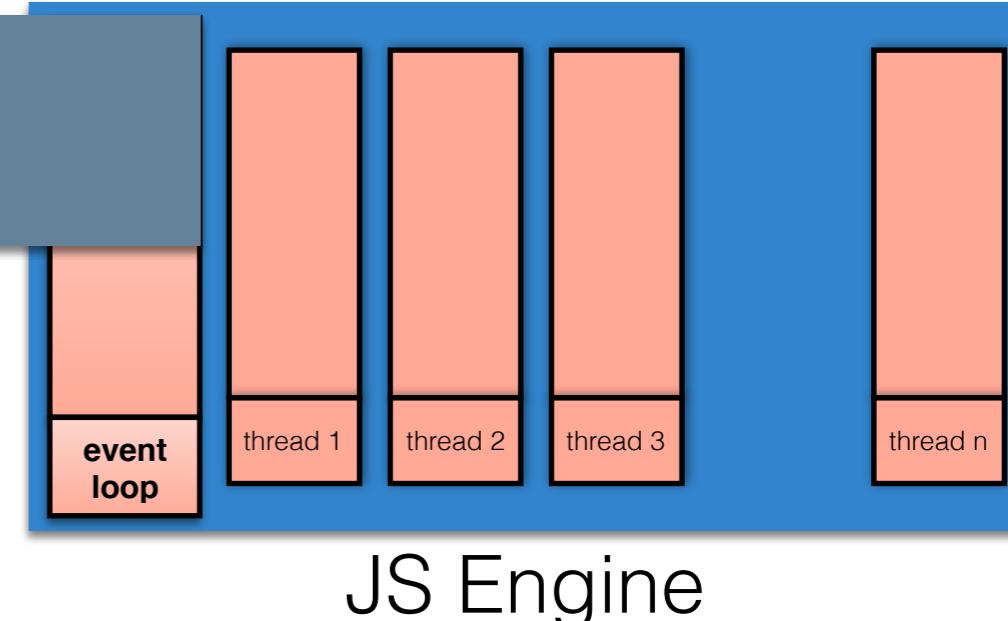
Event Being Processed:

The Event Loop

Event Queue

response from
facebook.com

response from
gmu.edu



JS Engine

Event Being Processed:

response from
google.com

Are there any listeners registered for this event?

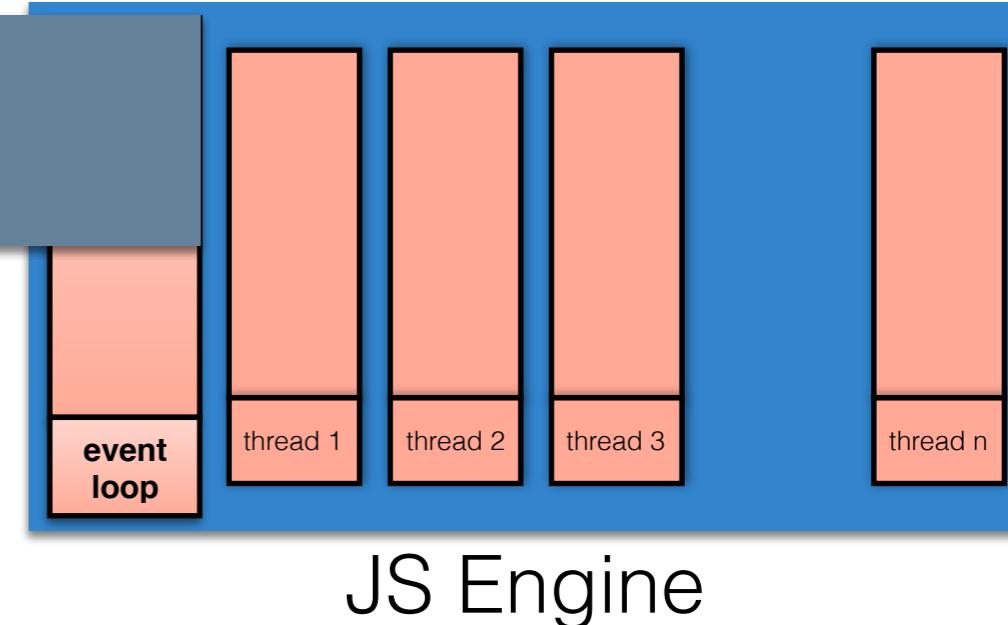
If so, call listener with event

After the listener is finished, repeat

The Event Loop

Event Queue

response from
gmu.edu



JS Engine

Event Being Processed:

response from
facebook.com

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



Event Being Processed:

response from
gmu.edu

- 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



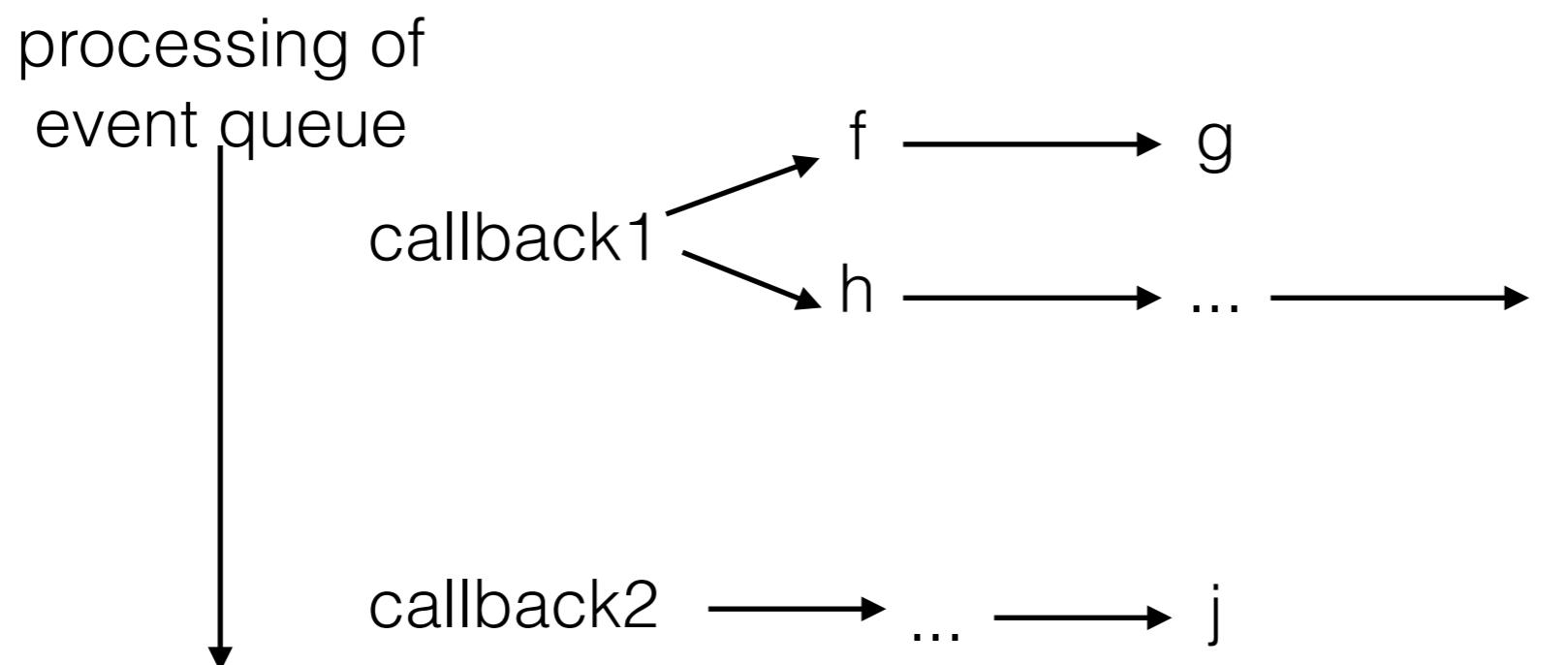
<https://nodejs.org/en/docs/guides/event-loop-timers-and-nexttick/>

Benefits vs. Explicit Threading (Java)

- Writing your own threads is 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

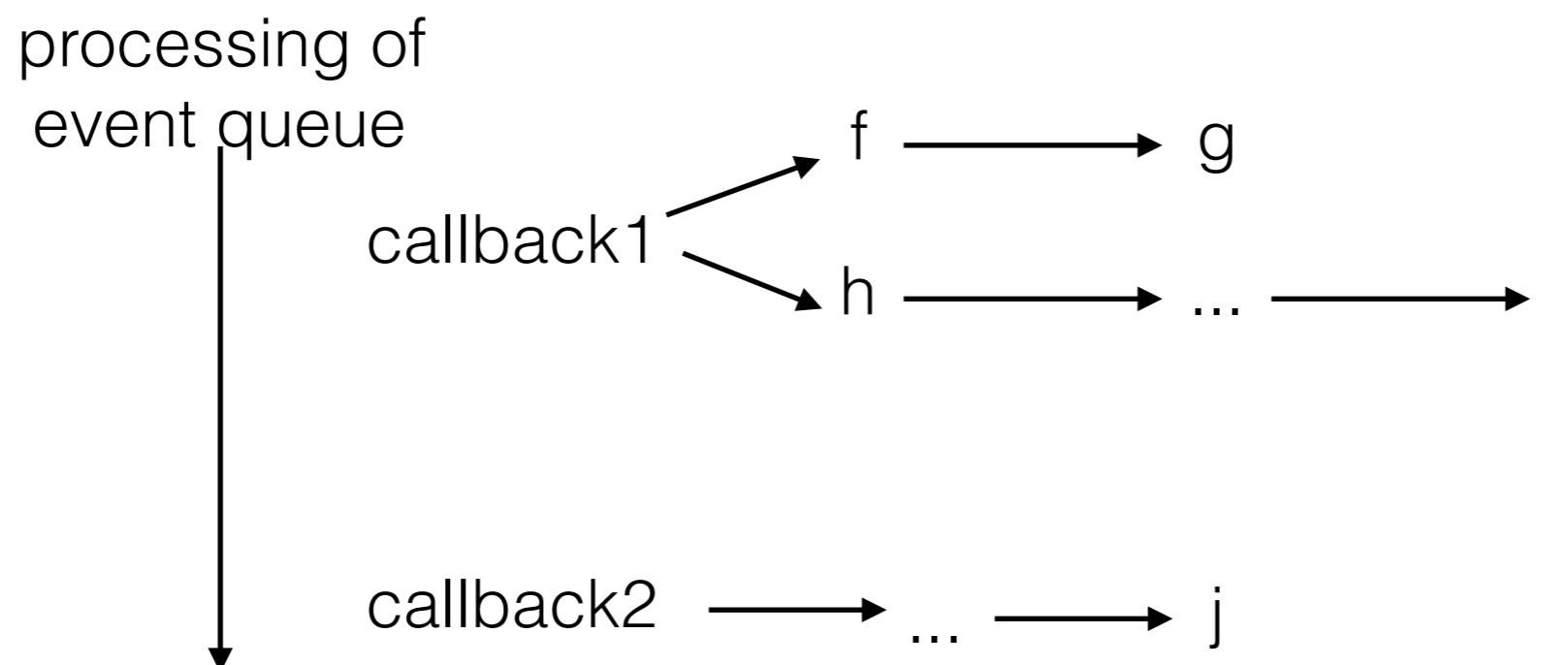
Run-to-completion semantics

- 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

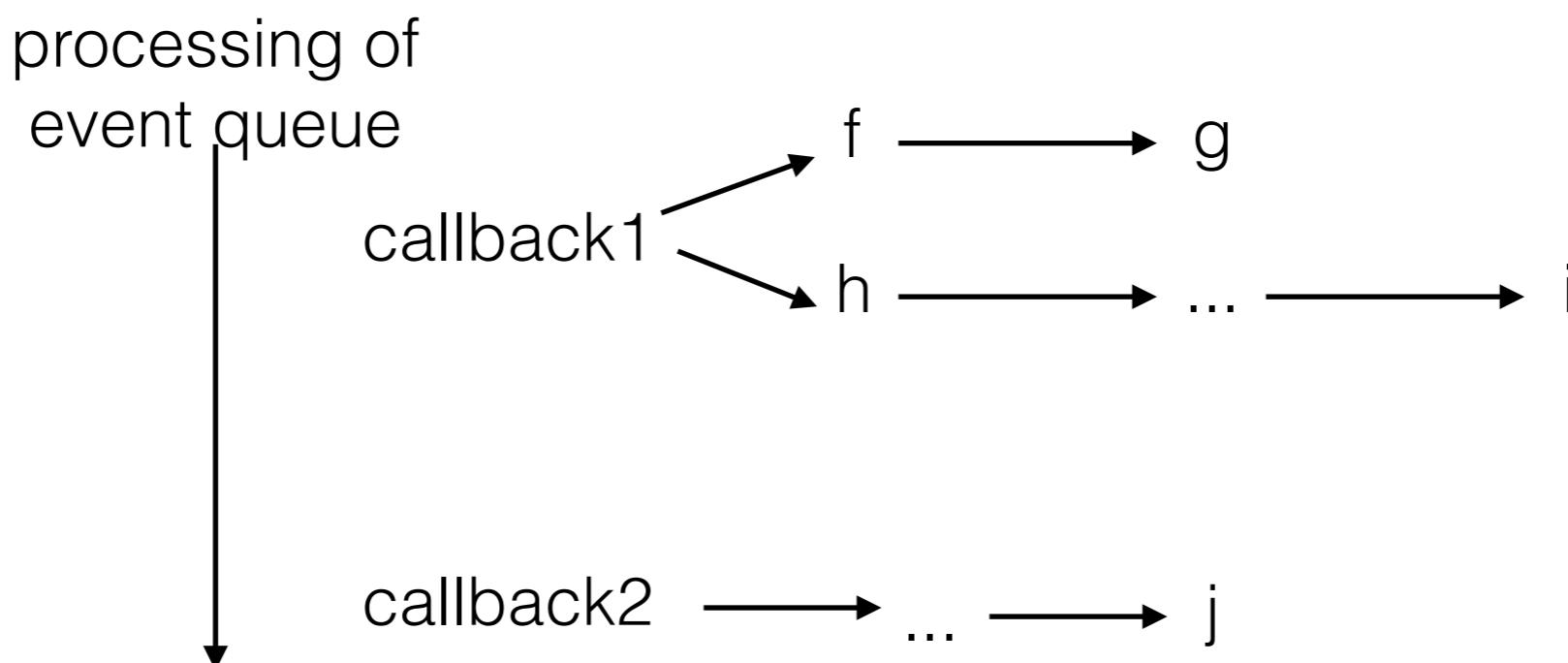
- Good news: no other code will run until you finish (no worries about other threads overwriting your data)



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
 - Application
 - leaving data in inconsistent state...
 - Loading some data from API, but not all of it...

Example: Writing Asynchronous Tasks

- From an array of 10 URL's:
 - Request each URL
 - Then for each page, save it to disk
 - Then once all of the pages are downloaded and saved, print out the total size of all of the files that were saved

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:
 - Is unresolved
 - Succeeds
 - Fails

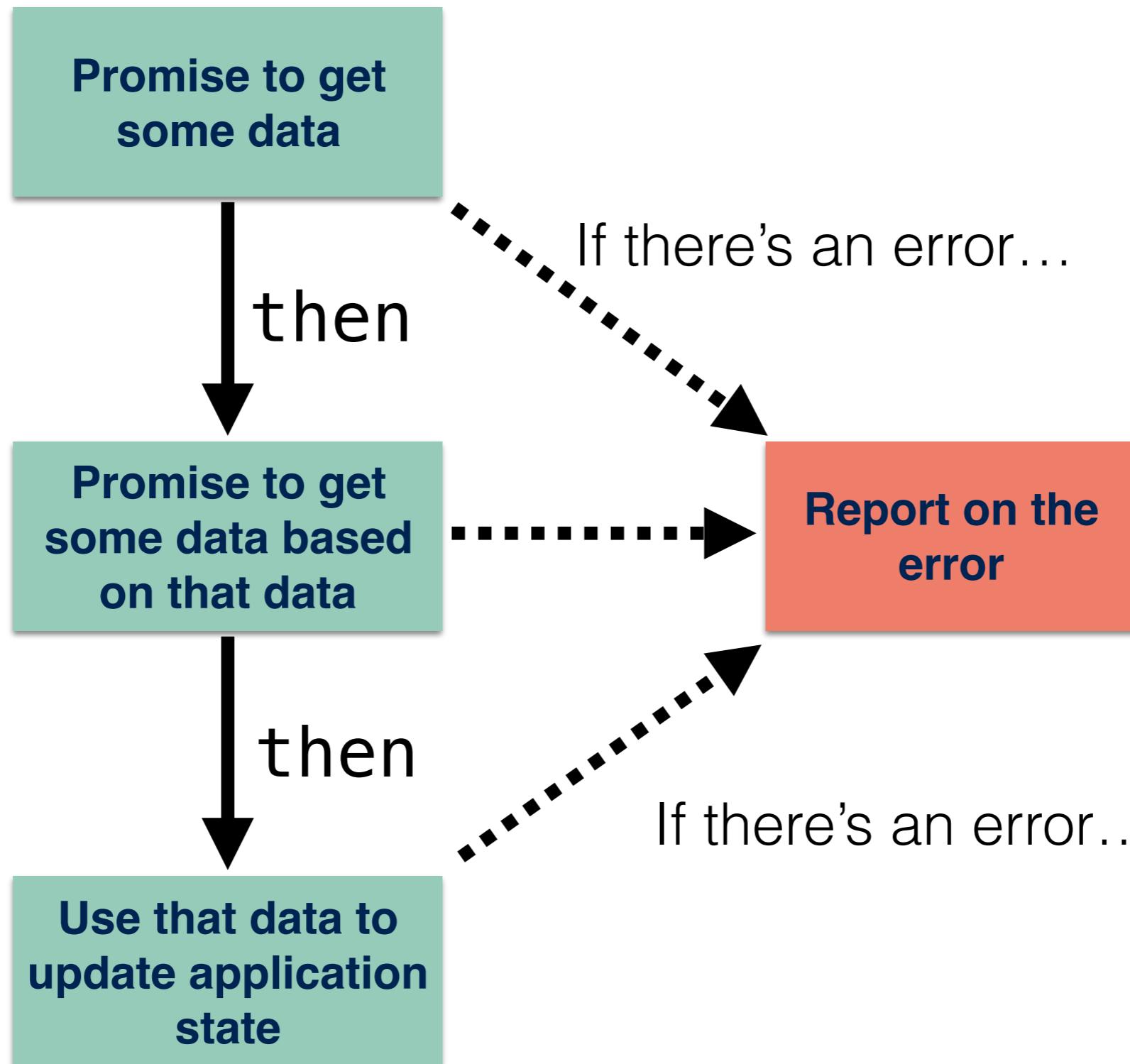
Using a Promise

- 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;      Do this
  })
  .then(function(theText){          Then, do this
    todosRef.push({'text' : "Seriously: " + theText});
  })
  .then(function(){                Then do this
    console.log("OK!");
  })
  .catch(function(error){
    //something went wrong
  });

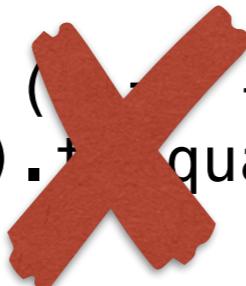
```

And if you ever had an error, do this

Testing Promises

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

```
it('works with promises', () => {  
  expect(user.getUserName(4).then).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>

Next Time

- More asynchronous examples
- `async/await` keywords
- Threading in JS