Asynchronous Programming

SWE 432, Fall 2017

Design and Implementation of Software for the Web

Today

- What is asynchronous programming?
- What are threads?
- How does JS keep programs responsive?
- Writing asynchronous code with Promises and timers

What does this code do?

```
var global;
var fetch = require('node-fetch');

fetch('https://api.wmata.com/Incidents.svc/json/
ElevatorIncidents',
    { headers: { api_key:
"e1eee2b5677f408da40af8480a5fd5a8"} })
    .then(function(res) {
        return res.json();
    }).then(function(json) {
    global = json;
});
console.log(global.ElevatorIncidents[0]);
```

Why write asynchronous programs?

- Asynchronous programs occur when there are events which occur outside the control flow of your program
  - Data arrived back from an HTTP request made earlier
  - A timer went off
  - The OS sent a message
  - (Client-side) The user clicked a button

What's wrong with this program?

```
var global;
var fetch = require('node-fetch');

global = fetch('https://api.wmata.com/Incidents.svc/json/
ElevatorIncidents',
    { headers: { api_key:
"e1eee2b5677f408da40af8480a5fd5a8"} }).json();

console.log(global.ElevatorIncidents[0]);
```

Note: this code is hypothetical and does not reflect the actual behavior of fetch.

The perils of blocking

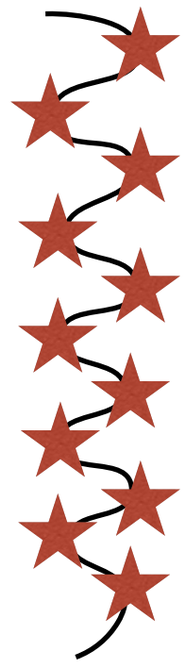
- Asynchronous events might take a **long time** to occur
  - Waiting for data from a server
  - A button that the user never clicks on

- Want to execute code that occurs after such an event occurs
- But, in the meantime, want application to be **responsive** so that other computation can occur and over events can be handled

Solution 1: Threads

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

App Starts



App Ends

Solution 1: Threads

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

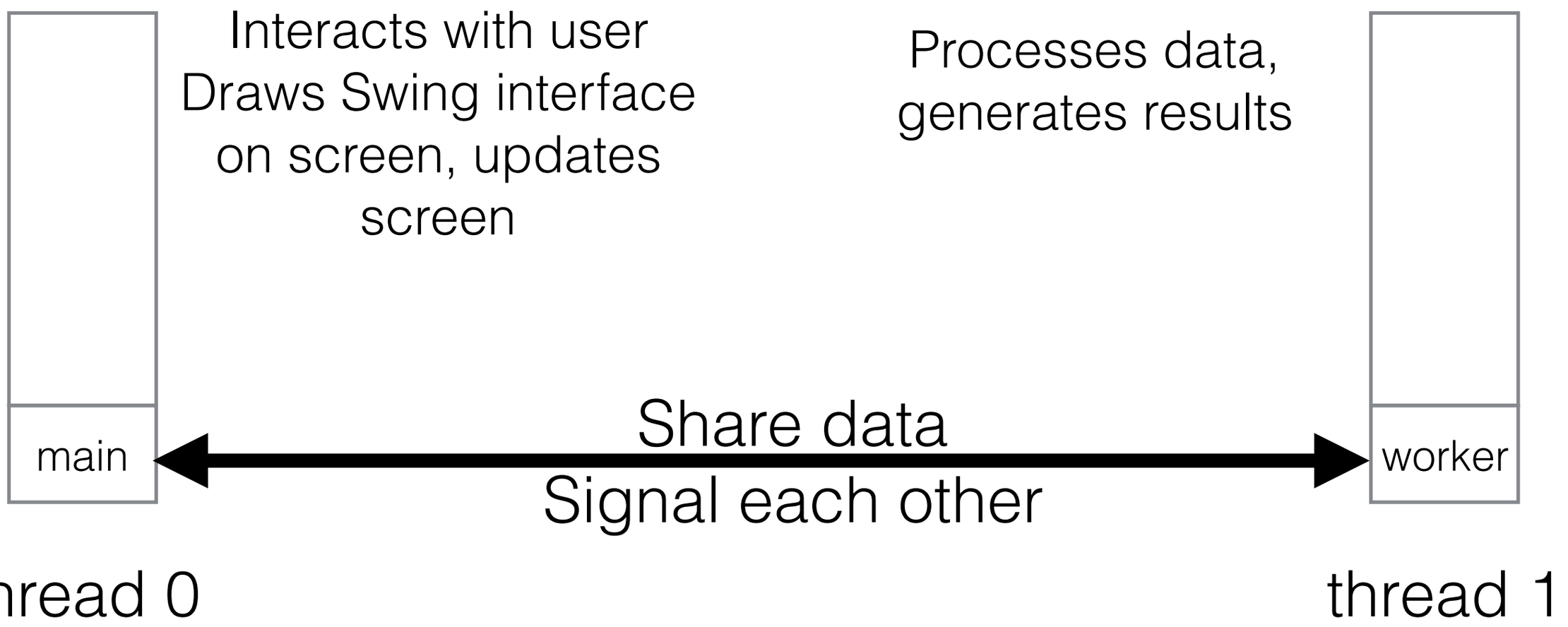
App Starts

App Ends

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

Multi-Threading in Java

- Allowing more than one thread is **multi-threading**
- Multi-Threading enables responsiveness by allowing computation to occur in parallel
- May occur physically through multiple cores and/or logically through 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;
}
```

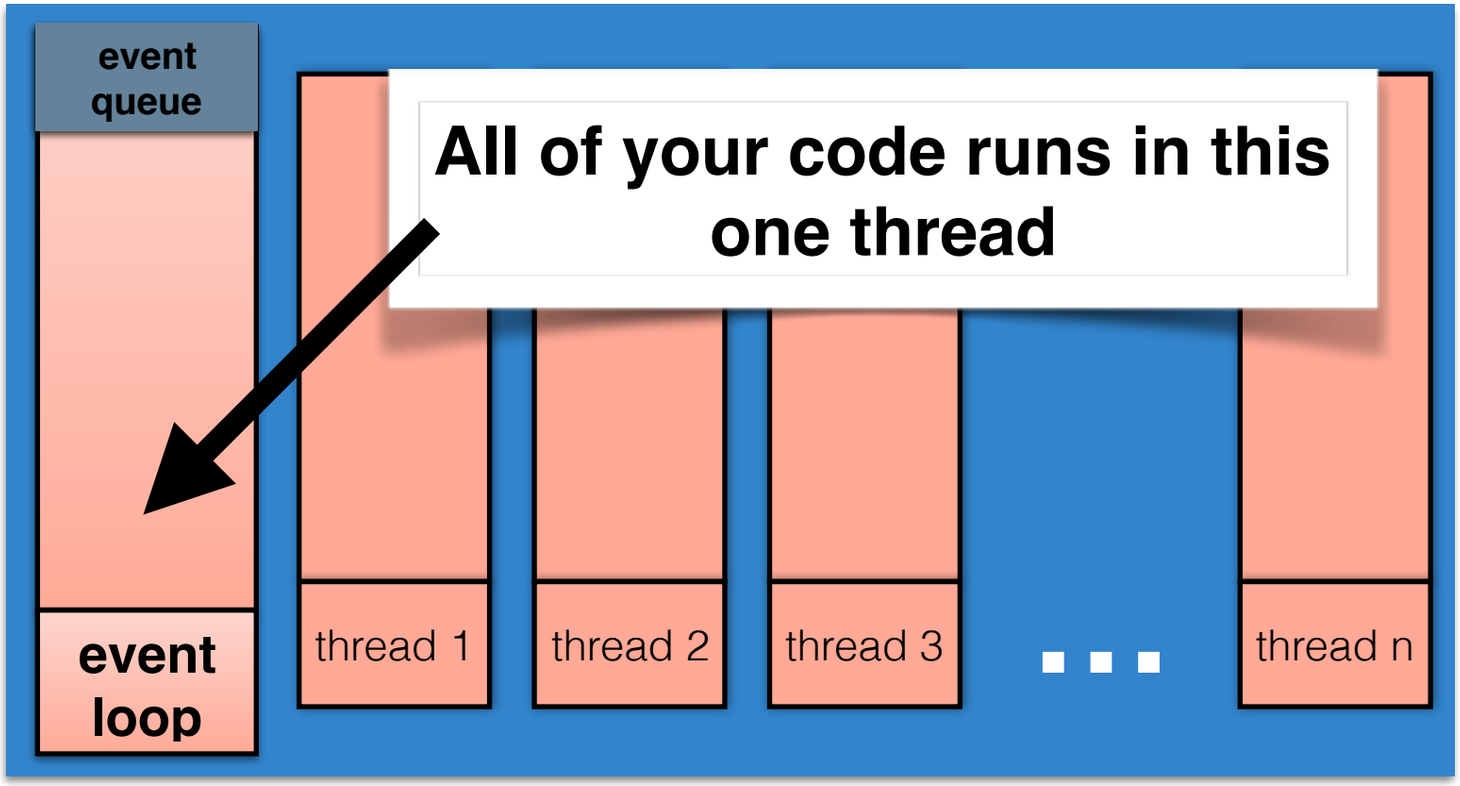
This is a data race: the println in thread1 might see either 2 OR 4

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)	

Solution 2: Single thread w/ event loop

- All of your code will run in a **single thread**
- Since you are not sharing data between threads, races don't happen as easily
- **Event-driven:** Event loop maintains queue of events, and invokes handler for each event
- (JavaScript engine itself may still be multithreaded)



The Event Loop

Event Being Processed:

The Event Loop

Event Being Processed:

GET resource1

Are there any listeners registered for this event?

If so, call listener with event

After the listener is finished, repeat

The Event Loop

Event Being Processed:

POST resource5

Are there any listeners registered for this event?

If so, call listener with event

After the listener is finished, repeat

The Event Loop

Event Being Processed:

timer fired

Are there any listeners registered for this event?

If so, call listener with event

After the listener is finished, repeat

The Event Loop

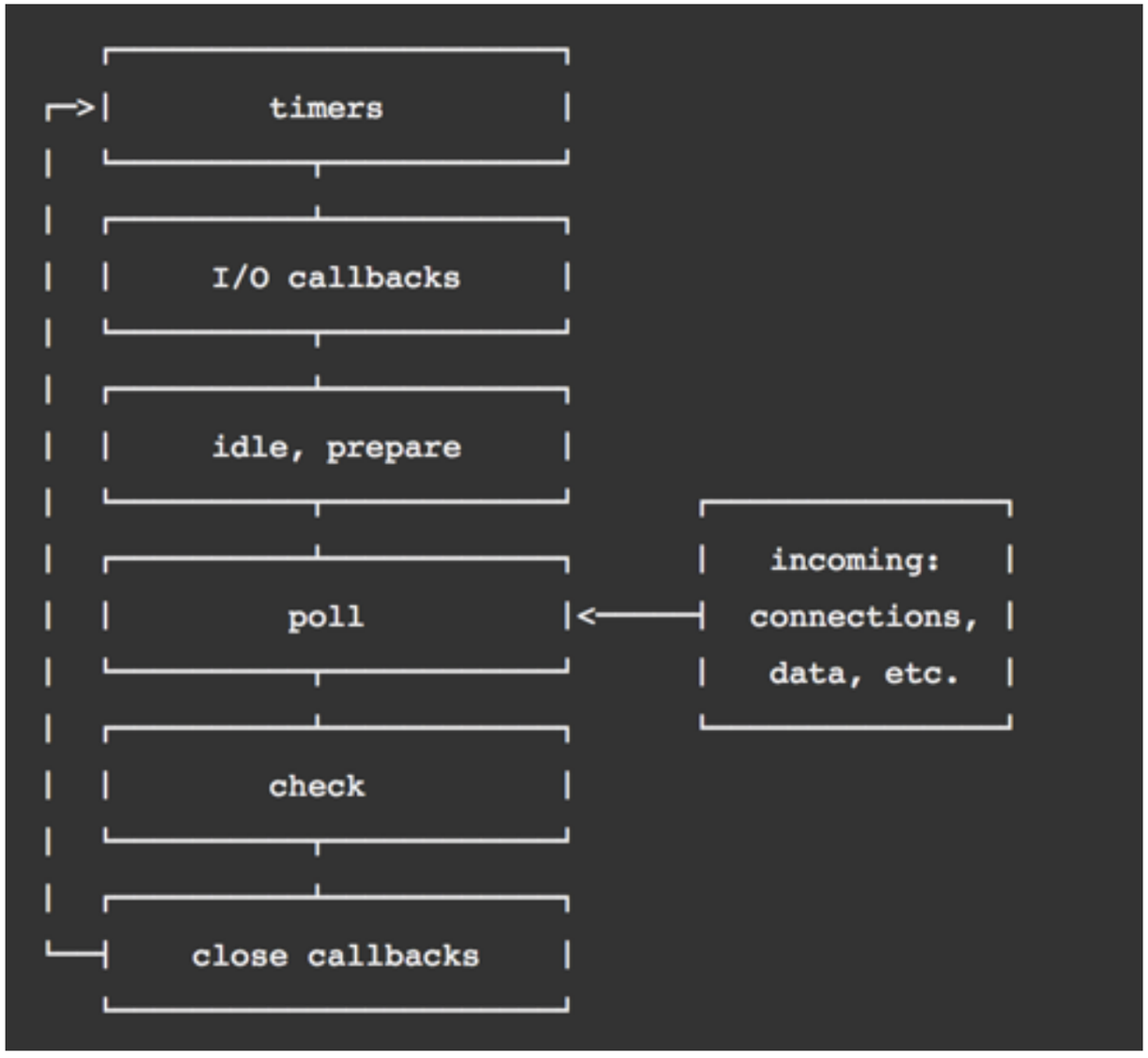
```
fetch('https://api.wmata.com/Incidents.svc/json/
ElevatorIncidents',
    { headers: { api_key:
"e1eee2b5677f408da40af8480a5fd5a8"} })
    .then(function(res) {
        return res.json();
    }).then(function(json) {
    global = json;
});
```

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

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

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



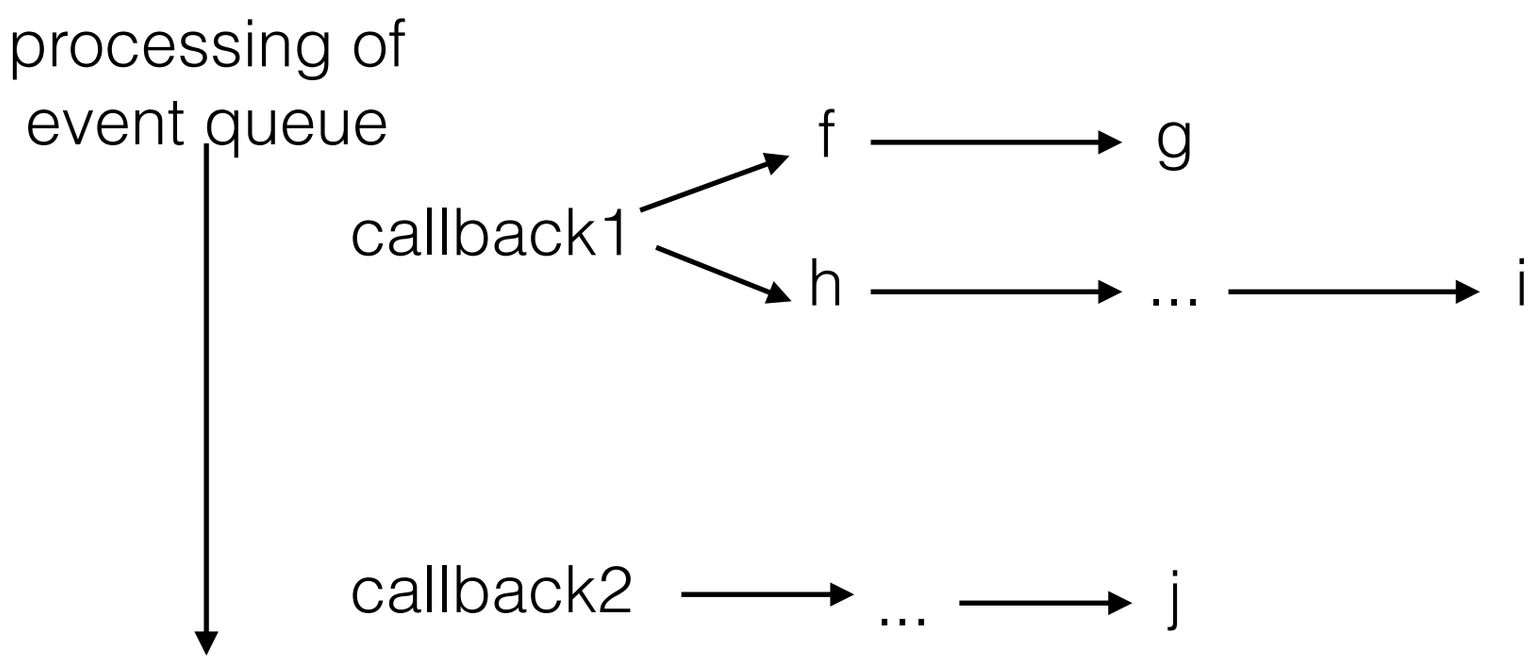
https://nodejs.org/en/docs/guides/event-loop-timers-and-nexttick/

Advantages of single-threaded event loops

- Managing dependencies between data in different threads is difficult to understand and get right and tricky to debug
  - When threads share data, need to ensure they correctly **synchronize** on it to avoid race conditions
- But there are downsides
  - Can not have slow event handlers
  - Can still have data races, although easier to reason about (data races can only occur at event boundaries)

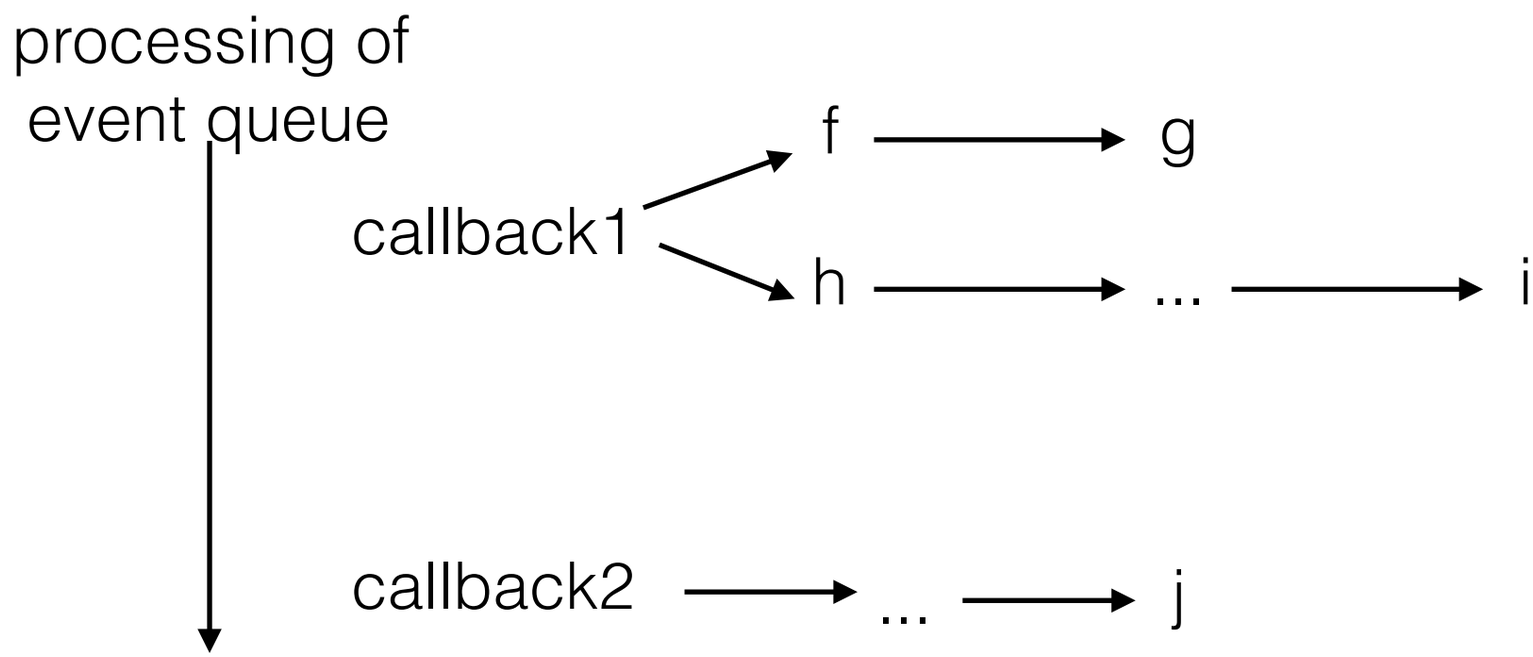
Run-to-completion semantics

- 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

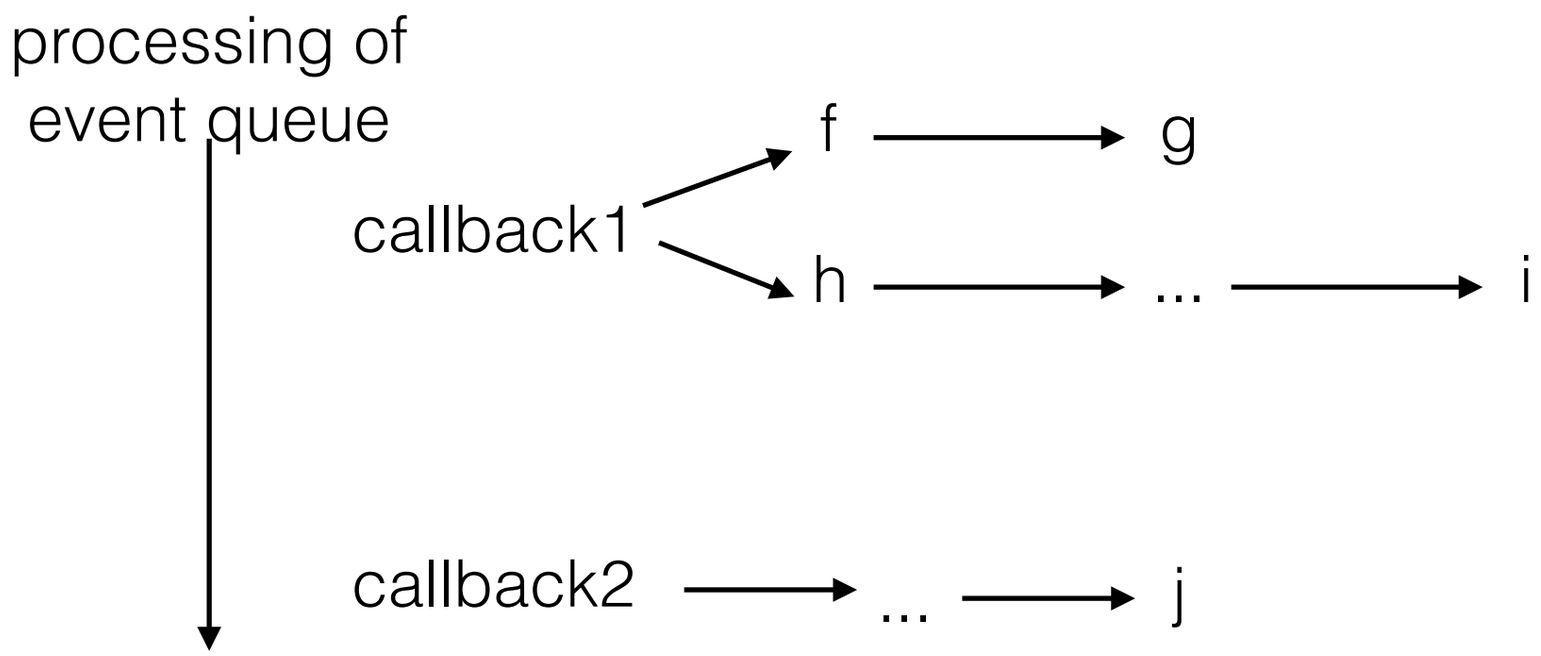
- Good news: no other code will run until you finish (no worries about other threads overwriting your data)



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...

When good requests go bad

- What happens if an error occurs in an asynchronous function?
- Most async functions let you register a second callback to be used in case of errors
- You *must* check for errors and fail gracefully
- Not ok to assume that errors will never happen.

Pyramid of doom

```
fs.readdir(source, function (err, files) {
  if (err) {
    console.log('Error finding files: ' + err)
  } else {
    files.forEach(function (filename, fileIndex) {
      console.log(filename)
      gm(source + filename).size(function (err, values) {
        if (err) {
          console.log('Error identifying file size: ' + err)
        } else {
          console.log(filename + ' : ' + values)
          aspect = (values.width / values.height)
          widths.forEach(function (width, widthIndex) {
            height = Math.round(width / aspect)
            console.log('resizing ' + filename + 'to ' + height + 'x' + height)
            this.resize(width, height).write(dest + 'w' + width + '_' + filename, function(err) {
              if (err) console.log('Error writing file: ' + err)
            })
          }.bind(this))
        }
      })
    })
  }
})
```

From http://callbackhell.com/

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

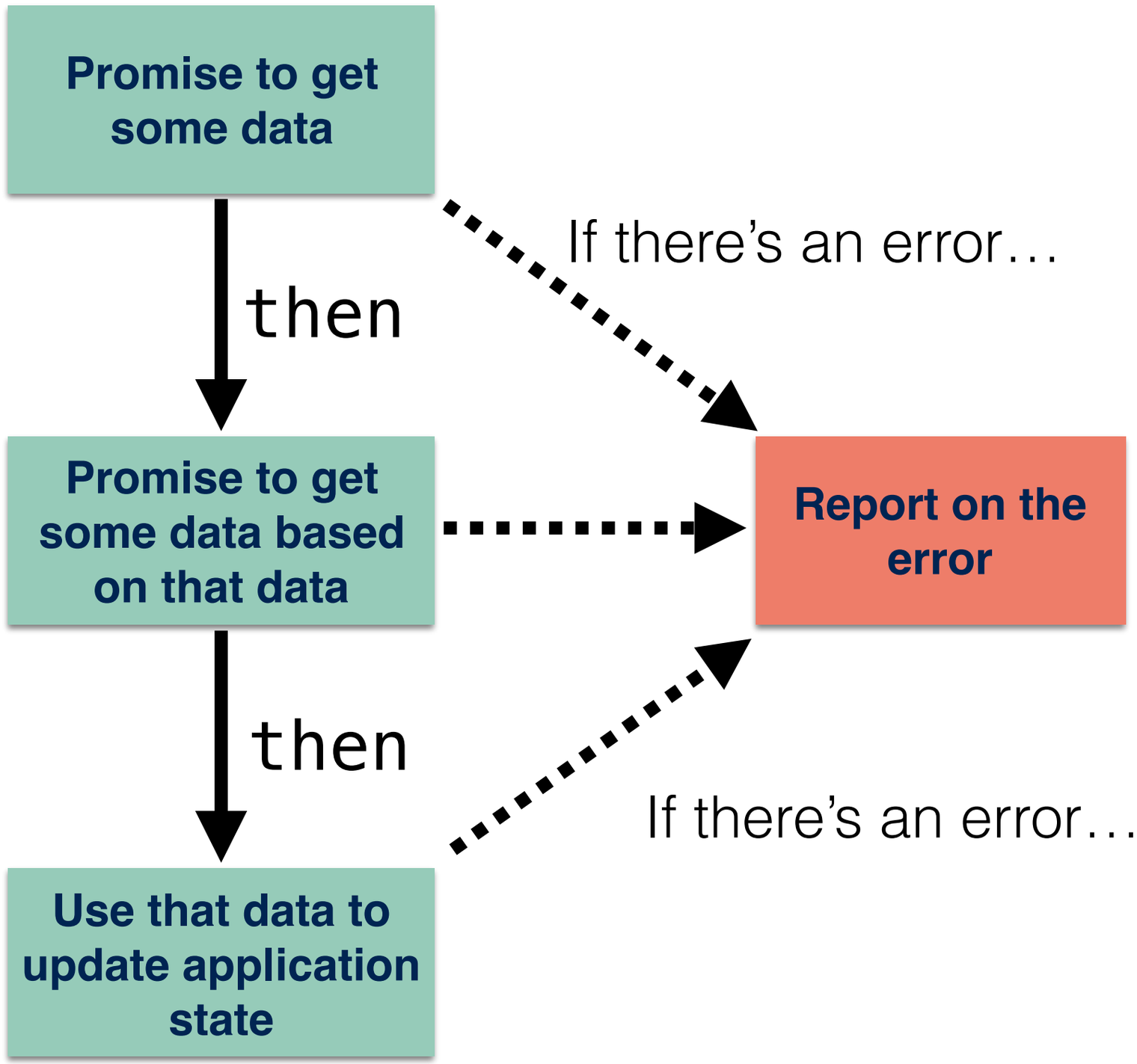
Using a Promise

- 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){

});
```

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(“JonBell.jpg")])
  .then(function (imgArray) {
        imgArray.forEach(img => {document.body.appendChild(img)})
    })
.catch(function (e) {
  console.log("Oops");
  console.log(e);
});
```

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

Timers

```
function myFunc(arg) {
  console.log(`arg was => ${arg}`);
}
setTimeout(myFunc, 1500, 'funky');
```

Run myFunc no sooner than 1500 ms

```
setInterval(() => {
  console.log('interval executing');
}, 500);
```

Run code every 500 ms

```
setImmediate((arg) => {
  console.log(`executing immediate: ${arg}`);
}, 'so immediate');
```

Run code after any I/O operations in current cycle and before timers from next cycle

Stopping timers

```
const timeoutObj = setTimeout(() => {
  console.log('execute after 1500 ms');
}, 1500);

const intervalObj = setInterval(() => {
  console.log('execute every 500 ms');
}, 500);

const immediateObj = setImmediate(() => {
  console.log('execute after IO operations');
});

clearTimeout(timeoutObj);
clearImmediate(immediateObj);
clearInterval(intervalObj);
```

Demo: Promises and Timers

Readings for next time

- 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/