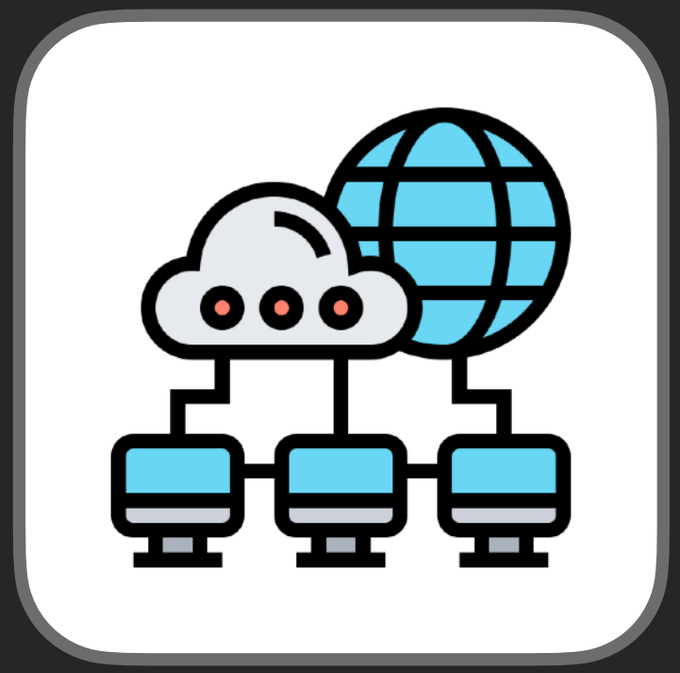
SWE 432 -Web Application Development

Fall 2021

George Mason University

Dr. Kevin Moran

Week 2: Asynchronous Programming



Administrivia

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

Class Overview

Class Overview

- *Part 1 - Asynchronous Programming I:* Communicating between web app components?
- *10 minute Break*
- *Part 2 - Asynchronous Programming II:* More communication strategies
- *Part 3 - In-Class Activity:* Exploring Asynchronous Programming

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/

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
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It “**closes up**” those references

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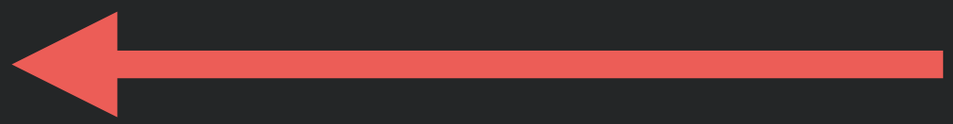

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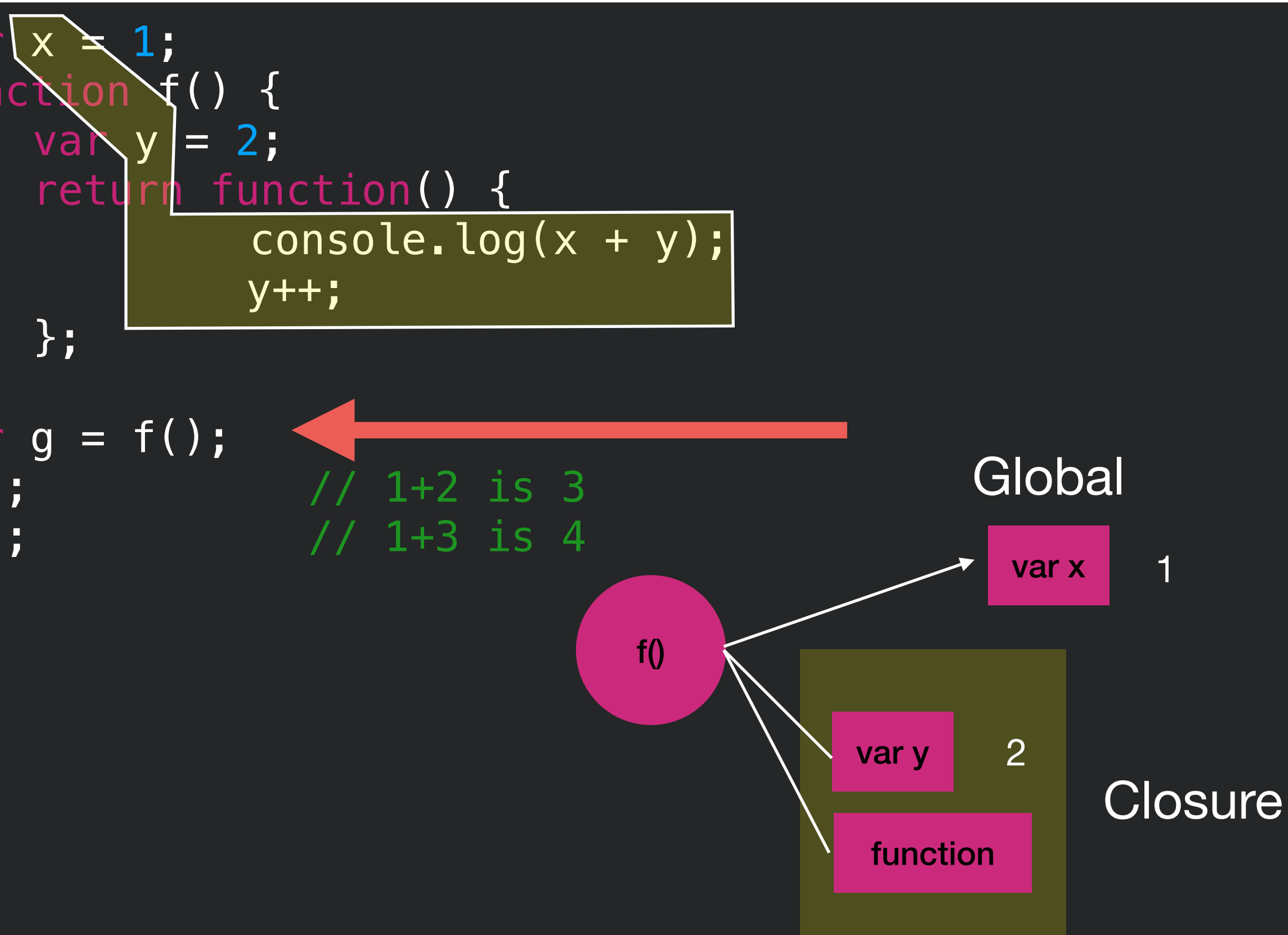

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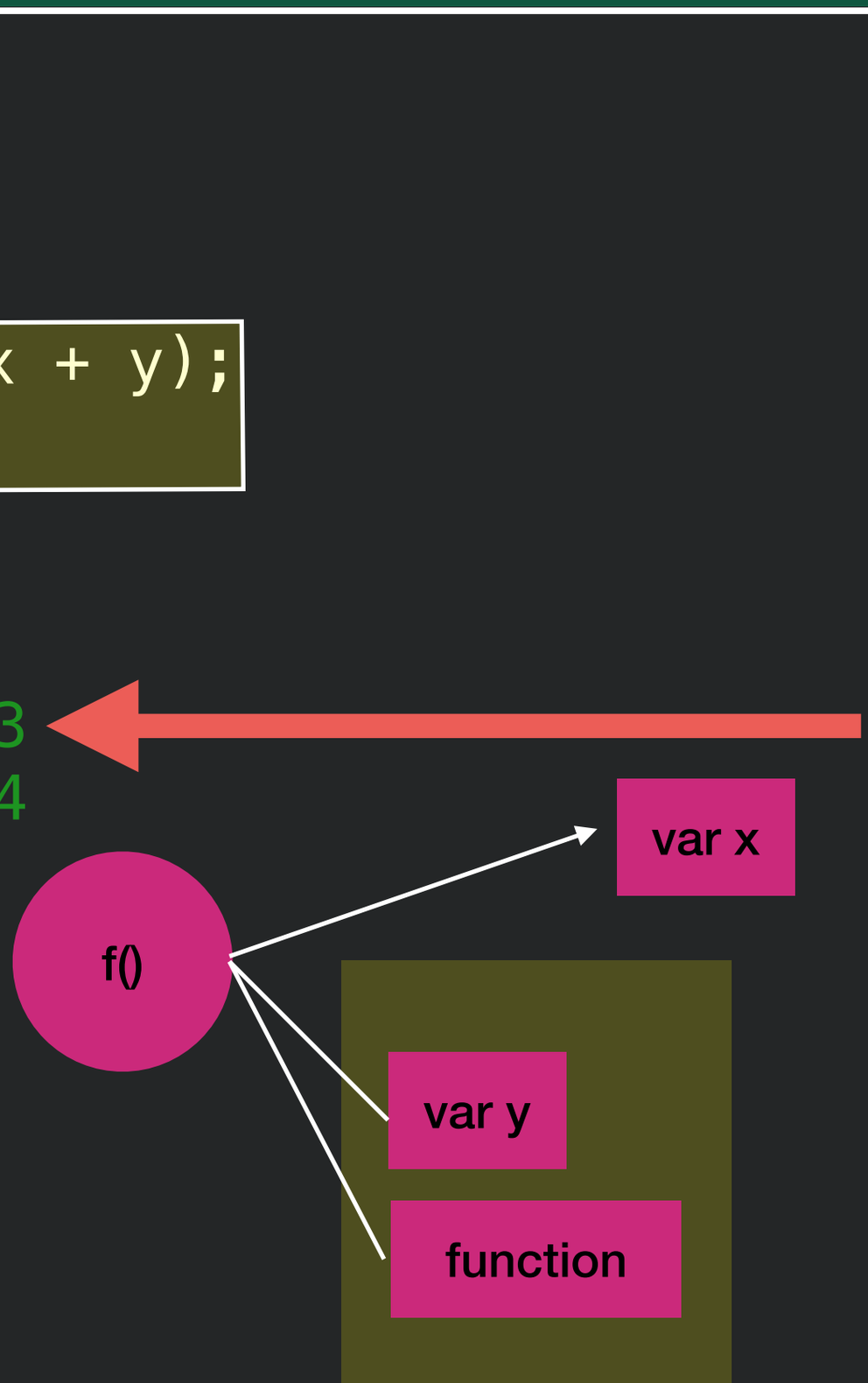

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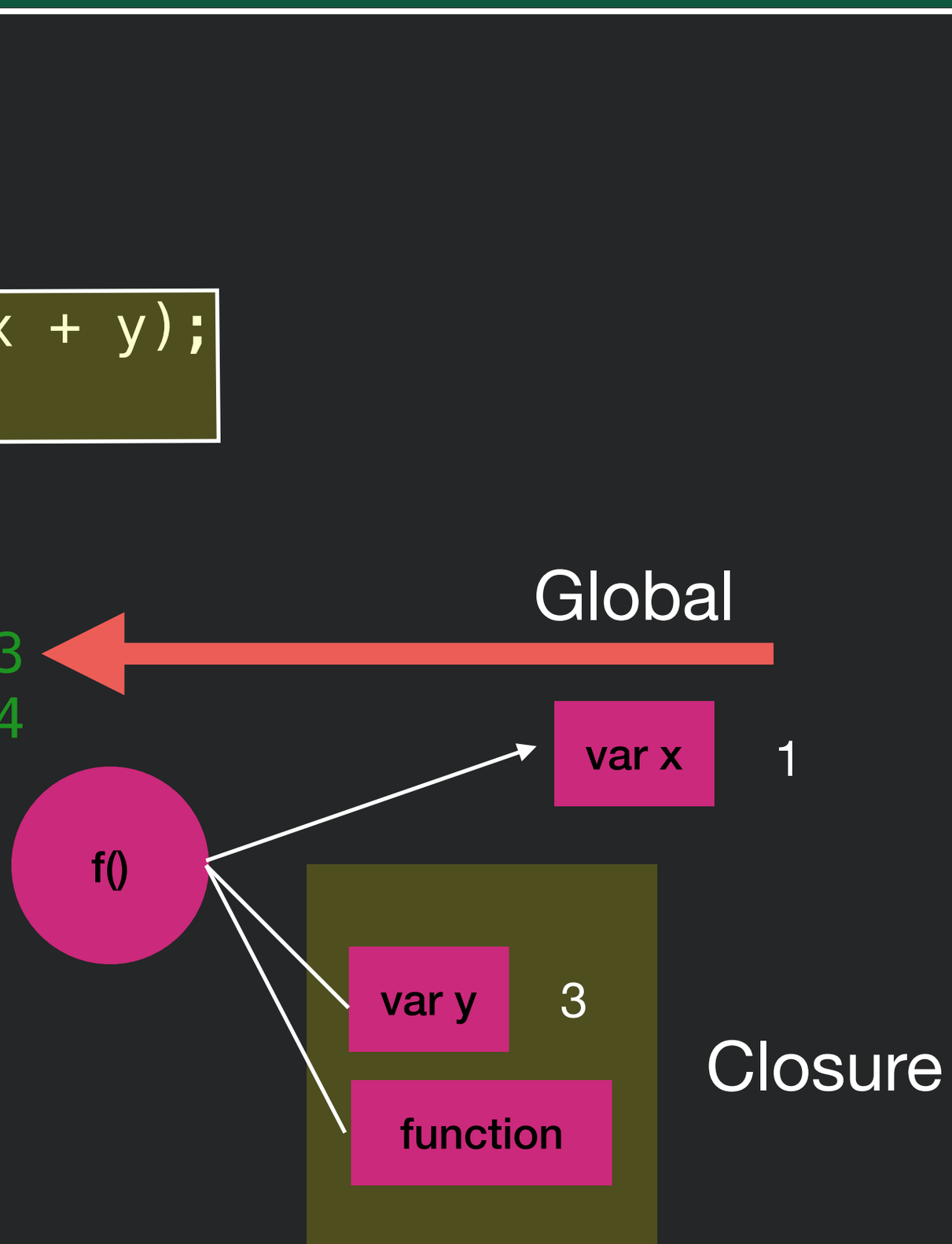

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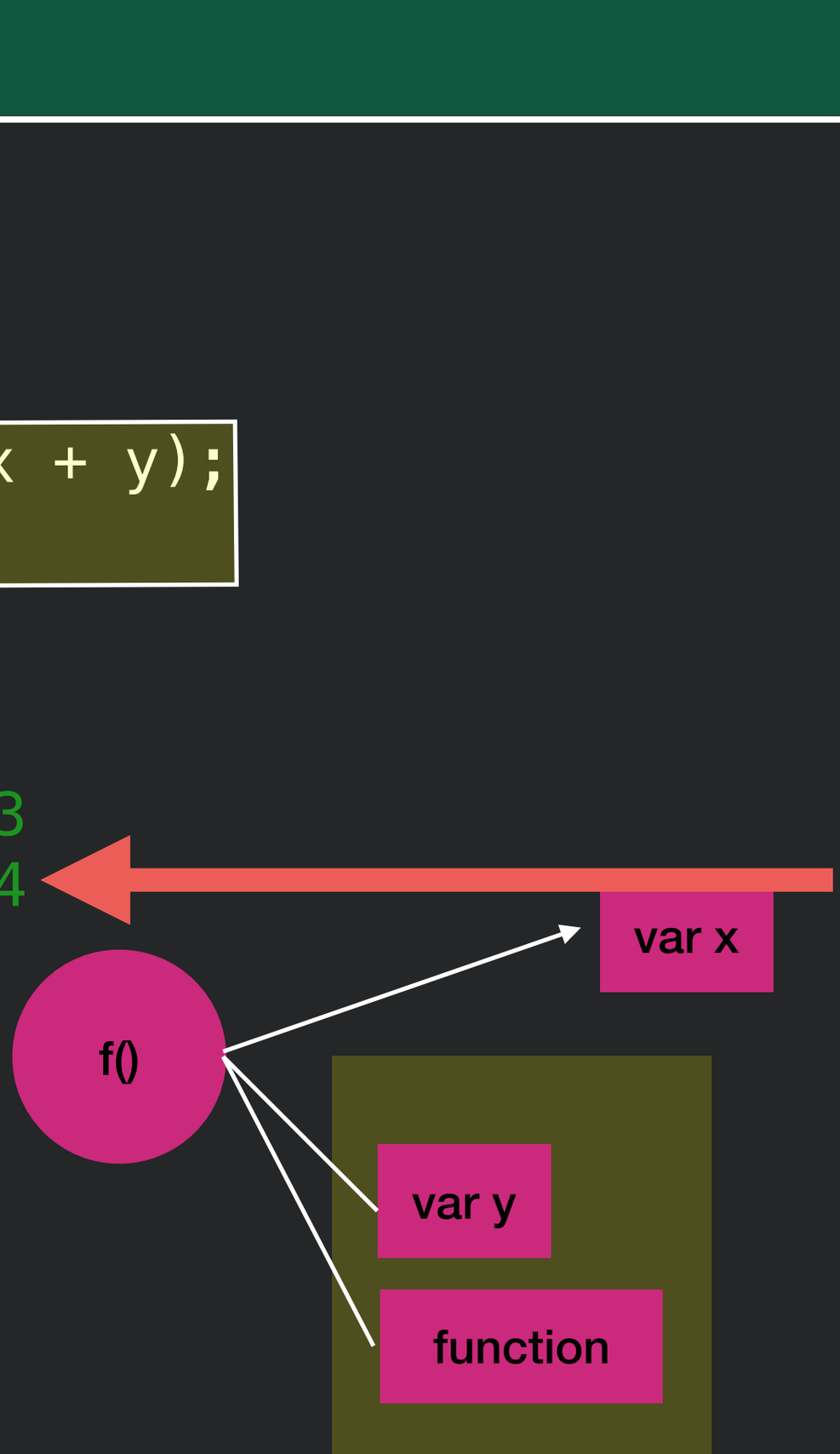

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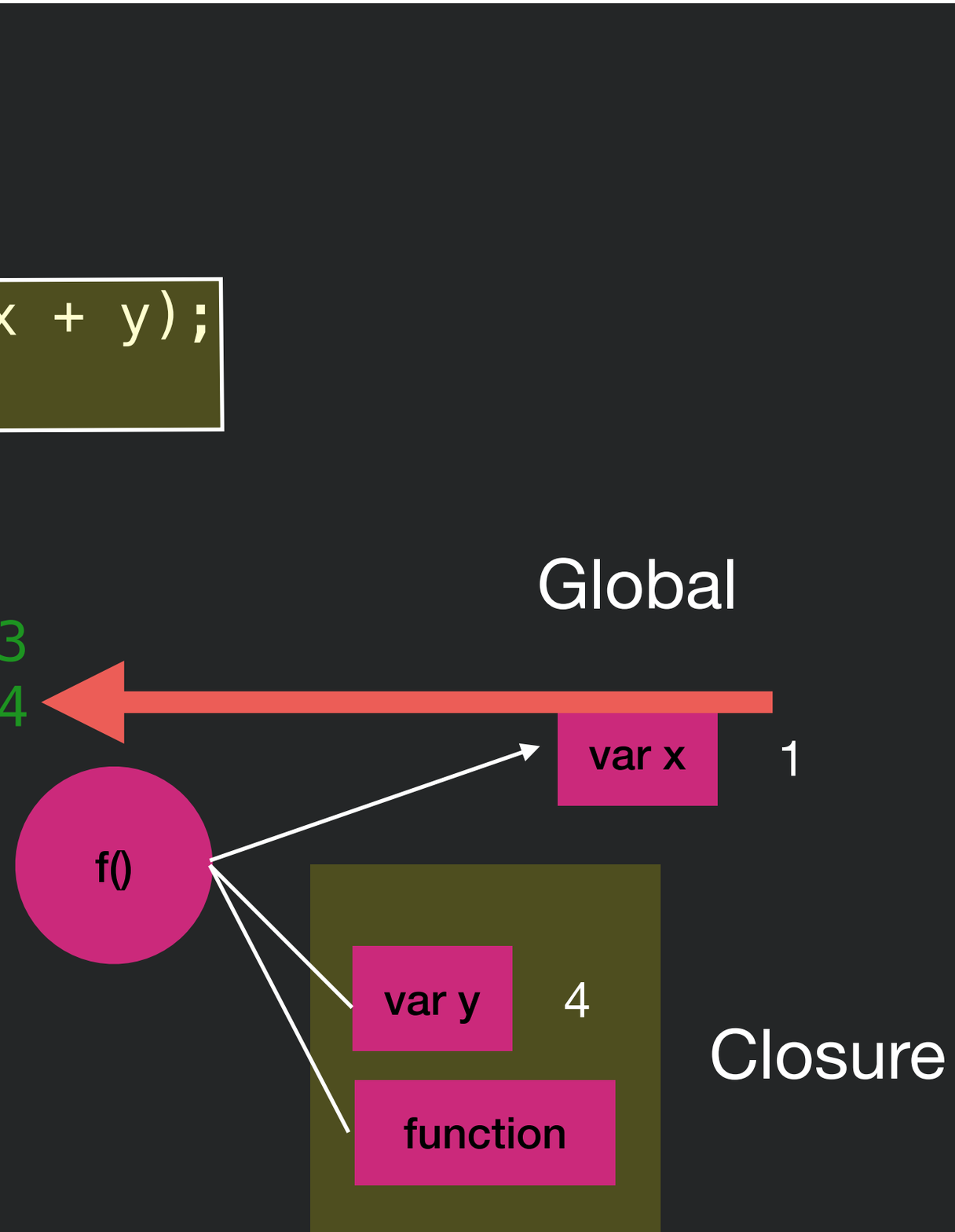

Why Asynchronous?

- 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)

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App Starts

App Ends

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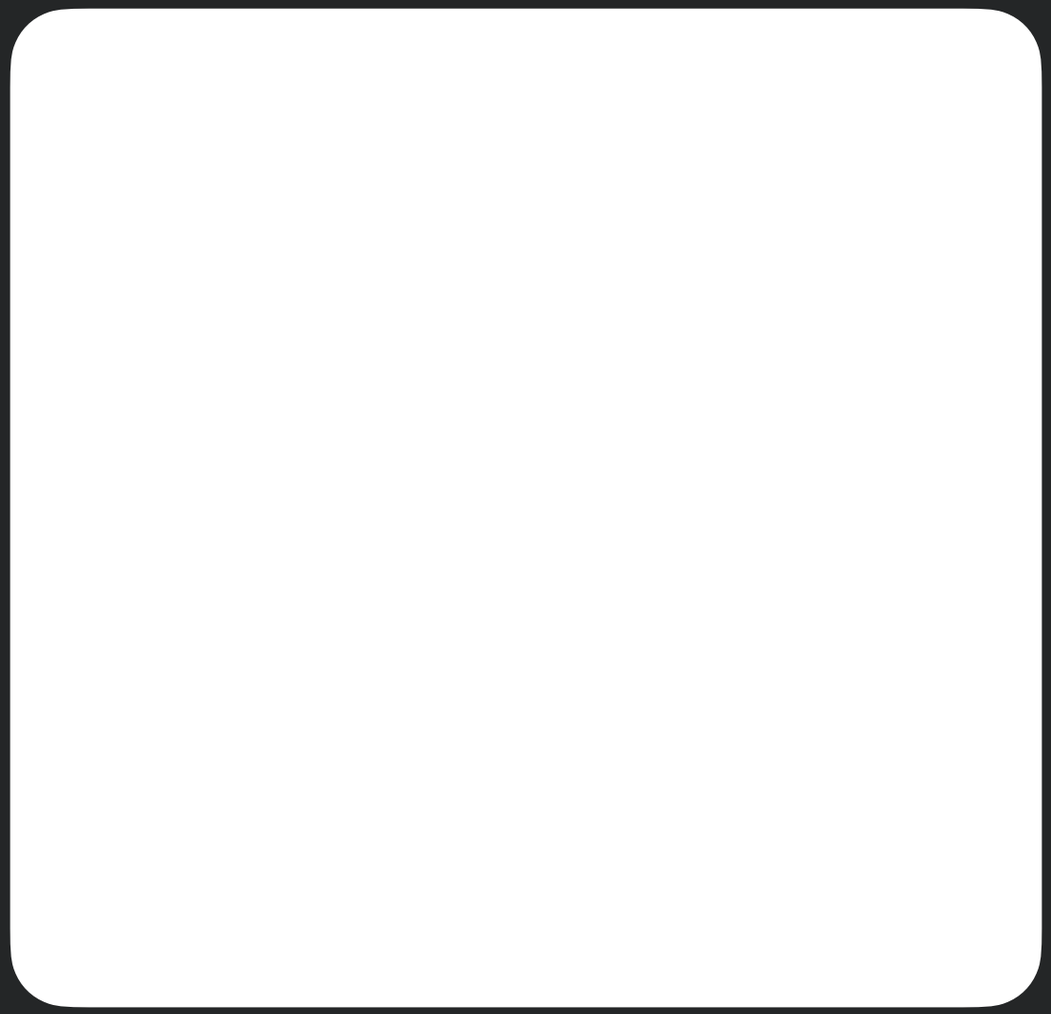

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Multiple threads can run at once -> allows for asynchronous code

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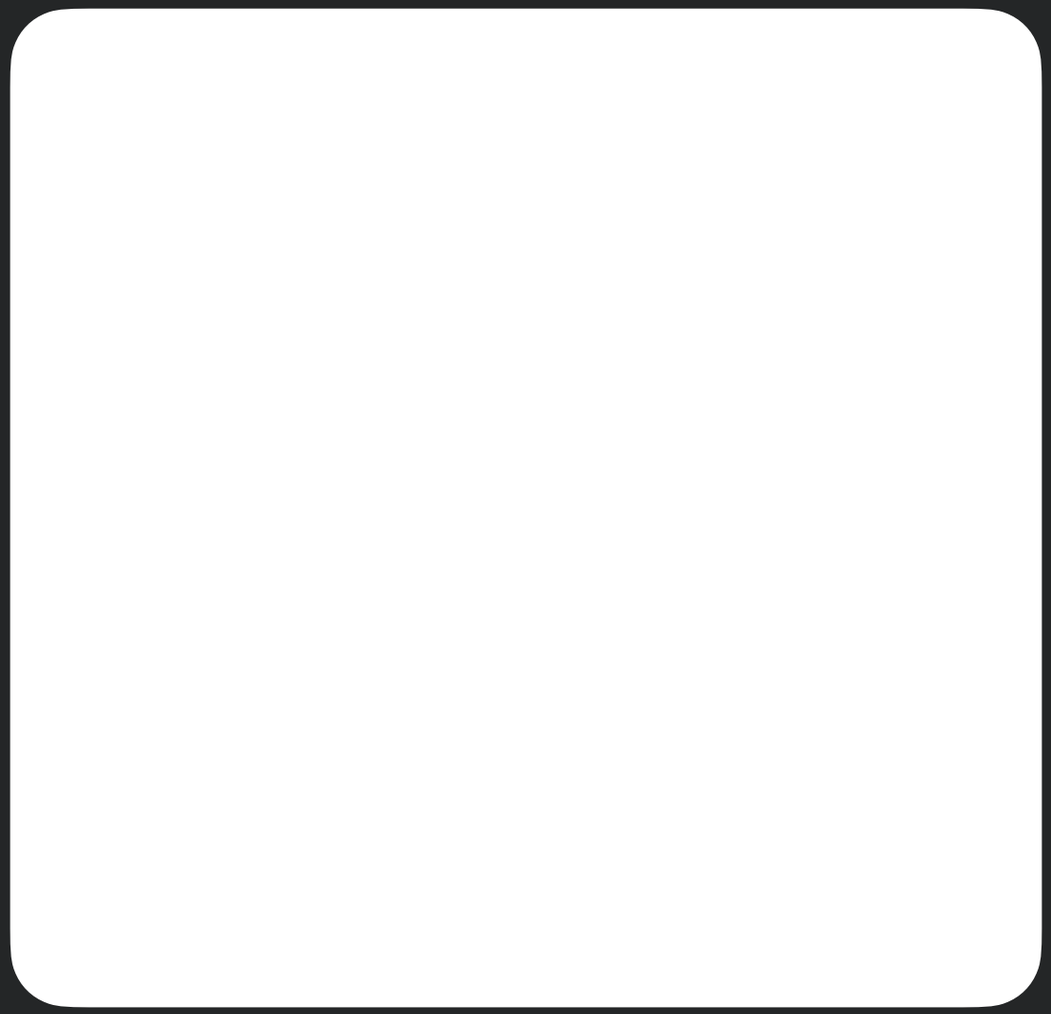

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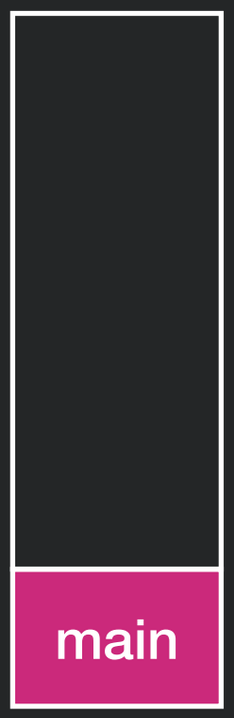

Interacts with user
Draws Swing interface on screen, updates screen

thread 0

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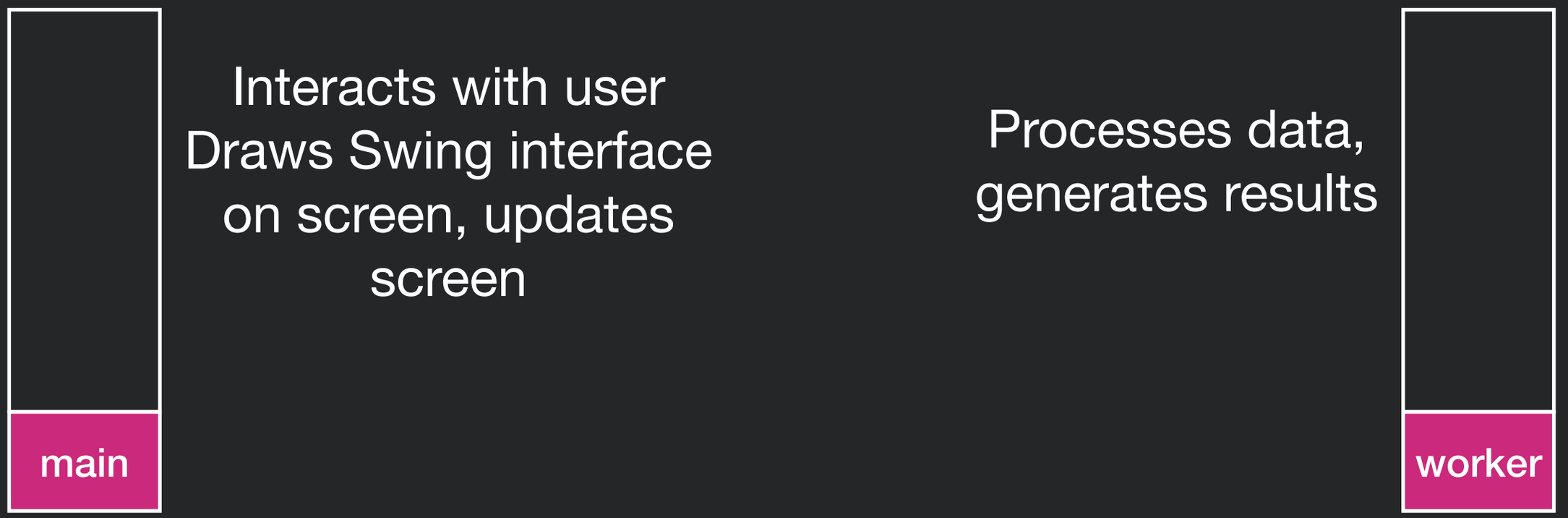

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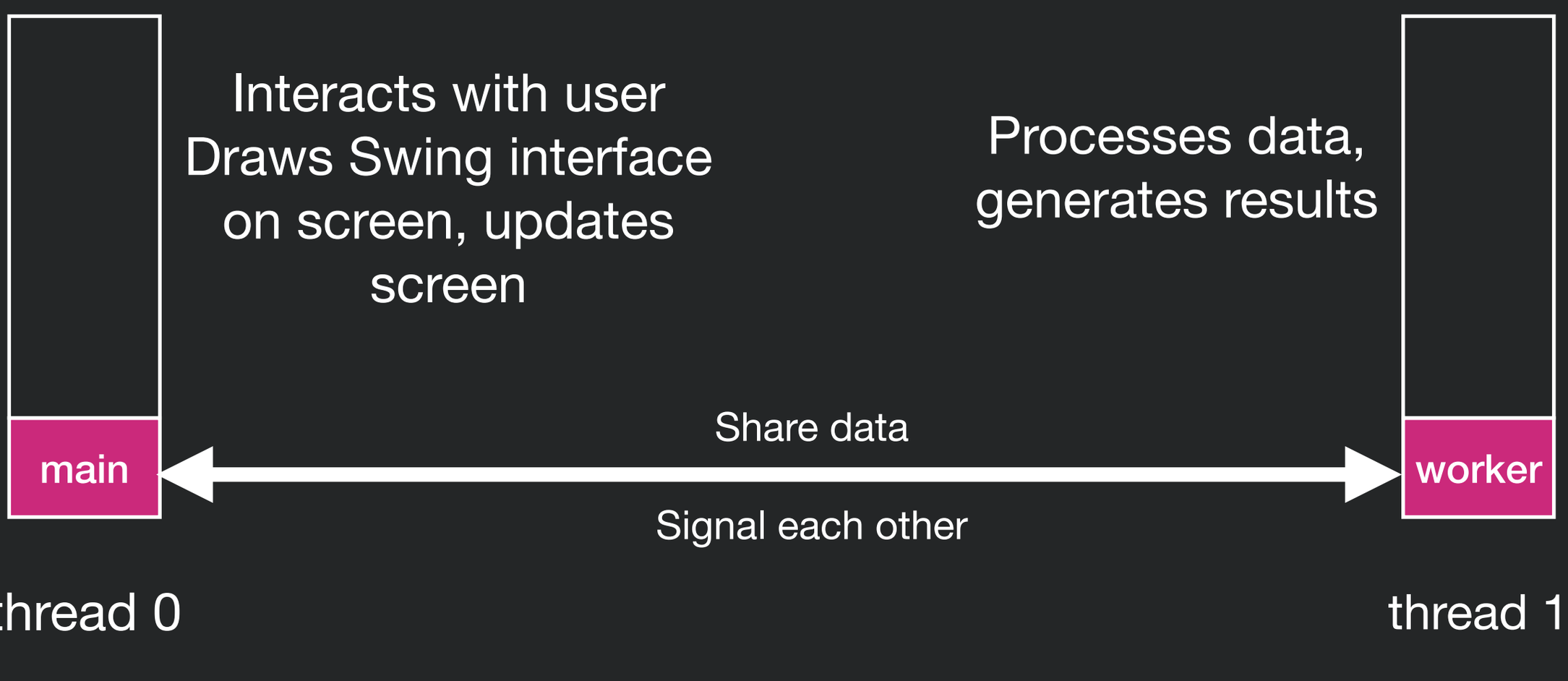

Woes of Multi-Threading

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

```
public static void thread2()
{
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```

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

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Multi-Threading in JS

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var request = require('request');
request('http://www.google.com', function (error, response,
body) {
    console.log("Heard back from Google!");
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console.log("Made request");
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Request is an ***asynchronous call***

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```

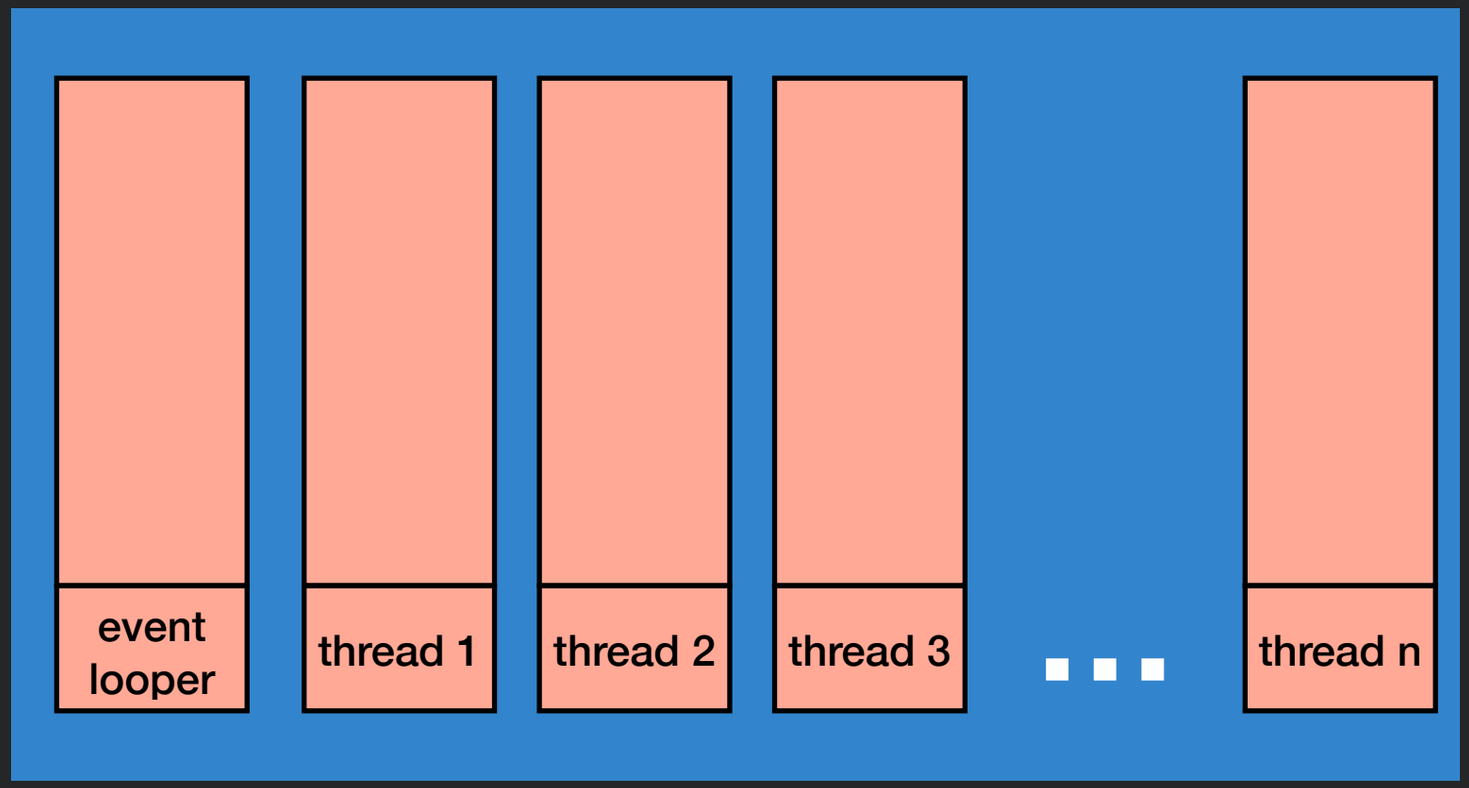
Output:

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

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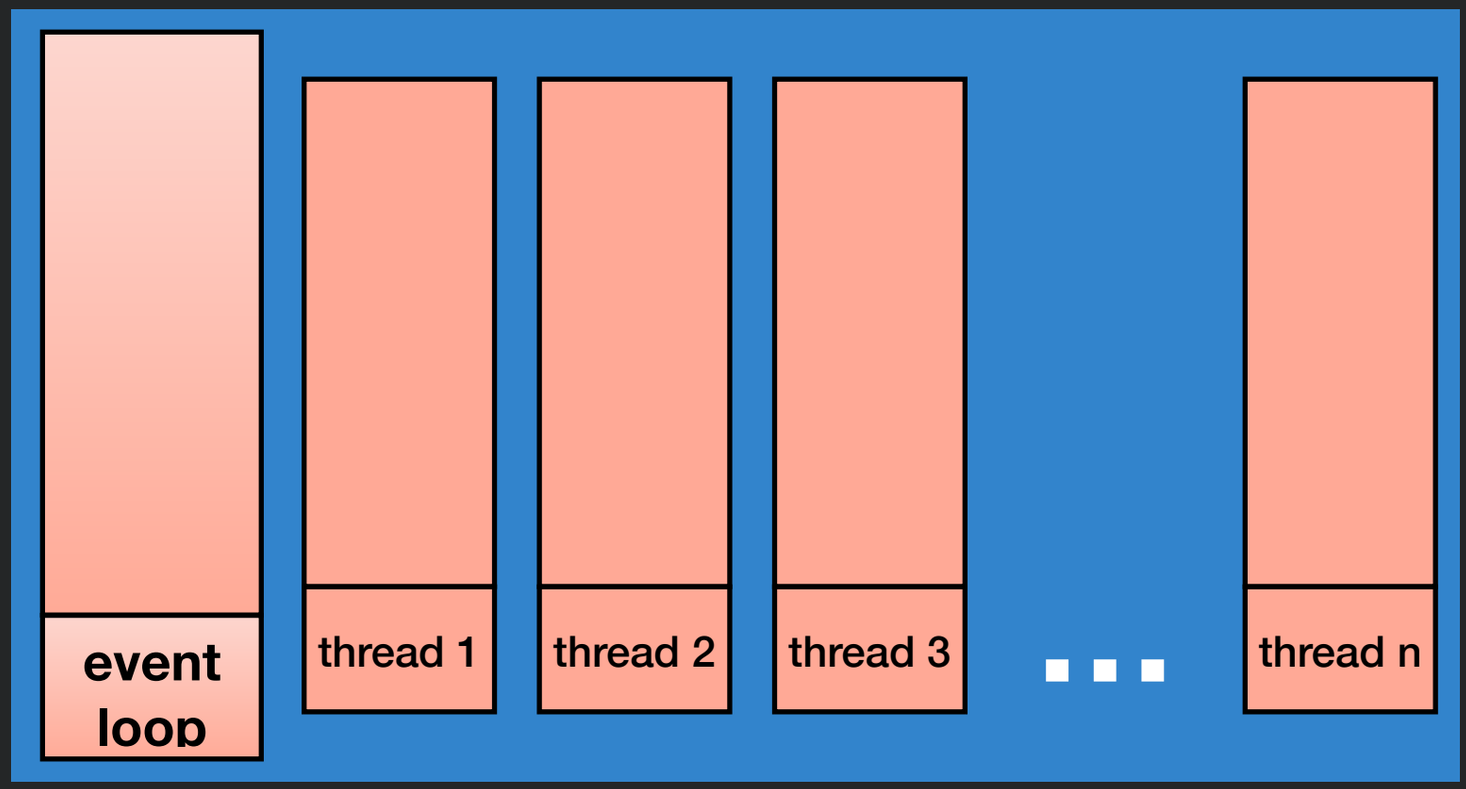

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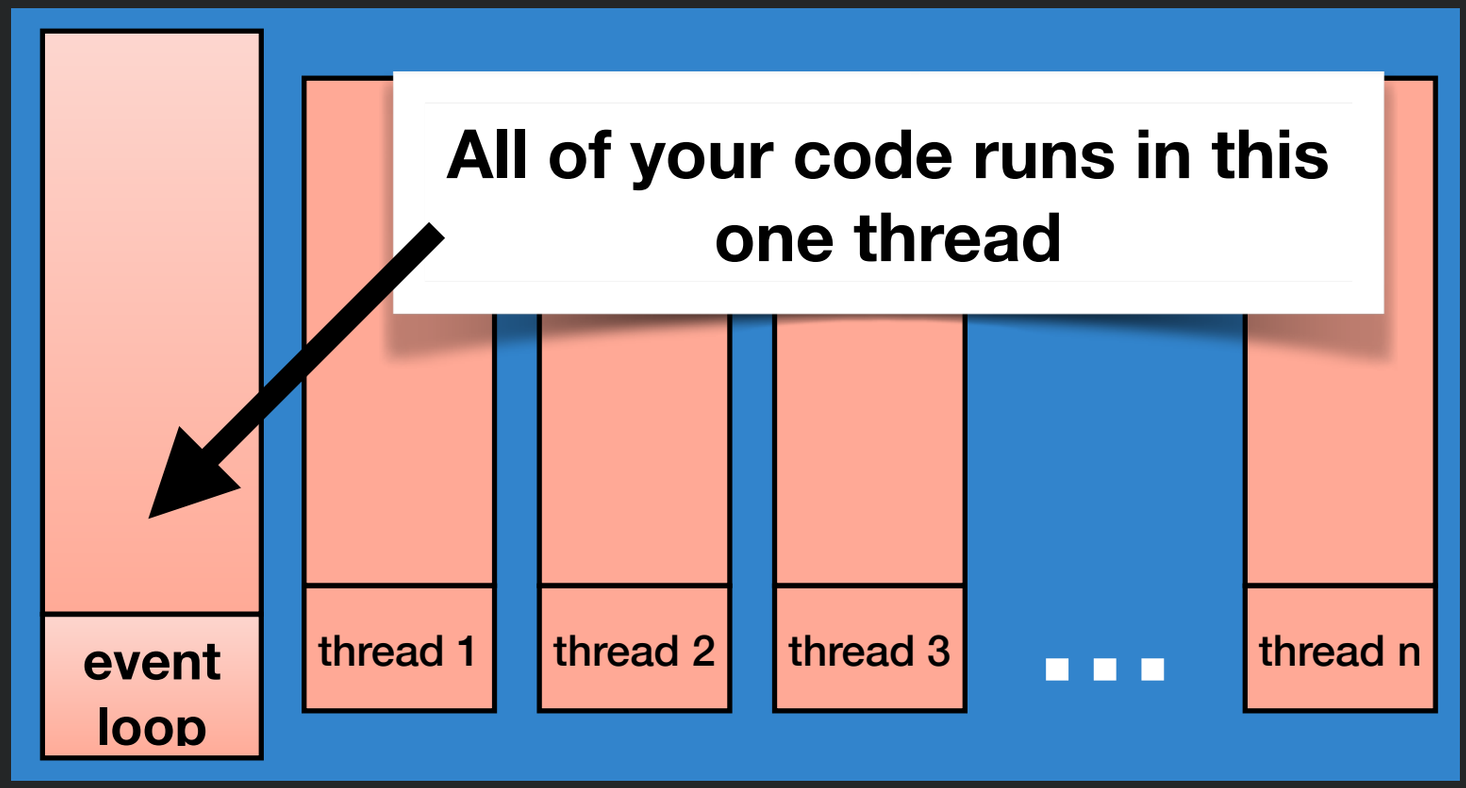

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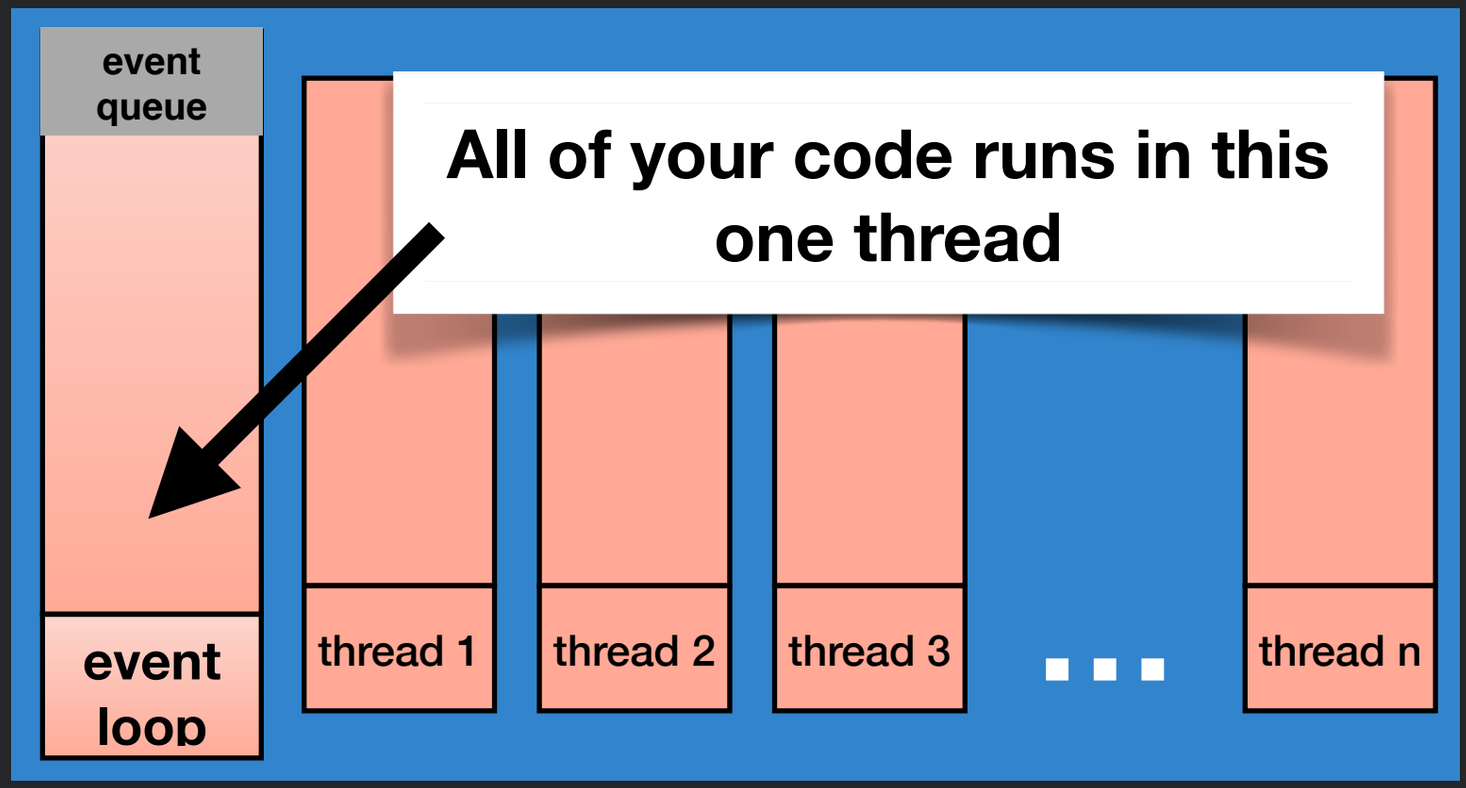
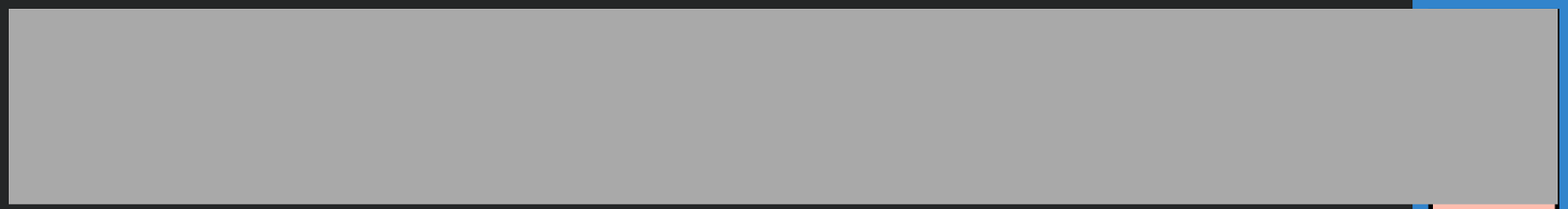
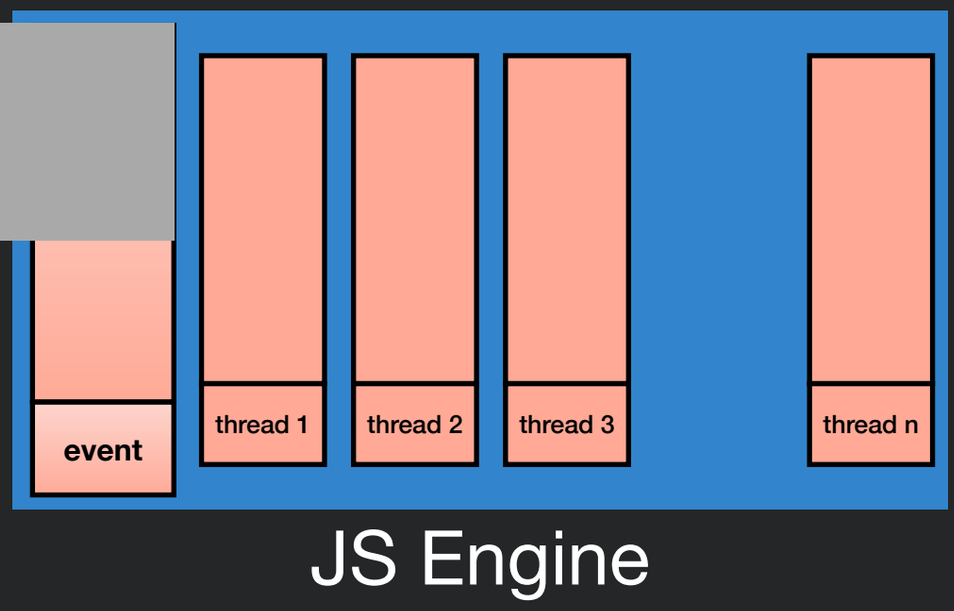


The Event Loop

Event Queue





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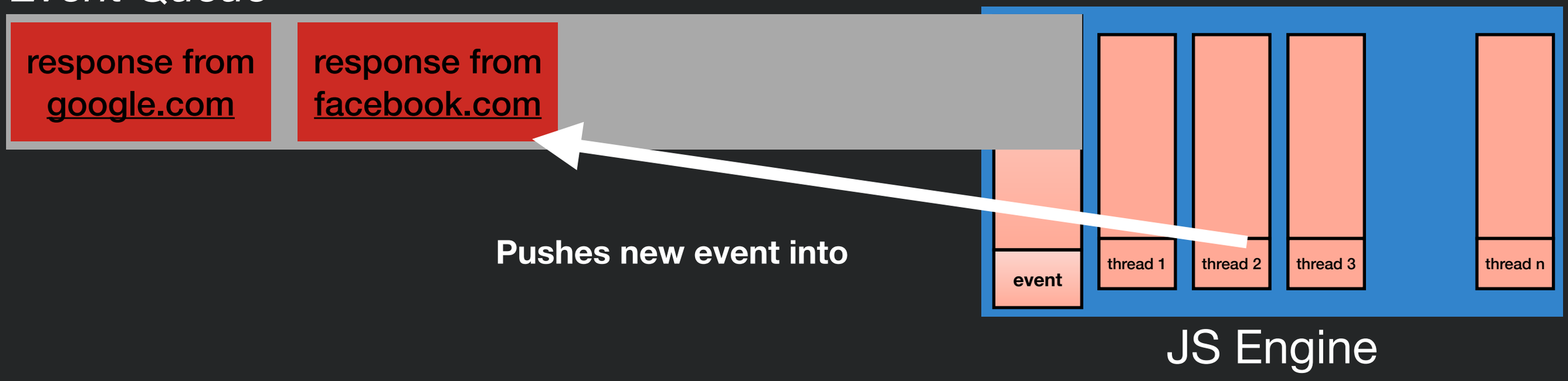

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Event Queue

response from google.com

response from facebook.com

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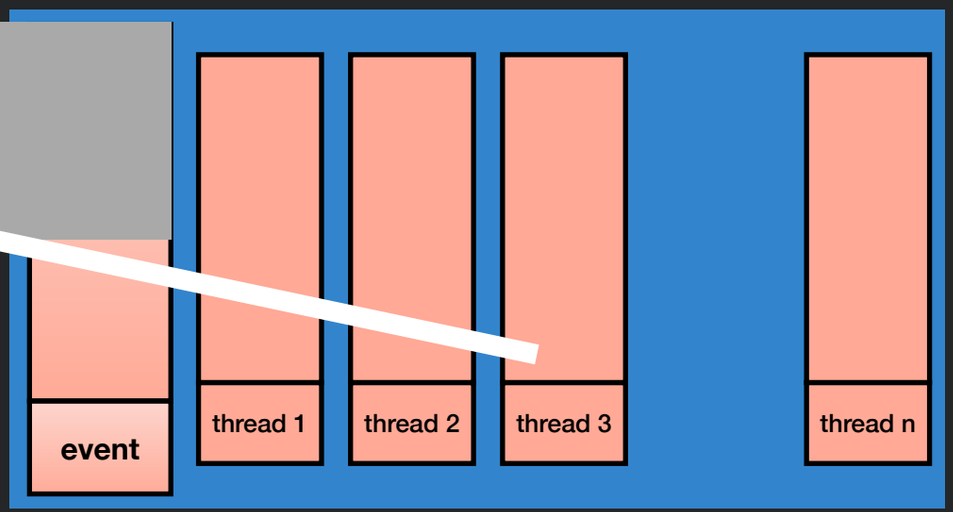

Pushes new event into queue

JS Engine

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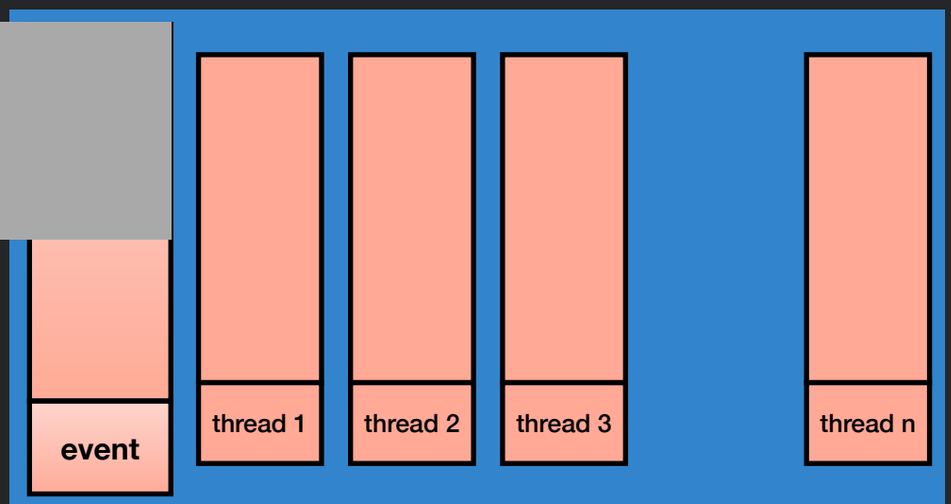

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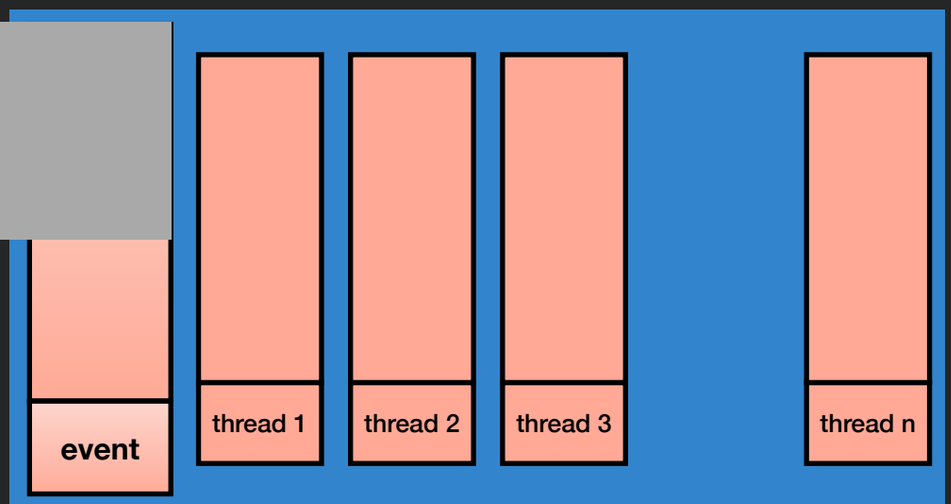

Event Being Processed:

JS Engine

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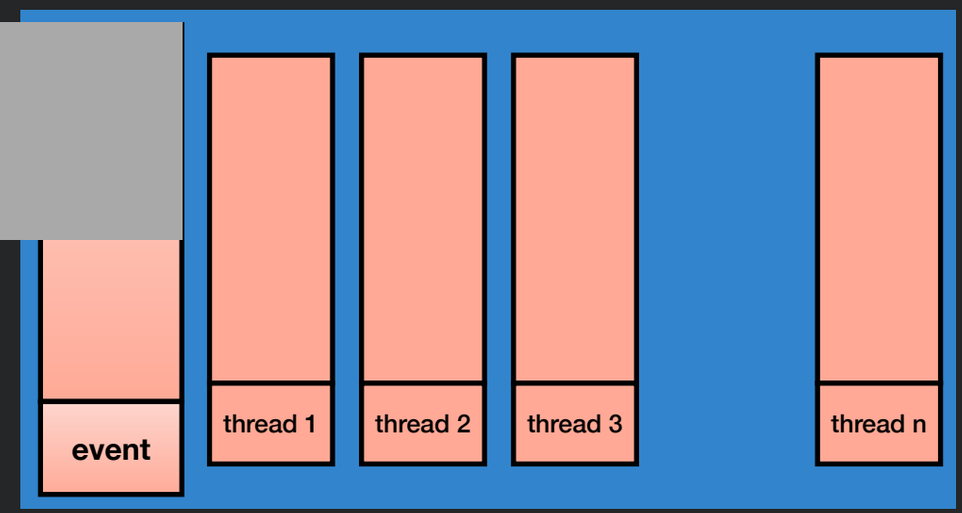

JS Engine

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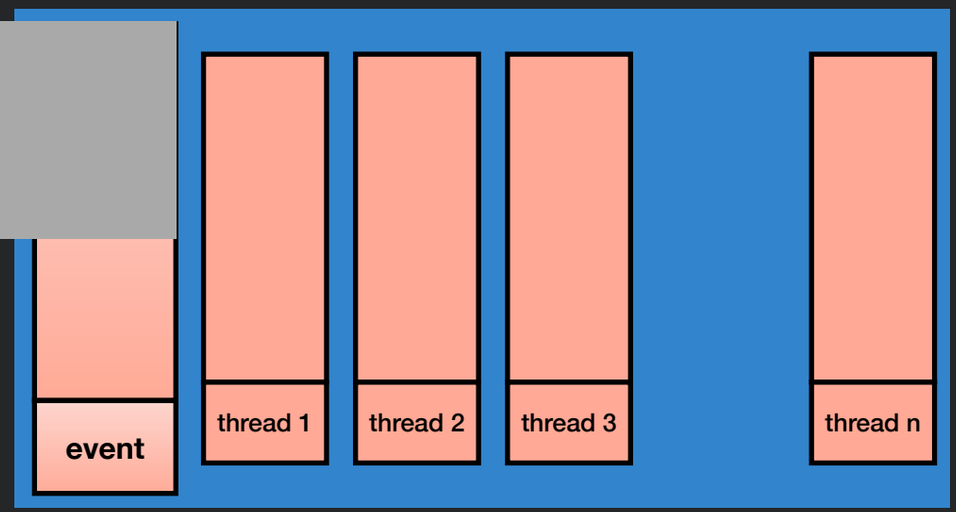

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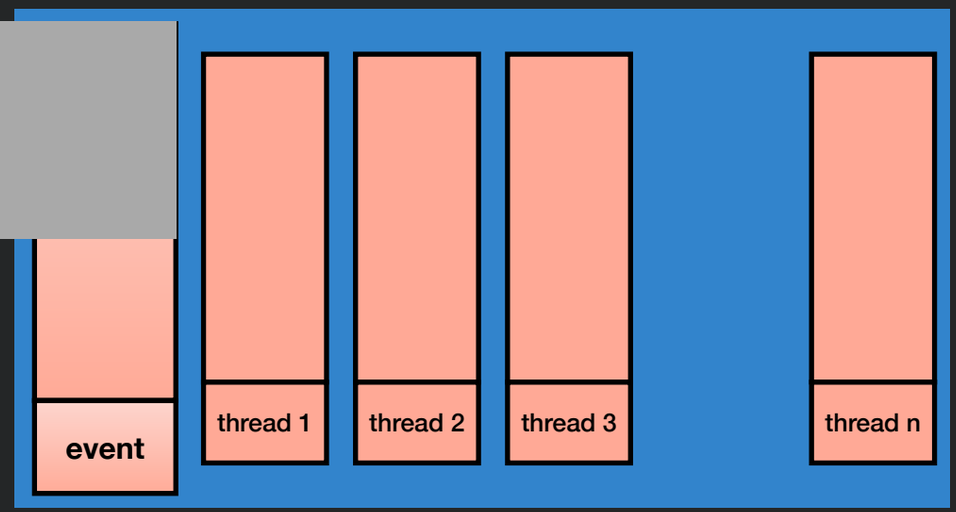

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JS Engine

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The Event Loop

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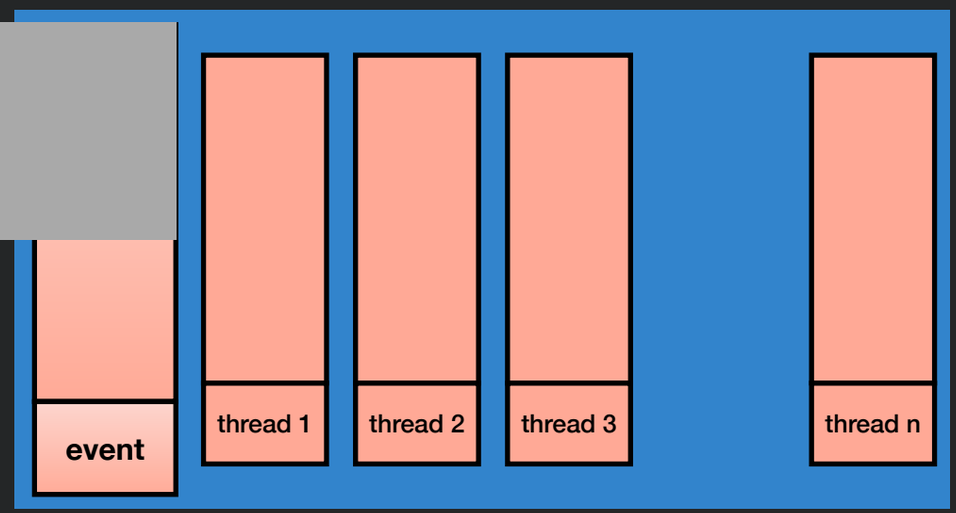

Event Being Processed:

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If so, call listener with event

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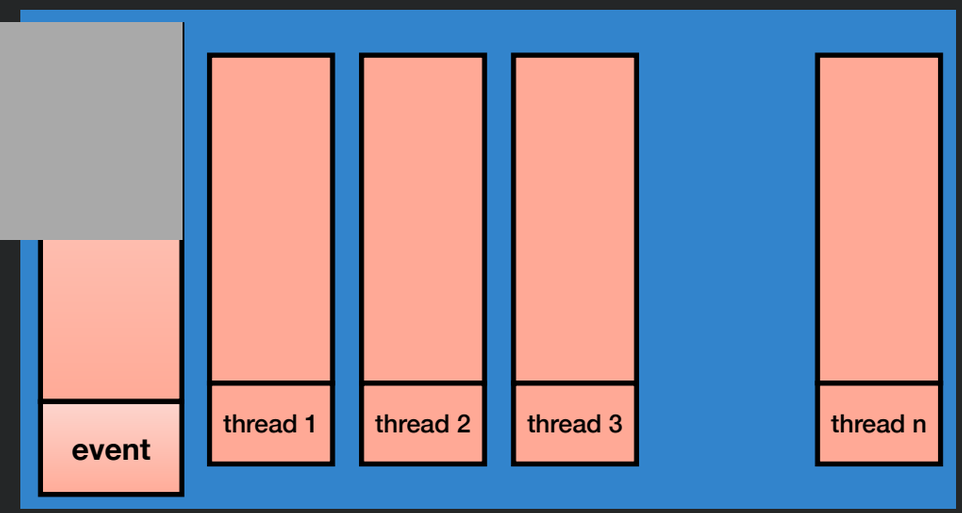

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After the listener is finished, repeat

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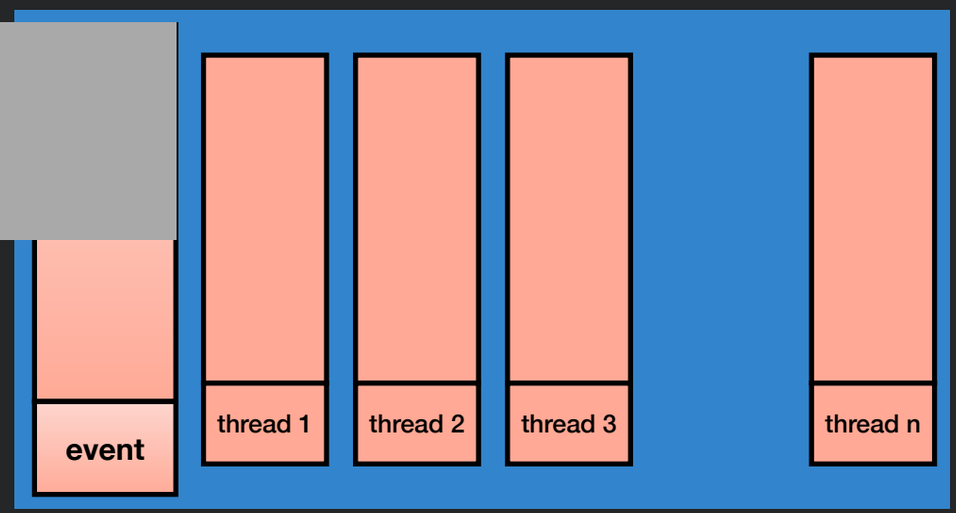

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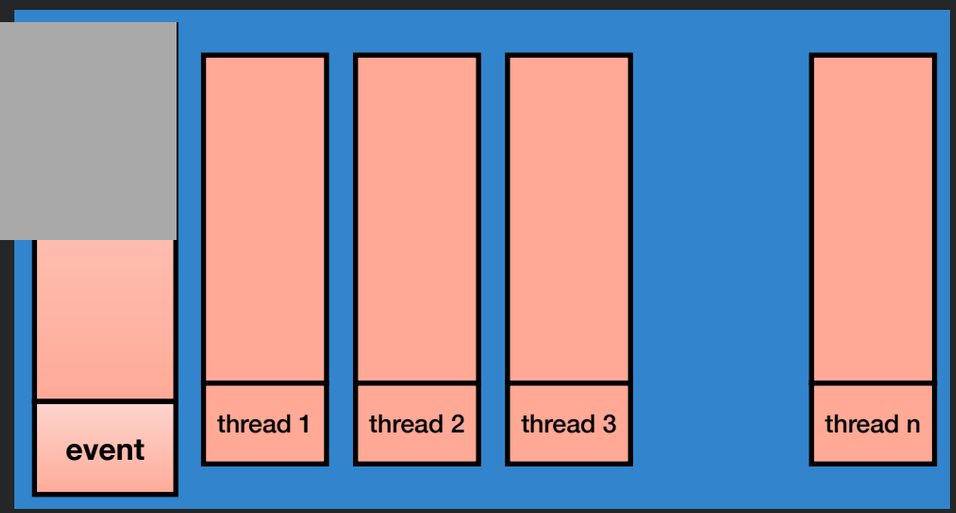

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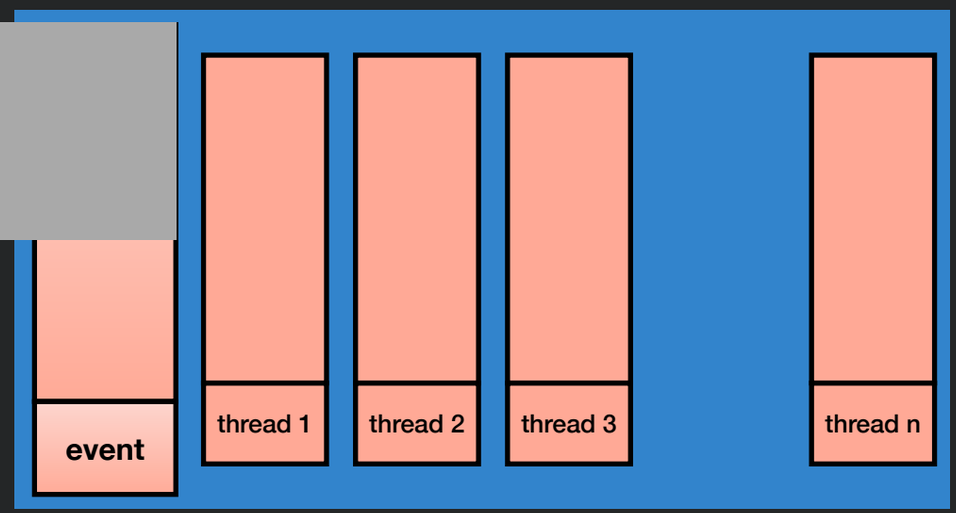

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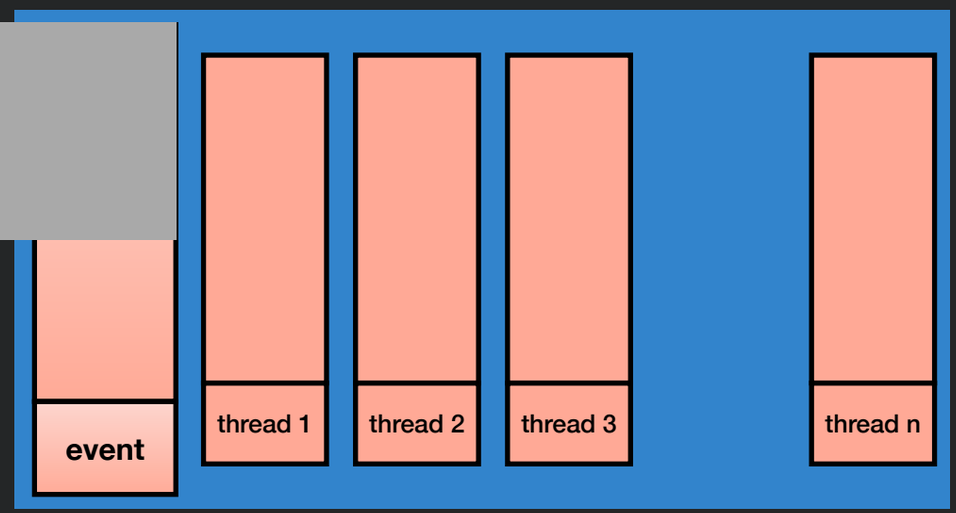

Event Being Processed:

response from facebook.com

JS Engine

Are there any listeners registered for this event?

If so, call listener with event

The Event Loop

Event Queue

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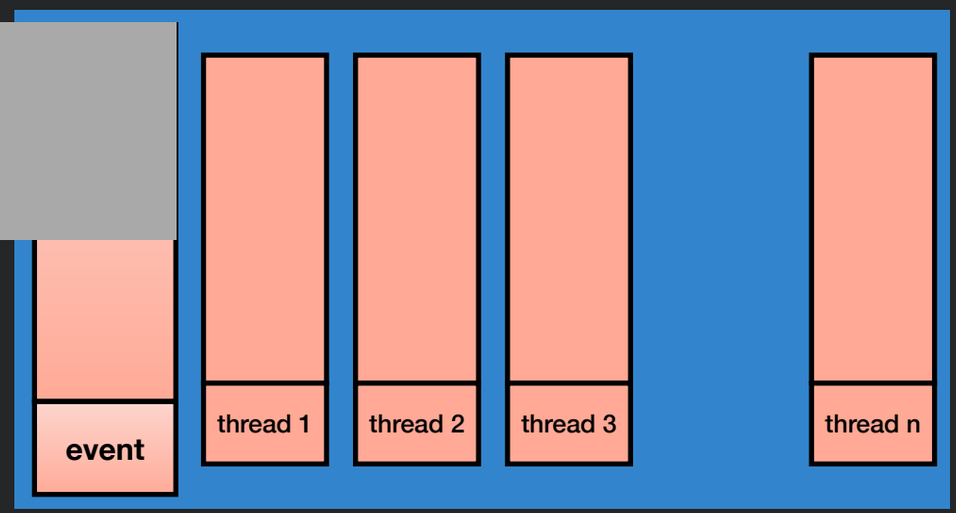

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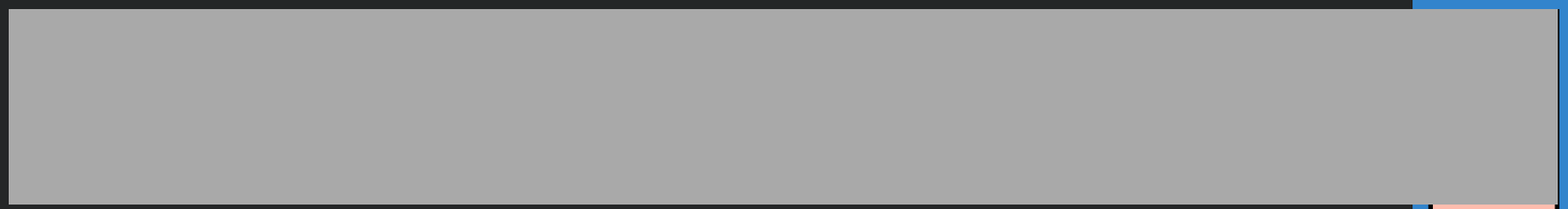

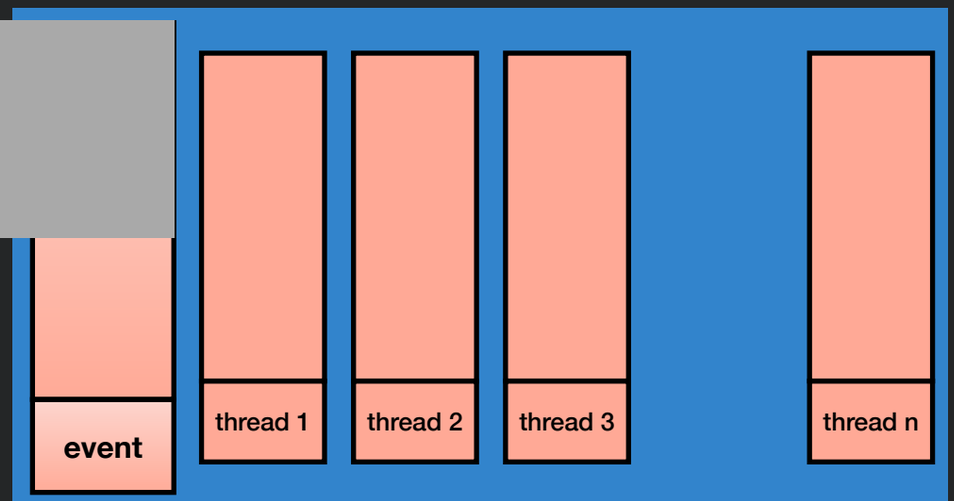

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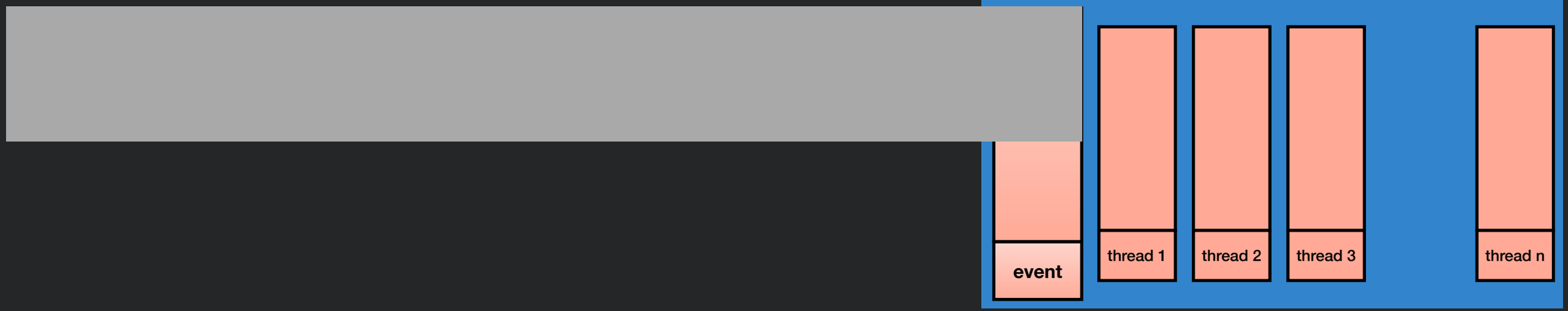

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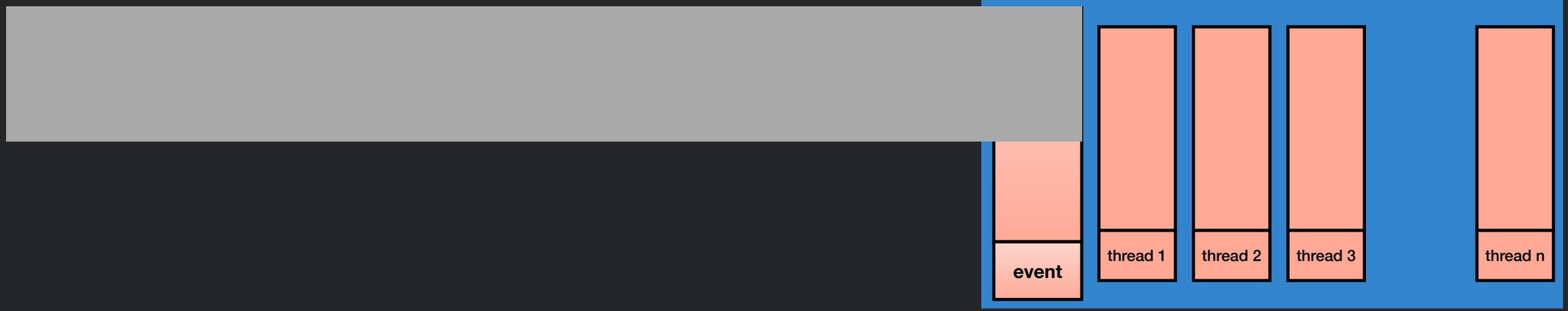

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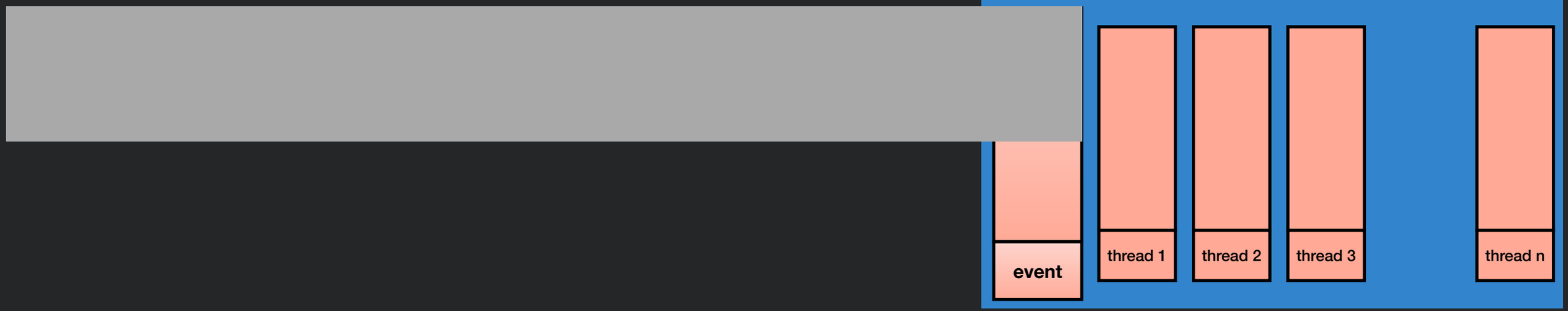

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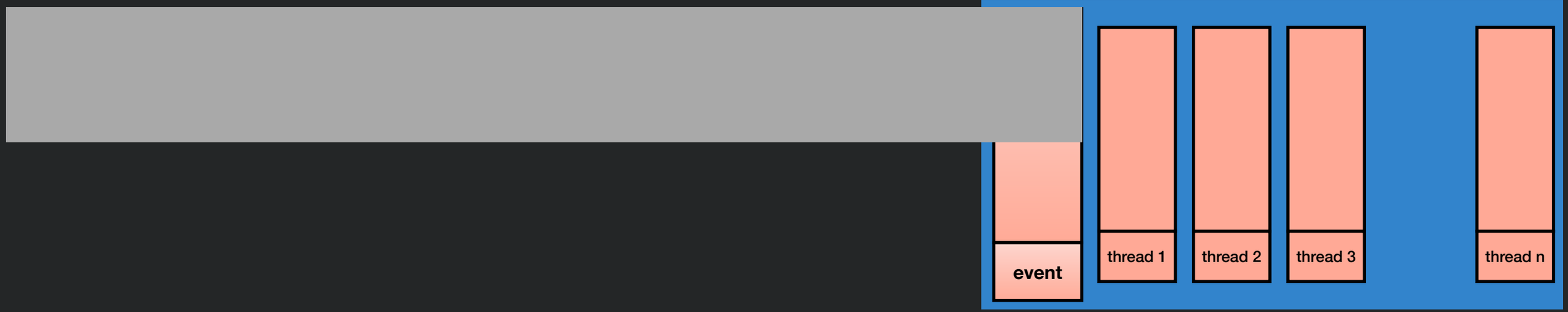

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JS Engine

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

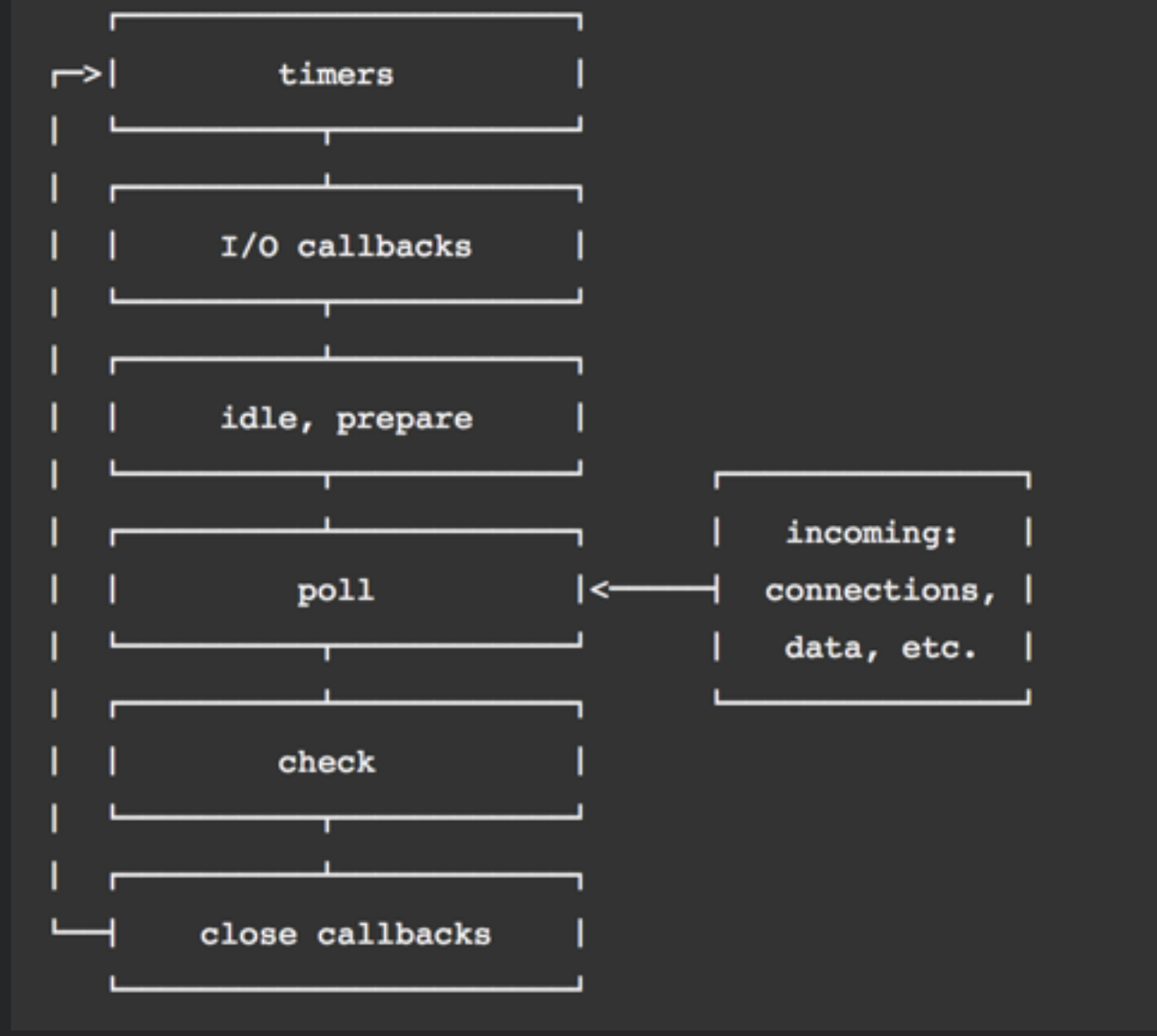
More Properties of Good Handlers

- 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

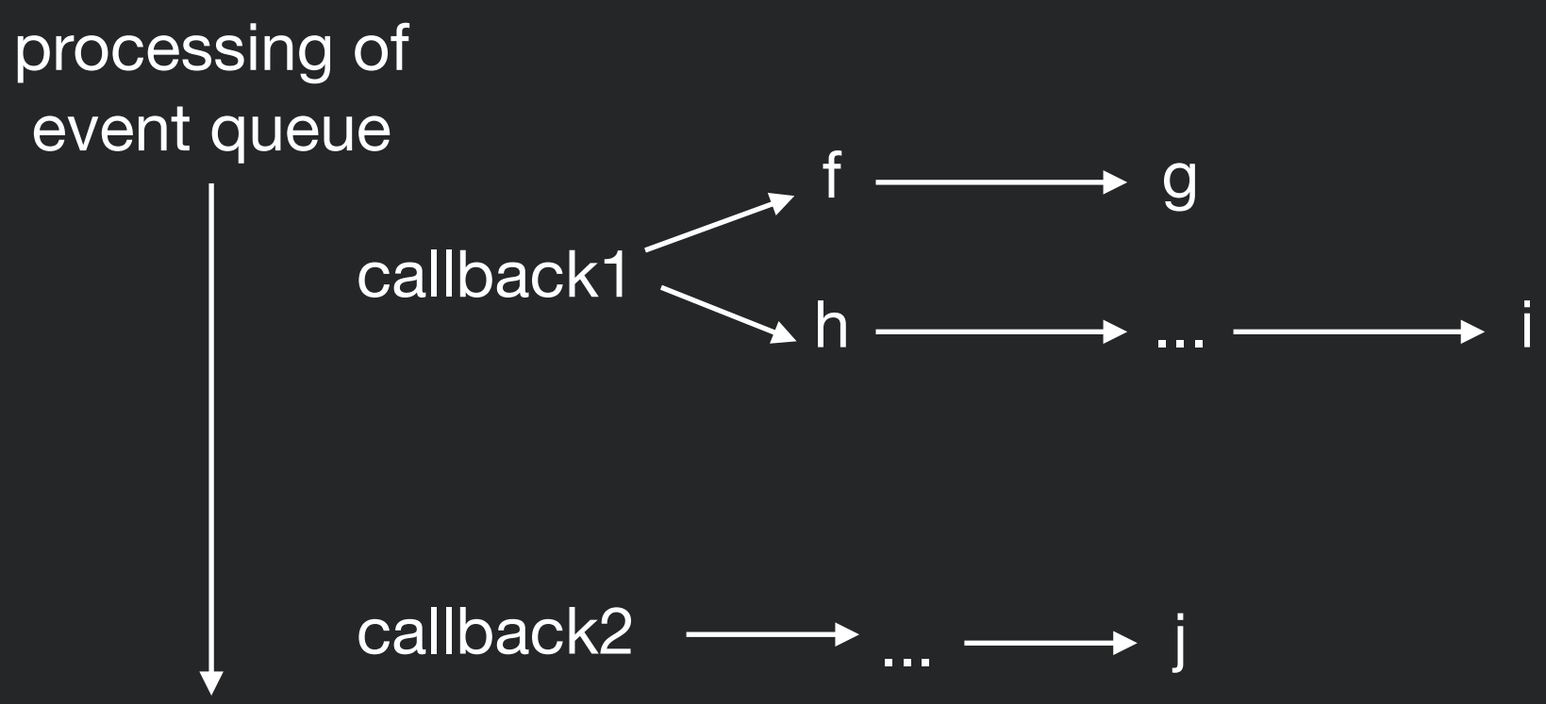
https://nodejs.org/en/docs/guides/event-loop-timers-and-nexttick/

Benefits vs. Explicit Threading (Java)

- Writing your own threads is 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.



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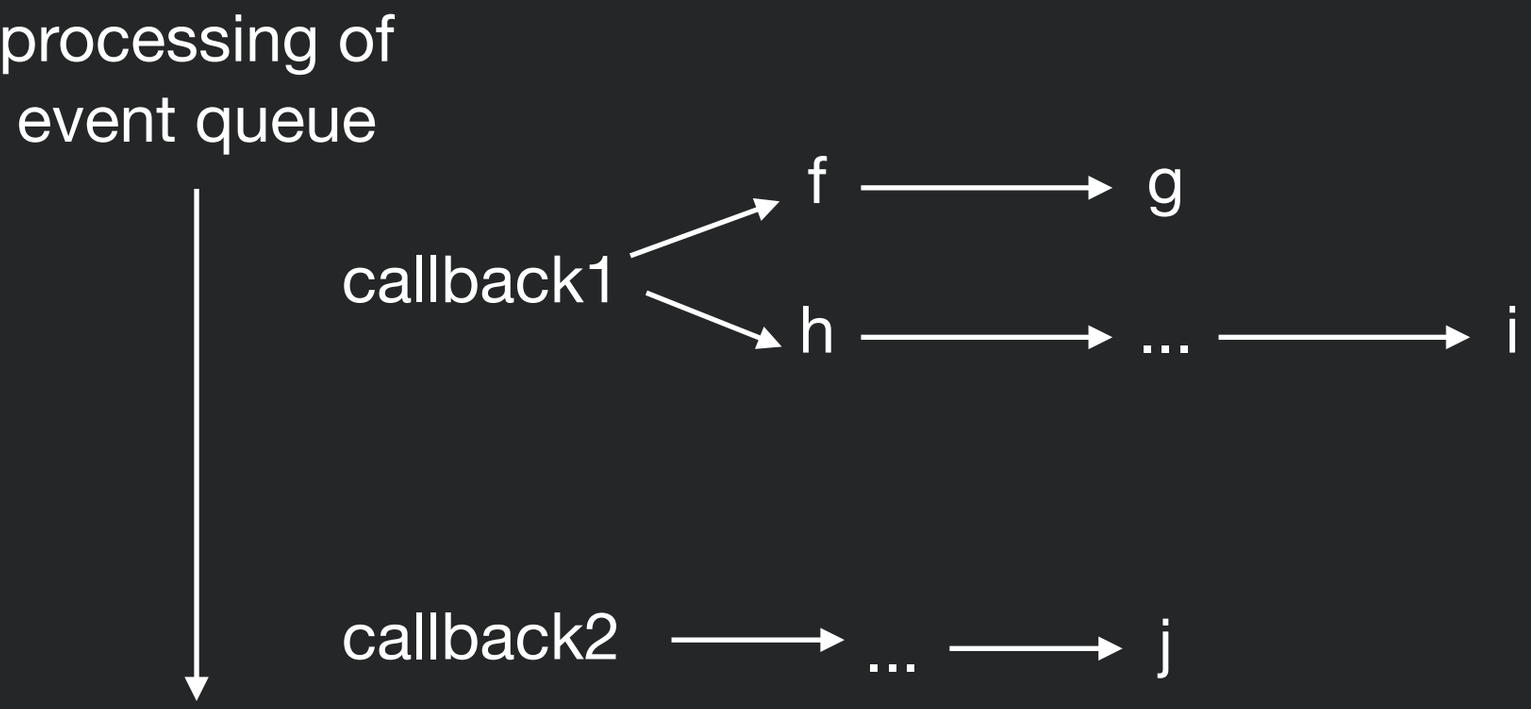

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Implications of run-to-completion

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  - Event handlers should never block (e.g., wait for input) --> all callbacks waiting for network response or user input are **always** asynchronous
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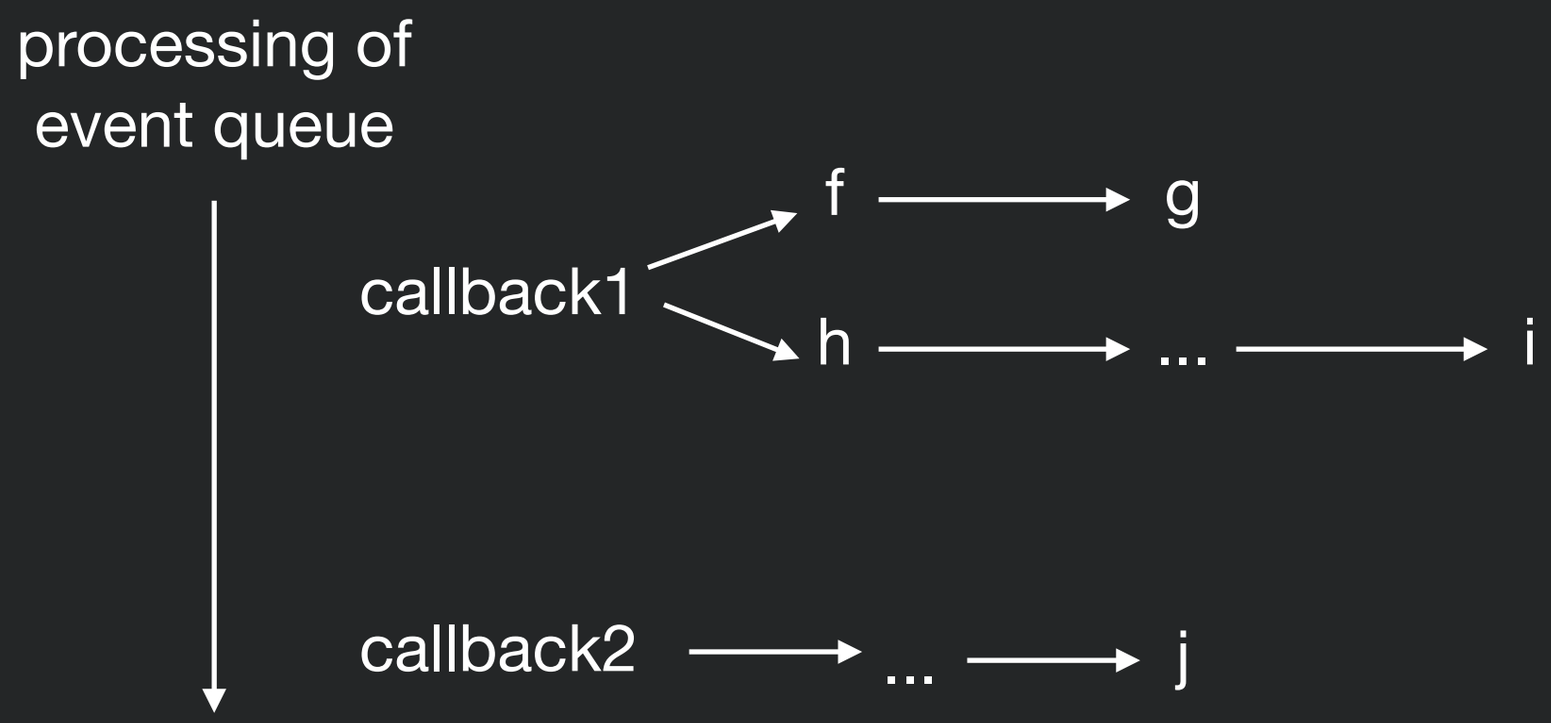


`j` will not execute until `i` finishes

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`)

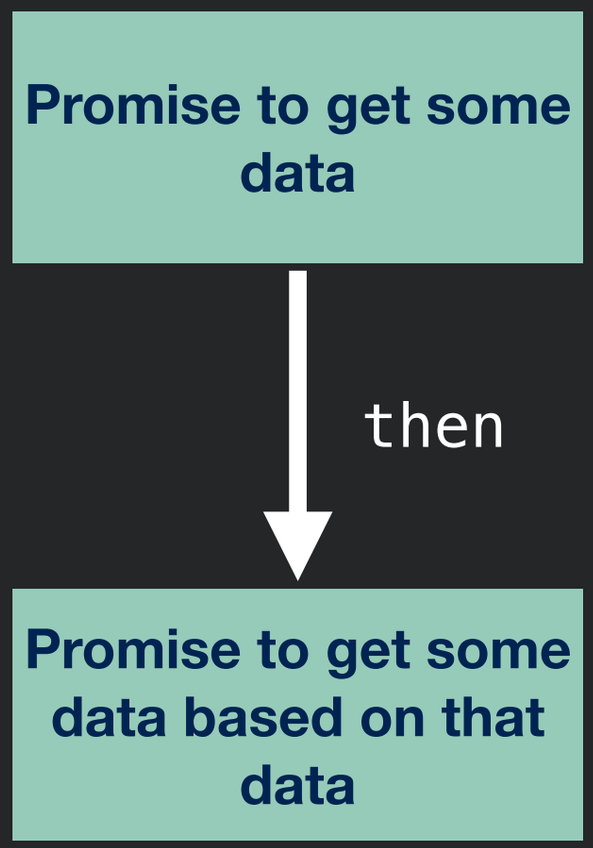
```
fetch('https://github.com/')
    .then(function(res) {
        return res.text();
    });
```

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

Promise One Thing Then Another

Promise to get some data

Promise One Thing Then Another



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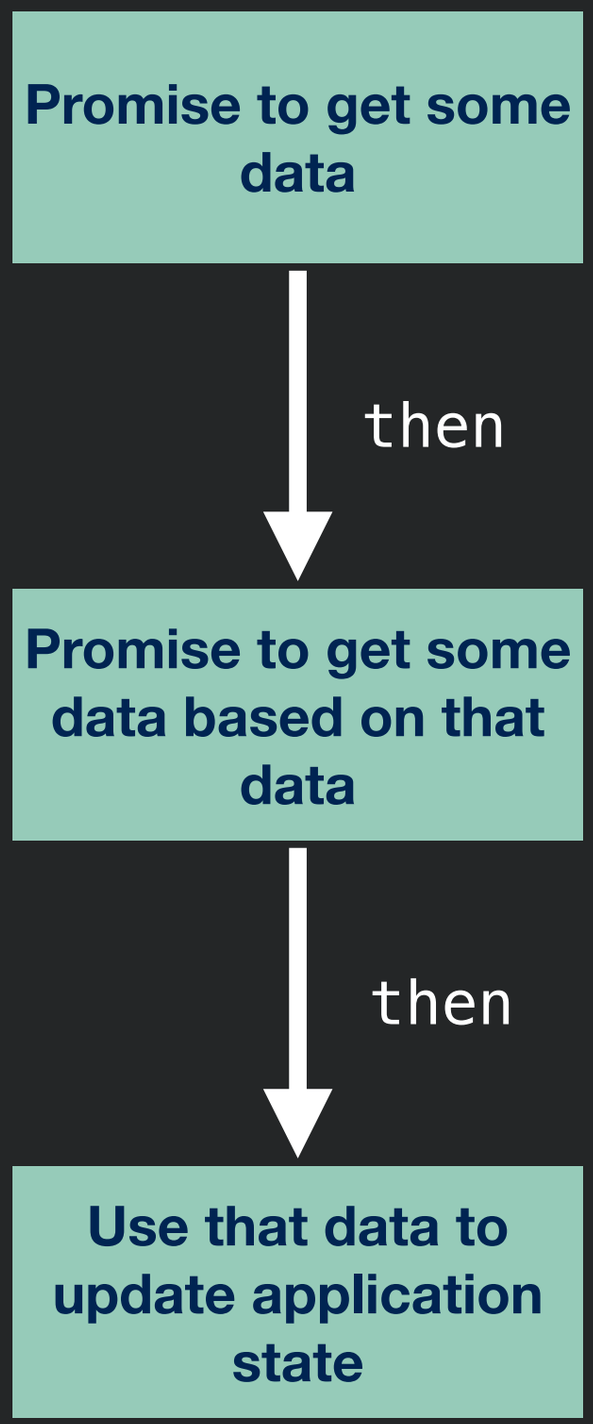

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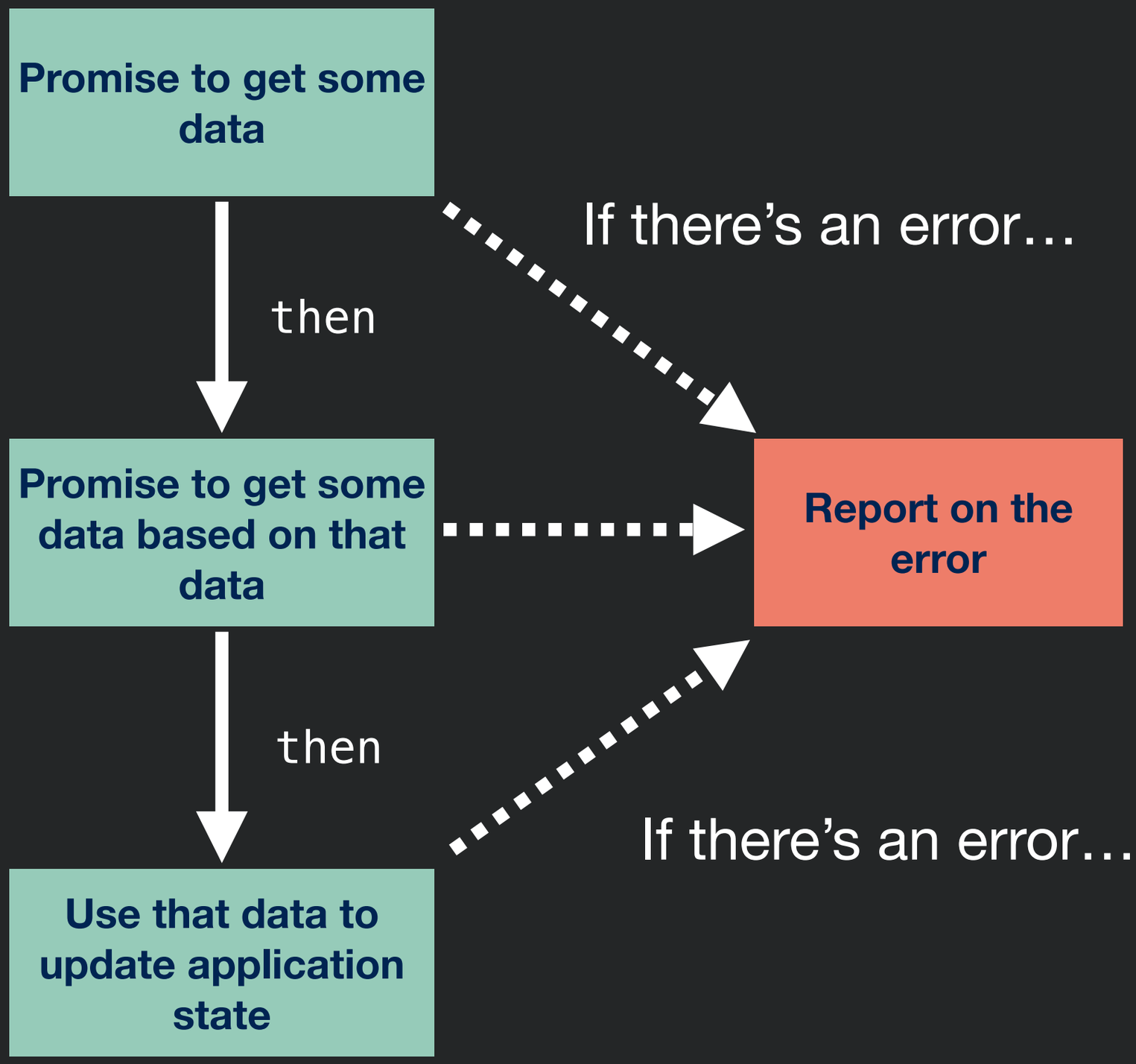

Chaining Promises

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

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    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

Promises in Action

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

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```
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
    });
```

Promises in Action

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Do this

Promises in Action

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Do this

Then, do this

Promises in Action

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```

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Then, do this

Then do this

Promises in Action

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    })
    .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);
}
```

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

Testing Promises

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

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

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```
it('works with promises', () => {
    expect.assertions(1);
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});
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});


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

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Testing Promises

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

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return expect(user.getUserName(5)).resolves.toEqual('Paul');
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```

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SWE 432 - Web Application Development

George Mason University

Instructor:
Dr. Kevin Moran

Teaching Assistant:
David Gonzalez Samudio

Class will start in:

10:01

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Asynchronous Programming II

Review: Asynchronous

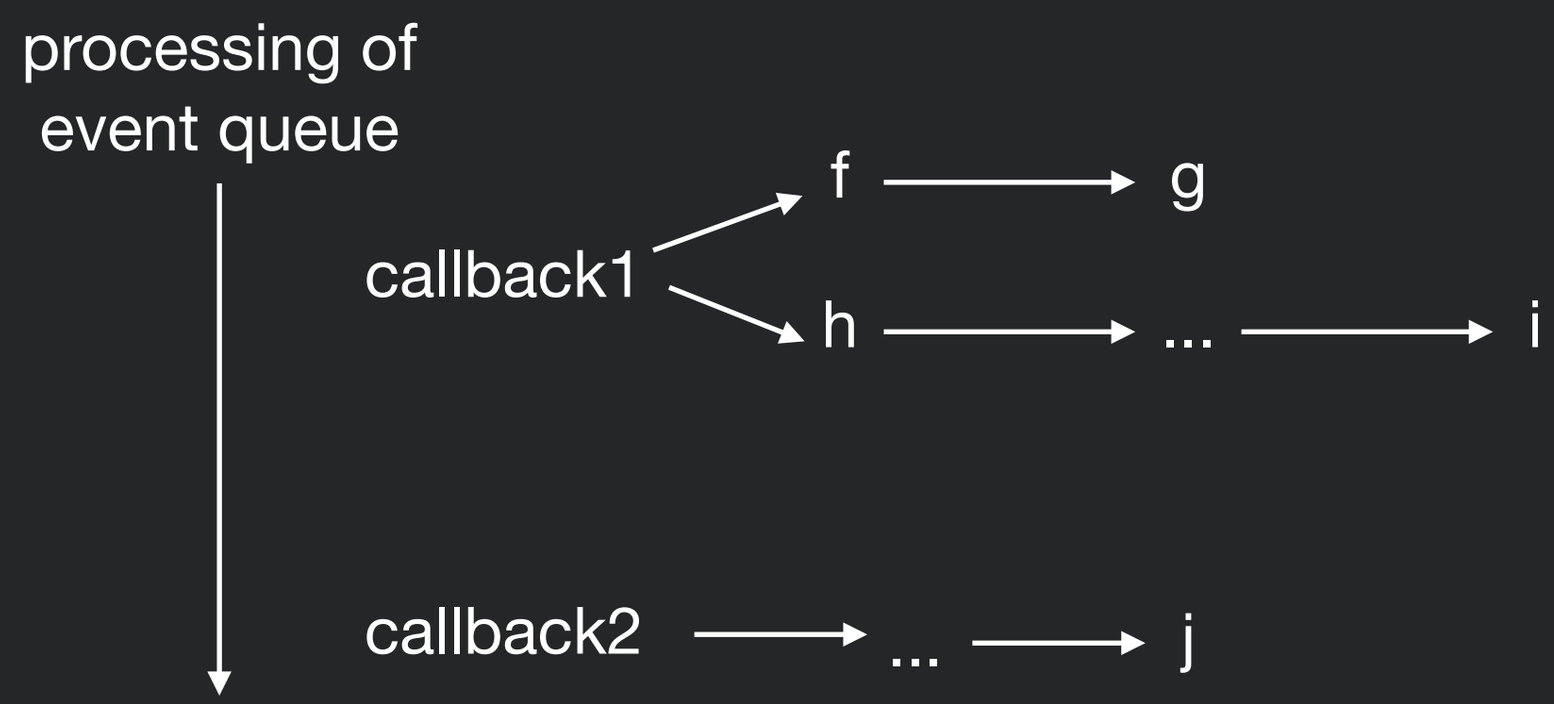
- Synchronous:
  - Make a function call
  - When function call returns, the work is done
- Asynchronous:
  - Make a function call
  - Function returns immediately, before completing work!

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.
  - The JS engine will not handle the next event until the event handler finishes.



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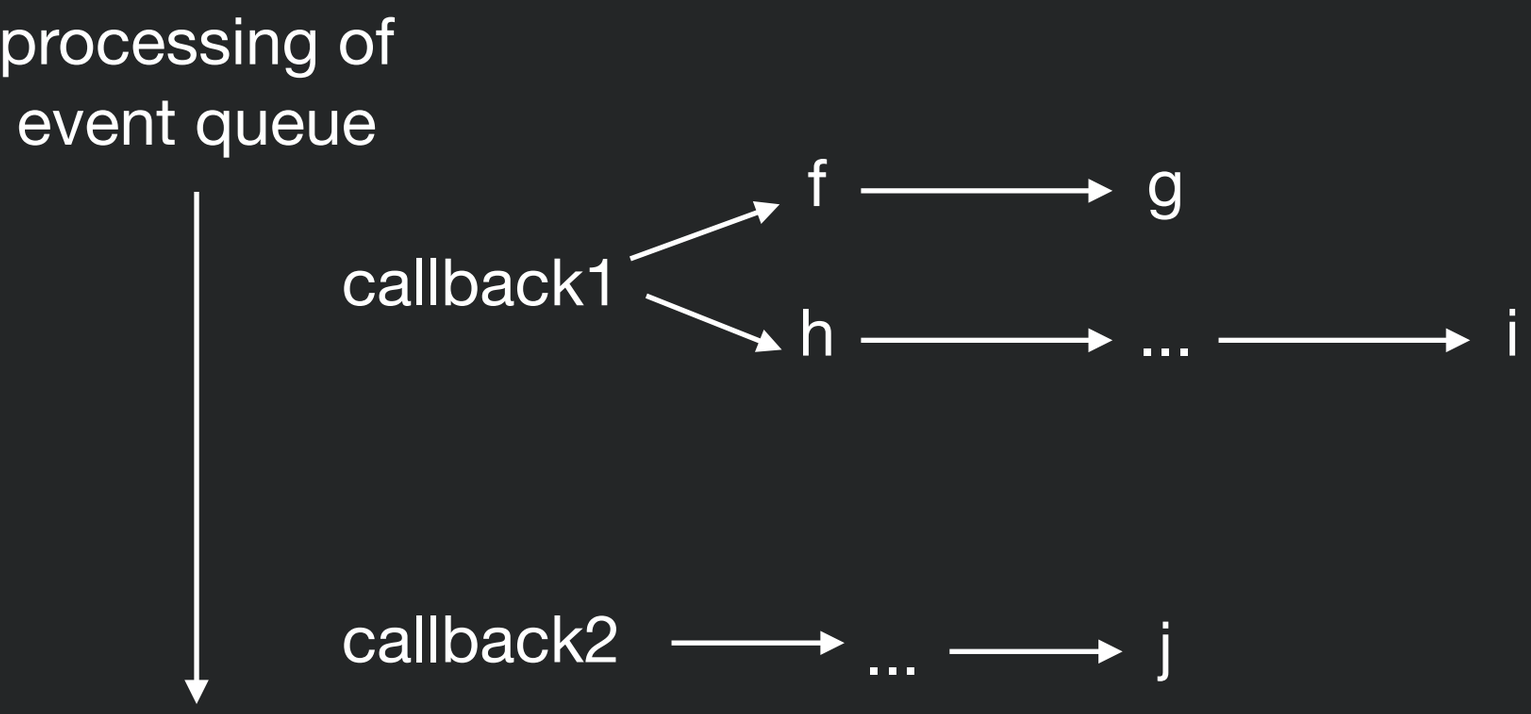

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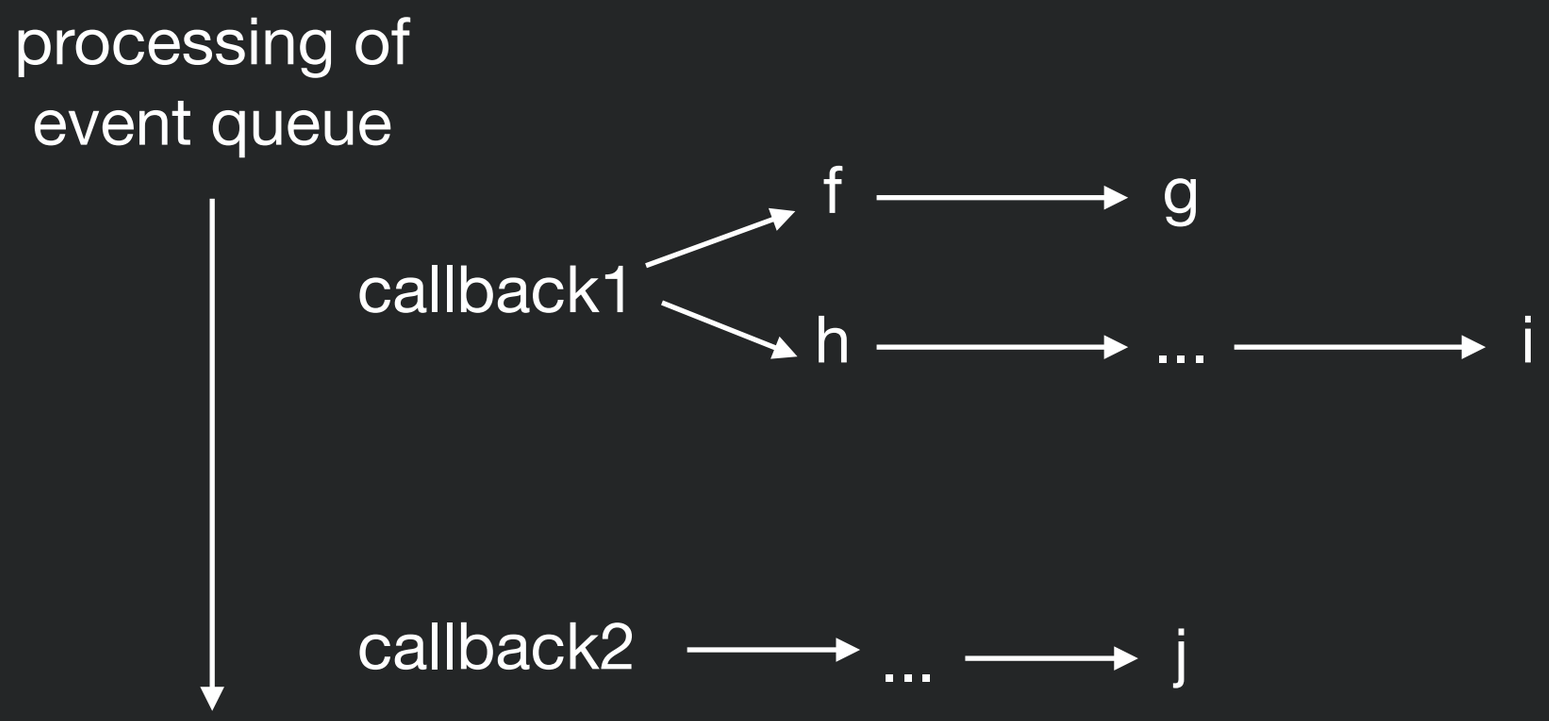

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Review: Chaining Promises

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    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

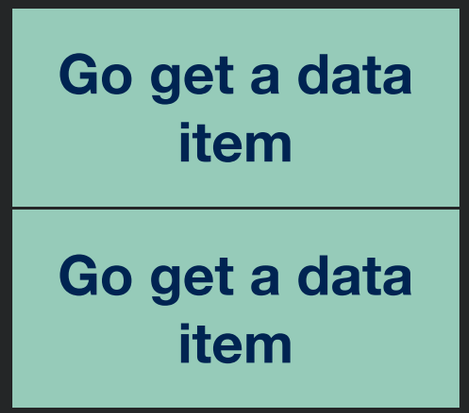
Explain example

Synchronous Version

Synchronous Version

Go get a data item

Synchronous Version



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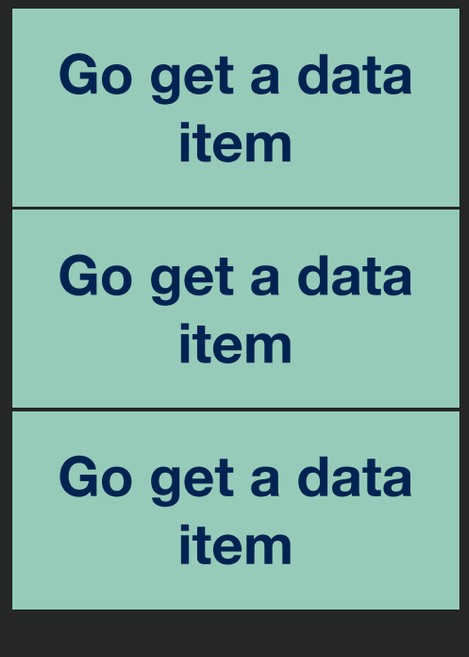
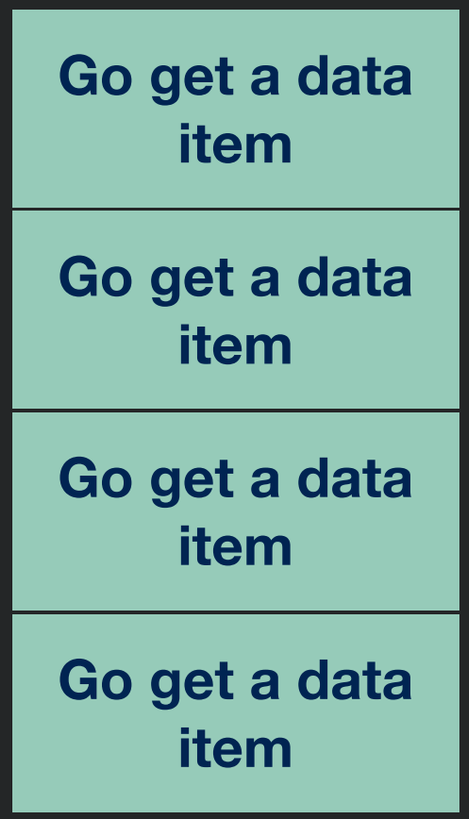


Synchronous Version



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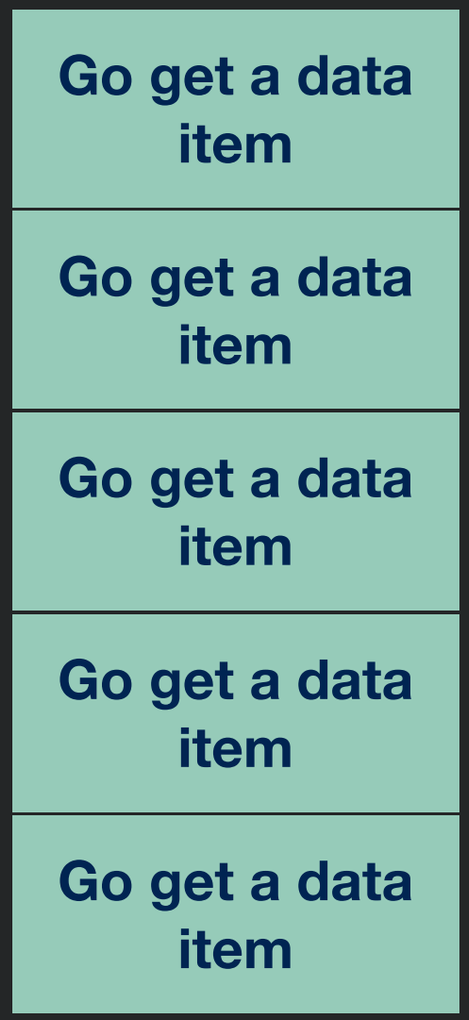

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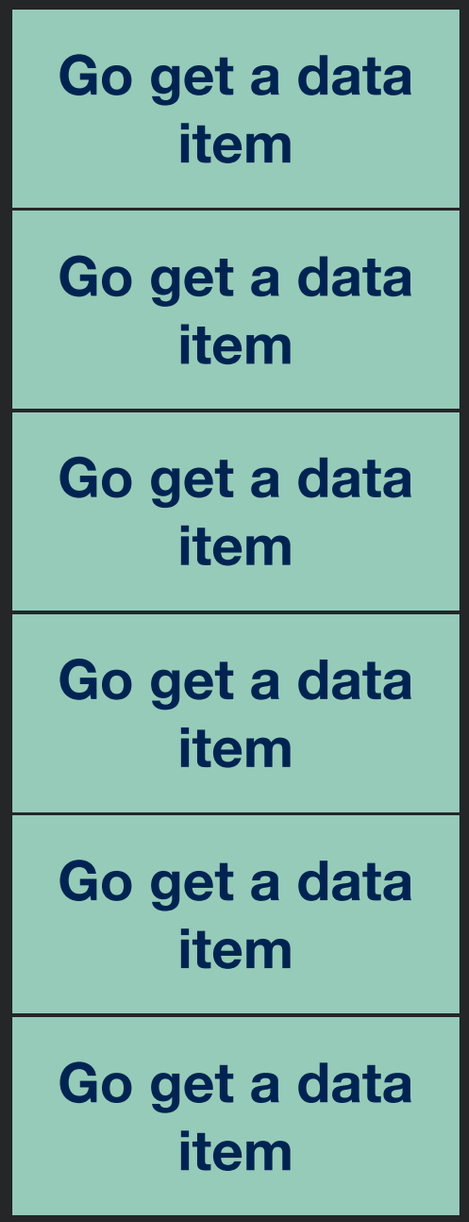

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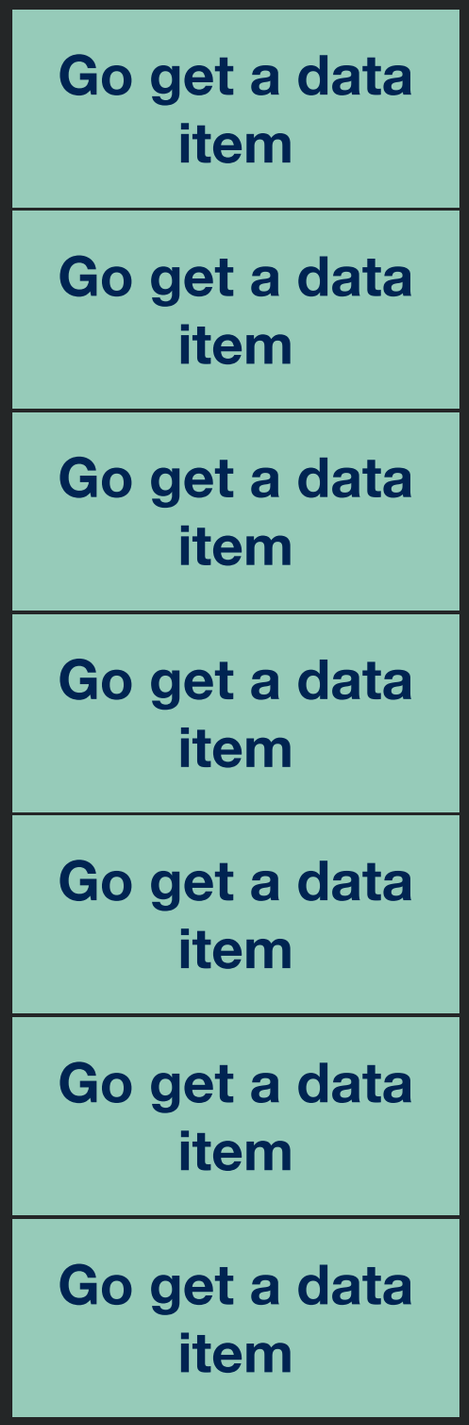
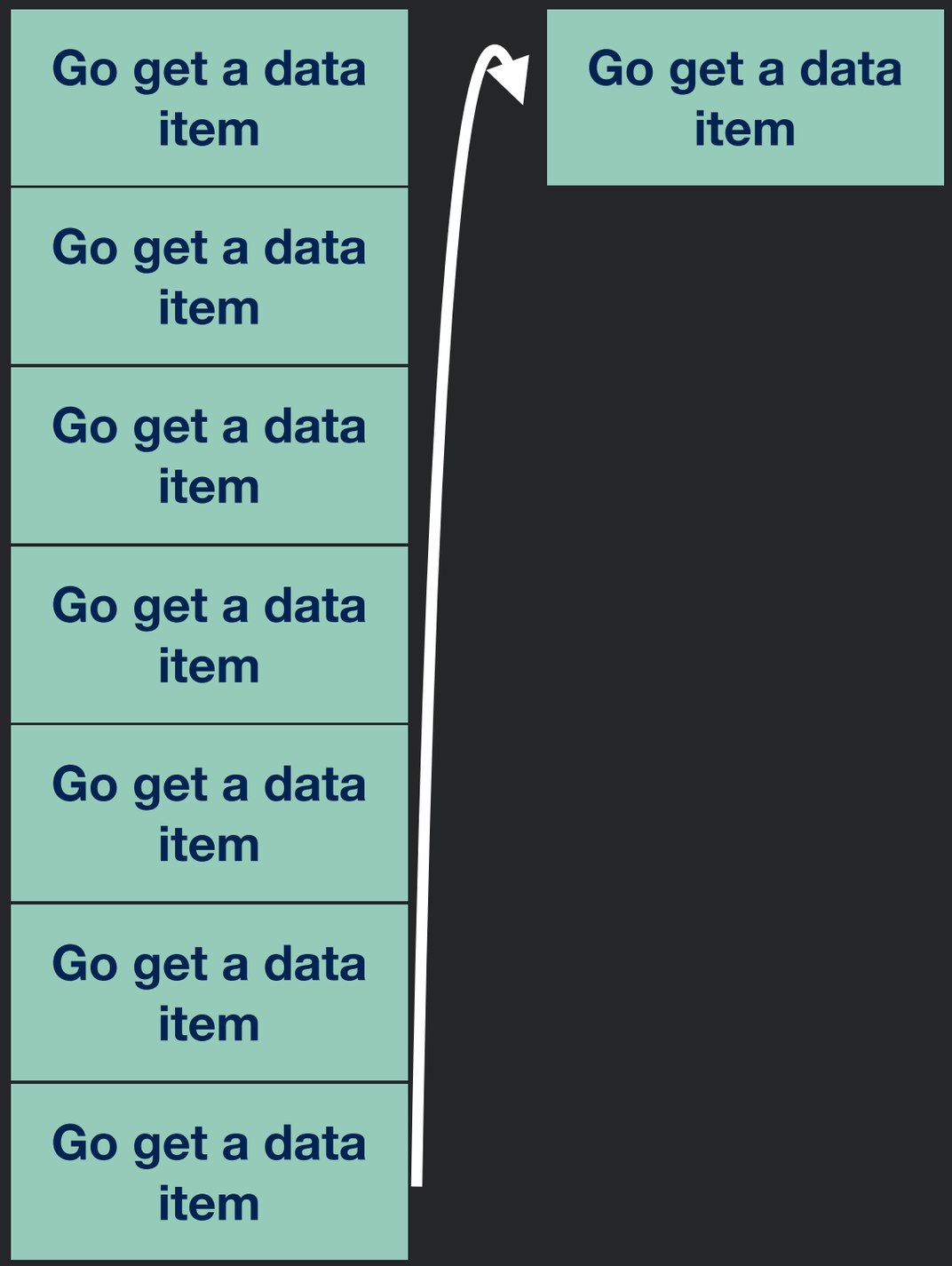


Synchronous Version

Synchronous Version



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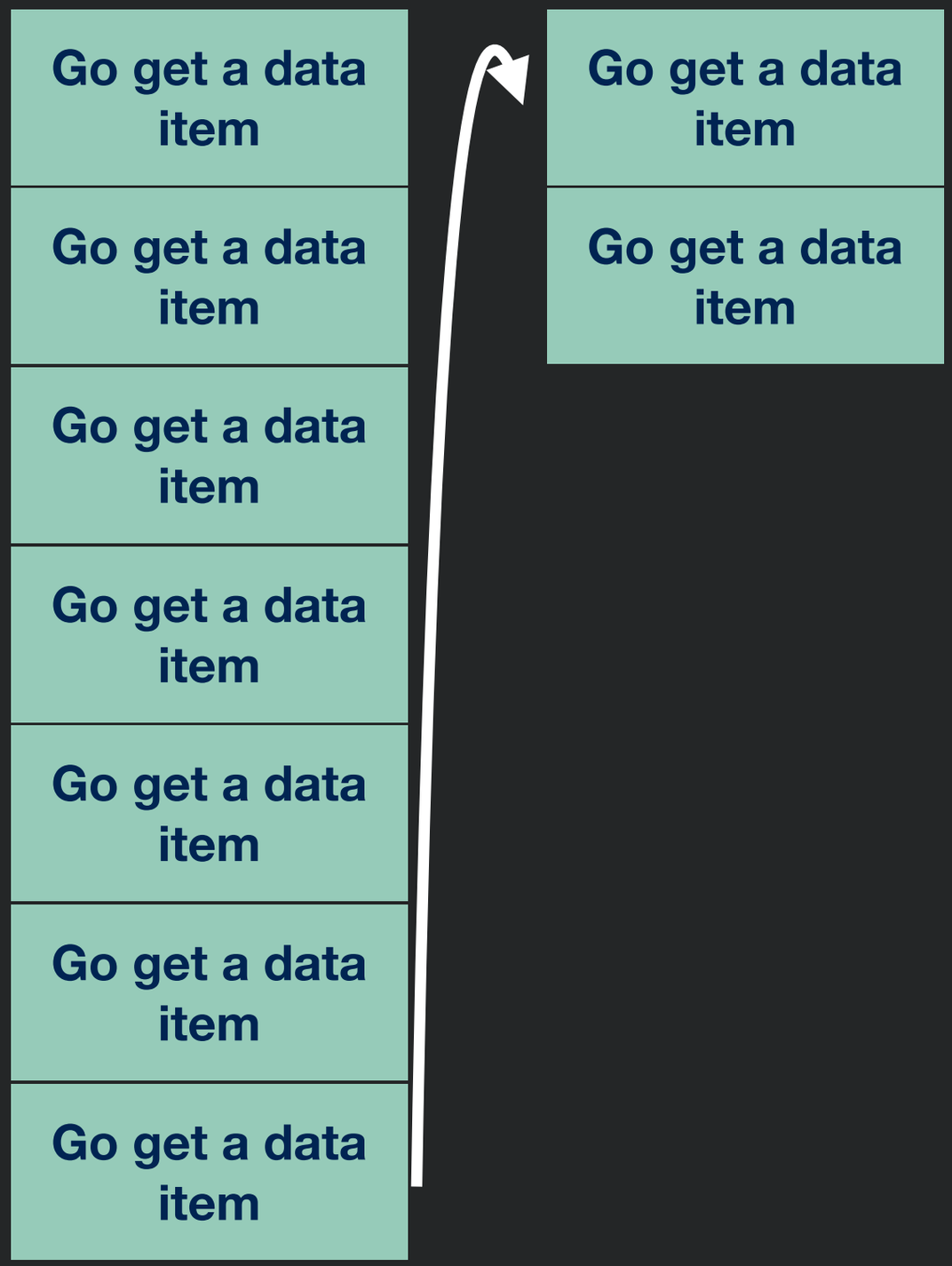

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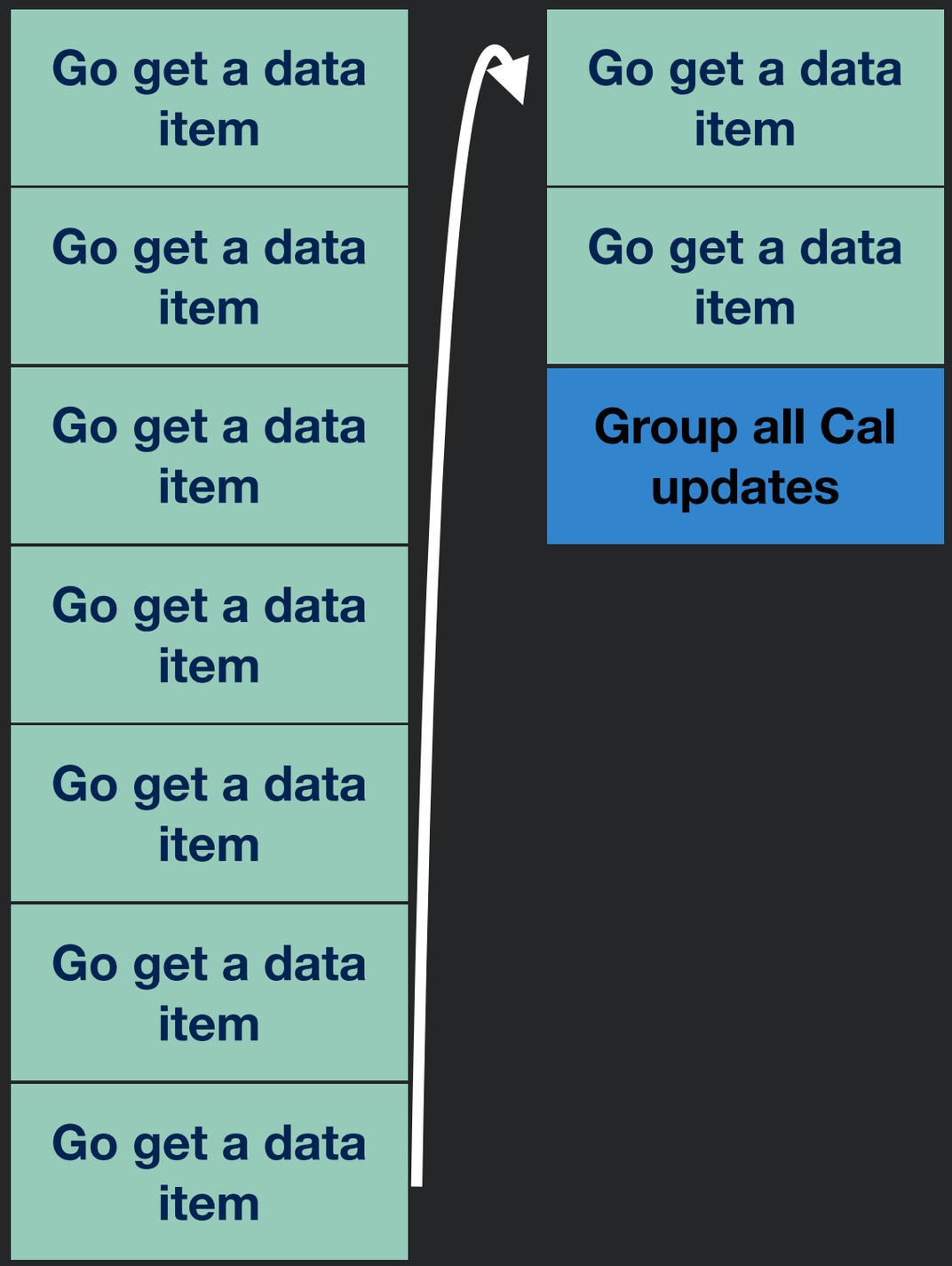

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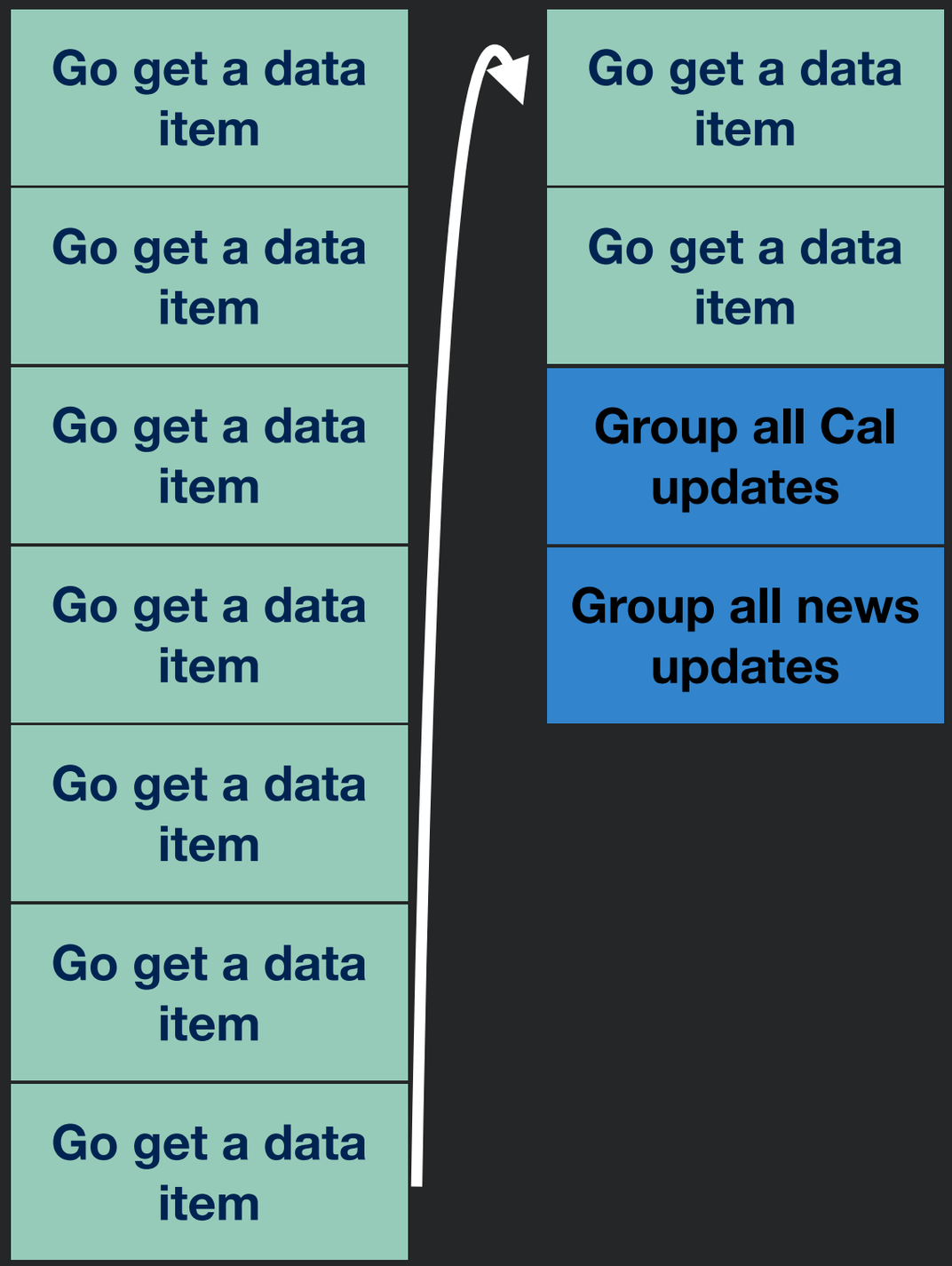

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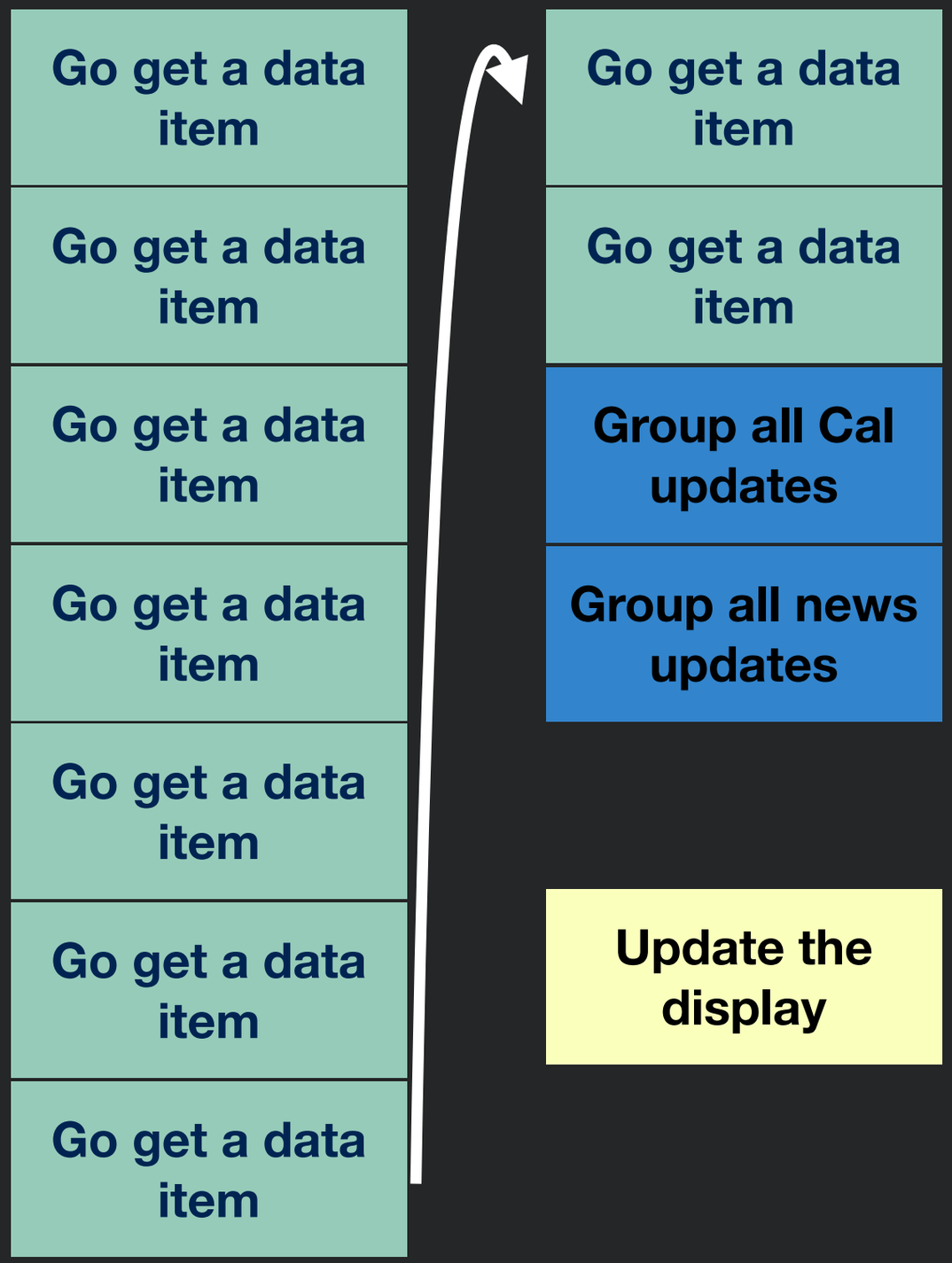

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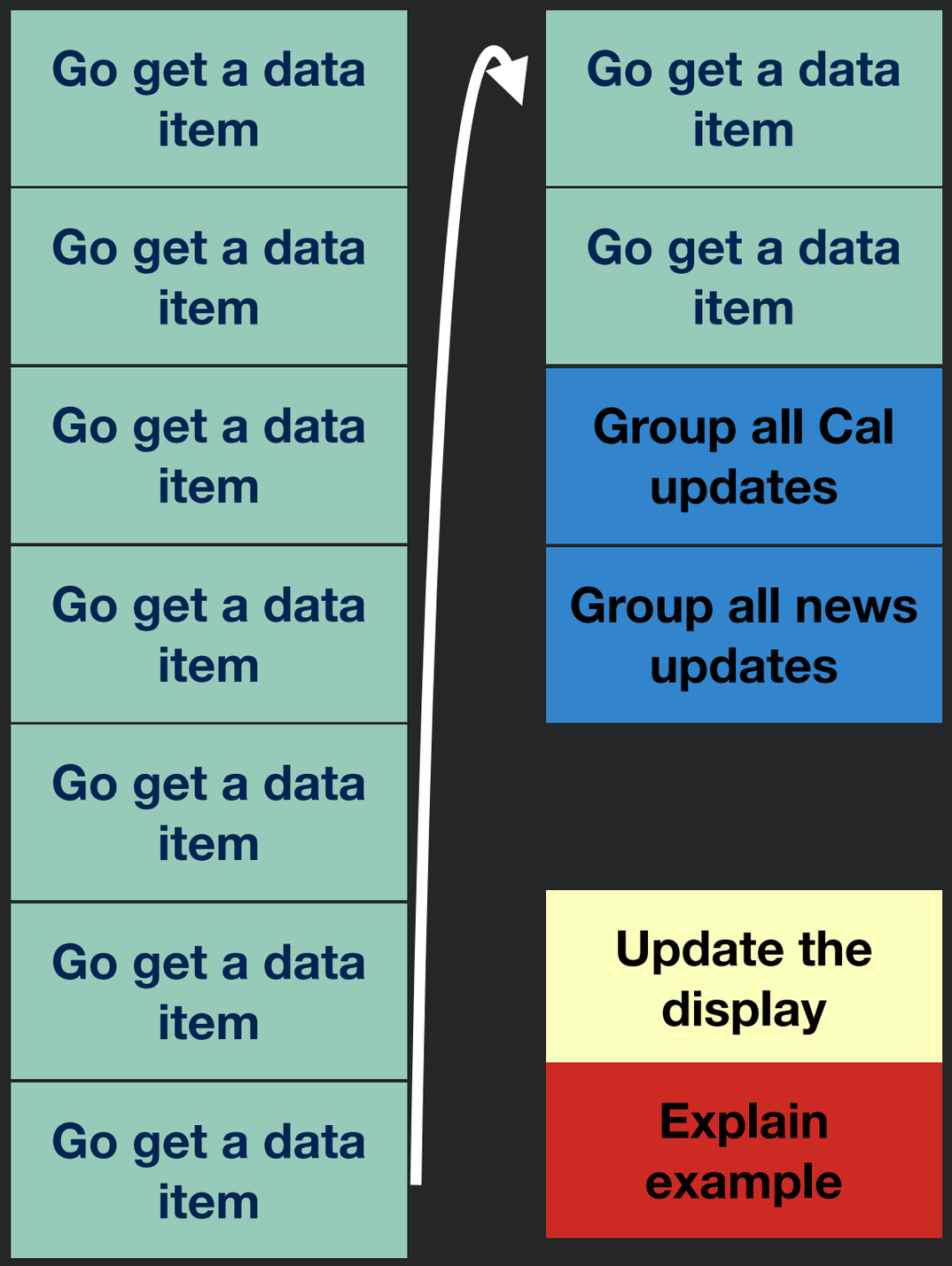
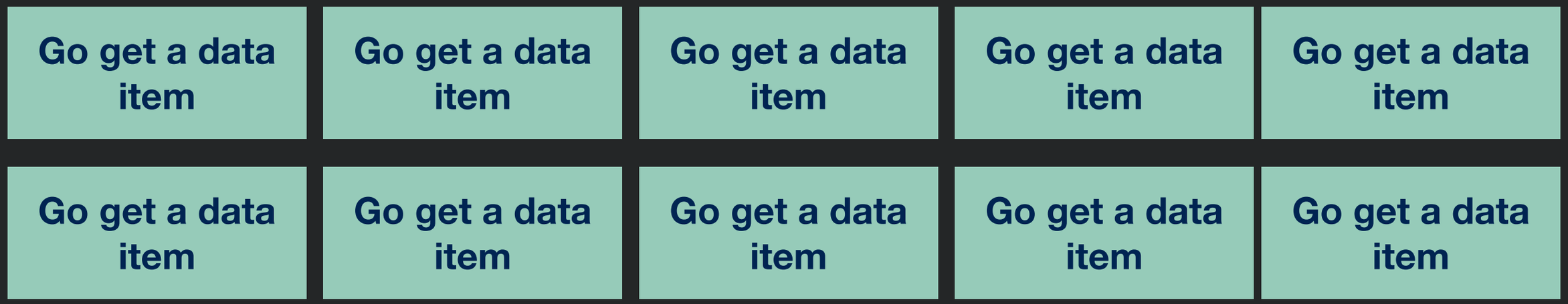


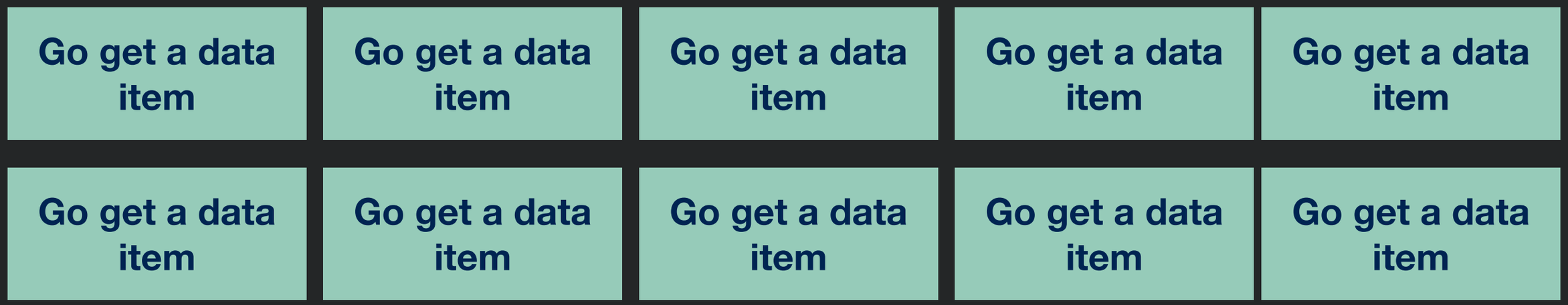
Asynchronous Version

Asynchronous Version

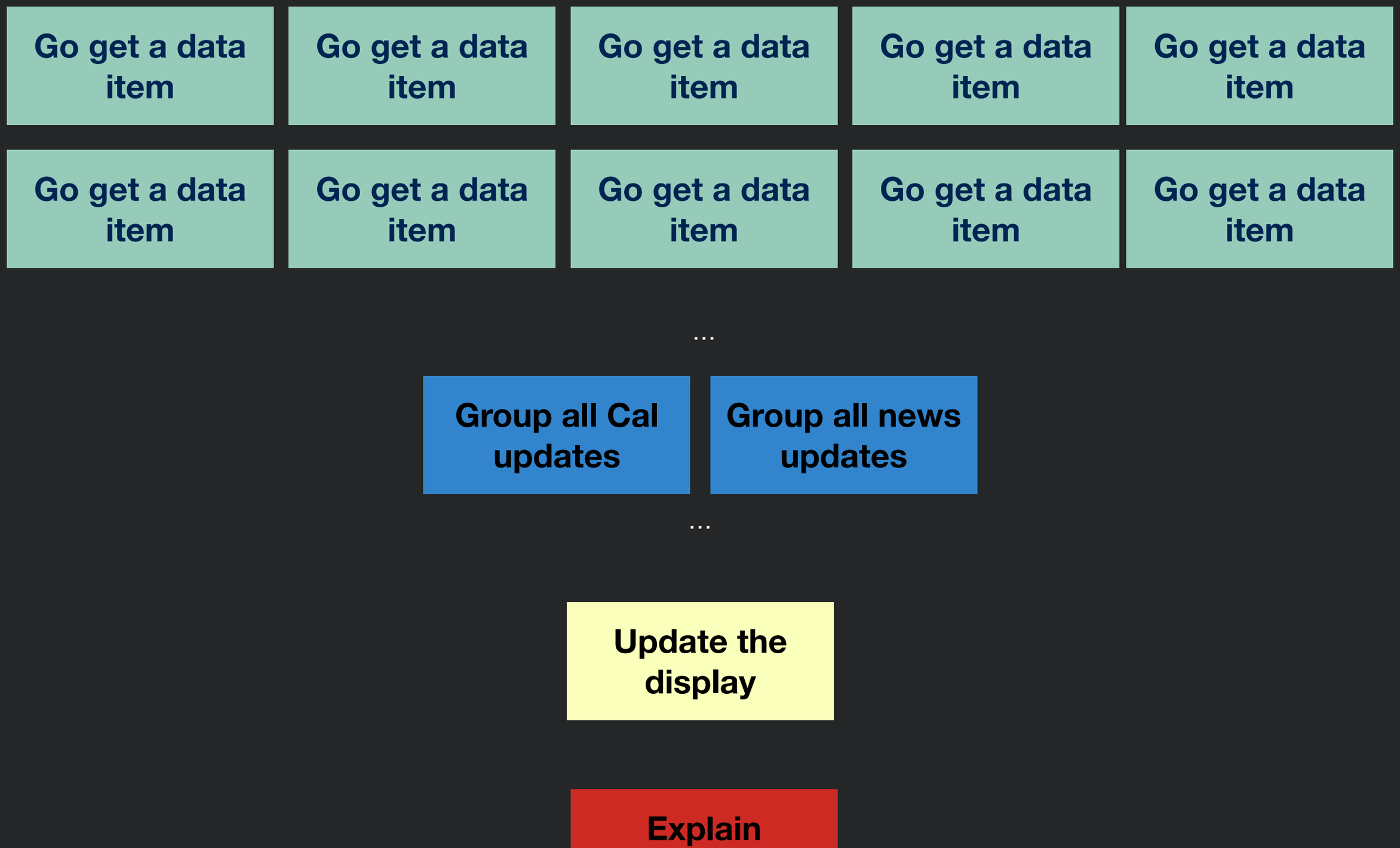


Explain example

Asynchronous Version



Asynchronous Version



Async Programming Example (Sync)

```
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");
```

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");
```

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");
            })
        }
    });
}
```

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]);
    }
```

Async Programming Example (Promises)

```
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");
});
```

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'
}

asyncCall();
```

https://jsbin.com/jivacodefo/edit?js,console

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();
```

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");
...
}
```