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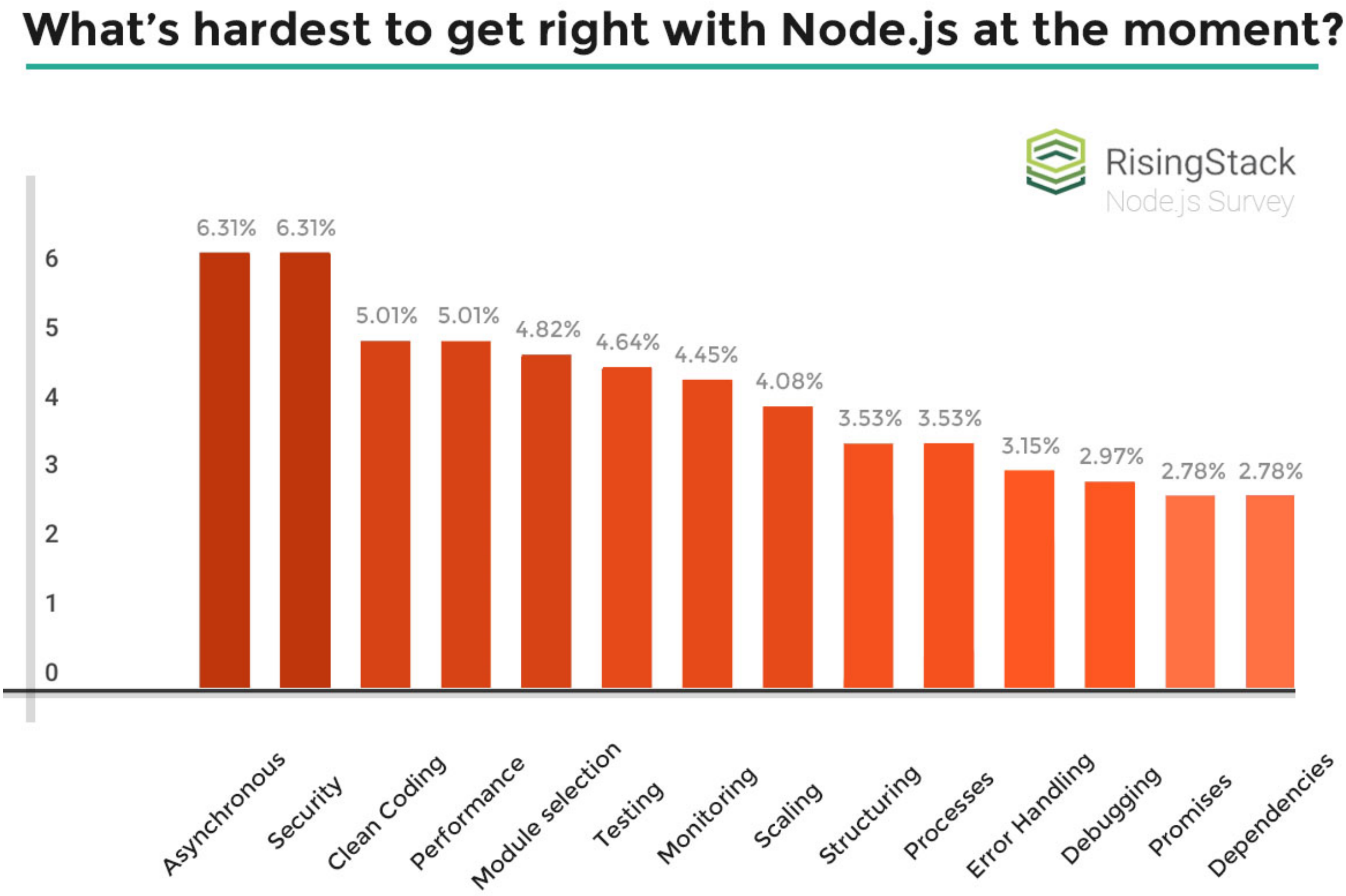
How To Use This Book

Async/await is the single most valuable feature to land in the JavaScript language spec in the last 15 years. The event loop and asynchronous programming in general are exceptional for building GUIs and servers, but callbacks make error handling tedious and code hard to read. For example, when RisingStack asked Node.js developers what they struggled with in 2017, asynchronous programming topped the list.



Async/await promises to make asynchronous code as clean and easy to read as synchronous code in most use cases. Tangled promise chains and complex user-land libraries like async can be replaced with `for` loops, `if` statements, and `try/catch` blocks that even the most junior of engineers can make sense of.

The following JavaScript from a 2012 blog post is a typical example of where code goes wrong with callbacks. This code works, but it has a lot of error handling boilerplate and deeply nested `if` statements that obfuscate the actual logic. Wrapping your mind around it takes a while, and proper error handling means copy/pasting `if (err != null)` into every callback.

```
function getWikipediaHeaders() {
  // i. check if headers.txt exists
  fs.stat('./headers.txt', function(err, stats) {
    if (err != null) { throw err; }
    if (stats == undefined) {
      // ii. fetch the HTTP headers
      var options = { host: 'www.wikipedia.org', port: 80 };
      http.get(options, function(err, res) {
        if (err != null) { throw err; }
        var headers = JSON.stringify(res.headers);
        // iii. write the headers to headers.txt
        fs.writeFile('./headers.txt', headers, function(err) {
          if (err != null) { throw err; }
          console.log('Great Success!');
        });
      });
    } else { console.log('headers already collected'); }
  });
}
```

Below is the same code using async/await, assuming that `stat()`, `get()`, and `writeFile()` are properly promisified.

```
async function getWikipediaHeaders() {
  if (await stat('./headers.txt') != null) {
    console.log('headers already collected');
  }
  const res = await get({ host: 'www.wikipedia.org', port: 80 });
  await writeFile('./headers.txt', JSON.stringify(res.headers));
  console.log('Great success!');
}
```

You might not think async/await is a big deal. You might even think async/await is a bad idea. I've been in your shoes: when I first learned about async/await in 2013, I thought it was unnecessary at best. But when I started working with generator-based coroutines (the 2015 predecessor to async/await), I was shocked at how quickly server crashes due to `TypeError: Cannot read property 'x' of undefined` vanished. By the time async/await became part of the JavaScript language spec in 2017, async/await was an indispensable part of my dev practice.

Just because async/await is now officially part of JavaScript doesn't mean the world is all sunshine and rainbows. Async/await is a new pattern that promises to make day-to-day development work easier, but, like any pattern, you need to understand it or you'll do more harm than good. If your async/await code is a patchwork of copy/pasted StackOverflow answers, you're just trading callback hell for the newly minted async/await hell.

The purpose of this book is to take you from someone who is casually acquainted with promises and async/await to someone who is comfortable building and debugging a complex app whose core logic is built on async/await. This book is only 50 pages and is meant to be read in about 2 hours total. You may read it all in one sitting, but you would be better served reading one chapter at a time, studying the exercises at the end, and getting a good night's sleep in between chapters to really internalize the information.

This book is broken up into 4 chapters. Each chapter is 12 pages, including exercises at the end of each chapter that highlight key lessons from the chapter. The exercises require more thought than code and should be easy to answer within a few minutes.

The first 3 chapters are focused on promise and async/await fundamentals, and strive to avoid frameworks and outside dependencies. In particular, the first 3 chapters' code samples and exercises are meant to run in Node.js 8.x and the first 3 chapters will **not** cover transpilers. In the interest of providing realistic examples, the code samples will use the `superagent` module for making HTTP requests. The 4th chapter will discuss transpilers and integrating async/await with some common npm modules.

If you find any issues with the code samples or exercises, please report them at github.com/vkarpov15/mastering-async-await-issues.

Are you ready to master async/await? Let's get started!

Async/Await: The Good Parts

The `async` and `await` keywords are new additions to JavaScript as part of the 2017 edition of the language specification. The `async` keyword modifies a function, either a normal `function() {}` or an arrow function `() => {}`, to mark it as an *async function*. In an async function, you can use the `await` keyword to pause the function's execution until a promise settles. In the below function, the `await` keyword pauses the function's execution for approximately 1 second.

Example 1.1

```
async function test() {
  // This function will print "Hello, World!" after 1 second.
  await new Promise(resolve => setTimeout(() => resolve(), 1000));
  console.log('Hello, World!');
}

test();
```

You can use the `await` keyword anywhere in the body of an async function. This means you can use `await` in `if` statements, `for` loops, and `try/catch` blocks. Below is another way to pause an async function's execution for about 1 second.

Example 1.2

```
async function test() {
  // Wait for 100ms 10 times. This function also prints after 1 second.
  for (let i = 0; i < 10; ++i) {
    await new Promise(resolve => setTimeout(() => resolve(), 100));
  }
  console.log('Hello, World!');
}

test();
```

There is one major restriction for using `await`: you can only use `await` within the body of a function that's marked `async`. The following code throws a `SyntaxError`.

Example 1.3

```
function test() {
  const p = new Promise(resolve => setTimeout(() => resolve(), 1000));
  // SyntaxError: Unexpected identifier
  await p;
}

test();
```

In particular, you can't use `await` in a closure embedded in an async function, unless the closure is also an async function. The below code also throws a `SyntaxError`.

Example 1.4

```
const assert = require('assert');

async function test() {
  const p = Promise.resolve('test');
  assert.doesNotThrow(function() {
    // "SyntaxError: Unexpected identifier" because the above function
    // is **not** marked async. "Closure" = function inside a function
    await p;
  });
}
```

As long as you don't create a new function, you can use `await` underneath any number of `for` loops and `if` statements.

Example 1.5

```
async function test() {
  while (true) {
    // Convoluted way to print out "Hello, World!" once per second by
    // pausing execution for 200ms 5 times
    for (let i = 0; i < 10; ++i) {
      if (i % 2 === 0) {
        await new Promise(resolve => setTimeout(() => resolve(), 200));
      }
    }
    console.log('Hello, World!');
  }
}
```

Return Values

You can use `async/await` for more than just pausing execution. The return value of `await` is the value the promise is fulfilled with. This means you can assign a variable to an asynchronously-computed value in code that looks synchronous.

Example 1.6

```
async function test() {
  // You can `await` on a non-promise without getting an error.
  let res = await 'Hello World!';
  console.log(res); // "Hello, World!"

  const promise = new Promise(resolve => {
    // This promise resolves to "Hello, World!" after 1s
    setTimeout(() => resolve('Hello, World!'), 1000);
  });
  res = await promise;
  // Prints "Hello, World!". `res` is equal to the value the
  // promise resolved to.
  console.log(res);

  // Prints "Hello, World!". You can use `await` in function params!
  console.log(await promise);
}
```

An async function **always** returns a promise. When you `return` from an async function, JavaScript resolves the promise to the value you returned. This means calling async functions from other async functions is very natural. You can `await` on the async function call and get the async function's "return value".

Example 1.7

```
async function computeValue() {
  await new Promise(resolve => setTimeout(() => resolve(), 1000));
  // "Hello, World" is the _resolved value_ for this function call
  return 'Hello, World!';
}

async function test() {
  // Prints "Hello, World!" after 1s. `computeValue` returns a promise!
  console.log(await computeValue());
}
```

This book will refer to the value you `return` from an async function as the *resolved value*. In `computeValue` above, "Hello, World!" is the resolved value, `computeValue()` still returns a promise. This distinction is subtle but important: the value you `return` from an async function body is **not** the value that an async function call like `computeValue()` without `await` returns.

You can also return a promise from an async function. In that case, the promise the async function returns will be fulfilled or rejected whenever the resolved value promise is fulfilled or rejected. Below is another async function that fulfills to 'Hello, World!' after 1 second:

Example 1.8

```
async function computeValue() {
  // The resolved value is a promise. The promise returned from
  // `computeValue()` will be fulfilled with 'Hello, World!'
  return new Promise(resolve => {
    setTimeout(() => resolve('Hello, World!'));
  }, 1000);
}
```

If you `return` a promise from an async function, the resolved value will still not equal the return value. The below example demonstrates that the `resolvedValue` promise that the function body returns is not the same as the return value from `computeValue()`.

Example 1.9

```
let resolvedValue = Promise.resolve('Hello, World!');
const computeValue = async () => resolvedValue;

async function test() {
  // No `await` below, so `returnValue` will be a promise
  const returnValue = computeValue();
  // `false`. The return value and resolved value are always different
  console.log(returnValue === resolvedValue);
}
```

Async/await beginners often mistakenly think they need to `return` a promise from an async function. They likely read that an async function always returns a promise and think they're responsible for returning a promise. An async function always returns a promise, but, like in example 1.9, JavaScript creates the returned promise for you.

Example 1.10

```
async function computeValue() {
  // Adding `Promise.resolve()` below is unnecessary. It adds
  // perf overhead because you're creating an unnecessary promise.
  // "Unnecessary code is not as harmless as I used to think. It
  // sends the misleading signal that it's necessary." - Paul Graham
  return Promise.resolve('Hello, World!');
}
```

Error Handling

One of the most important properties of async/await is that you can use `try/catch` to handle asynchronous errors. Remember that a promise may be either fulfilled or rejected. When a promise `p` is fulfilled, JavaScript evaluates `await p` to the promise's value. What about if `p` is rejected?

Example 1.11

```
async function test() {
  try {
    const p = Promise.reject(new Error('Oops!'));
    // The below `await` throws
    await p;
  } catch (error) {
    console.log(err.message); // "Oops!"
  }
}
```

If `p` is rejected, `await p` throws an error that you can catch with a normal JavaScript `try/catch`. Note that the `await` statement is what throws an error, **not** the promise instantiation.

This `try/catch` behavior is a powerful tool for consolidating error handling. The `try/catch` block above can catch synchronous errors as well as asynchronous ones. Suppose you have code that throws a `TypeError: cannot read property 'x' of undefined` error:

Example 1.12

```
async function test() {
  try {
    const bad = undefined;
    bad.x;
    const p = Promise.reject(new Error('Oops!'));
    await p;
  } catch (error) {
    // "cannot read property 'x' of undefined"
    console.log(err.message);
  }
}
```

In callback-based code, you had to watch out for synchronous errors like `TypeError` separately from asynchronous errors. This lead to a lot of server crashes and red text in Chrome consoles, because discipline doesn't scale.

Consider using a callback-based approach instead of async/await. Suppose you have a black-box function `test()` that takes a single parameter, a `callback`. If you want to ensure you catch every possible error, you need 2 `try/catch` calls: one around `test()` and one around `callback()`.

You also need to check whether `test()` called your callback with an error. In other words, every single async operation needs 3 distinct error handling patterns!

Example 1.13

```
function testWrapper(callback) {
  try {
    // There might be a sync error in `test()`
    test(function(error, res) {
      // `test()` might also call the callback with an error
      if (error) {
        return callback(error);
      }
      // And you also need to be careful that accessing `res.x` doesn't
      // throw **and** calling `callback()` doesn't throw.
      try {
        return callback(null, res.x);
      } catch (error) {
        return callback(error);
      }
    });
  }
}
```

When there's this much boilerplate for error handling, even the most rigorous and disciplined developers end up missing a spot. The result is uncaught errors, server downtime, and buggy user interfaces. Below is an equivalent example with async/await. You can handle the 3 distinct error cases from example 1.12 with a single pattern.

Example 1.14

```
async function testWrapper() {
  try {
    // `try/catch` will catch sync errors in `test()`, async promise
    // rejections, and errors with accessing `res.x`.
    const res = await test();
    return res.x;
  } catch (error) {
    throw error;
  }
}
```

Let's take a look at how the `throw` keyword works with async functions now that you've seen how `try/catch` works. When you `throw` in an async function, JavaScript will reject the returned promise. Remember that the value you `return` from an async function is called the resolved value. Similarly, this book will refer to the value you `throw` in an async function as the *rejected value*.

Example 1.15

```
async function computeValue() {
  // `err` is the "rejected value"
  const err = new Error('Oops!');
  throw err;
}

async function test() {
  try {
    const res = await computeValue();
    // Never runs
    console.log(res);
  } catch (error) {
    console.log(error.message); // "Oops!"
  }
}
```

Remember that the `computeValue()` function call itself does **not** throw an error in the `test()` function. The `await` keyword is what throws an error that you can handle with `try/catch`. The below code will print "No Error" unless you uncomment the `await` block.

Example 1.16

```
async function computeValue() {
  throw new Error('Oops!');
};

async function test() {
  try {
    const promise = computeValue();
    // With the below line commented out, no error will be thrown
    // await promise;
    console.log("No Error");
  } catch (error) {
    console.log(error.message); // Won't run
  }
}
```

Just because you can `try/catch` around a promise doesn't necessarily mean you should. Since async functions return promises, you can also use `.catch()`:

Example 1.17

```
async function computeValue() {
  throw new Error('Oops!');
};

async function test() {
  let err = null;
  await computeValue().catch(_err => { err = _err; });
  console.log(err.message);
}
```

Both `try/catch` and `catch()` have their place. In particular, `catch()` makes it easier to centralize your error handling. A common async/await novice mistake is putting `try/catch` at the top of every single function. If you want a common `handleError()` function to ensure you're handing all errors, you're better off using `catch()`.

Example 1.18

```
// If you find yourself doing this, stop!
async function fn1() {
  try {
    /* Bunch of logic here */
  } catch (err) {
    handleError(err);
  }
}

// Do this instead
async function fn2() {
  /* Bunch of logic here */
}

fn2().catch(handleError);
```

Retrying Failed Requests

Let's tie together loops, return values, and error handling to handle a challenge that's painful with callbacks: retrying failed requests. Suppose you had to make HTTP requests to an unreliable API.

With callbacks or promise chains, retrying failed requests requires recursion, and recursion is less readable than the synchronous alternative of writing a `for` loop. Below is a simplified implementation of a `getWithRetry()` function using callbacks and the `superagent` HTTP client.

Example 1.19

```
function getWithRetry(url, numRetries, callback, retriedCount) {
  retriedCount = retriedCount || 0;
  superagent.get(url).end(function(error, res) {
    if (error) {
      if (retriedCount >= numRetries) { return callback(error); }
      return getWithRetry(url, numRetries, callback, retriedCount + 1);
    }
    return callback(null, res.body);
  });
}
```

Recursion is subtle and tricky to understand relative to a loop. Plus, the above code ignores the possibility of sync errors, because the `try/catch` spaghetti highlighted in example 1.13 would make this example unreadable. In short, this pattern is both brittle and cumbersome.

With async/await, you don't need recursion and you need one `try/catch` to handle sync and async errors. The async/await implementation is built on `for` loops, `try/catch`, and other constructs that should be familiar to even the most junior of engineers.

Example 1.20

```
async function getWithRetry(url, numRetries) {
  let lastError = null;
  for (let i = 0; i < numRetries; ++i) {
    try {
      // Note that `await superagent.get(url).body` does **not** work
      const res = await superagent.get(url);
      // Early return with async functions works as you'd expect
      return res.body;
    } catch (error) {
      lastError = error;
    }
  }
  throw lastError;
}
```

More generally, async/await makes executing async operations in series trivial. For example, let's say you had to load a list of blog posts from an HTTP API and then execute a separate HTTP request to load the comments for each blog post. This example uses the excellent JSONPlaceholder API that provides good test data.

Example 1.21

```
async function run() {
  const root = 'https://jsonplaceholder.typicode.com';
  const posts = await getWithRetry(`${root}/posts`, 3);
  for (const { id } of posts) {
    const comments =
      await getWithRetry(`${root}/comments?postId=${id}`, 3);
    console.log(comments);
  }
}
```

If this example seems trivial, that's good, because that's how programming should be. The JavaScript community has created an incredible hodge-podge of tools for executing asynchronous tasks in series, from `async.waterfall()` to Redux sagas to zones to co. Async/await makes all of these libraries and more unnecessary. Do you even need Redux middleware anymore?

This isn't the whole story with async/await. This chapter glossed over numerous important details, including how promises integrate with async/await and what happens when two asynchronous functions run simultaneously. Chapter 2 will focus on the internals of promises, including the difference between "resolved" and "fulfilled", and explain why promises are perfectly suited for async/await.

Exercise 1: HTTP Request Loops

The purpose of this exercise is to get comfortable with using loops and `if` statements with async/await. You will need to use the `fetch()` API to get a list of blog posts on thecodebarbarian.com, and then execute a separate `fetch()` to get the raw markdown `content` for each blog post.

Below are the API endpoints. The API endpoints are hosted on Google Cloud Functions at `https://us-central1-mastering-async-await.cloudfunctions.net`.

- `/posts` gets a list of blog posts. Below is an example post:

```
{ "src":"./lib/posts/20160304_circle_ci.md",
  "title":"Setting Up Circle CI With Node.js",
  "date":"2016-03-04T00:00:00.000Z",
  "tags":["NodeJS"],
  "id":51 }
```

- `/post?id=${id}` gets the markdown content of a blog post by its `id` property. The above blog post has `id` = 0, so you can get its content from this endpoint: `https://us-central1-mastering-async-await.cloudfunctions.net/post?id=0`. Try opening this URL in your browser, the output looks like this:

```
{"content":"*This post was featured as a guest blog post..."}
```

Loop through the blog posts and find the id of the first post whose `content` contains the string "async/await hell".

Below is the starter code. You may copy this code and run it in Node.js using the `node-fetch` npm module, or you may complete this exercise in your browser on CodePen at `http://bit.ly/async-await-exercise-1`

```
const root = 'https://' +
  'us-central1-mastering-async-await.cloudfunctions.net';

async function run() {
  // Example of using `fetch()` API
  const res = await fetch(`${root}/posts`);
  console.log(await res.json());
}

run().catch(error => console.error(error.stack));
```

Exercise 2: Retrying Failed Requests

The purpose of this exercise is to implement a function that retries failed HTTP requests using async/await and `try/catch` to handle errors. This example builds on the correct answer to exercise 1.1, but with the added caveat that every other `fetch()` request fails.

For this exercise, you need to implement the `getWithRetry()` function below. This function should `fetch()` the `url`, and if the request fails this function should retry the request up to `numRetries` times. If you see "Correct answer: 76", congratulations, you completed this exercise.

Like exercise 1.1, you can complete this exercise locally by copying the below code and using the `node-fetch` npm module. You can also complete this exercise in your browser on CodePen at the following url: http://bit.ly/async-await-exercise-2.

```
async function getWithRetry(url, numRetries) {
  return fetch(url).then(res => res.json());
}

// Correct answer for exercise 1.1 below
async function run() {
  const root = 'https://' +
    'us-central1-mastering-async-await.cloudfunctions.net';
  const posts = await getWithRetry(`${root}/posts`, 3);

  for (const post of posts) {
    console.log(`Fetch post ${post.id}`);
    const content = await getWithRetry(`${root}/post?id=${post.id}`, 3);
    if (content.content.includes('async/await hell')) {
      console.log(`Correct answer: ${post.id}`);
      break;
    }
  }
}

run().catch(error => console.error(error.stack));

// This makes every 2nd `fetch()` fail
const _fetch = fetch;
let calls = 0;
(window || global).fetch = function(url) {
  const err = new Error('Hard-coded fetch() error');
  return (++calls % 2 === 0) ? Promise.reject(err) : _fetch(url);
}
```

Promises From The Ground Up

Async/await is built on top of promises. Async functions return promises, and `await` only pauses an async function when it operates on a promise. In order to grok the internals of async/await, you need to understand how promises work from base principles. JavaScript promises didn't become what they are by accident, they were carefully designed to enable paradigms like async/await.

In the ES6 spec, a promise is a class whose constructor takes an `executor` function. Instances of the Promise class have a `then()` function. Promises in the ES6 spec have several other properties, but for now you can ignore them. Below is a skeleton of a simplified `Promise` class.

Example 2.1

```
class Promise {
  // `executor` takes 2 parameters, `resolve()` and `reject()`.
  // The executor function is responsible for calling `resolve()`
  // or `reject()` when the async operation succeeded or failed
  constructor(executor) {}

  // `onFulfilled` is called if the promise is fulfilled, and
  // `onRejected` if the promise is rejected. For now, you can
  // think of 'fulfilled' and 'resolved' as the same thing.
  then(onFulfilled, onRejected) {}
}
```

A promise is a state machine with 3 states:

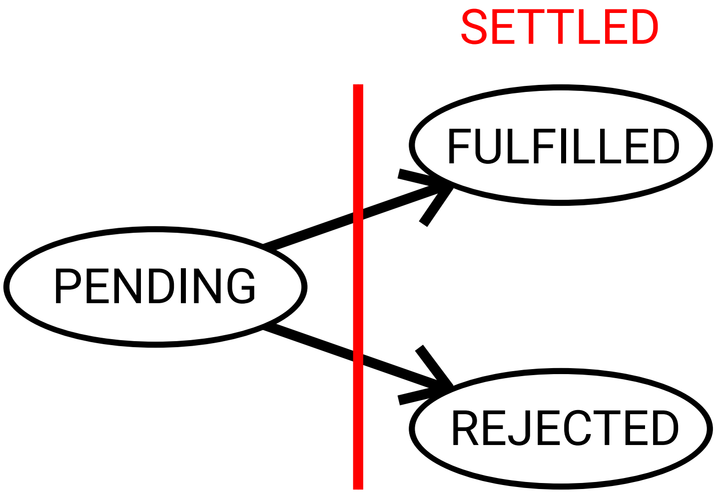
- pending: the initial state, means that the underlying operation is in progress
- fulfilled: the underlying operation succeeded and has an associated value
- rejected: the underlying operation failed and has an associated error

A promise that is not pending is called *settled*. In other words, a settled promise is either fulfilled or rejected. Once a promise is settled, it **cannot** change state. For example, the below promise will remain fulfilled despite the `reject()` call. Once you've called `resolve()` or `reject()` once, calling `resolve()` or `reject()` is a no-op. This detail is pivotal for async/await, because how would `await` work if a promise changed state from 'FULFILLED' to 'REJECTED' after an async function was done?

Example 2.2

```
const p = new Promise((resolve, reject) => {
  resolve('foo');
  // The below `reject()` is a no-op. A fulfilled promise stays
  // fulfilled with the same value forever.
  reject(new Error('bar'));
});
```

Below is a diagram showing the promise state machine.



With this in mind, below is a first draft of a promise constructor that implements the state transitions. Note that the property names `state`, `resolve`, `reject`, and `value` used below are non-standard. Actual ES6 promises do **not** expose these properties publicly, so don't try to use `p.value` or `p.resolve()` with a native JavaScript promise.

Example 2.4

```
class Promise {
  constructor(executor) {
    this.state = 'PENDING';
    this.chained = []; // Not used yet
    this.value = undefined;

    try {
      // Reject if the executor throws a sync error
      executor(v => this.resolve(v), err => this.reject(err));
    } catch (err) { this.reject(err); }
  }
  // Define `resolve()` and `reject()` to change the promise state
  resolve(value) {
    if (this.state !== 'PENDING') return;
    this.state = 'FULFILLED';
    this.value = value;
  }
  reject(value) {
    if (this.state !== 'PENDING') return;
    this.state = 'REJECTED';
    this.value = value;
  }
}
```

The promise constructor manages the promise's state and calls the executor function. You also need to implement the `then()` function that let clients define handlers that run when a promise is settled. The `then()` function takes 2 function parameters, `onFulfilled()` and `onRejected()`. A promise must call the `onFulfilled()` callback if the promise is fulfilled, and `onRejected()` if the promise is rejected.

For now, `then()` is simple, it push `onFulfilled()` and `onRejected()` onto an array `chained`. Then, `resolve()` and `reject()` will call them when the promise is fulfilled or rejected. If the promise is already settled, the `then()` function will queue up `onFulfilled()` or `onRejected()` to run on the next tick of the event loop using `setImmediate()`.

Example 2.5

```
class Promise {
  // Constructor is the same as before, omitted for brevity
  then(onFulfilled, onRejected) {
    const { value, state } = this;
    // If promise is already settled, enqueue the right handler
    if (state === 'FULFILLED') return setImmediate(onFulfilled, value);
    if (state === 'REJECTED') return setImmediate(onRejected, value);
    // Otherwise, track `onFulfilled` and `onRejected` for later
    this.chained.push({ onFulfilled, onRejected });
  }
  resolve(value) {
    if (this.state !== 'PENDING') return;
    this.state = 'FULFILLED';
    this.value = value;
    // Loop through the `chained` array and find all `onFulfilled()`
    // functions. Remember that `.then(null, onRejected)` is valid.
    this.chained.
      filter(({ onFulfilled }) => typeof onFulfilled === 'function').
      // The ES6 spec section 25.4 says `onFulfilled` and
      // `onRejected` must be called on a separate event loop tick
      forEach(({ onFulfilled }) => setImmediate(onFulfilled, value));
  }
  reject(value) {
    if (this.state !== 'PENDING') return;
    this.state = 'REJECTED';
    this.value = value;
    this.chained.
      filter(({ onRejected }) => typeof onRejected === 'function').
      forEach(({ onFulfilled }) => setImmediate(onFulfilled, value));
  }
}
```

This `Promise` class, while simple, represents most of the work necessary to integrate with async/await. The `await` keyword doesn't explicitly check if the value it operates on is `instanceof Promise`, it only checks for the presence of a `then()` function. In general, any object that has a `then()` function is called a *thenable* in JavaScript. Below is an example of using the custom `Promise` class with async/await.

Example 2.6

```
async function test() {
  // Works, even though this is a custom `Promise` class. All you
  // need is a `then()` function to integrate with `await`.
  const res = await new Promise(resolve => {
    setTimeout(() => resolve('Hello'), 50);
  });
  assert.equal(res, 'Hello');
}
```

Promise Chaining

One key feature that the promise implementation thus far does not support is promise chaining. Promise chaining is a common pattern for keeping async code flat, although it has become far less useful now that generators and async/await have widespread support. Here's how the `getWikipediaHeaders()` function from the introduction looks with promise chaining:

Example 2.7

```
function getWikipediaHeaders() {
  return stat('./headers.txt').
    then(res => {
      if (res == null) {
        // If you return a promise from `onFulfilled()`, the next
        // `then()` call's `onFulfilled()` will get called when
        // the returned promise is fulfilled...
        return get({ host: 'www.wikipedia.org', port: 80 });
      }
      return res;
    }).
    then(res => {
      // So whether the above `onFulfilled()` returns a primitive or a
      // promise, this `onFulfilled()` gets the headers object
      return writeFile('./headers.txt', JSON.stringify(res.headers));
    }).
    then(() => console.log('Great success!')).
    catch(err => console.err(err.stack));
}
```

While async/await is a superior pattern, promise chaining is still useful, and still necessary to complete a robust promise implementation. In order to implement promise chaining, you need to make 3 changes to the promise implementation from example 2.5:

1. The `then()` function needs to return a promise. The promise returned from `then()` should be resolved with the value returned from `onFulfilled()`
2. The `resolve()` function needs to check if `value` is a thenable, and, if so, transition to fulfilled or rejected only when `value` transitions to fulfilled or rejected.
3. If `resolve()` is called with a thenable, the promise needs to stay 'PENDING', but future calls to `resolve()` and `reject()` must be ignored.

The first change, improving the `then()` function, is shown below. There are two other changes: `onFulfilled()` and `onRejected()` now have default values, and are wrapped in a try/catch.

Example 2.8

```
then(_onFulfilled, _onRejected) {
  // `onFulfilled` is a no-op by default...
  if (typeof _onFulfilled !== 'function') _onFulfilled = (v => v);
  // and `onRejected` just rethrows the error by default
  if (typeof _onRejected !== 'function') {
    _onRejected = err => { throw err; };
  }
  return new Promise((resolve, reject) => {
    // Wrap `onFulfilled` and `onRejected` for two reasons:
    // consistent async and `try/catch`
    const onFulfilled = res => setImmediate(() => {
      try {
        resolve(_onFulfilled(res));
      } catch (err) { reject(err); }
    });
    const onRejected = err => setImmediate(() => {
      try {
        // Note this is `resolve()`, **not** `reject()`. The `then()`
        // promise will be fulfilled if `onRejected` doesn't rethrow
        resolve(_onRejected(err));
      } catch (err) { reject(err); }
    });

    if (this.state === 'FULFILLED') return onFulfilled(this.value);
    if (this.state === 'REJECTED') return onRejected(this.value);
    this.chained.push({ onFulfilled, onRejected });
  });
}
```

Now `then()` returns a promise. However, there's still work to be done: if `onFulfilled()` returns a promise, `resolve()` needs to be able to handle it. In order to support this, the `resolve()` function will need to use `then()` in a two-step recursive dance. Below is the expanded `resolve()` function that shows the 2nd necessary change.

Example 2.9

```
resolve(value) {
  if (this.state !== 'PENDING') return;
  if (value === this) {
    return this.reject(TypeError(`Can't resolve promise with itself`));
  }
  // Is `value` a thenable? If so, fulfill/reject this promise when
  // `value` fulfills or rejects. The Promises/A+ spec calls this
  // process "assimilating" the other promise (resistance is futile).
  const then = this._getThenProperty(value);
  if (typeof then === 'function') {
    try {
      return then.call(value, v => this.resolve(v),
        err => this.reject(err));
    } catch (error) {
      return reject(error);
    }
  }

  // If `value` is **not** a thenable, transition to fulfilled
  this.state = 'FULFILLED';
  this.value = value;
  this.chained.
    forEach(({ onFulfilled }) => setImmediate(onFulfilled, value));
}
// Helper to wrap getting the `then()` property because the Promises/A+
// spec has 2 tricky details: you can only access the `then` property
// once, and if getting `value.then` throws the promise should reject
_getThenProperty(value) {
  if (value == null) return null;
  if (!['object', 'function'].includes(typeof value)) return null;
  try {
    return value.then;
  } catch (error) {
    // Unlikely edge case, Promises/A+ section 2.3.3.2 enforces this
    this.reject(error);
  }
}
```

Finally, the third change, ensuring that a promise doesn't change state once `resolve()` is called with a thenable, requires changes to both `resolve()` and the promise constructor. The motivation for this change is to ensure that `p2` in the below example is fulfilled, **not** rejected.

Example 2.10

```
const p1 = new Promise(resolve => setTimeout(resolve, 50));
const p2 = new Promise(resolve => {
  resolve(p1);
  throw new Error('Oops!'); // Ignored because `resolve()` was called
});
```

One way to achieve this is to create a helper function that wraps `this.resolve()` and `this.reject()` that ensures `resolve()` and `reject()` can only be called once.

Example 2.11

```
// After you call `resolve()` with a promise, extra `resolve()` and
// `reject()` calls will be ignored despite the 'PENDING' state
_wrapResolveReject() {
  let called = false;
  const resolve = v => {
    if (called) return;
    called = true;
    this.resolve(v);
  };
  const reject = err => {
    if (called) return;
    called = true;
    this.reject(err);
  };
  return { resolve, reject };
}
```

Once you have this `_wrapResolveReject()` helper, you need to use it in `resolve()`:

Example 2.12

```
resolve(value) { // Beginning omitted for brevity
  if (typeof then === 'function') {
    // If `then()` calls `resolve()` with a 'PENDING' promise and then
    // throws, the `then()` promise will be fulfilled like example 2.10
    const { resolve, reject } = this._wrapResolveReject();
    try {
      return then.call(value, resolve, reject);
    } catch (error) { return reject(error); }
  }
} // End omitted for brevity
```

Also, you need to use `_wrapResolveReject()` in the constructor itself:

Example 2.13

```
constructor(executor) { // Beginning omitted for brevity
  // This makes the promise class handle example 2.10 correctly...
  const { resolve, reject } = this._wrapResolveReject();
  try {
    executor(resolve, reject);
    // because if `executor` calls `resolve()` and then throws,
    // the below `reject()` is a no-op
  } catch (err) { reject(err); }
}
```

With all these changes, the complete promise implementation, which you can find at bit.ly/simple-promise, now passes all 872 test cases in the Promises/A+ spec. The Promises/A+ spec is a subset of the ES6 promise spec that focuses on `then()` and the promise constructor.

`catch()` and Other Helpers

The ES6 promise spec is a superset of the Promises/A+ spec that adds several convenient helper methods on top of the `then()` function. The most commonly used helper is the `catch()` function. Like the synchronous `catch` keyword, the `catch()` function typically appears at the end of a promise chain to handle any errors that occurred.

The `catch()` function may sound complex, but it is just a thin layer of syntactic sugar on top of `then()`. The `catch()` is so sticky because the name `catch()` is a powerful metaphor for explaining what this helper is used for. Below is the full implementation of `catch()`.

Example 2.14

```
catch(onRejected) {
  return this.then(null, onRejected);
}
```

Why does this work? Recall from example 2.8 that `then()` has a default `onRejected()` argument that rethrows the error. So when a promise is rejected, subsequent `then()` calls that only specify an `onFulfilled()` handler are skipped.

Example 2.15

```
const originalError = new Error('Oops!');
const p = new Promise((_, reject) => reject(originalError)).
  then(() => console.log('This will not print')).
  then(() => console.log('Nor will this')).
  // The `onFulfilled()` handlers above get skipped. Each of the
  // `then()` promises above reject with the original error
  catch(err => assert.ok(err === originalError));
```

There are several other helpers in the ES6 promise spec. The `Promise.resolve()` and `Promise.reject()` helpers are both commonly used for testing and examples, as well as to convert a thenable into a fully fledged promise.

Example 2.16

```
// Yes, this is actually a thenable. When it comes to promises, the
// letter of the law overrules the spirit of the law.
const thenable = { then: () => { throw new Error('Oops!'); } };
// But `thenable` doesn't have `catch()`, so use `Promise.resolve()`
// to convert it to a promise and use `catch()`
const p = Promise.resolve(thenable).
  catch(err => console.log(err.message)); // Prints "Oops!"
```

Below is the implementation of `resolve()` and `reject()`.

Example 2.17

```
static resolve(v) {
  return new Promise(resolve => resolve(v));
}
static reject(err) {
  return new Promise((resolve, reject) => reject(err));
}
```

The `Promise.all()` function is another important helper, because it lets you execute multiple promises in parallel and `await` on the result. The below code will run two instances of the `run()` function in parallel, and pause execution until they're both done.

Example 2.18

```
async function run() {
  await new Promise(resolve => setTimeout(resolve, 50));
  console.log('run(): running');
  await new Promise(resolve => setTimeout(resolve, 50));
  console.log('run(): done');
}

console.log('Start running');
await Promise.all([run(), run()]);
console.log('Done');
// Start running
// run(): running
// run(): running
// run(): done
// run(): done
// Done
```

`Promise.all()` is the preferred mechanism for executing async functions in parallel. To execute async functions in series, you would use a `for` loop and `await` on each function call.

`Promise.all()` is just a convenient wrapper around calling `then()` on an array of promises and waiting for the result. Below is a simplified implementation of `Promise.all()`:

Example 2.19

```
static all(arr) {
  let remaining = arr.length;
  if (remaining === 0) return Promise.resolve([]);
  // `result` stores the value that each promise is fulfilled with
  let result = [];
  return new Promise((resolve, reject) => {
    // Loop through every promise in the array and call `then()`. If
    // the promise fulfills, store the fulfilled value in `result`.
    // If any promise rejects, the `all()` promise rejects immediately.
    arr.forEach((p, i) => p.then(
      res => {
        result[i] = res;
        --remaining || resolve(result);
      },
      err => reject(err)));
  });
}
```

There is one more helper function defined in the ES6 spec, `Promise.race()`, that will be an exercise. Other than `race()` and some minor details like support for subclassing, the promise implementation in this chapter is compliant with the ES6 spec. In the next chapter, you'll use your understanding of promises to monkey-patch async/await and figure out what's happening under the hood.

The key takeaways from this journey of building a promise library from scratch are:

- A promise can be in one of 3 states: pending, fulfilled, or rejected. It can also be locked in to match the state of another promise if you call `resolve(promise)`.
- Once a promise is settled, it stays settled with the same value forever
- The `then()` function and the promise constructor are the basis for all other promise functions. The `catch()`, `all()`, `resolve()`, and `reject()` helpers are all syntactic sugar on top of `then()` and the constructor.

But before you start tinkering with the internals of async/await, here's 2 exercises to expand your understanding of promises.

Exercise 1: Promise Chains in Action

The purpose of this exercise is to get comfortable with using promise chaining. While promise chaining is less useful now that async/await exists, promise chaining is a useful complement to async/await in much the same way that `forEach()` and `filter()` are useful for chaining array transformations.

Using the same endpoints as Exercise 1.1, which are explained below, find the blog post entitled "Unhandled Promise Rejections in Node.js", load its content, and find the number of times the phrase "async/await" appears in the `content`.

Below are the API endpoints. The API endpoints are hosted on Google Cloud Functions at `https://us-central1-mastering-async-await.cloudfunctions.net`

- `/posts` gets a list of blog posts. Below is an example post:

```
{ "src":"./lib/posts/20160304_circle_ci.md",
  "title":"Setting Up Circle CI With Node.js",
  "date":"2016-03-04T00:00:00.000Z",
  "tags":["NodeJS"],
  "id":51 }
```

- `/post?id=${id}` gets the markdown content of a blog post by its `id` property. The above blog post has `id` = 0, so you can get its content from this endpoint: `https://us-central1-mastering-async-await.cloudfunctions.net/post?id=0`. Try opening this URL in your browser, the output looks like this:

```
{"content":"*This post was featured as a guest blog post..."}
```

Below is the starter code. You may copy this code and run it in Node.js using the `node-fetch` npm module, or you may complete this exercise in your browser on CodePen at `http://bit.ly/async-await-exercise-21`

```
const root = 'https://' +
  'us-central1-mastering-async-await.cloudfunctions.net';

function run() {
  // Example of using `fetch()` API
  return fetch(`${root}/posts`).
    then(res => res.json()).
    then(posts => console.log(posts[0]));
}
run().catch(error => console.error(error.stack));
```

Exercise 2: `Promise.race()`

The ES6 promise spec has one more helper method that this book hasn't covered yet: `Promise.race()`. Like `Promise.all()`, `Promise.race()` takes in an array of promises, but `Promise.race()` returns a promise that resolves or rejects to the same value that the first promise to settle resolves or rejects to. For example:

```
const p1 = new Promise(resolve => setTimeout(() => resolve(1), 50));
const p2 = new Promise(resolve => setTimeout(() => resolve(2), 250));
// Prints "1", because `p1` resolves first
Promise.race([p1, p2]).then(res => console.log(res));
```

Implement a function `race()`, that, given an array of promises, returns a promise that resolves or rejects as soon as one of the promises in the array settles, with the same value.

Hint: remember, once a promise is settled, calling `resolve()` or `reject()` is a no-op.

Below is the starter code. You may copy this code and complete this exercise in Node.js, or you may complete it in your browser on CodePen at `http://bit.ly/async-await-exercise-22`.

```
function race(arr) {
  return Promise.reject(new Error('Implement this function'));
}

// The below are tests to help you check your `race()` implementation
test1().then(test2).then(() => console.log('Done!')).
  catch(error => console.error(error.stack));
function test1() {
  const p1 = new Promise(resolve => setTimeout(() => resolve(1), 10));
  const p2 = new Promise(resolve => setTimeout(() => resolve(2), 100));
  const f = v => { if (v !== 1) throw Error('test1 failed!'); };
  return race([p1, p2]).then(f);
}
function test2() {
  const error = new Error('Expected error');
  const p1 = new Promise(resolve => setTimeout(() => resolve(1), 100));
  const p2 = new Promise(resolve => setTimeout(() => resolve(2), 100));
  const p3 = new Promise((resolve, reject) => reject(error));
  return race([p1, p2, p3]).then(
    () => { throw Error('test2: `race()` promise must reject'); },
    e => { if (e !== error) throw Error('test2: wrong error'); });
}
```

Async/Await Internals

Promises are the fundamental tool for integrating with async/await. Now that you've seen how promises work from the ground up, it's time to go from the micro to the macro and see what happens when you `await` on a promise. Even though async functions are flat like synchronous functions, they're as asynchronous as the most callback-laden banana code under the hood.

As you might have already guessed, `await` makes JavaScript call `then()` under the hood.

Example 3.1

```
const p = {
  then: onFulfilled => {
    // Prints "then(): function () { [native code] }"
    console.log('then():', onFulfilled.toString());
    // Only one entry in the stack:
    // Error
    //     at Object.then (/examples/chapter3.test.js:8:21)
    console.log(new Error().stack);
    onFulfilled('Hello, World!');
  }
};

console.log(await p); // Prints "Hello, World!"
```

The `await` keyword causes JavaScript to *pause* execution until the next iteration of the event loop. In the below code, the `console.log()` after the `await` runs **after** the `++currentId` code, even though the increment is in a callback. The `await` keyword causes the async function to pause and then resume later.

Example 3.2

```
const startId = 0;
let currentId = 0;
process.nextTick(() => ++currentId);
const p = {
  then: onFulfilled => {
    console.log('then():', currentId - startId); // "then(): 1"
    onFulfilled('Hello, World!');
  }
};

console.log('Before:', currentId - startId); // "Before: 0"
await p;
console.log('After:', currentId - startId); // "After: 1"
```

Notice that the `then()` function runs on the next tick, even though it is fully synchronous. This means that `await` always pauses execution until at least the next tick, even if the thenable is not async.The same thing happens when the awaited promise is rejected. If you call `onRejected(err)`, the `await` keyword throws `err` in your function body.

Example 3.3

```
const startId = 0;
let currentId = 0;
process.nextTick(() => ++currentId);
const p = {
  then: (onFulfilled, onRejected) => {
    console.log('then():', currentId - startId); // "then(): 1
    return onRejected(Error('Oops!'));
  }
};

try {
  console.log('Before:', currentId - startId); // "Before: 0"
  await p;
  console.log('This does not print');
} catch (error) {
  console.log('After:', currentId - startId); // "After: 1"
}
```

`await` vs `return`

Recall that `return` in an async function resolves the promise that the async function returns. This means you can `return` a promise. What's the difference between `await` and `return`? The obvious answer is that, when you `await` on a promise, JavaScript pauses execution of the async function and resumes later, but when you `return` a promise, JavaScript finishes executing the async function. JavaScript doesn't "resume" executing the function after you `return`.

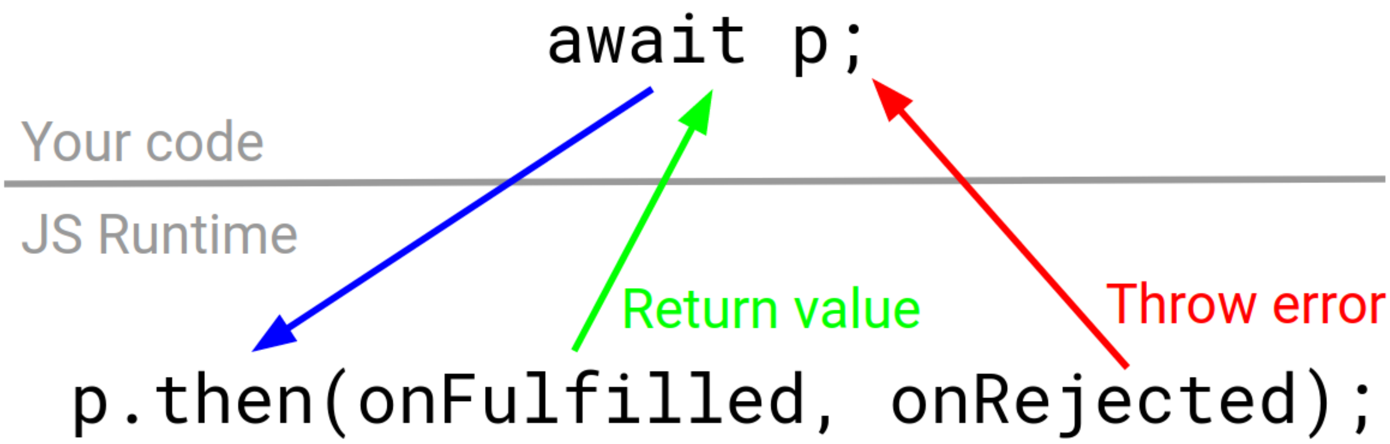
The obvious answer is correct, but has some non-obvious implications that tease out how `await` works. If you wrap `await p` in a `try/catch` and `p` is rejected, you can catch the error. What happens if you instead `return p`?

Example 3.4

```
async function test() {
  try {
    return Promise.reject(new Error('Oops!'));
  } catch (error) { return 'ok'; }
}
// Prints "Oops!"
test().then(v => console.log(v), err => console.log(err.message));
```

Notice that `try/catch` does **not** catch the rejected promise that you returned. Why does only `await` give you a catchable error when the promise is rejected? Because `await` throws the error when it *resumes* execution. When you `return` a promise, JavaScript stops executing your async function body and kicks off the `resolve()` process on the async function promise.

On the other hand, when you `await` on a promise, JavaScript pauses executing your async function and resumes once the promise is settled. When JavaScript resumes your async function after `await`, it throws an error if the awaited promise rejected. Below is a flow chart showing what happens when you await on a promise.



On the other hand, when you `return` a promise from an async function, your promise goes into the JavaScript runtime and never goes back into your code, so `try/catch` won't handle the error in example 3.4. Below are a couple alternatives that `catch` the error: example 3.5 assigns `await p` to a variable `v` and then returns the variable, and example 3.6 uses `return await`.

Example 3.5

```
async function test() {
  try {
    const v = await Promise.reject(new Error('Oops!'));
    return v;
  } catch (error) { return 'ok'; }
}
// Prints "ok"
test().then(v => console.log(v), err => console.log(err.message));
```

Example 3.6

```
async function test() {
  try {
    return await Promise.reject(new Error('Oops!'));
  } catch (error) { return 'ok'; }
}
// Prints "ok"
test().then(v => console.log(v), err => console.log(err.message));
```

Both approaches work, but example 3.5 is simpler and less confusing. Seeing `return await` is a head-scratcher for engineers that aren't JavaScript experts, and that's antithetical to the goal of making asynchronous code easy for average developers.

Concurrency

So far, you've seen that `await p` makes JavaScript pause your async function, call `p.then()`, and resume once the promise is settled. What does this mean for running multiple async functions in parallel, especially given that JavaScript is single threaded?

The "JavaScript is single threaded" concept means that, when a normal JavaScript function is running, no other JavaScript can run. For example, the below code will never print anything. In other languages, a construct like `setImmediate()` may run logic in a separate thread and print even while an infinite loop is spinning, but JavaScript does not allow that.

Example 3.7

```
setImmediate(() => console.log('Hello, World!'));
// This loop will spin forever, and so you'll never get back into
// the event loop and the above `console.log()` will never run.
while (true) {}
```

JavaScript functions are like the Pauli Exclusion Principle in physics: no two normal JavaScript functions can be running in the same memory space at the same time. Closures (callbacks) are separate functions, so in the below example, `foo()`, `bar()`, and `baz()` all run separately.

Example 3.8

```
function foo() {
  let x = 0;

  // When `foo()` is done, `bar()` will run later but still have
  // access to `x`
  setImmediate(bar);
  // Stop running `foo()` until `baz()` is done
  baz();

  function bar() {
    ++x;
  }

  function baz() {
    ++x;
  }
}
```

Async functions follow the same rule: no two functions can be running at the same time. But, any number of async functions can be *paused* at the same time as long as you don't run out of memory, and other functions can run when an async function is paused.

Example 3.9

```
run().catch(error => console.error(error.stack));

async function run() {
  // This will print, because `run()` is paused when you `await`
  setImmediate(() => console.log('Hello, World!'));
  // Each iteration of the loop pauses the function
  while (true) { await new Promise(resolve => setImmediate(resolve)); }
}
```

This makes async functions useful for breaking up long-running synchronous functions. For example, suppose you want to run two functions in parallel that each compute a large Fibonacci number. Without async/await, you'd need tricky recursion. Async/await makes this task trivial.

Example 3.10

```
await Promise.all([fibonacci(50000), fibonacci(50000)]);
async function fibonacci(n) {
  let [prev2, prev1, cur] = [1, 1, 1];
  for (let i = 2; i < n; ++i) {
    // Pause this `fibonacci()` call, let the other call make progress
    await new Promise(resolve => setImmediate(resolve));
    // "Fib: 10000"
    // "Fib: 10000"
    // "Fib: 20000" ...
    if (i % 10000 === 0) console.log('Fib:', i);
    cur = prev1 + prev2;
    prev2 = prev1;
    prev1 = cur;
  }
  return cur;
}
```

This example is simple but contrived. A more realistic example would be an Express API endpoint that runs a potentially expensive algorithm like clustering. I have used this pattern in a production Express API to run an `O(n^5)` clustering algorithm in a route without blocking other routes.

The key takeaway here is that an async function will run with no interruptions unless you pause it with `await` or exit the function with `return` or `throw`. JavaScript is still single threaded in the conventional sense, so two async functions can't be running at the same time, but you can pause your async function using `await` to give the event loop and other functions a chance to run.

Async/Await vs Generators

Async/await has a lot in common with generators, a feature that JavaScript introduced in the 2015 edition of the language spec. Like async functions, generator functions can be paused and later resumed. There are two major differences between generator functions and async functions:

1. The keyword you use to pause a generator function is `yield`, not `await`.
2. When you pause a generator function, control goes back to your JavaScript code, rather than the JS interpreter. You resume the generator function by calling `next()` on a generator object.

The below example demonstrates using `yield` to pause the generator and `next()` to resume it.

Example 3.11

```
// The `function*` syntax makes this function a generator function
const generatorFunction = function*() {
  console.log('Step 1');
  yield 1;
  console.log('Step 2');
  yield 2;
  console.log('Done');
};

// The return value of a generator function is a generator object.
// The generator function doesn't start until you call `next()`.
const generatorObject = generatorFunction();

let yielded = generatorObject.next(); // Prints "Step 1"
console.log(yielded.value); // Prints "1"
yielded = generatorObject.next(); // Prints "Step 2"
console.log(yielded.value); // Prints "2"
generatorObject.next(); // Prints "Done"
```

With the help of a library, generators support a pattern virtually identical to async/await. The most popular generator concurrency library is co. Here's example 1.1 with co instead of async/await.

Example 3.12

```
const co = require('co');
// `co.wrap()` converts a generator into an async-like function
const runCo = co.wrap(function*() {
  // This function will print "Hello, World!" after 1 second.
  yield new Promise(resolve => setTimeout(() => resolve(), 1000));
  console.log('Hello, World!');
});
// In particular, wrapped functions return a promise
runCo().catch(error => console.log(error.stack));
```

Co offers several neat features that async/await does not natively support. By virtue of being a userland library, co can be more extensible. For example, co can handle when you `yield` an array of promises or a map of promises.

Example 3.13

```
const runCo = co.wrap(function*() {
  const p1 = Promise.resolve('Hello');
  const p2 = Promise.resolve('World');
  // Co can convert arrays of promises and objects with promise
  // properties for you. With async/await, you'd have to use
  // `Promise.all()` on your own to `await` on an array of promises
  console.log(yield [p1, p2]); // [ 'Hello', 'World' ]
  console.log(yield { p1, p2 }); // { p1: 'Hello', p2: 'World' }
});
```

The flip-side of co's implicit promise conversion is that co throws an error if you `yield` something that it can't convert to a promise.

Example 3.14

```
const runCo = co.wrap(function*() {
  // 'TypeError: You may only yield a function, promise, generator,
  // array, or object but the following object was passed: "1"'
  yield 1;
});
```

In practice, co treating `yield 1` as an error helps catch a lot of errors, but also causes a lot of unnecessary errors. With async/await, `await 1` is valid and evaluates to `1`, which is more robust.

Async/await has a few other advantages over co and generators. The biggest advantage is that async/await is built-in to Node.js and modern browsers, so you don't need an external library like co. Async/await also has cleaner stack traces. Co stack traces often have a lot of `generator.next()` and `onFulfilled` lines that obscure the actual error.

Example 3.15

```
const runCo = co.wrap(function*() {
  yield new Promise(resolve => setImmediate(resolve));
  throw new Error('Oops!');
});
// Error: Oops!
//     at /test.js:3:9
//     at Generator.next (<anonymous>)
//     at onFulfilled (/node_modules/co/index.js:65:19)
//     at <anonymous>
runCo().catch(error => console.log(error.stack));
```

The equivalent async/await stack trace has the function name and omits `generator.next()` and `onFulfilled`. Async/await's `onFulfilled` runs in the JavaScript interpreter, not userland.

Example 3.16

```
async function runAsync() {
  await new Promise(resolve => setImmediate(resolve));
  throw new Error('Oops!');
}
// Error: Oops!
//    at runAsync (/home/val/test.js:5:9)
//    at <anonymous>
runAsync().catch(error => console.error(error.stack));
```

In general, async/await is the better paradigm because it is built in to JavaScript, throws fewer unnecessary errors, and has most of the functionality you need. Co has some neat syntactic sugar and works in older browsers, but that is not enough to justify including an external library.

Core Principles

So far, this chapter has covered the technical details of what it means for an async function to be paused. What does all this mean for a developer looking to use async/await for their application? Here's some core principles to remember based on the behaviors this chapter covered.

Don't `await` on a value that can't be a promise

Just because you can `await 1` doesn't mean you should. A lot of async/await beginners abuse `await` and `await` on everything.

Example 3.17

```
async function findSubstr(arr, str) {
  // Don't do this! There's no reason for this function to be async
  for (let i = await 0; i < arr.length; ++i) {
    if (await arr[i].includes(str)) return arr[i];
  }
}
```

In general, you should use `await` on a value you expect to be a promise. There is no reason to `await` on a value that will never be a promise, and it falsely implies that the value may be a promise. If a function can be synchronous, it should be synchronous.

The only reason to make the `findSubstr()` function async would be to pause execution and let other functions run like in example 3.10. This is only potentially beneficial if `findSubstr()` runs on a massive array. In that case, you should use `await new Promise(setImmediate)` in order to make sure all other tasks have a chance to run.

Similarly, you must convert any value you want to `await` on into a promise. For example, if you want to `await` on multiple promises in parallel you must use `Promise.all()`.

Example 3.18

```
async function run() {
  const p1 = Promise.resolve(1);
  const p2 = Promise.resolve(2);
  // Won't work, `arr1` will be an array of promises
  const arr1 = await [p1, p2];
  // Works! `arr1` will equal `[1, 2]`
  const arr2 = await Promise.all(p1, p2);
}
```

Prefer using `return` with a non-promise

As demonstrated in example 3.4, you can `return` a promise from an async function, but doing so has some nuances and corner cases. Instead of using a promise as the resolved value, use `await` to resolve the value and then `return` the value. It is generally easier to use `await` and return the resolved value than to explain the difference between `async` and `return`.

Example 3.19

```
async function fn1() {
  // Fine, but has some issues with `try/catch` as shown in example 3.4
  return asyncFunction();
}
async function fn2() {
  // More verbose, but less error prone. Use this method unless you do
  // not intend to handle `asyncFunction()` errors in this function.
  const ret = await asyncFunction();
  return ret;
}
```

Use loops rather than array helpers like `forEach()` and `map()` with `await`

Because you can only `await` in an async function, async functions behave differently than synchronous functions when it comes to functional array methods like `forEach()`. For example, the below code throws a `SyntaxError` because `await` is not in an async function.

Example 3.20

```
async function test() {
  const p1 = Promise.resolve(1);
  const p2 = Promise.resolve(2);
  // SyntaxError: Unexpected identifier
  [p1, p2].forEach(p => { await p; });
}
```

You might think that all you need is an async arrow function. But that does **not** pause `test()`.

Example 3.21

```
async function test() {
  const p1 = Promise.resolve(1);
  const p2 = Promise.resolve(2);
  // This sets off two async functions in parallel, but does **not**
  // pause `test()` because `await p` pauses the arrow function.
  [p1, p2].forEach(async (p) => { console.log(await p); });
  // 'Done' will print **before** '1' and '2' because `await p`
  // pauses the arrow functions, **not** `test()`
  console.log('Done');
}
```

Make sure you handle errors with `.catch()`

Consolidated error handling is one of the most powerful features of async/await. Using `.catch()` on an async function call lets you handle all errors (synchronous and asynchronous) that occur in the async function. Use `.catch()` for catch-all error handlers rather than `try/catch`.

Example 3.22

```
async function fn1() {
  // Bad! Doesn't handle returned promise rejections and is clunky
  try { /* Complex function here */ } catch (err) { handleError(err); }
}
async function fn2() { /* Complex function here */ }
// Do this instead. Handles `return` errors and has less boilerplate
fn2().catch(handleError);
```

In general, any error in an async function should end up in a `.catch()` handler. If you see async/await based code with no `.catch()` calls, there's an unhandled error somewhere. Good async/await code uses some centralized mechanism like a `wrap()` function to ensure every async function call gets a `.catch()` at the end.

Example 3.23

```
const wrap = fn => function() {
  // Ensure function call has an error handler
  return fn.apply(null, arguments).catch(error => console.log(error));
};
const [fn1, fn2] = [
  async function() { throw Error('err1'); },
  async function() { throw Error('err2'); }
].map(wrap);
fn1(); // Prints "err1"
fn2(); // Prints "err2"
```

Exercise 1: `return` and `.catch()`