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by Nicolas Bevacqua

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Modular JS: Practical ES6

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CHAPTER 1

ECMAScript and the Future of JavaScript

JavaScript has gone from being a 1995 marketing ploy to gain a tactical advantage, to becoming the core programming experience in the world's most widely used application runtime platform in 2017. The language doesn't merely run in browsers anymore, but is also used to create desktop and mobile applications, in hardware devices, and even in the vacuum of space.

How did JavaScript get here, and where is it going next?

1.1 A Brief History of JavaScript Standards

Back in 1995, Netscape envisioned a dynamic web beyond what HTML could offer. Brendan Eich was initially brought into Netscape to develop a language that was functionally akin to Scheme, but for the browser. Once he joined, he learned that upper management wanted it to look like Java and a deal to that effect was already underway.

Brendan created the first JavaScript prototype in ten days, taking Scheme's first-class functions and Self's prototypes as its main ingredients. The initial version of JavaScript was code-named Mocha. It didn't have array or object literals, and every error resulted in an alert. The lack of exception handling is why, to this day, many operations result in `NaN` or `undefined`. Brendan's work on DOM level 0 and the first edition of JavaScript set the stage for standards work.

This revision of JavaScript was marketed as LiveScript when it started shipping with a beta release of Netscape Navigator 2.0, in September 1995. It was rebranded as JavaScript (trademarked by Sun, now owned by Oracle) when Navigator 2.0 beta 3 was released in December 1995. Soon after this release, Netscape introduced a server-side JavaScript implementation for scripting in Netscape Enterprise Server, and named it

LiveWire[1]. JScript, Microsoft's reverse-engineered implementation of JavaScript, was bundled with IE3 in 1996. JScript was available for Internet Information Server (IIS) in the server-side.

The language started being standardized under the ECMAScript name (ES) into the ECMA-262 specification in 1996, under a technical commitee at ECMA known as TC39. Sun wouldn't transfer ownership of the JavaScript trademark to ECMA, and while Microsoft offered JScript, other member companies didn't want to use that name, so ECMAScript stuck.

Disputes by competing implementations, JavaScript by Netscape and JScript by Microsoft, dominated most of the TC39 standards commitee meetings at the time. Even so, the committee was already bearing fruit: backward compatibility was established as a golden rule, bringing about strict equality operators (`===` and `!==`) instead of breaking existing programs that relied on the loose equality comparision algorithm.

The first edition of ECMA-262 was released June, 1997. A year later, in June 1998, the specification was refined under the ISO/IEC 16262 international standard, after much scrutiny from national ISO bodies, and formalized as the second edition.

By December 1999 the third edition was published, standardizing regular expressions, the `switch` statement, `do/while`, `try/catch` and `Object#hasOwnProperty`, among a few other changes. Most of these features were already available in the wild through Netscape's JavaScript runtime, SpiderMonkey.

Drafts for an ES4 specification were soon afterwards published by TC39. This early work on ES4 led to JScript.NET in mid 2000[2] and, eventually, to ActionScript 3 for Flash in 2006[3].

Conflicting opinions on how JavaScript was to move forward brought work on the specification to a standstill. This was a delicate time for web standards: Microsoft had all but monopolized the web and they had little interest in standards development.

As AOL laid off 50 Netscape employees in 2003[4], the Mozilla Foundation was formed. With over 95% of web browsing market share now in the hands of Microsoft, TC39 was disbanded.

1 A booklet from 1998 explains the intricacies of Server-Side JavaScript with LiveWire: *https://mjavascript.com/out/serverside*.

2 You can read the original announcement here: *https://mjavascript.com/out/jscript-net* (July, 2000).

3 Listen to Brendan Eich in the JavaScript Jabber podcast, talking about the origin of JavaScript: *https://mjavascript.com/out/brendan-devchat*.

4 You can read a news report from July 2003 at: *https://mjavascript.com/out/aol-netscape*.

It took two years until Brendan, now at Mozilla, had ECMA resurrect work on TC39 by using Firefox's growing market share as leverage to get Microsoft back in the fold. By mid 2005, TC39 started meeting regularly once again. As for ES4, there were plans for introducing a module system, classes, iterators, generators, destructuring, type annotations, proper tail calls, algebraic typing, and an assortment of other features. Due to how ambitious the project was, work on ES4 was repeatedly delayed.

By 2007 the commitee was split in two: ES3.1, which hailed a more incremental approach to ES3; and ES4, which was overdesigned and underspecified. It wouldn't be until August 2008[5] when ES3.1 was agreed upon as the way forward, but later rebranded as ES5. Although ES4 would be abandoned, many of its features eventually made its way into ES6 (which was dubbed Harmony at the time of this resolution), while some of them still remain under consideration. The ES3.1 update served as the foundation on top of which the ES4 specification could be laid upon in bits and pieces.

In December 2009, on the ten-year anniversary since the publication of ES3, the fifth edition of ECMAScript was published. This edition codified de facto extensions to the language specification that had become common among browser implementations, adding get and set accessors, functional improvements to the `Array` prototype, reflection and introspection, as well as native support for JSON parsing, and strict mode.

A couple of years later, in June 2011, the specification was once again reviewed and edited to become the third edition of the international standard ISO/IEC 16262:2011, and formalized under ECMAScript 5.1.

It took TC39 another four years to formalize ECMAScript 6, in June 2015. The sixth edition is the largest update to the language that made its way into publication, implementing many of the ES4 proposals that were deferred as part of the Harmony resolution. Throughout this book, we'll be exploring ES6 in depth.

In parallel with the ES6 effort, in 2012 the WHATWG (a standards body interested in pushing the web forward) set out to document the differences between ES5.1 and browser implementations, in terms of compatibility and interoperability requirements. The taskforce standardized `String#substr`, which was previously unspecified; unified several methods for wrapping strings in HTML tags, which were inconsistent across browsers; and documented `Object.prototype` properties like *`proto`* and *`defineGetter`*, among other improvements[6]. This effort was condensed into a separate Web ECMAScript specification, which eventually made its way into Annex B in 2015.

5 Brendan Eich sent an email to the es-discuss mailing list in 2008 where he summarized the situation, almost ten years after ES3 had been released: *https://mjavascript.com/out/harmony*.

6 For the full set of changes made when merging the Web ECMAScript specification upstream, see: *https://mjavascript.com/out/javascript-standard*.

Annex B was an informative section of the core ECMAScript specification, meaning implementations weren't required to follow its suggestions. Jointly with this update, Annex B was also made normative and required for web browsers.

The sixth edition is a significant milestone in the history of JavaScript. Besides the dozens of new features, ES6 marks a key inflection point where ECMAScript would become a rolling standard.

1.2 ECMAScript as a Rolling Standard

Having spent ten years without observing significant change to the language specification after ES3, and four years for ES6 to materialize, it was clear the TC39 process needed to improve. The revision process used to be deadline-driven. Any delay in arriving at consensus would cause long wait periods between revisions, which lead to feature creep, causing more delays. Minor revisions were delayed by large additions to the specification, and large additions faced pressure to finalize so that the revision would be pushed through avoiding further delays.

Since ES6 came out, TC39 has streamlined[7] its proposal revisioning process and adjusted it to meet modern expectations: the need to iterate more often and consistently, and to democratize specification development. At this point, TC39 moved from an ancient Word-based flow to using Ecmarkup and GitHub Pull Requests, greatly increasing the number of proposals[8] being created as well as external participation by non-members.

Firefox, Chrome, Edge, Safari and Node.js all offer over 95% compliancy of the ES6 specification,[9] but we've been able to use the features as they came out in each of these browsers rather than having to wait until the flip of a switch when their implementation of ES6 was 100% finalized.

The new process involves four different maturity stages[10]. The more mature a proposal is, the more likely it is to eventually make it into the specification.

Any discussion, idea or proposal for a change or addition which has not been submitted as a formal proposal is considered to be an aspirational "strawman" proposal

7 You can find the September 2013 presentation which lead to the streamlined proposal revisioning process here: *https://mjavascript.com/out/tc39-improvement*.

8 You can find all proposals being considered by TC39 at *https://mjavascript.com/out/tc39-proposals*.

9 For a detailed ES6 compatibility report across browsers, check out the following table: *https://mjavascript.com/out/es6-compat*.

10 The TC39 proposal process documentation can be found at *https://mjavascript.com/out/tc39-process*.

(stage 0) and has no acceptance requirements. At the time of this writing, there's over a dozen active stage 0 proposals[11].

At stage 1 a proposal is formalized and expected to address cross-cutting concerns, interactions with other proposals, and implementation concerns. Proposals at this stage should identify a discrete problem and offer a concrete solution to the problem. A stage 1 proposal often includes a high level API description, illustrative usage examples and a discussion of internal semantics and algorithms. Stage 1 proposals are likely to change significantly as they make their way through the process.

Proposals in stage 2 offer an initial draft of the specification. At this point, it's reasonable to begin experimenting with actual implementations in runtimes. The implementation could come in the form of a polyfill, user code that mangles the runtime into adhering to the proposal; an engine implementation, natively providing support for the proposal; or compiled into something existing engines can execute, using build-time tools to transform source code.

Proposals in stage 3 are candidate recommendations. At this point, implementors have expressed interest in the proposal. In practice, proposals move to this level with at least one browser implementation, a high-fidelity polyfill or when supported by a build-time compiler like Babel. At this stage, a proposal is unlikely to change beyond fixes to issues identified in the wild.

In order for a proposal to attain stage 4 status, two independent implementations need to pass acceptance tests. Proposals that make their way through to stage four will be included in the next revision of ECMAScript.

New releases of the specification are expected to be published every year from now on. To accommodate the yearly release schedule, versions will now be referred to by their publication year. Thus ES6 becomes ES2015, then we have ES2016 instead of ES7, ES2017, and so on. Colloquially, ES2015 hasn't taken and is still largely regarded as ES6. ES2016 had been announced before the naming convention changed, thus it is sometimes still referred to as ES7. When we leave out ES6 due to its pervasiveness in the community, we end up with: ES6, ES2016, ES2017, ES2018, and so on.

The streamlined proposal process combined with the yearly cut into standardization translates into a more consistent publication process, and it also means specification revision numbers are becoming less important. The focus is now on proposal stages[8], and we can expect references to specific revisions of the ECMAScript standard to become more uncommon.

11 You can track stage 0 proposals here: *https://mjavascript.com/out/tc39-stage0*.

1.3 Browser Support and Complementary Tooling

A stage 3 candidate recommendation proposal is most likely to make it into the specification in the next cut, provided two independent implementations land in JavaScript engines. Effectively, stage 3 proposals are considered safe to use in real-world applications, be it through an experimental engine implementation, a polyfill, or using a compiler. Stage 2 and earlier proposals are also used in the wild by JavaScript developers, tightening the feedback loop between implementors and consumers.

Babel and similar compilers that take code as input and produce output native to the web platform (HTML, CSS or JavaScript) are often referred to as transpilers, which are considered to be a subset of compilers. When we want to leverage a proposal that's not widely implemented in JavaScript engines in our code, compilers like Babel can transform the portions of code using that new proposal into something that's more widely supported by existing JavaScript implementations.

This transformation can be done at build-time, so that consumers receive code that's well supported by their JavaScript runtime of choice. This mechanism improves the runtime support baseline, giving JavaScript developers the ability to take advantage of new language features and syntax sooner. It is also significantly beneficial to specification writers and implementors, as it allows them to collect feedback regarding viability, desirability, and possible bugs or corner cases.

A transpiler can take the ES6 source code we write and produce ES5 code that browsers can interpret more consistently. This is the most reliable way of running ES6 code in production today: using a build step to produce ES5 code that any modern browser can execute.

The same applies to ES7 and beyond. As new versions of the language specification are released every year, we can expect compilers to support ES2017 input, ES2018 input and beyond. Similarly, as browser support becomes better, we can also expect compilers to reduce complexity in favor of ES6 output, then ES7 output, and so on. In this sense, we can think of JavaScript-to-JavaScript transpilers as a moving window that takes code written using the latest available language semantics and produces the most modern code they can output without compromising browser support.

Let's talk about how you can use Babel in your programs.

1.3.1 Introduction to the Babel transpiler

Babel can compile modern JavaScript code using ES6 features into ES5. It produces human-readable code, making it more welcoming when we don't have a firm grasp on all of the new features we're using.

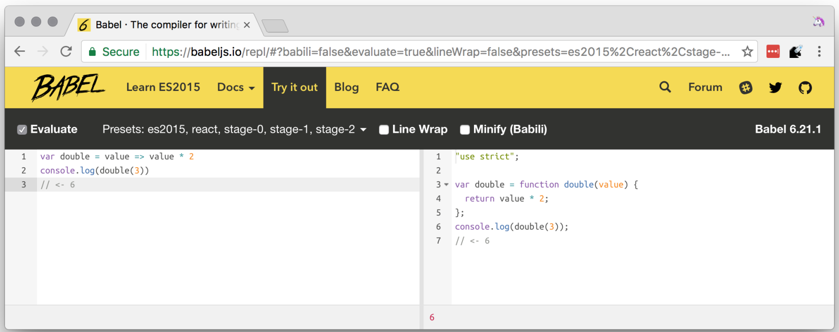
The online Babel REPL (Read-Evaluate-Print Loop) is an excellent way of jumping right into learning ES6, without any of the hassle of installing Node.js, the `babel` CLI, and manually compiling source code. You can find the REPL at: *https://mjavascript.com/out/babel-repl*.

The REPL provides us with a source code input area that gets automatically compiled in real-time. We can see the compiled code to the right of our source code.

Let's write some code into the REPL. You can use the following code snippet to get started.

```
var double = value => value * 2
console.log(double(3))
// <- 6
```

To the right of the source code we've entered, you'll see the transpiled ES5 equivalent. As you update your source code, the transpiled result is also updated in real-time.



The Babel REPL is an effective companion as a way of trying out some of the features introduced in this book. However, note that Babel doesn't transpile new built-ins, such as `Symbol`, `Proxy` and `WeakMap`. Those references are instead left untouched, and it's up to the runtime executing the Babel output to provide those built-ins. If we want to support runtimes that haven't yet implemented these built-ins, we could import the `babel-polyfill` package in our code.

In older versions of JavaScript, semantically correct implementations of these features are hard to accomplish or downright impossible. Polyfills may mitigate the problem, but they often can't cover all use cases and thus some compromises need to be made. We need to be careful and test our assumptions before we release transpiled code that relies on built-ins or polyfills into the wild.

Given the situation, it might be best to wait until browsers support new built-ins holistically before we start using them. It is suggested that you consider alternative solutions that don't rely on built-ins. At the same time, it's important to learn about these features, as to not fall behind in our understanding of the JavaScript language.

Modern browsers like Chrome, Firefox and Edge now support a large portion of ES2015 and beyond, making their developer tools useful when we want to take the semantics of a particular feature for a spin, provided it's supported by the browser. When it comes to production-grade applications that rely on modern JavaScript features, a transpilation build-step is advisable so that your application supports a wider array of JavaScript runtimes.

Besides the REPL, Babel offers a command-line tool written as a Node.js package. You can install it through `npm`, the package manager for Node.

> You can download Node.js from their website: *https://mjavascript.com/out/node*. After installing Node, you'll be able to use the `npm` command-line tool in your terminal.

Before getting started we'll create a project directory and a `package.json` file, which is a manifest used to describe Node.js applications. We'll create a `package.json` file through the `npm` CLI as well.

```
mkdir babel-setup
cd babel-setup
npm init --yes
```

> Passing the `--yes` flag to the `init` command configures `package.json` using the default values provided by `npm`, instead of asking us any questions.

Let's also create a file named `example.js`, containing the following bits of ES6 code. Save it to the `babel-setup` directory you've just created, under a `src` sub-directory.

```
var double = value => value * 2
console.log(double(3))
// <- 6
```

To install Babel, enter the following couple of commands into your favorite terminal.

```
npm install babel-cli@6 --save-dev
npm install babel-preset-es2015@6 --save-dev
```

Packages installed by `npm` will be placed in a `node_modules` directory at the project root. We can then access these packages by creating npm scripts or by using `require` statements in our application.

Using the `--save-dev` flag will add these packages to our `package.json` manifest as development dependencies, so that when copying our project to new environments we can reinstall every dependency just by running `npm install`.

The `@` notation indicates we want to install a specific version of a package. Using `@6` we're telling `npm` to install the latest version of `babel-cli` in the `6.x` range. This preference is handy to future-proof our applications, as it would never install version, which might contain breaking changes that could not have been foreseen at the time of this writing.

For the next step, we'll replace the value of the `scripts` property in `package.json` with the following. The `babel` command-line utility provided by `babel-cli` can take the entire contents of our `src` directory, compile them into the desired output format, and save the results to a `dist` directory, while preserving the original directory structure under a different root.

```
{
  "build": "babel src --out-dir dist"
}
```

Together with the packages we've installed in the previous step, a minimal `package.json` file could look like the code in the following snippet.

```
{
  "scripts": {
    "build": "babel src --out-dir dist"
  },
  "devDependencies": {
    "babel-cli": "6.18.0",
    "babel-preset-es2015": "6.18.0"
  }
}
```

Any commands enumerated in the `scripts` object can be executed through `npm run <name>`, which modifies the `$PATH` environment variable so that we can run the command-line executables found in `babel-cli` without installing `babel-cli` globally on our system.

If you execute `npm run build` in your terminal now, you'll note that a `dist/example.js` file is created. The output file will be identical to our original file, because

Babel doesn't make assumptions, and we have to configure it first. Create a `.babelrc` file next to `package.json`, and write the following JSON in it.

```
{
  "presets": ["es2015"]
}
```

The `es2015` preset, which we had installed earlier via `npm`, adds a series of plugins to Babel which transform different bits of ES6 code into ES5. Among other things, this preset transforms arrow functions like the one in our `example.js` file into ES5 code.

Once we run our build script again, we'll observe that the output is now valid ES5 code.

```
» npm run build
» cat dist/example.js
"use strict";

var double = function double(value) {
  return value * 2;
};
console.log(double(3));
// <- 6
```

Let's jump into a different kind of tool, the `eslint` code linter, which can help us establish a code quality baseline for our applications.

1.3.2 Code Quality and Consistency with ESLint

As we develop a codebase we factor out snippets that are redundant or no longer useful, write new pieces of code, delete features that are no longer relevant or necessary, and shift chunks of code around while accomodating a new architecture. As the codebase grows, the team working on it changes as well: at first it may be a handful of people or even one person, but as the project grows in size so might the team.

A lint tool can be used to identify syntax errors. Modern linters are often customizable, helping establish a coding style convention that works for everyone on the team. By adhering to a consistent set of style rules and a quality baseline, we bring the team closer together in terms of coding style. Every team member has different opinions about coding styles, but those opinions can be condensed into style rules once we put a linter in place and agree upon a configuration.

Beyond ensuring a program can be parsed, we might want to prevent `throw` statements throwing string literals as exceptions, or disallow `console.log` and `debugger` statements in production code. However, a rule demanding that every function call must have exactly one argument is probably too harsh.

While linters are effective at defining and enforcing a coding style, we should be careful when devising a set of rules. If the lint step is too stringent, developers may become frustrated to the point where productivity is affected. If the lint step is too lenient, it may not yield a consistent coding style across our codebase.

In order to strike the right balance, we may consider avoiding style rules that don't improve our programs in the majority of cases when they're applied. Whenever we're considering a new rule, we should ask ourselves whether it would noticeably improve our existing codebase, as well as new code going forward.

ESLint is a modern linter that packs several plugins, sporting different rules, allowing us to pick and choose which ones we want to enforce. We decide whether failing to stick by these rules should result in a warning being printed as part of the output, or a halting error. To install `eslint`, we'll use `npm` just like we did with `babel` in the previous section.

```
npm install eslint@3 --save-dev
```

Next, we need to configure ESLint. Since we installed `eslint` as a local dependency, we'll find its command-line tool in `node_modules/.bin`. Executing the following command will guide us through configuring ESLint for our project for the first time. To get started, indicate you want to use a popular style guide and choose Standard, then pick JSON format for the configuration file.

```
./node_modules/.bin/eslint --init
? How would you like to configure ESLint? Use a popular style guide
? Which style guide do you want to follow? Standard
? What format do you want your config file to be in? JSON
```

Besides individual rules, `eslint` allows us to extend predefined sets of rules, which are packaged up as Node.js modules. This is useful when sharing configuration across multiple projects, and even across a community. After picking Standard, we'll notice that ESLint adds a few dependencies to `package.json`, namely the packages that define the predefined Standard ruleset; and then creates a configuration file, named `.eslintrc.json`, with the following contents.

```
{
  "extends": "standard",
  "plugins": [
    "standard",
    "promise"
  ]
}
```

Referencing the `node_modules/.bin` directory, an implementation detail of how npm works, is far from ideal. While we used it when initializing our ESLint configuration, we shouldn't keep this reference around nor type it out whenever we lint our codebase. To solve this problem, we'll add the `lint` script in the next code snippet to our `package.json`.

```
"lint": "eslint ."
```

As you might recall from the Babel example, `npm` add `node_modules` to the `PATH` when executing scripts. To lint our codebase, we can execute `npm run lint` and npm will find the ESLint CLI embedded deep in the `node_modules` directory.

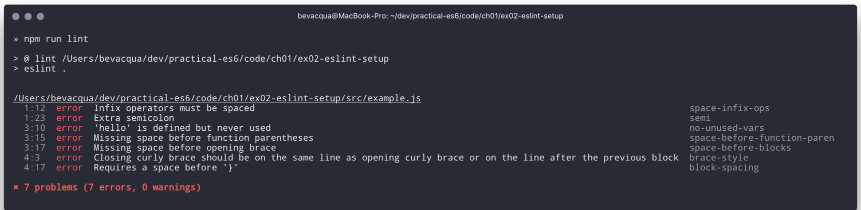
Let's consider the following `example.js` file, which is purposely ridden with style issues, to demonstrate what ESLint does.

```
var goodbye='Goodbye!';

function hello(){
  return goodbye}

if(false){}
```

When we run the `lint` script, ESLint describes everything that's wrong with the file.



ESLint is able to fix most style problems automatically if we pass in a `--fix` flag. Add the following script to your `package.json`.

```
"lint-fix": "eslint . --fix"
```

When we run `lint-fix` we'll only get a pair of errors: `hello` is never used and `false` is a constant condition. Every other error has been fixed in place, resulting in the bit of source code found below. The remaining errors weren't fixed because ESLint avoids making assumptions about our code, and prefers not to incur in semantic changes. In doing so, `--fix` becomes a useful tool to resolve code style wrinkles without risking a broken program as a result.

```
var goodbye = 'Goodbye!'

function hello () {
  return goodbye
}

if (false) {}
```

Now that you know how to compile modern JavaScript into something every browser understands, and how to properly lint your code, let's jump into ES6 feature themes and the future of JavaScript.

1.4 Feature Themes in ES6

ES6 is big: the language specification went from 258 pages in ES5.1 to over double that amount in ES6, at 566 pages. Each change to the specification falls in some of a few different categories:

- Syntactic sugar
- New mechanics
- Better semantics
- More built-ins and methods
- Non-breaking solutions to existing limitations

Syntactic sugar is one of the most significant drivers in ES6. The new version offers a shorter ways of expressing object inheritance, using the new class syntax; functions, using a shorthand syntax known as arrow functions; and properties, using property value shorthands. Several other features we'll explore, such as destructuring, rest and spread, also offer semantically sound ways of writing programs. Chapters 2 and 3 attack these aspects of ES6.

We get several new mechanics to describe asynchronous code flows in ES6: promises, which represent the eventual result of an operation; iterators, which represent a sequence of values; and generators, a special kind of iterator which can produce a sequence of values. In ES2017, `async`/`await` builds on top of these new concepts and constructs, letting us write asynchronous routines that appear synchronous. We'll evaluate all of these iteration and flow control mechanisms in chapter 4.

There's a common practice in JavaScript where developers use plain objects to create hash maps with arbitrary string keys. This can lead to vulnerabilities if we're not careful and let user input end up defining those keys. ES6 introduces a few different native built-ins to manage sets and maps, which don't have the limitation of using string keys exclusively. These collections are explored in chapter 5.

Proxy objects redefine what can be done through JavaScript reflection. Proxy objects are similar to proxies in other contexts, such as web traffic routing. They can intercept any interaction with a JavaScript object such as defining, deleting, or accessing a property. Given the mechanics of how proxies work, they are impossible to implement holistically as a polyfill. We'll devote chapter 6 to understanding proxies.

Besides new built-ins, ES6 comes with several updates to `Number`, `Math`, `Array`, and strings. In chapter 7 we'll go over a plethora of new instance and static methods added to these built-ins.

We are getting a new module system that's native to JavaScript. After going over the CommonJS module format that's used in Node.js, chapter 8 explains the semantics we can expect from native JavaScript modules.

Due to the sheer amount of changes introduced by ES6, it's hard to reconcile its new features with our pre-existing knowledge of JavaScript. We'll spend all of chapter 9 analyzing the merits and importance of different individual features in ES6, so that you have a practical grounding upon which you can start experimenting with ES6 right away.

1.5 Future of JavaScript

The JavaScript language has evolved from its humble beginnings in 1995, to the formidable language it is today. While ES6 is a great step forward, it's not the finish line. Given we can expect new specification updates every year, it's important to learn how to stay up to date with the specification.

Having gone over the rolling standard specification development process in section 1.2, one of the best ways to keep up with the standard is by periodically visiting the TC39 proposals repository[8]. Keep an eye on candidate recommendations (stage 3), which are likely to make their way into the specification.

Describing an ever-evolving language in a book can be challenging, given the rolling nature of the standards process. An effective way of keeping up to date with the latest JavaScript updates is by watching the TC39 proposals repository, subscribing to weekly email newsletters[12] and reading JavaScript blogs[13].

At the time of this writing, the long awaited Async Functions proposal has made it into the specification and is slated for publication in ES2017. There are several candidates at the moment, such as dynamic `import()`, which enables asynchronous loading of native JavaScript modules, and a proposal to describe object property enumerations using the new rest and spread syntax that was first introduced for parameter lists and arrays in ES6.

While the primary focus in this book is on ES6, we'll also learn about important candidate recommendations such as the aforementioned async functions, dynamic `import()` calls, or object rest/spread.

12 Consider Pony Foo Weekly (*https://mjavascript.com/out/pfw*) and JavaScript Weekly (*https://mjavascript.com/out/jsw*). There's many other newsletters you can follow.

13 Many of the articles on Pony Foo (*https://mjavascript.com/out/pf*) and by Axel Rauschmayer (*https://mjavascript.com/out/ar*) focus on ECMAScript development

CHAPTER 2

ES6 Essentials

The sixth edition of the language comes with a plethora of non-breaking syntax improvements, most of which we'll tackle throughout this chapter. Many of these changes are syntactic sugar, that is: they could be represented in ES5, albeit using more complicated pieces of code. There are also changes that aren't merely syntactic sugar but a completely different way of declaring variables using `let` and `const`, as we'll see towards the end of the chapter.

Object literals get a few syntax changes in ES6, and they're a good place to start.

2.1 Object Literals

An object literal is any object declaration using the `{}` shorthand syntax, such as the following example.

```
var book = {
  title: 'Modular ES6',
  author: 'Nicolas',
  publisher: 'O´Reilly'
}
```

There's a few improvements coming to object literal syntax in ES6: property value shorthands, computed property names, and method definitions. Let's go through them and describe their use cases as well.

2.1.1 Property Value Shorthands

Sometimes we declare objects with one or more properties whose values are references to variables by the same name. For example we might have a `listeners` collection, and in order to assign it to a property called `listeners` of an object literal, we have to repeat its name. The following snippet has a typical example where we have an object literal declaration with a couple of these repetitive properties.

```
var listeners = []
function listen () {}
var api = {
  listeners: listeners,
  listen: listen
}
```

Whenever you find yourself in this situation, you can omit the property value and the colon by taking advantage of the new property value shorthand syntax in ES6. As shown in the following example, the new ES6 syntax makes the assignment implicit.

```
var listeners = []
function listen () {}
var api = { listeners, listen }
```

As we'll further explore in the second part of the book, property value shorthands help de-duplicate the code we write without diluting its meaning. In the following snippet I re-implemented part of `localStorage`, a browser API for persistent storage, as an in-memory polyfill. If it weren't for the shorthand syntax, the `api` object would be more verbose to type out.

```
var store = {}
var api = { getItem,  setItem, clear }
function getItem (key) {
  return key in store ? store[key] : null
}
function setItem (key, value) {
  store[key] = value
}
function clear () {
  store = {}
}
```

That's the first of many ES6 features that are aimed towards reducing complexity in the code you have to maintain. Once you get used to the syntax, you'll notice that code readability and developer productivity get boosts as well.

2.1.2 Computed Property Names

Sometimes you have to declare objects that contain properties with names based on variables or other JavaScript expressions, as shown in the following piece of code written in ES5. For this example, assume that `expertise` is provided to you as a function parameter, and is not a value you know beforehand.

```
var expertise = 'journalism'
var person = {
  name: 'Sharon',
  age: 27
```

```
}
person[expertise] = {
  years: 5,
  interests: ['international', 'politics', 'internet']
}
```

Object literals in ES6 aren't constrained to declarations with static names. With computed property names, you can wrap any expression in square brackets, and use that as the property name. When the declaration is reached, your expression is evaluated and used as the property name. The following example shows how the piece of code we just saw could declare the person object in a single step, without having to resort to a second statement adding the person's `expertise`.

```
var expertise = 'journalism'
var person = {
  name: 'Sharon',
  age: 27,
  [expertise]: {
    years: 5,
    interests: ['international', 'politics', 'internet']
  }
}
```

You can't combine the property value shorthands with computed property names. Value shorthands are simple compile-time syntactic sugar that helps avoid repetition, while computed property names are evaluated at runtime. Given that we're trying to mix these two incompatible features, the following example would throw a syntax error. In most cases this combination would lead to code that's hard to interpret for other humans, so it's probably a good thing that you can't combine the two.

```
var expertise = 'journalism'
var journalism = {
  years: 5,
  interests: ['international', 'politics', 'internet']
}
var person = {
  name: 'Sharon',
  age: 27,
  [expertise] // this is a syntax error!
}
```

A common scenario for computed property names is when we want to add an entity to an object map that uses the `entity.id` field as its keys, as shown next. Instead of having to have a third statement where we add the `grocery` to the `groceries` map, we can inline that declaration in the `groceries` object literal itself.

```
var grocery = {
  id: 'bananas',
  name: 'Bananas',
  units: 6,
  price: 10,
```

```
  currency: 'USD'
}
var groceries = {
  [grocery.id]: grocery
}
```

Another case may be whenever a function receives a parameter that it should then use to build out an object. In ES5 code, you'd need to allocate a variable declaring an object literal, then add the dynamic property, and then return the object. The following example shows exactly that, when creating an envelope that could later be used for AJAX messages which follow a convention: they have an `error` property with a description when something goes wrong, and a `success` property when things turn out okay.

```
function getEnvelope (type, description) {
  var envelope = {
    data: {}
  }
  envelope[type] = description
  return envelope
}
```

Computed property names help us write the same function more concisely, using a single statement.

```
function getEnvelope (type, description) {
  return {
    data: {},
    [type]: description
  }
}
```

The last enhancement coming to object literals is about functions.

2.1.3 Method Definitions

Typically, you can declare methods on an object by adding properties to it. In the next snippet we're creating an small event emitter which supports multiple kinds of events. It comes with an `emitter#on` method that can be used to register event listeners, and an `emitter#emit` method that can be used to raise events.

```
var emitter = {
  events: {},
  on: function (type, fn) {
    if (this.events[type] === undefined) {
      this.events[type] = []
    }
    this.events[type].push(fn)
  },
  emit: function (type, event) {
    if (this.events[type] === undefined) {
```

```
      return
    }
    this.events[type].forEach(function (fn) {
      fn(event)
    })
  }
}
```

Starting in ES6, you can declare methods on an object literal using the new method definition syntax. In this case, we can omit the colon and the `function` keyword. This is meant as a terse alternative to traditional method declarations where you need to use the `function` keyword. The following example shows how our `emitter` object would look like when using method definitions.

```
var emitter = {
  events: {},
  on (type, fn) {
    if (this.events[type] === undefined) {
      this.events[type] = []
    }
    this.events[type].push(fn)
  },
  emit (type, event) {
    if (this.events[type] === undefined) {
      return
    }
    this.events[type].forEach(function (fn) {
      fn(event)
    })
  }
}
```

One problem with this syntax is that it tightly couples a method to an object. In terms of modular design, it would be cleaner to keep your code decoupled, and the syntax discourages it. By dropping the `function` keyword and inferring the property name from the method, we are making it hard to extract `deplete` from the object literal.

Arrow functions are another way of declaring functions in ES6, and they come in several flavors. Let's investigate what arrow functions are, how they can be declared, and how they behave semantically.

2.2 Arrow Functions

In JavaScript you typically declare functions using code like the following, where you have a name, a list of parameters, and a function body.

```
function name (parameters) {
  // function body
}
```

You could also create anonymous functions, by omitting the name, when assigning the function to a variable, a property, or a function call.

```
var example = function (parameters) {
  // function body
}
```

Starting with ES6, you can use arrow functions as another way of writing anonymous functions. Keep in mind, there's several slightly different ways of writing them. The following piece of code shows an arrow function that's very similar to the anonymous function we just saw. The only difference seems to be the missing `function` keyword and the arrow to the right of the parameter list.

```
var example = (parameters) => {
  // function body
}
```

While arrow functions look very similar to your typical anonymous function, they are fundamentally different: arrow functions can't have a name, and they are bound to their lexical scope. Let's dig into their semantic differences with traditional functions, the many ways to declare an arrow function, and practical use cases.

2.2.1 Lexical Scoping

In the body of an arrow function, `this` and `arguments` both point to the containing scope. Consider the following example. We have a `timer` object with a `seconds` counter and a `start` method defined using the syntax we've learned about earlier. We then start the timer, wait for a few seconds, and log the current amount of ellapsed `seconds`.

```
var timer = {
  seconds: 0,
  start () {
    setInterval(() => {
      this.seconds++
    }, 1000)
  }
}
timer.start()
setTimeout(function () {
  console.log(timer.seconds)
}, 3500)
// <- 3
```

If we had defined the function passed to `setInterval` as a regular anonymous function instead of using an arrow function, `this` would've been bound to the context of the anonymous function, instead of the context of the `start` method. We could have implemented `timer` with a declaration like `var self = this` at the beginning of the `start` method, and then referencing `self` instead of `this`. With arrow functions, the added complexity of keeping context references around fades away and we can focus on the functionality of our code.

In a similar fashion, lexical binding in ES6 arrow functions also means that function calls won't be able to change the `this` context when using `.call`, `.apply`, `.bind`, etc. That limitation is usually more useful than not, as it ensures that the context will always be preserved and constant.

I've mentioned there's several flavors of arrow functions, but so far we've only looked at their fully fleshed version. What are the others way to represent an arrow function?

2.2.2 Arrow Function Flavors

Let's look one more time at the arrow function syntax we've learned so far.

```
var example = (parameters) => {
  // function body
}
```

An arrow function with exactly one parameter can omit the parenthesis. This is optional. It's useful when passing the arrow function to another method, as it reduces the amount of parenthesis involved, making it easier for humans to parse the code.

```
var double = value => {
  return value * 2
}
```

Arrow functions are heavily used for simple functions, such as the `double` function we just saw. The following flavor of arrow functions does away with the function body. Instead, you provide an expression such as `value * 2`. When the function is called, the expression is evaluated and its result is returned. The `return` statement is implicit, and there's no need for brackets denoting the function body anymore, as you can only use a single expression.

```
var double = (value) => value * 2
```

Note that you can combine implicit parenthesis and implicit return, making for concise arrow functions.

```
var double = value => value * 2
```

Implicitly Returning Object Literals

When you need to implicitly return an object literal, you'll need to wrap that object literal expression in parenthesis. Otherwise, the compiler would interpret your brackets as the start and the end of the function block.

```
var objectFactory = () => ({ modular: 'es6' })
```

In the following example, JavaScript interprets the brackets as the body of our arrow function. Furthermore, `number` is interpreted as a label[1] and then figures out we have a `value` expression that doesn't do anything. Since we're in a block and not returning anything, the mapped values will be `undefined`.

```
[1, 2, 3].map(value => { number: value })
// <- [undefined, undefined, undefined]
```

If our attempt at implicitly returning an object literal had more than a single property, then the compiler wouldn't be able to make sense of the second property, and it'd throw a `SyntaxError`.

```
[1, 2, 3].map(value => { number: value, verified: true })
// <- SyntaxError
```

Wrapping the expression in parenthesis fixes these issues, because the compiler would no longer interpret it as a function block. Instead, the object declaration becomes an expression that evaluates to the object literal we want to return implicitly.

```
[1, 2, 3].map(value => ({ number: value, verified: true }))
/* <- [
  { number: 1, verified: true },
  { number: 2, verified: true },
  { number: 3, verified: true }]
*/
```

Now that you understand arrow functions, let's ponder about their merits and where they might be a good fit.

2.2.3 Merits and Use Cases

As a rule of thumb, you shouldn't blindly adopt ES6 features wherever you can. Instead, it's best to reason about each case individually and see whether adopting the new feature actually improves code readibility and maintainability. ES6 features are not strictly better than what we had all along, and it's a bad idea to treat them as such.

There's a few situations where arrow functions may not be the best tool. For example, if you have a large function with several lines of code, replacing `function` for is hardly going to improve your code. Arrow functions are often most effective for short routines, where the `function` keyword and syntax boilerplate make up a significant portion of the function expression.

1 Labels are used as a way of identifying instructions. Labels can be used by `goto` statements, to indicate what instruction we should jump to; `break` statements, to indicate the sequence we want to break out of; and `continue` statements, to indicate the sequence we want to advance. You can learn more about labels at: *https://mjavascript.com/out/label*.

Properly naming a function adds context to make it easier for humans to interpret them. Arrow functions can't be explicitly named, but they can be named implicitly by assigning them to a variable. In the following example, we assign an arrow function to the `throwError` variable. When calling this function results in an error, the stack trace properly identifies the arrow function as `throwError`.

```
var throwError = message => {
  throw new Error(message)
}
throwError('this is a warning')
<- Uncaught Error: this is a warning
  at throwError
```

Arrow functions are neat when it comes to defining anonymous functions that should probably be lexically bound anyways, and they can definitely make your code more terse in some situations. They are particularly useful in most functional programming situations such as when using `.map`, `.filter`, or `.reduce` on collections, as shown in the following example.

```
[1, 2, 3, 4]
  .map(value => value * 2)
  .filter(value => value > 2)
  .forEach(value => console.log(value))
// <- 4
// <- 6
// <- 8
```

The next feature we'll analyze is destructuring in assignment. Let's see what that's all about.

2.3 Assignment Destructuring

This is one of the most flexible and expressive features in ES6. It's also one of the simplest. It binds properties to as many variables as you need. It works with objects, arrays, and even in `function` parameter lists. Let's go step by step, starting with objects.

2.3.1 Destructuring Objects

Imagine you had a program with some comic book characters, Bruno Diaz being one of them, and you want to refer to properties in the object that describes him. Here's the example object we'll be using for Batman.

```
var character = {
  name: 'Bruno',
  pseudonym: 'Batman',
  metadata: {
    age: 34,
    gender: 'male'
```

```
  },
  batarang: ['gas pellet', 'bat-mobile control', 'bat-cuffs']
}
```

If you wanted a `pseudonym` variable referencing `character.pseudonym`, you could write the following bit of ES5 code. This is commonplace when, for instance, you'll be referencing `pseudonym` in several places in your codebase and you'd prefer to avoid typing out `character.pseudonym` each time.

```
var pseudonym = character.pseudonym
```

With destructuring in assignment, the syntax becomes a bit more clear. As you can see in the next example, you don't have to write `pseudonym` twice, while still clearly conveying intent. The following statement is equivalent to the previous one written in ES5 code.

```
var { pseudonym } = character
```

Just like you could declare multiple comma-separated variables with a single `var` statement, you can also declare multiple variables within the brackets of a destructuring expression.

```
var { pseudonym, name } = character
```

In a similar fashion, you could mix and match destructuring with regular variable declarations in the same `var` statement. While this might look a bit confusing at first, it'll be up to any JavaScript coding style guides you follow to determine whether it's appropriate to declare several variables in a single statement. In any case, it goes to show the flexibility offered by destructuring syntax.

```
var { pseudonym, name } = character, two = 2
```

If you want to extract a property named `pseudonym` but would like to declare it as a variable named `alias`, you can use the following destructuring syntax known as aliasing. Note that you can use `alias` or any other valid variable name.

```
var { pseudonym: alias } = character
console.log(alias)
// <- 'Batman'
```

While aliases don't look any simpler than the ES5 flavor, `alias = character.pseudonym`, they start making sense when you consider the fact that destructuring supports deep structures as in the following example.

```
var { metadata: { gender } } = character
```

In cases like the previous one, where you have deeply nested properties being destructured, you might be able to convey a property name more clearly if you choose an alias. Consider the next snippet, where a property named `code` wouldn't have been as indicative of its contents as `colorCode` could be.

```
var palette = {
  color: {
    name: 'Red',
    code: '#f00'
  }
}
var { color: { code: colorCode } } = palette
```

The scenario we just saw repeats itself frequently, because properties are often named in the context of their host object. While `palette.color.code` is perfectly descriptive, `code` on its own could mean a wide variety of things, and aliases such as `colorCode` can help you bring context back into the variable name while still using destructuring.

Whenever you access an inexistent property in ES5 notation, you get a value of `undefined`.

```
console.log(character.boots)
// <- undefined
console.log(character['boots'])
// <- undefined
```

With destructuring, the same behavior prevails. When declaring a destructured variable for a property that's missing, you'll get back `undefined` as well.

```
var { boots } = character
console.log(boots)
// <- undefined
```

A destructured declaration accessing a nested property of a parent object that's `null` or `undefined` will throw an `Exception`, just like regular attempts to access properties of `null` or `undefined` would, in other cases.

```
var { batmobile: { gear } } = character
// <- Exception
var { missing } = null
// <- Exception
```

When you think of that piece of code as the equivalent ES5 code shown next, it becomes evident why the expression must throw, given that destructuring is mostly syntactic sugar.

```
var nothing = null
var missing = nothing.missing
// <- Exception
```

As part of destructuring, you can provide default values for those cases where the value is `undefined`. The default value can be anything you can think of: numbers, strings, functions, objects, a reference to another variable, etc.

```
var { boots = true } = character
console.log(boots)
// <- true
```

Default values can also be provided in nested property destructuring.

```
var { metadata: { enemy = 'Satan' } } = character
console.log(enemy)
// <- 'Satan'
```

For use in combination with aliases, you should place the alias first, and then the default value, as shown next.

```
var { boots: footwear = true } = character
```

It's possible to use the computed property names syntax in destructuring patterns. In this case, however, you're required to provide an alias to be used as the variable name. That's because computed property names allow arbitrary expressions and thus the compiler isn't always able to infer a variable name. In the following example we use the `value` alias, and a computed property name to extract the `scientist` property from the `person` object.

```
var person = { scientist: true }
var { ['scient' + 'ist']: value } = person
console.log(value)
// <- true
```

This flavor of destructuring is probably the least useful, as `value = person[type]` is easier to read than `{ [type]: value } = person`, as it's a more sequential statement. That being said, the feature could still be useful in some deep destructuring scenarios.

That's it, as far as objects go, in terms of destructuring. What about arrays?

2.3.2 Destructuring Arrays

The syntax for destructuring arrays is similar to that of objects. The following example shows a `coordinates` object that's destructured into two variables: `x` and `y`. Note how the notation uses square brackets instead of curly braces, this denotes we're using array destructuring instead of object destructuring. Instead of having to sprinkle your code with implementation details like `x = coordinates[0]`, with destructuring you can convey your meaning clearly and without explicitly referencing the indices, naming the values instead.

```
var coordinates = [12, -7]
var [x, y] = coordinates
console.log(x)
// <- 12
```

When destructuring arrays, you can skip uninteresting properties or those that you otherwise don't need to reference.

```
var names = ['James', 'L.', 'Howlett']
var [ firstName,, lastName ] = names
console.log(lastName)
// <- 'Howlett'
```

Array destructuring allows for default values just like object destructuring.

```
var names = ['James', 'L.']
var [ firstName = 'John',, lastName = 'Doe' ] = names
console.log(lastName)
// <- 'Doe'
```

In ES5, when you have to swap the values of two variables, you typically resort to a third, temporary variable, as in the following snippet.

```
var left = 5
var right = 7
var aux = left
left = right
right = aux
```

Destructuring helps you avoid the `aux` declaration and focus on your intent. Once again, destructuring helps us convey intent more tersely and effectively for the use case.

```
var left = 5
var right = 7
[left, right] = [right, left]
```

The last area of destructuring we'll be covering is function parameters.

2.3.3 Function Parameter Defaults and Destructuring

Function parameters in ES6 enjoy the ability of specifying default values as well. The following example defines a default `exponent` with the most commonly used value.

```
function powerOf (base, exponent = 2) {
  return Math.pow(base, exponent)
}
```

Defaults can be applied to arrow function parameters as well. When we have default values in an arrow function we must wrap the parameter list in parenthesis, even when there's a single parameter.

```
var double = (input = 0) => input * 2
```

Default values aren't limited to the rightmost parameters of a function, as is commonplace in other programming languages. You could provide default values for any parameter, in any position.

```
function sumOf (a = 1, b = 2, c = 3) {
  return a + b + c
}
```

```
console.log(sumOf(undefined, undefined, 4))
// <- 1 + 2 + 4 = 7
```

In JavaScript it's not uncommon to provide a function with an `options` object, containing several properties. You could determine a default `options` object if one isn't provided, as shown in the next snippet.

```
function carFactory (options = { brand: 'Volkswagen', make: 1999 }) {
  console.log(options.brand)
  console.log(options.make)
}
carFactory()
// <- 'Volkswagen'
// <- 1999
```

The problem with this approach is that as soon as the consumer of `carFactory` provides an `options` object, you lose all of your defaults.

```
carFactory({ make: 2000 })
// <- undefined
// <- 2000
```

A better approach would be to destructure `options` entirely, providing default values for each property, individually, within the destructuring pattern. This approach also lets you reference each option without going through an `options` object, but you lose the ability to reference `options` directly, which might represent an issue in some situations.

```
function carFactory ({ brand = 'Volkswagen', make = 1999 }) {
  console.log(brand)
  console.log(make)
}
carFactory({ make: 2000 })
// <- 'Volkswagen'
// <- 2000
```

In this case, however, we've once again lost the default value for the case where the consumer doesn't provide any `options`. Meaning `carFactory()` will now throw when an `options` object isn't provided. This can be remedied by using the syntax shown in the following snippet of code, which adds a default `options` value of an empty object. The empty object is then filled, property by property, with the default values on the destructuring pattern.

```
function carFactory ({ brand = 'Volkswagen', make = 1999 } = {}) {
  console.log(brand)
  console.log(make)
}
carFactory()
// <- 'Volkswagen'
// <- 1999
```

Besides default values, you can use destructuring in function parameters to describe the shape of objects your function can handle. Consider the following code snippet, where we have a `car` object with several properties. The `car` object describes its owner, what kind of car it is, who manufactured it, when, and the owner's preferences when he purchased the car.

```
const car = {
  owner: {
    id: 'e2c3503a4181968c',
    name: 'Donald Draper'
  },
  brand: 'Peugeot',
  make: 2015,
  model: '208',
  preferences: {
    airbags: true,
    airconditioning: false,
    color: 'red'
  }
}
```

If we wanted to implement a function that only takes into account certain properties of a parameter, it might be a good idea to reference those properties explicitly by destructuring up front. The upside is that we become aware of every required property upon reading the function's signature.

When we destructure everything up front, it's easy to spot when input doesn't adhere to the contract of a function. The following example shows how every property we need could be specified in the parameter list, laying bare the shape of the objects we can handle in the `getCarProductModel` API.

```
const getCarProductModel = ({ brand, make, model }) => ({
  sku: brand + ':' make + ':' + model,
  brand,
  make,
  model
})
getCarProductModel(car)
```

Besides default values and filling an `options` object, let's explore what else destructuring is good at.

2.3.4 Use Cases for Destructuring

Whenever there's a function that returns an object or an array, destructuring makes it much terser to interact with. The following example shows a function that returns an object with some coordinates, where we grab only the ones we're interested in: `x` and `y`. We're avoiding an intermediate `point` variable declaration that often gets in the way without adding a lot of value to the readability of your code.

```
function getCoordinates () {
  return { x: 10, y: 22, z: -1, type: '3d' }
}
var { x, y } = getCoordinates()
```

The case for default option values bears repeating. Imagine you have a `random` function which yields random integers between a `min` and a `max` value, and that it should default to values between 1 and 10. This is particularly interesting as an alternative to named parameters in other languages like Python and C#. This pattern, where you're able to define default values for options and then let consumers override them individually, offers great flexibility.

```
function random ({ min = 1, max = 10 } = {}) {
  return Math.floor(Math.random() * (max - min)) + min
}
console.log(random())
// <- 7
console.log(random({ max: 24 }))
// <- 18
```

Regular expressions are another great fit for destructuring. Destructuring empowers you to name groups from a match without having to resort to index numbers. Here's an example `RegExp` that could be used for parsing simple dates, and an example of destructuring those dates into each of its components. The first entry in the resulting array is reserved for the raw input string, and we can discard it.

```
function splitDate (date) {
  var rdate = /(\d+).(\d+).(\d+)/
  return rdate.exec(date)
}
var [, year, month, day] = splitDate('2015-11-06')
```

Let's turn our attention to spread and rest operators next.

2.4 Rest Parameters and Spread Operator

Before ES6, interacting with an arbitrary amount of function parameters was complicated. You had to use `arguments`, which isn't an array but has a `length` property. Usually you'd end up casting the `arguments` object into an actual array using `Array.prototype.slice.call`, and going from there, as shown in the following snippet.

```
function join () {
  var list = Array.prototype.slice.call(arguments)
  return list.join(', ')
}
join('first', 'second', 'third')
// <- 'first, second, third'
```

ES6 has a better solution to the problem, and that's rest parameters.

2.4.1 Rest Parameters

You can now precede the last parameter in any JavaScript function with three dots, converting it into an special "rest parameter". When the rest parameter is the only parameter in a function, it gets all arguments passed to the function: it works just like the `.slice` solution we saw earlier, but you avoid the need for a complicated construct like `arguments`, and it's specified in the parameter list.

```
function join (...list) {
  return list.join(', ')
}
join('first', 'second', 'third')
// <- 'first, second, third'
```

Named parameters before the rest parameter won't be included in the `list`.

```
function join (separator, ...list) {
  return list.join(separator)
}
join('; ', 'first', 'second', 'third')
// <- 'first; second; third'
```

Note that arrow functions with a rest parameter must include parenthesis, even when it's the only parameter. Otherwise, a `SyntaxError` would be thrown. The following piece of code is a beautiful example of how combining arrow functions and rest parameters can yield concise functional expressions.

```
var sumAll = (...numbers) => numbers.reduce((total, next) => total + next)
console.log(sumAll(1, 2, 5))
// <- 8
```

Compare that with the ES5 version of the same function. Granted, it's all in the complexity. While terse, the `sumAll` function can be confusing to readers unused to the `.reduce` method, or because it uses two arrow functions. This is a complexity tradeoff that we'll cover in the second part of the book.

```
function sumAll () {
  var numbers = Array.prototype.slice.call(arguments)
  return numbers.reduce(function (total, next) {
    return total + next
  })
}
console.log(sumAll(1, 2, 5))
// <- 8
```

Next up we have the spread operator. It's also denoted with three dots, but it serves a slightly different purpose.

2.4.2 Spread Operator

The spread operator can be used to cast any iterable object into an array. Spreading effectively expands an expression onto a target such as an array literal or a function call. The following example uses `...arguments` to cast function parameters into an array literal.

```
function cast () {
  return [...arguments]
}
cast('a', 'b', 'c')
// <- ['a', 'b', 'c']
```

We could use the spread operator to split a string into an array with each code point that makes up the string.

```
[...'show me']
// <- ['s', 'h', 'o', 'w', ' ', 'm', 'e']
```

You can place additional elements to the left and to the right of a spread operation and still get the result you would expect.

```
function cast () {
  return ['left', ...arguments, 'right']
}
cast('a', 'b', 'c')
// <- ['left', 'a', 'b', 'c', 'right']
```

Spread is an useful way of combining multiple arrays. The following example shows how you can spread arrays anywhere into an array literal, expanding their elements into place.

```
var all = [1, ...[2, 3], 4, ...[5], 6, 7]
console.log(all)
// <- [1, 2, 3, 4, 5, 6, 7]
```

Note that the spread operator isn't limited to arrays and `arguments`. The spread operator can be used with any iterable object. Iterable is a protocol in ES6 that allows you to turn any object into something that can be iterated over. We'll research the iterable protocol in chapter 4.

Shifting and Spreading

When you want to extract an element or two from the beginning of an array, the common approach is to use `.shift`. While functional, the snippet of code below can be hard to understand at a glance, because it uses `.shift` twice to grab a different item from the beginning of the `list` each time. The focus is, like in many other pre-ES6 situations, placed on getting the language to do what we want.

```
var list = ['a', 'b', 'c', 'd', 'e']
var first = list.shift()
var second = list.shift()
console.log(first)
// <- 'a'
```

In ES6, you can combine spread with array destructuring. The following piece of code is similar to the one above, except we're using a single line of code, and that single line is more descriptive of what we're doing that repeateadly calling `list.shift()` in the previous example.

```
var [first, second, ...rest] = ['a', 'b', 'c', 'd', 'e']
console.log(rest)
// <- ['c', 'd', 'e']
```

Using the spread operator you can focus on implementing the functionality you need while the language stays out of the way. Improving expressiveness and decreasing time spent working around language limitations is a common pattern we can observe in ES6 features.

Before ES6, whenever you had a dynamic list of arguments that need to be applied to a function call, you'd use `.apply`. This is inelegant because `.apply` also takes a context for `this` which, in this scenario, you don't want to concern yourself with.

```
fn.apply(null, ['a', 'b', 'c'])
```

Besides spreading onto arrays, you can also spread items onto function calls. The following example shows how you could use the spread operator to pass an arbitrary number of arguments to the `multiply` function.

```
function multiply (left, right) {
  return left * right
}
var result = multiply(...[2, 3])
console.log(result)
// <- 6
```

Spreading arguments onto a function call can be combined with regular arguments as much as necessary, just like with array literals. The next example calls `print` with a couple of regular arguments and a couple of arrays being spread over the parameter list. Note how conveniently the rest `list` parameter matches all the provided arguments. Spread and rest can help make code intent more clear without dilluting your codebase.

```
function print (...list) {
  console.log(list)
}
print(1, ...[2, 3], 4, ...[5])
// <- ['1', '2', '3', '4', '5']
```

Another limitation of .apply is that combining it with the new keyword, when instantiating an object, becomes very verbose. Here's an example of combining new and .apply to create a Date object. Ignore for a moment that months in JavaScript dates are zero-based, turning 11 into December, and consider how much of the following line of code is spent bending the language in our favor, just to instantiate a Date object.

```
new (Date.bind.apply(Date, [null, 2015, 11, 31]))
// <- Thu Dec 31 2015
```

As shown in the next snippet, the spread operator strips away all the complexity and we're only left with the important bits. It's a new instance, it uses ... to spread a dynamic list of arguments over the function call, and it's a Date. That's it.

```
new Date(...[2015, 11, 31])
// <- Thu Dec 31 2015
```

The following table summarizes the use cases we've discussed for the spread operator.

Use Case	ES5	ES6
Concatenation	`[1, 2].concat(more)`	`[1, 2, …more]`
Push onto list	`list.push.apply(list, [3, 4])`	`list.push(…[3, 4])`
Destructuring	`a = list[0], rest = list.slice(1)`	`[a, …rest] = list`
`new` and `apply`	`new (Date.bind.apply(Date, [null,2015,31,8]))`	`new Date(…[2015,31,8])`

2.5 Template Literals

Template literals are a vast improvement upon regular JavaScript strings. Instead of using single or double quotes, template literals are declared using backticks, as shown next.

```
var text = `This is my first template literal`
```

Given that template literals are delimited by backticks, you're now able to declare strings with both ' and " quotation marks in them without having to escape either, as shown below.

```
var text = `I'm "amazed" at these opportunities!`
```

One of the most appealing features of template literals is their ability to interpolate JavaScript expressions.

2.5.1 String Interpolation

With template literals, you're able to interpolate any JavaScript expressions inside your templates. When the template literal expression is reached, it's evaluated and you get back the compiled result. The following example interpolates a `name` variable into a template literal.

```
var name = 'Shannon'
var text = `Hello, ${ name }!`
console.log(text)
// <- 'Hello, Shannon!'
```

We've already established that you can use any JavaScript expressions, and not just variables. You can think of each expression in a template literal as defining a variable before the template runs, and then concatenating those value with the rest of the string. However, the code becomes easier to maintain because it doesn't involve manually concatenating strings and JavaScript expressions. The variables you use in those expressions, the functions you call, and so on, should all be available to the current scope.

It will be up to your coding style guides to decide how much logic you want to cram into the interpolation expressions. The following code snippet, for example, instantiates a `Date` object and formats it into a human-readable date inside a template literal.

```
`The time and date is ${ new Date().toLocaleString() }.`
// <- 'the time and date is 8/26/2015, 3:15:20 PM'
```

You could interpolate mathematical operations.

```
`The result of 2+3 equals ${ 2 + 3 }`
// <- 'The result of 2+3 equals 5'
```

You could even nest template literals, as they are also valid JavaScript expressions.

```
`This a template literal ${ `with another ${ 'one' } embedded inside it` }`
// <- 'This a template literal with another one embedded inside it'
```

Another perk of template literals is their multiline string representation support.

2.5.2 Multiline Template Literals

Before template literals, if you wanted to represent strings in multiple lines of JavaScript, you had to resort to escaping, concatenation, arrays, or even ellaborate hacks using comments. The following snippet summarizes some of the most common ways multiline string representations prior to ES6.

```
var escaped =
'The first line\n\
A second line\n\
Then a third line'
```

```
var concatenated =
'The first line\n' +
'A second line\n' +
'Then a third line'

var joined = [
'The first line',
'A second line',
'Then a third line'
].join('\n')
```

Under ES6, you could use backticks instead. Template literals support multiline strings by default. Note how there's no `\n` escapes, no concatenation, and no arrays involved.

```
var multiline =
`The first line
A second line
Then a third line`
```

Multiline strings really shine when you have, for instance, a chunk of HTML you want to interpolate some variables into. If you need to display a list within the template, you could iterate the list, mapping its items into the corresponding markup, and then return the joined result from an interpolated expression. This makes it a breeze to declare subcomponents within your templates, as shown in the following piece of code.

```
var book = {
  title: 'Modular ES6',
  excerpt: 'Here goes some properly sanitized HTML',
  tags: ['es6', 'template-literals', 'es6-in-depth']
}
var html = `<article>
  <header>
    <h1>${ book.title }</h1>
  </header>
  <section>${ book.excerpt }</section>
  <footer>
    <ul>
      ${
        book.tags
          .map(tag => `<li>${ tag }</li>`)
          .join('\n      ')
      }
    </ul>
  </footer>
</article>`
```

The template we've just prepared would produce output like what's shown in the following snippet of code. Note how spacing was preserved, and how `<li>` tags are properly indented thanks for how we joined them together using a few spaces.

```
<article>
  <header>
    <h1>Modular ES6</h1>
  </header>
  <section>Here goes some properly sanitized HTML</section>
  <footer>
    <ul>
      <li>es6</li>
      <li>template-literals</li>
      <li>es6-in-depth</li>
    </ul>
  </footer>
</article>
```

Sometimes, it might be a good idea to pre-process the results of expressions before inserting them into your templates. For these advanced kinds of use cases, it's possible to use another feature of template literals called tagged templates.

2.5.3 Tagged Templates

By default, JavaScript interprets `\` as an escape character with special meaning. For example, `\n` is interpreted as a newline, `\u00f1` is interpreted as ñ, etcetera. You could avoid these rules using the `String.raw` tagged template. The next snippet shows a template literal using `String.raw` which prevents `\n` from being interpreted as a newline.

```
var text = String.raw`The "\n" newline won't result in a new line.
It'll be escaped.`
console.log(text)
// The "\n" newline won't result in a new line.
// It'll be escaped.
```

The `String.raw` prefix we've added to our template literal is a tagged template. It's used to parse the template. Tagged templates receive a parameter with an array containing the static parts of the template, as well as the result of evaluating each expression, each in its own parameter.

A template literal like `Hello, ${ name }. I am ${ emotion } to meet you!`, for instance, will invoke a tagged template `tag` using the following parameters.

```
tag(['Hello, ', '. I am ', ' to meet you!'], 'Maurice', 'thrilled')
```

The template is built by taking each part of the template and placing one of the expressions next to it, until there's no more parts of the template left. It might be hard to interpret the argument list without looking at a potential implementation of the default template literal `tag`, so let's do that.

The following snippet of code shows a possible implementation of the default `tag`. It provides the same functionality as a template literal does when a tagged template isn't explicitly provided. It reduces the `parts` array into a single value, the result of evaluating the template literal. The result is initialized with the first `part`, and then each other `part` of the template is preceded by one of the `values`. We've used the rest parameter syntax for `...values` in order to make it easier to grab the result of evaluating each expression in the template. We're using an arrow function with an implicit `return` statement, given that its expression is relatively simple.

```
function tag (parts, ...values) {
  return parts.reduce(
    (all, part, i) => all + values[i - 1] + part
  )
}
```

You can try the `tag` template using code like in the following snippet. You'll notice you get the same output as if you omitted `tag`, since we're copying the default behavior.

```
var name = 'Maurice'
var emotion = 'thrilled'
var text = tag`Hello, ${ name }. I am ${ emotion } to meet you!`
console.log(text)
// <- 'Hello Maurice, I am thrilled to meet you!'
```

Multiple use cases apply to tagged templates. One possible use case might be to make user input uppercase, making the string sound satirical. That's what the following piece of code does. We've modified `tag` slightly so that any interpolated strings are uppercased.

```
function upper (parts, ...values) {
  return parts.reduce(
    (all, part, i) => all + values[i - 1].toUpperCase() + part
  )
}
var name = 'Maurice'
var emotion = 'thrilled'
var text = upper`Hello, ${ name }. I am ${ emotion } to meet you!`
console.log(text)
// <- 'Hello MAURICE, I am THRILLED to meet you!'
```

A decidedly more useful use case would be to sanitize expressions interpolated into your templates, automatically, using a tagged template. Given a template where all expressions are considered user-input, we could use a hypothetical `sanitize` library to remove HTML tags and similar hazards.

```
function sanitized (parts, ...values) {
  return parts.reduce(
    (all, part, i) => all + sanitize(values[i - 1]) + part
  )
}
var comment = 'A malicious comment<iframe src="http://evil.corp"></iframe>'
var html = sanitized`<div>${ comment }</div>`
```

```
console.log(html)
// <- '<div>A malicious comment</div>'
```

Phew, that malicious `<iframe>` almost got us. Rounding out ES6 syntax changes, we have the `let` and +const statements.

2.6 Let and Const Statements

The `let` statement is one of the most well-known features in ES6. It works like a `var` statement, but it has different scoping rules.

JavaScript has always had a complicated ruleset when it comes to scoping, driving many programmers crazy when they were first trying to figure out how variables work in JavaScript. Eventually, you discover hoisting, and JavaScript starts making a bit more sense to you. Hoisting means that variables get pulled from anywhere they were declared in user code to the top of their scope. For example, see the code below.

```
function isItTwo (value) {
  if (value === 2) {
    var two = true
  }
  return two
}
isItTwo(2)
// <- true
isItTwo('two')
// <- undefined
```

JavaScript code like this works, even though `two` was declared in a code branch and then accessed outside of said branch. The reason why, as we know, is that `var` bindings are bound to the enclosing scope, be it a function or the global scope. That, coupled with hoisting, means that what the code we've written earlier will be interpreted as if it were written in a similar way to the next piece of code.

```
function isItTwo (value) {
  var two
  if (value === 2) {
    two = true
  }
  return two
}
```

Whether we like it or not, hoisting is more confusing than having block-scoped variables would be. Block scoping works on the curly-braces level, rather than the function level.

2.6.1 Block Scoping and Let Statements

Instead of having to declare a new `function` if we want a deeper scoping level, block scoping allows you to just leverage existing code branches like those in `if`, `for`, or `while` statements; you could also create new `{}` blocks arbitrarily. As you may or may not know, the JavaScript language allows us to create an indiscriminate number of blocks, just because we want to.

```
{{{{{ var deep = 'This is available from outer scope.'; }}}}}
console.log(deep)
// <- 'This is available from outer scope.'
```

With `var`, because of lexical scoping, one could still access the `deep` variable from outside those blocks, and not get an error. Sometimes it can be very useful to get errors in these situations. Particularly if one or more of the following is true.

- Accessing the inner variable breaks some sort of encapsulation principle in our code
- The inner variable doesn't belong in the outer scope at all
- The block in question has many siblings that would also want to use the same variable name
- One of the parent blocks already has a variable with the name we need, but the name is still appropriate to use in the inner block

The `let` statement is an alternative to `var`. It follows block scoping rules instead of the default lexical scoping rules. With `var`, the only way of getting a deeper scope is to create a nested function, but with `let` you can just open another pair of brackets. This means you don't need entirely new functions to get a new scope: a simple `{}` block will do.

```
let topmost = {}
{
  let inner = {}
  {
    let innermost = {}
  }
  // attempts to access innermost here would throw
}
// attempts to access inner here would throw
// attempts to access innermost here would throw
```

One useful aspect of `let` statements is that you can use them when declaring a `for` loop, and variables will be scoped to the contents of the loop, as shown below.

```
for (let i = 0; i < 2; i++) {
  console.log(i)
  // <- 0
```

```
  // <- 1
}
console.log(i)
// <- i is not defined
```

One more thing of note about `let` is a concept called the "Temporal Dead Zone".

2.6.2 Temporal Dead Zone

In so many words: if you have code such as the following code snippet, it'll throw. Once execution enters a scope, and until a `let` statement is reached, attempting to access the variable for said `let` statement will throw. This is known as the Temporal Dead Zone (TDZ).

```
{
  console.log(name)
  // <- ReferenceError: name is not defined
  let name = 'Stephen Hawking'
}
```

If your code tries to access `name` in any way before the `let name` statement is reached, the program will throw. Declaring a function that references `name` before it's defined is okay, as long as the function doesn't get executed while `name` is in the TDZ, and `name` will be in the TDZ until the `let name` statement is reached. This snippet won't throw because `return name` isn't executed until after `name` leaves the TDZ.

```
function readName () {
  return name
}
let name = 'Stephen Hawking'
console.log(readName())
// <- 'Stephen Hawking'
```

But the following snippet will, because access to `name` occurs before leaving the TDZ for `name`.

```
function readName () {
  return name
}
console.log(readName())
// ReferenceError: name is not defined
let name = 'Stephen Hawking'
```

Note that the semantics for these examples doesn't change when `name` isn't actually assigned a value when initially declared. The next snippet throws as well, as it still tries to access `name` before leaving the TDZ.

```
function readName () {
  return name
}
console.log(readName())
```

```
// ReferenceError: name is not defined
let name
```

The following bit of code works because it leaves the TDZ before accessing `name` in any way.

```
function readName () {
  return name
}
let name
console.log(readName())
// <- undefined
```

The only tricky part to remember is that it's okay to declare functions that access a variable in the TDZ as long as the statements accessing TDZ variables aren't reached before the `let` declaration is reached.

The whole point of the TDZ is to make it easier to catch errors where accessing a variable before it's declared in user code leads to unexpected behavior. This happened a lot before ES6 due both to hoisting and poor coding conventions. In ES6 it's easier to avoid. Keep in mind that hoisting still applies for `let` as well. That means variables will be created when we enter the scope, and the TDZ will be born, but they will be inaccessible until code execution hits the place where the variable was actually declared, at which point we leave the TDZ and are allowed to access the variable.

We made it through the temporal dead zone! It's now time to cover `const`, a similar statement to `let` but with a few major differences.

2.6.3 Const Statements

The `const` statement is block scoped like `let`, and it follows TDZ semantics as well. In fact, TDZ semantics were implemented because of `const`, and then TDZ was also applied to `let` for consistency. The reason why `const` needed TDZ semantics is that it would otherwise have been possible to assign a value to a hoisted `const` variable before reaching the `const` declaration, meaning that the declaration itself would throw. The temporal dead zone defines a solution that solves the problem of making `const` assignment possible only at declaration time, helps avoid potential issues when using `let`, and also makes it easy to eventually implement other features that benefit from TDZ semantics.

The following snippet shows how `const` follows block scoping rules exactly like `let`.

```
const pi = 3.1415
{
  const pi = 6
  console.log(pi)
  // <- 6
}
```

```
console.log(pi)
// <- 3.1415
```

We've mentioned major differences between `let` and `const`. The first one is that `const` variables must be declared using an initializer. A `const` declaration must be accompanied by an initializer, as shown in the following snippet.

```
const pi = 3.1415
const e; // SyntaxError, missing initializer
```

Besides the assignment when initializing a `const`, variables declared using a `const` statement can't be assigned to. Once a `const` is initialized, you can't change its value. Under strict mode, attempts to change a `const` variable will throw. Outside of strict mode, they'll fail silently as demonstrated by the following piece of code.

```
const people = ['Tesla', 'Musk']
people = []
console.log(people)
// <- ['Tesla', 'Musk']
```

Note that creating a `const` variable doesn't mean that the assigned value becomes immutable. This is a common source of confusion, and it is strongly recommended that you pay attention when reading the following warning.

Variables declared using `const` are not immutable.

Using `const` only means that the variable will always have a reference to the same object or primitive value, because that reference can't change. The reference itself is immutable, but the value held by the variable does not become immutable.

The following example shows that even though the `people` reference couldn't be changed, the array itself can indeed be modified. If the array were immutable, this wouldn't be possible.

```
const people = ['Tesla', 'Musk']
people.push('Berners-Lee')
console.log(people)
// <- ['Tesla', 'Musk', 'Berners-Lee']
```

A `const` statement only prevents the variable binding from referencing a different value. Another way of representing that difference is the following piece of code, where we create a `people` variable using `const`, and later assign that variable to a plain `var` `humans` binding. We can reassign the `humans` variable to reference something else, because it wasn't declared using `const`. However, we can't reassign `people` to reference something else, because it was created using `const`.

```
const people = ['Tesla', 'Musk']
var humans = people
humans = 'evil'
console.log(humans)
// <- 'evil'
```

If our goal was to make the value immutable, then we'd have to use a function such as `Object.freeze`. Using `Object.freeze` prevents extensions to the provided object, as represented in the following code snippet.

```
const frozen = Object.freeze(['Ice', 'Icicle', 'Ice cube'])
frozen.push('Water')
// Uncaught TypeError: Can't add property 3, object is not extensible
```

Let's take a moment to discuss the merits of `const` and `let`.

2.6.4 Merits of Const and Let

New features should never be used for the sake of using new features. ES6 features should be used where they genuinely improve code readability and maintainability. The `let` statement is able to, in many cases, simplify pieces of code where you'd otherwise declare `var` statements at the top of a function just so that hoisting doesn't produce unexpected results. Using the `let` statement you'd be able to place your declarations at the top of a code block, instead of the top of the whole function, reducing the latency in mental trips to the top of the scope.

Using the `const` statement is a great way to prevent accidents. The following piece of code is an plausably error prone scenario where we pass of a reference to an `items` variable to a `checklist` function which then returns a `todo` API that in turn interacts with said `items` reference. When the `items` variable is changed to reference another list of items, we're in for a world of hurt: the `todo` API still works with the value `items` used to have, but `items` is referencing something else now.

```
var items = ['a', 'b', 'c']
var todo = checklist(items)
todo.check()
console.log(items)
// <- ['b', 'c']
items = ['d', 'e']
todo.check()
console.log(items)
// <- ['d', 'e'], would be ['c'] if items had been constant
function checklist (items) {
  return {
    check: () => items.shift()
  }
}
```

This type of problem is hard to debug because it might take a while until you figure out that the reference was modified. The `const` statement helps prevent this scenario by producing a runtime error (under strict mode), which should help capture the bug soon after it's introduced.

A similar benefit of using the `const` statement is its ability to visually identify variables that aren't reassigned. The `const` cue signals that the variable binding is read-only and thus we have one less thing to worry about when reading a piece of code.

If we choose to default to using `const` and use `let` for variables that need to be reassigned, all variables will follow the same scoping rules, which makes code easier to reason about. The reason why `const` is sometimes proposed as the "default" variable declaration type, is that it's the one that does the least: `const` prevents reassignment, follows block scoping, and the declared binding can't be accessed before the declaration statement is executed. The `let` statement allows reassignment, but behaves like `const`, so it naturally follows to choose `let` when we're in need for a reassignable variable.

On the counterside, `var` is a more complex declaration because it is hard to use in code branches due to function scoping rules, it allows reassignment, and it can be accessed before the declaration statement is reached. The `var` statement is inferior to `const` and `let`, which do less, and is thus less prominent in modern JavaScript codebases.

Throughout this book, we'll follow the practice of using `const` by default and `let` when reassignment is desirable. You can learn more about the rationale behind this choice in chapter 9.

CHAPTER 3
Classes, Symbols, and Objects

Now that we've covered the basic improvements to the syntax, we're in good shape to take aim at a few other additions to the language: classes, and symbols. Classes provide syntax to represent prototypal inheritance under the traditional class-based programming paradigm. Symbols are a new primitive value type in JavaScript useful for defining protocols, and we'll investigate what that means. When we're done with classes and symbols, we'll discuss a few new static methods added to the `Object` built-in in ES6.

3.1 Classes

Many features in ES6 such as destructuring are in fact syntactic sugar, and classes are no exception to that. As we know, JavaScript is a prototype-based language, and classes are syntactic sugar on top of prototypical inheritance. In that sense, JavaScript classes don't introduce any fundamental changes to the language: they're merely a different way of declaring object prototypes.

The `class` keyword acts, then, as a device that makes JavaScript more inviting to programmers coming from other paradigms, who might not be all that familiar with prototype chains.

3.1.1 Class Fundamentals

When learning about new language features, it's always a good idea to look at existing constructs first, and then see how the new feature improves those use cases. We'll start by looking at a simple prototype-based JavaScript constructor and then compare that with the newer classes syntax in ES6.

The code snippet shown below represents a fruit using a constructor function and adding a couple of methods to the prototype. The constructor function takes a `name` and the amount of `calories` for a fruit, and defaults to the fruit being in a single piece. There's a `.chop` method that will slice another piece of fruit, and then there's a `.bite` method. The `person` passed into `.bite` will eat a piece of fruit, getting satiety equal to the remaining calories divided by the amount of fruit pieces left.

```
function Fruit (name, calories) {
  this.name = name
  this.calories = calories
  this.pieces = 1
}
Fruit.prototype.chop = function () {
  this.pieces++
}
Fruit.prototype.bite = function (person) {
  if (this.pieces < 1) {
    return
  }
  const calories = this.calories / this.pieces
  person.satiety += calories
  this.calories -= calories
  this.pieces--
}
```

While fairly simple, the piece of code we just put together should be enough to note a few things. We have a constructor function that takes a couple of parameters, a pair of methods, and a number of properties. The next snippet codifies how one should create a `Fruit` and a `person` that chops the fruit into four slices and then takes three bites.

```
const person = { satiety: 0 }
const apple = new Fruit('apple', 140)
apple.chop()
apple.chop()
apple.chop()
apple.bite(person)
apple.bite(person)
apple.bite(person)
console.log(person.satiety)
// <- 105
console.log(apple.pieces)
// <- 1
console.log(apple.calories)
// <- 35
```

When using `class` syntax, as shown in the following code listing, the `constructor` function is declared as an explicit member of the `Fruit` class, and methods follow the object literal method definition syntax. When we compare the `class` syntax with the prototype-based syntax, you'll notice we're reducing the amount of boilerplate code quite a bit by avoiding explicit references to `Fruit.prototype` while declaring methods. The fact that the entire declaration is kept inside the `class` block also helps the reader understand the scope of this piece of code, making our classes' intent clearer. Lastly, having the constructor explicitly as a method member of `Fruit` makes the `class` syntax easier to understand when compared with the prototype-based flavor of class syntax.

```
class Fruit {
  constructor (name, calories) {
    this.name = name
    this.calories = calories
    this.pieces = 1
  }
  chop () {
    this.pieces++
  }
  bite (person) {
    if (this.pieces < 1) {
      return
    }
    const calories = this.calories / this.pieces
    person.satiety += calories
    this.calories -= calories
    this.pieces--
  }
}
```

A not-so-minor detail you might have missed is that there aren't any commas in between method declarations of the `Fruit` class. That's not a mistake our copious copy editors missed, but rather part of the `class` syntax. The distinction can help avoid mistakes where we treat plain objects and classes as interchangeable even though they're not, and at the same time it makes classes better suited for future improvements to the syntax such as class-scoped private functions.

The class-based solution is equivalent to the prototype-based piece of code we wrote earlier. Consuming a fruit wouldn't change in the slightest, the API for `Fruit` remains unchanged. The previous piece of code where we instantiated an apple, chopped it into smaller pieces and ate most of it would work well with our `class` flavored `Fruit` as well.

It's worth noting that class declarations aren't hoisted to the top of their scope, unlike function declarations. That means you won't be able to instantiate, or otherwise access, a class before its declaration is reached and executed.

```
new Person(); // <- ReferenceError: Person is not defined
class Person {
}
```

Besides the class declaration syntax presented above, classes can also be declared as expressions, just like with function declarations and function expressions. You are allowed to omit the name for a `class` expression, as shown in the following bit of code.

```
const Person = class {
  constructor (name) {
    this.name = name
  }
}
```

Class expressions could be easily returned from a function, making it possible to create a factory of classes with minimal effort. In the following example we create a `Jake` class dynamically in arrow function which takes a name parameter and then feeds that to the parent `Person` constructor via `super()`.

```
const createPersonClass = name => class extends Person {
  constructor () {
    super(name)
  }
}
const Jake = createPersonClass('Jake')
const jake = new Jake()
```

We'll dig deeper into class inheritance later. Let's take a more nuanced look at properties and methods first.

3.1.2 Properties and Methods in Classes

It should be noted that the `constructor` method declaration is an optional member of a `class` declaration. The following bit of code is an entirely valid `class` declaration that's comparable to an empty constructor function.

```
class Fruit {
}
// the constructor function below is equivalent to the class above
function Fruit () {
}
```

Any arguments passed to `new Log()` will be received as parameters to the `constructor` method for `Log`, as depicted next. You can use those parameters to initialize instances of the class.

```
class Log {
  constructor (...args) {
    console.log(args)
  }
}
new Log('a', 'b', 'c')
// <- ['a' 'b' 'c']
```

The following example shows a class where we create and initialize an instance property named `count` upon construction of each instance. The `get next` method declaration indicates instances of our `Counter` class will have a `next` property that will return the results of calling its method, whenever that property is accessed.

```
class Counter {
  constructor (start) {
    this.count = start
  }
  get next () {
    return this.count++
  }
}
```

In this case, you could consume the `Counter` class as shown in the next snippet. Each time the `.next` property is accessed, the count raises by one. While mildly useful, this sort of use case is usually better suited by methods than by magical `get` property accessors, and we need to be careful not to abuse property accesors, as consuming an object that abuses of accessors may become very confusing.

```
const counter = new Counter(2)
console.log(counter.next)
// <- 2
console.log(counter.next)
// <- 3
console.log(counter.next)
// <- 4
```

When paired with setters, though, accessors may provide an interesting bridge between an object and its underlying data store. Consider the following example where we define a class that can be used to store and retrieve JSON data from `localStorage` using the provided storage `key`.

```
class LocalStorage {
  constructor (key) {
    this.key = key
  }
  get data () {
    return JSON.parse(localStorage.getItem(this.key))
  }
  set data (data) {
    localStorage.setItem(this.key, JSON.stringify(data))
  }
}
```

Then you could use the `LocalStorage` class as shown in the next example. Any value that's assigned to `ls.data` will be converted to its JSON object string representation and stored in `localStorage`. Then, when the property is read from, the same `key` will be used to retrieve the previously stored contents, parse them as JSON into an object, and returned.

```
const ls = new LocalStorage('groceries')
ls.data = ['apples', 'bananas', 'grapes']
```

```
console.log(ls.data)
// <- ['apples', 'bananas', 'grapes']
```

Besides getters and setters, you can also define regular instance methods, as we've explored earlier when creating the `Fruit` class. The following code example creates a `Person` class that's able to eat `Fruit` instances as we had declared them earlier. We then instantiate a fruit and a person, and have the person eat the fruit. The person ends up with a satiety level equal to `40`, because they ate the whole fruit.

```
class Person {
  constructor () {
    this.satiety = 0
  }
  eat (fruit) {
    while (fruit.pieces > 0) {
      fruit.bite(this)
    }
  }
}
const plum = new Fruit('plum', 40)
const person = new Person()
person.eat(plum)
console.log(person.satiety)
// <- 40
```

Sometimes it's also important to have static methods at the class level, rather than at the instance level. JavaScript classes allow you to define such methods using the `static` keyword, much like you would use `get` or `set` as a prefix to a method definition that's a getter or a setter.

The following example defines a `MathHelper` class with a static `sum` method that's able to calculate the sum of all numbers passed to it in a function call, by taking advantage of the `Array.prototype.reduce` method.

```
class MathHelper {
  static sum (...numbers) {
    return numbers.reduce((a, b) => a + b)
  }
}
console.log(MathHelper.sum(1, 2, 3, 4, 5))
// <- 15
```

Finally, it's worth mentioning that you could also declare static property accessors, such as getters or setters (`static get`, `static set`). These might come in handy when maintaining global configuration state for a class, or when a class is used under a singleton pattern. Of course, you're probably better off using plain old JavaScript objects at that point, rather than creating a class you never intend to instantiate or only intend to instantiate once. This is JavaScript, a highly dynamic language, after all.

3.1.3 Extending JavaScript Classes

You could use plain JavaScript to extend the `Fruit` class, but as you will notice by reading the next code snippet, declaring a sub-class involves esoteric knowledge such as `Parent.call(this)` in order to pass in parameters to the parent class so that we can properly initialize the sub-class, and setting the prototype of the sub-class to an instance of the parent class' prototype. We won't be delving into detailed minutia about these constructs, as you can readily find heaps of information about prototypal inheritance around the web, and our focus in in the newly introduced `class` syntax anyways.

```
function Banana () {
  Fruit.call(this, 'banana', 105)
}
Banana.prototype = Object.create(Fruit.prototype)
Banana.prototype.slice = function () {
  this.pieces = 12
}
```

Given the ephemeral knowledge one has to remember, and the fact that `Object.create` was only made available in ES5, JavaScript developers have historically turned to libraries to resolve their prototype inheritance issues. One such example is `util.inherits` in Node.js, which is usually favored over `Object.create` for legacy support reasons.

```
const util = require('util')
function Banana () {
  Fruit.call(this, 'banana', 105)
}
util.inherits(Banana, Fruit)
Banana.prototype.slice = function () {
  this.pieces = 12
}
```

Consuming the `Banana` constructor is no different than how we used `Fruit`, except that the banana has a `name` and calories already assigned to it, and they come with an extra `slice` method we can use to promptly chop the banana instance into 12 pieces. The following piece of code shows the `Banana` in action as we take a bite.

```
const person = { satiety: 0 }
const banana = new Banana()
banana.slice()
banana.bite(person)
console.log(person.satiety)
// <- 8.75
console.log(banana.pieces)
// <- 11
console.log(banana.calories)
// <- 96.25
```

Classes consolidate prototypal inheritance, which up until recently had been highly contested in user-space by several libraries trying to make it easier to deal with prototypal inheritance in JavaScript.

The `Fruit` class is ripe for inheritance. In the following code snippet we create the `Banana` class as an extension of the `Fruit` class. Here, the syntax clearly signals our intent and we don't have to worry about thoroughly understanding prototypal inheritance in order to get to the results that we want. When we want to forward parameters to the underlying `Fruit` constructor, we can use `super`. The `super` keyword can also be used to call functions in the parent class, such as `super.chop`, and it's not just limited to the constructor for the parent class.

```
class Banana extends Fruit {
  constructor () {
    super('banana', 105)
  }
  slice () {
    this.pieces = 12
  }
}
```

Even though the `class` keyword is static we can still leverage JavaScript's flexible and functional properties when declaring classes. Any expression that returns a constructor function can be fed to `extends`. For example, we could have a constructor function factory and use that as the base class.

The following piece of code has a `createJuicyFruit` function where we forward the name and calories for a fruit to the `Fruit` class using a `super` call, and then all we have to do to create a `Plum` is extend the intermediary `JuicyFruit` class.

```
const createJuicyFruit = (...params) => class JuicyFruit extends Fruit {
  constructor () {
    this.juice = 0
    super(...params)
  }
  squeeze () {
    if (this.calories <= 0) {
      return
    }
    this.calories -= 10
    this.juice += 3
  }
}
class Plum extends createJuicyFruit('plum', 30) {
}
```

Let's move onto `Symbol`. While not iteration or flow control mechanism, learning about `Symbol` is crucial to shaping an understanding of iteration protocols, which are discussed at length later in the chapter.

3.2 Symbols

Symbols are a new primitive type in ES6, and the seventh type in JavaScript. It is an unique value type, like strings and numbers. Unlike strings and numbers, symbols don't have a literal representation such as `text` for strings, or `1` for numbers. The purpose of symbols is primarily to implement protocols. As we'll learn in section 3.3, the iterable protocol uses a symbol to define how objects are iterated.

There are three flavors of symbols, and each flavor is accessed in a different way. These are: local symbols, created with the `Symbol` built-in wrapper object and accessed by storing a reference or via reflection; global symbols, created using another API and shared across code realms; and "well-known" symbols, built into JavaScript and used to define internal language behavior.

We'll explore each of these, looking into possible use cases along the way. Let's begin with local symbols.

3.2.1 Local Symbols

Symbols can be created using the `Symbol` wrapper object. In the following piece of code, we create our `first` symbol.

```
const first = Symbol()
```

While you can use the `new` keyword with `Number` and `String`, the `new` operator throws a `TypeError` when we try it on `Symbol`. This avoids mistakes and confusing behavior like `new Number(3) !== Number(3)`. The following snippet shows the error being thrown.

```
const oops = new Symbol()
// <- TypeError, Symbol is not a constructor
```

For debugging purposes, you can create symbols using a description.

```
const mystery = Symbol('my symbol')
```

Like numbers or strings, symbols are immutable. Unlike other value types, however, symbols are unique. As shown in the next piece of code, descriptions don't affect that uniqueness. Symbols created using the same description are also unique and thus different from each other.

```
console.log(Symbol() === Symbol())
// <- false
console.log(Symbol('my symbol') === Symbol('my symbol'))
// <- false
console.log(Number(3) === Number(3))
// <- true
```

Symbols are of type `symbol`, new in ES6. The following snippet shows how `typeof` returns the new type string for symbols.

```
console.log(typeof Symbol())
// <- 'symbol'
console.log(typeof Symbol('my symbol'))
// <- 'symbol'
```

Symbols can be used as property keys on objects. Note how you can use a computed property name to avoid an extra statement just to add a `weapon` symbol key to the `character` object, as shown in the following example. Note also that, in order to access a symbol property, you'll need a reference to the symbol that was used to create said property.

```
const weapon = Symbol('weapon')
const character = {
  name: 'Penguin',
  [weapon]: 'umbrella'
}
console.log(character[weapon])
// <- 'umbrella'
```

Keep in mind that symbol keys are hidden from many of the traditional ways of pulling keys from an object. The next bit of code shows how `for..in`, `Object.keys`, and `Object.getOwnPropertyNames` fail to report on symbol properties.

```
for (key in character) {
  console.log(key)
  // <- 'name'
}
console.log(Object.keys(character))
// <- ['name']
console.log(Object.getOwnPropertyNames(character))
// <- ['name']
```

This aspect of symbols means that code that was written before ES6 and without symbols in mind won't unexpectedly start stumbling upon symbols. In a similar fashion, as shown next, symbol properties are discarded when representing an object as JSON.

```
console.log(JSON.stringify(character))
// <- '{"name":"Penguin"}'
```

That being said, symbols are by no means a safe mechanism to conceal properties. Even though you won't stumble upon symbol properties when using reflection or serialization methods, symbols are revealed by a dedicated method as shown in the next snippet of code. In other words, symbols are not non-enumerable, but hidden in plain sight. Note that `Object.getOwnPropertySymbols`

```
console.log(Object.getOwnPropertySymbols(character))
// <- [Symbol(weapon)]
```

Now that we've established how symbols work. What can we use them for?

3.2.2 Practical use cases for Symbols

Symbols could be used by a library to map objects to DOM elements. For example, a library that needs to associate the API object for a calendar to the provided DOM element. Before ES6, there wasn't a clear way of mapping DOM elements to objects. You could add a property to a DOM element pointing to the API, but polluting DOM elements with custom properties is a bad practice. You have to be careful to use property keys that won't be used by other libraries, or worse, by the language itself in the future. That leaves you with using an array lookup table containing an entry for each DOM/API pair. That, however, might be slow in long-running applications where the array lookup table might grow in size, slowing down the lookup operation over time.

Symbols, on the other hand, don't have these problem. They can be used as properties that don't have a risk of clashing with future language features, as they're unique. The following code snippet shows how a symbol could be used to map DOM elements into calendar API objects.

```
const cache = Symbol('calendar')
function createCalendar (el) {
  if (cache in el) { // check if the symbol exists in the element
    return el[cache]; // use the cache to avoid re-instantiation
  }
  const api = el[cache] = {
    // the calendar API goes here
  }
  return api
}
```

A `WeakMap` is an ES6 built-in that can be used to efficiently map objects to other objects without using regular properties, symbol properties, or arrays. In contrast with array lookup tables, `WeakMap` is O(1), just like using symbol properties. The `WeakMap` couldn't be accessed from outside the library unless explicitly exposed, unlike with symbols which can be accessed through `Object.getOwnPropertySymbols`. We'll explore `WeakMap` in chapter 5, alongside other ES6 collection built-ins.

Defining Protocols through Symbols

Earlier, we posited that a use case for symbols is to define protocols. A protocol is a communication contract or convention that defines behavior. In less abstract terms, a library could use a symbol that could then be used by objects that adhere to a convention from the library.

Consider the following bit of code, where we use the special `toJSON` method to determine the object serialized by `JSON.stringify`. As you can see, stringifying the `character` object produces a serialized version of the object returned by `toJSON`.

```
const character = {
  name: 'Thor',
```

```
  toJSON: () => ({
    key: 'value'
  })
}
console.log(JSON.stringify(character))
// <- '"{"key":"value"}"'
```

In contrast, if `toJSON` was anything other than a function, the original `character` object would be serialized, including the `toJSON` property, as shown next. This sort of inconsistency ensues from relying on regular properties to define behavior.

```
const character = {
  name: 'Thor',
  toJSON: true
}
console.log(JSON.stringify(character))
// <- '"{"name":"Thor","toJSON":true}"'
```

The reason why it would be better to implement the `toJSON` modifier as a symbol is that that way it wouldn't interfere with other object keys. Given that symbols are unique, never serialized, and never exposed unless explicitly requested through `Object.getOwnPropertySymbols`, they would represent a better choice when defining a contract between `JSON.stringify` and how objects want to be serialized. Consider the following piece of code with an alternative implementation of `toJSON` using a symbol to define serialization behavior for a `stringify` function.

```
const json = Symbol('alternative to toJSON')
const character = {
  name: 'Thor',
  [json]: () => ({
    key: 'value'
  })
}
stringify(character)
function stringify (target) {
  if (json in target) {
    return JSON.stringify(target[json]())
  }
  return JSON.stringify(target)
}
```

Using a symbol means we need to use a computed property name to define the `json` behavior directly on an object literal. It also means that the behavior won't clash with other user-defined properties or upcoming language features we couldn't foresee. Another difference is that the `json` symbol should be available to consumers of the `stringify` function, so that they can define their own behavior. We could easily add the following line of code to expose the `json` symbol directly through `stringify`, as shown below. That'd also tie the `stringify` function with the symbol that modifies its behavior.

```
stringify.as = json
```

By exposing the `stringify` function we'd be exposing the `stringify.as` symbol as well, allowing consumers to tweak behavior by minimally modifying objects, using the custom symbol.

When it comes to the merits of using a symbol to describe behavior, as opposed to an option passed as to the `stringify` function, there's a few considerations to keep in mind. First, adding option parameters to a function changes its public API, whereas changing the internal implementation of the function to support another symbol wouldn't affect the public API. Using an `options` object with different properties for each option mitigates this effect, but it's not always convenient to require an `options` object in every function call.

A benefit of defining behavior via symbols is that you could augment and customize the behavior of objects without changing anything other than the value assigned to a symbol property and perhaps the internal implementation of the piece of code that leverages that behavior. The benefit of using symbols over properties is that you're not subject to name clashes when new language features are introduced.

Besides local symbols, there's also a global symbol registry, accessible from across code realms. Let's look into what that means.

3.2.3 Global Symbol Registry

A code realm is any JavaScript execution context, such as the page your application is running in, an `<iframe>` within that page, an script running through `eval`, or a worker of any kind — such as web workers, service workers, or shared workers. Each of these execution contexts has its own global object. Global variables defined on the `window` object of a page, for example, aren't available to a `ServiceWorker`. In contrast, the global symbol registry is shared across all code realms.

There's two methods that interact with the runtime-wide global symbol registry: `Symbol.for` and `Symbol.keyFor`. What do they do?

Getting symbols with `Symbol.for(key)`

The `Symbol.for(key)` method looks up `key` in the runtime-wide symbol registry. If a symbol with the provided `key` exists in the global registry, that symbol is returned. If no symbol with that `key` is found in the registry, one is created and added to the registry under the provided `key`. That's to say, `Symbol.for(key)` is idempotent: it looks for a symbol under a `key`, creates one if it didn't already exist, and then returns the symbol.

In the following code snippet, the first call to `Symbol.for` creates a symbol identified as *`example`*, adds it to the registry, and returns it. The second call returns that same symbol because the key is already in the registry — and associated to the symbol returned by the first call.

```
const example = Symbol.for('example')
console.log(example === Symbol.for('example'))
// <- true
```

That contrasts with what we knew about symbols being unique. The global symbol registry keeps track of symbols by their key. Note that the key will also be used as a description when the symbols that go into the registry are created. Considering these symbols are global on a runtime-wide level, you might want to prefix symbol keys in the global registry with a value that identifies your library or component, mitigating potential name clashes.

Using Symbol.keyFor(symbol) to retrieve symbol keys

Given a symbol symbol, Symbol.keyFor(symbol) returns the key that was associated with symbol when the symbol was added to the global registry. The next example shows how we can grab a the key for a symbol using Symbol.keyFor.

```
const example = Symbol.for('example')
console.log(Symbol.keyFor(example))
// <- 'example'
```

Note that if the symbol isn't in the global runtime registry, then the method returns undefined.

```
console.log(Symbol.keyFor(Symbol()))
// <- undefined
```

Also keep in mind that it's not possible to match symbols in the global registry usign local symbols, even when they share the same description. The reason for that is that local symbols aren't part of the global registry, as shown in the following piece of code.

```
const example = Symbol.for('example')
console.log(Symbol.keyFor(Symbol('example')))
// <- undefined
```

Now that you've learned about the API for interacting with the global symbol registry, let's take some considerations into account.

Best Practices and Considerations

A runtime-wide registry means the symbols are accessible across code realms. The global registry returns a reference to the same object in any realm the code runs in. In the following example, we demonstrate how the Symbol.for API returns the same symbol in a page and within an <iframe>.

```
const d = document
const frame = d.body.appendChild(d.createElement('iframe'))
const framed = frame.contentWindow
const s1 = window.Symbol.for('example')
const s2 = framed.Symbol.for('example')
console.log(s1 === s2)
// <- true
```

There's tradeoffs in using widely available symbols. On the one hand, they make it easy for libraries to expose their own symbols, but on the other hand they could also expose their symbols on their own API, using local symbols. The symbol registry is obviously useful when symbols need to be shared across any two code realms, for example: `ServiceWorker` and a web page. The API is also convenient when you don't want to bother storing references to the symbols, you could use the registry directly for that, since every call with a given `key` is guaranteed to return the same `symbol`. You'll have to keep in mind, though, that these symbols are shared across the runtime and that might lead to unwanted consequences if you use generic symbol names like `each` or `contains`.

There's one more kind of symbols, the built-in well-known symbols.

3.2.4 Well-known Symbols

So far we've covered symbols you can create using the `Symbol` function and those you can create through `Symbol.for`. The third and last kind of symbols we're going to cover is the well-known symbols. These are built into the language instead of created by the user, and they provide hooks into internal language behavior allowing you to extend or customize aspects of the language that weren't accessible prior to ES6.

A great example of how symbols can add extensibility to the language without breaking existing code is the `Symbol.toPrimitive` well-known symbol. It can be assigned a function to determine how an object is casted into a primitive value. The function receives a `hint` parameter that can be *`string`*, *`number`*, or *`default`*, indicating what type of primitive value is expected.

```
const morphling = {
  [Symbol.toPrimitive](hint) {
    if (hint === 'number') {
      return Infinity
    }
    if (hint === 'string') {
      return 'a lot'
    }
    return '[object Morphling]'
  }
}
console.log(+morphling)
// <- Infinity
```

```
console.log(`That is ${ morphling }!`)
// <- 'That is a lot!'
console.log(morphling + ' is powerful')
// <- '[object Morphling] is powerful'
```

Another example of a well-known symbol is `Symbol.match`. A regular expression that sets `Symbol.match` to `false` will be treated as a string literal when passed to `.startsWith`, `.endsWith`, or `.includes`. These three functions are new string methods in ES6. First we have `.startsWith`, which can be used to determine if the string starts with another string. Then there's `.endsWith`, that finds out whether the string ends in another one. Lastly, the `.includes` method returns `true` if a string contains another one. The next snippet of code shows how `Symbol.match` can be used to compare a string with the string representation of a regular expression.

```
const text = '/an example string/'
const regex = /an example string/
regex[Symbol.match] = false
console.log(text.startsWith(regex))
// <- true
```

If the regular expression wasn't modified through the symbol, it would've thrown because the `.startsWith` method expects a string instead of a regular expression.

Shared across realms but not in the registry

Well-known symbols are shared across realms. The following example shows how `Symbol.iterator` is the same reference as that within the context of an `<iframe>` window.

```
const frame = document.createElement('iframe')
document.body.appendChild(frame)
console.log(Symbol.iterator === frame.contentWindow.Symbol.iterator)
// <- true
```

Note that even though well-known symbols are shared across code realms, they're not in the global registry. The following bit of code shows that `Symbol.iterator` produces `undefined` when we ask for its `key` in the registry. That means the symbol isn't listed in the global registry.

```
console.log(Symbol.keyFor(Symbol.iterator))
// <- undefined
```

One of the most useful well-known symbols is `Symbol.iterator`, used by a few different language constructs to iterate over a sequence, as defined by a function assigned to a property using that symbol on any object. In the next chapter we'll go over `Symbol.iterator` in detail, using it extensively along with the iterator and iterable protocols.

3.3 Object Built-in Improvements

While we've already addressed syntax enhancements coming to object literals in chapter 2, there's a few new static methods available to the `Object` built-in which we haven't addressed yet. It's time to take a look at what these methods bring to the table.

We've already looked at `Object.getOwnPropertySymbols`, but let's also take a look at `Object.assign`, `Object.is`, and `Object.setPrototypeOf`.

3.3.1 Extending objects with `Object.assign`

The need to provide default values for a configuration object is not at all uncommon. Typically, libraries and well-designed component interfaces come with sensible defaults that cater to the most frequented use cases.

A Markdown library, for example, might convert Markdown into HTML by providing only an `input` parameter. That's its most common use case, simply parsing Markdown, and so the library doesn't demand that the consumer provides any options. The library might, however, support many different options that could be used to tweak its parsing behavior. It could have an option to allow `<script>` or `<iframe>` tags, or an option to highlight keywords in code snippets using CSS.

Imagine, for example, that you want to provide a set of defaults like the one shown next.

```
const defaults = {
  scripts: false,
  iframes: false,
  highlightSyntax: true
}
```

One possibility would be to use the `defaults` object as the default value for the `options` parameter, using destructuring. In this case, the user must provide values for every option whenever they decide to provide any options at all.

```
function md (input, options=defaults) {
}
```

The default values have to be merged with user-provided configuration, somehow. That's where `Object.assign` comes in, as shown in the following example. Here, we start with an empty `{}` object, copy our default values over to it, and then copy the options on top. The resulting `config` object will have all of the default values plus the user-provided configuration.

```
function md (input, options) {
  const config = Object.assign({}, defaults, options)
}
```

For any properties that had a default value where the user also provided a value, the user-provided value will prevail. Here's how `Object.assign` works. First, it takes the first argument passed to it, let's call it `target`. It then iterates over all keys of each of the other arguments, let's call them `sources`. For each source in `sources`, all of its properties are iterated and assigned to `target`. The end result is that right-most sources — in our case, the `options` object — overwrite any previously assigned values, as shown in the following bit of code.

```
const defaults = {
  first: 'first',
  second: 'second'
}
function print (options) {
  console.log(Object.assign({}, defaults, options))
}
print()
// <- { first: 'first', second: 'second' }
print({ third: 3 })
// <- { first: 'first', second: 'second', third: 3 }
print({ second: false })
// <- { first: 'first', second: false }
```

Before `Object.assign` made its way into the language, there were numerous similar implementations of this technique in user-land JavaScript, with names like assign, or extend. Adding `Object.assign` to the language consolidates these options into a single method.

Note, however, that `Object.assign` doesn't cater to every need. While most user-land implementations have the ability to perform deep assignment, `Object.assign` doesn't offer a recursive treatment of objects. Object values are assigned as properties on `target` directly, instead of being recursively assigned key by key.

In the following bit of code you might expect the `f` property to be added to `target.a` while keeping `b.c` and `b.d` intact, but the `b.c` and `b.d` properties are lost when using `Object.assign`.

```
Object.assign({}, { a: { b: 'c', d: 'e' } }, { a: { f: 'g' } })
// <- { a: { f: 'g' } }
```

In the same vein, arrays don't get any special treatment either. If you expected recursive behavior in `Object.assign` the following snippet of code may also come as a surprise, where you may have expected the resulting object to have *d* in the third position of the array.

```
Object.assign({}, { a: ['b', 'c', 'd'] }, { a: ['e', 'f'] })
// <- { a: ['e', 'f'] }
```

At the time of this writing, there's an ECMAScript stage 3 proposal to implement spread in objects, similar to how you can spread iterable objects onto an array in ES6.

Spreading an object onto another is equivalent to using an `Object.assign` function call.

The following piece of code shows a few cases where we're spreading the properties of an object onto another one, and the `Object.assign` counterpart. As you can see, using object spread is more succint and should be preferred where possible.

```
const grocery = { ...details }
// Object.assign({}, details)
const grocery = { type: 'fruit', ...details }
// Object.assign({ type: 'fruit' }, details)
const grocery = { type: 'fruit', ...details, ...fruit }
// Object.assign({ type: 'fruit' }, details, fruit)
const grocery = { type: 'fruit', ...details, color: 'red' }
// Object.assign({ type: 'fruit' }, details, { color: 'red' })
```

As a counterpart to object spread, the proposal includes object rest properties, which is similar to the array rest pattern. We can use object rest whenever we're destructuring an object.

The following example shows how we could leverage object rest to get an object containing only properties that we haven't explicitly named in the parameter list. Note that the object rest property must be in the last position of destructuring, just like the array rest pattern.

```
const getUnknownProperties = ({ name, type, ...unknown }) => unknown
getUnknownProperties({
  name: 'Carrot',
  type: 'vegetable',
  color: 'orange'
})
// <- { color: 'orange' }
```

We could take a similar approach when destructuring an object in a variable declaration statement. In the next example, every property that's not explicitly destructured is placed in a `meta` object.

```
const { name, type, ...meta } = {
  name: 'Carrot',
  type: 'vegetable',
  color: 'orange'
}
// <- name = 'Carrot'
// <- type = 'vegetable'
// <- meta = { color: 'orange' }
```

We dive deeper into object rest and spread in chapter 9.

3.3.2 Comparing objects with `Object.is`

The `Object.is` method is a slightly different version of the strict equality comparison operator, `===`. For the most part, `Object.is(a, b)` is equal to `a === b`. There are two differences: the case of `NaN` and the case of `-0` and `+0`.

When `NaN` is compared to `NaN`, the strict equality comparison operator returns `false` because `NaN` is not equal to itself. The `Object.is` method, however, returns `true` in this special case.

```
NaN === NaN
// <- false
Object.is(NaN, NaN)
// <- true
```

Similarly, when `-0` is compared to `+0`, the `===` operator produces `true` while `Object.is` returns `false`.

```
-0 === +0
// <- true
Object.is(-0, +0)
// <- false
```

These differences may not seem like much, but dealing with `NaN` has always been cumbersome because of its special quirks, such as `typeof NaN` being *`number`* and it not being equal to itself.

3.3.3 `Object.setPrototypeOf`

The `Object.setPrototypeOf` method does exactly what its name conveys: it sets the prototype of an object to a reference to another object. It's considered the proper way of setting the prototype, as opposed to using *`proto`* which is a legacy feature.

Before ES6, we were introduced to `Object.create` in ES5. Using that method, we could create an object based on any prototype passed into `Object.create`, as shown next.

```
const baseCat = { type: 'cat', legs: 4 }
const cat = Object.create(baseCat)
cat.name = 'Milanesita'
```

The `Object.create` method is, however, limited to newly created objects. In contrast, we could use `Object.setPrototypeOf` to change the prototype of an object that already exists, as shown in the following code snippet.

```
const baseCat = { type: 'cat', legs: 4 }
const cat = Object.setPrototypeOf({ name: 'Milanesita' }, baseCat)
```

Note however that there are serious performance implications when using `Obect.setPrototypeOf` as opposed to `Object.create`, and some careful consideration is in order before you decide to go ahead and sprinkle `Object.setPrototypeOf` all over a codebase.

> **Performance issues**
>
> Using `Object.setPrototypeOf` to change the prototype of an object is an expensive operation. Here is what the Mozilla Developer Network documentation has to say about the matter.
>
> > Changing the prototype of an object is, by the nature of how modern JavaScript engines optimize property accesses, a very slow operation, in every browser and JavaScript engine. The effects on performance of altering inheritance are subtle and far-flung, and are not limited to simply the time spent in a obj.*proto* = … statement, but may extend to any code that has access to any object whose prototype has been altered. If you care about performance you should avoid setting the prototype of an object. Instead, create a new object with the desired prototype using `Object.create()`.
> >
> > —Mozilla Developer Network

In the following chapter we'll look at more features coming in ES6 and how they can be used to iterate over any JavaScript objects, as well as how to master flow control using promises and generators.

CHAPTER 4

Iteration and Flow Control

Having covered the essential aspects of ES6 in chapter 2, and symbols in chapter 3, we're now in great shape to understand promises, iterators, and generators. Promises offer a different way of attacking asynchronous code flows. Iterators dictate how an object is iterated, producing the sequence of values that gets iterated over. Generators can be used to write code that looks sequential but works asynchronously, in the background, as we'll learn towards the end of the chapter.

To kick off the chapter, we'll start by discussing promises. Promises have existed in user-land for a long time, but they're a native part of the language starting in ES6.

4.1 Promises

Promises can be vaguely defined as "a proxy for a value that will eventually become available". They can be used for both synchronous and asynchronous code flows, although they make asynchronous flows easier to reason about — once you've mastered promises, that is.

4.1.1 Getting Started with Promises

As an example, let's take a look at the upcoming browser `fetch` API. This API is a simplification of `XMLHttpRequest`. It aims to be super simple to use for the most basic use cases: making a `GET` request against an HTTP resource. It also provides a comprehensive API that caters to advanced use cases as well, but that's not our focus for now. In its most basic incarnation, you can make a `GET /items` request using a piece of code like the following.

```
fetch('/items')
```

The `fetch(/items)` statement doesn't seem all that exciting. It makes a "fire and forget" `GET` request against `/items`, meaning you ignore the response and whether the request succeeded. The `fetch` method returns a `Promise`. You can chain a callback using the `.then` method on that promise, and that callback will be executed once the `/items` resource finishes loading, receiving a `response` object parameter.

```
fetch('/items').then(response => {
  // do something
})
```

An alternative to callbacks and events

Traditionally JavaScript relied on callbacks instead of promises and chaining. If the `fetch` function asked for a callback, you'd have to add one that would then get executed whenever the fetch operation ends. Typical asynchronous code flow conventions in Node.js established a best practice of reserving the first parameter in the callback for errors — that may or may not occur — during the fetching process. The rest of the parameters can be used to read the results of the asynchronous operation. Most commonly, a single data parameter is used. The next bit of code shows how `fetch` would look like if it had a callback-based API.

```
fetch('/items', (err, res) => {
  if (err) {
    // handle error
  } else {
    // handle response
  }
})
```

The callback wouldn't be invoked until the `/items` resource has been retrieved, or an error arises from the `fetch` operation. Execution remains asynchronous and non-blocking. Note that in this model you could only specify a single callback. That callback would be responsible for all functionality derived from the response, and it'd be up to the consumer to come up with a mechanism to compose different aspects of handling the response into that single callback.

Besides traditional callbacks, another API design choice might have been to use an event-driven model. In this case the object returned by `fetch` would be able to register callbacks for different kinds of events, binding as many event handlers as needed for any events — just like when you attach event listeners to the browser DOM. Typically there's an `error` event that's raised when things go awry, and other events that are raised when something notable happens. In the following piece of code, we show how `fetch` would look like if it had an event-based API.

```
fetch('/items')
  .on('error', err => {
    // handle error
  })
```

```
    .on('data', res => {
      // handle response
    })
```

Binding several listeners for each type of event would eliminate the concern we had earlier about having to centralize response handling in a single callback. Events however make it hard to chain callbacks and have them fire when another asynchronous task is fulfilled, and that's where promises come in.

The following bit of code displays the promise-based API with which `fetch` is actually implemented in browsers. Calls to `fetch` return a `Promise` object. Much like with events, you can bind as many reactions as you'd like, using the `.then` and `.catch` methods.

```
const p = fetch('/items')
p.then(res => {
  // handle response
})
p.catch(error => {
  // handle error
})
```

Reactions passed to `.then` can be used to handle the fulfillment of a promise, which is accompanied by a fulfillment value; and reactions passed to `.catch` are executed with a rejection `reason` that can be used when handling rejections. You can also register a reaction to rejections in the second argument passed to `.then`. The previous piece of code could also be expressed as the following.

```
const p = fetch('/items')
p.then(
  res => {
    // handle response
  },
  err => {
    // handle error
  }
)
```

Another alternative is to omit the fulfillment reaction in `.then(fulfillment, rejection)`, this being similar to the omission of a rejection reaction when calling `.then`. Using `.then(null, rejection)` is equivalent to `.catch(rejection)`, as shown in the following snippet of code.

```
const p = fetch('/items')
p.then(res => {
  // handle response
})
p.then(null, error => {
```

```
  // handle error
})
```

When it comes to promises, chaining is a major source of confusion. In an event-based API, chaining is made possible by having the `.on` method attach the event listener and then returning the event emitter itself. Promises are different. The `.then` and `.catch` methods return a new promise every time. That's important because chaining can have wildly different results depending on where you append a `.then` or a `.catch` call onto.

A major source of confusion

The `.then` and `.catch` methods return a new promise every time, creating a tree-like data structure. If you had a `p1` promise and a `p2` promise returned by `p1.then`, the `p1` and `p2` promises would be nodes connected by the `p1.then` reaction handler. Reactions create new promises that are attached to the tree as children of the promise they're reacting to.

A promise is created by passing the `Promise` constructor a resolver that decides how and when the promise is settled, by calling either a `resolve` method that will settle the promise in fulfillment or a `reject` method that'd settle the promise as a rejection. Until the promise is settled by calling either function, it'll be in pending state and any reactions attached to it won't be executed. The following snippet of code creates a promise from scratch where we'll wait for a second before randomly settling the promise with a fulfillment or rejection result.

```
new Promise(function (resolve, reject) {
  setTimeout(function () {
    if (Math.random() > 0.5) {
      resolve('random success')
    } else {
      reject(new Error('random failure'))
    }
  }, 1000)
})
```

Promises can also be created using `Promise.resolve` and `Promise.reject`, these methods create promises that will immediately settle with a fulfillment value and a rejection reason respectively.

```
Promise
  .resolve({ result: 123 })
  .then(data => console.log(data.result))
// <- 123
```

When a `p` promise is fulfilled, reactions registered with `p.then` are executed. When a `p` promise is rejected, reactions registered with `p.catch` are executed. Those reactions can, in turn, result in three different situations depending on whether they return a value, `throw` an error, or return a `Promise` or thenable. Thenables are objects considered promise-like that can be casted into a `Promise` using `Promise.resolve` as observed in section 4.1.3.

A reaction may return a value, which would cause the promise returned by `.then` to become fulfilled with that value. In this sense, promises can be chained to transform the fulfillment value of the previous promise over and over, as shown in the following snippet of code.

```
Promise
  .resolve(2)
  .then(x => x * 7)
  .then(x => x - 3)
  .then(x => console.log(x))
// <- 11
```

A reaction may return a promise. In contrast with the previous piece of code, the promise returned by the first `.then` call in the following snippet will be blocked until the one returned by its reaction is fulfilled, which will take two seconds to settle because of the `setTimeout` call.

```
Promise
  .resolve(2)
  .then(x => new Promise(function (resolve) {
    setTimeout(() => resolve(x * 1000), x * 1000)
  }))
  .then(x => console.log(x))
// <- 2000
```

A reaction may also `throw` an error, which would cause the promise returned by `.then` to become rejected and thus follow the `.catch` branch, using said error as the rejection reason. The following example shows how we attach a fulfillment reaction to the `fetch` operation. Once the `fetch` is fulfilled the reaction will throw an error and cause the rejection reaction attached to the promise returned by `.then` to be executed.

```
const p = fetch('/items')
  .then(res => { throw new Error('unexpectedly'); })
  .catch(error => console.error(error))
```

Let's take a step back and pace ourselves, walking over more examples in each particular use case.

4.1.2 Promise Continuation and Chaining

In the previous section we've established that you can chain any number of `.then` calls, each returning its own new promise, but how exactly does this work? What is a good mental model of promises, and what happens when an error is raised?

When an error happens in a promise resolver, you can catch that error using `p.catch` as shown next.

```
new Promise((resolve, reject) => reject(new Error('oops')))
  .catch(err => console.error(err))
```

A promise will settle as a rejection when the resolver calls `reject`, but also if an exception is thrown inside the resolver as well, as demonstrated by the next snippet.

```
new Promise((resolve, reject) => { throw new Error('oops'); })
  .catch(err => console.error(err))
```

Errors that occur while executing a fulfillment or rejection reaction behave in the same way: they result in a promise being rejected, the one returned by the `.then` or `.catch` call that was passed the reaction where the error originated. It's easier to explain this with code, such as the following piece.

```
Promise
  .resolve(2)
  .then(x => { throw new Error('failed'); })
  .catch(err => console.error(err))
```

It might be easier to decompose that series of chained method calls into variables, as shown next. The following piece of code might help you visualize the fact that, if you attached the `.catch` reaction to `p1`, you wouldn't be able to catch the error originated in the `.then` reaction. While `p1` is fulfilled, `p2` — a different promise than `p1`, resulting from calling `p1.then` — is rejected due to the error being thrown. That error could be caught, instead, if we attached the rejection reaction to `p2`.

```
const p1 = Promise.resolve(2)
const p2 = p1.then(x => { throw new Error('failed'); })
const p3 = p2.catch(err => console.error(err))
```

Here is another situation where it might help you to think of promises as a tree-like data structure. In the following illustration it becomes obvious that, given the error originates in the `p2` node, we couldn't notice it by attaching a rejection reaction to `p1`.

We've established that the promise you attach your reactions onto is important, as it determines what errors it can capture and what errors it can not. It's also worth noting that as long as an error remains uncaught in a promise chain, a rejection handler will be able to capture it. In the following example we've introduced an intermediary `.then` call in between `p2`, where the error originated; and `p4`, where we attach the rejection reaction. When `p2` settles with a rejection, `p3` becomes settled with a rejection as it depends on `p2` directly. When `p3` settles with a rejection, the rejection handler in `p4` fires.

```
const p1 = Promise.resolve(2)
const p2 = p1.then(x => { throw new Error('failed'); })
const p3 = p2.then(x => x * 2)
const p4 = p3.catch(err => console.error(err))
```

Typically, promises like `p4` fulfill because the rejection handler in `.catch` doesn't raise any errors. That means a fulfillment handler attached with `p4.then` would be executed afterwards. The following example shows how you could print a statement to the browser console by creating a `p4` fulfillment handler that depends on `p3` to settle successfully with fulfillment.

```
const p1 = Promise.resolve(2)
const p2 = p1.then(x => { throw new Error('failed'); })
const p3 = p2.catch(err => console.error(err))
const p4 = p3.then(() => console.log('crisis averted'))
```

Similarly, if an error occurred in the `p3` rejection handler, we could capture that one as well using `.catch`. The next piece of code shows how an exception being thrown in `p3` could be captured using `p3.catch` just like with any other errors arising in previous examples.

```
const p1 = Promise.resolve(2)
const p2 = p1.then(x => { throw new Error('failed'); })
const p3 = p2.catch(err => { throw new Error('oops', err); })
const p4 = p3.catch(err => console.error(err))
```

The following example prints `err.message` once instead of twice. That's because no errors happened in the first `.catch`, so the rejection branch for that promise wasn't executed.

```
fetch('/items')
  .then(res => res.a.prop.that.does.not.exist)
  .catch(err => console.error(err.message))
  .catch(err => console.error(err.message))
// <- 'Cannot read property "prop" of undefined'
```

In contrast, the next snippet will print `err.message` twice. It works by saving a reference to the promise returned by `.then`, and then tacking two `.catch` reactions onto it. The second `.catch` in the previous example was capturing errors produced in the promise returned from the first `.catch`, while in this case both rejection handlers branch off of `p`.

```
const p = fetch('/items').then(res => res.a.prop.that.does.not.exist)
p.catch(err => console.error(err.message))
p.catch(err => console.error(err.message))
// <- 'Cannot read property "prop" of undefined'
// <- 'Cannot read property "prop" of undefined'
```

We should observe, then, that promises can be chained arbitrarily. As we just saw, you can save a reference to any point in the promise chain and then append more promises on top of it. This is one of the fundamental points to understanding promises.

Let's use the following snippet as a crutch to enumerate the sequence of events that arise from creating and chaining a few promises. Take a moment to inspect the following bit of code.

```
const p1 = fetch('/items')
const p2 = p1.then(res => res.a.prop.that.does.not.exist)
const p3 = p2.catch(err => {})
const p4 = p3.catch(err => console.error(err.message))
```

Here is an enumeration of what is going on as that piece of code is executed.

1. `fetch` returns a brand new `p1` promise
2. `p1.then` returns a brand new `p2` promise, which will react if `p1` is fulfilled
3. `p2.catch` returns a brand new `p3` promise, which will react if `p2` is rejected
4. `p3.catch` returns a brand new `p4` promise, which will react if `p3` is rejected
5. When `p1` is fulfilled, the `p1.then` reaction is executed
6. Afterwards, `p2` is rejected because of an error in the `p1.then` reaction
7. Since `p2` was rejected, `p2.catch` reactions are executed, and the `p2.then` branch is ignored
8. The `p3` promise from `p2.catch` is fulfilled, because it doesn't produce an error or result in a rejected promise
9. Because `p3` was fulfilled, the `p3.catch` is never followed. The `p3.then` branch would've been used instead

You should think of promises as a tree structure. This bears repetition: you should think of promises as a tree structure. It all starts with a single promise, which we'll next learn how to construct. Then you add branches with `.then` or `.catch`. You can tack as many `.then` or `.catch` calls as you want onto each branch, creating new branches, and so on.

4.1.3 Creating a Promise From Scratch

We already know that promises can be created using a function such as `fetch`, `Promise.resolve`, `Promise.reject`, or the `Promise` constructor function. We've already used `fetch` extensively to create promises in previous examples. Let's take a more nuanced look at the other three ways we can create a promise.

Promises can be created from scratch by using `new Promise(resolver)`. The `resolver` parameter is a function that will be used to settle the promise. The `resolver` takes two arguments, a `resolve` function and a `reject` function.

The pair of promises shown in the next snippet are settled in fulfillment and rejection, respectively. Here we're settling the first promise with a fulfillment value of *`result`*, and rejecting the second promise with an `Error` object, specifying *`reason`* as its message.

```
new Promise(resolve => resolve('result'))
new Promise((resolve, reject) => reject(new Error('reason')))
```

Resolving and rejecting promises without a value is possible, but not that useful. Usually promises will fulfill with a `result` such as the response from an AJAX call as we've seen with `fetch`. You'll definitely want to state the `reason` for your rejections — typically wrapping them in an `Error` object so that you can report back a stack trace.

As you may have guessed, there's nothing inherently synchronous about promises. Settlement can be completely asynchronous for fulfillment and rejection alike. That's the whole point of promises! The following example creates a promise that becomes fulfilled after two seconds elapse.

```
new Promise(resolve => setTimeout(resolve, 2000))
```

Note that only the first call made to one of these functions will have an impact — once a promise is settled its outcome can't change. The following code snippet creates a promise that's fulfilled after the provided `delay` or rejected after a three second timeout. We're taking advantage of the fact that calling either of these functions after a promise has been settled have no effect, in order to create a race condition where the first call to be made will be the one that sticks.

```
function resolveUnderThreeSeconds (delay) {
  return new Promise(function (resolve, reject) {
    setTimeout(resolve, delay)
    setTimeout(reject, 3000)
  })
}
resolveUnderThreeSeconds(2000); // becomes fulfilled after 2s
resolveUnderThreeSeconds(7000); // becomes rejected after 3s
```

When creating a new promise `p1`, you could call `resolve` with another promise `p2` — besides calling `resolve` with non-promise values. In those cases, `p1` will be resolved but blocked on the outcome of `p2`. Once `p2` settles, `p1` will be settled with its value and outcome. The following bit of code is, thus, effectively the same as simply doing `fetch(/items)`.

```
new Promise(resolve => resolve(fetch('/items')))
```

Note that you this behavior is only possible when using `resolve`. If you try to replicate the same behavior with `reject` you'll find that the `p1` promise is rejected with the `p2` promise as the rejection `reason`. While `resolve` may result in a promise being fulfilled or rejected, `reject` always results in the promise being rejected. If you `resolve` to a rejected promise or a promise that's eventually rejected, then your promise will be rejected as well. The opposite isn't true for rejections. If you `reject` in a resolver, the promise will be rejected no matter what value is passed into `reject`.

In some cases you'll know beforehand about a value you want to settle a promise with. In these cases you could create a promise from scratch, as shown next. This can be convenient when you want to set off the benefits of promise chaining, but don't otherwise have a clear initiator which returns a `Promise` — such as a call to `fetch`.

```
new Promise(resolve => resolve(12))
```

That could prove to be too verbose when you don't need anything other than a pre-settled promise. You could use `Promise.resolve` instead, as a shortcut. The following statement is equivalent to the previous one. The differences between this statement and the previous one are purely semantics: you avoid declaring a `resolver` function and the syntax is more friendly to promise continuation and chaining when it comes to readability.

```
Promise.resolve(12)
```

Like in the `resolve(fetch)` case we saw earlier, you could use `Promise.resolve` as a way of wrapping another promise or casting a thenable into a proper promise. The following piece of code shows how you could use `Promise.resolve` to cast a thenable into a proper promise and then consume it as if it were any other promise.

```
Promise
  .resolve({ then: resolve => resolve(12) })
  .then(x => console.log(x))
// <- 12
```

When you already know the rejection reason for a promise, you can use `Promise.reject`. The following piece of code creates a promise that's going to settle into a rejection along with the specified `reason`. You can use `Promise.reject` within a reaction as a dynamic alternative to `throw` statements. Another use for `Promise.reject` is as an implicit return value for an arrow function, something that can't be done with a `throw` statements.

```
Promise.reject(reason)
fetch('/items').then(() => Promise.reject(new Error('arbitrarily')))
fetch('/items').then(() => { throw new Error('arbitrarily')})
```

Presumably, you won't be calling `new Promise` directly very often. The promise constructor is often invoked internally by libraries that support promises or native functions like `fetch`. Given that `.then` and `.catch` provide tree structures that unfold beyond the original promise, a single call to `new Promise` in the entry point to an API is often sufficient. Regardless, understanding promise creation is essential when leveraging promise-based control flows.

4.1.4 Promise States and Fates

Promises can be in three distinct states: pending, fulfilled, and rejected. Pending is the default state. A promise can then transition into either fulfillment or rejection.

A promise can be resolved or rejected exactly once. Attempting to resolve or reject a promise for a second time won't have any effect.

When a promise is resolved with a non-promise, non-thenable value, it settles in fulfillment. When a promise is rejected, it's also considered to be settled.

A promise `p1` that's resolved to another promise or thenable `p2` stays in the pending state, but is nevertheless resolved: it can't be resolved again nor rejected. When `p2` settles, its outcome is forwarded to `p1`, which becomes settled as well.

Once a promise is fulfilled, reactions that were attached with `p.then` will be executed as soon as possible. The same goes for rejected promises and `p.catch` reactions. Reactions attached after a promise is settled are also executed as soon as possible.

The contrived example shown next could be used to explain how you can make a `fetch` request, and create a second `fetch` promise in a `.then` reaction to the first request. The second request will only begin when and if the first promise settles in fulfillment. The `console.log` statement will only begin when and if the second promise settles in fulfillment, printing `done` to the console.

```
fetch('/items')
  .then(() => fetch('/item/first'))
  .then(() => console.log('done'))
```

A less contrived example would involve other steps. In the following piece of code we use the outcome of the first `fetch` request in order to construct the second request. To do that, we use the `res.json` method which returns a promise that resolves to the object from parsing a JSON response. Then we use that object to construct the endpoint we want to request in our second call to `fetch`, and finally we print the `item` object from the second response to the console.

```
fetch('/items')
  .then(res => res.json())
  .then(items => fetch(`/item/${ items[0].slug }`))
  .then(res => res.json())
  .then(item => console.log(item))
```

We're not limited to returning promises or thenables. We could also return values from `.then` and `.catch` reactions. Those values would be passed to the next reaction in the chain. In this sense, a reaction can be regarded as the transformation of input from the previous reaction in the chain into the input for the next reaction in the chain. The example below starts by creating a promise fulfilled with `[1, 2, 3]`. Then there's a reaction which maps those values into `[2, 4, 6]`. Those values are then printed to the console in the following reaction in the chain.

```
Promise
  .resolve([1, 2, 3])
  .then(values => values.map(value => value * 2))
```

```
  .then(values => console.log(values))
  // <- [2, 4, 6]
```

Note that you can transform data in rejection branches as well. Keep in mind that, as we first learned in section 4.1.3, when a `.catch` reaction executes without errors, it will fulfill, following `.then` reactions.

4.1.5 Leveraging `Promise.all` and `Promise.race`

When writing asynchronous code flows, there are pairs of tasks where one of them depends on the outcome of another, so they must run in series. There's also pairs of tasks that don't need to know the outcome of each other in order to run, so they can be executed concurrently. Promises already excell at asynchronous series flows, as a single promise can trigger a chain of events that happen one after another. Promises also offer a couple of solutions for concurrent tasks, in the form of two API methods: `Promise.all` and `Promise.race`.

In most cases you'll want code that can be executed concurrently to take advantage of that, as it could make your code run much faster. Suppose you wanted to pull the description of two products in your catalog, using two distinct API calls, and then print out both of them to the console. The following piece of code would run both operations concurrently, but it would need separate print statements. In the case of printing to the console, that wouldn't make much of a difference, but if we needed to make single function call passing in both products, we couldn't do that with two separate `fetch` requests.

```
fetch('/products/chair')
  .then(r => r.json())
  .then(p => console.log(p))
fetch('/products/table')
  .then(r => r.json())
  .then(p => console.log(p))
```

The `Promise.all` method takes an array of promises and returns a single promise `p`. When all promises passed to `Promise.all` are fulfilled, `p` becomes fulfilled as well with an array of results sorted according to the provided promises. If a single promise becomes rejected, `p` settles with its rejection reason immediately. The following example uses `Promise.all` to fetch both products and print them to the console using a single `console.log` statement.

```
Promise
  .all([
    fetch('/products/chair'),
    fetch('/products/table')
  ])
  .then(products => console.log(products[0], products[1]))
```

Given that the results are provided as an array, its indices have no semantic meaning to our code. Using parameter destructuring to pull out variable names for each product might make more sense when reading the code. The following example uses destructuring to clean that up. Keep in mind that even though there's a single argument, destructuring forces us to use parenthesis in the arrow function parameter declaration.

```
Promise
  .all([
    fetch('/products/chair'),
    fetch('/products/table')
  ])
  .then(([chair, table]) => console.log(chair, table))
```

The following example shows how if a single promise is rejected, `p` will be rejected as well. It's important to understand that as a single rejected promise might prevent an otherwise fulfilled array of promises from fulfilling `p`. In the example, rather than wait until `p2` and `p3` settle, `p` becomes immediately rejected.

```
const p1 = Promise.reject('failed')
const p2 = fetch('/products/chair')
const p3 = fetch('/products/table')
const p = Promise
  .all([p1, p2, p3])
  .catch(reason => console.log(reason))
  // <- 'failed'
```

In summary, `Promise.all` has three possible outcomes.

- Settle with all fulfillment `results` as soon as all of its dependencies are fulfilled
- Settle with a single rejection `reason` as soon as one of its dependencies is rejected
- Stay in a pending state because at least one dependency stays in pending state and no dependencies are rejected

The `Promise.race` method is similar to `Promise.all`, except the first dependency to settle will "win" the race, and its result will be passed along to the promise returned by `Promise.race`.

```
Promise
  .race([
    new Promise(resolve => setTimeout(() => resolve(1), 1000)),
    new Promise(resolve => setTimeout(() => resolve(2), 2000))
  ])
  .then(result => console.log(result))
  // <- 1
```

Rejections will also finish the race, and the resulting promise will be rejected. Using `Promise.race` could be useful in scenarios where we want to time out a promise we otherwise have no control over. For instance, in the following piece of code there's a race between a `fetch` request and a promise that becomes rejected after a five second timeout. If the request takes more than five seconds the race will be rejected.

```
function timeout (delay) {
  return new Promise(function (resolve, reject) {
    setTimeout(() => reject('timeout'), delay)
  })
}
Promise
  .race([
    fetch('/large-resource-download'),
    timeout(5000)
  ])
  .then(res => console.log(res))
  .catch(err => console.log(err))
```

4.2 Iterator Protocol and Iterable Protocol

JavaScript gets two new protocols in ES6: iterators and iterables. These two protocols are used to define iteration behavior for any object. We'll start by learning about how to turn an object into an iterable sequence. Later, we'll look into lazyness and how iterators can define infinite sequences. Lastly, we'll go over practical considerations while defining iterables.

4.2.1 Understanding Iteration Principles

Any object can adhere to the iterable protocol by assigning a function to the `Symbol.iterator` property for that object. Whenever an object needs to be iterated its iterable protocol method, assigned to `Symbol.iterator`, is called once.

The spread operator was first introduced in chapter 2, and it's one of a few language features in ES6 that leverage iteration protocols. When using the spread operator on a hypothetical `iterable` object, as shown in the following code snippet, `Symbol.iterator` would be asked for an object that adheres to the iterator protocol. The returned iterator will be used to obtain values out of the object.

```
const sequence = [...iterable]
```

As you might remember, symbol properties can't be directly embedded into object literal keys. The following bit of code shows how you'd add a Symbol property using pre-ES6 language semantics.

```
const example = {}
example[Symbol.iterator] = fn
```

We could, however, use a computed property name to fit the symbol key in the object literal, avoiding an extra statement like the one in the previous snippet, as demonstrated next.

```
const example = {
  [Symbol.iterator]: fn
}
```

The method assigned to `Symbol.iterator` must return an object that adheres to the iterator protocol. That protocol defines how to get values out of an iterable sequence. The protocol dictates iterators must be objects with a `next` method. The `next` method takes no arguments and should return an object with the two properties found below.

- `value` is the current item in the sequence
- `done` is a boolean indicating whether the sequence has ended

Let's use the following piece of code as a crutch to understand the concepts behind iteration protocols. We're turning the `sequence` object into an iterable by adding a `Symbol.iterator` property. The iterable returns an iterator object. Each time `next` is asked for the following value in the sequence, an element from the `items` array is provided, until there's no more `items` left.

```
const sequence = {
  [Symbol.iterator]() {
    const items = ['i', 't', 'e', 'r', 'a', 'b', 'l', 'e']
    return {
      next: () => ({
        done: items.length === 0,
        value: items.shift()
      })
    }
  }
}
```

JavaScript is a progressive language: new features are additive, and they practically never break existing code. For that reason, iterables can't be taken advantage of in existing constructs such as `forEach` and `for..in`. In ES6, there's a few ways to go over iterables: `for..of`, the ... spread operator, and `Array.from`.

The `for..of` iteration method can be used to loop over any iterable. The following example demonstrates how we could use `for..of` to loop over the `sequence` object we put together in the previous example, because it is an iterable object.

```
for (let item of sequence) {
  console.log(item)
  // <- 'i'
  // <- 't'
  // <- 'e'
  // <- 'r'
  // <- 'a'
  // <- 'b'
  // <- 'l'
```

```
  // <- 'e'
}
```

Regular objects can be made iterable with `Symbol.iterator`, as we've just learned. Under the ES6 paradigm, constructs like `Array`, `String`, `NodeList` in the DOM, and `arguments` are all iterable by default, giving `for..of` increased usability. To get an array out of any iterable sequence of values, you could use the spread operator, spreading every `item` in the sequence onto an element in the resulting array. We could also use `Array.from` to the same effect. In addition, `Array.from` can also cast array-like objects, those with a `length` property and items in zero-based integer properties, into arrays.

```
console.log([...sequence])
// <- ['i', 't', 'e', 'r', 'a', 'b', 'l', 'e']
console.log(Array.from(sequence))
// <- ['i', 't', 'e', 'r', 'a', 'b', 'l', 'e']
console.log(Array.from({ 0: 'a', 1: 'b', 2: 'c', length: 3 }))
// <- ['a', 'b', 'c']
```

As a recap, the `sequence` object adheres to the iterable protocol by assigning a method to `[Symbol.iterator]`. That means that the object is iterable: it can be iterated. Said method returns an object that adheres to the `iterator` protocol. The iterator method is called once whenever we need to start iterating over the object, and the returned iterator is used to pull values out of `sequence`. To iterate over iterables, we can use `for..of`, the spread operator, or `Array.from`.

In essence, the selling point about these protocols is that they provide expressive ways to effortlessly iterate over collections and array-likes. Having the ability to define how any object may be iterated is huge, because it enables libraries to converge under a protocol the language natively understands: iterables. The upside is that implementing the iterator protocol in doesn't have a high effort cost because, due to its additive nature, it won't break existing behavior.

For example, jQuery and `document.querySelectorAll` both return array-likes. If jQuery implemented the iterator protocol on their collection's prototype, then you could iterate over collection elements using the native `for..of` construct.

```
for (let element of $('li')) {
  console.log(element)
  // <- a <li> in the jQuery collection
}
```

Iterable sequences aren't necessarily finite. They may have an uncountable amount of elements. Let's delve into that topic and its implications.

4.2.2 Infinite Sequences

Iterators are lazy in nature. Elements in an iterator sequence are generated one at a time, even when the sequence is finite. Note that infinite sequences couldn't be represented without the lazyness property. An infinite sequence can't be represented as an array, meaning that using the spread operator or `Array.from` to cast a sequence into an array would crash JavaScript execution, as we'd go into an infinite loop.

The following example shows an iterator that represents an infinite sequence of random floating numbers between 0 and 1. Note how items returned by `next` don't ever have a `done` property set to `true`, which would signal that the sequence has ended. It uses a pair of arrow functions that implicitly return objects. The first one returns the iterator object used to loop over the infinite sequence of random numbers. The second arrow function is used to pull each individual value in the sequence, using `Math.random`.

```
const random = {
  [Symbol.iterator]: () => ({
    next: () => ({ value: Math.random() })
  })
}
```

Attempting to cast the iterable `random` object into an array using either `Array.from(random)` or `[…random]` would crash our program, since the sequence never ends. We must be very careful with these types of sequences as they can easily crash and burn our browser and Node.js server processes.

There's a few different ways you can access a sequence safely, without risking an infinite loop. The first option is to use destructuring to pull values in specific positions of the sequence, as shown in the following piece of code.

```
const [one, another] = random
console.log(one)
// <- 0.23235511826351285
console.log(another)
// <- 0.28749457537196577
```

Destructuring infinite sequences doesn't scale very well, particularly if we want to apply dynamic conditions, such as pulling the first `i` values out of the sequence or pulling values until we find one that doesn't match a condition. In those cases we're better off using `for..of`, where we're better able to define conditions that prevent infinite loops while taking as many elements as we need, in a programmatic fashion. The next example loops over our infinite sequence using `for..of`, but it breaks the loop as soon as a value is higher than `0.8`. Given that `Math.random` produces values anywhere between `0` and `1`, the loop will eventually break.

```
for (let value of random) {
  if (value > 0.8) {
```

```
    break
  }
  console.log(value)
}
```

It can be hard to understand code like that when reading it later, as a lot of the code is focused on how the sequence is iterated, printing values from `random` until one value is large enough; and not on what the sequence looks like, the first N values until a larger value is found. Abstracting away part of the logic into another method might make the code more readable.

As another example, a common pattern when extracting values from an infinite or very large sequence is to "take" the first few elements in the sequence. While you could accommodate that use case through `for..of` and `break`, you'd be better off abstracting it into a `take` method. The following example shows a potential implementation of `take`. It receives a `sequence` parameter and the `amount` of entries you'd like to take from the `sequence`. It returns an iterable object, and whenever that object is iterated it constructs an iterator for the provided `sequence`. The `next` method defers to the original `sequence` while the `amount` is at least `1`, and then ends the sequence.

```
function take (sequence, amount) {
  return {
    [Symbol.iterator]() {
      const iterator = sequence[Symbol.iterator]()
      return {
        next() {
          if (amount-- < 1) {
            return { done: true }
          }
          return iterator.next()
        }
      }
    }
  }
}
```

Our implementation works great on infinite sequences because it provides them with a constant exit condition: whenever the `amount` is depleted, the sequence returned by `take` ends. Instead of looping to pull values out of `random`, you can now write a piece of code like the following.

```
[...take(random, 2)]
// <- [0.304253100650385, 0.5851333604659885]
```

This pattern allows you to reduce any infinite sequence into a finite one. If your desired finite sequence wasn't just "the first N values", but rather our original "all values before the first one larger than 0.8", you could easily adapt `take` by changing its exit condition. The `range` function shown next has a `low` parameter that defaults to `0`, and a `high` parameter defaulting to `1`. Whenever a value in the sequence is out of bounds, we stop pulling values from it.

```
function range (sequence, low=0, high=1) {
  return {
    [Symbol.iterator]() {
      const iterator = sequence[Symbol.iterator]()
      return {
        next() {
          const item = iterator.next()
          if (item.value < low || item.value > high) {
            return { done: true }
          }
          return item
        }
      }
    }
  }
}
```

Now, instead of breaking in the `for..of` loop because we fear that the infinite sequence will never end, we guaranteed that the loop will eventually break outside of our desired range. This way, your code becomes less concerned with how the sequence is generated, and more concerned with what the sequence will be used for. As shown in the example below, you won't even need a `for..of` loop here either, because the escape condition now resides in the intermediary `range` function.

```
const low = [...range(random, 0, 0.8)]
// <- [0.68912092433331105, 0.05978861474432051, 0.0939619520213455]
```

This sort of abstraction of complexity into another function often helps keep code focused on its intent, while striving to avoid a `for..of` loop when all we wanted was to produce a derivated sequence. It also shows how sequences can be composed and piped into one another. In this case, we first created a multi-purpose and infinite `random` sequence, and then piped it through a `range` function that returns a derivated sequence that ends when it meets values that are below or above a desired range. An important aspect of iterators is that despite having been composed, the iterators produced by the `range` function can be lazily iterated as well, effectively meaning you can compose as many iterators you need into mapping, filtering, and exit condition helpers.

Identifying infinite sequences

Iterators don't have any knowledge that the sequences they produce are infinite. In a similar situation to the famous halting problem, there is no way of knowing whether the sequence is infinite or not in code.

You typically have a good idea of whether a sequence is infinite or not. Whenever you have an infinite sequence it's up to you to add an escape condition that ensures the program won't crash in an attempt to loop over every single value in the sequence. While `for..of` won't run into the problem unless there's no escape condition, using mechanisms such as spread or `Array.from` would immediately result in the program crashing into an infinite loop in the case of infinite sequences.

Besides the technical implications of creating iterable objects, lets go over a couple of practical examples on how we can benefit from iterators.

4.2.3 Iterating Object Maps as Key-Value Pairs

There's an abundance of practical situations that benefit from turning an object into an iterable. Object maps, pseudo-arrays that are meant to be iterated, the random number generator we came up with in section 4.2.2, and classes or plain objects with properties that are often iterated could all turn a profit from following the iterable protocol.

Oftentimes, JavaScript objects are used to represent a map between string keys and arbitrary values. In the next snippet, as an example, we have a map of color names and hexadecimal RGB representations of that color. There are cases when you'd welcome the ability to effortlessly looping over the different color names, hexadecimal representations, or key-value pairs.

```
const colors = {
  green: '#0e0',
  orange: '#f50',
  pink: '#e07'
}
```

The following code snippet implements an iterable that produces a `[key, value]` sequence for each color in the `colors` map. Given that that's assigned to the `Symbol.iterator` property, we'd be able to go over the list with minimal effort.

```
const colors = {
  green: '#0e0',
  orange: '#f50',
  pink: '#e07',
  [Symbol.iterator] () {
    const keys = Object.keys(colors)
    return {
      next () {
        const done = keys.length === 0
        const key = keys.shift()
        return {
          done,
          value: [key, colors[key]]
        }
      }
    }
  }
}
```

When we wanted to pull out all the key-value pairs, we could use the ... spread operator as shown in the following bit of code.

```
console.log([...colors])
// <- [['green', '#0e0'], ['orange', '#f50'], ['pink', '#e07']]
```

The fact that we're polluting our previously-tiny `colors` map with a large iterable definition could represent a problem, as the iterable behavior has little to do with the concern of storing pairs of color names and codes. A good way of decoupling the two aspects of `colors` would be to extract the logic that attaches a key-value pair iterator into a reusable function. This way, we could eventually move `keyValueIterable` somewhere else in our codebase and leverage it for other use cases as well.

```
function keyValueIterable (target) {
  target[Symbol.iterator] = function () {
    const keys = Object.keys(target)
    return {
      next () {
        const done = keys.length === 0
        const key = keys.shift()
        return {
          done,
          value: [key, target[key]]
```

```
        }
      }
    }
  }
  return target
}
```

We could then call `keyValueIterable` passing in the `colors` object, turning `colors` into an iterable object. You could in fact use `keyValueIterable` on any objects where you want to iterate over key-value pairs, as the iteration behavior doesn't make assumptions about the object. Once we've attached a `Symbol.iterator` behavior, we'll be able to treat the object as an iterable. In the next code snippet, we iterate over the key-value pairs and print only the color codes.

```
const colors = keyValueIterable({
  green: '#0e0',
  orange: '#f50',
  pink: '#e07'
})
for (let [, color] of colors) {
  console.log(color)
  // <- '#0e0'
  // <- '#f50'
  // <- '#e07'
}
```

A song player might be another interesting use case.

4.2.4 Building Versatility Into Iterating a Playlist

Imagine you were developing a song player where a playlist could be reproduced once and then stop or on "repeat" (indefinitely). Whenever you have a use case of looping through a list indefinitely, you could leverage the iterable protocol as well.

Suppose a human adds a few songs to their library, and they are stored in an array as shown in the next bit of code.

```
const songs = [
  `Bad moon rising – Creedence`,
  `Don't stop me now – Queen`,
  `The Scientist – Coldplay`,
  `Somewhere only we know – Keane`
]
```

We could create a `playlist` function that returns a sequence, representing all the songs that will be played by our application. This function would take the `songs` provided by the human as well as the `repeat` value, which indicates how many times they want the songs to be reproduced in a loop — once, twice, or `Infinity` times — before coming to an end.

The following piece of code shows how we could implement `playlist`. We could start with an empty playlist. In each turn of the loop we'll check if there are any songs left to play. If there aren't any songs left, and we have a `repeat` value above zero, we'll create a `copy` of the song list provided by the user. We use that `copy` as state, to know where we are in their song list. We'll return the first song in the list by pulling it with `.shift`, until there aren't any songs left in our `copy`. The sequence ends when there aren't any songs left and `repeat` is zero or less.

```
function playlist (songs, repeat) {
  return {
    [Symbol.iterator] () {
      let copy = []
      return {
        next () {
          if (copy.length === 0) {
            if (repeat < 1) {
              return { done: true }
            }
            copy = songs.slice()
            repeat--
          }
          return {
            value: copy.shift(), done: false
          }
        }
      }
    }
  }
}
```

The following bit of code shows how the `playlist` function can take an array and produce a sequence that goes over the provided array for the specified amount of times. If we specified `Infinity`, the resulting sequence would be infinite, and otherwise it'd be finite.

```
console.log([...playlist(['a', 'b'], 3)])
// <- ['a', 'b', 'a', 'b', 'a', 'b']
```

To iterate over the playlist we'd probably come up with a `player` function. Assuming a `playSong` function that reproduces a song and invokes a callback when the song ends, our `player` implementation could look like the following function, where we asynchronously loop the iterator coming from a sequence, requesting new songs as previous ones finish playback. Given that there's always a considerable waiting period in between `g.next` calls — while the songs are actually played inside `playSong` — there's no risk of running into an infinite loop even when the sequence produced by `playlist` is infinite.

```
function player (sequence) {
  const g = sequence()
```

```
  more()
  function more () {
    const item = g.next()
    if (item.done) {
      return
    }
    playSong(item.value, more)
  }
}
```

Putting everything together, the music library would play a song list on repeat with a few lines of code, as presented in the next code snippet.

```
const songs = [
  `Bad moon rising - Creedence`,
  `Don't stop me now - Queen`,
  `The Scientist - Coldplay`,
  `Somewhere only we know - Keane`
]
const sequence = playlist(songs, Infinity)
player(sequence)
```

A change allowing the human to shuffle their playlist wouldn't be complicated to introduce. We'd have to tweak the `playlist` function to include a `shuffle` flag. That way, each step where we reproduce the list of user-provided songs could

```
function playlist (songs, repeat, shuffle) {
  return {
    [Symbol.iterator] () {
      let copy = []
      return {
        next () {
          if (copy.length === 0) {
            if (repeat < 1) {
              return { done: true }
            }
            copy = songs.slice()
            repeat--
          }
          const value = shuffle ? randomSong() : nextSong()
          return { done: false, value }
        }
      }
      function randomSong () {
        const index = Math.floor(Math.random() * copy.length)
        return copy.splice(index, 1)[0]
      }
      function nextSong () {
        return copy.shift()
      }
    }
  }
}
```

Lastly, we'd have to pass in the `shuffle` flag as `true` if we wanted to shuffle songs in each repeat cycle. Otherwise, songs would be reproduced in the original order provided by the user. Here again we've abstracted away something that usually would involve many lines of code used to decide what song comes next into a neatly decoupled function that's only concerned with producing a sequence of songs to be reproduced by a song player.

```
console.log([...playlist(['a', 'b'], 3, true)])
// <- ['a', 'b', 'b', 'a', 'a', 'b']
```

Iterators are an important tool in ES6 that help us not only to decouple code but also to come up with constructs that were previously harder to implement, such as the ability of dealing with a sequence of songs indistinctly — regardless of whether the sequence is finite or infinite. This indifference is, in part, what makes writing code leveraging the iterator protocol more elegant. It also makes it risky to cast an unknown iterable into an array (with, say, the … spread operator), as you're risking crashing your program due to an infinite loop.

Generators are an alternative way of creating functions that return an iterable object, without explicitly declaring an object literal with a `Symbol.iterator` method. They make it easier to implement functions, such as the `range` or `take` functions in section 4.2.2, while also allowing for a few more interesting use cases.

4.3 Generator Functions and Generator Objects

Generators are a new feature in ES6. The way they work is that you declare a generator function that returns generator objects `g`. Those `g` objects can then be iterated using any of `Array.from(g)`, `[…g]`, or `for..of` loops. Generator functions allow you to declare a special kind of `iterator`. These iterators can suspend execution while retaining their context.

4.3.1 Generator Fundamentals

We already examined iterators in the previous section, learning how their `.next()` method is called once at a time to pull values from a sequence. Instead of a `next` method whenever you return a value, generators use the `yield` keyword to add values into the sequence.

Here is an example generator function. Note the `*` after `function`. That's not a typo, that's how you mark a generator function as a generator.

```
function* abc () {
  yield 'a'
  yield 'b'
  yield 'c'
}
```

Generator objects conform to both the iterable protocol and the iterator protocol.

- A generator object `chars` is built using the `abc` function
- Object `chars` is an iterable because it has a `Symbol.iterator` method
- Object `chars` is also an iterator because it has a `.next` method
- The iterator for `chars` is itself

The same statements can also be demonstrated using JavaScript code.

```
const chars = abc()
typeof chars[Symbol.iterator] === 'function'
typeof chars.next === 'function'
chars[Symbol.iterator]() === chars
console.log(Array.from(chars))
// <- ['a', 'b', 'c']
console.log([...chars])
// <- ['a', 'b', 'c']
```

When you create a generator object, you'll get an iterator that uses the generator function to produce an iterable sequence. Whenever a `yield` expression is reached, its value is emitted by the iterator and generator function execution becomes suspended.

The following example shows how iteration can trigger side-effects within the generator function. The `console.log` statements after each `yield` statement will be executed when generator function execution becomes unsuspended and asked for the next element in the sequence.

```
function* numbers () {
  yield 1
  console.log('a')
  yield 2
  console.log('b')
  yield 3
  console.log('c')
}
```

Suppose you created a generator object for `numbers`, spread its contents onto an array, and printed it to the console. Taking into account the side-effects in `numbers`, can you guess what the console output would look like for the following piece of code? Given that the spread operator iterates over the sequence to completion in order to give you an array, all side-effects would be executed while constructing the array via destructuring, before the `console.log` statement printing the array is ever reached.

```
console.log([...numbers()])
// <- 'a'
// <- 'b'
```

```
// <- 'c'
// <- [1, 2, 3]
```

If we now used a `for..of` loop instead, we'd be able to preserve the order declared in the `numbers` generator function. In the next example, elements in the `numbers` sequence are printed one at a time in a `for..of` loop. The first time the generator function is asked for a `number`, it yields `1` and execution becomes suspended. The second time, execution is unsuspended where the generator left off, *a* is printed to the console as a side-effect, and `2` is yielded. The third time, *b* is the side-effect, and `3` is yielded. The fourth time, *c* is a side-effect and the generator signals that the sequence has ended.

```
for (let number of numbers()) {
  console.log(number)
  // <- 1
  // <- 'a'
  // <- 2
  // <- 'b'
  // <- 3
  // <- 'c'
}
```

Using `yield*` to delegate sequence generation

Generator functions can use `yield*` to delegate to a generator object or any other iterable object.

Given that strings in ES6 adhere to the iterable protocol, you could write a piece of code like the following to split `hello` into individual characters.

```
function* salute () {
  yield* 'hello'
}
console.log([...salute()])
// <- ['h', 'e', 'l', 'l', 'o']
```

Naturally, you could use `[...hello]` as a simpler alternative. However, it's when combining multiple `yield` statements that we'll start to see the value in delegating to another iterable. The next example shows a `salute` generator modified into taking a `name` parameter and producing array that contains the characters for the *hello you* string.

```
function* salute (name) {
  yield* 'hello '
  yield* name
}
console.log([...salute('you')])
// <- ['h', 'e', 'l', 'l', 'o', ' ', 'y', 'o', 'u']
```

To reiterate, you can yield* anything that adheres to the iterable protocol, not merely strings. That includes generator objects, arrays, arguments, NodeList in the browser, and just about anything provided it implements System.iterator. The following example demonstrates how you could mix yield and yield* statements to describe a sequence of values using generator functions, an iterable object, and the spread operator. Can you deduce what the console.log statement would print?

```
const salute = {
  [Symbol.iterator]() {
    const items = ['h', 'e', 'l', 'l', 'o']
    return {
      next: () => ({
        done: items.length === 0,
        value: items.shift()
      })
    }
  }
}
function* multiplied (base, multiplier) {
  yield base + 1 * multiplier
  yield base + 2 * multiplier
}
function* trailmix () {
  yield* salute
  yield 0
  yield* [1, 2]
  yield* [...multiplied(3, 2)]
  yield [...multiplied(6, 3)]
  yield* multiplied(15, 5)
}
console.log([...trailmix()])
```

Here's the sequence produced by the trailmix generator function.

```
['h', 'e', 'l', 'l', 'o', 0, 1, 2, 5, 7, [9, 12], 20, 25]
```

Besides iterating over a generator object using spread, for..of, and Array.from, we could use the generator object directly, and iterate over that. Let's investigate how that'd work.

4.3.2 Iterating over Generators by Hand

Generator iteration isn't limited to for..of, Array.from, or the spread operator. Just like with any iterable object, you can use its Symbol.iterator to pull values on demand using .next, rather than in an strictly synchronous for..of loop or all at once with Array.from or spread. Given that a generator object is both iterable and iterator, you won't need to call g[Symbol.iterator]() to get an iterator: you can use `g` directly because it's the same object as the one returned by the `Symbol.iterator` method.

Assuming the `numbers` iterator we created earlier, the following example shows how you could iterate it by hand using the generator object and a `while` loop. Remember that any items returned by an iterator need a `done` property that indicates whether the sequence has ended, and a `value` property indicating the current value in the sequence.

```
const g = numbers()
while (true) {
  let item = g.next()
  if (item.done) {
    break
  }
  console.log(item.value)
}
```

Using iterators to loop over a generator might look like a complicated way of implementing a `for..of` loop, but it also allows for some interesting use cases. Particularly: `for..of` is always a synchronous loop, whereas with iterators we're in charge of deciding when to invoke `g.next`. In turn, that translates into additional opportunities such as running an asynchronous operation and then calling `g.next` once we have a result.

Whenever `.next()` is called on a generator, there are four different kinds of "events" that can suspend execution in the generator while returning a result to the caller of `.next()`. We'll promptly explore each of these scenarios.

- A `yield` expression returning the next value in the sequence
- A `return` statement returning the last value in the sequence
- A `throw` statement halts execution in the generator entirely
- Reaching the end of the generator function signals `{ done: true }`

Once the `g` generator ended iterating over a sequence, subsequent calls to `g.next()` will have no effect and just return `{ done: true }`. The following code snippet demonstrates the idempotence we can observe when calling `g.next` repeatedly once a sequence has ended.

```
function* generator () {
  yield 'only'
}
const g = generator()
console.log(g.next())
// <- { done: false, value: 'only' }
console.log(g.next())
// <- { done: true }
```

```
console.log(g.next())
// <- { done: true }
```

Moving onto a more practical example, let's write a magic 8-ball generator where we'll put that sort of message-passing into action.

4.3.3 Coding A Magic 8-ball Generator

A magic 8-ball consists of an interface that, when asked a question, returns a vague, random answer, as a result. The following function returns an answer at random, out of a pool of ten possible values. Note how I used template literals to define every string: that way, I don't need to worry about escaping single or double quotes in my strings.

```
const answers = [
  `It is certain`,
  `Yes definitely`,
  `Most likely`,
  `Yes`,
  `Ask again later`,
  `Better not tell you now`,
  `Cannot predict now`,
  `Don't count on it`,
  `My sources say no`,
  `Very doubtful`
]
function answer () {
  return answers[Math.floor(Math.random() * answers.length)]
}
```

Now that we're able to randomly generate vague answers, we can use a generator function to define an infinite sequence of answers. Here, again, I'm using a template literal to embed an arbitrary JavaScript expression, the `answer()` function call, in the yielded string.

```
function* ball () {
  while (true) {
    yield `[a] ${ answer() }`
  }
}
```

Each step of the sequence would contain one of the vague answers, generated at random.

```
const g = ball()
g.next()
// <- { value: '[a] Better not tell you now', done: false }
g.next()
// <- { value: '[a] Most likely', done: false }
```

The generator is blindly producing answers even though we're not passing in any questions. We could make a couple of changes to the `ball` generator so that it prints questions as you read values out of the sequence.

Interestingly, `yield` expressions are not just used to produce output from the generator when calling `g.next`, but can also be used when the generator needs input. Any value passed to the `g.next` method will be passed into the generator as the result of the `yield` expression.

```
function* ball () {
  let question
  while (true) {
    question = yield `[a] ${ answer() }`
    console.log(`[q] ${ question }`)
  }
}
```

The next piece of code shows how we can use the `ball` generator to ask questions, have them printed, and then print out the answers. Note how we discard the first result from `g.next()`. That's because the first call to `.next` enters the generator and there's no `yield` expression waiting to capture the `value` from `g.next(value)`.

```
const g = ball()
g.next()
console.log(g.next('Will JavaScript fall out of grace?').value)
// <- '[q] Will JavaScript fall out of grace?'
// <- '[a] My sources say no'
console.log(g.next('How do you know that?').value)
// <- '[q] How do you know that?'
// <- '[a] Concentrate and ask again'
```

As a consumer of the `ball` generator, the first call to `g.next` doesn't seem something you should need to do. Similarly, using `g.next` to pull sequence values out of a generator and pass input into the generator doesn't seem like a responsibility that should befall the consumer of your generator code. If we flipped responsibilities around, by writing the looping code and having the consumer of a piece of code create a generator function, the resulting code would be more pleasant to both read and write.

4.3.4 Consuming Generator Functions for Flexibility

In the previous section our 8-ball was a generator function, while the user code using the 8-ball was in charge of looping over the generator's sequence. Now, we'll be writing the questions in a generator function that gets passed to a method, which loops over the generator we provide and answers each question at a time.

At first, you might think that writing code like this is unconventional, but most libraries built around generators work in fact have their users write generators, while retaining control of their iteration. Starting with the API you wish you could use is an excellent way to come up with a great API. This is something we missed in the previous section and `ball` turned out to be pretty cumbersome to use, having to manually call `g.next`, using `.value` to pull out sequence items, not to mention the initial `g.next` call.

The following bit of code could be used as an example of how we'd like `ball` to work. The consumer provides a generator function that yields questions. Answers are printed one at a time, alongside questions, to the console.

```
ball(function* questions () {
  yield 'Will JavaScript fall out of grace?'
  yield 'How do you know that?'
})
// <- '[q] Will JavaScript fall out of grace?'
// <- '[a] Yes'
// <- '[q] How do you know that?'
// <- '[a] It is certain'
```

Whenever a question is yielded by the user-provided generator, execution in the generator function is suspended until the iterator calls `g.next` again, even allowing `g.next` to be called asynchronously. The following iteration of the `ball` function iterates over the `questions` generator until its sequence is exhausted, using a synchronous `for..of` loop that calls `g.next` on your behalf at every turn of the loop. Our `ball` implementation becomes even simpler than before, and the interface for consumers — who now only need to provide a generator that yields questions — is simplified as well.

```
function ball (questions) {
  for (let question of questions()) {
    console.log(`[q] ${ question }`)
    console.log(`[a] ${ answer() }`)
  }
}
```

One trade-off that you might've noticed is that `ball` is no longer iterable and offers little control to the consumer: it has become very opinionated. The generator now only relays the questions, and the iterator prints everything to the console. A potential fix could be to turn `ball` into a generator function as well, where we `yield` question/answer tuples instead of printing them to the `console` directly, as shown in the following piece of code.

```
function* ball (questions) {
  for (let question of questions()) {
    yield [
      `[q] ${ question }`,
      `[a] ${ answer() }`
    ]
  }
}
```

The consumer of `ball` can now pass in a generator function with their questions, and get back an iterable generator object consisting of `[q,a]` pairs. Destructuring allows you to effortlessly consume the tuples in that sequence which you can then print to the `console`, push onto an array, or further compose with other generator functions such as `take` from section 4.2.2, which allowed us to lazily take only the first few items in an iterable sequence.

```
function* questions () {
  yield 'Will JavaScript fall out of grace?'
  yield 'How do you know that?'
}
for (let [q,a] of ball(questions)) {
  console.log(q)
  console.log(a)
}
```

When we compare the API in the previous section with the one we've just created, it becomes quite clear that the latter is superior in terms of usability, composability, extensibility, and even readability. Writing maintainable and usable components is a hard-to-master art, but the focus should always be in designing a pleasant API first and then working your way into the implementation from there.

Yet another benefit of asking consumers to provide a generator function is that providing them with the `yield` keyword opens up a world of possibilities where execution in their code may be suspended while your iterator performs an asynchronous operation in between `g.next` calls. Let's explore asynchronous uses of generators in the next section.

4.3.5 Dealing with asynchronous flows

Staying on the subject of our magic 8-ball, and going back to the example where we call `ball` with a user-provided `questions` generator, let's reminisce about what would change about our code if the answers were to be provided asynchronously. The beauty of generators is that if the way we iterate over the questions were to become asynchronous, the generator wouldn't have to change at all. We already have the ability to suspend execution in the generator while we fetch the answers to the questions, and all it'd take would be to ask a service for the answer to the current question, return that value via an intermediary `yield` statement or in some other way, and then call `g.next` on the `questions` generator object.

Let's assume we're back at the following usage of `ball`.

```
ball(function* questions () {
  yield 'Will JavaScript fall out of grace?'
  yield 'How do you know that?'
})
```

We'll be using `fetch` to make requests for each HTTP resource — which, as you may recall, returns a `Promise`. Note that in an asynchronous scenario we can no longer use `for..of`, as we now need to rely on manually calling `g.next` ourselves, while `for..of` only supports synchronous loops.

The next code snippet sends an HTTP request for each question and then prints the answer alongside them.

```
function ball (questions) {
  const g = questions()
  ask()
  function ask () {
    const question = g.next()
    if (question.done) {
      return
    }
    fetch(`/ask?q=${ encodeURIComponent(question.value) }`)
      .then(response => response.text())
      .then(answer => {
        console.log(`[q] ${ question.value }`)
        console.log(`[a] ${ answer }`)
        ask()
      })
  }
}
```

The problem when taking this approach is that we're back at the case where the consumer didn't have control over how answers are used. To solve that, we could use the `g.next(value)` message-passing feature that we discussed in section 4.3.3 as a way of forwarding answers to the user-provided generator.

```
function ball (questions) {
  const g = questions()
  let question = g.next()
  ask()
  function ask () {
    if (question.done) {
      return
    }
    fetch(`/ask?q=${ encodeURIComponent(question.value) }`)
      .then(response => response.text())
      .then(answer => question = g.next(answer))
      .then(ask)
  }
}
```

The user-provided generator would have to change, slightly. The answers would now be provided as the result when evaluating `yield` expressions, and you could print those results to the `console` as part of a template literal.

```
ball(function* questions () {
  console.log(`[a-1] ${ yield 'Will JavaScript fall out of grace?' }`)
  console.log(`[a-2] ${ yield 'How do you know that?' }`)
})
```

Always keep in mind that while a `yield` expression is being evaluated, execution of the generator function is paused until the next item in the sequence — the next question, in our example — is requested to the iterator. In this sense, code in a generator function looks and feels as if it were synchronous, even though `yield` pauses execution in the generator until `g.next` resumes execution.

While generators let us write asynchronous code that appears synchronous, this introduces an inconvenience. How do we handle errors that arise in the iteration? If an HTTP request fails, for instance, how do we notify the generator and then handle the error notification in the generator function?

4.3.6 Throwing Errors at a Generator

Before shifting our thinking into user-provided generators, where they retain control of seemingly-synchronous functions thanks to `yield` and suspension, we would've been hard pressed to find a user case for `g.throw`, a method found on generator objects that can be used to report errors that take place while the generator is suspended. Its applications become apparent when we think in terms of the flow control code driving the moments spent in between `yield` expressions, where things could go wrong. When something goes wrong processing an item in the sequence, the code that's consuming the generator needs to be able to `throw` that error into the generator.

In the case of our magic 8-ball, the iterator may experience network issues — or a malformed HTTP response — and fail to answer a question. In the snippet of code below, I've modified the `fetch` step by adding an error callback that will be executed if parsing fails in `response.text()`, in which case we'll throw the exception at the generator function.

```
fetch(`/ask?q=${ encodeURIComponent(question.value) }`)
  .then(response => response.text())
  .then(answer => question = g.next(answer), reason => g.throw(reason))
  .then(ask)
```

When `g.next` is called, execution in generator code is unsuspended. The `g.throw` method also unsuspends the generator, but it causes an exception to be thrown at the location of the `yield` expression. An unhandled exception in a generator would stop iteration by preventing other `yield` expressions from being reachable. Generator code could wrap `yield` expressions in `try`/`catch` blocks to gracefully manage exceptions forwarded by iteration code — as shown in the following code snippet. This would allow subsequent `yield` expressions to be reached, suspending the generator and putting the iterator in charge once again.

```js
ball(function* questions () {
  try {
    console.log(`[a-1] ${ yield 'Will JavaScript fall out of grace?' }`)
  } catch (e) {
    console.error('[a-1] Oops!', e)
  }
  try {
    console.log(`[a-2] ${ yield 'How do you know that?' }`)
  } catch (e) {
    console.error('[a-2] Oops!', e)
  }
})
```

Generator functions allow you to use error handling semantics — `try`, `catch`, and `throw` — which were previously only useful in synchronous code paths. Having the ability to use `try`/`catch` blocks in generator code lets us treat the code as if it were synchronous, even when there's HTTP requests sitting behind `yield` expressions, in iterator code.

4.3.7 Returning on Behalf of a Generator

Besides `g.next` and `g.throw`, generator objects have one more method at their disposal to determine how a generator sequence is iterated: `g.return(value)`. This method unsuspends the generator function and executes `return value` at the location of `yield`, typically ending the sequence being iterated by the generator object. This is no different to what would occur if the generator function actually had a `return` statement in it.

```js
function* numbers () {
  yield 1
  yield 2
  yield 3
}
const g = numbers()
console.log(g.next())
// <- { done: false, value: 1 }
console.log(g.return())
// <- { done: true }
console.log(g.next())
// <- { done: true }
```

Given that `g.return(value)` performs `return value` at the location of `yield` where the generator function was last suspended, a `try`/`finally` block could avoid immediate termination of the generated sequence, as statements in the `finally` block would be executed right before exiting. As shown in the following piece of code, that means `yield` expressions within the `finally` block can continue producing items for the sequence.

```
function* numbers () {
  try {
    yield 1
  } finally {
    yield 2
    yield 3
  }
  yield 4
  yield 5
}
const g = numbers()
console.log(g.next())
// <- { done: false, value: 1 }
console.log(g.return(-1))
// <- { done: false, value: 2 }
console.log(g.next())
// <- { done: false, value: 3 }
console.log(g.next())
// <- { done: true, value -1 }
```

Let's now look at a simple generator function, where a few values are yielded and then a `return` statement is encountered.

```
function* numbers () {
  yield 1
  yield 2
  return 3
  yield 4
}
```

While you may place `return value` statements anywhere in a generator function, the returned `value` won't show up when itearting the generator using the spread operator or `Array.from` to build an array, nor when using `for..of`, as shown next.

```
console.log([...numbers()])
// <- [1, 2]
console.log(Array.from(numbers()))
// <- [1, 2]
for (let number of numbers()) {
  console.log(number)
  // <- 1
  // <- 2
}
```

This happens because the iterator result provided by executing `g.return` or a `return` statement contains the `done: true` signal, indicating that the sequence has ended. Even though that same iterator result also contains a sequence `value`, none of the previously shown methods take it into account when pulling a sequence from the generator. In this sense, `return` statements in generators should mostly be used as circuit-breakers and not as a way of providing the last value in a sequence.

The only way of actually accessing the `value` returned from a generator is to iterate over it using a generator object, and capturing the iterator result `value` even though `done: true` is present, as displayed in the following snippet.

```
const g = numbers()
console.log(g.next())
// <- { done: false, value: 1 }
console.log(g.next())
// <- { done: false, value: 2 }
console.log(g.next())
// <- { done: true, value: 3 }
console.log(g.next())
// <- { done: true }
```

Due to the confusing nature of the differences between `yield` expressions and `return` statements, `return` in generators would be best avoided except in cases where a specific method wants to treat `yield` and `return` differently, the end goal always being to provide an abstraction in exchange for a simplified development experience.

In the following section, we'll build an iterator that leverages differences in `yield` versus `return` to perform both input and output based on the same generator function.

4.3.8 Asynchronous I/O Using Generators

The following piece of code shows a self-describing generator function where we indicate input sources and an output destination. This hypothetical method could be used to pull product information from the yielded endpoints, which could then be saved to the returned endpoint. An interesting aspect of this interface is that as a user you don't have to spend any time figuring out how to read and write information. You merely determine the sources and destination, and the underlying implementation figures out the rest.

```
saveProducts(function* () {
  yield '/products/javascript-application-design'
  yield '/products/modular-es6'
  return '/wishlists/books'
})
```

As a bonus, we'll have `saveProducts` return a promise that's fulfilled after the order is pushed to the returned endpoint, meaning the consumer will be able to execute callbacks after the order is filed. The generator function should also receive product data via the `yield` expressions, which can be passed into it by calling `g.next` with the associated product data.

```
saveProducts(function* () {
  const p1 = yield '/products/javascript-application-design'
  const p2 = yield '/products/modular-es6'
  return '/wishlists/books'
}).then(response => {
```

```
    // continue after storing the product list
  })
```

Conditional logic could be used to allow `saveProducts` to target a user's shopping cart instead of one of their wish lists.

```
saveProducts(function* () {
  yield '/products/javascript-application-design'
  yield '/products/modular-es6'
  if (addToCart) {
    return '/cart'
  }
  return '/wishlists/books'
})
```

One of the benefits of taking this blanket "inputs and output" approach is that the implementation could be changed in a variety of ways, while keeping the API largely unchanged. The input resources could be pulled via HTTP requests or from a temporary cache, they could be pulled one by one or concurrently, or there could be a mechanism that combines all yielded resources into a single HTTP request. Other than semantic differences of pulling one value at a time versus pulling them all at the same time to combine them into a single request, the API would barely change in the face of significant changes to the implementation.

We'll go over an implementation of `saveProducts` bit by bit. First off, the following piece of code shows how we could combine `fetch` and it's promise-based API to make an HTTP request for a JSON document about the first yielded product.

```
function saveProducts (productList) {
  const g = productList()
  const item = g.next()
  fetch(item.value)
    .then(res => res.json())
    .then(product => {})
}
```

In order to pull product data in a concurrent series — asynchronously, but one at a time — we'll wrap the `fetch` call in a recursive function that gets invoked as we get responses about each product. Each step of the way we'll be fetching a product, calling `g.next` to unsuspend the generator function asking for the next yielded item in the sequence, and then calling `more` to fetch that item.

```
function saveProducts (productList) {
  const g = productList()
  more(g.next())
  function more (item) {
    if (item.done) {
      return
    }
    fetch(item.value)
      .then(res => res.json())
```

```
        .then(product => {
          more(g.next(product))
        })
    }
  }
```

Thus far we're pulling all inputs and passing their details back to the generator via `g.next(product)` — an item at a time. In order to leverage the `return` statement, we'll save the products in a temporary array and then `POST` the list onto the output endpoint present on the iterator `item` when the sequence is marked as having ended.

```
function saveProducts (productList) {
  const products = []
  const g = productList()
  more(g.next())
  function more (item) {
    if (item.done) {
      save(item.value)
    } else {
      details(item.value)
    }
  }
  function details (endpoint) {
    fetch(endpoint)
      .then(res => res.json())
      .then(product => {
        products.push(product)
        more(g.next(product))
      })
  }
  function save (endpoint) {
    fetch(endpoint, {
      method: 'POST',
      body: JSON.stringify({ products })
    })
  }
}
```

At this point product descriptions are being pulled down, cached in the `products` array, forwarded to the generator body, and eventually saved in one fell swoop using the endpoint provided by the `return` statement.

In our original API design we suggested we'd return a promise from `saveProducts` so that callbacks could be chained and executed after the `save` operation. As we mentioned earlier, `fetch` returns a promise. By adding `return` statements all the way through our function calls, you can observe how `saveProducts` returns the output of `more`, which returns the output of `save` or `details`, both of which return the promise created by a `fetch` call. In addition, each `details` call returns the result of calling `more` from inside the `details` promise, meaning the original `fetch` won't be fulfilled until the second `fetch` is fulfilled, allowing us to chain these promises which will ultimately resolve when the `save` call is executed and resolved.

```
function saveProducts (productList) {
  const products = []
  const g = productList()
  return more(g.next())
  function more (item) {
    if (item.done) {
      return save(item.value)
    }
    return details(item.value)
  }
  function details (endpoint) {
    return fetch(endpoint)
      .then(res => res.json())
      .then(product => {
        products.push(product)
        return more(g.next(product))
      })
  }
  function save (endpoint) {
    return fetch(endpoint, {
        method: 'POST',
        body: JSON.stringify({ products })
      })
      .then(res => res.json())
  }
}
```

As you may have noticed, the implementation doesn't hardcode any important aspects of the operation, which means you could use the inputs and output pattern in a generic way as long as you have zero or more inputs you want to pipe into one output. The consumer ends up with an elegant-looking method that's easy to understand — they `yield` input stores and `return` an output store. Furthermore, our use of promises makes it easy to concatenate this operation with others. This way, we're keeping a potential tangle of conditional statements and flow control mechanisms in check, by abstracting away flow control into the iteration mechanism under the `saveProducts` method.

We've looked into flow control mechanisms such as callbacks, events, promises, iterators, and generators. The following two sections delve into `async` / `await`, async iterators, and async generators, all of which build upon a mixture of the flow control mechanisms we've uncovered thus far in this chapter.

4.4 Async Functions

Languages like Python and C# have had `async` / `await` for a while. In ES2017, JavaScript gained native syntax that can be used to describe asynchronous operations.

Let's go over a quick recap comparing promises, callbacks and generators. Afterwards we'll look into Async Functions in JavaScript, and how this new feature can help make our code more readable.

4.4.1 Flavors of Async Code

Let's suppose we had code like the following. Here I'm wrapping a `fetch` request in a `getRandomArticle` function. The promise fulfills with the JSON `body` when successful, and follows standard `fetch` rejection mechanics otherwise.

```
function getRandomArticle () {
  return fetch('/articles/random', {
    headers: new Headers({
      Accept: 'application/json'
    })
  })
  .then(res => res.json())
}
```

The next piece of code shows how typical usage for `getRandomArticle` might look like. We build a promise chain that takes the JSON object for the article and passes it through an asynchronous `renderView` view rendering function, which fulfills as an HTML page. We then replace the contents of our page with that HTML. In order to avoid silent errors, we'll also print any rejection reasons using `console.error`.

```
getRandomArticle()
  .then(model => renderView(model))
  .then(html => setPageContents(html))
  .then(() => console.log('Successfully changed page!'))
  .catch(reason => console.error(reason));
```

Chaining promises can become hard to debug: the root cause of a flow control error can be challenging to track down, and writing promise-based code flows is typically much easier than reading them, which leads to code that becomes difficult to maintain over time.

If we were to use plain JavaScript callbacks, our code would become repetitive, as demonstrated in the next code listing. At the same time, we're running into callback hell: we're adding a level of indentation for each step in our asynchronous code flow, making our code increasingly harder to read with each step we add.

```
getRandomArticle((err, model) => {
  if (err) {
    return console.error(reason)
```

```
    }
    renderView(model, (err, html) => {
      if (err) {
        return console.error(reason)
      }
      setPageContents(html, err => {
        if (err) {
          return console.error(reason)
        }
        console.log('Successfully changed page!')
      })
    })
  })
```

Libraries can, of course, help with callback hell and repetitive error handling. Libraries like `async` take advantage of normalized callbacks where the first argument is reserved for errors. Using their `waterfall` method, our code becomes terse again.

```
async.waterfall([
  getRandomArticle,
  renderView,
  setPageContents
], (err, html) => {
  if (err) {
    return console.error(reason)
  }
  console.log('Successfully changed page!')
})
```

Let's look at a similar example, but this time we'll be using generators. The following is a rewrite of `getRandomArticle` where we consume a generator for the sole purpose of changing the way in which `getRandomArticle` is consumed.

```
function getRandomArticle (gen) {
  const g = gen();
  fetch('/articles/random', {
    headers: new Headers({
      Accept: 'application/json'
    })
  })
  .then(res => res.json())
  .then(json => g.next(json))
  .catch(error => g.throw(error))
}
```

The following piece of code shows how you can pull the `json` from `getRandomArticle` by way of a `yield` expression. Even though that looks somewhat synchronous, there's now a generator function wrapper involved. As soon as we want to add more steps, we need to heavily modify `getRandomArticle` so that it yields the results we want, and make the necessary changes to the generator function in order to consume the updated sequence of results.

```
getRandomArticle(function* printRandomArticle () {
  const json = yield;
  // render view
});
```

Generators may not be the most straightforward way of accomplishing the results that we want in this case: you're only moving the complexity somewhere else. We might as well stick with Promises.

Besides involving an unintuitive syntax into the mix, your iterator code will be highly coupled to the generator function that's being consumed. That means you'll have to change it often as you add new `yield` expressions to the generator code.

A better alternative would be to use an Async Function.

4.4.2 Using `async` / `await`

Async Functions let us take a `Promise`-based implementation and take advantage of the synchronous-looking generator style. A huge benefit in this approach is that you won't have to change the original `getRandomArticle` at all: as long as it returns a promise it can be awaited.

Note that `await` may only be used inside Async Functions, marked with the `async` keyword. Async Functions work similarly to generators, by suspending execution in the local context until a promise settles. If the awaited expression isn't originally a promise, it gets casted into a promise.

The following piece of code consumes our original `getRandomArticle`, which relied on promises. Then it runs that model through an asynchronous `renderView` function, which returns a bit of HTML, and updates the page. Note how we can use `try` / `catch` to handle errors in awaited promises from within the `async` function, treating completely asynchronous code as if it were synchronous.

```
async function read () {
  try {
    const model = await getRandomArticle()
    const html = await renderView(model)
    await setPageContents(html)
    console.log('Successfully changed page!')
  } catch (err) {
    console.error(err)
  }
}

read()
```

An Async Function always returns a `Promise`. In the case of uncaught exceptions, the returned promise settles in rejection. Otherwise, the returned promise resolves to the return value. This aspect of Async Functions allows us to mix them with regular promise-based continuation as well. The following example shows how the two may be combined.

```
async function read () {
  const model = await getRandomArticle()
  const html = await renderView(model)
  await setPageContents(html)
  return 'Successfully changed page!'
}

read()
  .then(message => console.log(message))
  .catch(err => console.error(err))
```

Making the `read` function a bit more reusable, we could return the resulting `html`, and allow consumers to do continuation using promises or yet another Async Function. That way, your `read` function becomes only concerned with pulling down the HTML for a view.

```
async function read () {
  const model = await getRandomArticle()
  const html = await renderView(model)
  return html
}
```

Following the example, we can use plain promises to prints the HTML.

```
read().then(html => console.log(html))
```

Using Async Functions wouldn't be all that difficult for continuation, either. In the next snippet, we create a `write` function used for continuation.

```
async function write () {
  const html = await read()
  console.log(html)
}
```

What about concurrent asynchronous flows?

4.4.3 Concurrent Async Flows

In asynchronous code flows, it is commonplace to execute two or more tasks concurrently. While Async Functions make it easier to write asynchronous code, they also lend themselves to code that executes one asynchronous operation at a time. A function with multiple `await` expressions in it will be suspended once at a time on each `await` expression until that `Promise` is settled, before unsuspending execution and moving onto the next `await` expression — this is a similar case to what we observe with generators and `yield`.

```
async function concurrent () {
  const p1 = new Promise(resolve => setTimeout(resolve, 500, 'fast'))
```

```
  const p2 = new Promise(resolve => setTimeout(resolve, 200, 'faster'))
  const p3 = new Promise(resolve => setTimeout(resolve, 100, 'fastest'))
  const r1 = await p1 // execution is blocked until p1 settles
  const r2 = await p2
  const r3 = await p3
}
```

We can use `Promise.all` to work around that issue, creating a single promise that we can `await` on. This way, our code blocks until every promise in a list is settled, and they can be resolved concurrently.

The following example shows how you could `await` on three different promises that could be resolved concurrently. Given that `await` suspends your `async` function and the `await Promise.all` expression ultimately resolves into a `results` array, we can take advantage of destructuring to pull individual results out of that array.

```
async function concurrent () {
  const p1 = new Promise(resolve => setTimeout(resolve, 500, 'fast'))
  const p2 = new Promise(resolve => setTimeout(resolve, 200, 'faster'))
  const p3 = new Promise(resolve => setTimeout(resolve, 100, 'fastest'))
  const [r1, r2, r3] = await Promise.all([p1, p2, p3])
  console.log(r1, r2, r3)
  // 'fast', 'faster', 'fastest'
}
```

Promises offer an alternative to `Promise.all` in `Promise.race`. We can use `Promise.race` to get the result from the promise that fulfills quicker.

```
async function race () {
  const p1 = new Promise(resolve => setTimeout(resolve, 500, 'fast'))
  const p2 = new Promise(resolve => setTimeout(resolve, 200, 'faster'))
  const p3 = new Promise(resolve => setTimeout(resolve, 100, 'fastest'))
  const result = await Promise.race([p1, p2, p3])
  console.log(result)
  // 'fastest'
}
```

4.4.4 Error Handling

Errors are swallowed silently within an `async` function, just like inside normal Promises, due to Async Functions being wrapped in a `Promise`. Uncaught exceptions raised in the body of your Async Function or during suspended execution while evaluating an `await` expresion will reject the promise returned by the `async` function.

That is, unless we add `try` / `catch` blocks around `await` expressions. For the portion of the Async Function code that's wrapped, errors are treated under typical `try` / `catch` semantics.

Naturally, this can be seen as a strength: you can leverage `try` / `catch` conventions, something you were unable to do with asynchronous callbacks, and somewhat able to when using promises. In this sense, Async Functions are akin to generators, where we can take advantage of `try` / `catch` thanks to function execution suspension turning asynchronous flows into seemingly synchronous code.

Furthermore, you're able to catch these exceptions from outside the `async` function, by adding a `.catch` clause to the promise they return. While this is a flexible way of combining the `try` / `catch` error handling flavor with `.catch` clauses in Promises, it can also lead to confusion and ultimately cause to errors going unhandled, unless everyone reading the code is comfortable with async function semantics in terms of the promise wrapper and how `try` / `catch` works under this context.

```
read()
  .then(html => console.log(html))
  .catch(err => console.error(err))
```

As you can see, there's quite a few ways in which we can notice exceptions and then handle, log, or offload them.

4.4.6 Understanding Async Function Internals

Async Functions leverage both generators and promises internally. Let's suppose we have the following Async Function.

```
async function example (a, b, c) {
  // example function body
}
```

The next bit shows how the `example` declaration could be converted into a plain old `function` which returns the result of feeding a generator function to a `spawn` helper.

```
function example (a, b, c) {
  return spawn(function* () {
    // example function body
  })
}
```

Inside the generator function, we'll assume `yield` to be the syntactic equivalent of `await`.

In `spawn`, a promise is wrapped around code that will step through the generator function — made out of user code — in series, forwarding values to the generator code (the `async` function's body).

The following listing should aid you in understanding how the `async` / `await` algorithm iterates over a sequence of `await` expressions using a generator. Each item in the sequence is wrapped in a promise and then gets chained with the next step in the sequence. The promise returned by the underlying generator function becomes settled when the sequence ends or one of the promises is rejected.

```
function spawn (generator) {
  // wrap everything in a promise
  return new Promise((resolve, reject) => {
    const g = generator()

    // run the first step
    step(() => g.next())

    function step (nextFn) {
      const next = runNext(nextFn)
      if (next.done) {
        // finished with success, resolve the promise
        resolve(next.value)
        return
      }
      // not finished, chain off the yielded promise and run next step
      Promise
        .resolve(next.value)
        .then(
          value => step(() => g.next(value)),
          err => step(() => g.throw(err))
        )
    }

    function runNext (nextFn) {
      try {
        // resume the generator
        return nextFn()
      } catch (err) {
        // finished with failure, reject the promise
        reject(err)
      }
    }
  })
}
```

Consider the following Async Function. In order to print the result, we're also using promise-based continuation. Let's follow the code as a thought exercise.

```
async function exercise () {
  const r1 = await new Promise(resolve => setTimeout(resolve, 500, 'slowest'))
  const r2 = await new Promise(resolve => setTimeout(resolve, 200, 'slow'))
  return [r1, r2]
}

exercise().then(result => console.log(result))
// <- ['slowest', 'slow']
```

First, we could translate the function to our `spawn` based logic. We wrap the body of our Async Function in a generator passed to `spawn`, and replace any `await` expressions with `yield`.

```
function exercise () {
  return spawn(function* () {
    const r1 = yield new Promise(resolve => setTimeout(resolve, 500, 'slowest'))
    const r2 = yield new Promise(resolve => setTimeout(resolve, 200, 'slow'))
    return [r1, r2]
  })
}

exercise().then(result => console.log(result))
// <- ['slowest', 'slow']
```

When `spawn` is called with the generator function, it immediately creates a generator object and executes `step` a first time, as seen in the next code snippet. The `step` function will also be used whenever we reach a `yield` expression, which are equivalent to the `await` expressions in our Async Function.

```
function spawn (generator) {
  // wrap everything in a promise
  return new Promise((resolve, reject) => {
    const g = generator()

    // run the first step
    step(() => g.next())
    // ...
  })
}
```

The first thing that happens in the `step` function is calling the `nextFn` function inside a `try` / `catch` block. This resumes execution in the generator function. If the generator function were to produce an error, we'd fall into the `catch` clause, and the underlying promise for our Async Function would be rejected without any further steps, as shown next.

```
function step (nextFn) {
  const next = runNext(nextFx)
  // ...
}

function runNext (nextFn) {
  try {
    // resume the generator
    return nextFn()
  } catch (err) {
    // finished with failure, reject the promise
    reject(err)
  }
}
```

Back to the Async Function, code up until the following expression is evaluated. No errors are incurred, and execution in the Async Function is suspended once again.

```
yield new Promise(resolve => setTimeout(resolve, 500, 'slowest'))
```

The yielded expression is received by `step` as `next.value`, while `next.done` indicates whether the generator sequence has ended. In this case, we receive the `Promise` in the function controlling exactly how iteration should occur. At this time, `next.done` is `false, meaning we won't be resolving the async function's wrapper Promise. We wrap +next.value` in a fulfilled `Promise`, just in case we haven't received a `Promise`.

We then wait on the `Promise` to be fulfilled or rejected. If the promise is fulfilled, we push the fulfillment value to the generator function by advancing the generator sequence with `value`. If the promise is rejected, we would've used `g.throw`, which would've resulted in an error being raised in the generator function, causing the Async Function's wrapper promise to be rejected at `runNext`.

```
function step (nextFn) {
  const next = runNext(nextFn)
  if (next.done) {
    // finished with success, resolve the promise
    resolve(next.value)
    return
  }
  // not finished, chain off the yielded promise and run next step
  Promise
    .resolve(next.value)
    .then(
      value => step(() => g.next(value)),
      err => step(() => g.throw(err))
    )
}
```

Using `g.next()` on its own means that the generator function resumes execution. By passing a value to `g.next(value)`, we've made it so that the `yield` expression evaluates to that `value`. The `value` in question is, in this case, the fulfillment value of the originally yielded `Promise`, which is *`slowest`*.

Back in the generator function, we assign *`slowest`* `to +r1`.

```
const r1 = yield new Promise(resolve => setTimeout(resolve, 500, 'slowest'))
```

Then, execution runs up until the second `yield` statement. The `yield` expression once again causes execution in the Async Function to be suspended, and sends the new `Promise` to the `spawn` iterator.

```
yield new Promise(resolve => setTimeout(resolve, 200, 'slow'))
```

The same process is repeated this time: `next.done` is `false` because we haven't reached the end of the generator function. We wrap the Promise in another promise just in case, and once the promise settles with *`slow`*, we resume execution in the generator function.

Then we reach the return statement in the generator function. Once again, execution is suspended in the generator function, and returned to the iterator.

```
return [r1, r2]
```

At this point, `next` evaluates to the following object.

```
{
  value: ['slowest', 'slow']
  done: true
}
```

Immediately, the iterator checks that `next.done` is indeed `true`, and resolves the Async Function to `[slowest, slow]`.

```
if (next.done) {
  // finished with success, resolve the promise
  resolve(next.value)
  return
}
```

Now that the promise returned by `exercise` is settled in fulfillment, the log statement is finally printed.

```
exercise().then(result => console.log(result))
// <- ['slowest', 'slow']
```

Async Functions, then, are little more than a sensible default when it comes to iterating generator functions in such a way that makes passing values back and forth as frictionless as possible. Some syntactic sugar hides away the generator function, the `spawn` function used to iterate over the sequence of yielded expressions, and `yield` becomes `await`.

Noting that Async Functions are syntactic sugar on top of generators and promises, we can also make a point about the importance of learning how each of these constructs work in order to get better insight into how you can mix, match, and combine all the different flavors of asynchronous code flows together.

4.5 Asynchronous Iteration

As explained in section 4.2, You may recall how iterators leverage `Symbol.iterator` as an interface to define how an object is to be iterated.

```
const sequence = {
  [Symbol.iterator]() {
    const items = ['i', 't', 'e', 'r', 'a', 'b', 'l', 'e']
    return {
      next: () => ({
        done: items.length === 0,
        value: items.shift()
      })
```

```
      }
    }
  }
```

You may also recall that the `sequence` object can be iterated in a number of different ways such as the spread operator, `Array.from` and `for..of`, among others.

```
[...sequence]
// <- ['i', 't', 'e', 'r', 'a', 'b', 'l', 'e']
Array.from(sequence)
// <- ['i', 't', 'e', 'r', 'a', 'b', 'l', 'e']

for (const item of sequence) {
  console.log(item)
  // <- 'i'
  // <- 't'
  // <- 'e'
  // <- 'r'
  // <- 'a'
  // <- 'b'
  // <- 'l'
  // <- 'e'
}
```

The contract for an iterator mandates that the `next` method of `Symbol.iterator` instances returns an object with `value` and `done` properties. The `value` property indicates the current value in the sequence, while `done` is a boolean indicating whether the sequence has ended.

4.5.1 Async Iterators

In **async iterators**, the contract has a subtle difference: `next` is supposed to return a `Promise` that resolves to an object containing `value` and `done` properties. The promise enables the sequence to define asynchronous tasks before the next item in the series is resolved. A new `Symbol.asyncIterator` is introduced to declare asynchronous iterators, in order to avoid confusion that would result of reusing `Symbol.iterator`.

The `sequence` iterable could be made compatible with the async iterator interface with two small changes: we replace `Symbol.iterator` with `Symbol.asyncIterator`, and we wrap the return value for the `next` method in `Promise.resolve`, thus returning a `Promise`.

```
const sequence = {
  [Symbol.asyncIterator]() {
    const items = ['i', 't', 'e', 'r', 'a', 'b', 'l', 'e']
    return {
      next: () => Promise.resolve({
        done: items.length === 0,
        value: items.shift()
```

```
        })
      }
    }
  }
```

A case could be made for an infinite sequence that increases its value at a certain time interval. The following example has an `interval` function which returns an infinite async sequence. Each step resolves to the next value in the sequence after `duration`.

```
const interval = duration => ({
  [Symbol.asyncIterator]: () => ({
    i: 0,
    next () {
      return new Promise(resolve =>
        setTimeout(() => resolve({
          value: this.i++,
          done: false
        }), duration)
      )
    }
  })
})
```

In order to consume an async iterator, we can leverage the new `for await..of` construct introduced alongside Async Iterators. This is yet another way of writing code that behaves asynchronously yet looks synchronous. Note that `for await..of` statements are only allowed inside Async Functions.

```
async function print () {
  for await (const i of interval(1000)) {
    console.log(`${i} seconds ellapsed.`)
  }
}
print()
```

4.5.2 Async Generators

Like with regular iterators, there's async generators to complement async iterators. An async generator function is like a generator function, except that it also supports `await` and `for await..of` declarations. The following example shows a `fetchInterval` generator that fetches a resource periodically at an interval.

```
async function* fetchInterval(duration, ...params) {
  for await (const i of interval(duration)) {
    yield await fetch(...params)
  }
}
```

When stepped over, async generators return objects with a `{ next, return, throw }` signature, whose methods return promises for `{ next, done }`. This is in contrast with regular generators which return `{ next, done }` directly.

You can consume the `interval` async generator in exactly the same way you could consume the object-oriented async iterator. The following example consumes the `fetchInterval` generator to poll an `/api/status` HTTP resource and leverage its JSON response. After each step ends, we wait for a second and repeat the process.

```
async function process () {
  for await (const response of fetchInterval(1000, '/api/status')) {
    const data = await response.json()
    // use updated data
  }
}
process()
```

As highlighted in section 4.2.2, it's important to break out of this kinds of sequences, in order to avoid infinite loops.

CHAPTER 5

Leveraging ECMAScript Collections

JavaScript data structures are flexible enough that we're able to turn any object into a hash-map, where we map string keys to arbitrary values. For example, one might use an object to map `npm` package names to their metadata, as shown next.

```
const registry = {}
function add (name, meta) {
  registry[name] = meta
}
function get (name) {
  return registry[name]
}
add('contra', { description: 'Asynchronous flow control' })
add('dragula', { description: 'Drag and drop' })
add('woofmark', { description: 'Markdown and WYSIWYG editor' })
```

There's several problems with this approach, outlined below.

- Security issues where user-provided keys like *proto*, `toString`, or anything in `Object.prototype` break expectations and make interaction with this kind of hash-map data structures more cumbersome
- Iteration over list items is verbose with `Object.keys(registry).forEach`
- Keys are limited to strings, making it hard to create hash-maps where you'd like to index values by DOM elements or other non-string references

The first problem could be fixed using a prefix, and being careful to always get or set values in the hash-map through functions that add those prefixes, to avoid mistakes.

```
const registry = {}
function add (name, meta) {
  registry['pkg:' + name] = meta
}
```

```
function get (name) {
  return registry['pkg:' + name]
}
```

An alternative could also be using `Object.create(null)` instead of an empty object literal. In this case, the created object won't inherit from `Object.prototype`, meaning it won't be harmed by *proto* and friends.

```
const registry = Object.create(null)
function add (name, meta) {
  registry[name] = meta
}
function get (name) {
  return registry[name]
}
```

For iteration we could create a `list` function that returns key/value tuples.

```
const registry = Object.create(null)
function list () {
  return Object.keys(registry).map(key => [key, registry[key]])
}
```

Or we could implement the iterator protocol on our hash-map. Here we are trading complexity in favor of convenience: the iterator code is more complicated to read than the former case where we had a `list` function with familiar `Object.keys` and `Array#map` methods. In the following example, however, accessing the list is even easier and more convenient than through `list`: following the iterator protocol means there's no need for a custom `list` function.

```
const registry = Object.create(null)
registry[Symbol.iterator] = () => {
  const keys = Object.keys(registry)
  return {
    next () {
      const done = keys.length === 0
      const key = keys.shift()
      const value = [key, registry[key]]
      return { done, value }
    }
  }
}
console.log([...registry])
```

When it comes to using non-string keys, though, we hit a hard limit in ES5 code. Luckily for us, though, ES6 collections provide us with an even better solution. ES6 collections don't have key-naming issues, and they facilitate collection behaviors, like the iterator we've implemented on our custom hash-map, out the box. At the same time, ES6 collections allow arbitrary keys, and aren't limited to string keys like regular JavaScript objects.

Let's plunge into their practical usage and inner workings.

5.1 Using ES6 Maps

ES6 introduces built-in collections, such as `Map`, meant to alleviate implementation of patterns such as those we outlined earlier when building our own hash-map from scratch. `Map` is a key/value data structure in ES6 that more naturally and efficiently lends itself to creating maps in JavaScript without the need for object literals.

5.1.1 First Look into ES6 Maps

Here's how what we had earlier would have looked like when using ES6 maps. As you can see, the implementation details we've had to come up with for our custom ES5 hash-map are already built into `Map`, vastly simplifying our use case.

```
const map = new Map()
map.set('contra', { description: 'Asynchronous flow control' })
map.set('dragula', { description: 'Drag and drop' })
map.set('woofmark', { description: 'Markdown and WYSIWYG editor' })
console.log([...map])
```

Once you have a map, you can query whether it contains an entry by a `key` provided via the `map.has` method.

```
map.has('contra')
// <- true
map.has('jquery')
// <- false
```

Earlier, we pointed out that maps don't cast keys the way traditional objects do. This is typically an advantage, but you need to keep in mind that they won't be treated the same when querying the map, either.

```
const map = new Map([[1, 'a']])
map.has(1)
// <- true
map.has('1')
// <- false
```

The `map.get` method takes a map entry `key` and returns the `value` if an entry by the provided key is found.

```
map.get('contra')
// <- { description: 'Asynchronous flow control' }
```

Deleting values from the map is possible through the `map.delete` method, providing the `key` for the entry you want to remove.

```
map.delete('contra')
map.get('contra')
// <- undefined
```

You can clear the entries for a `Map` entirely, without losing the reference to the map itself. This can be handy in cases where you want to reset state for an object.

```
const map = new Map([[1, 2], [3, 4], [5, 6]])
map.has(1)
// <- true
map.clear()
map.has(1)
// <- false
[...map]
// <- []
```

Maps come with a read-only `.size` property that behaves similarly to `Array#length` — at any point in time it gives you the current amount of entries in the map.

```
const map = new Map([[1, 2], [3, 4], [5, 6]])
map.size
// <- 3
map.delete(3)
map.size
// <- 2
map.clear()
map.size
// <- 0
```

You're able to use arbitrary objects when choosing map keys: you're not limited to using primitive values like symbols, numbers, or strings. Instead, you can use functions, objects, dates — and even DOM elements, too. Keys won't be casted to strings as we observe with plain JavaScript objects, but instead their references are preserved.

```
const map = new Map()
map.set(new Date(), function today () {})
map.set(() => 'key', { key: 'door' })
map.set(Symbol('items'), [1, 2])
```

As an example, if we chose to use a symbol as the key for a map entry, we'd have to use a reference to that same symbol to get the item back, as demonstrated in the following snippet of code.

```
const map = new Map()
const key = Symbol('items')
map.set(key, [1, 2])
map.get(Symbol('items')); // not the same reference as "key"
// <- undefined
map.get(key)
// <- [1, 2]
```

Assuming an array of key/value pair `items` you want to include on a map, we could use a `for..of` loop to iterate over those `items` and add each pair to the map using `map.set`, as shown in the following code snippet. Note how we're using destructuring during the `for..of` loop in order to effortlessly pull the `key` and `value` out of each two-dimensional item in `items`.

```
const items = [
  [new Date(), function today () {}],
  [() => 'key', { key: 'door' }],
  [Symbol('items'), [1, 2]]
]
const map = new Map()
for (let [key, value] of items) {
  map.set(key, value)
}
```

Maps are iterable objects as well, because they implement a `Symbol.iterator` method. Thus, a copy of the map can be created using a `for..of` loop using similar code to what we've just used to create a map out of the `items` array.

```
const copy = new Map()
for (let [key, value] of map) {
  copy.set(key, value)
}
```

In order to keep things simple, you can initialize maps directly using any object that follows the iterable protocol and produces a collection of `[key, value]` items. The following code snippet uses an array to seed a newly created `Map`. In this case, iteration occurs entirely in the `Map` constructor.

```
const items = [
  [new Date(), function today () {}],
  [() => 'key', { key: 'door' }],
  [Symbol('items'), [1, 2]]
]
const map = new Map(items)
```

Creating a copy of a map is even easier: you feed the map you want to copy into a new map's constructor, and get a copy back. There isn't a special `new Map(Map)` overload. Instead, we take advantage that map implements the iterable protocol and also consumes iterables when constructing a new map. The following code snippet demonstrates how simple that is.

```
const copy = new Map(map)
```

Just like maps are easily fed into other maps because they're iterable objects, they're also easy to consume. The following piece of code demonstrates how we can use the spread operator to this effect.

```
const map = new Map()
map.set(1, 'one')
map.set(2, 'two')
map.set(3, 'three')
console.log([...map])
// <- [[1, 'one'], [2, 'two'], [3, 'three']]
```

In the following piece of code we've combined several new features in ES6: `Map`, the `for..of` loop, `let` variables, and template literals.

```
const map = new Map()
map.set(1, 'one')
map.set(2, 'two')
map.set(3, 'three')
for (let [key, value] of map) {
  console.log(`${ key }: ${ value }`)
  // <- '1: one'
  // <- '2: two'
  // <- '3: three'
}
```

Even though map items are accessed through programmatic API, their keys are unique, just like with hash-maps. Setting a key over and over again will only overwrite its value. The following code snippet demonstrates how writing the *a* item over and over again results in a map containing only a single item.

```
const map = new Map()
map.set('a', 1)
map.set('a', 2)
map.set('a', 3)
console.log([...map])
// <- [['a', 3]]
```

In ES6 maps, `NaN` becomes a "corner-case" that gets treated as a value that's equal to itself, even though the `NaN === NaN` expression evaluates to `false`. A number of ECMAScript features introduced in ES6 and later use a different comparison algorithm than that of ES5 and earlier where `NaN` is equal to `NaN`, although `NaN !== NaN`; and `0+ is different from -0, even though` 0 === -0+. The following piece of code shows how even though `NaN` is typically evaluated to be different than itself, `Map` considers `NaN` to be a constant value that's always the same.

```
console.log(NaN === NaN)
// <- false
const map = new Map()
map.set(NaN, 'a')
map.set(NaN, 'b')
console.log([...map])
// <- [[NaN, 'b']]
```

When you iterate over a `Map`, you are actually looping over its `.entries()`. That means that you don't need to explicitly iterate over `.entries()`. It'll be done on your behalf anyways: `map[Symbol.iterator]` points to `map.entries`. The `.entries()` method returns an iterator for the key/value pairs in the map.

```
map[Symbol.iterator] === map.entries
// <- true
```

There are has two other `Map` iterators you can leverage: `.keys()` and `.values()`. The first enumerates keys in a map while the second enumerates values, as opposed to `.entries()` which enumerates key/value pairs. The following snippet illustrates the differences between all three methods.

```
const map = new Map([[1, 2], [3, 4], [5, 6]])
[...map.keys()]
// <- [1, 3, 5]
[...map.values()]
// <- [2, 4, 6]
[...map.entries()]
// <- [[1, 2], [3, 4], [5, 6]]
```

Map entries are always iterated in insertion order. This contrasts with `Object.keys`, which is specified to follow an arbitrary order. Although, in practice, insertion order is typically preserved by JavaScript engines regardless of the specification.

Maps have a `.forEach` method that's identical in behavior to that in ES5 `Array` objects. Once again, keys do not get casted into strings in the case of `Map`, as demonstrated below.

```
const map = new Map([[NaN, 1], [Symbol(), 2], ['key', 'value']])
map.forEach((value, key) => console.log(key, value))
// <- NaN 1
// <- Symbol() 2
// <- 'key' 'value'
```

Earlier, we brought up the ability of providing arbitrary object references as the key to a `Map` entry. Let's go into a concrete use case for that API.

5.1.2 Hash-Maps and the DOM

In ES5, whenever we wanted to associate a DOM element with an API object connecting that element with some library, we had to implement a verbose and slow pattern such as the one in the following code listing. That code returns an API object with a few methods associated to a given DOM element, allowing us to put DOM elements on a map from which we can later retrieve the API object for a DOM element.

```
const map = []
function customThing (el) {
  const mapped = findByElement(el)
  if (mapped) {
    return mapped
  }
  const api = {
    // custom thing api methods
  }
  const entry = storeInMap(el, api)
  api.destroy = destroy.bind(null, entry)
  return api
```

```
}
function storeInMap (el, api) {
  const entry = { el: el, api: api }
  map.push(entry)
  return entry
}
function findByElement (el) {
  for (const i = 0; i < map.length; i++) {
    if (map[i].el === el) {
      return map[i].api
    }
  }
}
function destroy (entry) {
  const i = map.indexOf(entry)
  map.splice(i, 1)
}
```

One of the most valuable aspects of `Map` is the ability to index by DOM elements. That, combined with the fact that `Map` also has collection manipulation abilities greatly simplifies things.

```
const map = new Map()
function customThing (el) {
  const mapped = findByElement(el)
  if (mapped) {
    return mapped
  }
  const api = {
    // custom thing api methods
    destroy: destroy.bind(null, el)
  }
  storeInMap(el, api)
  return api
}
function storeInMap (el, api) {
  map.set(el, api)
}
function findByElement (el) {
  return map.get(el)
}
function destroy (el) {
  map.delete(el)
}
```

The fact that mapping functions have become one liners thanks to native `Map` methods means we could inline those functions instead, as readability is no longer an issue. The following piece of code is a vastly simplified alternative to the ES5 piece of code we started with. Here we're not concerned with implementation details anymore, but have instead boiled the DOM-to-API mapping to its bare essentials.

```
const map = new Map()
function customThing (el) {
  const mapped = map.get(el)
  if (mapped) {
    return mapped
  }
  const api = {
    // custom thing api methods
    destroy: () => map.delete(el)
  }
  map.set(el, api)
  return api
}
```

Maps aren't the only kind of built-in collection in ES6, there's also `WeakMap`, `Set`, and `WeakSet`. Let's proceed by digging into `WeakMap`.

5.2 Understanding and Using WeakMap

For the most part, you can think of `WeakMap` as a subset of `Map`. The `WeakMap` collection imposes a number of limitations that we didn't find in `Map`. The biggest limitation is that `WeakMap` is not iterable like `Map`: there is no iterable protocol in `WeakMap`, no `WeakMap#entries`, no `WeakMap#keys`, no `WeakMap#values`, no `WeakMap#forEach` and no `WeakMap#clear` methods.

Another distinction found in `WeakMap` is that every `key` must be an object. This is in contrast with `Map` where, while object references were allowed as keys, they weren't enforced. Remember that `Symbol` is a value type, and as such, they're not allowed either.

```
const map = new WeakMap()
map.set(Date.now, 'now')
map.set(1, 1)
// <- TypeError
map.set(Symbol(), 2)
// <- TypeError
```

In exchange for having a more limited feature set, `WeakMap` key references are weakly held, meaning that the objects referenced by `WeakMap` keys are subject to garbage collection if there are no other references to them. This kind of behavior is useful when you have metadata about a `person`, for example, but you want the `person` to be garbage collected when and if the only reference back to `person` is their metadata. You can now keep that metadata in a `WeakMap` using `person` as the key.

With `WeakMap`, you are still able to provide an iterable for initialization.

```
const map = new WeakMap([
  [new Date(), 'foo'],
```

```
  [() => 'bar', 'baz']
])
```

While WeakMap has a smaller API surface in order to effectively allow for weak references, it still carries .has, .get, and .delete methods like Map does. The brief snippet of code shown next demonstrates these methods.

```
const date = new Date()
const map = new WeakMap([[date, 'foo'], [() => 'bar', 'baz']])
map.has(date)
// <- true
map.get(date)
// <- 'foo'
map.delete(date)
map.has(date)
// <- false
```

5.2.1 Is WeakMap Strictly Worse Than Map?

The distinction that makes WeakMap worth the trouble is in its name. Given that WeakMap holds references to its keys weakly, those object are subject to garbage collection if there are no other references to them other than as WeakMap keys. This is in contrast with Map which holds strong object references, preventing Map keys from being garbage collected.

Correspondingly, use cases for WeakMap revolve around the need to specify metadata or extend an object while still being able to garbage collect that object if there are no other references to it. A perfect example might be the underlying implementation for process.on(*unhandledRejection*) in Node.js, which uses a WeakMap to keep track of rejected promises that weren't dealt with. By using WeakMap, the implementation prevents memory leaks because the WeakMap won't be grabbing onto those promises strongly. In this case, we have a simple map that weakly holds onto promises, but is flexible enough to handle entries being removed from the map when they're no longer referenced anywhere else.

Keeping data about DOM elements that should be released from memory when they're no longer of interest is another important use case, and in this regard using WeakMap is an even better solution to the DOM-related API caching solution we implemented earlier using Map.

In so many words, then: no, WeakMap is not strictly worse than Map — they just cater to different use cases.

5.3 Sets in ES6

A set is a grouping of values. Sets are also a new collection type in ES6. Sets are similar to Map.

- `Set` is also iterable
- `Set` constructor also accepts an iterable
- `Set` also has a `.size` property
- Keys can be arbitrary values or object references
- Keys must be unique
- `NaN` equals `NaN` when it comes to `Set` too
- All of `.keys`, `.values`, `.entries`, `.forEach`, `.has`, `.delete`, and `.clear`

At the same time, sets are different from `Map` in a few key ways. Sets don't hold key value pairs, there's only one dimension. You can think of sets as being similar to arrays where every element is distinct from each other.

There isn't a `.get` method in `Set`. A `set.get(key)` method would be redundant: if you already have the `key` then there isn't anything else to get, as that's the only dimension. If we wanted to check for whether the `key` is in the set, there's `set.has(key)` to fulfill that role.

Similarly, a `set.set(key)` method wouldn't be aptly named, as you aren't setting a `value` to a `key`, but merely adding a value to the set instead. Thus, the method to add values to a set is `set.add`, as demonstrated in the next snippet.

```
const set = new Set()
set.add({ an: 'example' })
```

Sets are iterable, but unlike maps you only iterate over keys, not key value pairs. The following example demonstrates how sets can be spread over an array using the spread operator and creating a single dimensional list.

```
const set = new Set(['a', 'b', 'c'])
console.log([...set])
// <- ['a', 'b', 'c']
```

In the following example you can note how a set won't contain duplicate entries: every element in a `Set` must be unique.

```
const set = new Set(['a', 'b', 'b', 'c', 'c'])
console.log([...set])
// <- ['a', 'b', 'c']
```

The following piece of code creates a `Set` with all of the `<div>` elements on a page and then prints how many were found. Then, we query the DOM again and call `set.add` again for every DOM element. Given that they're all already in the `set`, the `.size` property won't change, meaning the `set` remains the same.

```
function divs () {
  return [...document.querySelectorAll('div')]
```

```
}
const set = new Set(divs())
console.log(set.size)
// <- 56
divs().forEach(div => set.add(div))
console.log(set.size)
// <- 56
```

5.4 ES6 WeakSets

In a similar fashion to `Map` and `WeakMap`, `WeakSet` is the weak version of `Set` that can't be iterated over. You can't iterate over a `WeakSet`. The values in a `WeakSet` must be unique object references. If nothing else is referencing a `value` found in a `WeakSet`, it'll be subject to garbage collection.

Much like in `WeakMap`, you can only `.add`, `.delete`, and check if `WeakSet#has` a given `value`. Just like in `Set`, there's no `.get` because sets are one-dimensional.

We aren't allowed to add primitive values such as strings or symbols to a `WeakSet`.

```
const set = new WeakSet()
set.add('a')
// <- TypeError
set.add(Symbol())
// <- TypeError
```

Passing iterators to the constructor is allowed, even though a `WeakSet` instance is not iterable itself. That iterable will be iterated when the set is constructed, adding each entry in the iterable sequence to the set. The following snippet of code serves as an example.

```
const set = new WeakSet([
  new Date(),
  {},
  () => {},
  [1]
])
```

As a use case for `WeakSet`, you may consider the following piece of code where we have a `Car` class that ensures its methods are only called upon car objects that are instances of the `Car` class by using a `WeakSet`.

```
const cars = new WeakSet()
class Car {
  constructor() {
    cars.add(this)
  }
  fuelUp () {
    if (!cars.has(this)) {
      throw new TypeError('Car#fuelUp called on incompatible object!')
    }
```

```
  }
}
```

When it comes to deciding whether to use `Map`, `WeakMap`, `Set`, or `WeakSet`, there's a series of questions you should ask yourself. For instance, if you are using the collection to extend objects using metadata, then you should know to look at the weak collections. If your only concern is whether something is present, then you probably need a `Set`. If you are looking to create a cache, you should probably use a `Map`.

Collections in ES6 provide built-in solutions for common use cases that were previously cumbersome to implement by users, such as the case of `Map`, or hard to execute correctly, as in the case of `WeakMap` where we allow references to be released if they're no longer interesting, avoiding memory leaks.

CHAPTER 6

Managing Property Access with Proxies

Proxies are an interesting and powerful feature coming in ES6 that act as intermediaries between API consumers and objects. In a nutshell, you can use a `Proxy` to determine the desired behavior whenever the properties of an underlying `target` object are accessed. A `handler` object can be used to configure traps for your `Proxy`, which define and restrict how the underlying object is accessed, as we'll see in a bit.

6.1 Getting Started with Proxy

By default, proxies don't do much — in fact they don't do anything. If you don't provide any configuration, your `proxy` will just work as a pass-through to the `target` object, also known as a "no-op forwarding `Proxy`" meaning that all operations on the `Proxy` object defer to the underlying object.

In the following piece of code, we create a no-op forwarding `Proxy`. You can observe how by assigning a value to `proxy.exposed`, that value is passed onto `target.exposed`. You could think of proxies as the gatekeepers of their underlying objects: they may allow certain operations to go through and prevent others from passing, but they carefully inspect every single interaction with their underlying objects.

```
const target = {}
const handler = {}
const proxy = new Proxy(target, handler)
proxy.exposed = true
console.log(target.exposed)
// <- true
console.log(proxy.somethingElse)
// <- undefined
```

We can make the proxy object a bit more interesting by adding traps. Traps allow you to intercept interactions with `target` in several different ways, as long as those interactions happen through the `proxy` object. For instance, we could use a `get` trap to log every attempt to pull a value out of a property in `target`, or a `set` trap to prevent certain properties from being written to. Let's kick things off by learning more about `get` traps.

6.1.1 Trapping `get` accessors

The proxy in the following code listing is able to track any and every property access event because it has a `handler.get` trap. It can also be used to transform the value returned by accessing any given property before returning a value to the accessor. We can already imagine `Proxy` becoming a staple when it comes to developer tooling, as it's particularly well equipped for code instrumentation and introspection.

```
const handler = {
  get (target, key) {
    console.log(`Get on property "${ key }"`)
    return target[key]
  }
}
const target = {}
const proxy = new Proxy(target, handler)
proxy.numbers = 123
proxy.numbers
// 'Get on property "numbers"'
// <- 123
proxy['something-else']
// 'Get on property "something-else"'
// <- undefined
```

As a complement to proxies, ES6 introduces a `Reflect` built-in object. The traps in ES6 proxies are mapped one-to-one to the `Reflect` API: For every trap, there's a matching reflection method in `Reflect`. These methods can be particularly useful when we want to provide the default behavior of proxy traps, but we don't want to concern ourselves with the implementation of that behavior.

In the following code snippet we use `Reflect.get` to provide the default behavior for `get` operations, while not worrying about accessing the `key` property in `target` by hand. While in this case the operation may seem trivial, the default behavior for other traps may be harder to remember and implement correctly. However, when using the `Reflect` API, we just need to forward the method call to the reflection API and return the result.

```
const handler = {
  get (target, key) {
    console.log(`Get on property "${ key }"`)
    return Reflect.get(target, key)
```

```
  }
}
const target = {}
const proxy = new Proxy(target, handler)
```

The `get` trap doesn't necessarily have to return the original `target[key]` value. Imagine the case where you wanted properties prefixed by an underscore to be inaccessible. In this case, you could throw an error, letting the consumer know that the property is inaccessible through the proxy.

```
const handler = {
  get (target, key) {
    const [prefix] = key
    if (prefix === '_') {
      throw new Error(`Property "${ key }" cannot be read through this proxy.`)
    }
    return Reflect.get(target, key)
  }
}
const target = {}
const proxy = new Proxy(target, handler)
proxy._secret
// <- Uncaught Error: Property "_secret" cannot be read through this proxy.
```

To the keen observer, it may be apparent that disallowing access to certain properties through the proxy becomes most useful when creating a proxy with clearly defined access rules for the underlying `target` object, and exposing that proxy instead of the `target` object. That way you can still access the underlying object freely, but consumers are forced to go through the proxy and play by its rules, putting you in control of exactly how they can interact with the object. This wasn't possible before proxies were introduced in ES6.

6.1.2 Trapping `set` accessors

As the counterpart of `get` traps, `set` traps can intercept property assignment. Suppose we wanted to prevent assignment on properties starting with an underscore. We could replicate the `get` trap we implemented earlier to block assignment as well.

The `Proxy` in the next example prevents underscored property access for both `get` and `set` when accessing `target` through `proxy`. Note how the `set` trap returns `true` here? Returning `true` in a `set` trap means that setting the property `key` to the provided `value` should succeed. If the return value for the `set` trap is `false`, setting the property value will throw a `TypeError` under strict mode, and otherwise fail silently. If we were using `Reflect.set` instead, as brought up earlier, we wouldn't need to concern ourselves with these implementation details: we could just `return Reflect.set(target, key, value)`. That way, when somebody reads our code later, they'll be able to understand that we're using `Reflect.set`, which is equivalent to the default operation, equivalent to the case where a `Proxy` object isn't part of the equation.

```
const handler = {
  get (target, key) {
    invariant(key, 'get')
    return Reflect.get(target, key)
  },
  set (target, key, value) {
    invariant(key, 'set')
    return Reflect.set(target, key, value)
  }
}
function invariant (key, action) {
  if (key.startsWith('_')) {
    throw new Error(`Invalid attempt to ${ action } private "${ key }" property`)
  }
}
const target = {}
const proxy = new Proxy(target, handler)
```

The following piece of code demonstrates how the `proxy` responds to consumer interaction.

```
proxy.text = 'the great black pony ate your lunch'
console.log(target.text)
// <- 'the great black pony ate your lunch'
proxy._secret
// <- Error: Invalid attempt to get private "_secret" property
proxy._secret = 'invalidate'
// <- Error: Invalid attempt to set private "_secret" property
```

The object being proxied, `target` in our latest example, should be completely hidden from consumers, so that they are forced to access it exclusively through `proxy`. Preventing direct access to the `target` object means that they will have to obey the access rules defined on the `proxy` object — such as *"properties prefixed with an underscore are off-limits"*.

To that end, you could wrap the proxied object in a function and then return the `proxy`.

```
function proxied () {
  const target = {}
  const handler = {
    get (target, key) {
      invariant(key, 'get')
      return Reflect.get(target, key)
    },
    set (target, key, value) {
      invariant(key, 'set')
      return Reflect.set(target, key, value)
    }
```

```
    }
    return new Proxy(target, handler)
  }
  function invariant (key, action) {
    if (key.startsWith('_')) {
      throw new Error(`Invalid attempt to ${ action } private "${ key }" property`)
    }
  }
```

Usage stays the same, except that now access to `target` is completely governed by `proxy` and its mischievous traps. At this point, any `_secret` properties in `target` are completely inaccessible through the proxy, and since `target` can't be accessed directly from outside the `proxied` function, they're sealed off from consumers for good.

A general purpose approach would be to offer a proxying function that takes an `original` object and returns a proxy. You can then call that function whenever you're about to expose a public API, as shown in the following code block. The `concealWithPrefix` function wraps the `original` object in a `Proxy` where properties prefixed with a `prefix` value (or `_` if none is provided) can't be accessed.

```
function concealWithPrefix (original, prefix='_') {
  const handler = {
    get (original, key) {
      invariant(key, 'get')
      return Reflect.get(original, key)
    },
    set (original, key, value) {
      invariant(key, 'set')
      return Reflect.set(original, key, value)
    }
  }
  return new Proxy(original, handler)
  function invariant (key, action) {
    if (key.startsWith(prefix)) {
      throw new Error(`Invalid attempt to ${ action } private "${ key }" property`)
    }
  }
}
const target = {
  _secret: 'secret',
  text: 'everyone-can-read-this'
}
const proxy = concealWithPrefix(target)
// expose proxy to consumers
```

You might be tempted to argue that you could achieve the same behavior in ES5 simply by using variables privately scoped to the `concealWithPrefix` function, without the need for the `Proxy` itself. The difference is that proxies allow you to "privatize" property access dynamically. Without relying on `Proxy`, you couldn't mark every property that starts with an underscore as private. You could use `Object.freeze` on the object, but then you wouldn't be able to modify the properties yourself, either. Or you could define get and set accessors for every property, but then again you wouldn't be able to block access on every single property, only the ones you explicitly configured getters and setters for.

6.1.3 Schema Validation with Proxies

Sometimes we have an object with user input that we want to validate against a schema, a model of how that input is supposed to be structured, what properties it should have, what types those properties should be, and how those properties should be filled. We'd like to verify that a `customer` email field contains an email address, a numeric `cost` field contains a number, and a required `name` field isn't missing.

There is a number of ways in which you could do schema validation. You could use a validation function that throws errors if an invalid value is found on the object, but you'd have to ensure the object is off limits once you've deemed it valid. You could validate each property individually, but you'd have to remember to validate them whenever they're changed. You could also use a `Proxy`. By providing consumers with a `Proxy` to the actual model object, you'd ensure that the object never enters an invalid state, as an exception would be thrown otherwise.

Another aspect of schema validation via `Proxy` is that it helps you separate validation concerns from the `target` object, where validation occurs sometimes in the wild. The `target` object would stay as a plain old JavaScript object (or POJO, for short), meaning that while you give consumers a validating proxy, you keep an untainted version of the data that's always valid, as guaranteed by the proxy.

Just like a validation function, the handler settings can be reutilized across several `Proxy` instances, without having to rely on prototypal inheritance or ES6 classes.

In the following example, we have a simple `validator` object, with a `set` trap that looks up properties in a map. When a property gets set through the proxy, its key is looked up on the map. If the map contains a rule for that property, it'll run that function to assert whether the assignment is deemed valid. As long as the `person` properties are set through a proxy using the `validator`, the model invariants will be satisfied according to our predefined validation rules.

```
const validations = new Map()
const validator = {
  set (target, key, value) {
    if (validations.has(key)) {
      return validations[key](value)
    }
    return true
  }
}
validations.set('age', validateAge)
```

```
function validateAge (value) {
  if (typeof value !== 'number' || Number.isNaN(value)) {
    throw new TypeError('Age must be a number')
  }
  if (value <= 0) {
    throw new TypeError('Age must be a positive number')
  }
  return true
}
```

The following piece of code shows how we could consume the `validator` handler. This general-purpose proxy handler is passed into a `Proxy` for the `person` object. The handler then enforces our schema by ensuring that values set through the proxy pass the schema validation rules for any given property. In this case, we've added a validation rule that says `age` must be a positive numeric value.

```
const person = {}
const proxy = new Proxy(person, validator)
proxy.age = 'twenty three'
// <- TypeError: Age must be a number
proxy.age = NaN
// <- TypeError: Age must be a number
proxy.age = 0
// <- TypeError: Age must be a positive number
proxy.age = 28
console.log(person.age)
// <- 28
```

While proxies offer previously-unavailable granular control over what a consumer can and cannot do with an object, as defined by access rules defined by the implementor, there's also a harsher variant of proxies that allows us to completely shut off access to `target` whenever we deem it necessary: revocable proxies.

6.2 Revocable Proxies

Revocable proxies offer more fine-grained control than plain `Proxy` objects. The API is a bit different in that there is no `new` keyword involved, as opposed to `new Proxy(target, handler)`; and a `{ proxy, revoke }` object is returned, instead of just the `proxy` object being returned. Once `revoke()` is called, the `proxy` will throw an error on any operation.

Let's go back to our pass-through `Proxy` example and make it revocable. Note how we're no longer using `new`, how calling `revoke()` over and over has no effect, and how an error is thrown if we attempt to interact with the underlying object in any way.

```
const target = {}
const handler = {}
const { proxy, revoke } = Proxy.revocable(target, handler)
```

```
proxy.isUsable = true
console.log(proxy.isUsable)
// <- true
revoke()
revoke()
revoke()
console.log(proxy.isUsable)
// <- TypeError: illegal operation attempted on a revoked proxy
```

This type of `Proxy` is particularly useful because you can completely cut off access to the `proxy` granted to a consumer. You could expose a revocable `Proxy` and keep around the `revoke` method, perhaps in a `WeakMap` collection. When it becomes clear that the consumer shouldn't have access to `target` anymore, — not even through `proxy` — you `.revoke()` their access rights.

The following example shows two functions. The `getStorage` function can be used to get proxied access into `storage`, and it keeps a reference to the `revoke` function for the returned `proxy` object. Whenever we want to cut off access to `storage` for a given `proxy`, `revokeStorage` will call its associated `revoke` function and remove the entry from the `WeakMap`. Note that making both functions accessible to the same set of consumers won't pose security concerns: once access through a proxy has been revoked, it can't be restored.

```
const proxies = new WeakMap()
const storage = {}

function getStorage () {
  const handler = {}
  const { proxy, revoke } = Proxy.revocable(storage, handler)
  proxies.set(proxy, { revoke })
  return proxy
}

function revokeStorage (proxy) {
  proxies.get(proxy).revoke()
  proxies.delete(proxy)
}
```

Given that `revoke` is available on the same scope where your `handler` traps are defined, you could set up unforgiving access rules such that if a consumer attempts to access a private property more than once you revoke their `proxy` access entirely.

6.3 Proxy Trap Handlers

Perhaps the most interesting aspect of proxies is how you can use them to intercept just about any interaction with the `target` object — not only plain `get` or `set` operations.

We've already covered `get`, which traps property access; and `set`, which traps property assignment. Next up we'll discuss the different kinds of traps you can set up.

6.3.1 has Trap

We can use `handler.has` to conceal any property you want. It's a trap for the `in` operator. In the `set` trap code samples we prevented changes and even access to properties with a certain prefix, but unwanted accessors could still probe the `proxy` to figure out whether these properties exist. There are three alternatives here.

- Do nothing, in which case `key in proxy` falls through to `Reflect.has(target, key)`, the equivalent of `key in target`
- Return `true` or `false` regardless of whether `key` is or is not present in `target`
- Throw an error signaling that the `in` operation is illegal

Throwing an error is quite final, and it certainly doesn't help in those cases where you want to conceal the fact that the property even exists. You would be acknowledging that the property is, in fact, protected. Throwing is, however, valid in those cases where you want the consumer to understand why the operation is failing, as you can explain the failure reason in an error message.

It's often best to indicate that the property is not `in` the object, by returning `false` instead of throwing. A fall-through case where you return the result of the `key in target` expression is a good default case to have.

Going back to the getter/setter example in section 6.1.2, we'll want to return `false` for properties in the prefixed property space and use the default for all other properties. This will keep our inaccessible properties well hidden from unwanted visitors.

```
const handler = {
  get (target, key) {
    invariant(key, 'get')
    return Reflect.get(target, key)
  },
  set (target, key, value) {
    invariant(key, 'set')
    return Reflect.set(target, key, value)
  },
  has (target, key) {
    if (key.startsWith('_')) {
      return false
    }
    return Reflect.has(target, key)
  }
}
function invariant (key, action) {
  if (key.startsWith('_')) {
```

```
      throw new Error(`Invalid attempt to ${ action } private "${ key }" property`)
    }
  }
```

Note how accessing properties through the proxy will now return `false` when querying one of the private properties, with the consumer being none the wiser — completely unaware that we've intentionally hid the property from them. Note how `_secret in target` returns `true` because we're bypassing the proxy. That means we can still use the underlying object unchallenged by tight access control rules while consumers have no choice but to stick to the proxy's rules.

```
const target = {
  _secret: 'securely-stored-value',
  wellKnown: 'publicly-known-value'
}
const proxy = new Proxy(target, handler)
console.log('wellKnown' in proxy)
// <- true
console.log('_secret' in proxy)
// <- false
console.log('_secret' in target)
// <- true
```

We could've thrown an exception instead. That would be useful in situations where attempts to access properties in the private space is seen as a mistake that would've resulted in an invalid state, rather than as a security concern in code that aims to be embedded into third party websites.

6.3.2 deleteProperty Trap

Setting a property to `undefined` clears its value, but the property is still part of the object. Using the `delete` operator on a property with code like `delete cat.furBall` means that the `furBall` property will be forever gone from the `cat` object.

```
const cat = { furBall: true }
cat.furBall = undefined
console.log('furBall' in cat)
// <- true
delete cat.furBall
console.log('furBall' in cat)
// <- false
```

The code in the last example where we prevented access to prefixed properties has a problem: you can't change the value of a `_secret` property, nor even use `in` to learn about its existence, but you still can remove the property entirely using the `delete` operator through the `proxy` object. The following code sample shows that shortcoming in action.

```
const target = { _secret: 'foo' }
const proxy = new Proxy(target, handler)
```

```
console.log('_secret' in proxy)
// <- false
console.log('_secret' in target)
// <- true
delete proxy._secret
console.log('_secret' in target)
// <- false
```

We can use `handler.deleteProperty` to prevent a `delete` operation from working. Just like with the `get` and `set` traps, throwing in the `deleteProperty` trap will be enough to prevent the deletion of a property. In this case, throwing is okay because we want the consumer to know that external operations on prefixed properties are forbidden.

```
const handler = {
  get (target, key) {
    invariant(key, 'get')
    return Reflect.get(target, key)
  },
  set (target, key, value) {
    invariant(key, 'set')
    return Reflect.set(target, key, value)
  },
  deleteProperty (target, key) {
    invariant(key, 'delete')
    return Reflect.deleteProperty(target, key)
  }
}
function invariant (key, action) {
  if (key.startsWith('_')) {
    throw new Error(`Invalid attempt to ${ action } private "${ key }" property`)
  }
}
```

If we ran the exact same piece of code we tried earlier, we'd run into the exception while trying to delete `_secret` from the `proxy`. The following example shows the mechanics of the updated `handler`.

```
const target = { _secret: 'foo' }
const proxy = new Proxy(target, handler)
console.log('_secret' in proxy)
// <- true
delete proxy._secret
// <- Error: Invalid attempt to delete private "_secret" property
```

Consumers interacting with `target` through the `proxy` can no longer delete properties in the `_secret` property space. That's one less thing to worry about!

6.3.3 `defineProperty` Trap

The `Object.defineProperty` function can be used to add new properties to a `target` object, using a property `key` and a property `descriptor`. For the most part, `Object.defineProperty(target, key, descriptor)` is used in two kinds of situations.

1. When we need to ensure cross-browser support of getters and setters
2. When we want to define a custom property accessor

Properties added by hand are read-write, they are deletable, and they are enumerable.

Properties added through `Object.defineProperty`, in contrast, default to being read-only, non-deletable, and non-enumerable. By default, the property is akin to bindings declared using the `const` statement in that it's read-only, but that doesn't make it immutable.

When creating properties through `defineProperty`, you can customize the following aspects of the property descriptor.

- `configurable = false` disables most changes to the property descriptor and makes the property undeletable
- `enumerable = false` hides the property from `for..in` loops and `Object.keys`
- `writable = false` makes the property value read-only
- `value = undefined` is the initial value for the property
- `get = undefined` is a method that acts as the getter for the property
- `set = undefined` is a method that receives the new `value` and updates the property's `value`

Note that you'll have to choose between configuring the `value` and `writable` pair or `get` and `set` pair. When choosing the former you're configuring a data descriptor. You get a data descriptor when creating plain properties, such as in `pizza.topping =` *ham*, too. In that case, `topping` has a `value` and it may or may not be `writable`. If you pick the second pair of options, you're creating an accessor descriptor which is entirely defined by the methods you can use to `get()` or `set(value)` for the property.

The following code sample shows how property descriptors can be completely different depending on whether we use the declarative option or go through the programmatic API. We use `Object.getOwnPropertyDescriptor`, which receives a `target` object+ and a property `key`, to pull the object descriptor for properties we create.

```
const pizza = {}
pizza.topping = 'ham'
```

```
Object.defineProperty(pizza, 'extraCheese', { value: true })
console.log(Object.getOwnPropertyDescriptor(pizza, 'topping'))
// <- { value: 'ham', writable: true, enumerable: true, configurable: true }
console.log(Object.getOwnPropertyDescriptor(pizza, 'extraCheese'))
// <- { value: true, writable: false, enumerable: false, configurable: false }
```

The `handler.defineProperty` trap can be used to intercept properties being defined. Note that this trap intercepts the declarative `pizza.extraCheese = false` property declaration flavor as well as `Object.defineProperty` calls. As arguments for the trap, you get the `target` object, the property `key` and the `descriptor`.

The next example prevents the addition of any properties added through the `proxy`. When the handler returns false, the property declaration fails loudly with an exception under strict mode, and silently without an exception when we're in sloppy mode. Strict mode is superior to sloppy mode due to its performance gains and hardened semantics. It is also the default mode in ES6 modules, as we'll see in chapter 8. For those reasons, we'll assume strict mode in all the code examples.

```
const handler = {
  defineProperty (target, key, descriptor) {
    return false
  }
}
const target = {}
const proxy = new Proxy(target, handler)
proxy.extraCheese = false
// <- TypeError: 'defineProperty' on proxy: trap returned false for property 'extraCheese'
```

If we go back to the prefixed properties use case, we could add a `defineProperty` trap to prevent the creation of private properties through the proxy. In the following example we will `throw` on attempts to define a property in the private prefixed space by reusing the `invariant` function.

```
const handler = {
  defineProperty (target, key, descriptor) {
    invariant(key, 'define')
    return Reflect.defineProperty(target, key, descriptor)
  }
}
function invariant (key, action) {
  if (key.startsWith('_')) {
    throw new Error(`Invalid attempt to ${ action } private "${ key }" property`)
  }
}
```

Let's try it out on a `target` object. We'll attempt to declare a property with and without the prefix. Setting a property in the private property space at the `proxy` level will now throw an error.

```
const target = {}
const proxy = new Proxy(target, handler)
```

```
proxy.topping = 'cheese'
proxy._secretIngredient = 'salsa'
// <- Error: Invalid attempt to define private "_secretIngredient" property
```

The `proxy` object is safely hiding `_secret` properties behind a trap that guards them from definition through either `proxy[key] = value` or `Object.defineProperty(proxy, key, { value })`. If we factor in the previous traps we saw, we could prevent `_secret` properties from being read, written, queried, and created.

There's one more trap that can help conceal `_secret` properties.

6.3.4 ownKeys Trap

The `handler.ownKeys` method may be used to return an `Array` of properties that will be used as a result for `Reflect.ownKeys()`. It should include all properties of `target`: enumerable, non-enumerable, and symbols as well. A default implementation, as always, could pass throught to the reflection method on the proxied `target` object.

```
const handler = {
  ownKeys (target) {
    return Reflect.ownKeys(target)
  }
}
```

Interception wouldn't affect the output of `Object.keys` in this case, since we're simply passing through to the default implementation.

```
const target = {
  [Symbol('id')]: 'ba3dfcc0',
  _secret: 'sauce',
  _toppingCount: 3,
  toppings: ['cheese', 'tomato', 'bacon']
}
const proxy = new Proxy(target, handler)
for (let key of Object.keys(proxy)) {
  console.log(key)
  // <- '_secret'
  // <- '_toppingCount'
  // <- 'toppings'
}
```

Do note that the `ownKeys` interceptor is used during all of the following operations.

- `Reflect.ownKeys()` return every own key on the object
- `Object.getOwnPropertyNames()` returns only non-symbol properties
- `Object.getOwnPropertySymbols()` returns only symbol properties
- `Object.keys()` returns only non-symbol enumerable properties

- `for..in` returns only non-symbol enumerable properties

In the use case where we want to shut off access to a prefixed property space, we could take the output of `Reflect.ownKeys(target)` and filter off of that. That'd be the same approach that methods such as `Object.getOwnPropertySymbols` follow internally.

In the next example, we're careful to ensure that any keys that aren't strings, namely `Symbol` property keys, always return true. Then, we filter out string keys that begin with `_`.

```
const handler = {
  ownKeys (target) {
    return Reflect.ownKeys(target).filter(key => {
      const isStringKey = typeof key === 'string'
      if (isStringKey) {
        return !key.startsWith('_')
      }
      return true
    })
  }
}
```

If we now used the `handler` in the snippet above to pull the object keys, we'll only find the properties in the public, non-prefixed space. Note how the `Symbol` isn't being returned either. That's because `Object.keys` filters out `Symbol` property keys before returning its result.

```
const target = {
  [Symbol('id')]: 'ba3dfcc0',
  _secret: 'sauce',
  _toppingCount: 3,
  toppings: ['cheese', 'tomato', 'bacon']
}
const proxy = new Proxy(target, handler)
for (let key of Object.keys(proxy)) {
  console.log(key)
  // <- 'toppings'
}
```

Symbol iteration wouldn't be affected by our `handler` because Symbol keys have a type of *`symbol`*, which would cause our `.filter` function to return true.

```
const target = {
  [Symbol('id')]: 'ba3dfcc0',
  _secret: 'sauce',
  _toppingCount: 3,
  toppings: ['cheese', 'tomato', 'bacon']
}
const proxy = new Proxy(target, handler)
for (let key of Object.getOwnPropertySymbols(proxy)) {
```

```
  console.log(key)
  // <- Symbol(id)
}
```

We were able to hide properties prefixed with _ from key enumeration while leaving symbols and other properties unaffected. What's more, there's no need to repeat ourselves in several trap handlers: a single ownKeys trap took care of all different enumeration methods. The only caveat is that we need to be careful about handling Symbol property keys.

6.4 Advanced Proxy Traps

For the most part, the traps that we discussed so far have to do with property access and manipulation. Up next is the last trap we'll cover that's related to property access. Every other trap in this section has to do with the object we are proxying itself, instead of its properties.

6.4.1 getOwnPropertyDescriptor Trap

The getOwnPropertyDescriptor trap is triggered when querying an object for the property descriptor for some key. It should return a property descriptor or undefined when the property doesn't exist. There is also the option of throwing an exception, aborting the operation entirely.

If we go back to the canonical private property space example, we could implement a trap, such as the one in the next code snippet, to prevent consumers from learning about property descriptors of private properties.

```
const handler = {
  getOwnPropertyDescriptor (target, key) {
    invariant(key, 'get property descriptor for')
    return Reflect.getOwnPropertyDescriptor(target, key)
  }
}
function invariant (key, action) {
  if (key.startsWith('_')) {
    throw new Error(`Invalid attempt to ${ action } private "${ key }" property`)
  }
}
const target = {}
const proxy = new Proxy(target, handler)
Reflect.getOwnPropertyDescriptor(proxy, '_secret')
// <- Error: Invalid attempt to get property descriptor for private "_secret" property
```

One problem with this approach might be that you're effectively telling external consumers that they're unauthorized to access prefixed properties. It might be best to conceal them entirely by returning undefined. That way, private properties will behave no differently than properties that are truly absent from the target object.

The following example shows how `Object.getOwnPropertyDescriptor` returns `undefined` for an inexistent `dressing` property, and how it does the same for a `_secret` property. Existing properties that aren't in the private property space produce their property descriptors as usual.

```
const handler = {
  getOwnPropertyDescriptor (target, key) {
    if (key.startsWith('_')) {
      return
    }
    return Reflect.getOwnPropertyDescriptor(target, key)
  }
}
const target = {
  _secret: 'sauce',
  topping: 'mozzarella'
}
const proxy = new Proxy(target, handler)
console.log(Object.getOwnPropertyDescriptor(proxy, 'dressing'))
// <- undefined
console.log(Object.getOwnPropertyDescriptor(proxy, '_secret'))
// <- undefined
console.log(Object.getOwnPropertyDescriptor(proxy, 'topping'))
// <- { value: 'mozzarella', writable: true, enumerable: true, configurable: true }
```

When you're trying to hide things, it's best to have them try and behave as if they fell in some other category than the category they're actually in, thus concealing their behavior and passing it off for something else. Throwing, however, sends the wrong message when we want to conceal something: why does a property throw instead of return `undefined`? It must exist but be inaccessible. This is not unlike situations in HTTP API design where we might prefer to return "404 Not Found" responses for sensitive resources, such as an administration back end, when the user is unauthorized to access them, instead of the technically correct "401 Unauthorized" status code.

When debugging concerns outweight security concerns, you should at least consider the `throw` statement. In any case, it's important to understand your use case in order to figure out the optimal and least surprising behavior for a given component.

6.4.2 `apply` Trap

The `apply` trap is quite interesting, it's specifically tailored to work with functions. When the proxied `target` function is invoked, the `apply` trap is triggered. All of the statements in the following code sample would go through the `apply` trap in your proxy `handler` object.

```
proxy('cats', 'dogs')
proxy(...['cats', 'dogs'])
proxy.call(null, 'cats', 'dogs')
```

```
proxy.apply(null, ['cats', 'dogs'])
Reflect.apply(proxy, null, ['cat', 'dogs'])
```

The `apply` trap receives three arguments.

- `target` is the function being proxied
- `ctx` is the context passed as `this` to `target` when applying a call
- `args` is the arguments passed to `target` when applying the call

The default implementation that doesn't alter the outcome would return the results of calling `Reflect.apply`.

```
const handler = {
  apply (target, ctx, args) {
    return Reflect.apply(target, ctx, args)
  }
}
```

Besides being able to log all parameters of every function call for `proxy`, this trap could also be used to add extra parameters or to modify the results of a function call. All of these examples would work without changing the underlying `target` function, which makes the trap reusable across any functions that need the extra functionality.

The example below proxies a `sum` function through a `twice` trap handler that doubles the results of `sum` without affecting the code around it other than using the `proxy` instead of the `sum` function directly.

```
const twice = {
  apply (target, ctx, args) {
    return Reflect.apply(target, ctx, args) * 2
  }
}
function sum (a, b) {
  return a + b
}
const proxy = new Proxy(sum, twice)
console.log(proxy(1, 2))
// <- 6
```

Moving onto another use case, suppose we want to preserve the context for `this` across function calls. In the following example we have a `logger` object with a `.get` method that returns the `logger` object itself.

```
const logger = {
  test () {
    return this
  }
}
```

If we want to ensure that `get` always returns `logger`, we could bind that method to `logger`, as shown next.

```
logger.test = logger.test.bind(logger)
```

The problem with that approach is that we'd have to do it for every single function on `logger` that relies on `this` being a reference to the `logger` object itself. A better solution could involve using a proxy with a `get` trap handler, where we modify returned functions by binding them to the `target` object.

```
const selfish = {
  get (target, key) {
    const value = Reflect.get(target, key)
    if (typeof value !== 'function') {
      return value
    }
    return value.bind(target)
  }
}
const proxy = new Proxy(logger, selfish)
```

This would work for any kind of object, even class instances, without any further modification. The following snippet demonstrates how the original logger is vulnerable to `.call` and similar operations that can change the `this` context, while the `proxy` object ignores those kinds of changes.

```
const something = {}
console.log(logger.test() === logger)
// <- true
console.log(logger.test.call(something) === something)
// <- true
console.log(proxy.test() === logger)
// <- true
console.log(proxy.test.call(something) === logger)
// <- true
```

There's a subtle problem that arises from using `selfish` in its current incarnation, though. Whenever we get a reference to a method through the `proxy`, we get a freshly created bound function that's the result of `value.bind(target)`. Consequently, methods no longer appear to be equal to themselves. As shown next, this can result in confusing behavior.

```
console.log(proxy.test !== proxy.test)
// <- true
```

This could be resolved using a `WeakMap`. We'll go back to our `selfish` trap handler options, and move that into a factory function. Within that function we'll keep a `cache` of bound methods, so that we create the bound version of each function only once. While we're at it, we'll make our `selfish` function receive the `target` object we want to be proxying, so that the details of how we are binding every method become an implementation concern.

```
function selfish (target) {
  const cache = new WeakMap()
  const handler = {
    get (target, key) {
      const value = Reflect.get(target, key)
      if (typeof value !== 'function') {
        return value
      }
      if (!cache.has(value)) {
        cache.set(value, value.bind(target))
      }
      return cache.get(value)
    }
  }
  const proxy = new Proxy(target, handler)
  return proxy
}
```

Now that we are caching bound functions and tracking them by the original value, the same object is always returned and simple comparisons don't surprise consumers of `selfish` anymore.

```
const selfishLogger = selfish(logger)
console.log(selfishLogger.test === selfishLogger.test)
// <- true
console.log(selfishLogger.test() === selfishLogger)
// <- true
console.log(selfishLogger.test.call(something) === selfishLogger)
// <- true
```

The `selfish` function can now be reused whenever we want all methods on an object to be bound to the host object itself. This is particularly convenient when dealing with classes that heavily rely on `this` being the instance object.

There are dozens of ways of binding methods to their parent object, all with their own sets of advantages and drawbacks. The proxy-based solution might be the most convenient and hassle-free, but browser support isn't great yet, and `Proxy` implementations are known to be pretty slow.

We haven't used an `apply` trap for the `selfish` examples, which illustrates that not everything is one-size-fits-all. Using an `apply` trap for this use case would involve the current `selfish` proxy returning proxies for `value` functions, and then returning a bound function in the `apply` trap for the `value` proxy. While this may sound more correct, in the sense that we're not using `.bind` but instead relying on `Reflect.apply`, we'd still need the `WeakMap` cache and `selfish` proxy. That is to say we'd be adding an extra layer of abstraction, a second proxy, and getting little value in terms of separation of concerns or maintainability, since both proxy layers would remain coupled to some degree, it'd be best to keep everything in a single layer. While abstractions are a great thing, too many abstractions can become more insurmountable than the problem they attempt to fix.

Up to what point is the abstraction justifiable over a few `.bind` statements in the `constructor` of a class object? These are hard questions that always depend on context, but they must be considered when designing a component system so that you don't add complexity for complexity's sake, while also adding abstraction layers that help you avoid repeating yourself.

6.4.3 `construct` Trap

The `construct` trap intercepts uses of the `new` operator. In the following code sample, we implement a custom `construct` trap that behaves identically to the `construct` trap. We use the spread operator, in combination with the `new` keyword, so that we can pass any arguments to the `Target` constructor.

```
const handler = {
  construct (Target, args) {
    return new Target(...args)
  }
}
```

The previous example is identical to using `Reflect.construct`, shown next. Note that in this case we're not spreading the `args` over the parameters to the method call. Reflection methods mirror the method signature of proxy traps, and as such `Reflect.construct` has a signature of `Target, args`, just like the `construct` trap method.

```
const handler = {
  construct (Target, args) {
    return Reflect.construct(Target, args)
  }
}
```

Traps like `construct` allow us to modify or extend the behavior of an object without using a factory function or changing the implementation, leading to more maintainable code. It should be noted, however, that proxies should always have a clearly defined goal, and that goal shouldn't meddle too much with the implementation of the underlying target. That is to say, a proxy trap for `construct` that acts as a switch for several different underlying classes is probably the wrong kind of abstraction: a simple function would do.

Use cases for `construct` traps should mostly revolve around rebalancing constructor parameters or doing things that should always be done around the constructor, such as logging and tracking object creation.

The following example shows how a proxy could be used to offer a slightly different experience to a portion of the consumers, without changing the implementation of the class. When using the `ProxiedTarget`, we can leverage the constructor parameters to declare a `name` property on the target instance.

```
const handler = {
  construct (Target, args) {
    const [ name ] = args
    const target = Reflect.construct(Target, args)
    target.name = name
    return target
  }
}
class Target {
  hello () {
    console.log(`Hello, ${ this.name }!`)
  }
}
```

In this case, we could've changed `Target` directly so that it receives a `name` parameter in its constructor and stores that as an instance property. That is not always the case. You could be unable to modify a class directly, either because you don't own that code or because other code relies on a particular structure already. The following code snippet shows the `Target` class in action, with its regular API and the modified `ProxiedTarget` API resulting from using proxy traps for `construct`.

```
const target = new Target()
target.name = `Nicolás`
target.hello()
// <- 'Hello, Nicolás'

const ProxiedTarget = new Proxy(Target, handler)
const proxy = new ProxiedTarget(`Nicolás`)
proxy.hello()
// <- 'Hello, Nicolás'
```

Let's move onto the next few traps.

6.4.4 `getPrototypeOf` Trap

We can use the `handler.getPrototypeOf` method as a trap for all of the following operations.

- `Object.prototype.`*`proto`* property
- `Object.prototype.isPrototypeOf` method
- `Object.getPrototypeOf` method
- `Reflect.getPrototypeOf` method

- `instanceof` operator

This traps is quite powerful, as it allows us to dynamically determine the reported underlying prototype for an object.

You could, for instance, use this trap to make an object pretend it's an `Array` when accessed through the proxy. The following example does exactly that, by returning `Array.prototype` as the prototype of proxied objects. Note that `instanceof` indeed returns `true` when asked if our plain object is an `Array`.

```
const handler = {
  getPrototypeOf: target => Array.prototype
}
const target = {}
const proxy = new Proxy(target, handler)
console.log(proxy instanceof Array)
// <- true
```

On its own, this isn't sufficient for the `proxy` to be a true `Array`. The following code snippet shows how the `Array#push` method isn't available on our `proxy` even though we're reporting a prototype of `Array`.

```
console.log(proxy.push)
// <- undefined
```

Naturally, we can keep patching the `proxy` until we get the behavior we want. In this case, we may want to use a `get` trap to mix the `Array.prototype` with the actual back-end `target`. Whenever a property isn't found on the `target`, we'll use reflection again to look the property up on `Array.prototype` as well. As it turns out, this behavior is good enough to be able to leverage `Array`'s methods.

```
const handler = {
  getPrototypeOf: target => Array.prototype,
  get (target, key) {
    return (
      Reflect.get(target, key) ||
      Reflect.get(Array.prototype, key)
    )
  }
}
const target = {}
const proxy = new Proxy(target, handler)
```

Note now how `proxy.push` points to the `Array#push` method, how we can use it unobtrusively as if we were working with an array object, and also how printing the object logs it as the object it is rather than as an array of `[`*`first, second`*`]`.

```
console.log(proxy.push)
// <- function push () { [native code] }
proxy.push('first', 'second')
```

```
console.log(proxy)
// <- { 0: 'first', 1: 'second', length: 2 }
```

Conversely to the `getPrototypeOf` trap, there's `setPrototypeOf`.

6.4.5 `setPrototypeOf` Trap

There is an `Object.setPrototypeOf` method in ES6 that can be used to change the prototype of an object into a reference to another object. It's considered the proper way of setting the prototype, as opposed to setting the special *`proto`* property, which is a feature that's supported in most browsers but was deprecated in ES6.

Deprecation means that browser vendors are discouraging the use of *`proto`*. In other contexts, deprecation also means that the feature might be removed in the future. The web platform, however, doesn't break backwards compatibility, and *`proto`* is unlikely to ever be removed. That being said, deprecation also means you're discouraged from using the feature. Thus, using `Object.setPrototypeOf` method is preferrable than changing *`proto`* when we want to modify the underlying prototype for an object.

You can use `handler.setPrototypeOf` to set up a trap for `Object.setPrototypeOf`. The snippet of code shown below doesn't alter the default behavior of changing a prototype into `base`. Note that, for completeness, there is a `Reflect.setPrototypeOf` method that's equivalent to `Object.setPrototypeOf`.

```
const handler = {
  setPrototypeOf (target, proto) {
    Object.setPrototypeOf(target, proto)
  }
}
const base = {}
function Target () {}
const proxy = new Proxy(Target, handler)
proxy.setPrototypeOf(proxy, base)
console.log(proxy.prototype === base)
// <- true
```

There are several use cases for `setPrototypeOf` traps. You could have an empty method body, in which case the trap would sink calls to `Object.setPrototypeOf` into a no-op: an operation where nothing occurs. You could `throw` an exception making the failure explicit, if you deem the new prototype to be invalid or you want to prevent consumers from changing the prototype of the proxied object.

You could implement a trap like the following, which mitigates security concerns in a proxy that might be passed away to third party code, as a way of limiting access to the underlying `Target`. That way, consumers of `proxy` would be unable to modify the prototype of the underlying object.

```
const handler = {
  setPrototypeOf (target, proto) {
    throw new Error('Changing the prototype is forbidden')
  }
}
const base = {}
function Target () {}
const proxy = new Proxy(Target, handler)
proxy.setPrototypeOf(proxy, base)
// <- Error: Changing the prototype is forbidden
```

In these cases, it's best to fail with an exception so that consumers can understand what is going on. By explicitly disallowing prototype changes, the consumer can start looking elsewhere. If we didn't throw an exception, the consumer could still eventually learn that the prototype isn't changing through debugging. You may as well save them from the pain!

6.4.6 `isExtensible` Trap

An extensible object is an object that you can add new properties to, an object you can extend.

The `handler.isExtensible` method can be used for logging or auditing calls to `Object.isExtensible`, but not to decide whether an object is extensible. That's because this trap is subject to a harsh invariant that puts a hard limit to what you can do with it: a `TypeError` is thrown if `Object.isExtensible(proxy) !== Object.isExtensible(target)`.

If you didn't want consumers to know whether the underlying object is extensible or not, you could `throw` an error in an `isExtensible` trap.

While this trap is nearly useless, other than for auditing purposes, the hard invariant makes sense because there's also the `preventExtensions` trap that's a bit more permissive.

6.4.7 `preventExtensions` Trap

You can use `handler.preventExtensions` to trap the `Object.preventExtensions` method. When extensions are prevented on an object, new properties can't be added any longer: the object can't be extended.

Imagine a scenario where you want to be able to selectively `preventExtensions` on some objects, but not all of them. In that scenario, you could use a `WeakSet` to keep track of the objects that should be extensible. If an object is in the set, then the `preventExtensions` trap should be able to capture those requests and discard them.

The following snippet does exactly that: it keeps objects that can be extended in a `WeakSet` and prevents the rest from being extended. Note that the trap always returns the opposite of `Reflect.isExtensible(target)`. Returning `true` means the object can't be extended anymore, while `false` means the object can still be extended.

```
const canExtend = new WeakSet()
const handler = {
  preventExtensions (target) {
    const canPrevent = !canExtend.has(target)
    if (canPrevent) {
      Object.preventExtensions(target)
    }
    return !Reflect.isExtensible(target)
  }
}
```

Now that we've set up the `handler` and `WeakSet`, we can create a target object and a `proxy` for that target, adding the target to our set. Then, we could try `Object.preventExtensions` on the proxy and we'll notice it fails to prevent extensions to `target`. This is the intended behavior, as the `target` can be found in the `canExtend` set. Note that while we're seeing a `TypeError` exception, because the consumer intended to prevent extensions but failed to do so due to the trap, this would be a silent error under sloppy mode.

```
const target = {}
const proxy = new Proxy(target, handler)
canExtend.add(target)
Object.preventExtensions(proxy)
// <- TypeError: 'preventExtensions' on proxy: trap returned falsy
```

If we removed the `target` from the `canExtend` set before calling `Object.preventExtensions`, then `target` would be made non-extensible as originally intended. The following code snippet shows that behavior in action.

```
const target = {}
const proxy = new Proxy(target, handler)
canExtend.add(target)
canExtend.delete(target)
Object.preventExtensions(proxy)
console.log(Object.isExtensible(proxy))
// <- false
```

As we've learned over the last few pages, there's a myriad of use cases for proxies. We can use `Proxy` for all of the following, and that's just the tip of the iceberg.

- Add validation rules on plain old JavaScript objects, and enforce them
- Keep track of every interaction that goes through a proxy
- Implement your own observable objects

- Decorate and extend objects without changing their implementation
- Make certain properties on an object completely invisible to consumers
- Revoke access at will when the consumer should no longer be able to access an object
- Modify the arguments passed to a proxied method
- Modify the result produced by a proxied method
- Prevent deletion of specific properties through the proxy
- Prevent new definitions from succeeding, according to the desired property descriptor
- Shuffle arguments around in a constructor
- Return a result other than the object created via `new` and a constructor
- Swap out the prototype of an object for something else

Proxies are an extremely powerful feature in ES6, with infinite practical applications.

CHAPTER 7

Built-in Improvements in ES6

Thus far in the book, we've discussed entirely new language syntax, such as property value shorthands, arrow functions, destructuring, or generators; and entirely new built-ins, such as `WeakMap`, `Proxy`, or `Symbol`. This chapter, on the other hand, is mostly devoted to existing built-ins that were improved in ES6. These improvements consist mostly of new instance methods, properties, and utility methods.

7.1 Numbers

ES6 introduces numeric literal representations for binary and octal numbers.

7.1.1 Binary and Octal Literals

Before ES6, your best bet when it comes to binary representation of integers was to just pass them to `parseInt` with a radix of `2`.

```
parseInt(`101`, 2)
// <- 5
```

You can now use the new `0b` prefix to represent binary integer literals. You could also use the `0B` prefix, with a capital `B`. The two notations are equivalent.

```
console.log(0b000); // <- 0
console.log(0b001); // <- 1
console.log(0b010); // <- 2
console.log(0b011); // <- 3
console.log(0b100); // <- 4
console.log(0b101); // <- 5
console.log(0b110); // <- 6
console.log(0b111); // <- 7
```

In ES3, `parseInt` interpreted strings of digits starting with a `0` as an octal value. That meant things got weird quickly when you forgot to specify a radix of `10`. As a result, specifying the radix of `10` became a best practice, so that user input like `012` wouldn't unexpectedly be parsed as the integer `10`.

```
console.log(parseInt(`01`))
// <- 1
console.log(parseInt(`012`))
// <- 10
console.log(parseInt(`012`, 10))
// <- 12
```

When ES5 came around, the default radix in `parseInt` changed, from `8` to `10`. It was still recommended you specified a `radix` for backwards compatibility purposes. If you wanted to parse strings as octal values, you could explicitly pass in a radix of `8` as the second argument.

```
console.log(parseInt(`100`, `8`))
// <- 64
```

You can now use the `0o` prefix for octal literals, which are new in ES6. You could also use `0O`, which is equivalent. Having a `0` followed by an uppercase `O` may be hard to distinguish in some typefaces, which is why it is suggested that you stick with the lowercase `0o` notation.

```
console.log(0o001); // <- 1
console.log(0o010); // <- 8
console.log(0o100); // <- 64
```

You might be used to hexadecimal literals present in other languages, commonly prefixed with `0x`. Those were already introduced to the JavaScript language in ES5. The prefix for literal hexadecimal notation is either `0x`, or `0X`, as shown in the following code snippet.

```
console.log(0x0ff); // <- 255
console.log(0xf00); // <- 3840
```

Besides these minor syntax changes where octal and binary literals were introduced, a few methods were added to `Number` in ES6. The first four `Number` methods that we'll be discussing — `Number.isNaN`, `Number.isFinite`, `Number.parseInt`, and `Number.parseFloat` — already existed as functions in the global namespace. In addition, the methods in `Number` are slightly different in that they don't coerce non-numeric values into numbers before producing a result.

7.1.2 `Number.isNaN`

This method is almost identical to the global `isNaN` method. `Number.isNaN` returns whether the provided `value` is `NaN`, whereas `isNaN` returns whether `value` is not a number. These two questions have slightly different answers.

The next snippet quickly shows that, when passed to `Number.isNaN`, anything that's not `NaN` will return `false`, while `NaN` will produce `true`. Note how in the last case we're already passing `NaN` to `Number.isNaN`, as that's the result of dividing two strings.

```
Number.isNaN(123)
// <- false, integers are not NaN
Number.isNaN(Infinity)
// <- false, Infinity is not NaN
Number.isNaN(`a hundred`)
// <- false, `a hundred` is not NaN
Number.isNaN(NaN)
// <- true, NaN is NaN
Number.isNaN(`a hundred` / `two`)
// <- true, `a hundred` / `two` is NaN, NaN is NaN
```

The `isNaN` method, in contrast, casts non-numeric values passed to it before evaluating them against `NaN`. This results in significantly different return values. In the following example, each alternative produces different results because `isNaN`, unlike `Number.isNaN`, casts the `value` passed to it through `Number` first.

```
isNaN(`a hundred`)
// <- true, because Number(`a hundred`) is NaN
isNaN(new Date())
// <- false, because Number(new Date()) uses Date#valueOf, which returns a unix timestamp
```

`Number.isNaN` is more precise than its global counterpart, because it doesn't involve casting. There's still a few reasons why `Number.isNaN` can be a source of confusion.

1. `isNaN` casts input through `Number(value)` before comparison
2. `Number.isNaN` doesn't
3. Neither `Number.isNaN` nor `isNaN` answer the "is this not a number?" question
4. They answer whether `value` — or `Number(value)` — is `NaN`

In most cases, what you actually want to know is whether a value identifies as a number — `typeof NaN === number` — and is a number. The `isNumber` function in the following code snippet does just that. Note that it'd work with both `isNaN` and `Number.isNaN` due to type checking. Everything that reports a `typeof` value of `number` is a number, except for `NaN`, so we filter out those out as false positive results.

```
function isNumber (value) {
  return typeof value === `number` && !Number.isNaN(value)
}
```

You can use that method to figure out whether a `value` is a number or not. In the next snippet there's a few examples of how `isNumber` works.

```
isNumber(1)
// <- true
isNumber(Infinity)
// <- true
isNumber(NaN)
// <- false
isNumber(`two`)
// <- false
isNumber(new Date())
// <- false
```

There is a function, that was already in the language, that somewhat resembles our custom `isNumber` function: `isFinite`.

7.1.3 `Number.isFinite`

The rarely-promoted `isFinite` method has been available since ES3. It returns a boolean value indicating whether the provided `value` matches none of: `Infinity`, `-Infinity`, and `NaN`.

The `isFinite` method coerces values through `Number(value)`, while `Number.isFinite` doesn't. This means that values that can be coerced into non-`NaN` numbers will be considered finite numbers by `isNumber` — even though they aren't explicit numbers.

Here are a few examples using the global `isFinite` function.

```
isFinite(NaN)
// <- false
isFinite(Infinity)
// <- false
isFinite(-Infinity)
// <- false
isFinite(null)
// <- true, because Number(null) is 0
isFinite(-13)
// <- true, because Number(-13) is -13
isFinite(`10`)
// <- true, because Number(`10`) is 10
```

Using `Number.isFinite` is a safer bet, as it doesn't incur in unexpected casting. You could always use `Number.isFinite(Number(value))` if you did want the `value` to be cast into its numeric representation. Separating the two aspects, casting versus computing, results in more explicit code.

Here are a few examples using the `Number.isFinite` method.

```
Number.isFinite(NaN)
// <- false
Number.isFinite(Infinity)
// <- false
Number.isFinite(-Infinity)
// <- false
Number.isFinite(null)
// <- false, because null is not a number
Number.isFinite(-13)
// <- true
Number.isFinite(`10`)
// <- false, because `10` is not a number
```

Creating a polyfill for `Number.isFinite` would involve returning `false` for non-numeric values, effectively turning off the type-casting feature, and then calling `isFinite` on the input value.

```
Number.isFinite = value => typeof value === `number` && isFinite(value)
```

7.1.4 Number.parseInt

The `Number.parseInt` method works the same as `parseInt`. It is, in fact, the same.

```
console.log(Number.parseInt === parseInt)
// <- true
```

The `parseInt` function has support for hexadecimal literal notation in strings. Specifying the `radix` is not even necessary: based on the `0x` prefix, `parseInt` infers that the number must be base 16.

```
parseInt(`0xf00`)
// <- 3840
parseInt(`0xf00`, 16)
// <- 3840
```

If you provided another `radix`, `parseInt` would bail after the first non-digit character.

```
parseInt(`0xf00`, 10)
// <- 0
parseInt(`5xf00`, 10)
// <- 5, illustrating there's no special treatment here
```

While `parseInt` accepts input in hexadecimal literal notation strings, its interface hasn't changed in ES6. Therefore, binary and octal literal notation strings won't be interpreted as such. This introduces a new inconsistency in ES6, where `parseInt` understands `0x`, but not `0b` nor `0o`.

```
parseInt(`0b011`)
// <- 0
```

```
parseInt(`0b011`, 2)
// <- 0
parseInt(`0o100`)
// <- 0
parseInt(`0o100`, 8)
// <- 0
```

It's up to you to drop the prefix before `parseInt`, if you wanted to use `parseInt` to read these literals. You'll also need to specify the corresponding `radix` of 2 for binary numbers or 8 for octals.

```
parseInt(`0b011`.slice(2), 2)
// <- 3
parseInt(`0o110`.slice(2), 8)
// <- 72
```

To make matters even worse, the `Number` function is perfectly able to cast these strings into the correct numbers.

```
Number(`0b011`)
// <- 3
Number(`0o110`)
// <- 72
```

7.1.5 `Number.parseFloat`

Like `parseInt`, `parseFloat` was added to `Number` without any modifications whatsoever.

```
console.log(Number.parseFloat === parseFloat)
// <- true
```

Luckily, `parseFloat` didn't have any special behavior with regard to hexadecimal literal strings, meaning that `Number.parseFloat` is unlikely to introduce any confusion.

The `parseFloat` function was added to `Number` for completeness. In future versions of the language, there will be less global namespace pollution. When a function serves a specific purpose, it'll be added to the relevant built-in, rather than as a global.

7.1.6 `Number.isInteger`

This is a new method coming in ES6, and it wasn't previously available as a global function. The `isInteger` method returns `true` if the provided `value` is a finite number that doesn't have a decimal part.

```
console.log(Number.isInteger(Infinity)); // <- false
console.log(Number.isInteger(-Infinity)); // <- false
console.log(Number.isInteger(NaN)); // <- false
console.log(Number.isInteger(null)); // <- false
console.log(Number.isInteger(0)); // <- true
```

```
console.log(Number.isInteger(-10)); // <- true
console.log(Number.isInteger(10.3)); // <- false
```

You might want to consider the following code snippet as a polyfill for `Number.isInteger`. The modulus operator returns the remainder of dividing the same operands. If we divide by one, we're effectively getting the decimal part. If that's `0`, then it means the number is an integer.

```
Number.isInteger = value => Number.isFinite(value) && value % 1 === 0
```

Next up we'll dive into floating point arithmetic, which is well-documented as having interesting corner cases.

7.1.7 `Number.EPSILON`

The `EPSILON` property is a new constant value being added to the `Number` built-in. The following snippet shows its value.

```
Number.EPSILON
// <- 2.220446049250313e-16
Number.EPSILON.toFixed(20)
// <- `0.00000000000000022204`
```

Let's take a look at the canonical example of floating point arithmetic.

```
0.1 + 0.2
// <- 0.30000000000000004
0.1 + 0.2 === 0.3
// <- false
```

What's the margin of error in this operation? Let's move the operands around and find out.

```
0.1 + 0.2 - 0.3
// <- 5.551115123125783e-17
5.551115123125783e-17.toFixed(20)
// <- `0.00000000000000005551`
```

We could use `Number.EPSILON` to figure out whether the difference is small enough to be negligible, `Number.EPSILON` denotes a safe margin of error for floating point arithmetic rounding operations.

```
5.551115123125783e-17 < Number.EPSILON
// <- true
```

The following piece of code can be used to figure out out whether the result of a floating point operation is within the expected margin of error. We use `Math.abs`, because that way the order of `left` and `right` won't matter. In other words, `withinMarginOfError(left, right)` will produce the same result as `withinMarginOfError(right, left)`.

```
function withinMarginOfError (left, right) {
  return Math.abs(left - right) < Number.EPSILON
}
```

The next snippet shows `withinMarginOfError` in action.

```
withinMarginOfError(0.1 + 0.2, 0.3)
// <- true
withinMarginOfError(0.2 + 0.2, 0.3)
// <- false
```

Using floating point representation, not every integer can be represented precisely.

7.1.8 `Number.MAX_SAFE_INTEGER` and `Number.MIN_SAFE_INTEGER`

This is the largest integer that can be safely and precisely represented in JavaScript, or any language that represents integers using floating point as specified by the IEEE-754 standard[1], for that matter. The next bit of code shows exactly how large `Number.MAX_SAFE_INTEGER` is.

```
Number.MAX_SAFE_INTEGER === Math.pow(2, 53) - 1
// <- true
Number.MAX_SAFE_INTEGER === 9007199254740991
// <- true
```

As you might expect, there's also the opposite constant: the minimum. It's the negative value of `Number.MAX_SAFE_INTEGER`.

```
Number.MIN_SAFE_INTEGER === -Number.MAX_SAFE_INTEGER
// <- true
Number.MIN_SAFE_INTEGER === -9007199254740991
// <- true
```

Floating point arithmetic becomes unreliable beyond the `[MIN_SAFE_INTEGER, MAX_SAFE_INTEGER]` range. The `1 === 2` statement evaluates to `false`, because these are different values. If we add `Number.MAX_SAFE_INTEGER` to each operand, however, it'd seem `1 === 2` is indeed true.

```
1 === 2
// <- false
Number.MAX_SAFE_INTEGER + 1 === Number.MAX_SAFE_INTEGER + 2
// <- true
Number.MIN_SAFE_INTEGER - 1 === Number.MIN_SAFE_INTEGER - 2
// <- true
```

When it comes to checking whether an integer is safe, a `Number.isSafeInteger` function has been added to the language.

1 IEEE 754 is the Floating Point Standard. On Wikipedia: *https://mjavascript.com/out/floating-point*.

7.1.10 `Number.isSafeInteger`

This method returns `true` for any integer in the `[MIN_SAFE_INTEGER, MAX_SAFE_INTEGER]` range. Like with other `Number` methods introduced in ES6, there's no type coercion involved. The input must be numeric, an integer, and within the aforementioned bounds in order for the method to return `true`. The next snippet shows a comprehensive set of inputs and outputs.

```
Number.isSafeInteger(`one`); // <- false
Number.isSafeInteger(`0`); // <- false
Number.isSafeInteger(null); // <- false
Number.isSafeInteger(NaN); // <- false
Number.isSafeInteger(Infinity); // <- false
Number.isSafeInteger(-Infinity); // <- false
Number.isSafeInteger(Number.MIN_SAFE_INTEGER - 1); // <- false
Number.isSafeInteger(Number.MIN_SAFE_INTEGER); // <- true
Number.isSafeInteger(1); // <- true
Number.isSafeInteger(1.2); // <- false
Number.isSafeInteger(Number.MAX_SAFE_INTEGER); // <- true
Number.isSafeInteger(Number.MAX_SAFE_INTEGER + 1); // <- false
```

When we want to verify if the result of an operation is within bounds, we must verify not only the result but also both operands[2]. One — or both — of the operands may be out of bounds, while the result is within bounds but incorrect. Similarly, the result may be out of bounds even if both operands are within bounds. Checking all of `left`, `right`, and the result of `left op right` is, thus, necessary to verify that we can indeed trust the result.

In the following example both operands are within bounds, but the result is incorrect.

```
Number.isSafeInteger(9007199254740000)
// <- true
Number.isSafeInteger(993)
// <- true
Number.isSafeInteger(9007199254740000 + 993)
// <- false
9007199254740000 + 993
// <- 9007199254740992, should be 9007199254740993
```

Certain operations and numbers, such as the following code snippet, may return correct results even when operands are out of bounds. The fact that correct results can't be guaranteed, however, means that these operations can't be trusted.

```
9007199254740000 + 994
// <- 9007199254740994
```

2 Dr. Axel Rauschmayer points this out in an article titled "New number and Math features in ES6": *https://mjavascript.com/out/math-axel*.

In the next example, one of the operands is out of bounds, and thus we can't trust the result to be accurate.

```
Number.isSafeInteger(9007199254740993)
// <- false
Number.isSafeInteger(990)
// <- true
Number.isSafeInteger(9007199254740993 + 990)
// <- false
9007199254740993 + 990
// <-  9007199254741982, should be 9007199254741983
```

A subtraction in our last example would produce a result that is within bounds, but that result would also be inaccurate.

```
Number.isSafeInteger(9007199254740993)
// <- false
Number.isSafeInteger(990)
// <- true
Number.isSafeInteger(9007199254740993 - 990)
// <- true
9007199254740993 - 990
// <-  9007199254740002, should be 9007199254740003
```

If both operands are out of bounds, the output could end up in the safe space, even though the result is incorrect.

```
Number.isSafeInteger(9007199254740995)
// <- false
Number.isSafeInteger(9007199254740993)
// <- false
Number.isSafeInteger(9007199254740995 - 9007199254740993)
// <- true
9007199254740995 - 9007199254740993
// <- 4, should be 2
```

We can conclude that the only safe way to assert whether an operation produces correct output is with a utility function such as the one below. If we can't ascertain that the operation and both operands are within bounds, then the result may be inaccurate, and that's a problem. It's best to `throw` in those situations and have a way to error-correct, but that's specific to your programs. The important part is to actually catch these kinds of difficult bugs to deal with.

```
function safeOp (result, ...operands) {
  const values = [result, ...operands]
  if (!values.every(Number.isSafeInteger)) {
    throw new RangeError('Operation cannot be trusted!')
  }
  return result
}
```

You could use `safeOp` to ensure all operands, including the `result` are safely within bounds.

```
safeOp(9007199254740000 + 993, 9007199254740000, 993)
// <- RangeError: Operation cannot be trusted!
safeOp(9007199254740993 + 990, 9007199254740993, 990)
// <- RangeError: Operation cannot be trusted!
safeOp(9007199254740993 - 990, 9007199254740993, 990)
// <- RangeError: Operation cannot be trusted!
safeOp(9007199254740993 - 9007199254740995, 9007199254740993, 9007199254740995)
// <- RangeError: Operation cannot be trusted!
safeOp(1 + 2, 1, 2)
// <- 3
```

That's all there is when it comes to `Number`, but we're not done with arithmetics-related improvements quite yet. Let's turn our attention to the `Math` built-in.

7.2 Math

ES6 introduces heaps of new static methods to the `Math` built-in. Some of them were specifically engineered towards making it easier to compile C into JavaScript, and you'll seldom need them for day-to-day JavaScript application development. Others are complements to the existing rounding, exponentiation, and trigonometry API surface.

Let's get right to it.

7.2.1 `Math.sign`

Many languages have a mathematical `sign` method that returns a vector (`-1`, `0`, or `1`) representation for the sign of the provided input. JavaScript's `Math.sign` method does exactly that. However, the JavaScript flavor of this method has two more possible return values: `-0`, and `NaN`. Check out the examples in the following code snippet.

```
Math.sign(1); // <- 1
Math.sign(0); // <- 0
Math.sign(-0); // <- -0
Math.sign(-30); // <- -1
Math.sign(NaN); // <- NaN
Math.sign(`one`); // <- NaN, because Number(`one`) is NaN
Math.sign(`0`); // <- 0, because Number(`0`) is 0
Math.sign(`7`); // <- 1, because Number(`7`) is 7
```

Note how `Math.sign` casts its input into numeric values? While methods introduced to the `Number` built-in don't cast their input via `Number(value)`, most of the methods added to `Math` share this trait, as we shall see.

7.2.2 `Math.trunc`

We already had `Math.floor` and `Math.ceil` in JavaScript, with which we can round a number down or up, respectively. Now we also have `Math.trunc` as an alternative, which discards the decimal part without any rounding. Here, too, the input is coerced into a numeric value through `Number(value)`.

```
Math.trunc(12.34567); // <- 12
Math.trunc(-13.58); // <- -13
Math.trunc(-0.1234); // <- -0
Math.trunc(NaN); // <- NaN
Math.trunc(`one`); // <- NaN, because Number(`one`) is NaN
Math.trunc(`123.456`); // <- 123, because Number(`123.456`) is 123.456
```

Creating a simple polyfill for `Math.trunc` would involve checking whether the value is greater than zero and applying one of `Math.floor` or `Math.ceil`, as shown in the following code snippet.

```
Math.trunc = value => value > 0 ? Math.floor(value) : Math.ceil(value)
```

7.2.3 `Math.cbrt`

The `Math.cbrt` method is short for "cubic root", similarly to how `Math.sqrt` is short for "square root". The following snippet has a few usage examples.

```
Math.cbrt(-1); // <- -1
Math.cbrt(3); // <- 1.4422495703074083
Math.cbrt(8); // <- 2
Math.cbrt(27); // <- 3
```

Note that this method also coerces non-numerical values into numbers.

```
Math.cbrt(`8`); // <- 2, because Number(`8`) is 8
Math.cbrt(`one`); // <- NaN, because Number(`one`) is NaN
```

Let's move on.

7.2.4 `Math.expm1`

This operation is the result of computing `e` to the `value` minus `1`. In JavaScript, the `e` constant is defined as `Math.E`. The function in the following snippet is a rough equivalent of `Math.expm1`.

```
function expm1 (value) {
  return Math.pow(Math.E, value) - 1
}
```

The <code>e^{value}</code> operation can be expressed as `Math.exp(value)` as well.

```
function expm1 (value) {
  return Math.exp(value) - 1
}
```

Note that `Math.expm1` has higher precision than merely doing `Math.exp(value) - 1`, and should be the preferred alternative.

```
expm1(1e-20)
// <- 0
Math.expm1(1e-20)
// <- 1e-20
expm1(1e-10)
// <- 1.000000082740371e-10
Math.expm1(1e-10)
// <- 1.00000000005e-10
```

The inverse function of `Math.expm1` is `Math.log1p`.

7.2.5 `Math.log1p`

This is the natural logarithm of `value` plus `1`, — <code>ln(value + 1)</code> — and the inverse function of `Math.expm1`. The base `e` logarithm of a number can be expressed as `Math.log` in JavaScript.

```
function log1p (value) {
  return Math.log(value + 1)
}
```

Just like with `Math.expm1`, `Math.log1p` method is more precise than executing the `Math.log(value + 1)` operation by hand.

```
log1p(1.00000000005e-10)
// <- 1.000000082690371e-10
Math.log1p(1.00000000005e-10)
// <- 1e-10, exactly the inverse of Math.expm1(1e-10)
```

7.2.6 `Math.log10`

Base ten logarithm of a number — <code>log₁₀(value)</code>.

```
Math.log10(1000)
// <- 3
```

You could polyfill `Math.log10` using the `Math.LN10` constant.

```
function log10 (value) {
  return Math.log(x) / Math.LN10
}
```

And then there's `Math.log2`.

7.2.7 `Math.log2`

Base two logarithm of a number — <code>log₂(value)</code>.

```
Math.log2(1024)
// <- 10
```

You could polyfill `Math.log2` using the `Math.LN2` constant.

```
function log2 (value) {
  return Math.log(x) / Math.LN2
}
```

Note that the polyfilled version won't be as precise as `Math.log2`, as demonstrated in the following example. Keep in mind that the `<<` operator performs a "bitwise left shift"[3].

```
log2(1 << 29)
// <- 29.000000000000004
Math.log2(1 << 29)
// <- 29
```

7.2.8 Trigonometric Functions

The `Math` object is getting trigonometric functions in ES6.

- `Math.sinh(value)` returns the hyperbolic sine of `value`
- `Math.cosh(value)` returns the hyperbolic cosine of `value`
- `Math.tanh(value)` returns the hyperbolic tangent of `value`
- `Math.asinh(value)` returns the hyperbolic arc-sine of `value`
- `Math.acosh(value)` returns the hyperbolic arc-cosine of `value`
- `Math.atanh(value)` returns the hyperbolic arc-tangent of `value`

7.2.9 `Math.hypot`

Using `Math.hypot` returns the square root of the sum of the squares of every provided argument.

```
Math.hypot(1, 2, 3)
// <- 3.741657386773941, the square root of (1*1 + 2*2 + 3*3)
```

3 Definition on MDN: *https://mjavascript.com/out/bitwise-shift*.

We could polyfill `Math.hypot` by performing these operations manually. We can use `Math.sqrt` to compute the square root and +Array#reduce+[4], combined with the spread operator, to sum the squares.

```
function hypot (...values) {
  return Math.sqrt(values.reduce((sum, value) => sum + value * value, 0))
}
```

Our handmade function is, surprisingly, more precise than the native one for this particular use case. In the next code sample, we see the hand-rolled `hypot` function offers precision with one more decimal place.

```
Math.hypot(1, 2, 3)
// <- 3.741657386773941
hypot(1, 2, 3)
// <- 3.7416573867739413
```

7.2.10 Bitwise Computation Helpers

At the beginning of section 7.2, we talked about how some of the new `Math` methods are specifically engineered towards making it easier to compile C into JavaScript. Those are the last three methods we'll cover, and they help us deal with 32-bit numbers.

`Math.clz32`

The name for this method is an acronym for "count leading zero bits in 32-bit binary representations of a number". Keeping in mind that the `<<` operator performs a "bitwise left shift"[3], let's take a look at the next code snippet describing sample input and output for `Math.clz32`.

```
Math.clz32(0); // <- 32
Math.clz32(1); // <- 31
Math.clz32(1 << 1); // <- 30
Math.clz32(1 << 2); // <- 29
Math.clz32(1 << 29); // <- 2
Math.clz32(1 << 31); // <- 0
```

`Math.imul`

Returns the result of a C-like 32-bit multiplication.

`Math.fround`

Rounds `value` to the nearest 32-bit float representation of a number.

4 You can go deeper into functional Array methods by reading my "Fun with Native Arrays" article: *https://mjavascript.com/out/native-arrays*.

7.3 Strings and Unicode

You may recall template literals from section 2.5, and how those can be used to mix strings and variables, or any valid JavaScript expression, to produce string output.

```
function greet (name) {
  return `Hello, ${ name }!`
}
greet(`Gandalf`)
// <- `Hello, Gandalf!`
```

Strings are getting a number of new methods in ES6, besides the template literal syntax. These can be categorized as string manipulation methods and unicode related methods. Let's start with the former.

7.3.1 `String#startsWith`

Prior to ES6, whenever we wanted to check if a string begins with a certain other string, we'd use the `String#indexOf` method, as shown in the following code snippet. A result of `0` means that the string starts with the provided value.

```
`hello gary`.indexOf(`gary`)
// <- 6
`hello gary`.indexOf(`hello`)
// <- 0
`hello gary`.indexOf(`stephan`)
// <- -1
```

If you wanted to check if a string started with another one, then, you'd compare them with `String#indexOf` and check whether the lookup value is found at the beginning of the string: the `0` index.

```
`hello gary`.indexOf(`gary`) === 0
// <- false
`hello gary`.indexOf(`hello`) === 0
// <- true
`hello gary`.indexOf(`stephan`) === 0
// <- false
```

You can now use the `String#startsWith` method instead, avoiding the unnecessary complexity of checking whether an index matches `0`.

```
`hello gary`.startsWith(`gary`)
// <- false
`hello gary`.startsWith(`hello`)
// <- true
`hello gary`.startsWith(`stephan`)
// <- false
```

In order to figure out whether a string contains a value starting at an specific index, using `String#indexOf`, we would have to grab a slice of that string first.

```
`hello gary`.slice(6).indexOf(`gary`) === 0
// <- true
```

We can't simply check whether the index is `6`, because that this would give you false negatives when the queried value is found before reaching that index of `6`. The following example shows how, even when the query `ell` string is indeed at index `6`, merely comparing the `String#indexOf` result with `6` is insufficient to attain a correct result.

```
`hello ell`.indexOf(`ell`) === 6
// <- false, because the result was 1
```

We could use the `startIndex` parameter for `indexOf` to get around this problem without relying on `String#slice`. Note that we're still comparing against `6` in this case, because the string wasn't sliced up in a setup operation.

```
`hello ell`.indexOf(`ell`, 6) === 6
// <- true
```

Instead of keeping all of these string searching implementation details in your head and writing code that's most concerned with how to search, as opposed to what is being searched, we could use `String#startsWith` passing in the optional `startIndex` parameter as well.

```
`hello ell`.startsWith(`ell`, 6)
// <- true
```

7.3.2 `String#endsWith`

This method mirrors `String#startsWith` in the same way that `String#lastIndexOf` mirrors `String#indexOf`. It tells us whether a string ends with another string.

```
`hello gary`.endsWith(`gary`)
// <- true
`hello gary`.endsWith(`hello`)
// <- false
```

As the opposite of `String#startsWith`, there's a position index that indicates where the lookup should end, instead of where it should start. It defaults to the length of the string.

```
`hello gary`.endsWith(`gary`, 10)
// <- true
`hello gary`.endsWith(`gary`, 9)
// <- false, it ends with `gar` in this case
`hello gary`.endsWith(`hell`, 4)
// <- true
```

`String#includes` is one last method that can simplify a specific use case for `String#indexOf`.

7.3.3 String#includes

You can use `String#includes` to figure out whether a string contains another one, as shown in the following piece of code.

```
`hello gary`.includes(`hell`)
// <- true
`hello gary`.includes(`ga`)
// <- true
`hello gary`.includes(`rye`)
// <- false
```

This is equivalent to the ES5 use case of `String#indexOf` where we'd test the result against `-1`, checking to see whether the search string was anywhere to be found, as demonstrated in the next code snippet.

```
`hello gary`.indexOf(`ga`) !== -1
// <- true
`hello gary`.indexOf(`rye`) !== -1
// <- false
```

You can also provide `String#includes` with a start index where searching should begin.

```
`hello gary`.includes(`ga`, 4)
// <- true
`hello gary`.includes(`ga`, 7)
// <- false
```

Let's move onto something that's not just an `String#indexOf` alternative.

7.3.4 String#repeat

This handy method allows you to repeat a string `count` times.

```
`ha`.repeat(1)
// <- `ha`
`ha`.repeat(2)
// <- `haha`
`ha`.repeat(5)
// <- `hahahahaha`
`ha`.repeat(0)
// <- ``
```

The provided `count` should be a positive and finite number.

```
`ha`.repeat(Infinity)
// <- RangeError
`ha`.repeat(-1)
// <- RangeError
```

Decimal values are floored to the nearest integer.

```
`ha`.repeat(3.9)
// <- `hahaha`, count was floored to 3
```

Using `NaN` is interpreted as a `count` of `0`.

```
`ha`.repeat(NaN)
// <- ``
```

Non-numeric values are coerced into numbers.

```
`ha`.repeat(`ha`)
// <- ``, because Number(`ha`) is NaN
`ha`.repeat(`3`)
// <- `hahaha`, because Number(`3`) is 3
```

Values in the `(-1, 0)` range are rounded to `-0` becase `count` is passed through `ToInteger`, as documented by the specification[5]. That step in the specification dictates that `count` be casted with a formula like the one in the next code snippet.

```
function ToInteger (number) {
  return Math.floor(Math.abs(number)) * Math.sign(number)
}
```

The `ToInteger` function translates any values in the `(-1, 0)` range into `-0`. As a result, when passed to `String#repeat`, numbers in the `(-1, 0)` range will be treated as zero, while numbers in the `[-1, -Infinity)` range will result an exception, as we learned earlier.

```
`na`.repeat(-0.1)
// <- ``, because count was rounded to -0
`na`.repeat(-0.9)
// <- ``, because count was rounded to -0
`na`.repeat(-0.9999)
// <- ``, because count was rounded to -0
`na`.repeat(-1)
// <- Uncaught RangeError: Invalid count value
```

An example use case for `String#repeat` may be the typical padding function. The `leftPad` function shown below takes a multiline string and pads every line with as many `spaces` as desired, using a default of two spaces.

```
function leftPad (text, spaces = 2) {
  return text
    .split(`\n`)
    .map(line => ` `.repeat(spaces) + line)
    .join(`\n`)
}

leftPad(`a
```

5 `String#repeat` in ECMAScript 6 Specification, section 21.1.3.13: *https://mjavascript.com/out/array-repeat*.

```
b
c`, 2)
// <- `  a\n  b\n  c`
```

7.3.5 String Padding and Trimming

At the time of this writing, there's two new string padding methods slated for publication in ES2017: `String#padStart` and `String#padEnd`. When performing string manipulation, we often want to pad a string so that it's formatted consistently with a style we have in mind. This can be useful when formatting numbers, currency, HTML, and in a variety of other cases usually involving monospaced text.

Using `padStart`, we will specify the desired length for the target string and the padding string, which defaults to a single space character. If the original string is at least as long as the specified length, `padStart` will result in a null operation, returning the original string unchanged.

In the following example, the desired length of a properly padded string is 5, and the original string already has a length of at least 5, so it's returned unchanged.

```
'01.23'.padStart(5)
// <- '01.23'
```

In the next example, the original string has a length of 4, thus `padStart` adds a single space at the beginning of the string, bringing the length to the desired value of 5.

```
'1.23'.padStart(5)
// <- ' 1.23'
```

The next example is just like the previous one, except it uses `0` for padding instead of the default `' '` value.

```
'1.23'.padStart(5, '0')
// <- '01.23'
```

Note that `padStart` will keep padding the string until the maximum length is reached.

```
'1.23'.padStart(7, '0')
// <- '0001.23'
```

However, if the padding string is too long, it may be truncated. The provided length is the maximum length of the padded string, except in the case where the original string is already larger than that.

```
'1.23'.padStart(7, 'abcdef')
// <- 'abc1.23'
```

The `padEnd` method has a similar API, but it adds the padding at the end of the original string, instead of at the beginning. The following snippet illustrates the difference.

```
'01.23'.padEnd(5) // <- '01.23'
'1.23'.padEnd(5) // <- '1.23 '
'1.23'.padEnd(5, '0') // <- '1.230'
'1.23'.padEnd(7, '0') // <- '1.23000'
'1.23'.padEnd(7, 'abcdef') // <- '1.23abc'
```

At the time of this writing, there's a proposal for string trimming in stage 2, containing the `String#trimStart` and `String#trimEnd` methods. Using `trimStart` removes any whitespace from the beginning of a string, while using `trimEnd` removes any whitespace from the end of a string.

```
'   this should be left-aligned   '.trimStart()
// <- 'this should be left-aligned   '
'   this should be right-aligned   '.trimEnd()
// <- '   this should be right-aligned'
```

Let's switch protocols and learn about Unicode.

7.3.6 Unicode

JavaScript strings are represented using UTF-16 code units[6]. Each code unit can be used to represent a code point in the `[U+0000, U+FFFF]` range — also known as the BMP, short for basic multilingual plane. You can represent individual code points in the BMP plane using the `\u3456` syntax. You could also represent code units in the `[U+0000, U+0255]` using the `\x00..\xff` notation. For instance, `\xbb` represents », the `187` character, as you can verify by doing `parseInt(bb, 16)` — or `String.fromCharCode(187)`.

For code points beyond `U+FFFF`, you'd represent them as a surrogate pair. That is to say, two contiguous code units. For instance, the horse emoji code point is represented with the `\ud83d\udc0e` contiguous code units. In ES6 notation you can also represent code points using the `\u{1f40e}` notation (that example is also the horse emoji).

Note that the internal representation hasn't changed, so there's still two code units behind that single code point. In fact, `\u{1f40e}.length` evaluates to `2`, one for each code unit.

The `\ud83d\udc0e\ud83d\udc71\u2764` string, found in the next code snippet, evaluates to a few emoji.

```
`\ud83d\udc0e\ud83d\udc71\u2764`
// <- `   `
```

6 Learn more about UCS-2, UCS-4, UTF-16 and UTF-32 here: *https://mjavascript.com/out/unicode-encodings*.

While that string consists of 5 code units, we know that the length should really be 3 — as there's only 3 emoji.

```
`\ud83d\udc0e\ud83d\udc71\u2764`.length
// <- 5
`   `.length
// <- 5, still
```

Counting code points before ES6 was tricky, as the language didn't make an effort to help in the Unicode department. Take for instance `Object.keys`, as seen in the following code snippet. It returns five keys for our 3-emoji string, because those 3 code points use 5 code units in total.

```
Object.keys(`   `)
// <- [`0`, `1`, `2`, `3`, `4`]
```

If we now consider a `for` loop, we can observe more clearly how this is a problem. In the following example, we wanted to exfill each individual emoji from the `text` string, but we get each code point instead.

```
const text = '   '
for (let i = 0; i < text.length; i++) {
  console.log(text[i])
  // <- '\ud83d'
  // <- '\udc0e'
  // <- '\ud83d'
  // <- '\udc71'
  // <- '\u2764'
}
```

Luckily for us, in ES6 strings adhere to the iterable protocol. We can use the string iterator to go over code points, even when those code points are made of surrogate pairs.

7.3.7 String.prototype[Symbol.iterator]

Given the problems with looping by code units, the iterables produced by the string iterator yield code points instead.

```
for (let codePoint of `   `) {
  console.log(codePoint)
  // <- ' '
  // <- ' '
  // <- ' '
}
```

Measuring the length of a string in terms of code points, as we saw earlier, is impossible with `String#length`, because it counts code units instead. We can, however, use an iterator to split the string into its code points, like we did in the `for..of` example.

We could use the spread operator, which relies on the iterator protocol, to split an string into an array made up of its conforming code points and then pull that array's `length`, getting the correct code point count, as seen next.

```
[...`   `].length
// <- 3
```

Keep in mind that splitting strings into code points isn't enough if you want to be 100% precise about string length. Take for instance the combining overline Unicode code unit, represented with `\u0305`. On its own, this code unit is just an overline, as shown below.

```
`\u0305`
// <- ` `
```

When preceded by another code unit, however, they are combined together into a single glyph.

```
function overlined (text) {
  return `${ text }\u0305`
}

overlined(`o`)
// <- `o `
`hello world`.split(``).map(overlined).join(``)
// <- `h e l l o   w o r l d `
```

Attempts to näively figure out the actual length by counting code points prove insufficient, just like when using `String#length` to count code points, as shown next.

```
`o `.length
// <- 2
[...`o `].length
// <- 2, should be 1
[...`h e l l o   w o r l d `].length
// <- 22, should be 11
[...`h e l l o  world`].length
// <- 16, should be 11
```

As Unicode expert Mathias Bynens points out, splitting by code points isn't enough. Unlike surrogate pairs like the emojis we've used in our earlier examples, other grapheme clusters aren't taken into account by the string iterator[7]. In those cases we're out of luck, and have to fall back to regular expressions or utility libraries to correctly calculate string length. Forunately, these kinds of glyphs are used infrequently.

Let's look at more Unicode-related methods introduced in ES6.

7 See also "JavaScript has a Unicode problem", *https://mjavascript.com/out/unicode-mathias*.

7.3.8 String#codePointAt

We can use `String#codePointAt` to get the base-10 numeric representation of a code point at a given position in a string. Note that the expected start position is indexed by code unit, not by code point. In the example below we print the code points for each of the three emoji in our demo string.

```
const text = `\ud83d\udc0e\ud83d\udc71\u2764`
text.codePointAt(0)
// <- 128014
text.codePointAt(2)
// <- 128113
text.codePointAt(4)
// <- 10084
```

Identifying the indices that need to be provided to `String#codePointAt` may prove cumbersome, which is why you should instead loop through a string iterator that can identify them on your behalf. You can then call `.codePointAt(0)` for each code point in the sequence, and `0` will always be the correct start index.

```
const text = `\ud83d\udc0e\ud83d\udc71\u2764`
for (let codePoint of text) {
  console.log(codePoint.codePointAt(0))
  // <- 128014
  // <- 128113
  // <- 10084
}
```

We could also reduce our example to a single line of code by using a combination of the spread operator and `Array#map`.

```
const text = `\ud83d\udc0e\ud83d\udc71\u2764`
[...text].map(cp => cp.codePointAt(0))
// <- [128014, 128113, 10084]
```

You can take the base-16 representation of those base-10 code points, and use them to create a string with the new unicode code point escape syntax of `\u{codePoint}`. This syntax allows you to represent unicode code points that are beyond the BMP (or basic multilingual plane). That is, code points outside the `[U+0000, U+FFFF]` range that are typically represented using the `\u1234` syntax.

Let's start by updating our example to print the hexadecimal version of our code points.

```
const text = `\ud83d\udc0e\ud83d\udc71\u2764`
[...text].map(cp => cp.codePointAt(0).toString(16))
// <- [`1f40e`, `1f471`, `2764`]
```

We could wrap those base-16 values in `\u{codePoint}` and voilá: you'd get the emoji values once again.

```
`\u{1f40e}`
// <- ` `
`\u{1f471}`
// <- ` `
`\u{2764}`
// <- ` `
```

7.3.9 `String.fromCodePoint`

This method takes in a number and returns a code point. Note how I can use the `0x` prefix with the terse base-16 code points we got from `String#codePointAt` moments ago.

```
String.fromCodePoint(0x1f40e)
// <- ` `
String.fromCodePoint(0x1f471)
// <- ` `
String.fromCodePoint(0x2764)
// <- ` `
```

You can just as well use plain base-10 literals and achieve the same results.

```
String.fromCodePoint(128014)
// <- ` `
String.fromCodePoint(128113)
// <- ` `
String.fromCodePoint(10084)
// <- ` `
```

You can pass in as many code points as you'd like to `String.fromCodePoint`.

```
String.fromCodePoint(128014, 128113, 10084)
// <- '   '
```

As an exercise in futility, we could map a string to their numeric representation of code points, and back to the code points themselves.

```
const text = `\ud83d\udc0e\ud83d\udc71\u2764`
[...text]
  .map(cp => cp.codePointAt(0))
  .map(cp => String.fromCodePoint(cp))
  .join(``)
// <- `   `
```

Reversing an string has potential to cause issues as well.

7.3.10 Unicode-Aware String Reversal

Consider the following piece of code.

```
const text = `\ud83d\udc0e\ud83d\udc71\u2764`
text.split(``).map(cp => cp.codePointAt(0))
// <- [55357, 56334, 55357, 56433, 10084]
```

```
text.split(``).reverse().map(cp => cp.codePointAt(0))
// <- [10084, 56433, 128014, 55357]
```

The problem is that we're reversing individual code units, while we'd have to reverse code points for a correct solution. If, instead, we were to use the spread operator to split the string by its code points, and then reversed that, the code points would be preserved and the string would be properly reversed.

```
const text = `\ud83d\udc0e\ud83d\udc71\u2764`
[...text].reverse().join(``)
// <- '   '
```

This way we avoid breaking up code points. Once again, keep in mind that this won't work for all grapheme clusters[7].

```
[...`hello\u0305`].reverse().join(``)
// <- `  olleh`
```

The last Unicode-related method we'll be addressing is `.normalize`.

7.3.11 `String#normalize`

There are different ways of representing strings that look identical to humans even though their code points differ. Consider the following example, where two seemingly identical strings aren't deemed equal by any JavaScript runtime.

```
`mañana` === `mañana`
// <- false
```

What's going on here? We have an `ñ` on the left version, while the version on the right has a combining tilde character +˜+ and an `n`. The two are visually identical, but if we take a look at the code points, we'll notice they're different.

```
[...`mañana`].map(cp => cp.codePointAt(0).toString(16))
// <- [`6d`, `61`, `f1`, `61`, `6e`, `61`]
[...`mañana`].map(cp => cp.codePointAt(0).toString(16))
// <- [`6d`, `61`, `6e`, `303`, `61`, `6e`, `61`]
```

Just like with the `hello` examples, the second string has a length of `7`, even though visually it is also `6` glyphs long.

```
[...`mañana`].length
// <- 6
[...`mañana`].length
// <- 7
```

If we normalize the second version, using `String#normalize`, we'll get back the same code points we had in the first version.

```
const normalized = `mañana`.normalize()
[...normalized].map(cp => cp.codePointAt(0).toString(16))
// <- [`6d`, `61`, `f1`, `61`, `6e`, `61`]
```

```
normalized.length
// <- 6
```

Note that we should use `String#normalize` on both strings when comparing them if we want to test for equality.

```
function compare (left, right) {
  return left.normalize() === right.normalize()
}
const normal = `mañana`
const irregular = `mañana`
normal === irregular
// <- false
compare(normal, irregular)
// <- true
```

7.4 Array

Over the years, libraries like Underscore and Lodash spoke loudly of missing features when it came to arrays. As a result, ES5 brought in heaps of functional methods to arrays: `Array#filter`, `Array#map`, `Array#reduce`, `Array#reduceRight`, `Array#forEach`, `Array#some`, and `Array#every`.

ES6 brings a few more methods that will help manipulate, fill, and filter arrays.

7.4.1 `Array.from`

Before ES6, JavaScript developers often needed to cast `arguments` to a function into an array.

```
function cast () {
  return Array.prototype.slice.call(arguments)
}
cast(`a`, `b`)
// <- [`a`, `b`]
```

We've already explored more terse ways of doing this in chapter 2, when we first learned about rest and spread. You could, for instance, use the spread operator. As you no doubt remember, the spread operator leverages the iterator protocol to produce a sequence of values in arbitrary objects. The downside is that the objects we want to cast with spread must adhere to the iterator protocol by having implemeted `Symbol.iterator`. Luckily for us, `arguments` does implement the iterator protocol in ES6.

```
function cast () {
  return [...arguments]
}
cast(`a`, `b`)
// <- [`a`, `b`]
```

Using the function rest parameter would be better for this particular case as it wouldn't involve the `arguments` object, nor any added logic in the function body.

```
function cast (...params) {
  return params
}
cast(`a`, `b`)
// <- [`a`, `b`]
```

You may also want to cast `NodeList` DOM element collections, like those returned from `document.querySelectorAll`, through the spread operator. Once again, this is made possible thanks to ES6 adding conformance to the iterator protocol for `NodeList`.

```
[...document.querySelectorAll(`div`)]
// <- [<div>, <div>, <div>, ...]
```

What happens when we try to cast a jQuery collection through the spread operator? If you're on a modern version of jQuery that implements the iterator protocol, spreading a jQuery object will work, otherwise you may get an exception.

```
[...$(`div`)]
// <- [<div>, <div>, <div>, ...]
```

The new `Array.from` method is a bit different. It doesn't only rely on the iterator protocol to figure out how to pull values from an object. It has support for array-likes out the box, unlike the spread operator. The following code snippet will work with any version of jQuery.

```
Array.from($(`div`))
// <- [<div>, <div>, <div>, ...]
```

The one thing you cannot do with either `Array.from` nor the spread operator is to pick a start index. Suppose you wanted to pull every `<div>` after the first one. With `Array#slice`, you could do the following.

```
[].slice.call(document.querySelectorAll(`div`), 1)
```

Of course, there's nothing stopping you from using `Array#slice` after casting. This is a bit easier to read than the previous example, as it keeps the slice call closer to the index at which we want to slice the array.

```
Array.from(document.querySelectorAll(`div`)).slice(1)
```

`Array.from` has three arguments, although only the `input` is required. To wit:

- `input` — the array-like or iterable object you want to cast
- `map` — a mapping function that's executed on every item of `input`
- `context` — the `this` binding to use when calling `map`

With `Array.from` you cannot slice, but you can dice. The `map` function will efficiently map the values into something else as they're being added to the array that results from calling `Array.from`.

```
function typesOf () {
  return Array.from(arguments, value => typeof value)
}
typesOf(null, [], NaN)
// <- [`object`, `object`, `number`]
```

Do note that, for the specific case of dealing with `arguments`, you could also combine rest parameters and `Array#map`. In this case in particular, we may be better off just doing something like the snippet of code found next. It's not as verbose as the previous example. Like with the `Array#slice` example we saw earlier, the mapping is more explicit in this case.

```
function typesOf (...all) {
  return all.map(value => typeof value)
}
typesOf(null, [], NaN)
// <- [`object`, `object`, `number`]
```

When dealing with array-like objects, it makes sense to use `Array.from` if they don't implement `Symbol.iterator`.

```
const apple = {
  type: `fruit`,
  name: `Apple`,
  amount: 3
}
const onion = {
  type: `vegetable`,
  name: `Onion`,
  amount: 1
}
const groceries = {
  0: apple,
  1: onion,
  length: 2
}
Array.from(groceries)
// <- [apple, onion]
Array.from(groceries, grocery => grocery.type)
// <- [`fruit`, `vegetable`]
```

7.4.2 `Array.of`

The `Array.of` method is exactly like the `cast` function we played around with earlier. Next is a code snippet that shows how `Array.of` might be polyfilled.

```
Array.of = (...params) => params
```

You can think about `Array.of` as an alternative for `new Array` that doesn't have the `new Array(length)` overload. In the following code snippet, you'll find some of the unexpected ways in which `new Array` behaves thanks to its single-argument `length` overloaded constructor. If you're confused about the `undefined x ${ count }` notation in the browser console, that's indicating there are array holes in those positions. This is also known as an sparse array.

```
new Array(); // <- []
new Array(undefined); // <- [undefined]
new Array(1); // <- [undefined x 1]
new Array(3); // <- [undefined x 3]
new Array(`3`); // <- [`3`]
new Array(1, 2); // <- [1, 2]
new Array(-1, -2); // <- [-1, -2]
new Array(-1); // <- RangeError: Invalid array length
```

In contrast, `Array.of` has more consistent behavior because it doesn't have the special `length` case. This makes it a more desirable way of consistently creating new arrays programatically.

```
console.log(Array.of()); // <- []
console.log(Array.of(undefined)); // <- [undefined]
console.log(Array.of(1)); // <- [1]
console.log(Array.of(3)); // <- [3]
console.log(Array.of(`3`)); // <- [`3`]
console.log(Array.of(1, 2)); // <- [1, 2]
console.log(Array.of(-1, -2)); // <- [-1, -2]
console.log(Array.of(-1)); // <- [-1]
```

7.4.3 `Array#copyWithin`

Let's start with the signature of `Array#copyWithin`.

```
Array.prototype.copyWithin(target, start = 0, end = this.length)
```

The `Array#copyWithin` method copies a sequence of array elements within an array instance to the "paste position" starting at `target`. The elements to be copied are taken from the `[start, end)` range. The `Array#copyWithin` method returns the array instance itself.

Let's lead with a simple example. Consider the `items` array in the following code snippet.

```
const items = [1, 2, 3, ,,,,,,,]
// <- [1, 2, 3, undefined x 7]
```

The function call shown below takes the `items` array and determines that it'll start "pasting" items in the sixth position (zero-based). It further determines that the items to be copied will be taken starting in the second position, until the third position (not inclusive).

```
const items = [1, 2, 3, ,,,,,,,]
items.copyWithin(6, 1, 3)
// <- [1, 2, 3, undefined × 3, 2, 3, undefined × 2]
```

Reasoning about `Array#copyWithin` is hard. Let's break it down.

If we consider that the items to be copied were taken from the `[start, end)` range, then we could express that using an `Array#slice` call. These are the items that were pasted at the `target` position. We can use `.slice` to grab the copy.

```
const items = [1, 2, 3, ,,,,,,,]
const copy = items.slice(1, 3)
// <- [2, 3]
```

We could also consider the pasting part of the operation as an advanced usage of `Array#splice`. The next code snippet does just that, passing the paste position to splice, telling it to remove as many items as we want to copy, and inserting the pasted items. Note that we're using the spread operator so that elements are inserted individually, and not as an array, through `.splice`.

```
const items = [1, 2, 3, ,,,,,,,]
const copy = items.slice(1, 3)
// <- [2, 3]
items.splice(6, 3 - 1, ...copy)
console.log(items)
// <- [1, 2, 3, undefined × 3, 2, 3, undefined × 2]
```

Now that we better understand the internals of `Array#copyWithin`, we can generalize the example in order to implement the custom `copyWithin` function shown in the following code snippet.

```
function copyWithin (items, target, start = 0, end = items.length) {
  const copy = items.slice(start, end)
  const removed = end - start
  items.splice(target, removed, ...copy)
  return items
}
```

The example we've been trying so far would work just as well with our custom `copyWithin` function.

```
copyWithin([1, 2, 3, ,,,,,,,], 6, 1, 3)
// <- [1, 2, 3, undefined × 3, 2, 3, undefined × 2]
```

7.4.4 `Array#fill`

A convenient utility method to replace all items in an array with the provided `value`. Note that sparse arrays will be filled in their entirety, while existing items will be replaced by the fill value.

```
[`a`, `b`, `c`].fill(`x`); // <- [`x`, `x`, `x`]
new Array(3).fill(`x`); // <- [`x`, `x`, `x`]
```

You could also specify the starting index and end index. In this case, as shown next, only the items in those positions would be filled.

```
[`a`, `b`, `c`,,,].fill(`x`, 2)
// <- [`a`, `b`, `x`, `x`, `x`]
new Array(5).fill(`x`, `x`, 3)
// <- [`x`, `x`, `x`, undefined x 2]
```

The provided `value` can be anything, and is not just limited to primitive values.

```
new Array(3).fill({})
// <- [{}, {}, {}]
```

You can't fill arrays using a mapping method that takes an `index` parameter or anything like that.

```
const map = i => i * 2
new Array(3).fill(map)
// <- [map, map, map]
```

7.4.5 `Array#find` and `Array#findIndex`

The `Array#find` method runs a `callback` for each `item` in an array until the first one that returns `true`, and then returns that `item`. The method follows the signature of `(callback(item, i, array), context)` that's also present in `Array#map`, `Array#filter`, and others. You can think of `Array#find` as a version of `Array#some` that returns the matching element instead of just `true`.

```
[`a`, `b`, `c`, `d`, `e`].find(item => item === `c`)
// <- `c`
[`a`, `b`, `c`, `d`, `e`].find((item, i) => i === 0)
// <- `a`
[`a`, `b`, `c`, `d`, `e`].find(item => item === `z`)
// <- undefined
```

There's an `Array#findIndex` method as well, and it leverages the same signature. Instead of returning a boolean value, or the element itself, `Array.findIndex` returns the index of the matching element, or `-1` if no matches occur. Here's a few examples

```
[`a`, `b`, `c`, `d`, `e`].findIndex(item => item === `c`)
// <- 2
[`a`, `b`, `c`, `d`, `e`].findIndex((item, i) => i === 0)
// <- 0
[`a`, `b`, `c`, `d`, `e`].findIndex(item => item === `z`)
// <- -1
```

7.4.6 Array#keys

Returns an iterator that yields a sequence holding the keys for the array. The returned value is an iterator, meaning you can iterate over it with `for..of`, the spread operator, or by manually calling `.next()`.

```
[`a`, `b`, `c`, `d`].keys()
// <- ArrayIterator {}
```

Here's an example using `for..of`.

```
for (let key of [`a`, `b`, `c`, `d`].keys()) {
  console.log(key)
  // <- 0
  // <- 1
  // <- 2
  // <- 3
}
```

Unlike `Object.keys`, and most methods that iterate over arrays, this sequence doesn't ignore array holes.

```
Object.keys(new Array(4))
// <- []
[...new Array(4).keys()]
// <- [0, 1, 2, 3]
```

Now onto values.

7.4.7 Array#values

Same thing as `Array#keys()`, but the returned iterator is a sequence of values instead of keys. In practice, you'll want to iterate over the array itself most of the time, but getting an iterator can come in handy sometimes.

```
[`a`, `b`, `c`, `d`].values()
// <- ArrayIterator {}
```

You can use `for..of` or any other methods like a spread operator to pull out the iterable sequence. The example below uses the spread operator on an array's `.values()` to create a copy of that array.

```
[...[`a`, `b`, `c`, `d`].values()]
// <- [`a`, `b`, `c`, `d`]
```

Note that omitting the `.values()` method call would still produce a copy of the array: the sequence is iterated and spread over a new array.

7.4.8 Array#entries

Similar to both preceding methods, except `Array#entries` returns an iterator with a sequence of key-value pairs.

```
[`a`, `b`, `c`, `d`].entries()
// <- ArrayIterator {}
```

Each item in the sequence is a two dimensional array with the key and the value for an item in the array.

```
[...[`a`, `b`, `c`, `d`].entries()]
// <- [[0, `a`], [1, `b`], [2, `c`], [3, `d`]]
```

Great, one last method left!

7.4.9 Array.prototype[Symbol.iterator]

This is exactly the same as the `Array#values` method.

```
const list = [`a`, `b`, `c`, `d`]
list[Symbol.iterator] === list.values
// <- true
[...list[Symbol.iterator]()]
// <- [`a`, `b`, `c`, `d`]
```

The example below combines a spread operator, an array, and `Symbol.iterator` to iterate over its values. Can you follow the code?

```
[...[`a`, `b`, `c`, `d`][Symbol.iterator]()]
// <- [`a`, `b`, `c`, `d`]
```

Let's break it down. First, there's the array.

```
[`a`, `b`, `c`, `d`]
// <- [`a`, `b`, `c`, `d`]
```

Then we get an iterator.

```
[`a`, `b`, `c`, `d`][Symbol.iterator]()
// <- ArrayIterator {}
```

Last, we spread the iterator over a new array, creating a copy.

```
[...[`a`, `b`, `c`, `d`][Symbol.iterator]()]
// <- [`a`, `b`, `c`, `d`]
```

CHAPTER 8

JavaScript Modules

Over the years, we've seen multiple different ways in which to split code into more manageable units. For the longest time we've had the module pattern where you simply wrapped pieces of code in self-invoking function expressions. You had to be careful to sort your scripts so that each script came after all of its dependencies.

A while later, the RequireJS library was born. It provided a way of defining the dependencies of each module programmatically, so that a dependency graph is created and you wouldn't have to worry about sorting your scripts anymore. RequireJS demands that you provide an array of strings used to identify your dependencies and also wrap modules in a function call, which would then receive those dependencies as parameters. Many other libraries provide similar functionality but offer a slightly different API.

Other complexity management mechanisms exist, such as the dependency injection mechanism in AngularJS, where you define named components using functions where you can, in turn, specify other named component dependencies. AngularJS carries the load of dependency injection on your behalf, so you only have to name components and specify dependencies.

CommonJS (CJS) surfaced as an alternative to RequireJS, and it was swiftly popularized by Node.js soon afterwards. In this chapter we'll take a look at CommonJS, which is still heavily in use today. We'll then cover the module system introduced to native JavaScript in ES6, and lastly we'll explore interoperability between CommonJS and native JavaScript modules — also known as ECMAScript modules (ESM).

8.1 CommonJS

Unlike other module formats where modules are declared programatically, in CommonJS every file is a module. CommonJS modules have an implicit local scope, while the `global` scope needs to be accessed explicitly. CommonJS modules can dynamically export a public interface consumers can interact with. CommonJS modules import their dependencies dynamically as well, resolving dependencies through `require` function calls. These `require` function calls are synchronous and return the interface exposed by required modules.

Interpreting the definition of a module format without looking at some code can be confusing. The following code snippet shows how a reusable CommonJS module file may look like. Both the `has` and `union` functions are local to our module's scope. Given that we've assigned `union` to `module.exports`, that'll be the public API for our module.

```
function has (list, item) {
  return list.includes(item)
}
function union (list, item) {
  if (has(list, item)) {
    return list
  }
  return [...list, item]
}
module.exports = union
```

Suppose we take that snippet of code and save it as `union.js`. We can now consume `union.js` in another CommonJS module. Let's call that one `app.js`. In order to consume `union.js`, we call `require` passing in a relative path to the `union.js` file. We can omit the file extension as long as it's `.js` or `.json`.

```
const union = require(`./union`)
console.log(union([1, 2], 3))
// <- [1, 2, 3]
console.log(union([1, 2], 2))
// <- [1, 2]
```

We could run `app.js` in its current state through the CLI for Node.js, `node`, as seen in the next snippet.

```
» node app
# [1, 2, 3]
# [1, 2]
```

You can download Node.js from their website: *https://mjavascript.com/out/node*. After installing Node, you'll be able to use the `node` program in your terminal.

Note the `.js` file extension is optional when executing programs through `node`.

The `require` function in CJS can be treated dynamically, just like any other JavaScript function. This aspect of `require` is sometimes leveraged to dynamically `require` different modules that conform to one interface. As an example, let's conjure up a `templates` directory with a number of view template functions. Our templates will take a model and return an HTML string.

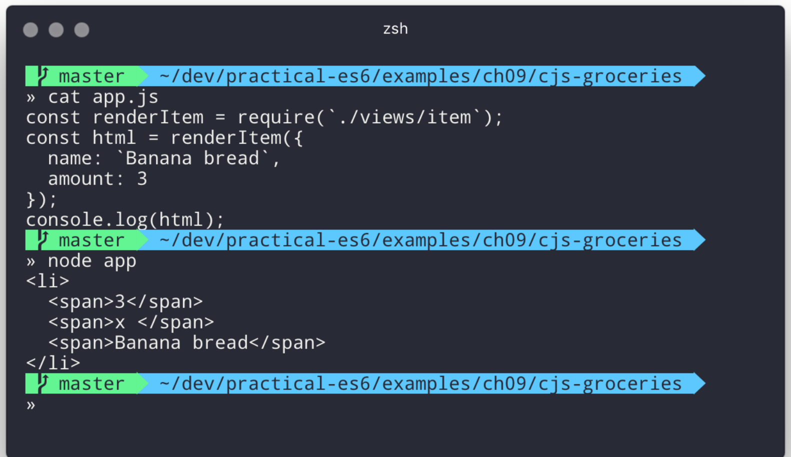
The template found in the following code snippet renders an item of a grocery shopping list by reading its attributes from a `model` object.

```
// views/item.js
module.exports = model => `<li>
  <span>${ model.amount }</span>
  <span>x </span>
  <span>${ model.name }</span>
</li>`
```

Our application could easily print a `<li>` by leveraging the `item.js` view template.

```
// app.js
const renderItem = require(`./views/item`)
const html = renderItem({
  name: `Banana bread`,
  amount: 3
})
console.log(html)
```

The following screenshot shows our tiny application in action.



The next template we'll make renders the grocery list itself. It receives an array of items, and renders each of them by reusing the `item.js` template from the previous code snippet.

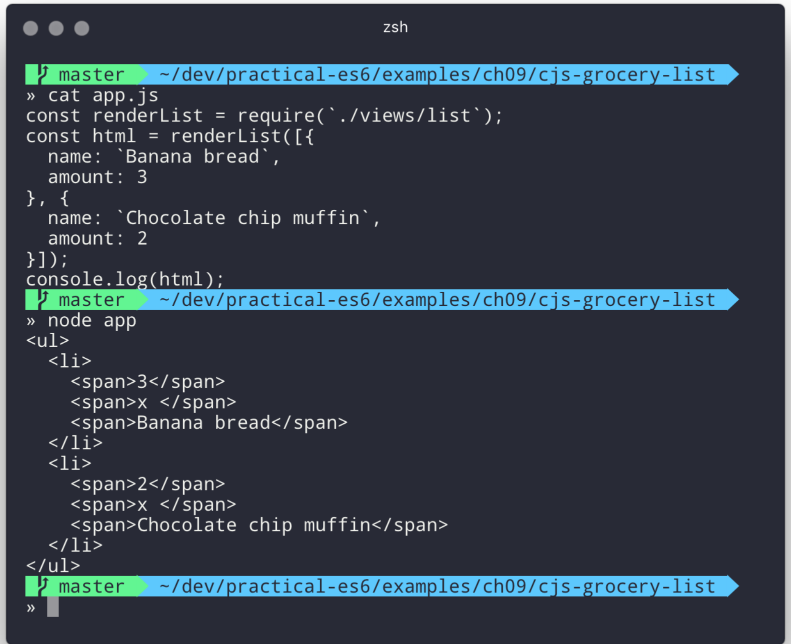
```
// views/list.js
const renderItem = require(`./item`)

module.exports = model => `<ul>
  ${ model.map(renderItem).join(`\n`) }
</ul>`
```

We can consume the `list.js` template in a very similar way than what we did before, but we'll need to adjust the model passed into the template so that we provide a collection of items instead of a single one.

```
// app.js
const renderList = require(`./views/list`)
const html = renderList([{
  name: `Banana bread`,
  amount: 3
}, {
  name: `Chocolate chip muffin`,
  amount: 2
}])
console.log(html)
```

The following screenshot shows our updated application in all its glory.



In the examples so far, we've written short modules that are only concerned with producing an HTML view after matching a `model` object with the corresponding view template. A simple API encourages reusability, which is why we're easily able to render the items for a list by mapping their models to the `item.js` templating function, and joining their HTML representations with newlines.

Given that the views all have a similar API where they take a model and return an HTML string, we can treat them uniformly. If we wanted a `render` function that could render any template, we could easily do that thanks to the dynamic nature of `require`. The next example shows how we can construct the path to a template module. An important distinction is how `require` calls doesn't necessarily need to be on the top level of a module. Calls to `require` can be anywhere, even embedded within other functions.

```
// render.js
module.exports = function render(template, model) {
  return require(`./views/${ template }`)(model)
}
```

Once we had such an API, we wouldn't have to worry about carefully constructing `require` statements that match the directory structure of our view templates, because the `render.js` module could take care of that. Rendering any template becomes a matter of calling the `render` function with the template's name and the model for that template.

```
// app.js
const render = require(`./render`)
console.log(render(`item`, {
  name: `Banana bread`,
  amount: 1
}))
console.log(render(`list`, [{
  name: `Apple pie`,
  amount: 2
}, {
  name: `Roasted almond`,
  amount: 25
}]))
```

Moving on, you'll notice that ES6 modules are heavily influenced by CommonJS. In the next few sections we'll look at `export` and `import` statements, and learn how ESM is compatible with CJS.

8.2 JavaScript Modules

As we explored the CommonJS module system, you might've noticed how the API is simple but powerful and flexible. ES6 modules offer an even simpler API that's almost as powerful at the expense of some flexibility.

8.2.1 Strict Mode

In the ES6 module system, strict mode is turned on by default. Strict mode is a feature[1] that disallows bad parts of the language, and turns some silent errors into loud exceptions being thrown. Taking into account these disallowed features, compilers can make optimizations making JavaScript runtime faster and safer.

- Variables must be declared
- Function parameters must have unique names
- Using `with` statements is forbidden
- Assignment to read-only properties results in errors being thrown
- Octal numbers like `00840` are syntax errors
- Attempts to `delete` undeletable properties throw an error
- `delete prop` is a syntax error, instead of assuming `delete global[prop]`
- `eval` doesn't introduce new variables into its surrounding scope
- `eval` and `arguments` can't be bound or assigned to
- `arguments` doesn't magically track changes to method parameters
- `arguments.callee` is no longer supported, throws a `TypeError`
- `arguments.caller` is no longer supported, throws a `TypeError`
- Context passed as `this` in method invocations is not "boxed" into an `Object`
- No longer able to use `fn.caller` and `fn.arguments` to access the JavaScript stack
- Reserved words (e.g `protected`, `static`, `interface`, etc) cannot be bound

Let's now dive into the `export` statement.

1 Read a comprehensive article about strict mode on Mozilla's MDN: *https://mjavascript.com/out/strict-mode*.

8.2.2 `export` Statements

In CommonJS modules, you export values by exposing them on `module.exports`. You can expose anything from a value type to an object, an array, or a function, as seen in the next few code snippets.

```
module.exports = `hello`
```

```
module.exports = { hello: `world` }
```

```
module.exports = [`hello`, 'world']
```

```
module.exports = function hello () {}
```

ES6 modules are files that may expose an API through `export` statements. Declarations in ESM are scoped to the local module, just like we observed about CommonJS. Any variables declared inside a module aren't available to other modules unless they're explicitly exported as part of that module's API and then imported in the module that wants to access them.

Exporting a Default Binding

You can mimic the CommonJS code we just saw by replacing `module.exports =` with `export default` statements.

```
export default `hello`
```

```
export default { hello: `world` }
```

```
export default [`hello`, `world`]
```

```
export default function hello () {}
```

In CommonJS, `module.exports` can be assigned-to dynamically.

```
function initialize () {
  module.exports = `hello!`
}
initialize()
```

In contrast with CJS, `export` statements in ESM can only be placed at the top level. "Top-level only" `export` statements is a good constraint to have, as there aren't many good reasons to dynamically define and expose an API based on method calls. This limitation also helps compilers and static analysis tools parse ES6 modules.

```
function initialize () {
  export default `hello!` // SyntaxError
}
initialize()
```

There are a few other ways of exposing an API in ESM, besides `export default` statements.

Named Exports

When you want to expose multiple values from CJS modules you don't necessarily need to explicitly export an object containing every one of those values. You could simply add properties onto the implicit `module.exports` object. There's still a single binding being exported, containing all properties the `module.exports` object ends up holding. While the following example exports two individual values, both are exposed as properties on the exported object.

```
module.exports.counter = 0
module.exports.count = () => counter++
```

We can replicate this behavior in ESM by using the named exports syntax. Instead of assigning properties to an implicit `module.exports` object like with CommonJS, in ES6 you declare the bindings you want to `export`, as shown in the following code snippet.

```
export let counter = 0
export const count = () => counter++
```

Note that the last bit of code cannot be refactored to extract the variable declarations into standalone statements that are later passed to `export` as a named export, as that'd be a syntax error.

```
let counter = 0
const count = () => counter++
export counter // SyntaxError
export count
```

By being rigid in how its declarative module syntax works, ESM favors static analysis, once again at the expense of flexibility. Flexibility inevitably comes at the cost of added complexity, which is a good reason not to offer flexible interfaces.

Exporting Lists

ES6 modules let you `export` lists of named top-level members, as seen in the following snippet. The syntax for export lists is easy to parse, and presents a solution to the problem we observed in the last code snippet from the previous section.

```
let counter = 0
const count = () => counter++
export { counter, count }
```

If you'd like to export a binding but give it a different name, you can use the aliasing syntax: `export { count as increment }`. In doing so, we're exposing the `count` binding from the local scope as a public method under the `increment` alias, as the following snippet shows.

```
let counter = 0
const count = () => counter++
export { counter, count as increment }
```

Finally, we can specify a default export when using the named member list syntax. The next bit of code uses `as default` to define a default export at the same time as we're enumerating named exports.

```
let counter = 0
const count = () => counter++
export { counter as default, count as increment }
```

The following piece of code is equivalent to the previous one, albeit a tad more verbose.

```
let counter = 0
const count = () => counter++
export default counter
export { count as increment }
```

It's important to keep in mind that we are exporting bindings, and not merely values.

Bindings, Not Values

ES6 modules export bindings, not values nor references. This means that a `counter` variable you export would be bound into the `counter` variable on the module, and its value would be subject to changes made to `counter`. While unexpectedly changing the public interface of a module after it has initially loaded can lead to confusion, this can indeed be useful in some cases.

In the next code snippet, our module's `counter` export would be initially bound to `0` and increase by `1` every second. Modules consuming this API would see the `counter` value changing every second.

```
export let counter = 0
setInterval(() => counter++, 1000)
```

Finally, the JavaScript module system offers an `export..from` syntax, where you can expose another module's interface.

Exporting from another module

We can expose another module's named exports using by adding a `from` clause to an `export` statement. The bindings are not imported into the local scope: our module acts as a pass-through where we expose another module's bindings without getting direct access to them.

```
export { increment } from './counter'
increment()
// ReferenceError: increment is not defined
```

You can give aliases to named exports, as they pass through your module. If the module in the following example were named `aliased`, then consumers could `import`

`{ add } from` *`./aliased`* to get a reference to the `increment` binding from the `counter` module.

```
export { increment as add } from './counter'
```

An ESM module could also expose every single named export found in another module by using a wildcard, as shown in the next snippet. Note that this wouldn't include the default binding exported by the `counter` module.

```
export * from './counter'
```

When we want to expose another module's `default` binding, we'll have to use the named export syntax adding an alias.

```
export { default as counter } from './counter'
```

We've now covered every way in which we can expose an API in ES6 modules. Let's jump over to `import` statements, which can be used to consume other modules.

8.2.3 `import` Statements

We can load a module from another one using `import` statements. The way modules are loaded is implementation-specific, that is: it's not defined by the specification. No browsers have implemented module loading as of this writing. We can write spec-compliant ES6 code today while smart people figure out how to deal with module loading in browsers.

Compilers like Babel are able to concatenate modules with the aid of a module system like CommonJS. That means `import` statements in Babel mostly follow the same semantics as `require` statements in CommonJS.

Let's suppose we have the following code snippet in a `./counter.js` module.

```
let counter = 0
const increment = () => counter++
const decrement = () => counter--
export { counter as default, increment, decrement }
```

The statement in the following code snippet could be used to load the `counter` module into our `app` module. It won't create any variables in the `app` scope, though. It will execute any code in the top level of the `counter` module, though, including that module's own `import` statements.

```
import './counter'
```

In the same fashion as `export` statements, `import` statements are only allowed in the top level of your module definitions. This limitation helps compilers simplify their module loading capabilities, as well as help other static analysis tools parse your codebase.

Importing Default Exports

CommonJS modules let you import other modules using `require` statements. When we need a reference to the default export, all we'd have to do is assign that to a variable.

```
const counter = require(`./counter`)
```

To import the default binding exported from an ES6 module, we'll have to give it a name. The syntax and semantics are a bit different than what we use when declaring a variable, because we're importing a binding and not just assigning values to variables. This distinction also makes it easier for static analysis tools and compilers to parse our code.

```
import counter from './counter'
console.log(counter)
// <- 0
```

Besides default exports, you could also import named exports and alias them.

Importing Named Exports

The following bit of code shows how we can import the `increment` method from our `counter` module. Reminiscent of assignment destructuring, the syntax for importing named exports is wrapped in braces.

```
import { increment } from './counter'
```

To import multiple bindings, we separate them using commas.

```
import { increment, decrement } from './counter'
```

The syntax and semantics are subtly different from destructuring. While destructuring relies on colons to create aliases, `import` statements use an `as` keyword, mirroring the syntax in `export` statements. The following statement imports the `increment` method as `add`.

```
import { increment as add } from './counter'
```

You can combine a default export with named exports by separating them with a comma.

```
import counter, { increment } from './counter'
```

You can also explicitly name the `default` binding, which needs an alias.

```
import { default as counter, increment } from './counter'
```

The following example demonstrates how ESM semantics differ from those of CJS. Remember: we're exporting and importing bindings, and not direct references. For practical purposes, you can think of the `counter` binding found in the next example as a property getter that reaches into the `counter` module and returns its local `counter` variable.

```
import counter, { increment } from './counter'
console.log(counter) // <- 0
increment()
console.log(counter) // <- 1
increment()
console.log(counter) // <- 2
```

Lastly, there are also namespace imports.

Wildcard `import` statements

We can import the namespace object for a module by using a wildcard. Instead of importing the named exports or the default value, it imports everything at once. Note that the `*` must be followed by an alias where all the bindings will be placed. If there was a `default` export, it'll be placed in the namespace binding as well.

```
import * as counter from './counter'
counter.increment()
counter.increment()
console.log(counter.default) // <- 2
```

8.2.4 Dynamic `import()`

At the time of this writing, a proposal for dynamic `import()+`[2] `expressions is sitting at stage 3 of the TC39 proposal review process. Unlike +import` statements, which are statically analyzed and linked, `import()` loads modules at runtime, returning a promise for the module namespace object after fetching, parsing, and executing the requested module and all of its dependencies.

The module specifier can be any string, like with `import` statements. Keep in mind `import` statements only allow statically defined plain string literals as module specifiers. In contrast, we're able to use template literals or any valid JavaScript expression to produce the module specifier string for `import()` function calls.

Imagine you're looking to internationalize an application based on the language provided by user agents. You might statically import a `localizationService`, and then dynamically import the localized data for a given language using `import()` and a module specifier built using a template literal which interpolates `navigator.language`, as shown in the following example.

---

2 You can find the proposal specification draft here: *https://mjavascript.com/out/dynamic-import*.

```
import localizationService from './localizationService'
import(`./localizations/${ navigator.language }.json`)
  .then(module => localizationService.use(module))
```

Just like with `import` statements, the mechanism for retrieving the module is unspecified and left up to the host environment.

The proposal does specify that once the module is resolved, the promise should fulfill with its namespace object. It also specifies that whenever an error results in the module failing to load, the promise should be rejected.

This allows for loading non-critical modules asynchronously, without blocking page load, and being able to gracefully handle failure scenarios when such module fails to load, as demonstrated next.

```
import(`./vendor/jquery.js`)
  .then($ => {
    // use jquery
  })
  .catch(() => {
    // failed to load jquery
  })
```

We could load multiple modules asynchronously using `Promise.all`. The following example imports three modules and then leverages destructuring to reference them directly in the `.then` clause.

```
const specifiers = [
  `./vendor/jquery.js`,
  `./vendor/backbone.js`,
  `./lib/util.js`
]
Promise
  .all(specifiers.map(specifier => import(specifier)))
  .then(([$, backbone, util]) => {
    // use modules
  })
```

In a similar fashion, you could load modules using synchonous loops or even `async`/`await`, as demonstrated next.

```
async function load () {
  const { map } = await import(`./vendor/jquery.js`)
  const $ = await import(`./vendor/jquery.js`)
  const response = await fetch(`/cats`)
  const cats = await response.json()
  $(`<div>`)
    .addClass(`container cats`)
    .html(map(cats, cat => cat.htmlSnippet))
    .appendTo(document.body)
}
load()
```

Using `await import()` makes dynamic module loading look and feel like static `import` statements. We need to watch out and remind ourselves that the modules are asynchronously loaded one by one, though.

Keep in mind that `import` is function-like, but it has different semantics from regular functions: `import` is not a function definition, it can't be extended, it can't be assigned properties, and it can't be destructured. In this sense, `import()` falls in a similar category as the `super()` call that's available in class constructors.

8.3 Practical Considerations for ES Modules

When using a module system, any module system, we gain the ability of explicitly publishing an API while keeping everything that doesn't need to be public in the local scope. Perfect information hiding like this is a sought out feature that was previously hard to reproduce: you'd have to rely on deep knowledge of JavaScript scoping rules, or blindly follow a pattern inside which you could hide information, as shown next. In this case, we create a `random` module with a locally scoped `calc` function, which computes a random number in the `[0, n)` range; and a public API with the `range` method, which computes a random number in the `[min, max]` range.

```
const random = (function() {
  const calc = n => Math.floor(Math.random() * n)
  const range = (max = 1, min = 0) => calc(max + 1 - min) + min
  return { range }
})()
```

Compare that to the following piece of code, used in an ESM module called `random`. The immediately-invoking function expression wrapper trick went away, along with the name for our module, which now resides in its filename. We've regained the simplicity from back in the day, when we wrote raw JavaScript inside plain HTML `<script>` tags.

```
const calc = n => Math.floor(Math.random() * n)
const range = (max = 1, min = 0) => calc(max + 1 - min) + min
export { range }
```

While we don't have the problem of having to wrap our modules in an IIFE anymore, we still have to be careful about how we define, test, document, and use each module.

Deciding what constitutes a module is difficult. A lot of factors come into play, some of which I've outlined in the form of questions below.

- Is it highly complex?
- Is it too large?
- How well-defined is its API?
- Is said API properly documented?

- Is it easy to write tests for the module?
- How hard is it to add new features?
- Is it difficult to remove existing functionality?

Complexity is a more powerful metric to track than length. A module can be several thousand lines long but simple, such as a dictionary that maps identifiers to localized strings in a particular language; or it could be a couple dozen lines long but very hard to reason about, such as a data model that also includes domain validation and business logic rules. Complexity can be mitigated by splitting our code up into smaller modules that are only concerned with one aspect of the problem we're trying to solve. As long as they're not highly complex, large modules are not as much of an issue.

Having a well-defined API that's also properly documented is a key aspect of effective modular application design. A module's API should be focused, and follow information hiding principles. That is: only reveal what is necessary for consumers to interact with it. By not exposing internal aspects of a module, which may be undocumented and prone to change, we keep a simple interface overall and avoid unintended usage patterns. By documenting the public API, even if its documented in code or self-documenting, we reduce the barrier of entry for humans looking to utilize the module.

Tests should only be written against the public interface to a module, while its internals must be treated as uninteresting implementation details. Tests need to cover the different aspects of a module's public interface, but changes to the internal implementation shouldn't break our test coverage as long as the API remains the same in terms of inputs and outputs.

Ease of adding or removing functionality from a module is yet another useful metric. How hard would it be to add a new feature? Do you have to edit several different modules in order to implement something? Is this a repetitive process? Maybe you could abstract those edits behind a higher level module that hides that complexity. Or maybe doing so would mostly add indirection and make following the codebase harder to read, but with little added benefit or justification. From the other end of the spectrum, how deeply entrenched is the API? Would it be easy to remove a portion of the module, delete it entirely, or even replace it with something else? If modules become too co-dependant, then it can be hard to make edits as the codebase ages, mutates and grows in size.

We'll plunge deeper into proper module design, effective module interaction and module testing over the next three books in this series.

With that said, let's turn over to the last chapter, on leveraging all of these new language features and syntax effectively.