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3RD EDITION

Mastering JavaScript Functional Programming

Write clean, robust, and maintainable web and server code using functional JavaScript and TypeScript

FEDERICO KEREKI

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Writing a book involves many people, and even if I cannot mention and name all of them, there are some who really deserve to be highlighted.

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There are some other people who deserve extra consideration. This book was written under unusual circumstances, around 10,000 miles away from home! I had gone from Uruguay, where I live, to work on a project in India, and that's where I wrote every single page of the text. This would not have been possible if I hadn't had complete support from my family, who stayed in Montevideo, but who were constantly nearby, thanks to the internet and modern communication. In particular, I must single out my wife, Sylvia Tosar, not only for supporting and aiding me both with the project and the book but also for dealing with everything and the rest of the family on her own in Uruguay—this book wouldn't have been possible otherwise, and she is the greatest reason the book could be written!

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For the third edition: Expanding the book for a third edition was, once more, a challenging task. In this case, I had support from Bhavya Rao, publishing product manager; Mark D'Souza, senior editor; Joseph Aloocaran, technical editor; and Anu Nagan and Markandey Pathak, reviewers, all of whom greatly aided my work, aiming for an even higher quality final text.

- Federico Kereki

Contributors

About the author

Federico Kereki is a Uruguayan systems engineer, with a master's degree in education, and over 30 years of experience as a consultant, system developer, and writer.

He is currently a subject matter expert at Globant, where he gets to use a good mixture of development frameworks, programming tools, and operating systems. He is familiar with languages such as JavaScript and TypeScript; modern backend runtime environments such as Node.js and Deno; frontend frameworks such as React, Vue, and Angular; and services, microservices, and cloud components for systems architecture.

He has taught several computer science courses at Universidad de la República, Universidad ORT Uruguay, and Universidad de la Empresa. He has also written texts for these courses.

He has written articles and booklets on programming, web development, security, and open source topics for blogs, magazines, and websites. He has also written several books, including *Modern JavaScript Web Development Cookbook* and the upcoming *Data Structures and Algorithms in JavaScript*.

Kereki has given talks on functional programming at public conferences (such as JSCONF 2016 and Development Week Santiago 2019) and has used functional programming techniques to develop internet systems for businesses in Uruguay and abroad.

His current interests tend toward software quality and software engineering – with Agile methodologies topmost – while on the practical side, he works with diverse languages, tools, and frameworks, and **Free/Libre Open Source Software** (**FLOSS**) wherever possible!

He resides, works, and teaches in Uruguay, but he wrote the first edition of this book while working in India, and the second edition during a sojourn in Mexico; the third edition was the first actually completed in his homeland!

About the reviewers

Markandey Pathak is an accomplished full-stack developer and software architect with over 11 years of experience. Currently, he works as an expert engineer and vice president with one of the biggest financial firms. He has also worked with top firms such as Deloitte, PwC, and Sapient in the past. In addition to his technical work, Markandey is also passionate about teaching coding to kids and playing with robots in his spare time. He is an avid traveler and enjoys spending time in nature and exploring new destinations with his wife and son whenever possible. Markandey's diverse interests and impressive professional experience make him a well-rounded and highly respected member of the software engineering community.

Anu Nagan G has worked in various corporate organizations, from a SaaS start-up (*Gendeep*) to a mid-size organization (*GAVS*) and a Fortune 500 company (*DXC*). He has held various positions such as technical product manager, full-stack product lead (Angular, Java, Python, and AWS), and delivery lead in his 9+ years of tenure. He has experience in leading advanced AI and analytics product Cortex AI (API automation), Salesforce CRM B2B automation, and mobile app development, and contributed to various AIOps products such as ZIF, Gcare, and Gavel in the past. Currently, he is leading parallel projects with Bounteous, which include data integration with the Braze marketing platform with a custom middleware and digital experience transformation for Fintech customers using AEM. He is an avid reader and cinephile who loves to play the guitar and make short films with his friends.

I would like to thank my wife, Hema, and my daughter, Chekhov, for always giving me the freedom to pursue my interests.

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Preface

In computer programming, paradigms abound. Some examples include imperative programming, structured (goto-less) programming, **object-oriented programming** (**OOP**), aspect-oriented programming, and declarative programming. Lately, there has been renewed interest in a particular paradigm that can arguably be considered to be older than most (if not all) of the cited ones—**functional programming** (**FP**). FP emphasizes writing functions and connecting them in simple ways to produce more understandable and more easily tested code. Thus, given the increased complexity of today's web applications, it's logical that a safer, cleaner way of programming would be of interest.

This interest in FP comes hand in hand with the evolution of JavaScript. Despite its somewhat hasty creation (reportedly achieved in only 10 days, in 1995, by Brendan Eich at Netscape), today, JavaScript is a standardized and quickly growing language, with features more advanced than most other similarly popular languages. The ubiquity of the language, which can now be found in browsers, servers, mobile phones, and whatnot, has also impelled interest in better development strategies. Also, even if JavaScript wasn't conceived as a functional language, the fact is that it provides all the features you'd require to work in that fashion, which is another plus.

That said, we must also comment on advances in the language and related tools. The benefits of data typing are generally acknowledged, and in recent years, TypeScript has gained wide adoption and has been used for both frontend and backend coding. It makes sense, then, to also include its usage in this book. This, we feel, will make the examples clearer, and also simplify the adoption of the presented code for "real-life" jobs.

It must also be said that FP hasn't been generally applied in industry, possibly because it has a certain aura of difficulty, and it is thought to be theoretical rather than practical, even mathematical, and possibly uses vocabulary and concepts that are foreign to developers—for example, functors, monads, folding, and category theory. While learning all this theory will certainly be of help, it can also be argued that even with zero knowledge of the previous terms, you can understand the tenets of FP, and see how to apply it to your own programming.

FP is not something that you have to do on your own, without any help. There are many libraries and frameworks that incorporate, to greater or lesser degrees, the concepts of FP. Starting with jQuery (which does include some FP concepts), passing through Underscore and its close relative, Lodash, and other libraries such as Ramda, and getting to more complete web development tools such as React and Redux, Angular, and Elm (a 100% functional language, which compiles into JavaScript), the list of functional aids for your coding is ever growing.

Learning how to use FP can be a worthwhile investment, and even though you may not get to use all of its methods and techniques, just starting to apply some of them will pay dividends in better code. You need not try to apply all the concepts of FP from the start, and you need not try to abandon every non-functional feature in JavaScript either. JavaScript assuredly has some bad features, but it also has several very good and powerful ones. The idea is not to throw away everything you've learned and use and adopt a 100% functional way; rather, the guiding idea is evolution, not revolution. In that sense, it can be said that what we'll be doing is not FP, but rather **Sorta Functional Programming** (**SFP**), aiming for a fusion of paradigms.

A final comment about the style of the code in this book—it is quite true that there are several very good libraries that provide you with FP tools: Underscore, Lodash, and Ramda are counted among them. However, I preferred to eschew their usage because I wanted to show how things really work. It's easy to apply a given function from some package or the other, but by coding everything out (vanilla FP, if you wish), it's my belief that you get to understand things more deeply. Also, as I will comment in some places, because of the power and clarity of arrow functions and other features, the pure JavaScript versions can be even simpler to understand!

Who this book is for

This book is geared toward programmers with a good working knowledge of JavaScript (or, better yet, TypeScript) working either on the client side (browsers) or the server side (Node.js), who are interested in applying techniques to be able to write better, testable, understandable, and maintainable code. Some background in computer science (including, for example, data structures) and good programming practices will also come in handy. In this book, we'll cover FP in a practical way, though, at times, we will mention some theoretical points.

What this book covers

Chapter 1, *Becoming Functional – Several Questions*, discusses FP, gives reasons for its usage, and lists the tools that you'll need to take advantage of the rest of the book.

Chapter 2, *Thinking Functionally – A First Example*, will provide the first example of FP by considering a common web-related problem and going over several solutions, to finally focus on a functional solution.

Chapter 3, *Starting Out with Functions – A Core Concept*, will go over the central concept of FP, that is, functions, and the different options available in JavaScript.

Chapter 4, *Behaving Properly – Pure Functions*, will consider the concept of purity and pure functions, and demonstrate how it leads to simpler coding and easier testing.

Chapter 5, *Programming Declaratively – A Better Style*, will use simple data structures to show how to produce results that work not in an imperative way, but in a declarative fashion.

Chapter 6, *Producing Functions – Higher-Order Functions*, will deal with higher-order functions, which receive other functions as parameters and produce new functions as results.

Chapter 7, *Transforming Functions – Currying and Partial Application*, will explore some methods for producing new and specialized functions from earlier ones.

Chapter 8, *Connecting Functions – Pipelining, Composition, and More*, will show the key concepts regarding how to build new functions by joining previously defined ones.

Chapter 9, *Designing Functions – Recursion*, will look at how a key concept in FP, recursion, can be applied to designing algorithms and functions.

Chapter 10, *Ensuring Purity – Immutability*, will present some tools that can help you to work in a pure fashion by providing immutable objects and data structures.

Chapter 11, *Implementing Design Patterns – The Functional Way*, will show how several popular OOP design patterns are implemented (or not needed!) when you program in FP ways.

Chapter 12, *Building Better Containers – Functional Data Types*, will explore some more high-level functional patterns, introducing types, containers, functors, monads, and several other more advanced FP concepts.

I have tried to keep the examples in this book simple and down to earth because I want to focus on the functional aspects and not on the intricacies of this or that problem. Some programming texts are geared toward learning, say, a given framework, and then working on a given problem, showing how to fully work it out with the chosen tools.

In fact, in the very early stages of planning for this book, I entertained the idea of developing an application that would use all the FP things I had in mind, but there was no way to fit all of that within a single project. Exaggerating a bit, I felt like an MD trying to find a patient on whom to apply all of his medical knowledge and treatments! So, I opted to show plenty of individual techniques, which can be used in multiple situations. Rather than building a house, I want to show you how to put bricks together, how to wire things up, and so on, so that you will be able to apply whatever you need as you see fit.

To get the most out of this book

To understand the concepts and code in this book, you don't need much more than a JavaScript environment and a text editor. To be honest, I even developed some of the examples working fully online, with tools such as JSFiddle (at `jsfiddle.net`) and the like, and absolutely nothing else.

In this book, we'll be using ES2022 and Node 19, and the code will run on any OS, such as Linux, macOS, or Windows.

You will need some experience with the latest version of JavaScript because it includes several features that can help you write more concise and compact code. We will frequently include pointers to online documentation, such as the documentation available on the **Mozilla Development Network** (**MDN**) at `developer.mozilla.org`, to help you get more in-depth knowledge.

We'll also be using the latest version of TypeScript, to add data typing to our JavaScript code. For more on the language, the must-read reference is www.`typescriptlang.org`, where you'll find documentation, tutorials, and even an online playground to directly test code there.

Download the example code files

You can download the example code files for this book from GitHub at `github.com/PacktPublishing/Mastering-JavaScript-Functional-Programming-3E`. If there's an update to the code, it will be updated in the GitHub repository.

We also have other code bundles from our rich catalog of books and videos available at `github.com/PacktPublishing/`. Check them out!

Download the color images

We also provide a PDF file that has color images of the screenshots and diagrams used in this book. You can download it here: `https://packt.link/UsFuE`.

Conventions used

There are a number of text conventions used throughout this book.

`Code in text`: Indicates code words in text, database table names, folder names, filenames, file extensions, pathnames, dummy URLs, user input, and Twitter handles. Here is an example: "There are several possible results: a single value with the `reduce()` operation, a new array with `map()`, or just about any kind of result with `forEach()`."

A block of code is set as follows:

```
// reverse.ts

const reverseString = (str: string): string => {
  const arr = str.split("");
  arr.reverse();
  return arr.join("");
};

console.log(reverseString("MONTEVIDEO"));      // OEDIVETNOM
```

When we wish to draw your attention to a particular part of a code block, the relevant lines or items are set in bold:

```
// continued...

const reverseString2 = (str: string): string =>
```

```
  str.split("").reduceRight((x, y) => x + y, "");

console.log(reverseString2("OEDIVETNOM")); // MONTEVIDEO
```

Any command-line input or output is written as follows:

```
START MAP
2022-10-29T01:47:06.726Z [ 10, 20, 30, 40 ]
END MAP
```

Bold: Indicates a new term, an important word, or words that you see onscreen.

> **Tips or important notes**
> Appear like this.

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1
Becoming Functional – Several Questions

Functional programming (or **FP**) has been around since the earliest days of computing and is going through a sort of revival because of its increased use with several frameworks and libraries, most particularly in **JavaScript**.

In this chapter, we shall do the following:

- Introduce some concepts of FP to give a small taste of what it means
- Show the benefits (and problems) implied by the usage of FP and why we should use it
- Start thinking about why JavaScript can be considered an appropriate language for FP
- Go over the language features and tools that you should be aware of to fully take advantage of everything in this book

By the end of this chapter, you'll have the basic tools that we'll be using throughout this book, so let's get started by learning about FP.

What is functional programming?

If you go back in computer history, you'll find that the second oldest programming language still in use, Lisp, is based on FP. Since then, there have been many more functional languages, and FP has been applied more widely. But even so, if you ask people what FP is, you'll probably get two widely dissimilar answers.

A bit of trivia

For trivia or history buffs, the oldest programming language still in use is Fortran, which appeared in 1957, a year before Lisp. Quite shortly after Lisp came another long-lived language, COBOL, for business-oriented programming.

Depending on whom you ask, you'll either learn that it's a modern, advanced, enlightened approach to programming that leaves every other paradigm behind or that it's mainly a theoretical thing, with more complications than benefits, that's practically impossible to implement in the real world. And, as usual, the real answer is not in the extremes, but somewhere in between. Let's start by looking at the theory versus practice and see how we plan to use FP.

Theory versus practice

In this book, we won't be going about FP in a theoretical way. Instead, our point is to show you how some of its techniques and tenets can be successfully applied to common, everyday JavaScript programming. But – and this is important – we won't be going about this dogmatically, but in a very practical way. We won't dismiss useful JavaScript constructs simply because they don't happen to fulfill the academic expectations of FP. Similarly, we won't avoid practical JavaScript features just to fit the FP paradigm. We could almost say that we'll be doing **Sorta Functional Programming** (**SFP**) because our code will be a mixture of FP features, more classical imperative ones, and **object-oriented programming** (**OOP**).

Be careful, though: what we just said doesn't mean that we'll be leaving all the theory by the side. We'll be picky, and just touch the main theoretical points, learn some vocabulary and definitions, and explain core FP concepts, but we'll always be keeping in sight the idea of producing actual, useful JavaScript code, rather than trying to meet some mystical, dogmatic FP criteria.

OOP has been a way to solve the inherent complexity of writing large programs and systems, and developing clean, extensible, scalable application architectures; however, because of the scale of today's web applications, the complexity of all code bases is continuously growing. Also, the newer features of JavaScript make it possible to develop applications that wouldn't even have been possible just a few years ago; think of mobile (hybrid) apps that are made with Ionic, Apache Cordova, or React Native or desktop apps that are made with Electron, Tauri, or NW.js, for example. JavaScript has also migrated to the backend with Node.js or Deno, so today, the scope of usage for the language has grown in a serious way that deals with all the added complexity of modern designs.

A different way of thinking

FP is a different way of writing programs and can sometimes be difficult to learn. In most languages, programming is done imperatively: a program is a sequence of statements, executed in a prescribed fashion, and the desired result is achieved by creating objects and manipulating them, which usually means modifying the objects themselves. FP is based on producing the desired result by evaluating expressions built out of functions that are composed together. In FP, it's common to pass functions around (such as passing parameters to other functions or returning functions as the result of a calculation), not use loops (opting for recursion instead), and skip side effects (such as modifying objects or global variables).

In other words, FP focuses on *what* should be done, rather than on *how* it should be done. Instead of worrying about loops or arrays, you work at a higher level, considering what needs to be done. After becoming accustomed to this style, you'll find that your code becomes simpler, shorter, and more elegant, and can be easily tested and debugged. However, don't fall into the trap of considering FP as the goal! Think of FP only as a means to an end, as with all software tools. Functional code isn't good just for being functional, and writing bad code is just as possible with FP as with any other technique!

FP and other programming paradigms

Programming paradigms classify programming languages according to their features. However, some languages may be classified into multiple paradigms – as is the case of JavaScript itself!

A primary division is *imperative* versus *declarative* languages. In the former, developers must instruct the machine on how to do its work, step by step. Programming may be *procedural* (if instructions are grouped into procedures) or *object-oriented* (if instructions are grouped with a related state).

In declarative languages, in opposition, developers just declare properties that the sought result must satisfy, but not how to calculate it. Declarative languages may be *logic-based* (based on logic rules and constraints), *reactive* (based on data and event streams), or *functional* (based on the application and combination of functions). In a sense, we could say that imperative languages focus on *how*, while declarative languages focus on *what*.

JavaScript is multi-paradigm: it's imperative (both procedural and object-oriented) but also allows declarative programming, both functional (like almost everything in this book! In particular, we will devote *Chapter 5*, *Programming Declaratively*, to this topic) and reactive (we'll see reactive FP in *Chapter 11*, *Implementing Design Patterns*).

Just to give you a basic example of the difference between imperative and declarative ways of solving a problem, let's solve a simple problem: assume you have an array of personal data of people, as follows:

```
// imperative.js

const data = [
  { name: "John", age: 23, other: "xxx" },
  { name: "Paul", age: 18, other: "yyy" },
  { name: "George", age: 16, other: "zzz" },
  { name: "Ringo", age: 25, other: "ttt" },
];
```

Imagine you want to extract the data for adults (at least 21 years old). Imperatively, you would do something like the following:

```
// continued...

const result1 = [];
```

```
for (let i = 0; i < data.length; i++) {
  if (data[i].age >= 21) {
    result1.push(data[i]);
  }
}
```

You have to initialize the output array (`result1`) for the selected people. Then, you must specify a loop, saying how the index variable (`i`) is to be initialized, tested, and updated. On each pass of the loop, you check the corresponding person's age, and if the person is an adult, you push the data to the output array. In other terms, you specify, step by step, everything that the code will have to do.

Working declaratively, you'd rather write something like this:

```
// declarative.js

const isAdult = (person) => person.age >= 21;
const result2 = data.filter(isAdult);
```

The first line declares how to test if a person is an adult; the second line says that the result is the result of filtering the data array, picking those elements that satisfy the given predicate. (For `isAdult()`, we're using an arrow function; we'll see more on that in the *Arrow functions* section, later in this chapter.) You don't have to initialize the output array, specify how to loop, or ensure that your array index doesn't go beyond the array's length, and so on – all those details are taken care of by the language, so you don't need to.

Reading and understanding the imperative version requires knowledge of both the programming language and algorithms or techniques for looping; the declarative version is shorter to write, easier to maintain, and much more readable.

What FP is not

Since we've been talking quite a bit about what FP is, let's also clear up some common misconceptions, and look at what FP is not:

- *FP isn't just an academic ivory tower thing*: The lambda calculus upon which it is based was developed by Alonzo Church in 1936 as a tool to prove an important result in theoretical computer science (which preceded modern computer languages by more than 20 years!); however, FP languages are being used today for all kinds of systems.
- *FP isn't the opposite of OOP*: It isn't a case of choosing declarative or imperative ways of programming. You can mix and match as best suits you, and we'll be doing this throughout this book, bringing together the best of all worlds.

- *FP isn't overly complex to learn*: Some of the FP languages are rather different from JavaScript, but the differences are mostly syntactic. Once you learn the basic concepts, you'll see that you can get the same results in JavaScript as with FP languages.

It may also be relevant to mention that several modern frameworks, such as the React and Redux combination, include FP ideas.

For example, in React, it's said that the view (whatever the user gets to see at a given moment) is a function of the current state. You use a function to compute what HTML and CSS must be produced at each moment, thinking in a black-box fashion.

Similarly, in Redux, you have the concept of actions that are processed by reducers. An action provides some data, and a reducer is a function that produces the new state for the application in a functional way out of the current state and the provided data.

So, both because of the theoretical advantages (we'll be getting to those in the following section) and the practical ones (such as getting to use the latest frameworks and libraries), it makes sense to consider FP coding. Let's get on with it.

Why use FP?

Throughout the years, there have been many programming styles and fads. However, FP has proven quite resilient and is of great interest today. Why would you want to use FP? Rather, the first question to ask should be, what do you need? And only then, does FP get you that? We'll answer these important questions in the following sections.

What we need

We can certainly agree that the following list of concerns is universal. Our code should have the following qualities:

- **Modular**: The functionality of your program should be divided into independent modules, each of which contains a part of the solution. Changes in a module or function shouldn't affect the rest of the code.
- **Understandable**: A reader of your program should be able to discern its components, functions, and relationships without undue effort. This is closely linked with the **maintainability** of the code; your code will have to be maintained in the future, whether to be changed or to have new functionality added.
- **Testable**: **Unit tests** try out small parts of your program, verifying their behavior independently of the rest of the code. Your programming style should favor writing code that simplifies the job of writing unit tests. Unit tests are also like documentation in that they can help readers understand what the code is supposed to do.

- **Extensible**: It's a fact that your program will someday require maintenance, possibly to add new functionality. Those changes should impact the structure and data flow of the original code only minimally (if at all). Small changes shouldn't imply large, serious refactoring of your code.
- **Reusable**: Code reuse has the goal of saving resources, time, and money, and reducing redundancy by taking advantage of previously written code. Some characteristics help with this goal, such as **modularity** (which we already mentioned), **high cohesion** (all the pieces in a module belong together), **low coupling** (modules are independent of each other), **separation of concerns** (the parts of a program should overlap in functionality as little as possible), and **information hiding** (internal changes in a module shouldn't affect the rest of the system).

What we get

So, does FP give you the five characteristics we just listed in the previous section?

- In FP, the goal is to write separate independent functions that are joined together to produce the final results.
- Programs that are written in a functional style usually tend to be cleaner, shorter, and easier to understand.
- Functions can be tested on their own, and FP code has advantages in achieving this.
- You can reuse functions in other programs because they stand on their own, not depending on the rest of the system. Most functional programs share common functions, several of which we'll be considering in this book.
- Functional code is free from side effects, which means you can understand the objective of a function by studying it without having to consider the rest of the program.

Finally, once you get used to the FP style of programming, code becomes more understandable and easier to extend. So, it seems that all five characteristics can be achieved with FP!

Why use FP?

For a well-balanced look at the reasons to use FP, I'd suggest reading *Why Functional Programming Matters*, by John Hughes; it's available online at `www.cs.kent.ac.uk/people/staff/dat/miranda/whyfp90.pdf`. It's not geared toward JavaScript, but the arguments are easily understandable.

Not all is gold

However, let's strive for a bit of balance. Using FP isn't a silver bullet that will automagically make your code better. Some FP solutions are tricky, and some developers greatly enjoy writing code and then asking, what does this do? If you aren't careful, your code may become write-only and practically impossible to maintain; there goes understandable, extensible, and reusable out the door!

Another disadvantage is that you may find it harder to find FP-savvy developers. (Quick question: how many *FP-sought* job ads have you ever seen?) The vast majority of today's web code is written in imperative, non-functional ways, and most coders are used to that way of working. For some, having to switch gears and start writing programs differently may prove an unpassable barrier.

Finally, if you try to go fully functional, you may find yourself at odds with JavaScript, and simple tasks may become hard to do. As we said at the beginning, we'll opt for **SFP**, so we won't be drastically rejecting any language features that aren't 100% functional. After all, we want to use FP to simplify our coding, not to make it more complex!

So, while I'll strive to show you the advantages of going functional in your code, as with any change, there will always be some difficulties. However, I'm fully convinced that you'll be able to surmount them and that your organization will develop better code by applying FP. Dare to change! So, given that you accept that FP may apply to your problems, let's consider the other question: can we use JavaScript in a functional way and is it appropriate?

Is JavaScript functional?

At about this time, there is another important question that you should be asking: *is JavaScript a functional language?* Usually, when thinking about FP, the list of languages that are mentioned does not include JavaScript, but does include less common options, such as Clojure, Erlang, Haskell, and Scala; however, there is no precise definition for FP languages or a precise set of features that such languages should include. The main point is that you can consider a language to be functional if it supports the common programming style associated with FP. Let's start by learning about why we would want to use JavaScript at all and how the language has evolved to its current version, and then see some of the key features that we'll be using to work in a functional way.

JavaScript as a tool

What is JavaScript? If you consider popularity indices, such as the ones at `www.tiobe.com/tiobe-index/` or `pypl.github.io/PYPL.html`, you'll find that JavaScript is consistently in the top 10 most popular languages. From a more academic point of view, the language is sort of a mixture, borrowing features from several different languages. Several libraries helped the growth of the language by providing features that weren't so easily available, such as classes and inheritance (today's version of the language does support classes, but that was not the case not too long ago), that otherwise had to be achieved by doing some prototype tricks.

What's in a name?

The name *JavaScript* was chosen to take advantage of the popularity of Java – just as a marketing ploy! Its first name was *Mocha*, then, *LiveScript*, and only then *JavaScript*.

JavaScript has grown to be incredibly powerful. But, as with all power tools, it gives you a way to not only produce great solutions but also to do great harm. FP could be considered as a way to reduce or leave aside some of the worst parts of the language and focus on working in a safer, better way; however, due to the immense amount of existing JavaScript code, you cannot expect it to facilitate large reworkings of the language that would cause most sites to fail. You must learn to live with the good and the bad, and simply avoid the latter part.

In addition, the language has a broad variety of available libraries that complete or extend the language in many ways. In this book, we'll be focusing on using JavaScript on its own, but we will make references to existing, available code.

If we ask whether JavaScript is functional, the answer will be, once again, "sorta". It can be seen as functional because of several features, such as first-class functions, anonymous functions, recursion, and closures – we'll get back to this later. On the other hand, it also has plenty of non-FP aspects, such as side effects (impurity), mutable objects, and practical limits to recursion. So, when programming in a functional way, we'll be taking advantage of all the relevant, appropriate language features, and we'll try to minimize the problems caused by the more conventional parts of the language. In this sense, JavaScript will or won't be functional, depending on your programming style!

If you want to use FP, you should decide which language to use; however, opting for fully functional languages may not be so wise. Today, developing code isn't as simple as just using a language; you will surely require frameworks, libraries, and other sundry tools. If we can take advantage of all the provided tools but at the same time introduce FP ways of working in our code, we'll be getting the best of both worlds, regardless of whether JavaScript is functional!

Going functional with JavaScript

JavaScript has evolved through the years, and the version we'll be using is (informally) called JS13, and (formally) ECMAScript 2022, usually shortened to ES2022 or ES13; this version was finalized in June 2022. The previous versions were as follows:

- ECMAScript 1, June 1997
- ECMAScript 2, June 1998, which was the same as the previous version, ECMAScript 3, December 1999, with several new functionalities
- ECMAScript 5, December 2009 (and no, there never was an ECMAScript 4, because it was abandoned)
- ECMAScript 5.1, June 2011
- ECMAScript 6 (or ES6; later renamed ES2015), June 2015 ECMAScript 7 (also ES7, or ES2016), June 2016 ECMAScript 8 (ES8 or ES2017), June 2017
- ECMAScript 9 (ES9 or ES2018), June 2018
- ECMAScript 10 (ES10 or ES2019), June 2019

- ECMAScript 11 (ES11 or ES2020), June 2020
- ECMAScript 12 (ES12 or ES2021), June 2021

What's ECMA?

ECMA originally stood for European Computer Manufacturers Association, but nowadays, the name isn't considered an acronym anymore. The organization is responsible for standards other than JavaScript as well, including JSON, C#, Dart, and others. For more details, go to its site at `www.ecma-international.org/`.

You can read the standard language specification at `www.ecma-international.org/publications-and-standards/standards/ecma-262/`. Whenever we refer to JavaScript in the text without further specification, ES13 (ES2022) is what is being referred to; however, in terms of the language features that are used in this book, if you were just to use ES2015, then you'd mostly have no problems with this book.

No browsers fully implement ES13; most provide an older version, JavaScript 5 (from 2009), with an (always growing) smattering of features from ES6 up to ES13. This will prove to be a problem, but fortunately, a solvable one; we'll get to this shortly. We'll be using ES13 throughout this book.

Differences, differences…

There are only a few differences between ES2016 and ES2015, such as the `Array.prototype.includes` method and the exponentiation operator, `**`. There are more differences between ES2017 and ES2016 – such as `async` and `await`, some string padding functions, and more – but they won't impact our code. We will also be looking at alternatives for even more modern additions, such as `flatMap()`, in later chapters.

As we are going to work with JavaScript, let's start by considering its most important features that pertain to our FP goals.

Key features of JavaScript

JavaScript isn't a purely functional language, but it has all the features that we need for it to work as if it were. The main features of the language that we will be using are as follows:

- Functions as first-class objects
- Recursion
- Closures
- Arrow functions
- Spread

Let's see some examples of each one and find out why they will be useful to us. Keep in mind, though, that there are more features of JavaScript that we will be using; the upcoming sections just highlight the most important features in terms of what we will be using for FP.

Functions as first-class objects

Saying that functions are **first-class objects** (also called **first-class entities** or **first-class citizens**) means that you can do everything with functions that you can do with other objects. For example, you can store a function in a variable, you can pass it to a function, you can print it out, and so on. This is really the key to doing FP; we will often be passing functions as parameters (to other functions) or returning a function as the result of a function call.

If you have been doing async Ajax calls, then you have already been using this feature: a **callback** is a function that will be called after the Ajax call finishes and is passed as a parameter. Using jQuery, you could write something like the following:

```
$.get("some/url", someData, function(result, status) {
  // check status, and do something
  // with the result
});
```

The `$.get()` function receives a callback function as a parameter and calls it after the result is obtained.

The way to go

This is better solved, in a more modern way, by using promises or `async/await`, but for the sake of our example, the old way is enough. We'll be getting back to promises, though, in *Chapter 12*, *Building Better Containers*, when we discuss monads; in particular, see the *Unexpected monads – promises* section.

Since functions can be stored in variables, you could also write something like the following. Pay attention to how we use the `doSomething` variable in the `$.get(...)` call:

```
var doSomething = function(result, status) {
  // check status, and do something
  // with the result
};

$.get("some/url", someData, doSomething);
```

We'll be seeing more examples of this in *Chapter 6*, *Producing Functions*.

Recursion

Recursion is the most potent tool for developing algorithms and a great aid for solving large classes of problems. The idea is that a function can, at a certain point, call itself and, when *that* call is done, continue working with whatever result it has received. This is usually quite helpful for certain classes of problems or definitions. The most often quoted example is the factorial function (the factorial of *n* is written as *n!*), as defined for nonnegative integer values:

- If *n* is 0, then *n*! = 1
- If *n* is greater than 0, then *n*! = *n* * (*n*-1)!

Arranging things

The value of *n!* is the number of ways that you can arrange *n* different elements in a row. For example, if you want to place five books in line, you can pick any of the five for the first place, and then order the other four in every possible way, so 5! = 5*4!. To order those four, you can pick any of them for the first place, and then order the other three in every way, so 4! = 4*3!. If you continue to work on this example, you'll end up with 5! = 5*4*3*2*1=120, and in general, *n*! is the product of all numbers up to *n*.

This can be immediately turned into code:

```
// factorial.js

function fact(n) {
  if (n === 0) {
    return 1;
  } else {
    return n * fact(n - 1);
  }
}

console.log(fact(5)); // 120
```

Recursion will be a great aid for designing algorithms. By using recursion, you could do without any `while` or `for` loops – not that we want to do that, but it's interesting that we can! We'll be devoting the entirety of *Chapter 9*, *Designing Functions*, to designing algorithms and writing functions recursively.

Closures

Closures are a way to implement data hiding (with private variables), which leads to modules and other nice features. The key concept of closures is that when you define a function, it can refer to not only its local variables but also to everything outside of the context of the function. We can write a counting function that will keep its `count` using a closure:

```
// closure.js

function newCounter() {
  let count = 0;
  return function () {
    count++;
    return count;
  };
}

const nc = newCounter();
console.log(nc()); // 1
console.log(nc()); // 2
console.log(nc()); // 3
```

Even after `newCounter()` exits, the inner function still has access to `count`, but that variable is not accessible to any other parts of your code.

This isn't a very good example of FP – a function (`nc()`, in this case) isn't expected to return different results when called with the same parameters!

We'll find several uses for closures, such as **memoization** (see *Chapter 4*, *Behaving Properly*, and *Chapter 6*, *Producing Functions*) and the **module pattern** (see *Chapter 3*, *Starting Out with Functions*, and *Chapter 11*, *Implementing Design Patterns*), among others.

Arrow functions

Arrow functions are just a shorter, more succinct way of creating an (unnamed) function. Arrow functions can be used almost everywhere a classical function can be used, except that they cannot be used as constructors. The syntax is either `(parameter, anotherparameter, ...etc) => { statements }` or `(parameter, anotherparameter, ...etc) => expression`. The first allows you to write as much code as you want, while the second is short for `{ return expression }`.

We could rewrite our earlier Ajax example as follows:

```
$.get("some/url", data, (result, status) => {
// check status, and do something
// with the result
});
```

A new version of the factorial code could be like the following code – the only difference is the usage of an arrow function:

```
// factorial.js, continued...

const fact2 = (n) => {
  if (n === 0) {
    return 1;
  } else {
    return n * fact2(n - 1);
  }
};
```

Functions, anonymous

Arrow functions are usually called anonymous functions because of their lack of a name. If you need to refer to an arrow function, you'll have to assign it to a variable or object attribute, as we did here; otherwise, you won't be able to use it. We'll learn more about this in the *Arrow functions – the modern way* section of *Chapter 3, Starting Out with Functions*.

You would probably write `fact2()` as a one-liner – can you see the equivalence to our earlier code? Using a ternary operator instead of `if` is quite common:

```
// continued...

const fact3 = (n) => (n === 0 ? 1 : n * fact3(n - 1));
```

With this shorter form, you don't have to write `return` – it's implied.

Functions – the lambda way

In lambda calculus, a function such as *x* => 2**x* would be represented as λ*x*.2**x*. Although there are syntactical differences, the definitions are analogous. Functions with more parameters are a bit more complicated; (*x*,*y*)=>*x*+*y* would be expressed as λ*x*.λ*y*.*x*+*y*. We'll learn more about this in the *Of lambdas and functions* section of *Chapter 3*, *Starting Out with Functions*, and in the *Currying* section of *Chapter 7, Transforming Functions*.

There's one other small thing to bear in mind: when the arrow function has a single parameter, you can omit the parentheses around it. I usually prefer leaving them, but I've applied a JavaScript beautifier, *Prettier*, to the code, which removes them. It's really up to you whether to include them or not! (For more on this tool, check out `github.com/prettier/prettier`.) By the way, my options for formatting were `--print-width 75 -- tab-width 2 --no-bracket-spacing`.

Spread

The spread `...` operator (see `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Operators/Spread_operator`) lets you expand an expression in places where you would otherwise require multiple arguments, elements, or variables. For example, you can replace arguments in a function call, as shown in the following code:

```
// sum3.js

function sum3(a, b, c) {
  return a + b + c;
}

const x  = [1, 2, 3];
const y = sum3(...x); // equivalent to sum3(1,2,3)
```

You can also create or join arrays, as shown in the following code:

```
// continued...

const f = [1, 2, 3];
const g = [4, ...f, 5]; // [4,1,2,3,5]
const h = [...f, ...g]; // [1,2,3,4,1,2,3,5]
```

It works with objects too:

```
// continued…

const p = { some: 3, data: 5 };
const q = { more: 8, ...p }; // { more:8, some:3, data:5 }
```

You can also use it to work with functions that expect separate parameters instead of an array. Common examples of this would be `Math.min()` and `Math.max()`:

```
// continued...

const numbers = [2, 2, 9, 6, 0, 1, 2, 4, 5, 6];

const minA = Math.min(...numbers); // 0

const maxArray = (arr) => Math.max(...arr);

const maxA = maxArray(numbers); // 9
```

We are specifying that `maxArray()` shall receive an array of numbers as an argument.

You can also write the following equality since the `.apply()` method requires an array of arguments, but `.call()` expects individual arguments, which you can get by spreading:

```
someFn.apply(thisArg, arr) === someFn.call(thisArg, ...arr)
```

A mnemonic for arguments

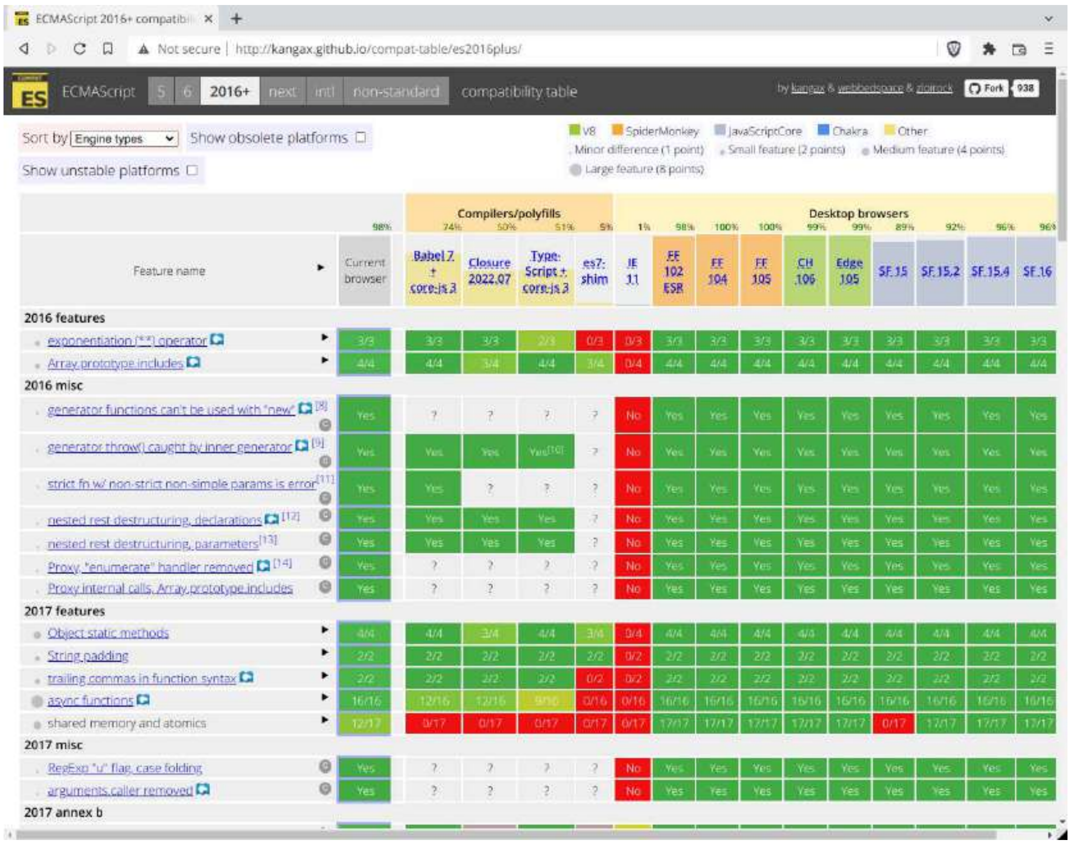
If you have problems remembering what arguments are required by `.apply()` and `.call()`, this mnemonic may help: *A is for Array, and C is for Comma*. See `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Function/apply` and `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Function/call` for more information.

Using the spread operator helps with writing shorter, more concise code, and we will be taking advantage of it. We have seen all of the most important JavaScript features that we will be using. Let's round off this chapter by looking at some tools that we'll be working with.

How do we work with JavaScript?

This is all well and good, but as we mentioned before, it so happens that the JavaScript version available almost everywhere isn't ES13, but rather the earlier JS5. An exception to this is Node.js. It is based on Chrome's V8 high-performance JavaScript engine, which already has several ES13 features available. Nonetheless, at the time of writing, ES13 coverage isn't 100% complete, and there are features that you will miss. (Check out `nodejs.org/en/docs/es6/` for more on Node.js and v8.) This is surely changing since Internet Explorer is fading away (support for it ended in June 2022), having been replaced with Microsoft's Edge browser, which shares Chrome's engine. In any case, we must still deal with older, less powerful engines.

If you want to be sure of your choices before using any given new feature, check out the compatibility table at `kangax.github.io/compat-table/es6/` (see *Figure 1.1*):

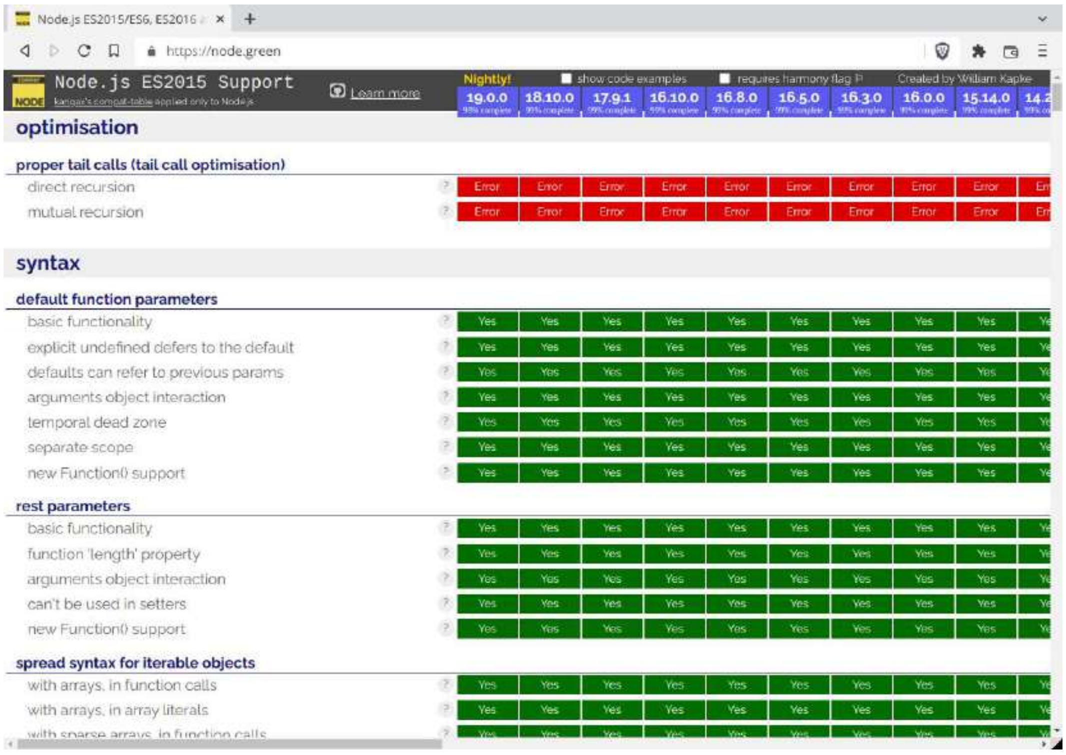

ECMAScript 2016+ compatibi
Not secure | http://kangax.github.io/compat-table/es2016plus/
ES
ECMAScript
5
6
2016+
next
intl
non-standard
compatibility table
by kangax & webbedspace & zloirock
Fork
938
Sort by Engine types
Show obsolete platforms ☐
Show unstable platforms ☐

🟩 V8 🟧 SpiderMonkey ▨ JavaScriptCore 🟦 Chakra 🟨 Other
Minor difference (1 point) ● Small feature (2 points) ● Medium feature (4 points)
● Large feature (8 points)

		Compilers/polyfills				Desktop browsers									
	98%	74%	50%	51%	5%	1%	98%	100%	100%	99%	99%	89%	92%	96%	96%
Feature name	Current browser	Babel 7 + core-js 3	Closure 2022.07	Type-Script + core-js 3	es7-shim	IE 11	FF 102 ESR	FF 104	FF 105	CH 106	Edge 105	SF 15	SF 15.2	SF 15.4	SF 16
2016 features															
exponentiation (**) operator	3/3	3/3	3/3	2/3	0/3	0/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
Array.prototype.includes	4/4	4/4	3/4	4/4	3/4	0/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4
2016 misc															
generator functions can't be used with "new" [8]	Yes	?	?	?	?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
generator throw() caught by inner generator [9]	Yes	Yes	Yes	Yes[10]	?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
strict fn w/ non-strict non-simple params is error[11]	Yes	Yes	?	?	?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
nested rest destructuring, declarations [12]	Yes	Yes	Yes	Yes	?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
nested rest destructuring, parameters[13]	Yes	Yes	Yes	Yes	?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Proxy, "enumerate" handler removed [14]	Yes	?	?	?	?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Proxy internal calls, Array.prototype.includes	Yes	?	?	?	?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2017 features															
Object static methods	4/4	4/4	3/4	4/4	3/4	0/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4
String padding	2/2	2/2	2/2	2/2	2/2	0/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2
trailing commas in function syntax	2/2	2/2	2/2	2/2	0/2	0/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2
async functions	16/16	12/16	12/16	9/16	0/16	0/16	16/16	16/16	16/16	16/16	16/16	16/16	16/16	16/16	16/16
shared memory and atomics	12/17	0/17	0/17	0/17	0/17	0/17	17/17	17/17	17/17	17/17	17/17	0/17	17/17	17/17	17/17
2017 misc															
RegExp "u" flag, case folding	Yes	?	?	?	?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
arguments.caller removed	Yes	?	?	?	?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2017 annex b															

Figure 1.1 – The latest JavaScript features may not be widely and fully supported, so you'll have to check before using them

For Node.js specifically, check out `node.green/`, which takes its data from the Kangax table; see *Figure 1.2*:



Node.js ES2015/ES6, ES2016

https://node.green

Node.js ES2015 Support
kangax's compat-table applied only to Node.js
Learn more

Nightly! | show code examples | requires harmony flag | Created by William Kapke

	19.0.0	18.10.0	17.9.1	16.10.0	16.8.0	16.5.0	16.3.0	16.0.0	15.14.0	14.2
optimisation										
proper tail calls (tail call optimisation)										
direct recursion	Error	Error	Error	Error	Error	Error	Error	Error	Error	Err
mutual recursion	Error	Error	Error	Error	Error	Error	Error	Error	Error	Err
syntax										
default function parameters										
basic functionality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
explicit undefined defers to the default	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
defaults can refer to previous params	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
arguments object interaction	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
temporal dead zone	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
separate scope	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
new Function() support	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
rest parameters										
basic functionality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
function 'length' property	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
arguments object interaction	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
can't be used in setters	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
new Function() support	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
spread syntax for iterable objects										
with arrays, in function calls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
with arrays, in array literals	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye
with sparse arrays, in function calls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Ye

Figure 1.2 – Compatibility table specifically for Node.js

So, what can you do if you want to code using the latest version, but the available one is an earlier, poorer one? Or what happens if most of your users are using older browsers, which don't support the fancy features you're keen on using? Let's see some solutions for this.

Using transpilers

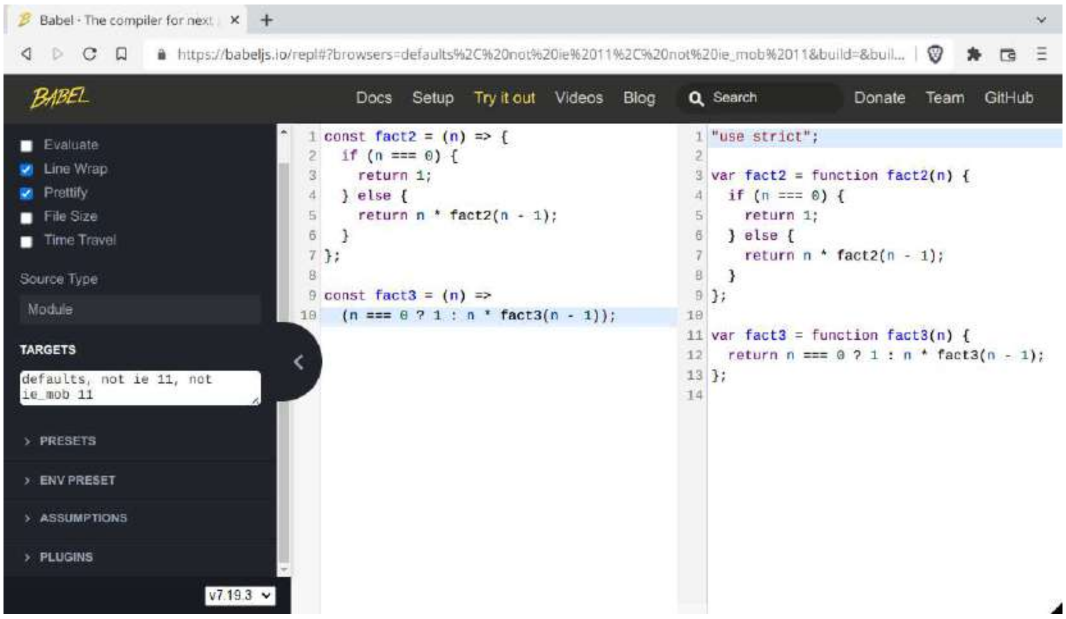
To get out of this availability and compatibility problem, there are a couple of transpilers that you can use. Transpilers take your original ES13 code, which might use the most modern JavaScript features, and transforms it into equivalent JS5 code. It's a source-to-source transformation, instead of source-to-object code that would be used in compilation. You can code using advanced ES13 features, but the user's browsers will receive JS5 code. A transpiler will also let you keep up with upcoming versions of the language, despite the time needed by browsers to adopt new standards across desktop and mobile devices.

On word origins

If you wonder where the word *transpiler* came from, it is a portmanteau of *translate* and *compiler*. There are many such combinations in technological speak: *email* (*electronic* and *mail*), *emoticon* (*emotion* and *icon*), *malware* (*malicious* and *software*), *alphanumeric* (*alphabetic* and *numeric*), and many more.

Currently, the most common transpiler for JavaScript is **Babel** (`babeljs.io/`); years ago, we also had **Traceur** (`github.com/google/traceur-compiler`), but that's not maintained any longer. Two other possibilities are **SWC** (`swc.rs/`) and **Sucrase** (`sucrase.io/`); in particular, the latter boasts a much faster transpilation speed.

With tools such as **npm** or **webpack**, it's fairly easy to configure things so that your code will get automatically transpiled and provided to end users. You can also carry out transpilation online; see *Figure 1.3* for an example of Babel's online environment:


Babel · The compiler for next
https://babeljs.io/repl#?browsers=defaults%2C%20not%20ie%2011%2C%20not%20ie_mob%2011&build=&buil...
BABEL
Docs
Setup
Try it out
Videos
Blog
Search
Donate
Team
GitHub
PRESETS
ENV PRESET
ASSUMPTIONS
PLUGINS

- [ ] Evaluate
- [x] Line Wrap
- [x] Prettify
- [ ] File Size
- [ ] Time Travel

Source Type: Module

TARGETS: defaults, not ie 11, not ie_mob 11

v7.19.3

```
const fact2 = (n) => {
  if (n === 0) {
    return 1;
  } else {
    return n * fact2(n - 1);
  }
};

const fact3 = (n) =>
  (n === 0 ? 1 : n * fact3(n - 1));
```

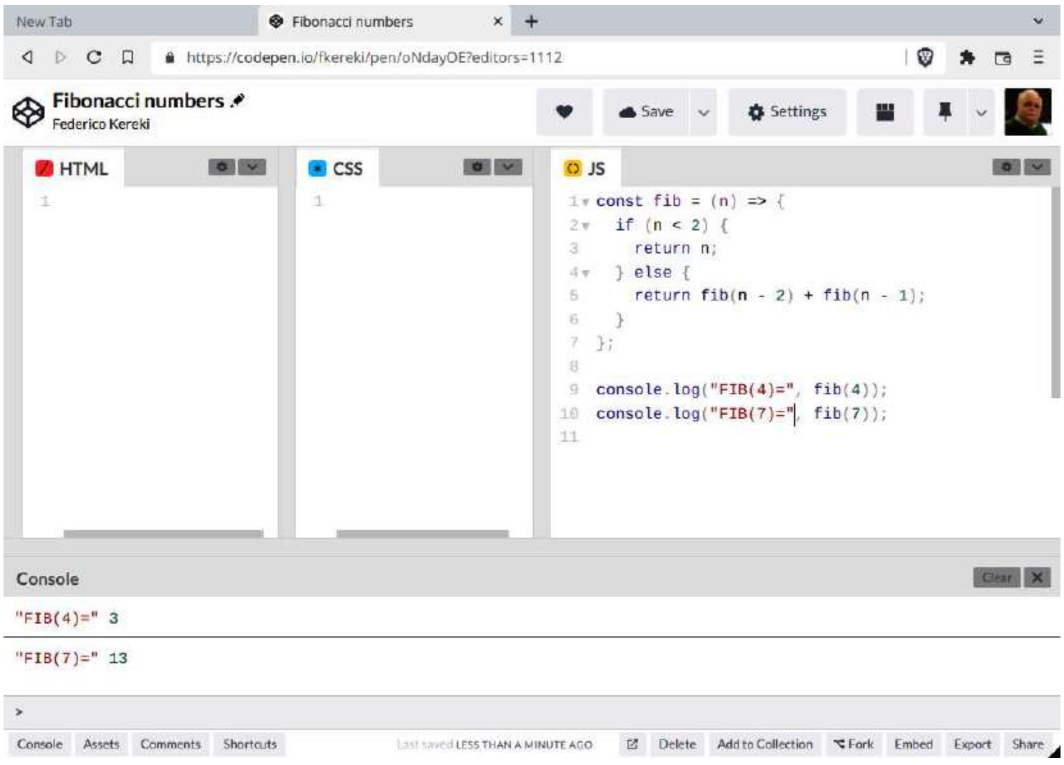
```
"use strict";

var fact2 = function fact2(n) {
  if (n === 0) {
    return 1;
  } else {
    return n * fact2(n - 1);
  }
};

var fact3 = function fact3(n) {
  return n === 0 ? 1 : n * fact3(n - 1);
};
```

Figure 1.3 – The Babel transpiler converts ES13 code into compatible JS5 code

There are specific ways of installing these tools for your programming environment, and usually, you won't have to do it by hand; check out `www.typescriptlang.org/download` for more information.

Working online

There are some more online tools that you can use to test out your JavaScript code. Check out **JSFiddle** (`jsfiddle.net/`), **CodePen** (`codepen.io/`), and **JSBin** (`jsbin.com/`), among others. You can see an example of CodePen in *Figure 1.4*:



```
const fib = (n) => {
  if (n < 2) {
    return n;
  } else {
    return fib(n - 2) + fib(n - 1);
  }
};

console.log("FIB(4)=", fib(4));
console.log("FIB(7)=", fib(7));
```

```
"FIB(4)=" 3
"FIB(7)=" 13
```

Figure 1.4 – CodePen lets you try out modern JavaScript code (plus HTML and CSS) without requiring any other tools

Using these tools provides a very quick way to try out code or do small experiments – and I can truly vouch for this since I've tested much of the code in this book in this way!

A step further – TypeScript

In the previous editions of this book, we went with straight JavaScript. Still, in the years since, Microsoft's **TypeScript** (`www.typescriptlang.org/`), a superset of the language that is itself compiled into JavaScript, has gained a lot of following, is now standard with many frameworks, and you can use both for frontend and backend code.

The main advantage of TypeScript is the ability to add (optional) static type checks to JavaScript, which helps detect programming errors at compile time. But beware: as with Babel, not all of ES13 will be available. However, it's entirely sufficient for our purposes, allowing us to be more careful with coding.

Most statistics about programming language popularity rank TypeScript in the top 10; *Figure 1.5* (from `spectrum.ieee.org/top-programming-languages-2022`) confirms this:

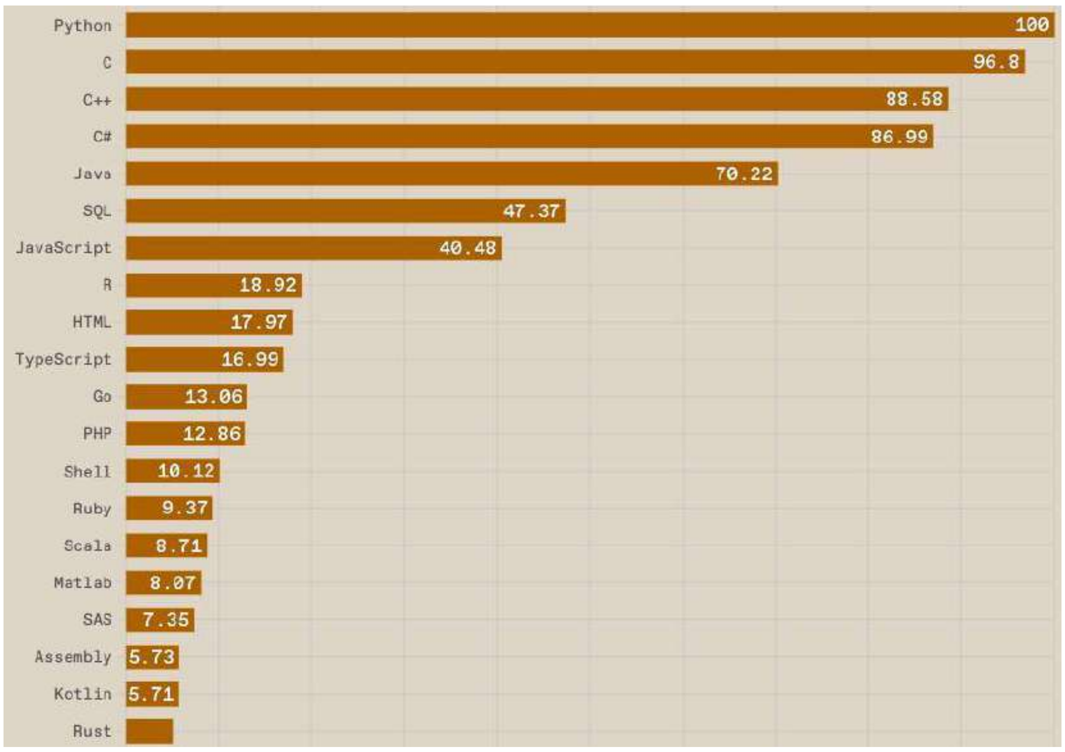


Figure 1.5 – Programming language popularity in 2022 according to IEEE Spectrum

Going to the source

Despite using TypeScript, in the rest of this book, we'll keep referring to JavaScript, which is, after all, the language that is executed.

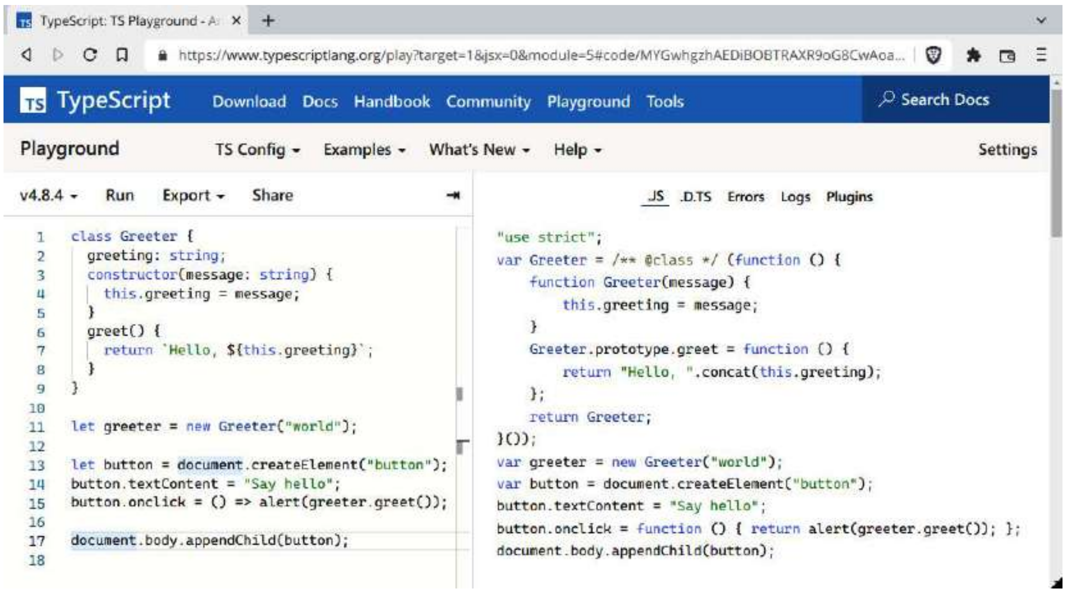
You can also perform type checks by using Facebook's **Flow** (`flow.org/`). However, there's more support for using external libraries with TypeScript than with Flow. Also, the tooling and installation for development are simpler for TypeScript.

Ignoring types?

There's a proposal (that may go nowhere – be warned!) to allow JavaScript to process (by ignoring) types, so you would be able to run TypeScript directly, with no preprocessing or transpiling of any kind. For more on this, go to `tc39.es/proposal-type-annotations/`.

It should be made clear that TypeScript is more than just a type checker; it's a language on its own (OK, it's very similar to JavaScript, but still…). For example, it adds interfaces, decorators, enumerated types, and more to the language, so you can use such features that are typical in other languages. In any case, if you don't care for TypeScript, you can just ignore the types-related syntax, and then you'll have plain JavaScript.

TypeScript is available via online tools, and you can also test it online on their playground (`www.typescriptlang.org/play/`). You can set options to be more or less strict with data type checks, and you can also run your code on the spot; see *Figure 1.6* for more details:



```
class Greeter {
  greeting: string;
  constructor(message: string) {
    this.greeting = message;
  }
  greet() {
    return `Hello, ${this.greeting}`;
  }
}

let greeter = new Greeter("world");

let button = document.createElement("button");
button.textContent = "Say hello";
button.onclick = () => alert(greeter.greet());

document.body.appendChild(button);
```

```
"use strict";
var Greeter = /** @class */ (function () {
    function Greeter(message) {
        this.greeting = message;
    }
    Greeter.prototype.greet = function () {
        return "Hello, ".concat(this.greeting);
    };
    return Greeter;
}());
var greeter = new Greeter("world");
var button = document.createElement("button");
button.textContent = "Say hello";
button.onclick = function () { return alert(greeter.greet()); };
document.body.appendChild(button);
```

Figure 1.6 – You can check and transpile your code online, on TypeScript's website

Later in this book, in the *Specifying data types* section of *Chapter 12*, *Building Better Containers*, we will consider a formal type system for FP languages (not just JavaScript) and we'll find out that our TypeScript work has allayed most difficulties.

A final admission: at times, TypeScript may seem more of a hindrance than a help when you have to deal with complex data typing expressions. (Updating all the code in this book to TypeScript sometimes led me to doubt my sanity in using it!) However, in the long run, code written in TypeScript is less prone to bugs, because its static type checks detect and avoid many common errors.

Testing

We will also touch on testing, which is, after all, one of FP's main advantages. In previous editions of this book, we went with **Jasmine** (`jasmine.github.io/`), but now, we've changed to Facebook's **Jest** (`jestjs.io/`) – which is built on top of Jasmine!

Jest has grown in popularity due to its ease of use and broad applicability: you can test frontend and backend code equally well, with little configuration. (See `jestjs.io/docs/getting-started` for its installation and configuration.) We won't be writing tests for every single piece of code in this book, but while following the ideas of **test-driven development** (**TDD**), we'll often do so.

Summary

In this chapter, we have seen the basics of FP, a bit of its history, its advantages (and also some possible disadvantages, to be fair), why we can apply it in JavaScript (which isn't usually considered a functional language), and what tools we'll need to go through the rest of this book.

In *Chapter 2*, *Thinking Functionally*, we'll go over an example of a simple problem, look at it in common ways, and end by solving it in a functional manner and analyzing the advantages of our method.

Questions

1.1 **TypeScript, please!** Let's keep our promise: convert the JavaScript examples provided in this chapter into TypeScript.

1.2 **Classes as first-class objects**: We learned that functions are first-class objects, but did you know that classes also are? (Though, of course, speaking of classes as objects does sound weird.) Look at the following example and see what makes it tick! Be careful: there's some purposefully weird code in it:

```
const makeSaluteClass = (term) =>
  class {
    constructor(x) {
      this.x = x;
    }

    salute(y) {
      console.log(`${this.x} says "${term}" to ${y}`);
    }
  };
```

```
const Spanish = makeSaluteClass("HOLA");

new Spanish("ALFA").salute("BETA");
// ALFA says "HOLA" to BETA

new (makeSaluteClass("HELLO"))("GAMMA").salute("DELTA");

// GAMMA says "HELLO" to DELTA

const fullSalute = (c, x, y) => new c(x).salute(y);

const French = makeSaluteClass("BON JOUR");

fullSalute(French, "EPSILON", "ZETA");
// EPSILON says "BON JOUR" to ZETA
```

1.3 **Climbing factorial**: Our implementation of a factorial starts by multiplying by *n*, then by *n*-1, then *n*-2, and so on in what we could call a downward fashion. Can you write a new version of the factorial function that will loop upwards?

1.4 **Factorial errors**: Factorials, as we defined them, should only be calculated for non-negative integers. However, the function that we wrote in the *Recursion* section doesn't check whether its argument is valid. Can you add the necessary checks? Try to avoid repeated, redundant tests!

1.5 **Factorial testing**: Write complete tests for the function in the previous question. Try to achieve 100% coverage.

1.6 **Code squeezing**: Not that it's a goal in itself, but by using arrow functions and some other JavaScript features, you can shorten `newCounter()` to half its length. Can you see how?

1.7 **What type is it?**: What is the type of the `newCounter()` function?

2
Thinking Functionally – A First Example

In *Chapter 1*, *Becoming Functional*, we went over what FP is, mentioned some advantages of applying it, and listed some tools we'd need in JavaScript. For now, let's leave the theory behind and start by considering a simple problem and how to solve it in a functional way.

In this chapter, we will do the following:

- Look at a simple, e-commerce-related problem
- Consider several usual ways to solve it (with their associated defects)
- Find a way to solve the problem by looking at it functionally
- Devise a higher-order solution that can be applied to other problems
- Work out how to carry out unit testing for functional solutions

In future chapters, we'll be returning to some of the topics listed here, so we won't be going into too much detail. We'll just show how FP can give a different outlook on our problem and leave further details for later.

After working through this chapter, you will have had a first look at a common problem and at a way of solving it by thinking functionally, as a prelude for the rest of this book.

Our problem – doing something only once

Let's consider a simple but common situation. You have developed an e-commerce site; the user can fill their shopping cart, and in the end, they must click on a **Bill me** button so that their credit card will be charged. However, the user shouldn't click twice (or more), or they will be billed several times.

The HTML part of your application might have something like this somewhere:

```
<button id="billButton"
    onclick="billTheUser(some, sales, data)">Bill me
      </button>
```

And, among the scripts, you'd have something similar to the following code:

```
function billTheUser(some, sales, data) {
  window.alert("Billing the user...");
  // actually bill the user
}
```

A bad example

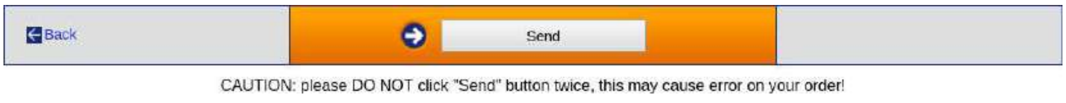
Assigning the events handler directly in HTML, the way I did it, isn't recommended. Instead, unobtrusively, you should set the handler through code. So, *do as I say, not as I do!*

This is a bare-bones explanation of the web page problem, but it's enough for our purposes. Now, let's get to thinking about ways of avoiding repeated clicks on that button. How can we manage to prevent the user from clicking more than once? That's an interesting problem, with several possible solutions – let's start by looking at bad ones!

How many ways can you think of to solve our problem? Let's go over several solutions and analyze their quality.

Solution 1 – hoping for the best!

How can we solve the problem? The first solution may seem like a joke: do nothing, tell the user not to click twice, and hope for the best! Your page might look like *Figure 2.1*:



CAUTION: please DO NOT click "Send" button twice, this may cause error on your order!

Figure 2.1 – An actual screenshot of a page, just warning you against clicking more than once

This is a way to weasel out of the problem; I've seen several websites that just warn the user about the risks of clicking more than once and do nothing to prevent the situation. So, the user got billed twice? We warned them... it's their fault!

Your solution might simply look like the following code:

```
<button
  id="billButton"
  onclick="billTheUser(some, sales, data)">Bill me
</button>
<b>WARNING: PRESS ONLY ONCE, DO NOT PRESS AGAIN!!</b>
```

Okay, this isn't an actual solution; let's move on to more serious proposals.

Solution 2 – using a global flag

The solution most people would probably think of first is using some global variable to record whether the user has already clicked on the button. You define a flag named something like `clicked`, initialized with `false`. When the user clicks on the button, if `clicked` is `false`, you change it to `true` and execute the function; otherwise, you do nothing at all. This can be seen in the following code:

```
let clicked = false;
.
.
.
function billTheUser(some, sales, data) {
  if (!clicked) {
    clicked = true;
    window.alert("Billing the user...");
    // actually bill the user
  }
}
```

This works, but it has several problems that must be addressed:

- You are using a global variable, and you could change its value by accident. Global variables aren't a good idea, in JavaScript or other languages. You must also remember to re-initialize it to `false` when the user starts buying again. If you don't, the user won't be able to make a second purchase because paying will become impossible.
- You will have difficulties testing this code because it depends on external things (that is, the clicked variable).

So, this isn't a very good solution. Let's keep thinking!

Solution 3 – removing the handler

We may go for a lateral kind of solution, and instead of having the function avoid repeated clicks, we might just remove the possibility of clicking altogether. The following code does just that; the first thing that `billTheUser()` does is remove the `onclick` handler from the button, so no further calls will be possible:

```
function billTheUser(some, sales, data) {
  document
    .getElementById("billButton")
    .onclick = null;

  window.alert("Billing the user...");
  // actually bill the user
}
```

This solution also has some problems:

- The code is tightly coupled to the button, so you won't be able to reuse it elsewhere
- You must remember to reset the handler; otherwise, the user won't be able to make a second purchase
- Testing will also be more complex because you'll have to provide some DOM elements

We can enhance this solution a bit and avoid coupling the function to the button by providing the latter's ID as an extra argument in the call. (This idea can also be applied to some of the further solutions that we'll see.) The HTML part would be as follows; note the extra argument to `billTheUser()`:

```
<button
  id="billButton"
  onclick="billTheUser('billButton', some, sales, data)"
>Bill me
</button>
```

We also have to change the called function so that it will use the received `buttonId` value to access the corresponding button:

```
function billTheUser(buttonId, some, sales, data) {
  document.getElementById(buttonId).onclick = null;
  window.alert("Billing the user...");
  // actually bill the user
}
```

This solution is somewhat better. But, in essence, we are still using a global element – not a variable, but the `onclick` value. So, despite the enhancement, this isn't a very good solution either. Let's move on.

Solution 4 – changing the handler

A variant to the previous solution would be not to remove the click function, but to assign a new one instead. We are using functions as first-class objects here when we assign the `alreadyBilled()` function to the click event. The function warning the user that they have already clicked could look something like this:

```
function alreadyBilled() {
  window.alert("Your billing process is running; don't
    click, please.");
}
```

Our `billTheUser()` function would then be like the following code – note how instead of assigning `null` to the `onclick` handler as in the previous section, now, the `alreadyBilled()` function is assigned:

```
function billTheUser(some, sales, data) {
  document
    .getElementById("billButton")
    .onclick = alreadyBilled;

  window.alert("Billing the user...");
  // actually bill the user
}
```

There's a good point to this solution; if the user clicks a second time, they'll get a warning not to do that, but they won't be billed again. (From the point of view of user experience, it's better.) However, this solution still has the very same objections as the previous one (code coupled to the button, needing to reset the handler, and harder testing), so we don't consider it quite good anyway.

Solution 5 – disabling the button

A similar idea here is instead of removing the event handler, we can disable the button so the user won't be able to click. You might have a function such as the one shown in the following code, which does exactly that by setting the `disabled` attribute of the button:

```
function billTheUser(some, sales, data) {
  document
```

```
     .getElementById("billButton")
     .setAttribute("disabled", "true");

  window.alert("Billing the user...");
  // actually bill the user
}
```

This also works, but we still have objections as with the previous solutions (coupling the code to the button, needing to re-enable the button, and harder testing), so we don't like this solution either.

Solution 6 – redefining the handler

Another idea: instead of changing anything in the button, let's have the event handler change itself. The trick is in the second line of the following code; by assigning a new value to the `billTheUser` variable, we are dynamically changing what the function does! The first time you call the function, it will do its thing, but it will also change itself out of existence by giving its name to a new function:

```
function billTheUser(some, sales, data) {
  billTheUser = function() {};
  window.alert("Billing the user...");
  // actually bill the user
}
```

There's a special trick in the solution. Functions are global, so the `billTheUser=...` line changes the function's inner workings. From that point on, `billTheUser` will be the new (null) function. This solution is still hard to test. Even worse, how would you restore the functionality of `billTheUser`, setting it back to its original objective?

Solution 7 – using a local flag

We can go back to the idea of using a flag, but instead of making it global (which was our main objection to the second solution), we can use an **Immediately Invoked Function Expression** (**IIFE**), which we'll see more about in *Chapter 3*, *Starting Out with Functions*, and *Chapter 11*, *Implementing Design Patterns*. With this, we can use a closure, so `clicked` will be local to the function and not visible anywhere else:

```
var billTheUser = (clicked => {
  return (some, sales, data) => {
    if (!clicked) {
      clicked = true;
      window.alert("Billing the user...");
      // actually bill the user
    }
  };
})(false);
```

This solution is along the lines of the global variable solution, but using a private, local variable is an enhancement. (Note how `clicked` gets its initial value from the call at the end.) The only drawback we could find is that we'll have to rework every function that needs to be called only once to work in this fashion (and, as we'll see in the following section, our FP solution is similar to it in some ways). Okay, it's not too hard to do, but don't forget the **Don't Repeat Yourself** (**DRY**), usual advice!

We have now gone through multiple ways of solving our "do something only once" problem – but as we've seen, they were not very good! Let's think about the problem functionally so that we get a more general solution.

A functional solution to our problem

Let's try to be more general; after all, requiring that some function or other be executed only once isn't that outlandish, and may be required elsewhere! Let's lay down some principles:

- The original function (the one that may be called only once) should do whatever it is expected to do and nothing else
- We don't want to modify the original function in any way
- We need a new function that will call the original one only once
- We want a general solution that we can apply to any number of original functions

A SOLID base

The first principle listed previously is the single responsibility principle (the S in the **SOLID** acronym), which states that every function should be responsible for a single functionality. For more on SOLID, check the article by Uncle Bob (Robert C. Martin, who wrote the five principles) at `butunclebob.com/ArticleS.UncleBob.PrinciplesOfOod`.

Can we do it? Yes, and we'll write a higher-order function, which we'll be able to apply to any function, to produce a new function that will work only once. Let's see how! We will introduce higher-order functions in *Chapter 6*, *Producing Functions*. There, we'll go about testing our functional solution, as well as making some enhancements to it.

A higher-order solution

If we don't want to modify the original function, we can create a higher-order function, which we'll (inspiredly!) name `once()`. This function will receive a function as a parameter and return a new function, which will work only once. (As we mentioned previously, we'll be seeing more of higher-order functions later; in particular, see the *Doing things once, revisited* section of *Chapter 6, Producing Functions*).

Many solutions

Underscore and Lodash already have a similar function, invoked as `_.once()`. Ramda also provides `R.once()`, and most FP libraries include similar functionality, so you wouldn't have to program it on your own.

Our `once()` function may seem imposing at first, but as you get accustomed to working in an FP fashion, you'll get used to this sort of code and find it to be quite understable:

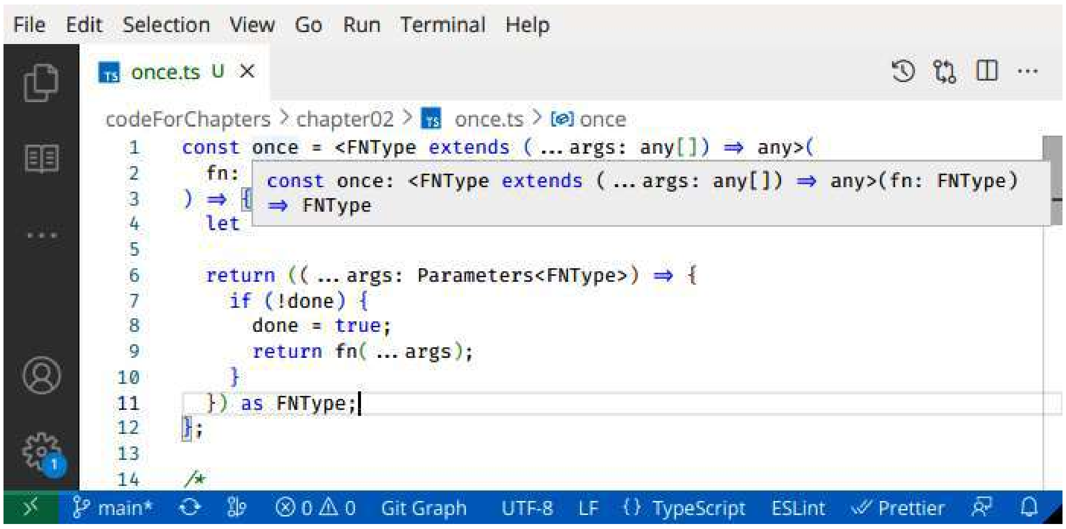
```
// once.ts

const once = <FNType extends (...args: any[]) => any>(
  fn: FNType
) => {
  let done = false;

  return ((...args: Parameters<FNType>) => {
    if (!done) {
      done = true;
      return fn(...args);
    }
  }) as FNType;
};
```

Let's go over some of the finer points of this function:

- Our `once()` function receives a function (`fn`) as its parameter and returns a new function, of the same type. (We'll discuss this typing in more detail shortly.)
- We define an internal, private `done` variable, by taking advantage of *closure*, as in *Solution 7*. We opted not to call it `clicked` (as we did previously) because you don't necessarily need to click on a button to call the function; we went for a more general term. Each time you apply `once()` to some function, a new, distinct `done` variable will be created and will be accessible only from the returned function.

- The `return` statement shows that `once()` will return a function, with the same type of parameters as the original `fn()` one. We are using the spread syntax we saw in *Chapter 1*, *Becoming Functional*. With older versions of JavaScript, you'd have to work with the arguments object; see `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Functions/arguments` for more on that. The modern way is simpler and shorter!
- We assign `done = true` before calling `fn()`, just in case that function throws an exception. Of course, if you don't want to disable the function unless it has successfully ended, you could move the assignment below the `fn()` call. (See *Question 2.4* in the *Questions* section for another take on this.)
- After the setting is done, we finally call the original function. Note the use of the spread operator to pass along whatever parameters the original `fn()` had.

Typing for `once()` may be obscure. We have to specify that the type of the input function and the type of `once()` are the same, and that's the reason for defining `FNType`. *Figure 2.2* shows that TypeScript correctly understands this (Check the answer to *Question 1.7* at the end of this book for another example of this):


File Edit Selection View Go Run Terminal Help
once.ts U
codeForChapters > chapter02 > once.ts > once
main*
0 0
Git Graph
UTF-8
LF
{} TypeScript
ESLint
Prettier

```
const once = <FNType extends (...args: any[]) => any>(
  fn:
) => {
  let

  return ((...args: Parameters<FNType>) => {
    if (!done) {
      done = true;
      return fn(...args);
    }
  }) as FNType;
};

/*
```

```
const once: <FNType extends (...args: any[]) => any>(fn: FNType)
=> FNType
```

Figure 2.2 – Hovering shows that the type of once()'s output matches the type of its input

If you're not still used to TypeScript, let's see the pure JavaScript equivalent, which is the same code but for typing:

```
// once_JS.js

const once = (fn) => {
  let done = false;

  return (...args) => {
    if (!done) {
      done = true;
      return fn(...args);
    }
  };
};
```

So, how would we use it? We first create a new version of the billing function.

```
const billOnce = once(billTheUser);
```

Then, we rewrite the `onclick` method as follows:

```
<button id="billButton"
  onclick="billOnce(some, sales, data)">Bill me
</button>;
```

When the user clicks on the button, the function that gets called with the `(some, sales, data)` argument isn't the original `billTheUser()` but rather the result of having applied `once()` to it. The result of that is a function that can be called only a single time.

You can't always get what you want!

Note that our `once()` function uses functions such as first-class objects, arrow functions, closures, and the spread operator. Back in *Chapter 1*, *Becoming Functional*, we said we'd be needing those, so we're keeping our word! All we are missing from that chapter is recursion, but as the Rolling Stones sang, *You Can't Always Get What You Want!*

We now have a functional way of getting a function to do its thing only once, but how would we test it? Let's get into that topic now.

Testing the solution manually

We can run a simple test. Let's write a `squeak()` function that will, appropriately, *squeak* when called! The code is simple:

```
// once.manual.ts

const squeak = a => console.log(a, " squeak!!");

squeak("original"); // "original squeak!!"
squeak("original"); // "original squeak!!"
squeak("original"); // "original squeak!!"
```

If we apply `once()` to it, we get a new function that will squeak only once. See the highlighted line in the following code:

```
// continued...

const squeakOnce = once(squeak);

squeakOnce("only once"); // "only once squeak!!"
squeakOnce("only once"); // no output
squeakOnce("only once"); // no output
```

The previous steps showed us how we could test our `once()` function by hand, but our method is not exactly ideal. In the next section, we'll see why and how to do better.

Testing the solution automatically

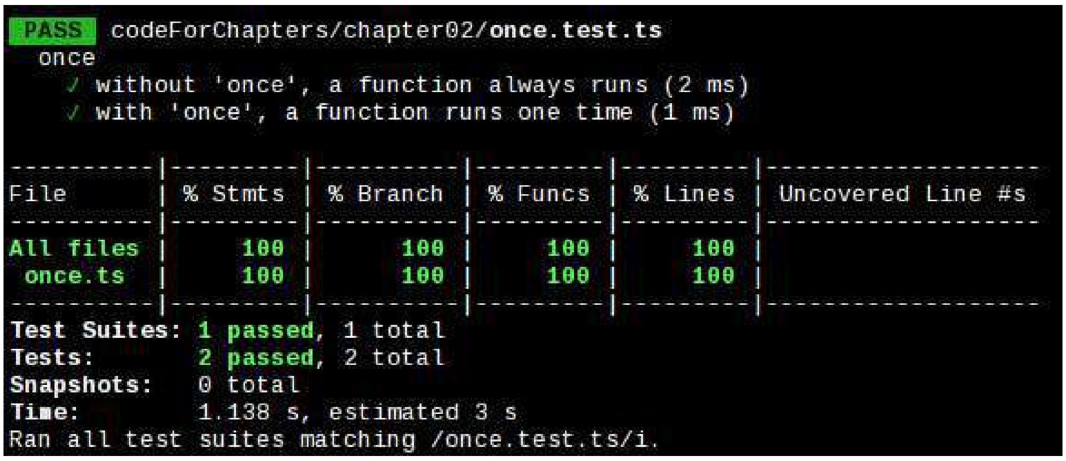
Running tests by hand isn't suitable: it gets tiresome and boring, and it leads, after a while, to not running the tests any longer. Let's do better and write some automatic tests with **Jest**:

```
// once.test.ts

import once } from "./once";

describe("once", () => {
  it("without 'once', a function always runs", () => {
    const myFn = jest.fn();
    myFn();
    myFn();
    myFn();

    expect(myFn).toHaveBeenCalledTimes(3);
  });

  it("with 'once', a function runs one time", () => {
    const myFn = jest.fn();
    const onceFn = jest.fn(once(myFn));

    onceFn();
    onceFn();
    onceFn();

    expect(onceFn).toHaveBeenCalledTimes(3);
    expect(myFn).toHaveBeenCalledTimes(1);
  });
});
```

There are several points to note here:

- To spy on a function (for instance, to count how many times it was called), we need to pass it as an argument to `jest.fn()`; we can apply tests to the result, which works exactly like the original function, but can be spied on.
- When you spy on a function, Jest intercepts your calls and registers that the function was called, with which arguments, and how many times it was called.
- The first test only checks that if we call the function several times, it gets called that number of times. This is trivial, but we'd be doing something wrong if that didn't happen!
- In the second test, we apply `once()` to a (dummy) `myFn()` function, and we call the result (`onceFn()`) several times. We then check that `myFn()` was called only once, though `onceFn()` was called three times.

We can see the results in *Figure 2.3*:



```
 PASS  codeForChapters/chapter02/once.test.ts
  once
    ✓ without 'once', a function always runs (2 ms)
    ✓ with 'once', a function runs one time (1 ms)

----------|---------|----------|---------|---------|-------------------
File      | % Stmts | % Branch | % Funcs | % Lines | Uncovered Line #s
----------|---------|----------|---------|---------|-------------------
All files |     100 |      100 |     100 |     100 |
 once.ts  |     100 |      100 |     100 |     100 |
----------|---------|----------|---------|---------|-------------------
Test Suites: 1 passed, 1 total
Tests:       2 passed, 2 total
Snapshots:   0 total
Time:        1.138 s, estimated 3 s
Ran all test suites matching /once.test.ts/i.
```

Figure 2.3 – Running automatic tests on our function with Jest

With that, we have seen not only how to test our functional solution by hand but also in an automatic way, so we are done with testing. Let's just finish by considering an even better solution, also achieved in a functional way.

Producing an even better solution

In one of the previous solutions, we mentioned that it would be a good idea to do something every time after the first click, and not silently ignore the user's clicks. We'll write a new higher-order function that takes a second parameter – a function to be called every time from the second call onward. Our new function will be called `onceAndAfter()` and can be written as follows:

```
// onceAndAfter.ts

const onceAndAfter = <
  FNType extends (...args: any[]) => any
>(
  f: FNType,
  g: FNType
) => {
  let done = false;
  return ((...args: Parameters<FNType>) => {
    if (!done) {
      done = true;
      return f(...args);
    } else {
      return g(...args);
    }
  }) as FNType;
};
```

We have ventured further into higher-order functions; `onceAndAfter()` takes two functions as parameters and produces a third one, which includes the other two within.

Function as default

You could make `onceAndAfter()` more powerful by giving a default value for `g`, such as `() => {}`, so if you didn't specify the second function, it would still work fine because the default do-nothing function would be called instead of causing an error.

We can do a quick-and-dirty test along the same lines as we did earlier. Let's add a `creak()` creaking function to our previous `squeak()` one and check out what happens if we apply `onceAndAfter()` to them. We can then get a `makeSound()` function that should squeak once and creak afterward:

```
// onceAndAfter.manual.ts

import { onceAndAfter } from "./onceAndAfter";

const squeak = (x: string) => console.log(x, "squeak!!");

const creak = (x: string) => console.log(x, "creak!!");

const makeSound = onceAndAfter(squeak, creak);

makeSound("door"); // "door squeak!!"
makeSound("door"); // "door creak!!"
makeSound("door"); // "door creak!!"
makeSound("door"); // "door creak!!"
```

Writing a test for this new function isn't hard, only a bit longer. We have to check which function was called and how many times:

```
// onceAndAfter.test.ts

import { onceAndAfter } from "./onceAndAfter";

describe("onceAndAfter", () => {
  it("calls the 1st function once & the 2nd after", () => {
    const func1 = jest.fn();
    const func2 = jest.fn();
    const testFn = jest.fn(onceAndAfter(func1, func2));

    testFn();
    testFn();
    testFn();
    testFn();

    expect(testFn).toHaveBeenCalledTimes(4);
    expect(func1).toHaveBeenCalledTimes(1);
    expect(func2).toHaveBeenCalledTimes(3);
  });
});
```

Notice that we always check that `func1()` is called only once. Similarly, we check `func2()`; the count of calls starts at zero (the time that `func1()` is called), and from then on, it goes up by one on each call.

Summary

In this chapter, we've seen a common, simple problem based on a real-life situation. After analyzing several typical ways of solving that, we went for a functional thinking solution. We saw how to apply FP to our problem and found a more general higher-order solution that we could apply to similar problems with no further code changes. We saw how to write unit tests for our code to round out the development job.

Finally, we produced an even better solution (from the point of view of the user experience) and saw how to code it and how to unit-test it. Now, you've started to get a grip on how to solve a problem functionally; next, in *Chapter 3*, *Starting Out with Functions*, we'll delve more deeply into functions, which are at the core of all FP.

Questions

2.1 **No extra variables**: Our functional implementation required using an extra variable, `done`, to mark whether the function had already been called. Not that it matters, but could you make do without using any extra variables? Note that we aren't telling you not to use any variables, it's just a matter of not adding any new ones, such as `done`, and only as an exercise!

2.2 **Alternating functions**: In the spirit of our `onceAndAfter()` function, can you write an `alternator()` higher-order function that gets two functions as arguments and, on each call, alternatively calls one and another? The expected behavior should be as in the following example:

```
const sayA = () => console.log("A");
const sayB = () => console.log("B");

const alt = alternator(sayA, sayB);

alt(); // A
alt(); // B
alt(); // A
alt(); // B
alt(); // A
alt(); // B
```

2.3 **Everything has a limit!** As an extension of `once()`, could you write a higher-order function, `thisManyTimes(fn,n)`, that would let you call the `fn()` function up to *n* times, but would do nothing afterward? To give an example, `once(fn)` and `thisManyTimes(fn,1)` would produce functions that behave the same way. Do also write tests for it.

2.4 **Allow for crashing**: Suppose we apply `once()` to a function, and the first time that function gets called, it crashes. Here, we may want to allow a second call to the function, hoping it wouldn't crash again. We want an `onceIfSuccess()` function, that will get a function as a parameter and produce a new function that will run successfully only once, but will be allowed to fail (throwing exceptions) many times if need be. Implement `onceIfSuccess()`, and don't forget to write unit tests for it.

2.5 **Say no to arrows**: Implement `once()` using classic functions, instead of arrow functions. This is just meant to help you explore the slightly different needed data typing syntax.

3
Starting Out with Functions – A Core Concept

In *Chapter 2*, *Thinking Functionally*, we discussed an example of FP thinking, but now, let's look at the basics and review functions.

In this chapter, we'll do the following:

- Discuss functions in JavaScript, including how to define them, with a particular focus on arrow functions
- Learn about currying and functions as first-class objects
- Explore several ways of using functions in an FP way

After going through all this content, you'll be up to date with the generic and specific concepts relating to functions, which are, after all, at the core of FP!

All about functions

Let's start with a short review of functions in JavaScript and their relationship to FP concepts. We will begin with something that we mainly mentioned in the *Functions as first-class objects* section of *Chapter 1, Becoming Functional,* and again in a couple of places in *Chapter 2*, *Thinking Functionally*, and then go on to several considerations about their usage in actual coding. In particular, we'll be looking at the following:

- Some basic concepts about lambda calculus, which is the theoretical basis for FP
- Arrow functions, which are the most direct translation of lambda calculus into JavaScript
- Using functions as first-class objects, a key concept in FP

Of lambdas and functions

In lambda calculus terms, a function can look like λ*x*.2***x*. The understanding is that the variable after the λ character (the Greek letter *lambda* in lowercase) is the parameter for the function, and the expression after the dot is where you would replace whatever value is passed as an argument. Later in this chapter, we will see that this particular example could be written as `(x) => 2*x` in JavaScript in arrow function form, which, as you can see, is very similar.

An alliterative aid

If you sometimes wonder about the difference between arguments and parameters, a mnemonic with some alliteration may help: *Parameters are Potential, Arguments are Actual*. Parameters are placeholders for potential values that will be passed, and arguments are the actual values passed to the function. In other words, when you define the function, you list its parameters, and when you call it, you provide arguments.

Applying a function means you provide an actual argument to it, which is written in the usual way, using parentheses. For example, (λ*x*.2***x*)(3) would be calculated as 6. What's the equivalent of these lambda functions in JavaScript? That's an interesting question! There are several ways of defining functions, and not all have the same meaning.

In how many ways can you define a function in JavaScript? The answer is probably in more ways than you thought! (A good article that shows the many ways of defining functions, methods, and more is *The Many Faces of Functions in JavaScript*, by Leo Balter and Rick Waldron, at `bocoup.com/blog/the-many-faces-of-functions-in-javascript` – give it a look!) At the very least, you could write the following – and I'll use vanilla JavaScript because here types aren't a concern:

- A named function declaration: `function first(...) {...};`
- An anonymous function expression: `var second = function(...) {...};`
- A named function expression: `var third = function someName(…) {...};`
- An immediately-invoked expression: `var fourth = (function() { ...; return function(...) {...}; })();`
- A function constructor: `var fifth = new Function(...);`
- An arrow function: `var sixth = (...) => {...};`

If you wanted, you could add object method declarations since they also imply functions, but the preceding list should be enough.

More function types

JavaScript also allows us to define **generator** functions (as in `function*(...) {...}`) that return a `Generator` object and `async` functions that are a mix of generators and promises. You can read more about them at `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Statements/function` and `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Statements/async_function`, respectively.

What's the difference between all these ways of defining functions, and why should we care? Let's go over them one by one:

- The first definition, `function first(...) {...}`, a standalone declaration starting with the `function` keyword, is probably the most used in JavaScript and defines a function named `first` (that is, `first.name==="first"`). Because of **hoisting**, this function will be accessible everywhere in the scope where it's defined; we'll touch on this again later in the *Functions as objects* section. (Of course, this only happens if you use a `var` definition; with `let` or `const`, hoisting doesn't apply. You can read more about hoisting at `developer.mozilla.org/en-US/docs/Glossary/Hoisting`. Remember that it applies only to declarations, not to initializations.)
- The `second = function(...) {...}` definition, which assigns a function to a variable, also produces a function, but an *anonymous* (that is, not named) one. However, many JavaScript engines can deduce what the name should be and will then set `second.name === "second"`. (Look at the following code, which shows a case where the anonymous function has no name assigned.) Since the assignment isn't hoisted, the function will only be accessible after the assignment has been executed. Also, you'd probably prefer defining the variable with `const` rather than `var`, because you wouldn't (shouldn't) be changing the function – take a look at the ESLint `no-var` and `prefer-const` rules to enforce this:

  ```
  var second = function() {};
  console.log(second.name);
  // "second"

  var myArray = new Array(3);
  myArray[1] = function() {};
  console.log(myArray[1].name);
  // ""
  ```

- The third definition, `third = function someName(…) {...}`, is the same as the second, except that the function now has its own name: `third.name === "someName"`. The name of a function is relevant when you want to call it and is needed for recursive calls; we'll return to this in *Chapter 9*, *Designing Functions*. If you just want a function for, say, a callback, you can use one without a name. However, note that named functions are more easily recognized in an error traceback, the kind of listing you use when trying to understand what happened, and which function called what.

- The fourth definition, `fourth = (function() { ...; return function(...) {...}; })()`, with an immediately-invoked expression, lets you use a closure. Going back to the counter-making function that we saw in the *Closures* section of *Chapter 1*, *Becoming Functional*, we could write something like the following. An inner function can use variables or other functions, defined in its outer function, in a private, encapsulated way. The outer function receives an argument (`77`, in this case) that is used as the initial value of `count` (if no initial value is provided, we start at `0`). The inner function can access `count` (because of the closure), but the variable cannot be accessed anywhere else. In all aspects, the returned function is common – the only difference is its access to private elements. This is also the basis of the **module** pattern:

```
const myCounter = (function myCounter(initialValue =
  0) {
  let count = initialValue;
  return function () {
    count++;
    return count;
  };
})(77);

console.log(myCounter()); // 78
console.log(myCounter()); // 79
console.log(myCounter()); // 80
```

- The fifth definition, `fifth = new Function(...)`, isn't safe and you shouldn't use it! You pass the names of the arguments first, then the actual function body as a string, and the equivalent of `eval()` is used to create the function – this allows many dangerous hacks, so don't do this! (Also, TypeScript cannot deduce the type of the produced function; it just assumes the generic `Function` type.) Just to whet your curiosity, let's look at an example of rewriting the very simple `sum3()` function we saw back in the *Spread* section of *Chapter 1, Becoming Functional*:

```
const sum3 = new Function(
  "x",
  "y",
  "z",
  "const t = x+y+z; return t;"
);

sum3(4, 6, 7); // 17
```

Quirks of eval()

This definition is not only unsafe but has some other quirks – they don't create closures with their creation contexts, so they are always global. See `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Function` for more on this, but remember that this way of creating functions isn't a good idea!

- Finally, the last definition, `sixth = (...) => {...}`, which uses an arrow, `=>`, is the most compact way to define a function and the one we'll try to use whenever possible.

At this point, we have seen several ways of defining a function, so let's focus on arrow functions, a style we'll favor in our coding for this book.

Arrow functions – the modern way

Even if arrow functions work in pretty much the same way as the other functions, there are some crucial differences (see `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Functions/Arrow_functions`) between them and the usual ones: arrow functions can implicitly return a value even with no return statement present; the value of `this` (the context for the function) is not bound; there is no `arguments` object; they cannot be used as constructors; they do not have a prototype property; and they cannot be used as generators because they don't allow the `yield` keyword.

In this section, we'll go into several JavaScript function-related topics, including these:

- How to return different values
- How to handle problems with the value of `this`
- How to work with varying numbers of arguments
- An important concept, currying, for which we'll find many usages in the rest of this book

Returning values

In the lambda coding style, functions only consist of a result. For the sake of brevity, the new arrow functions provide a syntax for this. When you write something such as `(x,y,z) =>` followed by an expression, a `return` is implied. For instance, the following two functions do the same as the `sum3()` function that we showed previously:

```
const f1 = (x: number, y: number, z: number): number =>
  x + y + z;

const f2 = (x: number, y: number, z: number): number => {
  return x + y + z;
};
```

If you want to return an object, you must use parentheses; otherwise, JavaScript will assume that code follows. Lest you think this is a wildly improbable case, check out *Question 3.1* in the *Questions* section later in this chapter for a very common scenario!

A matter of style

When you define an arrow function with only one parameter, you can omit the parentheses around it. For consistency, I prefer to always include them. Prettier, the formatting tool I use (we mentioned it in *Chapter 1*, *Becoming Functional*), originally didn't approve, but in version 2.0, it changed the default of its `arrow-parens` configuration item from `avoid` (meaning, try to do without parentheses) to `always`.

Handling the `this` *value*

A classic problem with JavaScript is handling `this`, whose value isn't always what you expect it to be. ES2015 solved this with arrow functions, which inherit the proper `this` value so that problems are avoided. Look at the following code for an example of the possible problems: by the time the timeout function is called, `this` will point to the global (`window`) variable instead of the new object, so you'll get `undefined` in the console:

```
function ShowItself1(identity: string) {
  this.identity = identity;
  setTimeout(function () {
    console.log(this.identity);
  }, 1000);
}

var x = new ShowItself1("Functional");
// after one second, undefined is displayed, not Functional
```

There are traditional ways of solving this with old-fashioned JavaScript:

- One solution uses a closure and defines a local variable (usually named `that` or sometimes `self`) that will get the original value of `this`, so it won't be undefined
- The second way uses `bind()`, so the timeout function will be bound to the correct value of this (we used `bind()` for a similar purpose in the *Of lambdas and functions* section)
- A third, more modern way just uses an arrow function, so `this` gets the correct value (pointing to the object) without further ado

Let's see the three solutions in actual code. We use a closure for the first timeout, binding for the second, and an arrow function for the third:

```
// continued...

function ShowItself2(identity: string) {
  this.identity = identity;
  const that = this;
  setTimeout(function () {
    console.log(that.identity);
  }, 1000);

  setTimeout(
    function () {
      console.log(this.identity);
    }.bind(this),
    2000
  );

  setTimeout(() => {
    console.log(this.identity);
  }, 3000);
}

const x2 = new ShowItself2("JavaScript");
// after one second, "JavaScript"
// after another second, the same
// after yet another second, once again
```

If you run this code, you'll get `JavaScript` after 1 second, then again after another second, and a third time after another second. All three methods worked correctly, so whichever you pick just depends on which you like better.

Working with arguments

In *Chapter 1*, *Becoming Functional*, and *Chapter 2*, *Thinking Functionally*, we saw some uses of the spread (`...`) operator. However, the most practical usage we'll be making of it has to do with working with arguments; we'll see some cases of this in *Chapter 6*, *Producing Functions*.

Let's review our `once()` function from *Chapter 2, Thinking Functionally*:

```
// once.ts

const once = <FNType extends (...args: any[]) => any>(
  fn: FNType
) => {
  let done = false;

  return ((...args: Parameters<FNType>) => {
    if (!done) {
      done = true;
      return fn(...args);
    }
  }) as FNType;
};
```

Why are we writing `return (...args) =>` and then afterward `func(...args)`? The answer has to do with the more modern way of handling a variable number (possibly zero) of arguments. How did you manage such kinds of code in older versions of JavaScript? The answer is the `arguments` object (not an array; read `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Functions/arguments`) that lets you access the actual arguments passed to the function.

It happens that `arguments` is an *array-like* object, not really an array – the only array property it has is `length`. You cannot use methods such as `map()`, `forEach()`, and others on `arguments`. To convert `arguments` into a real array, you have to use `slice()`; you would also have to use `apply()` to call another function, like so:

```
function useArguments() {
  ...
  var myArray = Array.prototype.slice.call(arguments);
  somethingElse.apply(null, myArray);
  ...
}
```

In modern JavaScript, you don't need to use arguments, slicing, or applying:

```
function useArguments2(...args) {
  ...
  somethingElse(...args);
```

```
    ...
}
```

You should bear in mind the following points when looking at this code:

- By writing `useArguments2(...args)`, we immediately and clearly express that our new function receives several (possibly zero) arguments
- You don't need to do anything to get an array; `args` is a genuine array
- Writing `somethingElse(...args)` is much clearer than using `apply()`

By the way, the `arguments` object is still available in the current version of JavaScript. If you want to create an array from it, you have two alternative ways of doing so without having to resort to the `Array.prototype.slice.call` trick:

- Use the `from()` method and write `myArray=Array.from(arguments)`
- Write `myArray=[...arguments]`, which shows yet another type of usage of the spread operator

When we get to the topic of higher-order functions, writing functions that deal with other functions, with a possibly unknown number of parameters, will be commonplace.

JavaScript provides a much shorter way of doing this, so you'll have to get accustomed to this usage. It's worth it!

One argument or many?

It's also possible to write functions that return functions, and in *Chapter 6*, *Producing Functions*, we will see more of this. For instance, in lambda calculus, you don't write functions with several parameters, but only one; you do this using a technique called **currying**. (But why would you do this? Hold that thought; we'll come to this later.)

Twice recognized

Currying gets its name from Haskell Curry, who developed the concept. A functional language, *Haskell*, is also named after him – double recognition!

For instance, the function that we saw previously that sums three numbers would be written as follows:

```
// sum3.ts

const altSum3 = (x: number) => (y: number) => (z: number)
  =>
    x + y + z;
```

Why did I change the function's name? Simply put, this is *not* the same function we saw previously. The type of `sum3()` is `(x: number, y: number, z: number) => number`, while that of `altSum3()` is `(x: number) => (y: number) => (z: number) => number`, which is different. (See *Question 3.3* for more on this.) As-is, though, it can be used to produce the very same results as our earlier function. Let's look at how you would use it, say, to sum the numbers 1, 2, and 3:

```
altSum3(1)(2)(3); // 6
```

Test yourself before reading on, and think about this: what would have been returned if you had written `altSum3(1,2,3)` instead? Tip: it would not be a number! For the full answer, keep reading.

How does this work? Separating it into many calls can help; this would be the way the previous expression is calculated by the JavaScript interpreter:

```
const fn1 = altSum3(1);
const fn2 = fn1(2);
const fn3 = fn2(3);
```

Think functionally! The result of calling `altSum3(1)` is, according to the definition, a function, which, in virtue of a closure, resolves to be equivalent to the following:

```
const fn1 = y => z => 1 + y + z;
```

Our `altSum3()` function is meant to receive a single argument, not three! The result of this call, `fn1`, is also a single-argument function. When you use `fn1(2)`, the result is again a function, also with a single parameter, which is equivalent to the following:

```
const fn2 = z => 1 + 2 + z;
```

And when you calculate `fn2(3)`, a value is finally returned – great! As we said, the function performs the same kind of calculations as we saw earlier, but in an intrinsically different way.

You might think that currying is a peculiar trick: who would want to use only single-argument functions? You'll see the reasons for this when we consider how to join functions together in *Chapter 8*, *Connecting Functions*, and *Chapter 12*, *Building Better Containers*, where it won't be feasible to pass more than one parameter from one step to the next.

Functions as objects

The concept of first-class objects means that functions can be created, assigned, changed, passed as parameters, and returned as a result of other functions in the same way you can with, say, numbers or strings. Let's start with its definition. Let's look at how you usually define a function – and do you recognize the function's name? (Hint: google "Colossal Cave Adventure"!)

```
function xyzzy(...) { ... }
```

This is (almost) equivalent to writing the following:

```
var xyzzy = function(...) { ... }
```

However, this is not true for hoisting, as we explained in the *Of lambdas and functions* section. JavaScript moves all definitions to the top of the current scope but does *not* move the assignments. With the first definition, you can invoke `xyzzy(...)` from any place in your code, but with the second, you cannot invoke the function until the assignment has been executed.

The point that we want to make is that a function can be assigned to a variable and can also be reassigned if desired. In a similar vein, we can define functions on the spot where they are needed. We can even do this without naming them: as with common expressions, if they are used only once, you don't need to name them or store them in a variable.

A colossal parallel

See the parallel with the *Colossal Cave Adventure* game from the 70s? Invoking `xyzzy()` anywhere won't always work! If you have never played that famous interactive fiction game, try it online – for example, at `www.web-adventures.org/cgi-bin/webfrotz?s=Adventure` or `www.amc.com/blogs/play-the-colossal-cave-adventure-game-just-like-halt-and-catch-fires-cameron-howe--1009966`.

Let's see an actual code example that involves assigning functions.

A React-Redux reducer

As we mentioned in *Chapter 1*, *Becoming Functional*, React-Redux works by dispatching actions that a *reducer* processes. (Read more about this at `redux.js.org/tutorials/fundamentals/part-3-state-actions-reducers`.) Usually, the reducer includes code with a switch. An example follows – and I'm using JavaScript (not TypeScript) to focus on logic aspects:

```
// reducer.ts

function doAction(
  state = initialState,
  action = emptyAction
) {
  const newState: State = {};
  switch (action?.type) {
    case "CREATE":
      // update state, generating newState,
      // depending on the action data
      // to create a new item
      return newState;

    case "DELETE":
      // update state, generating newState,
      // after deleting an item
      return newState;

    case "UPDATE":
      // update an item,
      // and generate an updated state
      return newState;

    default:
      return state;
  }
}
```

Initial state

Providing `initialState` as a default value for the state is a simple way of initializing the global state. Pay no attention to that `default`; it's irrelevant to our example, and I included it just for completeness. I'm also assuming the existence of `State`, `Action`, and others as types – see *Question 3.5*!

By taking advantage of the possibility of storing functions, we can build a **dispatch table** and simplify the preceding code. First, we initialize an object with the code for the functions for each action type. We are just taking the preceding code and creating separate functions:

```
// continued...

const dispatchTable = {
  CREATE: (state, action) => {
    // update state, generating newState,
    // depending on the action data
    // to create a new item
    const NewState = {
      /* updated State */
    };
    return NewState;
  },

  DELETE: (state, action) => {
    // update state, generating newState,
    // after deleting an item
    const NewState = {
      /* updated State */
    };
    return NewState;
  },

  UPDATE: (state, action) => {
    // update an item,
    // and generate an updated state
    const NewState = {
      /* updated State */
    };
    return NewState;
  },
};
```

We store the different functions that process each type of action as attributes in an object that will work as a dispatcher table. This object is created only once and is constant during the execution of the application. With it, we can now rewrite the action-processing code in a single line of code:

```
// continued...

function doAction2(state, action) {
  return dispatchTable[action.type]
    ? dispatchTable[action.type](state, action)
    : state;
}
```

Let's analyze it: given the action, if `action.type` matches an attribute in the dispatching object, we execute the corresponding function taken from the object where it was stored. If there isn't a match, we just return the current state as Redux requires. This kind of code wouldn't be possible if we couldn't handle functions (storing and recalling them) as first-class objects.

An unnecessary mistake

There is, however, a common (though, in fact, harmless) mistake that is usually made. You often see code like this:

```
fetch("some/url").then(function(data) {
  processResult(data);
});

fetch("some/url").then((data) => processResult(data));
```

What does this code do? The idea is that a remote URL is fetched, and when the data arrives, a function is called – and this function calls `processResult` with `data` as an argument. That is to say, in the `then()` part, we want a function that, given data, calculates `processResult(data)`. But don't we already have such a function?

There is a rule that you can apply whenever you see something like the following:

```
function someFunction(someData) {
  return someOtherFunction(someData);
}
```

This rule states that you can replace code resembling the preceding code with just `someOtherFunction`. So, in our example, we can directly write what follows:

```
fetch("some/url").then(processResult);
```

This code is equivalent to the previous method that we looked at (although it is infinitesimally quicker since you avoid one function call), but is it simpler to understand?

Some terminology

In lambda calculus terms, we are replacing $\lambda x.func\ x$ with simply *func* – this is called an **η (eta) conversion**, or more specifically, an **η reduction**. (If you were to do it the other way round, it would be an **η abstraction**.) In our case, it could be considered a (very, very small!) optimization, but its main advantage is shorter, more compact code.

This programming style is called **pointfree** (also **point-free**) or **tacit** style, and its defining characteristic is that you never specify the arguments for each function application. An advantage of this way of coding is that it helps the writer (and the future readers of the code) think about the functions and their meanings instead of working at a low level, passing data around, and working with it. In the shorter version of the code, there are no extraneous or irrelevant details: if you know what the called function does, you understand the meaning of the complete piece of code. We'll often (but not necessarily always) work this way in our text.

Old Unix style

Unix/Linux users are already accustomed to this style because they work in a similar way when they use pipes to pass the result of a command as input to another. When you write something as `ls|grep doc|sort`, the output of `ls` is the input to `grep`, and the latter's output is the input to `sort` – but input arguments aren't written out anywhere; they are implied. We'll come back to this in the *Pointfree style* section of *Chapter 8, Connecting Functions*.

Working with methods

However, there is a case that you should be aware of: what happens if you call an object's method? Look at the following code:

```
fetch("some/remote/url").then(function (data) {
  myObject.store(data);
});
```

If your original code had been something along the lines of the preceding code, then the seemingly obvious transformed code would fail:

```
fetch("some/remote/url").then(myObject.store); // Fail!
```

Why? The reason is that in the original code, the called method is bound to an object (`myObject`), but in the modified code, it isn't bound and is just a free function. We can fix it by using `bind()`:

```
fetch("some/remote/url").then(
  myObject.store.bind(myObject)
);
```

This is a general solution. When dealing with a method, you cannot just assign it; you must use `bind()` so that the correct context will be available. Look at the following code:

```
const doSomeMethod = (someData) => {
  return someObject.someMethod(someData);
}
```

Following this rule, such code should be converted into the following:

```
const doSomeMethod = someObject.someMethod.bind(someObject);
```

Tip

Read more on `bind()` at `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_objects/Function/bind`.

This looks rather awkward and not too elegant, but it's required so that the method will be associated with the correct object. We will see one application of this when we *promisify* functions in *Chapter 6, Producing Functions*. Even if this code isn't so nice to look at, whenever you have to work with objects (and remember, we didn't say that we would be trying to aim for fully FP code, and did say that we would accept other constructs if they made things easier), you'll have to remember to bind methods before passing them as first-class objects in pointfree style.

So far, we have been discussing many aspects of functions; now, let's get more into functions in FP, and see how we'll use them.

Using functions in FP ways

Several common coding patterns take advantage of the FP style, even if you aren't aware of it. In this section, we will go through them and look at the functional aspects of the code so that you can get more accustomed to this coding style.

Then, we'll look in detail at using functions in an FP way by considering several FP techniques, such as the following:

- **Injection**, which is needed for sorting different strategies, as well as other uses
- **Callbacks** and **promises**, introducing the **continuation-passing** style
- **Polyfilling** and **stubbing**
- **Immediate invocation** schemes

Injection – sorting it out

The `Array.prototype.sort()` method provides the first example of passing functions as parameters. If you have an array of strings and you want to sort it, you can just use the `sort()` method. For example, to alphabetically sort an array with the colors of the rainbow, we would write something like the following:

```
// sort.ts

const colors = [
  "violet",
  "indigo",
  "blue",
  "green",
  "yellow",
  "orange",
  "red",
];

colors.sort();

console.log(colors);
// 'blue', 'green', 'indigo', 'orange', 'red',
// 'violet', 'yellow'
```

Note that we didn't have to provide any parameters to the `sort()` call, but the array got sorted perfectly well. By default, this method sorts strings according to their ASCII internal representation. So, if you use this method to sort an array of numbers, it will fail because it will decide that 20 must be between 100 and 3, as 100 precedes 20 (taken as strings!) and the latter precedes 3, so this needs fixing! The following code shows the problem:

```
// continued...

const someNumbers = [3, 20, 100];

someNumbers.sort();

console.log(someNumbers);
// 100, 20, 3
```

But let's forget numbers for a while and stick to sorting strings. What would happen if we wanted to sort some Spanish words (*palabras*) while following the appropriate locale rules? We would be sorting strings, but the results wouldn't be correct:

```
// continued...

const palabras = [
  "ñandú",
  "oasis",
  "mano",
  "natural",
  "mítico",
  "musical",
];

palabras.sort();

console.log(palabras);
// "mano", "musical", "mítico",
// "natural", "oasis", "ñandú" -- wrong result!
```

What's in a word?

For language or biology buffs, *ñandú* in English is *rhea*, a running bird similar to an ostrich. There aren't many Spanish words beginning with *ñ*, and we happen to have these birds in my country, Uruguay, so that's the reason for the odd word!

Oops! In Spanish, *ñ* comes between *n* and *o*, but `"ñandú"` got sorted at the end. Also, `"mítico"` (in English, mythical; note the accented *í*) should appear between `"mano"` and `"musical"` because the tilde should be ignored. The appropriate way of solving this is by providing a comparison function to `sort()`. In this case, we can use the `localeCompare()` method as follows:

```
// continued...

palabras.sort((a: string, b: string) =>
  a.localeCompare(b, "es")
);

console.log(palabras);
// "mano", "mítico", "musical",
// "natural", "ñandú", "oasis" -- correct result!
```

The `a.localeCompare(b,"es")` call compares the `a` and `b` strings and returns a negative value should `a` precede `b`, a positive value should `a` follow `b`, and 0 if `a` and `b` are the same – but according to Spanish (`"es"`) ordering rules.

Now, things are right! And the code could be made clearer by introducing a new function, `spanishComparison()`, to perform the required strings comparison:

```
// continued...

const spanishComparison = (a: string, b: string) =>
  a.localeCompare(b, "es");

palabras.sort(spanishComparison); // same correct result
```

International sorting

For more on the `localeCompare()` possibilities, see `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/String/localeCompare`. You can specify which locale rules to apply, in which order to place upper/lowercase letters, whether to ignore punctuation, and much more. But be careful: not all browsers may support the required extra parameters.

In upcoming chapters, we will discuss how FP lets you write code in a more declarative fashion, producing more understandable code, and how this sort of minor change helps. When readers of the code get to the `sort` function, they will immediately deduce what is being done, even if the comment wasn't present.

Of strategies and patterns

This way of changing how the `sort()` function works by injecting different comparison functions is a case of the strategy **design pattern**. We'll learn more about this in *Chapter 11*, *Implementing Design Patterns*.

Providing a `sort` function as a parameter (in a very FP way!) can also help with several other problems, such as the following:

- `sort()` only works with strings by default. If you want to sort numbers (as we tried to do previously), you have to provide a function that will compare numerically. For example, you would write something like `myNumbers.sort((a:number, b:number) => a - b)`. (Why? See *Question 3.7*.)
- If you want to sort objects by a given attribute, you will use a function that compares to it. For example, you could sort people by age with something like `myPeople.sort((a:Person, b:Person) => a.age - b.age)`.

This is a simple example you have probably used before, but it's an FP pattern, after all. Let's move on to even more common usage of functions as parameters when you perform Ajax calls.

Callbacks and promises

Probably the most used example of functions passed as first-class objects has to do with callbacks and promises. In Node.js, reading a file is accomplished asynchronously with something like the following code:

```
const fs = require("fs");

fs.readFile("someFile.txt", (err, data) => {
  if (err) {
    // handle the error
  } else {
    // do something with the received data
  }
});
```

The `readFile()` function requires a callback – in this example, an anonymous function – that will get called when the file-reading operation is finished.

A better, more modern way is using promises; read more at `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Promise`. With this, when performing an Ajax web service call using the `fetch()` function, you could write something along the lines of the following code:

```
fetch("some/remote/url")
  .then((data) => {
    // do something with the received data
  })
  .catch((error) => {
    // handle the error
  });
```

Finally, you should also look into using `async/await`; read more about them at `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Statements/async_function` and `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Operators/await`, respectively.

Continuation-passing style

The preceding code, in which you call a function but also pass another function to be executed when the input/output operation is finished, can be considered something called **continuation-passing style** (**CPS**). What is this technique of coding? One way of looking at it is by thinking about the question: *how would you program if using the return statement was forbidden?*

At first glance, this may appear to be an impossible situation. However, we can get out of our fix by passing a callback to the called function so that when that procedure is ready to return to the caller, instead of returning, it invokes the given callback. By doing this, the callback provides the called function with the way to continue the process, hence the word *continuation*. We won't get into this now, but in *Chapter 9*, *Designing Functions*, we will study it in depth. In particular, CPS will help us to avoid an important recursion restriction, as we'll see.

Working out how to use continuations is sometimes challenging, but always possible. An exciting advantage of this way of coding is that by specifying how the process will continue, you can go beyond all the usual structures (`if`, `while`, `return`, and so on) and implement whatever mechanisms you want. This can be very useful in problems where the process isn't necessarily linear. Of course, this can also lead to you inventing a kind of control structure far worse than the possible usage of GOTO statements that you might imagine! *Figure 3.1* shows the dangers of that practice!

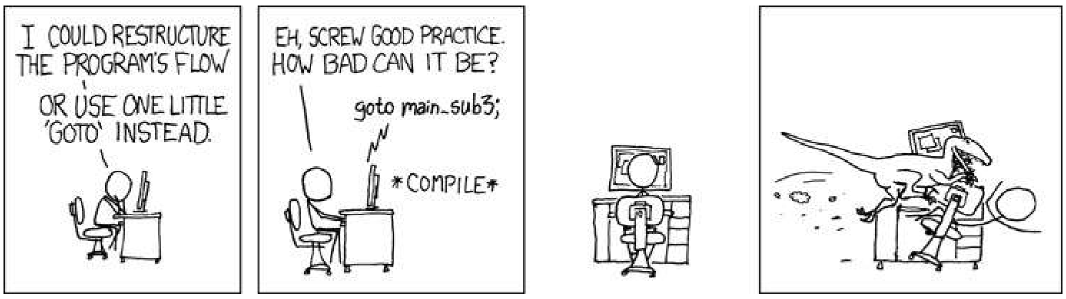

I COULD RESTRUCTURE THE PROGRAM'S FLOW
OR USE ONE LITTLE 'GOTO' INSTEAD.
EH, SCREW GOOD PRACTICE. HOW BAD CAN IT BE?
goto main_sub3;
COMPILE

Figure 3.1 – What's the worst that could happen if you start messing with the program flow? (This XKCD comic is available online at `xkcd.com/292/`)

You are not limited to passing a single continuation. As with promises, you can provide two or more alternative callbacks. And this, by the way, can provide a solution to the problem of how you would work with exceptions. If we simply allowed a function to throw an error, it would be an implied return to the caller, and we don't want this. The way out of this is to provide an alternative callback (that is, a different continuation) to be used whenever an exception is thrown (in *Chapter 12*, *Building Better Containers*, we'll find another solution using monads):

```
function doSomething(a, b, c,
  normalContinuation, errorContinuation) {
```

```
  let r = 0;
  // ... do some calculations involving a, b, and c,
  // and store the result in r
  // if an error happens, invoke:
  // errorContinuation("description of the error")
  // otherwise, invoke:
  // normalContinuation(r)
}
```

Using CPS can even allow you to go beyond the control structures that JavaScript provides, but that would be beyond the objectives of this book, so I'll let you research that on your own!

Polyfills

Being able to assign functions dynamically (in the same way that you can assign different values to a variable) also allows you to work more efficiently when defining polyfills.

Detecting Ajax

Let's go back a bit in time to when Ajax started to appear. Given that different browsers implemented Ajax calls in distinct fashions, you would always have to code around these differences. The following code shows how you would go about implementing an Ajax call by testing several different conditions:

```
// ajax.ts

function getAjax() {
  let ajax = null;
  if (window.XMLHttpRequest) {
    // modern browser? use XMLHttpRequest
    ajax = new XMLHttpRequest();
  } else if (window.ActiveXObject) {
    // otherwise, use ActiveX for IE5 and IE6
    ajax = new ActiveXObject("Microsoft.XMLHTTP");
  } else {
    throw new Error("No Ajax support!");
  }
  return ajax;
}
```

This worked but implied that you would redo the Ajax check for every call, even though the test results wouldn't ever change. There's a more efficient way to do this, and it has to do with using functions as first-class objects. We could define *two* different functions, test for the condition only once, and then assign the correct function to be used later; study the following code for such an alternative:

```
// continued...

(function initializeGetAjax() {
  let myAjax = null;

  if (window.XMLHttpRequest) {
    // modern browsers? use XMLHttpRequest
    myAjax = function () {
      return new XMLHttpRequest();
    };
  } else if (window.ActiveXObject) {
    // it's ActiveX for IE5 and IE6
    myAjax = function () {
      new ActiveXObject("Microsoft.XMLHTTP");
    };
  } else {
    myAjax = function () {
      throw new Error("No Ajax support!");
    };
  }
  window.getAjax = myAjax;
})();
```

This piece of code shows two important concepts. First, we can dynamically assign a function: when this code runs, `window.getAjax` (the global `getAjax` variable) will get one of three possible values according to the current browser. When you later call `getAjax()` in your code, the correct function will execute without you needing to do any further browser-detection tests.

The second interesting idea is that we define the `initializeGetAjax()` function and immediately run it – this pattern is called the **immediately invoked function expression** (**IIFE**), and we already saw it in the *Solution 7 – using a local flag* section in *Chapter 2, Thinking Functionally*. The function runs but cleans up after itself because all its variables are local and won't even exist after the function runs. We'll learn more about this later in this chapter.

Nowadays, you would use a module instead of an IIFE, as follows:

```
// ajax.module.ts

let getAjax = null;

if (window.XMLHttpRequest) {
  // modern browsers? use XMLHttpRequest
  getAjax = function () {
    return new XMLHttpRequest();
  };
} else if (window.ActiveXObject) {
  // it's ActiveX for IE5 and IE6
  getAjax = function () {
    new ActiveXObject("Microsoft.XMLHTTP");
  };
} else {
  getAjax = function () {
    throw new Error("No Ajax support!");
  };
}

export { getAjax };
```

The code in the module is guaranteed to run only once. Wherever you need to do an Ajax call, you would just `import { getAjax } from "/path/to/ajax.module"` and you could use `getAjax()` at will.

Adding missing functions

This idea of defining a function on the run also allows us to write polyfills that provide otherwise missing functions. For example, let's say that we had some code such as the following:

```
if (currentName.indexOf("Mr.") !== -1) {
  // it's a man
  ...
}
```

Instead of this, you might very much prefer using the newer `includes()` method and just write this:

```
if (currentName.includes("Mr.")) {
  // it's a man
  ...
}
```

What happens if your browser doesn't provide `includes()`? Once again, we can define the appropriate function on the fly, but only if needed. If `includes()` is available, you don't need to do anything, but if it is missing, you need to define a polyfill that will provide the same workings. (You can find links to polyfills on Mozilla's developer site.) The following code shows an example of such a polyfill:

```
if (!String.prototype.includes) {
  String.prototype.includes = function (search, start) {
    "use strict";
    if (typeof start !== "number") {
      start = 0;
    }

    if (start + search.length > this.length) {
      return false;
    } else {
      return this.indexOf(search, start) !== -1;
    }
  };
}
```

When this code runs, it checks whether the `String` prototype already has the `includes()` method. If not, it assigns a function to it that does the same job, so from that point onward, you'll be able to use `includes()` without further worries. By the way, there are other ways of defining a polyfill: check the answer to *Question 3.7* for an alternative. Yet another solution is the `core-js` package (`github.com/zloirock/core-js`), which provides polyfills for ECMAScript up to the latest version, and even some proposals that haven't made it into the language yet.

Good or bad?

Directly modifying a standard type's prototype object is usually frowned upon because, in essence, it's equivalent to using a global variable, and thus it's prone to errors; however, in this case (writing a polyfill for a well-established, known function) is quite unlikely to provoke any conflicts.

Finally, if you happened to think that the Ajax example shown previously was old hat, consider this: if you want to use the more modern `fetch()` way of calling services, you will also find that not all modern browsers support it (check `caniuse.com/#search=fetch` to verify this), so you'd have to use a polyfill, such as the one at `github.com/github/fetch`. Study the code, and you'll see that it uses the same method described previously to see whether a polyfill is needed and create it.

Stubbing

Here, we will look at a use case similar to using a polyfill: having a function do different work depending on the environment. The idea is to perform stubbing, an idea that comes from testing and involves replacing a function with another that does a simpler job instead of the actual work.

Stubbing is commonly used with logging functions. You may want the application to perform detailed logging when in development but not to say a peep when in production. A common solution would be to write something along the lines of the following:

```
let myLog = (someText) => {
  if (DEVELOPMENT) {
    console.log(someText); // or some other way of logging
  } else {
    // do nothing
  }
};
```

This works, but as in the example of Ajax detection, it does more work than it needs to because it checks whether the application is in development every time.

We could simplify the code (and get a really, really tiny performance gain!) if we stub out the logging function so that it won't log anything; an easy implementation is as follows:

```
let myLog;
if (DEVELOPMENT) {
  myLog = (someText: string) => console.log(someText);
} else {
  myLog = (someText: string) => {};
}
```

We can do even better with the ternary operator:

```
const myLog = DEVELOPMENT
  ? (someText: string) => console.log(someText)
  : (someText: string) => {};
```

This is a bit more cryptic, but I prefer it because it uses `const`, which cannot be modified.

There's yet another possibility: you could modify the original method like this:

```
if (DEVELOPMENT) {
  // do nothing, let things be
} else {
  console.log = (someText: string) => {};
}
```

In this case, we are directly changing how `console.log()` works, so it won't log anything.

Useless arguments – ignore or exclude?

Given that JavaScript allows us to call functions with more arguments than parameters, and given that we aren't doing anything in `myLog()` when we are not in development, we could also have written `() => {}` and it would have worked fine. However, I do prefer keeping the same signature, and that's why I specified the `someText` argument, even if it wouldn't be used. But, if you use ESLint's `no-unused-vars` rule to detect unused variables, you may have to tweak its configuration to allow unused arguments.

You'll notice that we are using the concept of functions as first-class objects over and over again; look through all the code samples and you'll see!

Immediate invocation (IIFE)

There's yet another common usage of functions, usually seen in popular libraries and frameworks, that lets you bring some modularity advantages from other languages into JavaScript (even the older versions!). The usual way of writing this is something like the following:

```
(function () {
  // do something...
})();
```

Alternatively, you may find `(function(){ ... }())` – note the different placement of the parentheses for the function call. Both styles have their fans; pick whichever suits you, and follow it consistently.

You can also pass some arguments to the function that will be used as the initial values for its parameters:

```
(function (a, b) {
  // do something, using the
  // received arguments for a and b...
})(some, values);
```

Finally, you could also return something from the function – usually, an object (with several methods) or a function:

```
let x = (function (a, b) {
  // ...return an object or function
})(some, values);
```

Note the parentheses around the function. These help the parser understand that we are writing an expression. If you were to omit the first set of parentheses, JavaScript would think you were writing a function declaration instead of an invocation. The parentheses also serve as a visual note, so readers of your code will immediately recognize the IIFE.

As previously mentioned, the pattern is called IIFE (pronounced *iffy*). The name is easy to understand: you define a function and call it right away so that it gets executed on the spot. Why would you do this, instead of simply writing the code inline? The reason has to do with scopes.

If you define any variables or functions within IIFE, then because of how JavaScript defines the scope of functions, those definitions will be internal, and no other part of your code will be able to access them. Imagine that you wanted to write some complicated initialization, such as the following:

```
function ready() { ... }

function set() { ... }

function go() { ... }

// initialize things calling ready(),
// set(), and go() appropriately
```

What could go wrong? The problem hinges on the fact that you could (by accident) have a function with the same name as any of the three here, and hoisting would imply that the last function would be called:

```
function ready() {
  console.log("ready");
}

function set() {
  console.log("set");
}

function go() {
  console.log("go");
}

ready();
set();
go();

function set() {
  console.log("UNEXPECTED...");
}

// "ready"
// "UNEXPECTED"
// "go"
```

Oops! If you had used IIFE, the problem wouldn't have happened. (Using ESLint's `no-func-assign` rule would have prevented this, too.) Also, the three inner functions wouldn't even be visible to the rest of the code, which helps to keep the global namespace less polluted. The following code shows a widespread pattern for this:

```
(function () {
  function ready() {
    console.log("ready");
  }

  function set() {
    console.log("set");
  }

  function go() {
    console.log("go");
  }

  ready();
  set();
  go();
})();

function set() {
  console.log("UNEXPECTED...");
}

// "ready"
// "set"
// "go"
```

To see an example involving returned values, we could revisit the example from *Chapter 1*, *Becoming Functional*, and write the following, which would create a single counter:

```
const myCounter = (function () {
  let count = 0;
  return function () {
    count++;
    return count;
  };
})();
```

Then, every call to `myCounter()` would return an incremented count, but there is no chance that any other part of your code will overwrite the inner `count` variable because it's only accessible within the returned function.

Summary

In this chapter, we went over several ways of defining functions in JavaScript, focusing mainly on arrow functions, which have several advantages over standard functions, including being terser. We learned about the concept of currying (which we'll be revisiting later), considered some aspects of functions as first-class objects, and reviewed several techniques that happen to be fully FP in concept. Rest assured that we'll be using everything in this chapter as the building blocks for more advanced techniques in the rest of this book; just wait and see!

In *Chapter 4*, *Behaving Properly*, we will delve even more deeply into functions and learn about the concept of pure functions, leading us to an even better programming style.

Questions

3.1 **Uninitialized object?** React-Redux programmers usually code action creators to simplify the creation of actions that will later be processed by a reducer. (We saw this in the *A React-Redux reducer* section.) Actions are objects with a `type` attribute, used to determine what kind of action you are creating. The following code supposedly produces an action, but can you explain the unexpected results?

```
const simpleAction = (t:string) => {
  type: t;
};

console.log(simpleAction("INITIALIZE"));
// undefined
```

3.2 **Are arrows allowed?** Would everything be the same if you defined `useArguments()` and `useArguments2()` from the *Working with arguments* section by using arrow functions instead of the way we did, with the `function` keyword?

3.3 **Three more types**: Back in the *One argument or many?* section, we showed the types of `sum3()` and `altsum3()`, but we didn't do that for `fn1`, `fn2`, and `fn3`. What are the types of those functions?

3.4 **One-liner**: A programmer, particularly thrifty with lines of code, suggested rewriting `doAction2()` as a one-liner, even though you can't tell this from the formatting! What do you think: is it correct or isn't it?

```
const doAction3 = (state = initialState, action) =>
  (dispatchTable[action.type] &&
    dispatchTable[action.type](state, action)) ||
  state;
```

3.5 **Reducing types**: In the *A React-Redux reducer* section, I used JavaScript instead of TypeScript to focus on the details of the needed logic. Can you provide TypeScript versions of `doAction()`, `dispatchTable`, and `doAction2()`? Be sure to describe all needed types, too.

3.6 **Spot the bug!** A programmer, working with a global store for state (similar in concept to those of Redux, Mobx, Vuex, and others used by different web frameworks), wanted to log (for debugging purposes) all calls to the store's `set()` method. After creating the new store object, he wrote the following so that the arguments to `store.set()` would be logged before being processed. Unfortunately, the code didn't work as expected. What's the problem? Can you spot the mistake?

```
window.store = new Store();
const oldSet = window.store.set;
window.store.set = (...data) => (
  console.log(...data), oldSet(...data)
);
```

3.7 **Bindless binding**: Suppose that `bind()` was not available; how could you do a polyfill for it?

3.8 **Mystery sort**: Back in the *Injection – sorting it out* section, we mentioned that we could sort numbers with something like `myNumbers.sort((a:number, b:number) => a-b)` – why/how does this work?

3.9 **Negative sort**: Earlier, in the *Injection – sorting it out* section, we saw that sorting numbers as strings produces unexpected results. What would the result be if the array included both negative and positive numbers?

3.10 **Lexicographic sorting**: When sorting, say, book titles or personal names, special collation rules are applied. For instance, "THE SHINING" would be sorted as "SHINING, THE," and "Stephen King" would be sorted as "King, Stephen." How could you (efficiently) implement such sorting?

3.11 **Stubbed logging**: In the *Stubbing* section, the stubbed `console.log()` method doesn't have the correct data type – for instance, our version just allows a single argument. Can you provide the right data type definition?

4
Behaving Properly – Pure Functions

In *Chapter 3*, *Starting Out with Functions*, we considered functions as the critical elements in **functional programming** (**FP**), went into detail about arrow functions, and introduced some concepts, such as injection, callbacks, polyfilling, and stubbing. In this chapter, we'll have the opportunity to revisit or apply some of those ideas.

In this chapter, we will do the following:

- Consider the notion of **purity** and why we should care about **pure functions**—and **impure functions** as well!
- Examine the concept of **referential transparency**
- Recognize the problems implied by side effects
- Show some advantages of pure functions
- Describe the main reasons behind impure functions
- Discover ways to minimize the number of impure functions
- Focus on ways of testing both pure and impure functions

Pure functions

Pure functions behave the same way as mathematical functions and provide various benefits. A function is pure if it satisfies two conditions:

- **Given the same arguments, the function always calculates and returns the same result**: This should be true no matter how many times it's invoked or under which conditions you call it. This result cannot depend on any outside information or state, which could change during the program execution and cause it to return a different value. Nor can the function result depend on I/O results, random numbers, some other external variable, or a value that is not directly controllable.

- **When calculating its result, the function doesn't cause any observable side effects**: This includes output to I/O devices, the mutation of objects, changes to a program's state outside of the function, and so on.

You can simply say that pure functions don't depend on (and don't modify) anything outside their scope and always return the same result for the same input arguments.

Another word used in this context is **idempotency**, but it's not exactly the same. An idempotent function can be called as many times as desired and will always produce the same result. However, this doesn't imply that the function is free from side effects.

Idempotency is usually mentioned in the context of RESTful services. Let's see a simple example showing the difference between purity and idempotency. A `PUT` call would cause a database record to be updated (a side effect), but if you repeat the call, the element will not be further modified, so the global state of the database won't change any further.

We might also invoke a software design principle and remind ourselves that a function should *do one thing, only one thing, and nothing but that thing*. If a function does something else and has some hidden functionality, then that dependency on the state will mean that we won't be able to predict the function's output and will make things harder for us as developers.

Let's look into these conditions in more detail.

Referential transparency

In mathematics, referential transparency is the property that lets you replace an expression with its value without changing the results of whatever you are doing. The counterpart of referential transparency is, appropriately enough, **referential opacity**. A referentially opaque function cannot guarantee that it will always produce the same result, even when called with the same arguments.

To give a simple example, let's consider what happens with an optimizing compiler that performs **constant folding**. Suppose you have a sentence like this:

```
const x = 1 + 2 * 3;
```

The compiler might optimize the code to the following by noting that `2*3` is a constant value:

```
const x = 1 + 6;
```

Even better, a new round of optimization could avoid the sum altogether:

```
const x = 7;
```

To save execution time, the compiler is taking advantage of the fact that all mathematical expressions and functions are (by definition) referentially transparent.

On the other hand, if the compiler cannot predict the output of a given expression, it won't be able to optimize the code in any fashion, and the calculation will have to be done at runtime.

(TypeScript does a similar type analysis, and given the original `const x = 1 + 2 * 3` line, it would correctly decide that `x` is of type `number`.)

Of lambdas and betas

In lambda calculus, if you replace the value of an expression involving a function with the calculated value for the function, then that operation is called a **β (beta) reduction**. Note that you can only do this safely with referentially transparent functions.

All arithmetical expressions (involving both mathematical operators and functions) are referentially transparent: `22*9` can always be replaced by `198`. Expressions involving I/O are not transparent, given that their results cannot be known until executed. For the same reason, expressions involving date- and time-related functions or random numbers are also not transparent.

Concerning JavaScript functions you can produce, it's pretty easy to write some that won't fulfill the referential transparency condition. In fact, a function is not even required to return a value, though the JavaScript interpreter will return `undefined` in that situation.

A matter of distinction

Some languages distinguish between functions, which are expected to return a value, and procedures, which do not return anything, but that's not the case with JavaScript. Some languages even provide the means to ensure that functions are referentially transparent.

If you wanted to, you could classify functions as follows:

- **Pure functions**: These return a value that depends only on its arguments and have no side effects whatsoever.
- **Side effects only**: These don't return anything (actually, in JavaScript, these functions return `undefined`, but that's not relevant here) but do produce some side effects.
- **Functions with side effects**: This means that they return a value that may not only depend on the function arguments but also involve side effects.

In FP, much emphasis is put on the first group: referentially transparent pure functions. A compiler can reason about the program behavior (and thus be able to optimize the generated code), and the programmer can more easily reason about the program and the relationship between its components. This, in turn, can help prove the correctness of an algorithm or optimize the code by replacing a function with an equivalent one.

Side effects

What are side effects? We can define these as a change in state or an interaction with outside elements (the user, a web service, another computer—whatever) that occurs during the execution of some calculations or a process.

There's a possible misunderstanding as to the scope of this meaning. In everyday speech, when you speak of side effects, it's a bit like talking about collateral damage—some unintended consequences for a given action; however, in computing, we include every possible effect or change outside the function. If you write a function meant to perform a `console.log()` call to display a result, that would be considered a side effect, even if it's exactly what you intended the function to do in the first place!

In this section, we will look at the following:

- Common side effects in JavaScript programming
- The problems that global and inner states cause
- The possibility of functions mutating their arguments
- Some functions that are always troublesome

Usual side effects

In programming, there are (too many!) things that are considered side effects. In JavaScript programming, including both front- and backend coding, the more common ones you may find include the following:

- Changing global variables.
- Mutating objects received as arguments.
- Performing any I/O, such as showing an alert message or logging some text.
- Working with, or changing, the filesystem.
- Querying or updating a database.
- Calling a web service.
- Querying or modifying the DOM.
- Triggering any external process.
- Just calling another function that produces a side effect of its own. You could say that impurity is contagious: a function that calls an impure function automatically becomes impure on its own!

With this definition, let's start looking at what can cause functional impurity (or referential opaqueness).

Global state

Of all the preceding points, the most common reason for side effects is the usage of nonlocal variables that share a global state with other parts of the program. Since pure functions, by definition, always return the same output value given the same input arguments, if a function refers to anything outside its internal state, it automatically becomes impure. Furthermore—and this is a hindrance to debugging—to understand what a function has done, you must understand how the state got its current values, which means understanding all of the past history from your program: not easy!

Let's write a function to detect whether a person is a legal adult by checking whether they were born at least 18 years ago. (OK—that's not precise enough because we are not considering the day and month of birth, but bear with me; the problem is elsewhere.) A version of an `isOldEnough()` function could be as follows:

```
// isOldEnough.ts

const limitYear = 2004; // only good for 2022!

const isOldEnough = (birthYear: number) =>
  birthYear <= limitYear;

console.log(isOldEnough(1960)); // true
console.log(isOldEnough(2010)); // false
```

The `isOldEnough()` function correctly detects whether a person is at least 18 years old, but it depends on an external variable—a variable good for 2022 only! Even though the function works, the implementation isn't the best that it could possibly be. You cannot tell what the function does unless you know about the external variable and how it got its value. Testing is also hard; you must remember to create the global `limitYear` variable, or all your tests will fail.

There is an exception to this rule. Check out the following case: is the following `circleArea()` function, which calculates the area of a circle given its radius, pure or not?

```
// area.ts

const PI = 3.14159265358979;

const circleArea = (r: number) => PI * r ** 2;
```

Even though the function is accessing an external state, the fact that `PI` is a constant (and thus cannot be modified) would allow us to substitute it inside `circleArea` with no functional change, and so we should accept that the function is pure. The function will always return the same value for the same argument and thus fulfills our purity requirements.

If you were to use `Math.PI` instead of a constant as we defined in the code (a better idea, by the way) the constant cannot be changed, so the function would remain pure.

Here, we have dealt with problems caused by the global state; let's move on to the inner state.

Inner state

The notion is also extended to internal variables, in which a local state is stored and used for future calls. The external state is unchanged, but internal side effects imply future differences regarding what the function will return. Let's imagine a `roundFix()` rounding function that considers whether it has been rounding up or down too much so that the next time, it will round the other way, bringing the accumulated difference closer to zero. Our function will have to accumulate the effects of previous roundings to decide how to proceed next. The implementation could be as follows:

```
// roundFix.ts

const roundFix = (function () {
  let accum = 0;
  return (n: number): number => {
    // reals get rounded up or down
    // depending on the sign of accum
    const nRounded =
      accum > 0 ? Math.ceil(n) : Math.floor(n);

    console.log(
      "accum",
      accum.toFixed(5),
      " result",
      nRounded
    );

    accum += n - nRounded;
    return nRounded;
  };
})();
```

Some comments regarding this function:

- The `console.log()` call is just for the sake of this example; it wouldn't be included in the real-world function. It lists the accumulated difference up to the point and the result it will return: the given number rounded up or down.
- We are using the IIFE pattern from the `myCounter()` example in the *Immediate invocation* section of *Chapter 3, Starting Out with Functions,* to get a hidden internal variable.
- The `nRounded` calculation could also be written as `Math[accum > 0 ? "ceil": "floor"](n)`—we test `accum` to see which method to invoke (`"ceil"` or `"floor"`) and then use the `Object["method"]` notation to indirectly invoke `Object.method()`. The way we used it, I think, is more clear, but I just wanted to give you a heads-up in case you happen to find this other coding style.

Running this function with just two values (recognize them?) shows that results are not always the same for a given input. The `result` part of the console log shows how the value got rounded, up or down:

```
roundFix(3.14159); // accum  0.00000  result 3
roundFix(2.71828); // accum  0.14159  result 3
roundFix(2.71828); // accum -0.14013  result 2
roundFix(3.14159); // accum  0.57815  result 4
roundFix(2.71828); // accum -0.28026  result 2
roundFix(2.71828); // accum  0.43802  result 3
roundFix(2.71828); // accum  0.15630  result 3
```

The first time around, `accum` is zero, so 3.14159 gets rounded down, and `accum` becomes 0.14159 in our favor. The second time, since `accum` is positive (meaning that we have been rounding in our favor), 2.71828 gets rounded up to 3, and now `accum` becomes negative. The third time, the same 2.71828 value gets rounded down to 2 because the accumulated difference was negative—we got different values for the same input! The rest of the example is similar; you can get the same value rounded up or down, depending on the accumulated differences, because the function's result depends on its inner state.

Why not OOP?

This usage of the internal state is why many FP programmers think that using objects is potentially flawed. In OOP, we developers are used to storing information (attributes) and using them for future calculations; however, this usage is considered impure insofar as repeated method calls may return different values, although the same arguments are being passed.

We have now dealt with the problems caused by both global and inner states, but there are still more possible side effects. For example, what happens if a function changes the values of its arguments? Let's consider this next.

Argument mutation

You also need to be aware of the possibility that an impure function will modify its arguments. In JavaScript, arguments are passed by value, except for arrays and objects, which are passed by reference. This implies that any modification to the function's parameters will affect an actual modification of the original object or array. This can be further obscured by the fact that several **mutator** methods change the underlying objects by definition. For example, say you wanted a function that would find the maximum element of an array of strings (of course, if it were an array of numbers, you could use `Math.max()` with no further ado). A short implementation could be as follows:

```
// maxStrings.ts

const maxStrings = (a: string[]) => a.sort().pop();

const countries = [
  "Argentina",
  "Uruguay",
  "Brasil",
  "Paraguay",
];

console.log(maxStrings(countries)); // "Uruguay"
```

The function does provide the correct result (and if you worry about foreign languages, we already saw a way around that in the *Injection – sorting it out* section of *Chapter 3, Starting Out with Functions*), but it has a defect. Let's see what happened with the original array:

```
console.log(countries);
// ["Argentina", "Brasil", "Paraguay"]
```

Oops—the original array was modified; this is a side effect by definition! (TypeScript would have helped detect this error if we had only written a complete type definition for `maxStrings()`; see *Question 4.2* for details.) If you were to call `maxStrings(countries)` again, then instead of returning the same result as before, it would produce another value; clearly, this is not a pure function.

In this case, a quick solution is to work on a copy of the array, and we can use the spread operator to help. Still, we'll be dealing with more ways of avoiding these sorts of problems in *Chapter 10, Ensuring Purity*:

```
// continued...

```

```
const maxStrings2 = (a: string[]) => [...a].sort().pop();

let countries = [
  "Argentina",
  "Uruguay",
  "Brasil",
  "Paraguay",
];

console.log(maxStrings2(countries));
// "Uruguay"

console.log(countries);
// ["Argentina", "Uruguay", "Brasil", "Paraguay"]
```

So now, we have found yet another cause for side effects: functions that modify their arguments. A final case to consider is functions that just have to be impure!

Troublesome functions

Finally, some functions also cause problems. For instance, `Math.random()` is impure: it doesn't always return the same value, and it would defeat its purpose if it did! Furthermore, each call to the function modifies a global seed value, from which the next random value will be calculated.

Not really random

The fact that random numbers are actually calculated by an internal function makes them not random at all; *pseudorandom* would be a better name for them. If you knew the used formula and the seed's initial value, you'd be able to predict the following numbers, in a totally non-random way.

For instance, consider the following function that generates random letters from `"A"` to `"Z"`:

```
// random.ts

const getRandomLetter = (): string => {
  const min = "A".charCodeAt(0);
  const max = "Z".charCodeAt(0);
  return String.fromCharCode(
    Math.floor(Math.random() * (1 + max - min)) + min
  );
};
```

The fact that it receives no arguments, but is expected to produce different results upon each call, clearly points out that this function is impure.

Random explanations

Go to `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Math/random` for an explanation of our `getRandomLetter()` function, and to `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/String/charCodeAt` for the `.charCodeAt()` method.

Impurity can be inherited by calling functions. If a function uses an impure function, it immediately becomes impure itself. We might want to use `getRandomLetter()` to generate random filenames with an optional given extension; our `getRandomFileName()` function could then be as follows:

```
// continued...

const getRandomFileName = (fileExtension = ""): string => {
  const NAME_LENGTH = 12;
  const namePart = new Array(NAME_LENGTH);
  for (let i = 0; i < NAME_LENGTH; i++) {
    namePart[i] = getRandomLetter();
  }
  return namePart.join("") + fileExtension;
};
```

Because of its usage of `getRandomLetter()`, `getRandomFileName()` is also impure, though it performs as expected, correctly producing totally random filenames:

```
getRandomFileName(".pdf"); // "SVHSSKHXPQKG.pdf"
getRandomFileName(".pdf"); // "DCHKTMNWFHYZ.pdf"
getRandomFileName(".pdf"); // "GBTEFTVVHADO.pdf"
getRandomFileName(".pdf"); // "ATCBVUOSXLXW.pdf"
getRandomFileName(".pdf"); // "OIFADZKKNVAH.pdf"
```

Keep this function in mind; we'll see some ways around the unit testing problem later in this chapter, and we'll rewrite it a bit to help with that.

The concern about impurity also extends to functions that access the current time or date because their results will depend on an external condition (namely, the time of day) that is part of the application's *global* state. We could rewrite our `isOldEnough()` function to remove the dependency upon a global variable, but it wouldn't help much. One attempt is as follows:

```
// isOldEnough.js

const isOldEnough2 = (birthYear: number): boolean =>
  birthYear <= new Date().getFullYear() - 18;

console.log(isOldEnough2(1960)); // true
console.log(isOldEnough2(2010)); // false
```

A problem has been removed—the new `isOldEnough2()` function is now safer. Also, as long as you don't use it near midnight just before New Year's Day, it will consistently return the same results, so you could say—paraphrasing the *Ivory Soap* slogan from the 19th century—that it's about *99.44% pure*; however, an inconvenience remains: how would you test it? If you were to write some tests that worked fine today, they'd start to fail next year. We'll have to work a bit to solve this, and we'll see how later.

Several other functions that are also impure are those that cause I/O. If a function gets input from a source (a web service, the user themself, a file, or some other source), then the result may obviously vary. You should also consider the possibility of an I/O error, so the very same function, calling the same service or reading the same file, might at some point fail for reasons outside its control (you should assume that your filesystem, database, socket, and so on could be unavailable, and thus a given function call might produce an error instead of the expected constant, unvarying, answer).

Even having a pure output and a generally safe statement (such as a `console.log()`) that doesn't change anything internally (at least in a visible way) causes some side effects because the user does see a change: namely, the produced output.

Does this imply that we won't ever be able to write a program that requires random numbers, handles dates, performs I/O, and also uses pure functions? Not at all—but it does mean that some functions won't be pure, and they will have some disadvantages that we will have to consider; we'll return to this in a bit.

Advantages of pure functions

The main advantage of using pure functions is that they don't have any side effects. When you call a pure function, you don't need to worry about anything other than which arguments you are passing to it. Also, more to the point, you can be sure that you will not cause any problems or break anything else because the function will only work with whatever you give it and not with outside sources. But this is not their only advantage. Let's learn more in the following sections.

Order of execution

Another way of looking at what we have been saying in this chapter is to see pure functions as robust. You know that their execution—in whichever order—won't ever impact the system. This idea can be extended further: you could evaluate pure functions in parallel, with the assurance that results wouldn't vary from what you would get in a single-threaded execution. (JavaScript doesn't provide Java-like threads, but we can make do, more or less, with workers. We'll cover this topic in *Chapter 5, Programming Declaratively*.)

Another consideration to keep in mind when you work with pure functions is that there's no explicit need to specify the order in which they should be called. If you work with mathematics, an expression such as `f(2)+f(5)` is always the same as `f(5)+f(2)`; this is called the *commutative property*.

However, when you deal with impure functions, that can be false, as shown in the following purposefully written tricky function:

```
// tricky.ts

let mult = 1;
const f = (x: number): number => {
  mult = -mult;
  return x * mult;
};

console.log(f(2) + f(5)); //  3
console.log(f(5) + f(2)); // -3
```

With impure functions such as the previous one, you cannot assume that calculating `f(3)+f(3)` would produce the same result as `2*f(3)` or that `f(4)-f(4)` would actually be zero; check it out for yourself... Common mathematical properties, down the drain!

Why should you care? When writing code, willingly or not, you always keep in mind those properties you learned about, such as the commutative property. So, while you might think that both expressions should produce the same result and code accordingly, you may be in for a surprise when using impure functions, with hard-to-find bugs that are difficult to fix.

Memoization

Since the output of a pure function for a given input is always the same, you can cache the function results and avoid a possibly costly recalculation. This process, which implies evaluating an expression only the first time and caching the result for later calls, is called **memoization**.

We will return to this idea in *Chapter 6*, *Producing Functions*, but let's look at an example done by hand. The Fibonacci sequence is always used for this example because of its simplicity and hidden calculation costs. This sequence is defined as follows:

- For *n*=0, fib(*n*)=0
- For *n*=1, fib(*n*)=1
- For *n*>1, fib(*n*)=fib(*n*-2)+fib(*n*-1)

Fibonacci who?

Fibonacci's name actually comes from *filius Bonacci* or *son of Bonacci*. He is best known for having introduced the usage of digits 0-9 as we know them today, instead of the cumbersome Roman numbers. He derived the sequence named after him as the answer to a puzzle involving rabbits! You can read more about it, and Fibonacci's life in general, at `en.wikipedia.org/wiki/Fibonacci_number#History` or `plus.maths.org/content/life-and-numbers-fibonacci`.

If you run the numbers, the sequence starts with 0, then 1, and from that point onward, each term is the sum of the two previous ones: 1 again, then 2, 3, 5, 8, 13, 21, 34, 55, and so on. Programming this series using recursion is simple; we'll revisit this example in *Chapter 9*, *Designing Functions*. The following code, a direct translation of the definition, will do—and see *Question 4.4* for an alternative:

```
// fibonacci.ts

const fib = (n: number): number => {
  if (n == 0) {
    return 0;
  } else if (n == 1) {
    return 1;
  } else {
    return fib(n - 2) + fib(n - 1);
  }
};

console.log(fib(10)); // 55, a bit slowly
```

If you try out this function for growing values of `n`, you'll soon realize that there is a problem, and computation starts taking too much time. For example, I took timings (measured in milliseconds) at my machine and plotted them on a graph. Since the function is quite speedy, I had to run calculations 100 times for values of `n` between 0 and 40. Even then, the times for small values of `n` were really tiny; it was only from 25 onward that I got interesting numbers.

The chart (see *Figure 4.1*) shows exponential growth, which bodes ill:

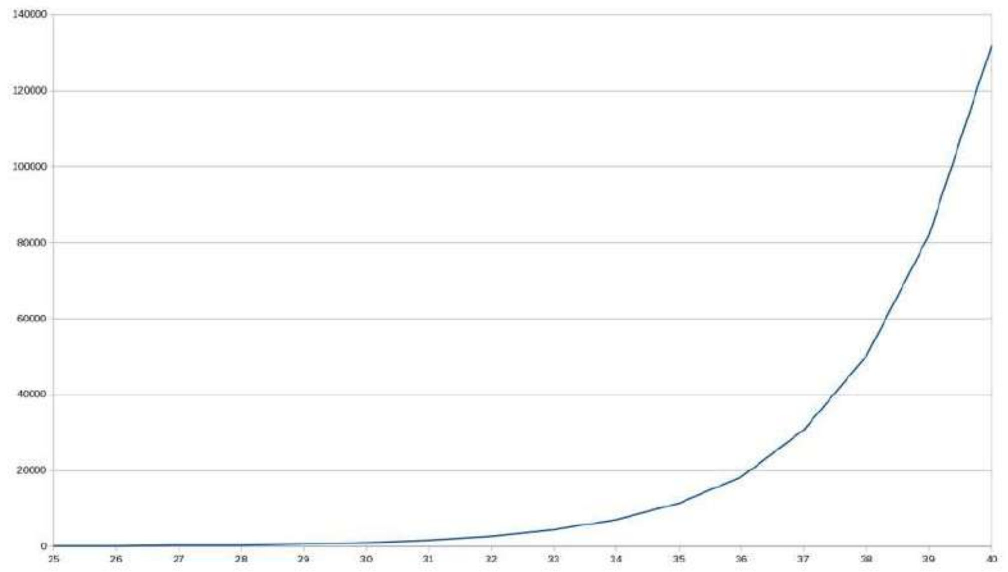


Figure 4.1 – Calculation times for the fib() recursive function go up exponentially

If we draw a diagram of all the calls required to calculate `fib(6)`, you'll notice the problem:

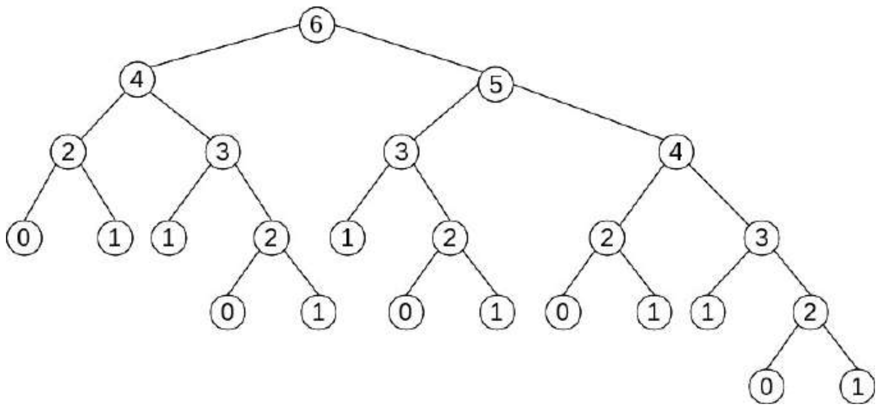


Figure 4.2 – The calculations needed for fib(6) show lots of duplication

Each node represents a call to compute `fib(n)`. We note the value of `n` in the node. Every call, except those for `n`=0 or `n`=1, requires further calls, as you can see in *Figure 4.2*.

The reason for the increasing delays becomes obvious: for example, the calculation for `fib(2)` was repeated on four different occasions, and `fib(3)` was itself calculated three times. Given that our function is pure, we could have stored the calculated values to avoid running the numbers over and over again. A possible version, using a cache array for previously calculated values, would be as follows:

```
// continued...

const cache: number[] = [];

const fib2 = (n: number): number => {
  if (cache[n] === undefined) {
    if (n === 0) {
      cache[0] = 0;
    } else if (n === 1) {
      cache[1] = 1;
    } else {
      cache[n] = fib2(n - 2) + fib2(n - 1);
    }
  }

  return cache[n];
};

console.log(fib2(10)); // 55, as before, but more quickly!
```

Initially, the `cache` array is empty. Whenever we need to calculate the value of `fib2(n)`, we check whether it was already calculated beforehand. If that's not true, we do the calculation, but with a twist: instead of immediately returning the value, we first store it in the cache and then return it. This means that no calculation will be done twice: after we have calculated `fib2(n)` for a particular `n` value, future calls will not repeat the procedure and will return the earlier evaluated result.

A few short notes:

- We memoized the function by hand, but we can do it with a higher-order function. We'll see this later in *Chapter 6*, *Producing Functions*. It is perfectly possible to memoize a function without having to change or rewrite it.
- Using a global `cache` variable isn't a very good practice; we could have used an IIFE and a closure to hide `cache` from sight—do you see how? (Also, see *Question 4.3* at the end of this chapter.) The `myCounter()` example in the *Immediate invocation* section of *Chapter 3, Starting Out with Functions,* shows how.

- Of course, you will be constrained by the available cache space, and it's possible you could eventually crash your application by eating up all available RAM. Resorting to external memory (a database, a file, or a cloud solution) would probably eat up all the performance advantages of caching. There are some standard solutions (involving eventually deleting items from the cache), but they are beyond the scope of this book.

Of course, you don't need to do this for every pure function in your program. You'd do this sort of optimization only for frequently called functions that take a significant amount of time; otherwise, the added cache management time would cost more than what you expected to save!

Self-documentation

Pure functions have another advantage. Since everything the function needs to work with is given to it through its parameters, with no hidden dependency whatsoever, when you read its source code, you have all you need to understand its objective.

An extra advantage: knowing that a function doesn't access anything beyond its parameters makes you more confident in using it since you won't be accidentally producing a side effect; the only thing the function will accomplish is what you already learned through its documentation.

Unit tests (which we'll cover in the next section) also work as documentation because they provide examples of what the function returns when given certain arguments. Most programmers will agree that the best kind of documentation is full of examples, and each unit test can be considered such a sample case.

Testing

Yet another advantage of pure functions—and one of the most important ones—has to do with unit testing. Pure functions have a single responsibility: producing their output in terms of their input. So, when you write tests for pure functions, your work is greatly simplified because there is no context to consider and no state to simulate.

You can focus on providing inputs and checking outputs because all function calls can be reproduced in isolation, independently from the rest of the world.

We have seen several aspects of pure functions. Let's move on, learn about impure functions a bit, and finish by testing both pure and impure functions.

Impure functions

If you decided to entirely forgo all kinds of side effects, then your programs would only be able to work with hardcoded inputs and wouldn't be able to show you the calculated results! Similarly, most web pages would be useless: you wouldn't be able to make web service calls or update the DOM; you'd only have static pages. And your Node code would be really useless for server-side work, as it wouldn't be able to perform any I/O.

Reducing side effects is a good goal in FP, but we shouldn't go overboard! So, let's think of how to avoid using impure functions, if possible, and how to deal with them if not, looking for the best way to contain or limit their scope.

Avoiding impure functions

Earlier in this chapter, we saw the more common reasons for using impure functions. Let's now consider how we can reduce the number of impure functions, even if doing away with all of them isn't really feasible. Basically, we'll have two methods for this:

- Avoiding the usage of state
- Using a programming pattern, **injection**, to control impurities

Avoiding the usage of state

With regard to the usage of the global state—both getting and setting it—the solution is well known. The key points to this are as follows:

- Provide whatever is needed of the global state to the function as arguments
- If the function needs to update the state, it shouldn't do it directly, but instead produce a new version of the state and return it
- It should be the caller's responsibility to take the returned state, if any, and update the global state

This is the technique that Redux uses for its reducers. (We saw this in the *What FP is not* section of *Chapter 1, Becoming Functional*, and the *Functions as objects* section of *Chapter 3, Starting Out with Functions*.) The signature for a reducer is `(previousState, action) => newState`, meaning that it takes a state and an action as parameters and returns a new state as the result. Most specifically, the reducer is not supposed to change the `previousState` argument, which must remain untouched (we'll learn more about this in *Chapter 10*, *Ensuring Purity*).

For our first version of the `isOldEnough()` function, which used a global `limitYear` variable, the change is simple enough: we have to provide `limitYear` as a parameter for the function. With this change, it will become pure since it will produce its result by only using its parameters.

Even better, we should provide the current year and let the function do the math instead of forcing the caller to do so. Our newer version of the adult age test could then be as follows:

```
// isOldEnough.ts

const isOldEnough3 = (
  birthYear: number,
  currentYear: number
): boolean => birthYear <= currentYear - 18;
```

Obviously, we'll have to change all the calls to provide the required `currentYear` argument (we could also use partial application, as we will see in *Chapter 7*, *Transforming Functions*). The responsibility for the value of `currentYear` remains outside of the function, as before, but we have managed to avoid a defect:

```
console.log(isOldEnough3(1960, 2022)); // true
console.log(isOldEnough3(2010, 2022)); // false
```

We can also apply this solution to our peculiar `roundFix()` function. As you will recall, the function worked by accumulating the differences caused by rounding and deciding whether to round up or down depending on the sign of that accumulator. We cannot avoid using that state, but we can split off the rounding part from the accumulating part. Our original code (with fewer comments, no logging, and using arrow functions throughout) would be as follows:

```
// roundFix.ts

const roundFix1 = (() => {
  let accum = 0;
  return (n: number): number => {
    const nRounded =
      accum > 0 ? Math.ceil(n) : Math.floor(n);
    accum += n - nRounded;
    return nRounded;
  };
})();
```

The newer version (see *Question 4.6* for more about this) would have two parameters:

```
// continued...

const roundFix2 = (accum: number, n: number) => {
  const nRounded = accum > 0 ? Math.ceil(n) : Math.floor(n);
  accum += n - nRounded;
  return { accum, nRounded };
};
```

How would you use this function? Initializing the accumulator, passing it to the function, and updating it afterward are now the responsibility of the caller code. You would have something like the following:

```
let accum = 0;

// ...some other code...

let { a, r } = roundFix2(accum, 3.1415);
accum = a;
console.log(accum, r); // 0.1415 3
```

Note the following:

- The `accum` value is now part of the global state of the application
- Since `roundFix2()` needs it, its value is provided in each call
- The caller is responsible for updating the global state, not `roundFix2()`

Spreading, once more

Note the usage of the destructuring assignment to allow a function to return more than a value and easily store each one in a different variable. For more on this, go to `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Operators/Destructuring_assignment`. For an alternative see *Question 4.7*.

This new `roundFix2()` function is totally pure and can be easily tested. If you want to hide the accumulator from the rest of the application, you could still use a closure, as we have seen in other examples, but that would again introduce impurity in your code—your call!

Injecting impure functions

If a function becomes impure because it needs to call another function that is itself impure, a way around this problem is to inject the required function in the call. This technique provides more flexibility in your code and allows for easier future changes and less complex unit testing.

Let's consider the random filename generator function that we saw earlier. The problematic part of this function is its usage of `getRandomLetter()` to produce the filename:

```
// random.ts

const getRandomFileNae = (fileExtension = ""): string => {
  …
```

```
    namePart[i] = getRandomLetter();
  ...

};
```

A way to solve this is to replace the impure function with an injected external one; we must now provide a `randomLetterFunc()` argument for our random filename function to use:

```
// continued...

const getRandomFileName2 = (
  fileExtension = "",
  randomLetterFunc: () => string
): string => {
  const NAME_LENGTH = 12;

  const namePart = new Array(NAME_LENGTH);
  for (let i = 0; i < NAME_LENGTH; i++) {
    namePart[i] = randomLetterFunc();
  }
  return namePart.join("") + fileExtension;
};
```

Now, we have removed the inherent impurity from this function. If we want to provide a predefined pseudorandom function that returns fixed, known values, we can easily unit-test this function; we'll see how in the following examples. The usage of the function will change, and we would have to write the following:

```
let fn = getRandomFileName2(".pdf", getRandomLetter);
```

If this bothers you, you may want to provide a default value for the `randomLetterFunc` parameter as follows:

```
// continued...

const getRandomFileName3 = (
  fileExtension = "",
  randomLetterFunc: () => string = getRandomLetter
): string => {
  const NAME_LENGTH = 12;
  const namePart = new Array(NAME_LENGTH);
  for (let i = 0; i < NAME_LENGTH; i++) {
    namePart[i] = randomLetterFunc();
  }
  return namePart.join("") + fileExtension;
};
```

You can also solve this using **partial application**, as we'll see in *Chapter 7*, *Transforming Functions*.

This hasn't actually avoided the usage of impure functions. Normally, you'll call `getRandomFileName()` by providing it with the random letter generator we wrote, so it will behave as an impure function. However, if for testing purposes you provide a function that returns predefined (that is, not random) letters, you'll be able to test it as if it were pure much more easily.

But what about the original problem function, `getRandomLetter()`? We can apply the same trick and write a new version, such as the following, which will have an argument that will produce random numbers:

```
// random.ts

const getRandomLetter2 = (
  getRandomNum: () => number = Math.random.bind(Math)
): string => {
  const min = "A".charCodeAt(0);
  const max = "Z".charCodeAt(0);
  return String.fromCharCode(
    Math.floor(getRandomNum() * (1 + max - min)) + min
  );
};
```

We should change `getRandomFileName3()` to call `getRandomLetter2()`. If it calls it without providing any parameters, `getRandomLetter2()` will behave in its expected random ways. But if we want to test whether `getRandomFileName3()` does what we wanted, we can run it with an injected function that will return whatever we decide, letting us test it thoroughly.

Bind them all

For the default of `getRandomNum`, we wrote `Math.random.bind(Math)`, as explained in the *Working with methods* section of the previous chapter. The alternative (arguably clearer for some people) is `() => Math.random()`; we'll use it in the *Is your function pure?* section later in this chapter, just for variety.

Let's finish this section with a more complex case: what happens with a function with multiple impurities? For instance, we could be working on a backend `calculateDebt()` service that calculates a person's debt, given their `id`. To do that, we could access a database, get the list of the person's invoices, and then call some service to get the amount owed in each invoice; the sum of those amounts would be the calculated debt. A skeleton of such a function could be as follows—and I'm using plain JavaScript to omit unnecessary details:

```
// calculateDebt.js

const calculateDebt = async (id) => {
  // access a database to get a list of invoices
  const listOfInvoices =
    await mySqlConn.query(/* SQL query to get invoices */);

  // call a remote service to learn what's owed for each
  const owedAmounts =
    await axios.get(/* API call to get owed amounts */);

  const calculatedDebt = owedAmounts.reduce(
    (x, y) => x + y,
    0
  );
  return calculatedDebt;
};
```

(If `calculatedDebt = wedAmounts.reduce(...)` is foreign to you, see the *Summing an array* section of *Chapter 5, Programming Declaratively*.)

We cannot easily test such a function because it depends on the availability of a database and another service. To *purify* it, we need to inject two functions: one to get data from a database and another to query a service. The purified function would become this:

```
// continued...

const calculateDebt2 = async (
  id,
  { getInvoices, getOwedAmounts } =
    { getInvoicesFromDb, getOwedAmountFromAPI }
) => {
  const listOfInvoices = await getInvoices(id);
```

```
    const owedAmounts = await getOwedAmounts(listOfInvoices);
    const calculatedDebt = owedAmounts.reduce(
      (x, y) => x + y,
      0
    );

    return calculatedDebt;
  };
```

In this code, `getInvoicesFromDb()` and `getOwedAmountFromAPI()` would be the functions that do the DB access and API call. Our `calculateDebt2()` function now doesn't know (or need to know) the details of how to access and work with the DB or the other service; that's a better software design.

Now, the function has two parameters: `id` (as before) and an optional object with the two functions to be injected. In regular use, we wouldn't supply the second parameter, and the function accesses the DB and calls the API as needed. But here's the point: for testing purposes, we inject an object with two mock functions and are then able to write simple tests. (If you are wondering why we injected an object, see *Question 4.8*.)

An extra detail: thorough real-world testing of functions is usually hard to achieve. For instance, how do you simulate a dropped connection or a failed service call? With injection, that's no problem; we can easily provide a mock that will return wrong values, throw an exception, and do anything else you need for your complete testing.

Using injection to avoid impurities is very important and has a broad spectrum of applications for other problems. For example, instead of having a function directly access the DOM, we can provide it with injected functions that would do this. For testing purposes, it would be simple to verify that the tested function does what it needs to do without really interacting with the DOM (of course, we'd have to find another way to test those DOM-related functions). This can also apply to functions that need to update the DOM, generate new elements, and do all sorts of manipulations—you use some intermediary functions. We'll even apply injection in *Chapter 11, Implementing Design Patterns,* to derive a better system architecture, so it's a powerful, key concept.

Is your function pure?

Let's end this section by considering an important question: can you ensure that a function is truly pure? To show the difficulties of this task, we'll go back to the simple `sum3()` function that we saw in the *Spread* section of *Chapter 1*, *Becoming Functional* , just rewritten to use arrow functions for brevity. Would you say that this function is pure? It certainly looks like it!

```
// sum3.ts (in chapter 3)
```

```
const sum3 = (x: number, y: number, z: number): number =>
  x + y + z;
```

Let's see: the function doesn't access anything but its parameters, doesn't even try to modify them (not that it could (or could it?)), doesn't perform any I/O, or work with any of the impure functions or methods that we mentioned earlier. What could go wrong?

The answer has to do with checking your assumptions. For example, who says the arguments for this function should be numbers? In plain JavaScript, we could call it with, say, strings, but we're now using TypeScript, and it's supposed to check that, right? And even if passing strings to the function, you might ask yourself: *OK, they could be strings, but the function would still be pure, wouldn't it?* For an (assuredly evil!) answer to that, see the following code:

```
// sum3.trick.ts

const x = {} as number;
x.valueOf = () => Math.random();

const y = 1;
const z = 2;

console.log(sum3(x, y, z)); // 3.2034400919849431
console.log(sum3(x, y, z)); // 3.8537045249277906
console.log(sum3(x, y, z)); // 3.0833258308458734
```

Evil coding!

We assigned a new function to the `x.valueOf()` method to make an object look like a number. We also lied when saying `x = {} as number`; otherwise, TypeScript would have objected that you were passing an object where a number was expected.

Well, `sum3()` ought to be pure, but that actually depends on whichever parameters you pass to it; you can make a pure function behave impurely! You might console yourself by thinking that surely no one would pass such arguments, but edge cases are usually where bugs reside. But you need not resign yourself to abandoning the idea of pure functions. As we see, you can even con TypeScript into accepting wrong data types, so you can never be totally sure that your code is always pure!

Throughout these sections, we have gone through the characteristics of pure and impure functions. Let's finish the chapter by looking at how we can test these sorts of functions.

Testing – pure versus impure

We have seen how pure functions are conceptually better than impure ones, but we cannot set out on a crusade to vanquish all impurities from our code. First, no one can deny that side effects can be useful, or at least unavoidable: you will need to interact with the DOM or call a web service, and there are no ways to do this in a pure way. So, rather than bemoaning the fact that you have to allow for impurity, try to structure your code to isolate the impure functions and let the rest of your code be the best it can possibly be.

With this in mind, you'll have to be able to write unit tests for all kinds of functions, pure or impure. Writing unit tests is different, in terms of difficulty and complexity, for pure and impure functions. While coding tests for the former is usually quite simple and follows a basic pattern, the latter usually requires scaffolding and complex setups. So, let's finish this chapter by seeing how to go about testing both types of functions.

Testing pure functions

Given the characteristics of pure functions that we have already described, most of your unit tests could be the following:

- Calling the function with a given set of arguments
- Verifying that the results match what you expected

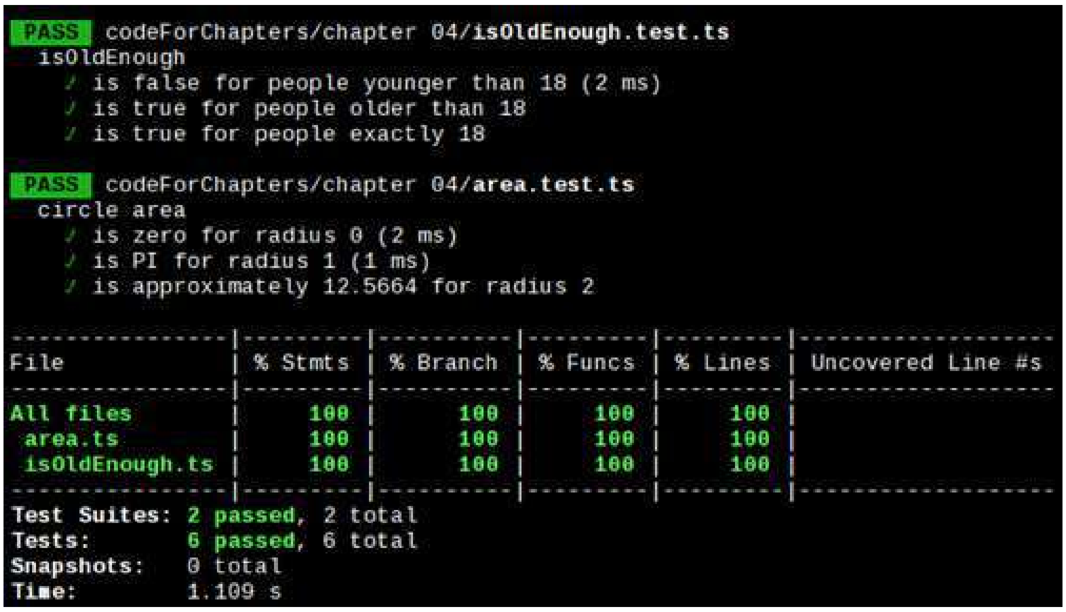
Let's start with a couple of simple examples. Testing the `isOldEnough()` function would have been more complex than we needed for the version that required access to a global variable. On the other hand, the last version, `isOldEnough3()`, which didn't require anything because it received two parameters, is simple to test:

```
// isOldEnough.test.ts

describe("isOldEnough", function () {
  it("is false for people younger than 18", () => {
    expect(isOldEnough3(2010, 2022)).toBe(false);
  });

  it("is true for people older than 18", () => {
    expect(isOldEnough3(1960, 2022)).toBe(true);
  });

  it("is true for people exactly 18", () => {
    expect(isOldEnough3(2004, 2022)).toBe(true);
  });
});
```

Testing another of the pure functions we wrote is equally simple, but we must be careful because of precision considerations. If we test the `circleArea` function, we must use the Jest `toBeCloseTo()` matcher, which allows for approximate equality when dealing with floating-point numbers. (See *Question 4.9* for more on math in JavaScript.) Other than this, the tests are just about the same—call the function with known arguments and check the expected results:

```
// area.test.ts

describe("circle area", function () {
  it("is zero for radius 0", () => {
    const area = circleArea(0);
    expect(area).toBe(0);
  });

  it("is PI for radius 1", () => {
    expect(circleArea(1)).toBeCloseTo(Math.PI);
  });

  it("is approximately 12.5664 for radius 2", () =>
    expect(circleArea(2)).toBeCloseTo(12.5664));
});
```

No difficulty whatsoever! (I wrote the three tests in different styles on purpose, just for variety.) The test run reports success for both suites (see *Figure 4.3*):



```
 PASS  codeForChapters/chapter 04/isOldEnough.test.ts
  isOldEnough
    ✓ is false for people younger than 18 (2 ms)
    ✓ is true for people older than 18
    ✓ is true for people exactly 18

 PASS  codeForChapters/chapter 04/area.test.ts
  circle area
    ✓ is zero for radius 0 (2 ms)
    ✓ is PI for radius 1 (1 ms)
    ✓ is approximately 12.5664 for radius 2

----------------|---------|----------|---------|---------|-------------------
File            | % Stmts | % Branch | % Funcs | % Lines | Uncovered Line #s
----------------|---------|----------|---------|---------|-------------------
All files       |     100 |      100 |     100 |     100 |
 area.ts        |     100 |      100 |     100 |     100 |
 isOldEnough.ts |     100 |      100 |     100 |     100 |
----------------|---------|----------|---------|---------|-------------------
Test Suites: 2 passed, 2 total
Tests:       6 passed, 6 total
Snapshots:   0 total
Time:        1.109 s
```

Figure 4.3 – A successful test run for a pair of pure functions

We don't have to worry about pure functions; let's move on to the impure ones we dealt with by transforming them into pure equivalents.

Testing purified functions

When we considered the following `roundFix()` special function that required us to use the state to accumulate the differences due to rounding, we produced a new version by providing the current state as an added parameter and by having the function return two values—the rounded one and the updated state:

```
// roundFix.ts

const roundFix2 = (accum: number, n: number) => {
  const nRounded = accum > 0 ? Math.ceil(n) :
    Math.floor(n);
  accum += n - nRounded;
  return { accum, nRounded };
};
```

This function is now pure, but testing it requires validating not only the returned values but also the updated states. We can base our tests on the experiments we did previously. Once again, we have to use `toBeCloseTo()` for dealing with floating-point numbers (and see *Question 4.10* for more on this), but we can use `toBe()` with integers, which produces no rounding errors. We could write our tests as follows:

```
// roundFix.test.ts

describe("roundFix2", function () {
  it("rounds 3.14159->3 if differences are 0", () => {
    const { accum, nRounded } = roundFix2(0.0, 3.14159);
    expect(accum).toBeCloseTo(0.14159);
    expect(nRounded).toBe(3);
  });

  it("rounds 2.71828->3 if differences are 0.14159", () => {
    const { accum, nRounded } = roundFix2(0.14159,
      2.71828);
    expect(accum).toBeCloseTo(-0.14013);
    expect(nRounded).toBe(3);
  });

  it("rounds 2.71828->2 if differences are -0.14013", () => {
    const { accum, nRounded } = roundFix2(
      -0.14013,
      2.71828
    );
    expect(accum).toBeCloseTo(0.57815);
    expect(nRounded).toBe(2);
  });

  it("rounds 3.14159->4 if differences are 0.57815", () => {
    const { accum, nRounded } = roundFix2(0.57815,
      3.14159);
    expect(accum).toBeCloseTo(-0.28026);
    expect(nRounded).toBe(4);
  });
});
```

We included several cases, with positive, zero, or negative accumulated differences, and checked whether they rounded up or down on each occasion. We could certainly go further by rounding negative numbers, but the idea is clear: if your function takes the current state as a parameter and updates it, the only difference with the pure functions' tests is that you will also have to test whether the returned state matches your expectations.

Let's now consider an alternative way of testing for our *purified* `getRandomLetter2()` function. This is simple: you have to provide a function that produces random numbers. (This kind of function, in testing parlance, is called a stub.) There's no limit to the complexity of a stub, but you'll want to keep it simple.

Based on our knowledge of the workings of the function, we can then do some tests to verify that low values produce an `"A"` output and values close to 1 produce a `"Z"` output so that we can have a little confidence that no extra values are produced. We should also test that a middle value (around 0.5) should generate a letter around the middle of the alphabet. However, this kind of test is not very good—if we implemented `getRandomLetter2()` in another way, it might work perfectly well but not pass this test! Our tests could be written as follows:

```
// random.test.ts

describe("getRandomLetter2", function () {
  it("returns A for values close to 0", () => {
    const letterSmall = getRandomLetter2(() => 0.0001);
    expect(letterSmall).toBe("A");
  });

  it("returns Z for values close to 1", () => {
    const letterBig = getRandomLetter2(() => 0.99999);
    expect(letterBig).toBe("Z");
  });

  it("returns middle letter for values around 0.5", () => {
    const letterMiddle = getRandomLetter2(() =>
      0.49384712);
    expect(letterMiddle > "G").toBeTruthy();
    expect(letterMiddle < "S").toBeTruthy();
  });
  it("returns ascending letters for ascending #s", () => {
    const letter1 = getRandomLetter2(() => 0.09);
    const letter2 = getRandomLetter2(() => 0.22);
    const letter3 = getRandomLetter2(() => 0.60);
    expect(letter1 < letter2).toBeTruthy();
    expect(letter2 < letter3).toBeTruthy();
  });
});
```

Testing our filename generator can be done similarly, by using stubs. We can provide a simple stub, `f()`, that will return the letters of `"SORTOFRANDOM"` in sequence (this function is quite impure; can you see why?). So, we can verify that the returned filename matches the expected name and a couple more properties of the returned filename, such as its length and extension. Our test could then be written as follows:

```
// continued...

describe("getRandomFileName3", function () {
  let a: string[] = [];
  const f = () => a.shift() as string;

  beforeEach(() => {
    a = "SORTOFRANDOM".split("");
  });

  it("uses the given letters for the file name", () => {
    const fileName = getRandomFileName3("", f);
    expect(fileName.startsWith("SORTOFRANDOM")).toBe(true);
  });

  it("includes right extension, has right length", () => {
    const fileName = getRandomFileName3(".pdf", f);
    expect(fileName.endsWith(".pdf")).toBe(true);
    expect(fileName.length).toBe(16);
  });
});
```

Testing *purified* impure functions is the same as testing originally pure functions. Now, we need to consider some cases of truly impure functions because, as we said, it's quite certain that at some time or another, you'll have to use such functions.

Testing impure functions

For starters, we'll return to our original `getRandomLetter()` function. With insider knowledge about its implementation (this is called **white-box testing**, as opposed to **black-box testing**, where we know nothing about the function's code itself), we can *spy on* (a Jest expression) on the `Math.random()` method and set a mock function that will return whichever values we desire.

We can revisit some of the test cases we went through in the previous section. In the first case, we set `Math.random()` to return 0.0001 (and test that it was actually called) and we also check that the final return is `"A"`. In the second case, just for variety, we set things up so that `Math.random()` will be called twice, returning two different values. We also verify that both results are `"Z"`. Our revisited tests could look as follows:

```
// continued...

describe("getRandomLetter", function () {
  afterEach(() => {
    // so count of calls to Math.random will be OK
    jest.restoreAllMocks();
  });

  it("returns A for values ~ 0", () => {
    jest.spyOn(Math, "random").mockReturnValue(0.00001);
    const letterSmall = getRandomLetter();
    expect(Math.random).toHaveBeenCalled();
    expect(letterSmall).toBe("A");
  });

  it("returns Z for values ~ 1", () => {
    jest
      .spyOn(Math, "random")
      .mockReturnValueOnce(0.988)
      .mockReturnValueOnce(0.999);
    const letterBig1 = getRandomLetter();
    const letterBig2 = getRandomLetter();
    expect(Math.random).toHaveBeenCalledTimes(2);
    expect(letterBig1).toBe("Z");
    expect(letterBig2).toBe("Z");
  });

  it("returns middle letter for values ~ 0.5", () => {
    jest.spyOn(Math, "random").mockReturnValue(0.49384712);
    const letterMiddle = getRandomLetter();
    expect(Math.random).toHaveBeenCalledTimes(1);
    expect(letterMiddle > "G").toBeTruthy();
    expect(letterMiddle < "S").toBeTruthy();
  });
});
```

(Of course, you wouldn't go around inventing whatever tests came into your head. In all likelihood, you'll work from the description of the desired `getRandomLetter()` function, which was written before you started to code or test it. In our case, I'm making do as if that specification did exist, and it pointedly said—for example—that values close to 0 should produce an `"A"` output, values close to 1 should return `"Z"`, and the function should return ascending letters for ascending random values.)

Now, how would you test the original `getRandomFileName()` function, the one that called the impure `getRandomLetter()` function? That's a much more complicated problem.

What kind of expectations do you have? You cannot know the results it will give, so you won't be able to write any `.toBe()` type of tests. What you can do is test for some properties of the expected results, and also, if your function implies randomness of some kind, you can repeat the tests as many times as you want so that you have a bigger chance of catching a bug. We could do some tests along the lines of the following code:

```
// continued...

describe("getRandomFileName+impure getRandomLetter", () => {
  it("generates 12 letter long names", () => {
    for (let i = 0; i < 100; i++) {
      expect(getRandomFileName().length).toBe(12);
    }
  });

  it("generates names with letters A to Z, only", () => {
    for (let i = 0; i < 100; i++) {
      const name = getRandomFileName();
      for (let j = 0; j < name.length; j++) {
        expect(name[j] >= "A" && name[j] <=
          "Z").toBe(true);
      }
    }
  });

  it("includes right extension if provided", () => {
    const fileName1 = getRandomFileName(".pdf");
    expect(fileName1.length).toBe(16);
    expect(fileName1.endsWith(".pdf")).toBe(true);
  });

  it("doesn't include extension if not provided", () => {
    const fileName2 = getRandomFileName();
    expect(fileName2.length).toBe(12);
    expect(fileName2.includes(".")).toBe(false);
  });
});
```

We are not passing any random letter generator function to `getFileName()`, so it will use the original, impure one. We ran some of the tests a hundred times, as extra insurance. Our tests check for the following:

- Filenames are 12 letters long
- Names only include letters "`A`" to "`Z`"
- Filenames include the provided extension
- If no extension is provided, none is included

Need for evidence

When testing code, always remember that *absence of evidence isn't evidence of absence*. Even if our repeated tests succeed, there is no guarantee that they won't produce an unexpected, hitherto undetected, error with some other random input.

Let's do another property test. Suppose we want to test a shuffling algorithm; we might decide to implement the Fisher–Yates version along the lines of the following code. (For more on this algorithm—including some pitfalls for the unwary programmer—see `en.wikipedia.org/wiki/Fisher-Yates_shuffle`.) As implemented, the algorithm is doubly impure: it doesn't always produce the same result (obviously!) and it modifies its input parameter:

```
// shuffle.test.ts

const shuffle = <T>(arr: T[]): T[] => {
  const len = arr.length;
  for (let i = 0; i < len - 1; i++) {
    let r = Math.floor(Math.random() * (len - i));
    [arr[i], arr[i + r]] = [arr[i + r], arr[i]];
  }
  return arr;
};

const xxx = [11, 22, 33, 44, 55, 66, 77, 88];
console.log(shuffle(xxx));
// [55, 77, 88, 44, 33, 11, 66, 22]
```

How could you test this algorithm? Given that the result won't be predictable, we can check for the properties of its output. We can call it with a known array and then test some properties—but see *Question 4.13* for an important detail:

```
// continued...

describe("shuffleTest", function () {
  it("shouldn't change the array length", () => {
    const a = [22, 9, 60, 12, 4, 56];
    shuffle(a);
    expect(a.length).toBe(6);
  });

  it("shouldn't change the values", () => {
    const a = [22, 9, 60, 12, 4, 56];
    shuffle(a);
    expect(a.includes(22)).toBe(true);
    expect(a.includes(9)).toBe(true);
    expect(a.includes(60)).toBe(true);
```

```
      expect(a.includes(12)).toBe(true);
      expect(a.includes(4)).toBe(true);
      expect(a.includes(56)).toBe(true);
    });
  });
```

We had to write the second part of the unit tests in that way because, as we saw, `shuffle()` modifies the input parameter. For tests for a different (and bad!) shuffling function, see *Question 4.14*.

Summary

In this chapter, we introduced the concept of pure functions and studied why they matter. We also saw the problems caused by side effects—one of the causes of impure functions—looked at some ways of purifying such impure functions, and finally, we saw several ways of performing unit tests for both pure and impure functions. With these techniques, you'll be able to favor using pure functions in your programming, and when impure functions are needed, you'll have some ways of using them in a controlled manner.

In *Chapter 5*, *Programming Declaratively*, we'll show other advantages of FP: how you can program in a declarative fashion at a higher level for more straightforward and robust code.

Questions

4.1 **Must return?**A simple, almost philosophical question: must pure functions always return something? Could you have a pure function that doesn't return anything?

4.2 **Well-specified return**: What would have happened if we had added the return type definition to `maxStrings()`?

```
const maxStrings = (a: string[]): string => a.sort().pop();
```

4.3 **Go for a closure**: As suggested in the *Memoization* section, use a closure to avoid needing a global `cache` array for the optimized `fib2()` function.

4.4 **Minimalistic function**: Functional programmers sometimes write code in a minimalistic way. Can you examine the following version of the Fibonacci function and explain whether it works, and if so, how?

```
// fibonacci.ts

const fib3 = (n: number): number =>
  n < 2 ? n : fib2(n - 2) + fib2(n - 1);
```

4.5 **A cheaper way**: The following version of the Fibonacci function is quite efficient, doesn't require memoization or caching, and doesn't require unnecessary or repeated computations. Can you see how? Here's a suggestion: try to calculate `fib4(6)` by hand and compare it with the example given earlier in the book:

```
// fibonacci.ts

const fib4 = (n: number, a = 0, b = 1): number =>
  n === 0 ? a : fib4(n - 1, b, a + b);
```

4.6 **Rounding type**: What's the type of the `roundFix2()` function? Even when TypeScript can work it out by itself (as in this case), I prefer spelling it out for extra checks.

4.7 **Tuples to go**: If we need to return more than one value from a function, we can return an array instead of an object. For better clarity, TypeScript allows using *tuples*, which are arrays of known length and data types. (See `www.typescriptlang.org/docs/handbook/2/objects.html#tuple-types` for more on this.) Rewrite `roundFix2()` so that it will return a tuple instead of a record. The input to this rewritten function could be two separate arguments or a single tuple argument.

4.8 **One injection or two?** Why is it better to inject an object with two functions rather than two separate functions? In other words, why not write something like the following?

```
const calculateDebt2 = async (
  id,
  getInvoices = getInvoicesFromDb,
  getOwedAmounts = getOwedAmountFromAPI
) => … ;
```

4.9 **JavaScript does math?** In the *Testing purified functions* section, we mentioned the need for `toBeCloseTo()` because of precision problems. A related question, often asked in job interviews, is *what will the following code output, and why?*

```
const a = 0.1;
const b = 0.2;
const c = 0.3;

if (a + b === c) {
  console.log("Math works!");
} else {
  console.log("Math failure?");
}
```

4.10 **Breaking laws**: Using `toBeCloseTo()` is practical but can cause problems. Some basic mathematics properties are as follows:

- A number should equal itself: for all numbers *a*, *a* should equal *a*
- If *a* equals *b*, then *b* should equal *a*
- If *a* equals *b*, and *b* equals *c*, then *a* should equal *c*
- If *a* equals *b*, and *c* equals *d*, then *a+c* should equal *b+d*, *a-c* should equal *b-d*, *a*c* should equal *b*d*, and *a/c* should equal *b/d*

Does `toBeCloseTo()` satisfy all these properties?

4.11 **Shuffling kinds**: Why did we need to use a generic type `<T>` in the definition of `shuffle()`?

4.12 **No return needed**: Given that `shuffle()` modifies the input array in place (a side effect!) we don't really need the final `return arr` line and could remove it. What would be the type definition of `shuffle()` then?

4.13. **A shuffle test**: How would you write unit tests for `shuffle()` to test whether it works correctly with arrays with repeated values? The tests we wrote are only valid for arrays with distinct values; can you see why?

4.14 **Popular, but wrong!** Many online articles suggest the following code as a way of shuffling. The idea is to sort the array, but, instead of using a correct comparison function to randomly return positive or negative values, these random comparisons should get the array in disorder. However, the idea is wrong and the algorithm is bad because it doesn't produce all possible outputs with equal probability. How can you check that?

```
const poorShuffle = (arr) =>
  arr.sort(() => Math.random() - 0.5);
```

4.15 **Shuffling by sorting**: Sorting and shuffling can be seen as opposite functions; one brings order, and the other produces disorder. However, there's a way to shuffle an array by sorting; can you figure out how? (And no, the answer is *not* the lousy algorithm shown in the previous question!) We are looking for an algorithm that can produce every possible output with the same probability, not favoring some outputs over others.

5

Programming Declaratively – A Better Style

Up to now, we haven't really been able to appreciate the possibilities of **functional programming** (**FP**) as it pertains to working in a higher-level, declarative fashion. In this chapter, we will correct this and start producing shorter, more concise, and easier-to-understand code, by using some **higher-order functions** (**HOFs**) —that is, functions that take functions as parameters, such as the following:

- `reduce()` and `reduceRight()` to apply an operation to a whole array, reducing it to a single result
- `map()` to transform one array into another by applying a function to each of its elements
- `flat()` to make a single array out of an array of arrays
- `flatMap()` to mix together mapping and flattening
- `forEach()` to simplify writing loops by abstracting the necessary looping code

We'll also be able to perform searches and selections with the following:

- `filter()` to pick some elements from an array
- `find()` and `findIndex()` to search for elements that satisfy a condition
- A pair of predicates, `every()` and `some()`, to check an array for a Boolean test

Using these functions will let you work more declaratively, and you'll see that your focus will shift to what you need to do and not so much to how it's going to be done; the dirty details are hidden inside our functions. Instead of writing a series of possibly nested loops, we'll focus on using functions as building blocks to specify our desired result.

We will use these functions to work with events in a declarative style, as we'll see in *Chapter 11*, *Implementing Design Patterns*, when we use the **observer** pattern. We will also be able to work in a *fluent* fashion, in which the output of a function becomes the input of the next one, a style we will look at later.

Transformations

The first set of operations that we are going to consider works on an array and processes it in the base of a function to produce certain results. There are several possible results: a single value with the `reduce()` operation, a new array with `map()`, or just about any kind of result with `forEach()`.

Caring about inefficiency

If you google around, you will find some articles declaring that these functions are inefficient because a loop done by hand can be faster. This, while possibly true, is practically irrelevant. Unless your code really suffers from speed problems and you can determine that the slowness derives from using these HOFs, trying to avoid them using longer code, with a higher probability of bugs, simply doesn't make much sense.

Let's start by considering the preceding list of functions in order, beginning with the most general of all, which, as we'll see, can even be used to emulate the rest of the transformations in this chapter!

Reducing an array to a value

Answer this question: how many times have you had to loop through an array, performing an operation (say, summing) to produce a single value (maybe the sum of all the array values) as a result? Probably many, many, many times. This kind of operation can usually be implemented functionally by applying `reduce()` and `reduceRight()`. Let's start with the former!

To fold or not to fold

Time for some terminology! In usual FP parlance, we speak of **folding operations**: `reduce()` is **foldl** (for *fold left*) or just plain **fold**, and `reduceRight()` is correspondingly known as **foldr**. In category theory terms, both operations are **catamorphisms**: the reduction of all the values in a container down to a single result.

The inner workings of the `reduce()` function are illustrated in *Figure 5.1*:

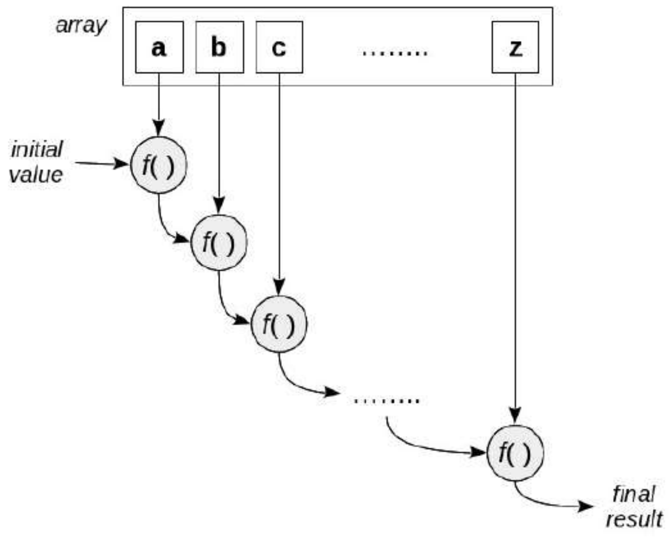


Figure 5.1 – The workings of the reduce() operation

See how `reduce()` traverses the array, applying a reducing function to each element and the accumulated value.

Why should you always try to use `reduce()` or `reduceRight()` instead of hand-coded loops? The following points might answer this question:

- All the aspects of loop control are automatically taken care of, so you don't even have the possibility of an off-by-one mistake
- The initialization and handling of the result values are also done implicitly
- Unless you work really hard at being impure and modifying the original array, your code will be free of side-effects

Now that we can `reduce()` an array, let's see some of its practical use cases.

Summing an array

The most common example of the application of `reduce()`, usually seen in all textbooks and on all web pages, is the summing of all of the elements of an array. So, to keep with tradition, let's start with precisely this example!

To reduce an array, you must provide a **dyadic** function (a function with two parameters; **binary** would be another name for that) and an initial value. In our case, the function will sum up its two arguments. Initially, the function will be applied to the provided initial value and the first element of the array. For us, the initial value to provide is a zero, and the first result will be the first element itself. Then, the function will be applied again, this time, to the result of the previous operation and the second element of the array, and so the second result will be the sum of the first two elements of the array. Progressing in this fashion along the whole array, the final result will be the sum of all its elements:

```
// sum.ts

const myArray = [22, 9, 60, 12, 4, 56];

const sum = (x: number, y: number): number => x + y;

const mySum = myArray.reduce(sum, 0); // 163
```

You don't actually need the sum definition—you could have just written `myArray.reduce((x,y) => x+y, 0)`—however, when written in this fashion, the meaning of the code is clearer: you want to reduce the array to a single value by `sum`-ming all its elements. (Would we be forgetting data types with this? No; TypeScript can deduce all the implied types on its own.)

Instead of writing out the loop, initializing a variable to hold the result of the calculations, and going through the array doing the sums, you just declare which operation should be performed. This is what I meant when I said that programming with functions such as those we'll see in this chapter allows you to work more declaratively, focusing on what rather than how.

You can also even use `reduce()` without providing the initial value: if you skip it, the first value of the array will be used, and the internal loop will start with the second element of the array; however, be careful if the array is empty and you skipped providing an initial value, as you'll get a runtime error! See `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Array/Reduce` for more details.

We can change the reducing function to see how it progresses through its calculations by just including a little bit of impurity!

```
// continued...

const sumAndLog = (x: number, y: number): number => {
  console.log(`${x}+${y}=${x + y}`);
  return x + y;
};
myArray.reduce(sumAndLog, 0);
```

The output would be as follows:

```
0+22=22
22+9=31
31+60=91
91+12=103
103+4=107
107+56=163
```

You can see how the first sum was done by adding the initial value (`0`) and the first element of the array, how that result was used in the second addition, and so on.

What's in a name?

Part of the reason for the *foldl* name seen previously (at least, its ending, *l*) should now be clear: the reducing operation proceeds from left to right, from the first element to the last. You may wonder, however, how it would have been named if it had been defined by a right-to-left language (such as Arabic, Hebrew, Farsi, or Urdu) speaker!

This example is common and well known; let's do something more complicated. As we'll find out, `reduce()` will be quite useful for many different objectives!

Calculating an average

Let's do a bit more work. How do you calculate the average of a list of numbers? If you were explaining this to someone, your answer would surely be something such as *sum all the elements in the list and divide that by the number of elements*. In programming terms, this is not a procedural description (you don't explain how to sum elements or traverse the array) but rather a declarative one since you say what to do, not how.

We can transform that description of the calculation into an almost self-explanatory function (In the *Averaging arrays* section of the next chapter, we'll extend arrays to include an averaging method, based on this code.):

```
// average.ts

const myArray = [22, 9, 60, 12, 4, 56];
const sum = (x: number, y: number): number => x + y;

const average = (arr: number[]): number =>
  arr.reduce(sum, 0) / arr.length;

console.log(average(myArray)); // 27.166667
```

The definition of `average()` follows what a verbal explanation would be: sum the elements of the array, starting from 0, and divide by the array's length—simpler: impossible!

Not-so-safe reducing

As we mentioned in the previous section, you could also have written `arr.reduce(sum)` without specifying the initial value (`0`) for the reduction; it's even shorter and closer to the verbal description of the required calculation. This, however, is less safe, because it would fail (producing a runtime error) should the array be empty. So, it's better to always provide the starting value.

This isn't, however, the only way of calculating the average. The reducing function also gets passed the index of the current position of the array as well as the array itself, so you could do something different from last time:

```
// continued...

const sumOrDivide = (
  sum: number,
  val: number,
  ind: number,
  arr: number[]
) => {
  sum += val;
  return ind == arr.length - 1 ? sum / arr.length : sum;
};

const average2 = (arr: number[]): number =>
  arr.reduce(sumOrDivide, 0);

console.log(myArray.reduce(average2, 0)); // 27.166667
```

Given the current index (and, obviously, having access to the array's length), we can do some trickery: in this case, our reducing `sumOrDivide()` function always sums values, but at the end of the array, it throws in a division so that the average value of the array will be returned. This is slick, but from the point of view of legibility, we can agree that the first version we saw was more declarative and closer to the mathematical definition than this second version.

Impurity warning!

Getting the array and the index means you could also turn the function into an impure one. Avoid this! Anybody who sees a `reduce()` call will automatically assume it's a pure function and will surely introduce bugs when using it.

This example and the previous one required calculating a single result, but it's possible to go beyond this and calculate several values in a single pass. Let's see how.

Calculating several values at once

What would you do if you needed to calculate two or more results instead of a single value? This would seem to be a case for providing a clear advantage for standard loops, but there's a trick that you can use. Let's yet again revisit the average calculation. We could do it the old-fashioned way by looping and simultaneously summing and counting all the numbers. Well, `reduce()` only lets you produce a single result, but there's no reason you can't return an object with as many fields as desired, as we did in the *Impure functions* section in *Chapter 4, Behaving Properly*:

```
// continued...

const average3 = (arr: number[]): number => {
  const sc = arr.reduce(
    (ac, val) => ({
      sum: val + ac.sum,
      count: ac.count + 1,
    }),
    { sum: 0, count: 0 }
  );
  return sc.sum / sc.count;
};

console.log(average3(myArray)); // 27.166667
```

Scrutinize the code carefully. We need two variables: one for the sum and one for the count of all numbers. We provide an object as the initial value for the accumulator, with two properties set to `0`, and our reducing function updates those two properties. After getting the final result with both `sum` and `count`, we divide to get the desired average.

By the way, there are options other than using an object. You could also produce any other data structure; let's see an example with a tuple. The resemblance is pretty obvious:

```
// continued...
```

```
const average4 = (arr: number[]) => {
  const sc = arr.reduce(
    (ac, val) => [ac[0] + val, ac[1] + 1],
    [0, 0]
  );
  return sc[0] / sc[1];
};

console.log(average4(myArray)); // 27.166667
```

To be frank, I think it's way more obscure than the solution with the object. Consider this an alternative (and not well-recommended) way of calculating many values simultaneously!

We have now seen several examples of the use of `reduce()`, so it's high time to meet a variant of it, `reduceRight()`, which works similarly.

Folding left and right

The complementary `reduceRight()` method works just as `reduce()` does, only starting at the end and looping until the beginning of the array. (Read more about `reduceRight()` at `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Array/ReduceRight`.) For many operations (such as the calculation of averages that we saw previously), this makes no difference, but there are some cases in which it will. See *Figure 5.2*.

We shall be seeing a clear case of this in *Chapter 8*, *Connecting Functions*; let's go with a simpler example here:

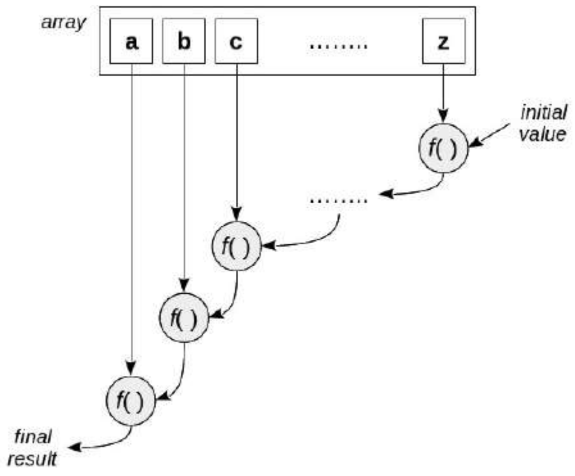


Figure 5.2 – The reduceRight() operation works the same way as reduce(), but in reverse order

Suppose that we want to implement a function to reverse a string. (And, obviously, also that we don't know that JavaScript already provides a `reverse()` method!) A solution could be to transform the string into an array by using `split()`, then reversing that array, and finally using `join()` to make it whole again:

```
// reverse.ts

const reverseString = (str: string): string => {
  const arr = str.split("");
  arr.reverse();
  return arr.join("");
};

console.log(reverseString("MONTEVIDEO"));  // OEDIVETNOM
```

This solution works (and yes, it can be shortened, but that's not the point here), but let's do it in another way, just to experiment with `reduceRight()`:

```
// continued...

const reverseString2 = (str: string): string =>
  str.split("").reduceRight((x, y) => x + y, "");

console.log(reverseString2("OEDIVETNOM")); // MONTEVIDEO
```

Note that we didn't need to specify data types for the reducing function; just like earlier in this chapter, TypeScript was able to figure them out. Also, if you like to re-use code, look at *Question 5.2*!

From the previous examples, you can also get an idea: if you first apply `reverse()` to an array and then use `reduce()`, the effect will be the same as if you had just applied `reduceRight()` to the original array. There is only one point to take into account: `reverse()` alters the given array, so you would be causing an unintended side-effect by reversing the original array! The only way out would be to first generate a copy of the array and only then do the rest. Too much work, so it's best to use `reduceRight()`!

However, we can draw another conclusion, showing a result we had foretold: it is possible, albeit more cumbersome, to use `reduce()` to simulate the same result as `reduceRight()`—and in later sections, we'll also use it to emulate the other functions in the chapter. Let's now move on to another common and powerful operation: **mapping**.

Applying an operation – map()

Processing lists of elements and applying some kind of operation to each of them is a quite common pattern in computer programming. Writing loops that systematically go through all the elements in an array or collection, starting at the first and looping until finishing with the last, and performing some kind of process on each of them is a basic coding exercise, usually learned in the first days of all programming courses. We already saw one such kind of operation in the previous section with `reduce()` and `reduceRight()`; let's now turn to a new one, called `map()`.

In mathematics, a **map** is a transformation of elements from a domain into elements of a codomain. For example, you might transform numbers into strings or strings into numbers, but also numbers into numbers, or strings into strings: the important point is that you have a way to transform an element of the first **kind** or **domain** (think **type**, if it helps) into an element of the second kind, or **codomain**. In our case, this will mean taking the elements of an array and applying a function to each of them to produce a new array. In more computer-like terms, the `map()` function transforms an array of inputs into an array of outputs.

Names, names, names…

Some more terminology: we would say that an array is a **functor** because it provides a mapping operation with some prespecified properties, which we shall see later. And, in category theory, which we'll talk about a little in *Chapter 12*, *Building Better Containers*, the mapping operation itself would be called a **morphism**.

The inner workings of the `map()` operation can be seen in *Figure 5.3*:

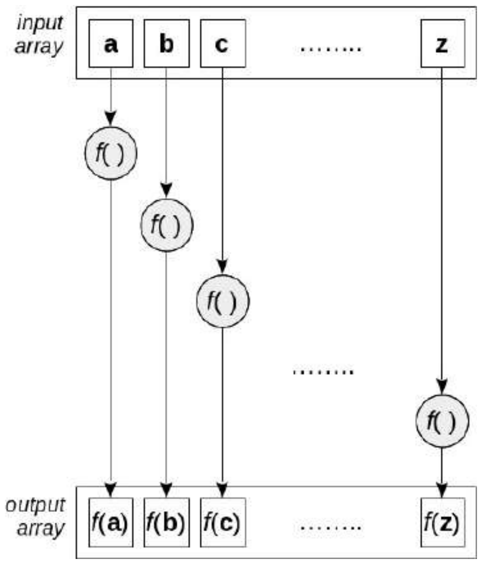


Figure 5.3 – The map() operation transforms each element of the input array by applying a mapping function

More maps available

The jQuery library provides a function, `$.map(array, callback)`, that is similar to the `map()` method. Be careful, though, because there are important differences. The jQuery function processes the undefined values of the array, while `map()` skips them. Also, if the applied function produces an array as its result, jQuery flattens it and adds each of its individual elements separately, while `map()` just includes those arrays in the result. Underscore, and Ramda also provide similar functions. Finally, JavaScript itself provides an alternative way of doing `map()`: check out the `Array.from()` method at `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Array/from` and pay special attention to its second argument!

What are the advantages of using `map()` over using a straightforward loop?

- First, you don't have to write any loops, so that's one less possible source of bugs
- Second, you don't even have to access the original array or the index position, even though they are there for you to use if you really need them
- Lastly, a new array is produced, so your code is pure (although, of course, if you really want to produce side effects, you can!)

There are only two caveats when doing this:

- Always return something from your mapping function. If you forget this, then you'll just produce an array filled with `undefined` values, because JavaScript always provides a default `return undefined` for all functions.
- If the input array elements are objects or arrays, and you include them in the output array, then JavaScript will still allow the original elements to be accessed.

Also, there's a restriction. In JavaScript, `map()` is basically available only for arrays (you can read more about this at `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Array/map`); however, in the *Extending current data types* section in *Chapter 12*, *Building Better Containers*, we will learn how to make it available for other basic types, such as numbers, Booleans, strings, and even functions. Also, libraries such as Lodash, Underscore, and Ramda, provide similar functionalities.

As we did earlier with `reduce()`, let's now look at some examples of the use of `map()` for common processes so that you'll better appreciate its power and convenience.

Extracting data from objects

Let's start with a simple example. Suppose that we have some geographic data (as shown in the following snippet) related to some South American countries and the coordinates (latitude and longitude) of their capitals. Let's say that we want to calculate the average position of those cities. (No, I don't have a clue why we'd want to do that.) How would we go about it?

```
// average.ts

const markers = [
  { name: "AR", lat: -34.6, lon: -58.4 },
  { name: "BO", lat: -16.5, lon: -68.1 },
  { name: "BR", lat: -15.8, lon: -47.9 },
  { name: "CL", lat: -33.4, lon: -70.7 },
  { name: "CO", lat:   4.6, lon: -74.0 },
  { name: "EC", lat:  -0.3, lon: -78.6 },
  { name: "PE", lat: -12.0, lon: -77.0 },
  { name: "PY", lat: -25.2, lon: -57.5 },
  { name: "UY", lat: -34.9, lon: -56.2 },
  { name: "VE", lat:  10.5, lon: -66.9 },
];
```

A lot of negativity?

In case you are wondering whether all the data is negative and if so, why, it's because the countries shown here are all south of the Equator and west of the Greenwich Meridian. However, some South American countries, such as Colombia and Venezuela, have positive latitudes. We'll return to these data a little later when we study the `some()` and `every()` methods.

We would want to use our `average()` function (which we developed earlier in this chapter), but there is a problem: that function can only be applied to an array of *numbers*, and what we have here is an array of *objects*. We can, however, do a trick: we can focus on calculating the average latitude (we can deal with the longitude later, in a similar fashion). We can map each element of the array to its latitude, and we would then have an appropriate input for `average()`. The solution would be something like the following:

```
// continued...

const averageLat = average(markers.map((x) => x.lat));
const averageLon = average(markers.map((x) => x.lon));

console.log(averageLat, averageLon); // -15.76, -65.53
```

Mapping an array to extract data is powerful, but you must be careful. Let's now look at a case that seems right but produces incorrect results!

Parsing numbers tacitly

Working with `map()` is usually far safer and simpler than looping by hand, but some edge cases may trip you up. Say you received an array of strings representing numeric values and wanted to parse them into actual numbers. Can you explain the following results?

```
["123.45", "67.8", "90"].map(parseFloat);
// [123.45, 67.8, 90]

["123.45", "-67.8", "90"].map(parseInt);
// [123, NaN, NaN]
```

Let's analyze the results. When we used `parseFloat()` to get floating-point results, everything was OK; however, when we wanted to truncate the results to integer values with `parseInt()`, the output was really awry, and weird `NaN` values appeared. What happened?

The answer lies in a problem with tacit programming. (We have already seen some uses of tacit programming in the *An unnecessary mistake* section of *Chapter 3*, *Starting Out with Functions*, and we'll see more in *Chapter 8*, *Connecting Functions*.) When you don't explicitly show the parameters to a function, it's easy for there to be oversights. Look at the following code, which will lead us to the solution:

```
["123.45", "-67.8", "90"].map((x) => parseFloat(x));
// [123.45, -67.8, 90]

["123.45", "-67.8", "90"].map((x) => parseInt(x));
// [123, -67, 90]
```

The reason for the unexpected behavior with `parseInt()` is that this function can also receive a second parameter—namely, the radix to use when converting the string into a number. For instance, a call such as `parseInt("100010100001", 2)` will convert a binary number of `100010100001` into a decimal.

Note:

You can read more about `parseInt()` at `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/parseInt`, where the radix parameter is explained in detail. You should always provide it because some browsers might interpret strings with a leading zero to be octal, which would once again produce unwanted results.

So, what happens when we provide `parseInt()` to `map()`? Remember that `map()` calls your mapping function with three parameters: the array element value, its index, and the array itself. When `parseInt` receives these values, it ignores the array but assumes that the provided index is actually a radix, and `NaN` values are produced since the original strings are not valid numbers in the given radix.

OK, some functions can lead you astray when mapping, and you now know what to look for. Let's keep enhancing the way we work by using ranges to write code that would usually require a hand-written loop.

Working with ranges

Let's now turn to a helper function, which will come in handy for many uses. We want a `range(start,stop)` function that generates an array of numbers, with values ranging from `start` (inclusive) to `stop` (exclusive):

```
// range.ts

const range = (start: number, stop: number): number[] =>
  new Array(stop - start).fill(0).map((v, i) => start + i);

range(2, 7); // [2, 3, 4, 5, 6]
```

Why `fill(0)`? Undefined array elements are skipped by `map()`, so we need to fill them with something or our code will have no effect.

Expanding your range

Libraries such as Underscore and Lodash provide a more powerful version of our `range()` function, letting us go in ascending or descending order and also specifying the step to use—as in `_.range(0, -8, -2)`, which produces `[0, -2, -4, -6]`—but for our needs, the version we wrote is enough. Refer to the *Questions* section at the end of this chapter.

How can we use it? In the following section, we'll see some uses for controlled looping with `forEach()`, but we can redo our factorial function by applying `range()` and then `reduce()`. The idea of this is to generate all the numbers from 1 to `n` and then multiply them together:

```
// continued...

const factorialByRange = (n: number): number =>
  range(1, n + 1).reduce((x, y) => x * y, 1);
```

It's important to check the border cases, but the function also works for zero; can you see why? The reason for this is that the produced range is empty: the call is `range(1,1)`, which returns an empty array. Then, `reduce()` doesn't do any calculations and returns the initial value (`1`), which is correct.

In *Chapter 7*, *Transforming Functions*, we'll have the opportunity to use `range()` to generate source code; check out the *Currying with eval()* and *Partial application with eval()* sections.

You could use these numeric ranges to produce other kinds of ranges. For example, should you need an array with the alphabet, you could certainly (and tediously) write `["A", "B", "C"`... up to ...`"X", "Y", "Z"]`. A simpler solution would be to generate a range with the ASCII codes for the alphabet and map those to letters:

```
// continued...

const ALPHABET = range(
  "A".charCodeAt(0),
  "Z".charCodeAt(0) + 1
).map((x) => String.fromCharCode(x));
// ["A", "B", "C", ... "X", "Y", "Z"]
```

Note the use of `charCodeAt()` to get the ASCII codes for the letters and `String.fromCharCode(x)` to transform the ASCII code into a character.

Mapping is very important and often used, so let's now analyze how you could implement it on your own, which could help you develop code for more complex cases.

Emulating map() with reduce()

Earlier in this chapter, we saw how `reduce()` could be used to implement `reduceRight()`. Now, let's see how `reduce()` can also be used to provide a polyfill for `map()` (not that you will need it because nowadays, browsers offer both methods, but it will give you more of an idea of what you can achieve with these tools).

Our own `myMap()` is a one-liner but can be hard to understand. We apply the function to each element of the array and use `concat()` to append the result to a result array (which is initially empty). When the loop finishes working with the input array, the result array will have the desired output values. Let's first see a plain JavaScript version before getting to data typing:

```
// map.js

const myMap = (arr, fn) =>
  arr.reduce((x, y) => x.concat(fn(y)), []);
```

We apply the mapping function to each array element, one by one, and we concatenate the result to the accumulated output array.

Let's test this with an array and a simple function. We will use both the original `map()` method and `myMap()`, and the results should match! Our mapping function will return double its input:

```
// continued...
```

```
const dup = (x: number): number => 2 * x;

console.log(myMap(myArray, dup));
console.log(myArray.map(dup));
// [44, 18, 120, 24, 8, 112] both times
```

The first log shows the expected result, produced by `map()`. The second output gives the same result, so it seems that `myMap()` works! And the final output is just to check that the original input array wasn't modified in any way; mapping operations should always produce a new array. See *Question 5.3* for testing our `myMap()` function more thoroughly.

Let's review our `myMap()` function and add typing. The needed data types are more complex, and we'll have a generic function:

```
// map.ts

const myMap = <T, R>(arr: T[], fn: (x: T) => R): R[] =>
  arr.reduce(
    (x: R[], y: T): R[] => x.concat(fn(y)),
    [] as R[]
  );
```

Our `myMap()` function receives an array of elements of type `T` and an `fn()` mapping function that transforms its `T` argument into an `R`-type result. The result of this mapping is an array of `R`-type elements. Examine the accumulator function by yourself; is its typing understandable?

Let's try a different mapping function to verify that our typing is correct. We'll use one that returns strings instead of numbers – it just adds dashes before and after its input, to produce a string.

```
// continued...

const addDashes = (x: number): string => `-${x}-`;

const myDashes = myArray.map(addDashes);
// [ '-22-', '-9-', '-60-', '-12-', '-4-', '-56-' ]
```

OK, it seems that our complex type definitions were correct!

All the previous examples in the chapter focused on simple arrays. But what happens if things get more complicated, say if you had to deal with an array whose elements were arrays themselves? Fortunately, there's a way out of that. Let's move on.

Dealing with arrays of arrays

So far, we have worked with an array of (single) values as an input, but what would happen if your input was an array of arrays? If you consider this to be a far-fetched case, there are many possible scenarios where this could apply:

- For some applications, you could have a table of distances, which in JavaScript requires an array of arrays: `distance[i][j]` would be the distance between `i` and `j`. How could you find the maximum distance between any two points? Finding the maximum is simple with a common array, but how do you deal with an array of arrays?
- A more complex example, also in a geographic vein, is that you could query a geographic API for cities matching a string, and the response could be an array of countries, each with an array of states, each itself with an array of matching cities: an array of arrays of arrays!

In the first case, you could want a single array with all distances, and in the second, an array with all cities; how would you manage this? A new operation, **flattening**, is required; let's take a look.

Flattening an array

In ES2019, two operations were added to JavaScript: `flat()`, which we'll look at now, and `flatMap()`, which we'll look at later. It's easier to show what they do than to explain—bear with me!

No flat() allowed?

As often happens, not all browsers have been updated to include these new methods, and Microsoft's Internet Explorer and others were deficient in this regard, so for web programming, a polyfill will be required. As usual, for updated compatibility data, check out the *Can I use?* site, in this case, at `caniuse.com/#feat=array-flat`. A piece of good news: since September 2018, all major browsers provide this feature natively!

The `flat()` method creates a new array, concatenating all elements of its subarrays to the desired level, which is, by default, `1`:

```
const a = [[1, 2], [3, 4, [5, 6, 7]], 8, [[[9]]]];

console.log(a.flat()); // or a.flat(1)
[ 1, 2, 3, 4, [ 5, 6, 7 ], 8, [ [ 9 ] ] ]

console.log(a.flat(2));
[ 1, 2, 3, 4, 5, 6, 7, 8, [ 9 ]]

console.log(a.flat(Infinity));
[ 1, 2, 3, 4, 5, 6, 7, 8, 9 ]
```

So, how could we use this function to solve our problems? Using `flat()`, spreading, and `Math.max()` answers the first question (as we saw back in the *Spread* section of *Chapter 1, Becoming Functional*; we could have used the `maxArray()` function we wrote back then), and we can also use `reduce()` for variety. Suppose we have the following table of distances:

```
const distances = [
  [0, 20, 35, 40],
  [20, 0, 10, 50],
  [35, 10, 0, 30],
  [40, 50, 30, 0],
];
```

Then, we can find our maximum distance in a couple of ways: we either flatten the array, spread it, and use `Math.max()`, or flatten the array and use reducing to explicitly find the maximum:

```
// flat.js

const maxDist1 = Math.max(...distances.flat()); // 50

const maxDist2 = distances
  .flat()
  .reduce((p, d) => Math.max(p, d), 0); // also 50
```

Let's go back to the second question. Suppose we queried a geographic API for cities that have `"LINCOLN"` (upper or lower case) in their names and got the following answer:

```
// continued...

const apiAnswer = [
  {
    country: "AR",
    name: "Argentine",
    states: [
      {
        state: "1",
        name: "Buenos Aires",
        cities: [{city: 3846864, name: "Lincoln"}],
      },
    ],
  },
  {
    country: "GB",
    name: "Great Britain",
    states: [
      {
        state: "ENG",
        name: "England",
        cities: [{city: 2644487, name: "Lincoln"}],
      },
    ],
  },
  {
    country: "US",
    name: "United States of America",
    states: [
      {
        state: "CA",
        name: "California",
        cities: [{city: 5072006, name: "Lincoln"}],
      },
      .
      .
      .
      {
        state: "IL",
        name: "Illinois",
        cities: [
          {city: 4899911, name: "Lincoln Park"},
          {city: 4899966, name: "Lincoln Square"},
        ],
      },
    ],
  },
];
```

Extracting the list of cities can be done by applying `map()` and `flat()` twice:

```
// continued...

console.log(
  apiAnswer
    .map(x => x.states)
    .flat()
    .map(y => y.cities)
    .flat()
);

/* Results:
[ { city: 3846864, name: 'Lincoln' },
  { city: 2644487, name: 'Lincoln' },
  { city: 5072006, name: 'Lincoln' },
  { city: 8531960, name: 'Lincoln' },
  { city: 4769608, name: 'Lincolnia' },
  { city: 4999311, name: 'Lincoln Park' },
  { city: 5072006, name: 'Lincoln' },
  { city: 4899911, name: 'Lincoln Park' },
  { city: 4899966, name: 'Lincoln Square' }
]
*/
```

We have seen how to use `flat()` to flatten an array; let's now see how to use `flatMap()`, an interesting mixture of `flat()` and `map()`, to further streamline our coding and even further shorten our preceding second solution! (And if you think this exercise wasn't hard enough and its output was sort of lame, try out *Question 5.10* for a more challenging version!)

Mapping and flattening – flatMap()

Basically, what `flatMap()` does is first apply a `map()` function and then apply `flat()` to the result of the mapping operation. This is an interesting combination because it lets you produce a new array with a different number of elements. (With the normal `map()` operation, the output array would be precisely the same length as the input array). If your mapping operation produces an array with two or more elements, then the output array will include many output values, and if you produce an empty array, the output array will include fewer values.

Let's look at a (somehow nonsensical) example. Assume that we have a list of names, such as `"Winston Spencer Churchill"`, `"Abraham Lincoln"`, and `"Socrates"`. Our rule is that if a name has several words, exclude the initial one (the first name, we assume) and separate the rest (last names), but if a name is a single word, drop it (assuming the person has no last name):

```
// continued...

const names = [
  "Winston Spencer Churchill",
  "Plato",
  "Abraham Lincoln",
  "Socrates",
  "Charles Darwin",
];

const lastNames = names.flatMap((x) => {
  const s = x.split(" ");
  return s.length === 1 ? [] : s.splice(1);
});
// [ 'Spencer', 'Churchill', 'Lincoln', 'Darwin' ]
```

As we can see, the output array has a different number of elements than the input array: just because of this, we could consider `flatMap()` to be an upgraded version of `map()`, even including some aspects of `filter()`, like when we excluded single names.

Let's now move on to a simple example. Keeping with the Lincolnian theme from the last section, let's count how many words are in Lincoln's Gettysburg address, given as an array of sentences. By the way, this address is usually considered to be 272 words long, but the version I found doesn't produce that number! This may be because there are five manuscript copies of the address written by Lincoln himself, plus another version transcribed from shorthand notes taken at the event. In any case, I will leave the discrepancy to historians and stick to coding!

We can use `flatMap()` to split each sentence into an array of words and then see the length of the flattened array:

```
const gettysburg = [
  "Four score and seven years ago our fathers",
  "brought forth, on this continent, a new nation,",
  "conceived in liberty, and dedicated to the",
  "proposition that all men are created equal.",
    "Now we are engaged in a great civil war,",
    "testing whether that nation, or any nation",
    "so conceived and so dedicated, can long endure.",
    "We are met on a great battle field of that",
    "war. We have come to dedicate a portion of",
    "that field, as a final resting place for",
    "those who here gave their lives, that that",
    "nation might live. It is altogether",
    "fitting and proper that we should do this.",
    "But, in a larger sense, we cannot dedicate,",
    "we cannot consecrate, we cannot hallow,",
    "this ground.",
    "The brave men, living and dead, who",
    "struggled here, have consecrated it far",
    "above our poor power to add or detract.",
    "The world will little note nor long",
    "remember what we say here, but it can",
    "never forget what they did here.",
    "It is for us the living, rather, to be",
    "dedicated here to the unfinished work",
    "which they who fought here have thus far",
    "so nobly advanced.",
    "It is rather for us to be here dedicated",
    "to the great task remaining before us—",
    "that from these honored dead we take",
    "increased devotion to that cause for",
    "which they here gave the last full",
    "measure of devotion— that we here highly",
    "resolve that these dead shall not have",
    "died in vain— that this nation, under",
    "God, shall have a new birth of freedom-",
    "and that government of the people, by",
    "the people, for the people, shall not",
    "perish from the earth.",
  ];

  console.log(
  gettysburg.flatMap((s: string) => s.split(" ")).length
);
// 270 ...not 272?
```

Let's go back to the problem with the cities. If we notice that each `map()` was followed by `flat()`, an alternative solution is immediately apparent. Compare this solution with the one we wrote in the *Flattening an array* section; it's essentially the same but conflates each `map()` with its following `flat()`:

```
// continued...

console.log(
  apiAnswer
    .flatMap((x) => x.states)
    .flatMap((y) => y.cities)
);
// same result as with separate map() and flat() calls
```

We have now seen the new operations. (And, yes, it's perfectly possible to solve the problems in this section without mapping, but that wouldn't be a good example for this section! See *Question 5.11* for an alternative to the word counting problem.) Let's now learn how to emulate these operations should you not have them readily available.

Emulating flat() and flatMap()

We have already seen how `reduce()` could be used to emulate `map()`. Let's now see how to work out equivalents for `flat()` and `flatMap()` to get more practice. We'll also throw in a recursive version, a topic we'll return to in *Chapter 9*, *Designing Functions*. As was mentioned earlier, we are not aiming for the fastest or smallest or any particular version of the code; instead, we want to focus on using the concepts we've been looking at in this book.

Totally flattening an array can be done with a recursive call. We use `reduce()` to process the array element by element, and if an element happens to be an array, we recursively flatten it:

```
// continued...

const flatAll = <T>(arr: T[]): T[] =>
  arr.reduce(
    (f: T[], v: T) =>
      f.concat(Array.isArray(v) ? flatAll(v) : v),
    [] as T[]
  );
```

Flattening an array to a given level (not infinity; let's leave that for later) is easy if you can first flatten an array one level. We can do this either by using spreading or with `reduce()`. Let's write a `flatOne()` function that flattens just a single level of an array. There are two versions of this; pick whichever you prefer:

```
// continued...

const flatOne1 = <T>(arr: T[]): T[] =>
  ([] as T[]).concat(...arr);

const flatOne2 = <T>(arr: T[]): T[] =>
  arr.reduce((f, v) => f.concat(v), [] as T[]);
```

Using either of these two functions, we can flatten an array of several levels, and we can do this in two different ways. Our two versions of a `flat()` function use our previous `flatOne()` and `flatAll()` functions, but the first one only uses standard looping, while the second one works in a fully recursive way. Which one do you prefer?

```
// continued...

const flat1 = <T>(arr: T[], n = 1): T[] => {
  if (n === Infinity) {
    return flatAll(arr);
  } else {
    let result = arr;
    range(0, n).forEach(() => {
      result = flatOne(result);
    });
    return result;
  }
};

const flat2 =  <T>(arr: T[], n = 1): T[] => {
  n === Infinity
    ? flatAll(arr)
    : n === 1
    ? flatOne(arr)
    : flat2(flatOne(arr), n - 1);
```

I think the recursive one is nicer and more aligned with the theme of this book. Still, it's up to you, really—although if you don't feel comfortable with the ternary operator, then the recursive version is definitely not for you!

If you wish to polyfill these functions (despite our suggestions not to), it's not complex, and is similar to what we did with the `average()` method previously. I took care not to create any extra methods:

```
// continued...

if (!Array.prototype.flat) {
  Array.prototype.flat = function (this, n): any[] {
    if (n === undefined || n === 1) {
      return flatOne(this as any[]);
    } else if (n === Infinity) {
      return flatAll(this as any[]);
    } else {
      return flatOne(this as any[]).flat(n - 1);
    }
  };
}
```

Our `flatOneX()` and `flatAllX()` methods are just copies of what we developed before, and you'll recognize the code of our previous `flat2()` function at the end of our implementation.

Finally, emulating `flatMap()` is simple in itself, and we can skip it because it's just a matter of applying `map()` first, and then `flat()`; no big deal!

We have seen how to work with arrays in several ways, but sometimes what you need isn't really well served by any of the functions we have seen. Let's move on to more general ways of looping, for greater power.

More general looping

The preceding examples that we've seen all loop through arrays, doing some work. However, sometimes, you need to loop, but the required process doesn't really fit `map()` or `reduce()`. So, what can be done in such cases? There is a `forEach()` method that can help. (Read more about it at `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Array/forEach`.)

You must provide a callback that will receive the value, the index, and the array on which you are operating. (The last two arguments are optional.) JavaScript will take care of the loop control, and you can do whatever you want at each step. For instance, we can program an object copying method by using `Object` methods to copy the source object attributes one at a time and generate a new object:

```
// copy.ts

const objCopy = <T>(obj: T): T => {
  const copy = Object.create(Object.getPrototypeOf(obj));
  Object.getOwnPropertyNames(obj).forEach((prop: string) =>
    Object.defineProperty(
      copy,
      prop,
      Object.getOwnPropertyDescriptor(obj, prop) as string
    )
  );
  return copy;
};

const myObj = { fk: 22, st: 12, desc: "couple" };
const myCopy = objCopy(myObj);

console.log(myObj, myCopy);
// {fk: 22, st: 12, desc: "couple"}, twice
```

The idea is: we create a `copy` object with the same prototype as the original `obj`, and then for each property in the original, we define an equivalent property in the copy. The function's signature makes clear that the input and output types are the same. One particular detail: given the loop we are writing, we know for sure that `Object.getOwnPropertyDescriptor(obj, prop)` will be a string (and not `undefined`), but TypeScript cannot tell; adding `as string` solves this.

Shallow or deep?

Yes, of course, we could have written `myCopy={...myObj}`, but where's the fun in that? It would be better, but I needed a nice example to use `forEach()` with. Sorry about that! Also, there are some hidden inconveniences in that code, which we'll explain in *Chapter 10*, *Ensuring Purity*, when we try to get frozen, unmodifiable objects. Just a hint: the new object may share values with the old one because we have a shallow copy, not a deep one. We'll learn more about this later in the book.

If we use the `range()` function that we defined previously, we can also perform common loops of the `for(let i=0; i<10; i++)` variety. We might write yet another version of factorial (!) using that:

```
// loops.ts
```

```
import { range } from "./range";

const fact4 = (n: number): number => {
  let result = 1;
  range(1, n + 1).forEach((v) => (result *= v));
  return result;
};

console.log(fact4(5)); // 120
```

This definition of factorial really matches the usual description: it generates all the numbers from 1 to *n* inclusive and multiplies them—simple!

For greater generality, consider expanding `range()` so it can generate ascending and descending ranges of values, possibly stepping by a number other than 1. This would allow you to replace all the loops in your code with `forEach()` loops.

At this point, we have seen many ways of processing arrays to generate results, but other objectives may be of interest, so let's now move on to logical functions, which will also simplify our coding needs.

Logical HOFs

Up to now, we have been using HOFs to produce new results. However, some other functions produce logical results by applying a predicate to all the elements of an array. (By the way, we'll see much more about HOFs in the next chapter.)

Many meanings

A bit of terminology: the word **predicate** can be used in several senses (as in predicate logic), but for us, in computer science, it has the meaning of *a function that returns true or false*. OK, this isn't a very formal definition, but it's enough for our needs. For example, saying that we will filter an array depending on a predicate means that we get to decide which elements are included or excluded depending on the predicate's result.

Using these functions implies that your code will become shorter: you can get results corresponding to a whole set of values with a single line of code.

Filtering an array

We will encounter a common need to filter the elements of an array according to a specific condition. The `filter()` method lets you inspect each element of an array in the same fashion as `map()`. The difference is that instead of producing a new element, the result of your function determines whether the input value will be kept in the output (if the function returned `true`) or if it will be skipped (if the function returned `false`). Also, similar to `map()`, `filter()` doesn't alter the original array but produces a new array with the chosen items. You can read more on the `filter()` function at `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/Array/filter`.

See *Figure 5.4* for a diagram showing the input and output:

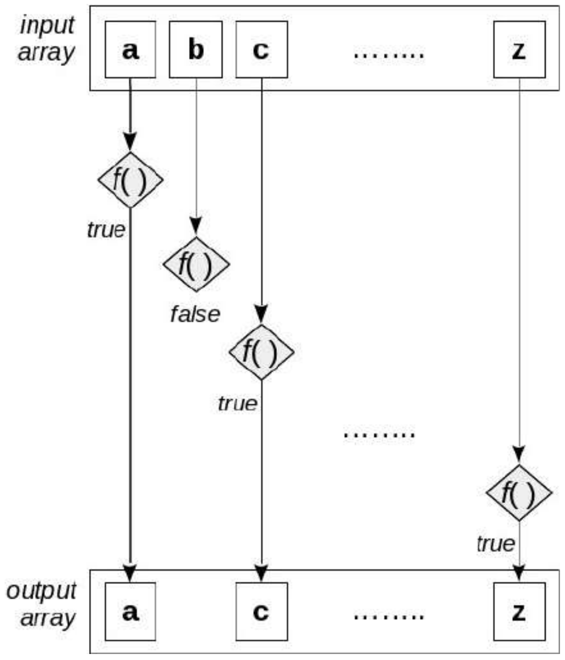


Figure 5.4 – The filter() method picks the elements of an array that satisfy a given predicate

There are a couple of things to remember when filtering an array:

- **Always return something from your predicate**: If you forget to include a return, the function will implicitly return `undefined`, and since that's a falsy value, the output will be an empty array
- **The copy that is made is shallow**: If the input array elements are objects or arrays, then the original elements will still be accessible

Let's get into more detail by seeing a practical example of `filter()` and then looking at how we could implement that functionality by using `reduce()`.

A filter() example

Let's look at a practical example. Suppose a service has returned a JSON object, which has an array of objects containing an account's `id` value and `balance`. How can we get the list of IDs *"in the red"*, with a negative balance? The input data could be as follows:

```
// filter.ts

const serviceResult = {
  accountsData: [
    { id: "F220960K", balance: 1024 },
    { id: "S120456T", balance: 2260 },
    { id: "J140793A", balance: -38 },
    { id: "M120396V", balance: -114 },
    { id: "A120289L", balance: 55000 },
  ],
};
```

We could get the delinquent accounts with something like the following. You can check that the value of the `delinquent` variable correctly includes the two IDs of accounts with a negative balance:

```
// continued...

const delinquent = serviceResult.accountsData.filter(
  (v) => v.balance < 0
);
console.log(delinquent);
// two objects, with id's J140793A and M120396V
```

By the way, given that the filtering operation produced yet another array, if you just wanted the accounts IDs, you could get them by mapping the output to only get the `id` field:

```
// continued...

const delinquentIds = delinquent.map((v) => v.id);
```

And if you didn't care for the intermediate result, a one-liner would have worked as well:

```
// continued...
```

```
const delinquentIds2 = serviceResult.accountsData
  .filter((v) => v.balance < 0)
  .map((v) => v.id);
```

Filtering is a very useful function, so now, to get a better handle on it, let's see how you can emulate it, which you could use as a basis for more sophisticated, powerful functions of your own.

Emulating filter() with reduce()

As we did before with `map()`, we can also create our own version of `filter()` by using `reduce()`. The idea is similar: loop through all the elements of the input array, apply the predicate to it, and if the result is `true`, add the original element to the output array. When the loop is done, the output array will only have those elements for which the predicate was `true`:

```
// continued...

const myFilter = <T>(arr: T[], fn: (x: T) => boolean) =>
  arr.reduce(
    (x: T[], y: T) => (fn(y) ? x.concat(y) : x),
    []
  );
```

Our function is generic; it takes an array of elements of type `T` and a predicate that accepts a `T`-type parameter and generates a new array of elements of type `T`. We can quickly see that our function works as expected:

```
myFilter(serviceResult.accountsData, (v) => v.balance < 0);
```

The output is the same pair of accounts that we saw earlier in this section.

Searching an array

Sometimes, instead of filtering all the elements of an array, you want to find an element that satisfies a given predicate. There are a couple of functions that can be used for this, depending on your specific needs:

- `find()` searches through the array and returns the value of the first element that satisfies a given condition, or `undefined` if no such element is found
- `findIndex()` performs a similar task, but instead of returning an element, it returns the index of the first element in the array that satisfies the condition, or `-1` if none were found

The similarity to `includes()` and `indexOf()` is clear; these functions search for a specific value instead of an element that satisfies a more general condition. We can easily write equivalent one-liners:

```
arr.includes(value);  // arr.find(v => v === value) arr.
indexOf(value);  // arr.findIndex(v => v === value)
```

Going back to the geographic data we used earlier, we could easily find a given country by using the `find()` method. For instance, let's get data for Brazil (`"BR"`); it just takes a single line of code:

```
// search.ts

import { markers } from "./average";

const brazilData = markers.find((v) => v.name === "BR");
// {name:"BR", lat:-15.8, lon:-47.9}
```

We can't use the simpler `includes()` method because we have to delve into the object to get the field we want. If we wanted the position of the country in the array, we would have used `findIndex()`:

```
// continued...

const brazilIndex = markers.findIndex(
  (v) => v.name === "BR"
);
// 2
```

OK, this was easy! What about a special case, which could even be a trick interview question? Read on!

A special search case

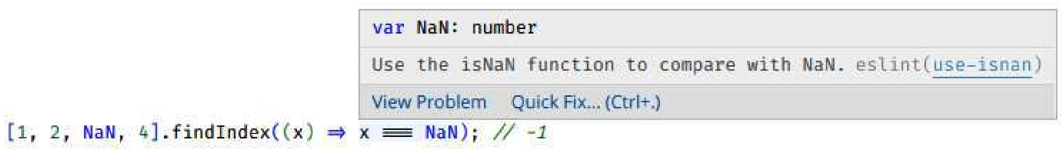
Suppose you had an array of numbers and wanted to run a sanity check, studying whether any of them were `NaN`. How would you do this? A tip: don't try checking the types of the array elements—even though `NaN` stands for not a number, `typeof NaN` *is* `"number"`. You'll get a surprising result if you try to search in an obvious way:

```
[1, 2, NaN, 4].findIndex((x) => x === NaN); // -1
```

What's going on here? It's a bit of interesting JavaScript trivia: `NaN` is the only value that isn't equal to itself. Should you need to look for `NaN`, you'll have to use the new `isNaN()` function as follows:

```
[1, 2, NaN, 4].findIndex(x => isNaN(x)); // 2
```

ESLint would help with the `use-isnan` rule: see `eslint.org/docs/latest/rules/use-isnan` for more on this. *Figure 5.5* shows the result.



```
var NaN: number
Use the isNaN function to compare with NaN. eslint(use-isnan)
View Problem    Quick Fix... (Ctrl+.)
[1, 2, NaN, 4].findIndex((x) => x === NaN); // -1
```

Figure 5.5 – ESLint prevents you from a NaN-related mistake

This was a particular case worth knowing about; I had to deal with it once! Now, let's continue as we have done previously, by emulating the searching methods with `reduce()` so that we can see more examples of the power of that function.

Emulating find() and findIndex() with reduce()

As with the other methods, let's finish this section by studying how to implement the methods we showed by using the omnipotent `reduce()`. This is a good exercise to get accustomed to working with HOFs, even if you will never actually use these polyfills!

The `find()` method requires a bit of work. We start the search with an `undefined` value, and if we find an array element so that the predicate is `true`, we change the accumulated value to that of the array:

```
arr.find(fn); // or arr.find((x) => fn(x));
arr.reduce(
  (x, y) => (x === undefined && fn(y) ? y : x),
  undefined
);
```

In terms of performance, there's a slight difference with the standard `find()` method. The language specification (at `tc39.es/ecma262/#sec-array.prototype.find`) shows that the search stops as soon as an element satisfies the search. Our code, however, keeps processing the rest of the array (because that's how `reduce()` works), although it doesn't evaluate the predicate again; can you see why?

For `findIndex()`, we must remember that the callback function receives the accumulated value, the array's current element, and the index of the current element, but other than that, the equivalent expression is quite similar to the one for `find()`; comparing them is worth the time:

```
arr.findIndex(fn);
arr.reduce((x, y, i) => (x == -1 && fn(y) ? i : x), -1);
```

The initial accumulated value is `-1` here, which will be the returned value if no element fulfills the predicate. Whenever the accumulated value is still `-1`, but we find an element that satisfies the predicate, we change the accumulated value to the array index.

OK, we are now done with searches: let's move on to considering higher-level predicates that will simplify testing arrays for a condition, but always in the declarative style we've been using so far.

Higher-level predicates – every() and some()

The last functions we will consider greatly simplify going through arrays to test for conditions. These functions are as follows:

- `every()`, which is `true` if and only if every element in the array satisfies a given predicate
- `some()`, which is `true` if at least one element in the array satisfies the predicate

For example, we could quickly check our hypothesis about all the countries having negative coordinates:

```
// continued...

markers.every((v) => v.lat < 0 && v.lon < 0); // false
markers.some((v) => v.lat < 0 && v.lon < 0);  // true
```

If we want to find equivalents to these two functions in terms of `reduce()`, the two alternatives show nice symmetry:

```
arr.every(fn);
arr.reduce((x, y) => x && fn(y), true);

arr.some(fn);
arr.reduce((x, y) => x || fn(y), false);
```

The first folding operation evaluates `fn(y)` and ANDs the result with the previous tests; the only way the final result will be `true` is if every test succeeds. The second folding operation is similar, but ORs the result with the previous results and will produce `true` unless every test fails.

Boolean duality

In terms of Boolean algebra, the alternative formulations for `every()` and `some()` exhibit duality. This duality is the same kind that appears in the `x === x && true` and `x === x || false` expressions; if `x` is a Boolean value, and we exchange `&&` and `||`, and also `true` and `false`, then we transform one expression into the other, and both are valid.

In this section, we saw how to check for a given Boolean condition. Let's finish by seeing how to check a negative condition by inventing a method of our own.

Checking negatives – none()

If you wanted, you could also define `none()` as the complement of `every()`. This new function would be `true` only if none of the elements of the array satisfied the given predicate. The simplest way of coding this would be by noting that if no elements satisfy the condition, then all elements satisfy the negation of the condition:

```
// continued...

const none = <T>(arr: T[], fn: (x: T) => boolean) =>
  arr.every((v) => !fn(v));
```

You can turn it into a method by modifying the array prototype, as we saw earlier. It's still a bad practice, but it's what we have until we start looking into better methods for composing and chaining functions, which we will do in *Chapter 8*, *Connecting Functions*:

```
// continued...

declare global {
  interface Array<T> {
    none(f: (x: T) => boolean): boolean;
  }
}

Array.prototype.none = function (fn) {
  return this.every((v) => !fn(v));
};
```

We had to use `function()` instead of an arrow function for the same reasons we saw on earlier occasions: we need `this` to be correctly assigned. We also had to add a global definition like when we used averages so that TypeScript wouldn't object to the newly added `none()` method. Other than that, it's simple coding, and we now have a `none()` method available for all arrays. In *Chapter 6*, *Producing Functions*, we will see yet other ways of negating a function by writing an appropriate HOF of our own.

In this and the preceding section, we worked with everyday problems and saw how to solve them declaratively. However, things change a bit when you start working with `async` functions. We will see in the following section that new solutions will be needed.

Working with async functions

All the examples and code we studied in the previous sections were meant to be used with common functions, specifically meaning *not* `async` ones. When you want to do mapping, filtering, reducing, and so on, but the function you are using is an `async` one, the results may surprise you. To simplify our work and not deal with actual API calls, let's create a `fakeAPI(delay, value)` function that will delay a while before returning the given value:

```
// async.ts

const fakeAPI = <T>(delay: number, value: T): Promise<T> =>
  new Promise((resolve) =>
    setTimeout(() => resolve(value), delay)
  );
```

Let's also have a function to display what `fakeAPI()` returns so that we can see that things are working as expected:

```
// continued...

const useResult = (x: any): void =>
  console.log(new Date(), x);
```

We are using the modern `async` and `await` features from ES2017 to simplify our code, and we are avoiding the top-level `await`:

```
// async.ts

(async () => {
  console.log("START");
  console.log(new Date());
  const result = await fakeAPI(1000, 229);
  useResult(result);
  console.log("END");
})();

/*
START
2022-10-29T01:28:12.986Z
2022-10-29T01:28:13.989Z 229
```

```
END
*/
```

The results are previsible: we get the `START` text, then about 1 second (1,000 milliseconds) later, the result of the fake API call (`229`), and finally the `END` text. What could go wrong?

Top-level await

Why are we using the immediate invocation pattern we saw in *Chapter 3*, *Starting Out with Functions*? The reason is that the use of `await` at the top level has been available for Node.js since version 14.8 (August 2020) and browsers since 2021, so it's not yet widespread. So, as you can only use `await` within an `async` function, I opted to go with an IIFE here for major compatibility.

The critical problem is that all the functions we saw earlier in this chapter are not `async`-*aware*, so they won't work as you'd expect. Let's start looking at this.

Some strange behaviors

Let's start with a simple quiz: are results what you expected? Let's look at a couple of examples of code involving `async` calls, and we'll see some unexpected results. First, let's look at a typical straightforward sequence of `async` calls:

```
// continued...

(async () => {
  console.log("START SEQUENCE");

  const x1 = await fakeAPI(1000, 1);
  useResult(x1);
  const x2 = await fakeAPI(2000, 2);
  useResult(x2);
  const x3 = await fakeAPI(3000, 3);
  useResult(x3);
  const x4 = await fakeAPI(4000, 4);
  useResult(x4);

  console.log("END SEQUENCE");
})();
```

If you run this code, you'll get the following results, which are indeed what you would expect—a `START SEQUENCE` text, four individual lines with the results of the fake API calls, and a final `END SEQUENCE` text. Nothing special here—everything is fine!

```
START SEQUENCE
2022-10-29T01:32:11.671Z 1
2022-10-29T01:32:13.677Z 2
2022-10-29T01:32:16.680Z 3
2022-10-29T01:32:20.683Z 4
END SEQUENCE
```

Let's go for an alternative second version, which you'd expect to be equivalent to the first one. The only difference here is that we are using looping to do the four API calls; it should be the same, shouldn't it? (We could also have used a `forEach()` loop with the `range()` function that we saw earlier, but that makes no difference.) I kept using an IIFE, though in this particular case, it wasn't needed; can you see why?

```
// continued...

(() => {
  console.log("START FOREACH");

  [1, 2, 3, 4].forEach(async (n) => {
    const x = await fakeAPI(n * 1000, n);
    useResult(x);
  });

  console.log("END FOREACH");
})();
```

This code certainly looks equivalent to the first one, but it produces something entirely different!

```
START FOREACH
END FOREACH
2022-10-29T01:34:06.287Z 1
2022-10-29T01:34:07.287Z 2
2022-10-29T01:34:08.286Z 3
2022-10-29T01:34:09.286Z 4
```

The END FOREACH text appears before the results of the API calls. What's happening? The answer is what we mentioned before: methods similar to forEach() and the like are meant to be used with standard, sync function calls and behave strangely with async function calls.

The key concept is that async functions always return promises, so after getting the START FOREACH text, the loop actually creates four promises (which will eventually be resolved at some point), *but without waiting for them*, and our code goes on to print the END FOREACH text.

The problem is not only with forEach() but also affects all other similar methods. Let's see how we can work around this situation and write async-aware functions to let us keep working in a declarative fashion, as we did earlier in the chapter.

Async-ready looping

If we cannot directly use methods such as forEach(), map(), and the like, we'll have to develop new versions of our own. Let's see how to achieve this.

Looping over async calls

Since async calls return promises, we can emulate forEach() with reduce() by starting with a resolved promise and chaining to it the promises for each value in the array. The then() methods will be called in the proper order, so the results will be correct. The following piece of code manages to get the right, expected results:

```
// continued...

const forEachAsync = <T>(
  arr: T[],
  fn: (x: T) => any
): Promise<any> =>
  arr.reduce(
    (promise: Promise<void>, value: T) =>
      promise.then(() => fn(value)),
    Promise.resolve()
  );

(async () => {
  console.log("START FOREACH VIA REDUCE");
  await forEachAsync([1, 2, 3, 4], async (n) => {
    const x = await fakeAPI(n * 1000, n);
    useResult(x);
  });
  console.log("END FOREACH VIA REDUCE");
})();
```

The result is as follows:

```
START FOREACH VIA REDUCE
2022-10-29T01:42:09.385Z 1
2022-10-29T01:42:11.388Z 2
2022-10-29T01:42:14.391Z 3
2022-10-29T01:42:18.392Z 4
END FOREACH VIA REDUCE
```

As `forEachAsync()` returns a promise, we must remember to await it before showing the final text message. Other than not forgetting all the `await` statements, the code is similar to what we build using `forEach()` with the crucial difference being that this does work as expected!

Mapping async calls

Can we use the other functions? Writing `mapAsync()`, a version of `map()` that can work with an `async` mapping function, is simple because you can take advantage of `Promise.all()` to create a promise out of an array of promises:

```
// continued...

const mapAsync = <T, R>(
  arr: T[],
  fn: (x: T) => Promise<R>
) => Promise.all(arr.map(fn));

(async () => {
  console.log("START MAP");

  const mapped = await mapAsync([1, 2, 3, 4], async (n) => {
    const x = await fakeAPI(n * 1000, n);
    return x * 10;
  });

  useResult(mapped);
  console.log("END MAP");
})();
```

We get the following:

```
START MAP
2022-10-29T01:47:06.726Z [ 10, 20, 30, 40 ]
END MAP
```

The structure of the solution is similar to the `forEachAsync()` code. As before, we must remember to `await` the result of `mapAsync()` before continuing the process. Other than that, the logic is straightforward, and the results are as expected; the mapping function delays for a while and returns 10 times its input argument, and we see the correct output is produced.

Filtering with async calls

Filtering with an `async` function is a tad more complicated. We will have to use `mapAsync()` to produce an array of `true` or `false` results and then use the standard `filter()` method to pick values out of the original array depending on what the `async` filtering function returned. Let's try out a simple example, calling the API and accepting only even results utilizing a `fakeFilter()` function, which, for our example, accepts even numbers and rejects odd ones:

```
// continued...

const fakeFilter = (value: number): Promise<boolean> =>
  new Promise((resolve) =>
    setTimeout(() => resolve(value % 2 === 0), 1000)
  );
```

The needed `async` filtering code is as follows:

```
// continued...

const filterAsync = <T>(
  arr: T[],
  fn: (x: T) => Promise<boolean>
) =>
  mapAsync(arr, fn).then((arr2) =>
    arr.filter((v, i) => Boolean(arr2[i]))
  );
```

```
(async () => {
  console.log("START FILTER");

  const filtered = await filterAsync(
    [1, 2, 3, 4],
    async (n) => {
      const x = await fakeFilter(n);
      return x;
    }
  );

  useResult(filtered);
  console.log("END FILTER");
})();
```

The result is as follows:

```
START FILTER
2022-10-29T01:56:19.798Z [ 2, 4 ]
END FILTER
```

Note that the result of the mapping of `async` calls is a Boolean array (`arr2`), which we then use with `filter()` to select elements from the original array of values (`arr`); this can be tricky to understand!

Reducing async calls

Finally, finding an equivalent for `reduce()` is a bit more complex, but not so much after the other functions that we've seen. The key idea is the same as for `forEachAsync()`: each function call will return a promise, which must be awaited in order to update the accumulator in an upcoming `then()`. We set up this iteration with an initial promise that immediately resolves to the initial value for the accumulator:

```
// continued...

const reduceAsync = <T, R>(
  arr: T[],
  fn: (acc: R, val: T) => Promise<R>,
  init: R
) =>
  Promise.resolve(init).then((accum) =>
    forEachAsync(arr, async (v: T) => {
      accum = await fn(accum, v);
    }).then(() => accum)
  );
```

To do the reducing, let's use an `async` `fakeSum()` function that will sum the API-returned values:

```
// continued...

const fakeSum = (
  value1: number,
  value2: number
): Promise<number> =>
  new Promise((resolve) =>
    setTimeout(() => resolve(value1 + value2), 1000)
  );

(async () => {
  console.log("START REDUCE");

  const summed = await reduceAsync(
    [1, 2, 3, 4],
    async (_accum, n) => {
      const accum = await _accum;
      const x = await fakeSum(accum, n);
      useResult(`accum=${accum} value=${x} `);
      return x;
    },
    0
  );

  useResult(summed);
  console.log("END REDUCE");
})();
```

Note the critical detail: in our reducing function, we must first `await` the value of the accumulator and only afterward `await` the result of our `async` function. This is an important point you must not miss: since we are reducing in an `async` fashion, getting the accumulator is also an `async` matter, so we need to `await` both the accumulator and the new API call.

The result shows four intermediate values and the final result:

```
START REDUCE
2022-10-29T02:04:20.862Z accum=0 value=1
2022-10-29T02:04:21.864Z accum=1 value=3
2022-10-29T02:04:22.865Z accum=3 value=6
2022-10-29T02:04:23.866Z accum=6 value=10
2022-10-29T02:04:23.866Z 10
END REDUCE
```

By looking at these equivalents, we have seen that `async` functions, despite producing problems with the usual declarative methods that we studied at the beginning of the chapter, may also be handled by similar new functions of our own, so we can keep the new style even for these cases. Even if we have to use a somewhat different set of functions, your code will still be declarative, tighter, and clearer; an all-around win!

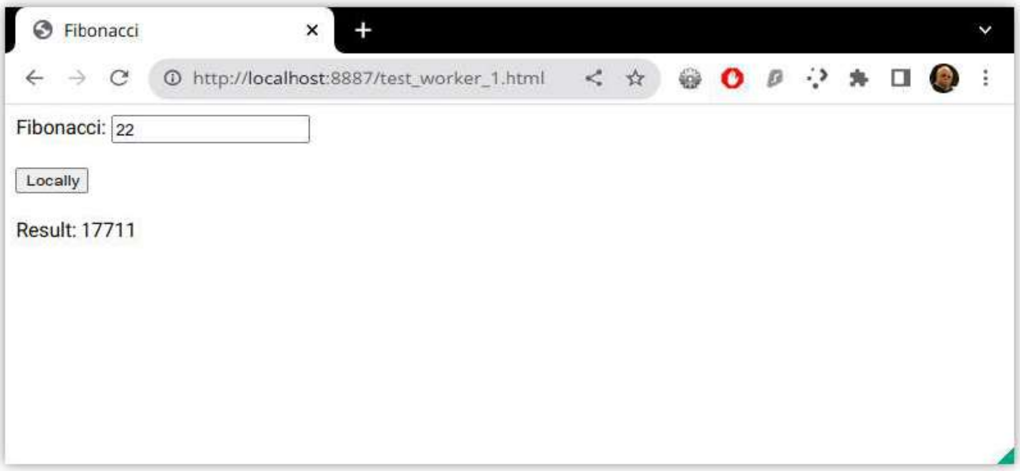
Working with parallel functions

JavaScript provides concurrency through `async` functions, meaning that several tasks can go on at the same time, even if a single CPU is doing all the jobs. **Web workers** (for the frontend) and **worker threads** (for the backend) allow processing in parallel in a different core, for better performance. This can offload work from the main thread and solve potential problems, in line with our FP approach.

In this section, we'll see how to avoid bottlenecks in frontend and backend programming by using workers in functional ways, along the lines of the previous sections in this chapter.

Unresponsive pages

Let's return to our Fibonacci slow-performing code from the *Memoization* section in the previous chapter. Suppose we want to create a web page that will allow users to enter a number and calculate the corresponding Fibonacci number, as in *Figure 5.6*.



Result: 17711

Figure 5.6 – A Fibonacci calculator

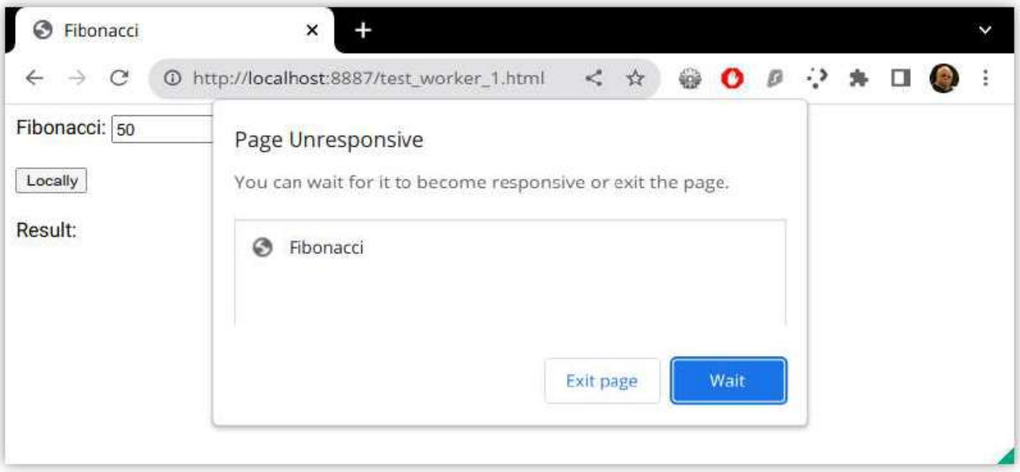
The code for this page is very basic—and no, I'm not even trying to do any styling; that's not the problem here!

```
// workers/test_worker_1.html

<!DOCTYPE html>
<html lang="en">
  <head>
    <meta charset="UTF-8" />
    <title>Fibonacci</title>
  </head>
  <body>
    Fibonacci:
    <input id="num" type="number" min="0" value="0" />
    <br />
    <br />
    <button onclick="locally()">Locally</button>
    <br />
    <br />
    Result: <span id="res"></span>

    <script src="test_worker_1.js"></script>
  </body>
</html>
```

The script code is as follows:

```
// workers/test_worker_1.ts

function fib(n: number): number {
  return n < 2 ? n : fib(n - 2) + fib(n - 1);
}

function getNumber(): number {
  return Number(
    (document.getElementById("num") as HTMLInputElement)
      .value
  );
}

function showResult(result: number): void {
  document.getElementById("res")!.innerText =
    String(result);
}

function locally(): void {
  showResult(fib(getNumber()));
}
```

The corresponding Fibonacci number is calculated and shown when the user enters a number and clicks on the **Locally** button, but what happens if a fairly large number (say, around 50) is entered? *Figure 5.7* illustrates the problem.


Fibonacci

http://localhost:8887/test_worker_1.html

Fibonacci: 50

Locally

Result:

Page Unresponsive

You can wait for it to become responsive or exit the page.

Fibonacci

Exit page Wait

Figure 5.7 – A long-running process eventually blocks the browser

As the code runs, the page becomes totally unresponsive, and you cannot click anywhere or enter a new number. Furthermore, if a process requires too much processing time, the browser will think there's a problem and offer the user to kill the page… not what we want!

What's the solution? We want to offload the calculation to a worker, which will run in parallel, freeing the browser. Let's see how we'd set this up in not a particularly functional way!

A frontend worker

Workers (see `developer.mozilla.org/en-US/docs/Web/API/Web_Workers_API` for web workers and `nodejs.org/api/worker_threads.html` for Node.js worker threads) work in similar ways. They are plain JavaScript code that can listen to messages, and after doing their work, they respond to their caller by sending another message.

For our Fibonacci calculation, the following would do:

```
// workers/web_fib_worker.ts

function fib(n: number): number {
  return n < 2 ? n : fib(n - 2) + fib(n - 1);
}

onmessage = (e: MessageEvent<number>) =>
  postMessage(fib(e.data));;
```

The last line of the code provides all the interaction between the caller and the worker. On getting a message, `e`, its `e.data` value is passed to the `fib()` function, and the result is posted back to the caller.

How would this be used? *Figure 5.8* shows the result we try to achieve. We now want to allow two ways of calculating Fibonacci numbers: locally, as before, subject to lengthy processing time problems, or in parallel, by offloading the job to a worker.

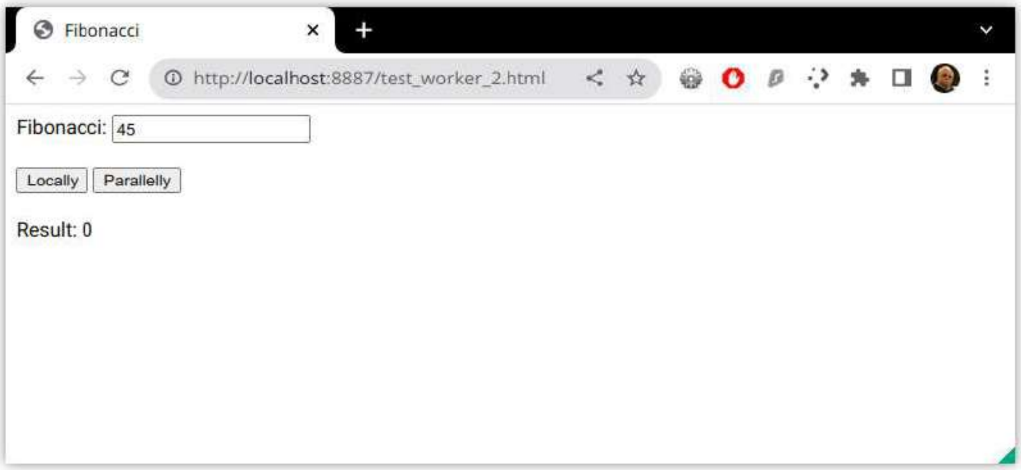


Figure 5.8 – Calculating Fibonacci numbers by using workers as an option

The new code is as follows; we'll highlight the additions:

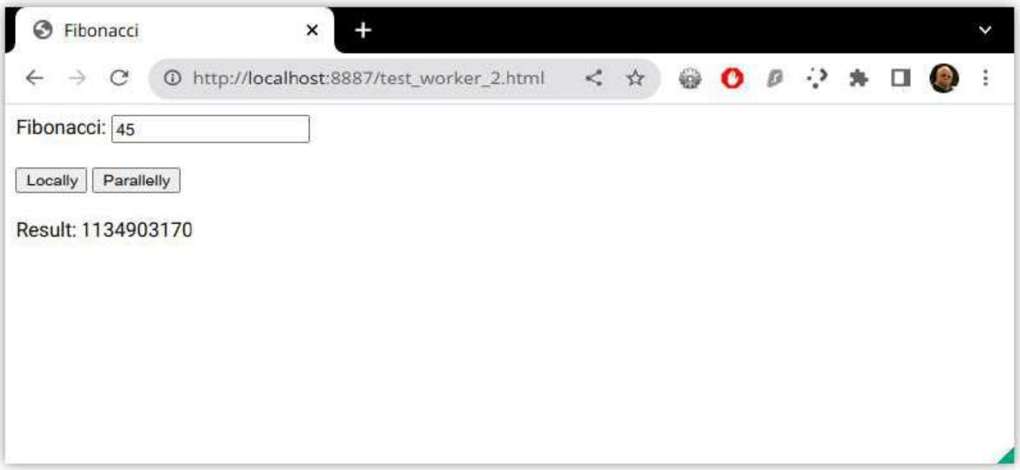
```
// workers/test_worker_2.html

<!DOCTYPE html>
<html lang="en">
  <head>
    <meta charset="UTF-8" />
    <title>Fibonacci</title>
  </head>
  <body>
    Fibonacci:
    <input id="num" type="number" min="0" value="0" />
    <br />
    <br />
    <button onclick="locally()">Locally</button>
    <button onclick="parallelly()">Parallelly</button>
    <br />
    <br />
    Result: <span id="res"></span>

    <script src="test_worker_2.js"></script>
  </body>
</html>
```

The new script file is just like the previous one, with some additions at the end:

```
// workers/test_worker_2.ts

.
.
.

const worker = new Worker(
  "http://localhost:8887/test_fib_worker.js"
);

worker.onmessage = (e: MessageEvent<number>) =>
  showResult(e.data);

/* eslint-disable-next-line */
function parallelly(): void {
  worker.postMessage(getNumber());
}
```

The new `Parallelly` button calls the corresponding `parallelly()` function. This function gets the number that the user entered and posts it via a message to the worker that had been created earlier. The `onmessage` method of that worker receives the calculated result and shows it onscreen.

Using this method, the user can ask for any Fibonacci number, and the window will remain responsive, and no warning will pop up for the user to close the page; see *Figure 5.9*.



Fibonacci: 45

Result: 1134903170

Figure 5.9 – The page remains responsive even as calculations take a long time

OK, using workers clearly helps if you have lots of calculations to perform at the frontend; let's see a similar implementation for the backend.

A backend worker

Let's see a quick example of a backend worker, as we could use with Node.js or similar. The example will be very bare-bones; in real life, we'd include route definitions and much more, but we want to focus on worker creation and usage here.

Our worker is similar to the web worker; the differences are easy to understand:

```
// workers/fib_worker.ts

import { parentPort } from "worker_threads";

function fib(n: number): number {
  return n < 2 ? n : fib(n - 2) + fib(n - 1);
}

parentPort!.on("message", (m: number) =>
  parentPort!.postMessage(fib(m))
);
```

The idea is precisely the same; when the `message` event occurs, we call `fib()` to calculate the corresponding Fibonacci number, and we use `postMessage()` to send it to the caller.

The caller code would be simple too:

```
// workers/fib_worker_test.ts

import { Worker } from "worker_threads";

const worker = new Worker("./fib_worker.js");

console.log("START");
worker.postMessage(40);
console.log("END");

worker.on("message", (msg) => {
  console.log("MESSAGE", msg);
  worker.terminate();
});
```

The code is totally analogous to the frontend code. We create a worker (with the `new Worker()` call), we post a message to it with `postMessage()`, and we listen to the worker's `message` event. When we receive the computed result, we display it, and `terminate()` the worker. Running this code produces the following simple result—the last line takes a while to appear!

```
START
END
MESSAGE 102334155
```

We have seen how to use workers in event-oriented programming, but this isn't particularly suited to our desired FP way of working; let's fix that.

Workers, FP style

Workers are appropriate for FP programming for the following reasons:

Workers run in separate contexts, so they cannot interact with the DOM or global variables.

All communication is done through messages; otherwise, workers are separated from their caller.

- Data passed to and from workers is a copy; it is serialized before it is passed and deserialized when received. Even if the worker were to modify the arguments it received, that wouldn't cause any problem for the caller.

We can work with events, but it would be better to wrap workers in promises so we can apply the `async` functions we developed in the previous section.

Events or promises?

Workers can send multiple messages to their caller. If this is the case, a promise won't be a good idea because it will be resolved after the first result, disregarding future messages. In most cases, a single result is expected, so promises are OK, but keep in mind there are other possibilities.

A direct way to wrap a worker would be the following:

```
// workers/fib_worker_test_with_promise.ts

import { Worker } from "worker_threads";

const callWorker = (filename: string, value: unknown) =>
  new Promise((resolve) => {
    const worker = new Worker(filename);
    worker.on("message", resolve);
    worker.postMessage(value);
  });

console.log("START");
const result = await callWorker("./fib_worker.js", 40);
console.log("AWAITED", result);
console.log("END");

/* Result:
START
AWAITED 102334155
END
*/
```

The `callWorker` object we create is a promise that will resolve when the worker sends back a result. Results are as expected: the `START` text, the `AWAITED` result from the worker, and the `END` text. Note that we are using a point-free style for processing the `message` event.

These code examples work well, but they have a performance issue: every time you call them, a worker is created (meaning that its JavaScript code must be read, parsed, and processed), so there will be delays. Let's think about ways to avoid that.

Long-living pooled workers

Workers can stay unterminated and will be able to receive new messages and reply to them. Messages get queued, so if you need to use the same worker more than once at the same time, there will be a logical delay; calls will go out sequentially. If you need a worker and it's free, you can call it directly, but if you need it and it's occupied, it makes sense to create a new worker. We'll keep a pool of threads, and whenever a call comes in, we'll check whether there's an available worker to deal with it or whether we need to create a new worker first.

Let's see how to do this. First, we'll need a pool:

```
// workers/pool.ts

import { Worker } from "worker_threads";

type PoolEntry = {
  worker: Worker;
  filename: string;
  value: any;
  inUse: boolean;
};

const pool: PoolEntry[] = [];
```

The `PoolEntry` objects will have the following:

- The `worker` object.
- The filename corresponding to the path with which the worker was created.
- The value with which it was called the last time we used this worker (just for logging; we can do without it).
- the `inUse` flag to show whether it's available or not. `pool` is just an array of `PoolEntry` objects.

We need a function that will allow us to call a worker; let's name it `workerCall()`. We'll have to specify the filename of the function to call, and the value to pass to it. The function will first see whether there's an appropriate available free worker (with the same filename and not in use) in a very declarative fashion; if no worker of this kind is found, it will create a new one. Then, the worker will be called by using a promise, as in the previous section, and when a result comes, the worker will be marked as not in use, ready for a new call:

```
// continued...
```

```
export const workerCall = (
  filename: string,
  value: any
): Promise<any> => {
  let available = pool
    .filter((v) => !v.inUse)
    .find((x) => x.filename === filename);

  if (available === undefined) {
    // console.log("CREATING", filename, value);

    available = {
      worker: new Worker(filename),
      filename,
      value,
      inUse: true,
    } as PoolEntry;

    pool.push(available);
  } else {
    // console.log("REUSING", filename, available.value);
  }

  return new Promise((resolve) => {
    available!.inUse = true;
    available!.worker.on("message", (x) => {
      resolve(x);
      available!.inUse = false;
      // console.log("RESOLVING", filename, value, x);
    });
    available!.worker.postMessage(value);
  });
};
```

We can see how this works with our previous Fibonacci worker, plus a new random one that delays a while before returning a random number:

```
// workers/random_worker.ts
```

```
import { parentPort } from "worker_threads";

async function random(n: number): Promise<number> {
  await new Promise((resolve) => setTimeout(resolve, n));
  return Math.floor(n * Math.random());
}

parentPort!.on("message", async (m) =>
  parentPort!.postMessage(await random(m))
);
```

We can verify this works:

```
// workers/pool_test.ts

import { workerCall } from "./pool";

const FIB_WORKER = "./fib_worker.js";
const RANDOM_WORKER = "./random_worker.js";

const showResult = (s: string) => (x: any) =>
  console.log(s, x);

workerCall(FIB_WORKER, 35).then(showResult("fib(35)"));
workerCall(RANDOM_WORKER, 3000).then(showResult("random"));
workerCall(FIB_WORKER, 20).then(showResult("fib(20)"));
workerCall(FIB_WORKER, 44).then(showResult("fib(44)"));
workerCall(FIB_WORKER, 10).then((x) => {
  console.log("fib(10)", x);
  workerCall(FIB_WORKER, 11).then((y) =>
    console.log("fib(11)", y)
  );
});
workerCall(RANDOM_WORKER, 2000).then(showResult("random"));
workerCall(RANDOM_WORKER, 1000).then(showResult("random"));
```

The results of running this code are as follows—but I disabled the `"Resolving"` logging line since I was also logging output in another way:

```
CREATING ./fib_worker.js 35
CREATING ./random_worker.js 3000
CREATING ./fib_worker.js 20
CREATING ./fib_worker.js 44
CREATING ./fib_worker.js 10
CREATING ./random_worker.js 2000
CREATING ./random_worker.js 1000
fib(10) 55
REUSING ./test_fib_worker.js 10
fib(11) 89
fib(20) 6765
fib(35) 9227465
random 602
random 135
random 17
fib(44) 701408733
```

The results of Fibonacci calls come in order; this is logical since we know their calculation time grows. The 3 calls to the random worker take a bit longer, but less than the calculation of the 44th Fibonacci number.

Notice that we didn't ask for the 11th Fibonacci number until the result for the 10th had come in. Our pool correctly detected it had an available worker to use, and it didn't create a new one.

You could explore several extra ideas (see the *Questions* section at the end of this chapter), but we achieved an efficient solution that let us run functional code in parallel with good performance; a nice win!

Summary

In this chapter, we started working with HOFs to show a more declarative way of working with shorter, more expressive code. We went over several operations: we used `reduce()` and `reduceRight()` to get a single result from an array, `map()` to apply a function to each element of an array, `forEach()` to simplify looping, `flat()` and `flatMap()` to work with arrays of arrays, `filter()` to pick elements from an array, `find()` and `findIndex()` to search in the arrays, and `every()` and `some()` (plus a made-up `none()`) to verify general logic conditions. We then considered some unexpected situations when you deal with `async` functions, and we wrote special functions for those cases. Finally, we showed how to do parallel work functionally for extra performance.

In *Chapter 6*, *Producing Functions*, we will continue working with HOFs, but we will write our own ones to gain more expressive power for our coding.

Questions

5.1 **Generating HTML code, with restrictions**: Using the `filter()` → `map()` → `reduce()` sequence is quite common (even though sometimes you won't use all three), and we'll come back to this in the *Functional design patterns* section of *Chapter 11, Implementing Design Patterns*. The problem here is how to use those functions (and no others!) to produce an unordered list of elements (`<ul>...</ul>`) that can later be used onscreen. Your input is an array of characters such as the following (does the list date me?), and you must produce a list of each name that corresponds to chess or checkers players:

```
const characters = [
  { name: "Fred", plays: "bowling" },
  { name: "Barney", plays: "chess" },
  { name: "Wilma", plays: "bridge" },
  { name: "Betty", plays: "checkers" },
  .
  .
  .
  { name: "Pebbles", plays: "chess" },
];
```

The output would be something like the following (although it doesn't matter if you don't generate spaces and indentation). It would be easier if you could use, say, `join()`, but in this case, it won't be allowed; only the three functions mentioned can be used:

```
<div>
  <ul>
    <li>Barney</li>
    <li>Betty</li>
    .
    .
    .
    <li>Pebbles</li>
  </ul>
</div>;
```

5.2 **More formal testing**: In some preceding examples, such as those in the *Emulating map() with reduce()* section, we didn't write actual unit tests but were satisfied with doing some console logging. Can you write appropriate unit tests instead?

5.3 **Reverse by summing**: When we wrote our `reverseString2()` function, we used a summing function for the reduction, but we already had written a `sum()` function in the *Summing an array* section; couldn't we use it here? Why not? How can we solve that?

```
const reverseString2 = (str: string): string =>
  str.split("").reduceRight(sum, "");
```

5.4 **Reversed reverse?**: What would happen with our `reverseString2()` function (see the previous question) if we summed `x` and `y` the reverse way, writing this instead?

```
const reversedReverse = (str: string): string =>
  str.split("").reduceRight((x, y) => y + x, "");
```

5.5 **Ranging far and wide**: The `range()` function we saw here has many uses but lacks a bit of generality. Can you expand it to allow for descending ranges, as in, `range(10,1)`? (What should the last number in the range be?) Could you also include a step size to specify the difference between consecutive numbers in the range? With this, `range(1,10,2)` would produce `[1, 3, 5, 7, 9]`.

5.6 **Range generators**: JavaScript's **generators** allow another solution to our `range()` function. Instead of first generating a whole array of numbers and then processing them, a generator-based solution generates the range numbers one at a time. Can you provide such an implementation?

5.7 **Doing the alphabet**: What would have happened in the *Working with ranges* section if instead of writing `map(x => String.fromCharCode(x))`, you had written `map(String.fromCharCode)`? Can you explain the different behavior? Hint: we have seen a similar problem elsewhere in this chapter.

5.8 **Producing a CSV**: In a certain scenario, you may want to enable the user to download a dataset as a **comma-separated value** (**CSV**) file by using a data URI. (You can read more about this at `en.wikipedia.org/wiki/Data_URI_scheme`.) Of course, the first problem is producing the CSV itself! Assume that you have an array of arrays of numeric values, as shown in the following snippet, and write a function that will transform that structure into a CSV string that you will then be able to plug into the URI. As usual, `\n` stands for the newline character:

```
let myData = [[1, 2, 3, 4], [5, 6, 7, 8], [9, 10, 11, 12]];
let myCSV = dataToCsv(myData);
// "1,2,3,4\n5,6,7,8\n9,10,11,12\n"
```

5.9 **An empty question?**: Check that `flat1()` and `flat2()` work properly if applied to arrays with empty places, such as `[22, , 9, , , 60, , ]`. Why do they work?

5.10 **Producing better output**: Modify the cities query to produce a list of strings that includes not only the name of the city but the state and country as well.

5.11 **Old-style code only!**: Can you rewrite the word-counting solution without using any mapping or reducing? This is more of a JavaScript problem than an FP one, but why not?

5.12 **Filtering... but what?**: Suppose you have an array called `someArray`, and apply the following `filter()` to it, which at first sight doesn't even look like valid JavaScript code. What will be in the new array, and why?

```
let newArray = someArray.filter(Boolean);
```

5.13 **Yet another factorial question**: Does `fact4(0)` produce the correct result, i.e., 1? Why, or why not?

5.14 **Async chaining**: Our `...Async()` functions are not methods; can you modify them and add them to `Array.prototype` so that we can write, for example, `[1,2,3,4].mapAsync(…)`? And by the way, will chaining work with your solution?

5.15 **Missing equivalents**: We wrote `forEach()`, `map()`, `filter()`, and `reduce()` equivalents for `async`, but we didn't do the same for `find()`, `findIndex()`, `some()`, and `every()`; can you?

5.16 **Emptying the pool**: As coded, the pool of workers can only grow in size. What can you do to prevent it from growing indefinitely? Try this idea: whenever there are more than, say, 10 workers not in use, remove some from the pool.

5.17 **Queueing for the pool**: You cannot have an unlimited number of parallel workers running simultaneously. Implement a queueing procedure so that all calls will be accepted, but they will only call a worker when the number of workers in use is below a certain threshold.

5.18 **Showing results**: The `showResult()` function in the last section is interesting; how does it work? It's a function that returns a function; an optimal example of FP!

5.19 **Double filtering?**: In `workerCall()` in the *Long-living pooled workers* section, we wrote the following—is this the best way to find the available workers?

```
  let available = pool
    .filter((v) => !v.inUse)
    .find((x) => x.filename === filename);
```

5.20 **Wishful thinking**: The way we are working with parallel calls, we assume everything will be all right, with no errors or problems. What should you add to make `workerCall()` more suited to real-world problems?

6

Producing Functions – Higher-Order Functions

In *Chapter 5*, *Programming Declaratively*, we worked with some declarative code so that we could gain understandability and more compact, shorter code. In this chapter, we will go further toward **higher-order functions** (**HOFs**) and develop our own. We can roughly classify the results that we are going to get into three groups:

- **Wrapped functions**: These keep their original functionality while adding some kind of new feature. In this group, we can consider logging (adding log production capacity to any function), timing (producing time and performance data for a given function), and memoization of functions and promises (caching results to avoid future rework).
- **Altered functions**: These differ in some key points from their original versions. Here, we can include the `once()` function (we covered this in *Chapter 2*, *Thinking Functionally*), which changes the original function so that it only runs once; functions such as `not()` or `invert()`, which alter what the function returns; arity-related conversions, which produce a new function with a fixed number of parameters; and throttling and debouncing functions for performance.
- **Other productions**: These provide new operations, turn functions into promises, allow enhanced search functions, decouple methods from objects, transform them into plain functions, and go the other way around, converting functions into methods. We shall leave a special case – *transducers* – for *Chapter 8*, *Connecting Functions*.

Wrapping functions – keeping behavior

In this section, we'll consider some HOFs that provide a wrapper around other functions to enhance them in some way but without altering their original objective. In terms of design patterns (which we'll be revisiting in *Chapter 11*, *Implementing Design Patterns*), we can also speak of **decorators**. This pattern is based on the concept of adding some behavior to an object (in our case, a function) without affecting other objects. The term decorator is also popular because of its usage in frameworks, such as Angular, or (in an experimental mode) for general programming in JavaScript.

Waiting for decorators

Decorators are being considered for general adoption in JavaScript. Currently (as of December 2022), they are at Stage 3, Candidate level, so it may still be a while until they get to Stage 4 (Finished, meaning "officially adopted"). You can read more about the proposal for decorators at `tc39.github.io/proposal-decorators/` and about the JavaScript adoption process, called TC39, at `tc39.es/process-document/`. See the *Questions* section in *Chapter 11, Implementing Design Patterns,* for more information.

As for the term *wrapper*, it's more important and pervasive than you might have thought; in fact, JavaScript uses it widely. Where? You already know that object properties and methods are accessed through dot notation. However, you also know that you can write code such as `myString.length` or `22.9.toPrecision(5)`, so where are those properties and methods coming from, given that neither strings nor numbers are objects? JavaScript actually creates a *wrapper object* around your primitive value. This object inherits all the methods that are appropriate to the wrapped value. As soon as the needed evaluation has been done, JavaScript throws away the just-created wrapper. We cannot do anything about these transient wrappers, but there is a concept we will come back to regarding a wrapper that allows methods to be called on things that are not of the appropriate type. This is an interesting idea; see *Chapter 12*, *Building Better Containers*, for more applications of that!

In this section, we'll look at three examples:

- Adding logging to a function
- Getting timing information from functions
- Using caching (*memoizing*) to improve the performance of functions

Let's get to work!

Logging

Let's start with a common problem. When debugging code, you usually need to add some logging information to see whether a function was called, with what arguments, what it returned, and so on. (Yes, of course, you can simply use a debugger and set breakpoints, but bear with me for this example!) Working normally, this means that you'll have to modify the code of the function itself, both at entry and on exit, to produce some logging output. For example, your original code could be something like the following:

```
function someFunction(param1, param2, param3) {
  // do something
  // do something else
  // and a bit more,
  // and finally
  return some expression;
}
```

In this case, you would have to modify it to look like the following. Here, we need to add an `auxValue` variable to store the value that we want to log and return:

```
function someFunction(param1, param2, param3) {
  console.log(
    "entering someFunction: ",
    param1,
    param2,
    param3
  );
  // do something
  // do something else
  // and a bit more,
  // and finally
  const auxValue = ...some expression... ;
  console.log("exiting someFunction: ", auxValue);
  return auxValue;
}
```

If the function can return at several places, you'll have to modify all the `return` statements to log the values to be returned. And if you are just calculating the return expression on the fly, you'll need an auxiliary variable to capture that value.

In the next section, we'll learn about logging and some special cases, such as functions that throw exceptions, and we'll work more purely.

Logging in a functional way

Logging by modifying your functions isn't difficult, but modifying code is always dangerous and prone to accidents. So, let's put our FP hats on and think of a new way of doing this. We have a function that performs some work, and we want to know the arguments it receives and the value it returns.

Here, we can write an HOF that will have a single parameter – the original function – and return a new function that will do the following in sequence:

1. Log the received arguments.
2. Call the original function, catching its returned value.
3. Log that value.
4. Return it to the caller.

A possible solution would be as follows, and let's use plain JavaScript first to focus on the implementation:

```
// logging.ts

function addLogging(fn) {
  return (...args) => {
    console.log(`entering ${fn.name}(${args})`);
    const valueToReturn = fn(...args);
    console.log(`exiting  ${fn.name}=>${valueToReturn}`);
    return valueToReturn;
  };
}
```

The function returned by `addLogging()` behaves as follows:

- The first `console.log(...)` line shows the original function's name and its list of arguments.
- Then, the original function, `fn()`, is called, and the returned value is stored. The second `console.log(...)` line shows the function name (again) and its returned value.
- Finally, the value that `fn()` calculated is returned.

A small comment: If you were doing this for a Node.js application, you would probably opt for a better way of logging than `console.log()` by using libraries such as *Winston*, *Morgan*, or *Bunyan*, depending on what you wanted to log. However, our focus is on how to wrap the original function, and the needed changes for using those libraries would be negligible.

Let's turn to a TypeScript implementation now:

```
// continued...

function addLogging<T extends (...args: any[]) => any>(
  fn: T
): (...args: Parameters<T>) => ReturnType<T> {
  return (...args: Parameters<T>): ReturnType<T> => {
    console.log(`entering ${fn.name}(${args})`);
    const valueToReturn = fn(...args);
    console.log(`exiting  ${fn.name} => ${valueToReturn}`);
    return valueToReturn;
  };
}
```

Our `addLogging()` function applies to a generic function `T` type and returns a new function of precisely the same type: its arguments (`Parameters<T>`) are those of `T`, and its result (`ReturnType<T>`) is also the same type as `T`'s. We will be using this kind of definition many times in this chapter and the rest of the book.

Let's have an example now. We can use `addLogging()` with the upcoming functions—which are written, I agree, in an overly complicated way, just to have an appropriate example! We'll have a function that accomplishes subtraction by changing the sign of the second number and then adding it to the first. And, just to have an error case, we'll have the function throw an error if we attempt to subtract zero. (Yes, of course, you can subtract zero from another number! But I wanted to have some kind of an error-throwing situation at any cost!) The following code does this:

```
// continued...

function subtract(a: number, b: number): number {
  if (b === 0) {
    throw new Error("We don't subtract zero!");
  } else {
    b = changeSign(b);
    return a + b;
  }
}

let changeSign = (a: number): number => -a;

// @ts-expect-error We want to reassign the function
subtract = addLogging(subtract);
subtract(8, 3);
console.log(); // to separate
changeSign = addLogging(changeSign);
subtract(7, 5);
```

What's that `@ts-expect-error` comment? TypeScript rejects the assignment in the following line, saying `Cannot assign to 'subtract' because it is a function.ts(2630)`. This prohibition keeps code safe, but since we are very sure that we won't be changing the `subtract()` type, we can include the comment, and TypeScript will let us get away with it.

The result of executing this would be the following lines of logging:

```
entering subtract(8,3)
exiting  subtract => 5
```

```
entering subtract(7,5)
entering changeSign(5)
exiting  changeSign => -5
exiting  subtract => 2
```

All the changes we had to make in our code were the reassignments of `subtract()` and `changeSign()`, which essentially replaced them everywhere with their new log-producing wrapped versions. Any call to those two functions will produce this output.

This works fine for most functions, but what would happen if the wrapped function threw an exception? Let's take a look.

Taking exceptions into account

Let's enhance our logging function a bit by considering an adjustment. What happens to your log if the function throws an error? Fortunately, this is easy to solve. We have to add a `try/catch` structure, as shown in the following code:

```
// continued...

function addLogging2<T extends (...args: any[]) => any>(
  fn: T
): (...args: Parameters<T>) => ReturnType<T> {
  return (...args: Parameters<T>): ReturnType<T> => {
    console.log(`entering ${fn.name}(${args})`);
    try {
      const valueToReturn = fn(...args);
      console.log(`exiting  ${fn.name}=>${valueToReturn}`);
      return valueToReturn;
    } catch (thrownError) {
      console.log(
        `exiting  ${fn.name}=>threw ${thrownError}`
      );
      throw thrownError;
    }
  };
}
```

With this change, if the function threw an error, you'd also get an appropriate logging message, and the exception would be rethrown for processing. The following is a quick demo of this:

```
try {
  subtract2(11, 0);
} catch (e) {
  /* nothing */
}
/*
entering subtract(11,0)
exiting  subtract=>threw Error: We don't subtract zero!
*/
```

Other changes to get an even better logging output would be up to you – adding date and time data, enhancing the way parameters are listed, and so on. However, our implementation still has an important defect; let's make it better and purer.

Working in a purer way

When we wrote the `addLogging()` function, we ignored some precepts we saw in *Chapter 4*, *Behaving Properly*, because we included an impure element (`console.log()`) in our code. With this, not only did we lose flexibility (would you be able to select an alternate way of logging?), but we also complicated our testing. We could manage to test it by spying on the `console.log()` method, but that isn't very clean: we depend on knowing the internals of the function we want to test instead of doing a purely black-box test. Take a look at the following example for a clearer understanding of this:

```
// logging.test.ts

import { addLogging2 } from "./logging";

describe("a logging function", function () {
  afterEach(() => {
    // so count of calls to Math.random will be OK
    jest.restoreAllMocks();
  });

  it("should log twice with well behaved functions", () => {
    jest.spyOn(global.console, "log");

    let something = (a: number, b: number): string =>
```

```
      `result=${a}:${b}`;

    something = addLogging2(something);

    something(22, 9);
    expect(global.console.log).toHaveBeenCalledTimes(2);
    expect(global.console.log).toHaveBeenNthCalledWith(
      1,
      "entering something(22,9)"
    );
    expect(global.console.log).toHaveBeenNthCalledWith(
      2,
      "exiting  something=>result=22:9"
    );
  });

  it("should report a thrown exception", () => {
    jest.spyOn(global.console, "log");

    let subtractZero = (x: number) => subtract(x, 0);
    subtractZero = addLogging2(subtractZero);

    expect(() => subtractZero(10)).toThrow();
    expect(global.console.log).toHaveBeenCalledTimes(2);
    expect(global.console.log).toHaveBeenNthCalledWith(
      1,
      "entering subtractZero(10)"
    );
    expect(global.console.log).toHaveBeenNthCalledWith(
      2,
      "exiting  subtractZero=>threw Error: We don't subtract
zero!"
    );
  });
  });
});
```

Running this test shows that `addLogging()` behaves as expected, so this is a solution. Our first test just does a simple subtraction and verifies that logging was called with appropriate data. The second test checks that our (purposefully failing) `subtract()` function throws an error to also verify that the correct logs were produced.

Even so, being able to test our function this way doesn't solve the lack of flexibility we mentioned. We should pay attention to what we wrote in the *Injecting impure functions* section in *Chapter 4, Behaving Properly*; the logging function should be passed as an argument to the wrapper function so that we can change it if we need to:

```
// logging3.ts

function addLogging3<T extends (...args: any[]) => any>(
  fn: T,
  logger = console.log.bind(console)
): (...args: Parameters<T>) => ReturnType<T> {
  return (...args: Parameters<T>): ReturnType<T> => {
    logger(`entering ${fn.name}(${args})`);
    try {
      const valueToReturn = fn(...args);
      logger(`exiting  ${fn.name}=>${valueToReturn}`);
      return valueToReturn;
    } catch (thrownError) {
      logger(`exiting  ${fn.name}=>threw ${thrownError}`);
      throw thrownError;
    }
  };
}
```

If we don't do anything, the logging wrapper will produce the same results as in the previous section. However, we could provide a different logger – for example, with Node.js, we could use the *winston* logging tool (see `github.com/winstonjs/winston` for more on it), and the results would vary accordingly:

```
// continued...

function subtract(...) { ... }
let changeSign = ... ;
```

```
// @ts-expect-error We want to reassign the function
subtract = addLogging3(subtract, myLogger);
subtract(8, 3);

console.log(); // to separate

changeSign = addLogging3(changeSign, myLogger);
subtract(7, 5);

/*
{"level":"debug","message":"entering subtract(8,3)"}
{"level":"debug","message":"exiting  subtract=>5"}

{"level":"debug","message":"entering subtract(7,5)"}
{"level":"debug","message":"entering changeSign(5)"}
{"level":"debug","message":"exiting  changeSign=>-5"}
{"level":"debug","message":"exiting  subtract=>2"}
*/
```

The log format is JSON by default. It's more usual to route it to a file for storage, so it isn't so clear as console output, but we could (if needed) reformat it more legibly. However, this suffices for our example, and we won't do anything else.

Now that we have followed our own advice, we can take advantage of stubs. The code for testing is practically the same as before; however, we are using a `dummy.logger()` stub with no provided functionality or side effects, so it's safer all around. In this case, the real function that was being invoked originally, `console.log()`, can't do any harm, but that's not always the case, so using a stub is recommended:

```
// logging3.test.ts

import { addLogging3 } from "./logging3";

describe("addLogging3()", function () {
  it("should call the provided logger", () => {
    const logger = jest.fn();

    let something = (a: number, b: number): string =>
      `result=${a}:${b}`;
    something = addLogging3(something, logger);

    something(22, 9);

    expect(logger).toHaveBeenCalledTimes(2);
    expect(logger).toHaveBeenNthCalledWith(
      1,
      "entering something(22,9)"
    );
    expect(logger).toHaveBeenNthCalledWith(
      2,
      "exiting  something=>result=22:9"
    );
  });

  it("a throwing function should be reported", () => {
    const logger = jest.fn();

    let thrower = () => {
      throw "CRASH!";
    };
    thrower = addLogging3(thrower, logger);

    try {
      thrower();
    } catch (e) {
      expect(logger).toHaveBeenCalledTimes(2);
      expect(logger).toHaveBeenNthCalledWith(
        1,
        "entering thrower()"
      );
      expect(logger).toHaveBeenNthCalledWith(
        2,
        "exiting  thrower=>threw CRASH!"
      );
      }
    });
  });
```

The preceding tests work exactly like the previous ones we wrote earlier (though, for variety, in the *Working in a purer way* section, we used `expect(…).toThrow()`, and here we used a `try/catch` structure to test error-throwing functions). We used and inspected the dummy logger instead of dealing with the original `console.log()` calls. Writing the test in this way avoids all possible problems due to side effects, so it's much cleaner and safer.

When applying FP techniques, remember that if you are somehow complicating your job – for example, making it difficult to test any of your functions – then you must be doing something wrong. In our case, the mere fact that the output of `addLogging()` was an impure function should have raised the alarm. Of course, given the simplicity of the code, in this particular case, you might decide that it's not worth a fix, that you can do without testing, and that you don't need to be able to change the way logging is produced. However, long experience in software development suggests that, sooner or later, you'll come to regret that sort of decision, so try to go with the cleaner solution instead.

Now that we have dealt with logging, we'll look at another need: timing functions for performance reasons.

Timing functions

Another possible application for wrapped functions is to record and log the timing of each function invocation in a fully transparent way. Simply put, we want to be able to tell how long a function call takes, most likely for performance studies. However, in the same way we dealt with logging, we don't want to have to modify the original function and will use an HOF instead.

The three rules for optimization

If you plan to optimize your code, remember the following three rules: *Don't do it*, *Don't do it yet*, and *Don't do it without measuring*. It has been mentioned that a lot of bad code arises from early attempts at optimization, so don't start by trying to write optimal code, don't try to optimize until you recognize the need for it, and don't do it haphazardly without trying to determine the reasons for the slowdown by measuring all the parts of your application.

Along the lines of the preceding example, we can write an `addTiming()` function that, given any function, will produce a wrapped version that will write out timing data on the console but will otherwise work in exactly the same way. Data types are very much what we saw in the previous section, so let's write TypeScript at once:

```
const myGet = (): number => performance.now();

const myPut = (
  text: string,
  name: string,
  tStart: number,
  tEnd: number
): void =>
  console.log(`${name} - ${text} ${tEnd - tStart} ms`);

function addTiming<T extends (...args: any[]) => any>(
  fn: T,
  { getTime, output } = {
    getTime: myGet,
    output: myPut,
  }
): (...args: Parameters<T>) => ReturnType<T> {
  return (...args: Parameters<T>): ReturnType<T> => {
    const tStart = getTime();
    try {
      const valueToReturn = fn(...args);
      output("normal exit", fn.name, tStart, getTime());
      return valueToReturn;
    } catch (thrownError) {
      output("exception!!", fn.name, tStart, getTime());
      throw thrownError;
    }
  };
}
```

Along the lines of the enhancement we applied in the previous section to the logging function, we are providing separate logger and time access functions. Writing tests for our `addTiming()` function should prove easy, given that we can inject both impure functions.

We can see how this works here:

```
// continued...

function subtract(...) { ... }
let changeSign = ... ;
```

```
// @ts-expect-error We want to reassign the function
subtract = addTiming(subtract, myLogger);
subtract(8, 3);

console.log(); // to separate

changeSign = addTiming(changeSign, myLogger);
subtract(7, 5);

/*
subtract - normal exit 0.0217440128326416 ms

changeSign - normal exit 0.0014679431915283203 ms
subtract - normal exit 0.0415341854095459 ms
*/
```

Accuracy matters

Using `performance.now()` provides the highest accuracy. If you don't need such precision as what's provided by that function (arguably, it is overkill), you could use `Date.now()` instead. For more on these alternatives, see `developer.mozilla.org/en-US/docs/Web/API/Performance/now` and `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/Date/now`. Consider using `console.time()` and `console.timeEnd()`; see `developer.mozilla.org/en-US/docs/Web/API/Console/time` for more information.

The preceding code is quite similar to the previous `addLogging()` function, and that's reasonable: in both cases, we add some code before the actual function call and then some new code after the function returns. You might even consider writing a *higher* HOF, which would receive three functions and produce a new HOF as output (such as `addLogging()` or `addTiming()`) that would call the first function at the beginning, and then the second function if the wrapped function returned a value, or the third function if an error had been thrown! How about that?

Memoizing functions

In *Chapter 4*, *Behaving Properly*, we considered the case of the Fibonacci function and learned how we could transform it, by hand, into a much more efficient version using *memoization*: caching calculated values to avoid recalculations. A *memoized* function would avoid redoing a process if the result was found earlier. We want to be able to turn any function into a memoized one so that we can get a more optimized version. However, a real-life memoizing solution should also take into account the available RAM and have some ways of avoiding filling it up; however, this is beyond the scope of this book, and we won't be looking into performance issues either; those optimizations are also beyond the scope of this book.

Of frameworks and memos

Some memoizing functionality is provided by tools such as React (the `useMemo()` hook) or Vue (the `v-memo` directive), but it's not really the same. In these cases, only the previous result is kept, and re-rendering is avoided if a value changes. With the kind of memoization we're discussing, *all* previous values are cached for reuse; React and Vue cache just one value.

For simplicity, let's only consider functions with a single, non-structured parameter and leave functions with more complex parameters (objects and arrays) or more than one parameter for later. The kind of values we can handle with ease are JavaScript's primitive values: data that aren't objects and have no methods. JavaScript has six of these: `boolean`, `null`, `number`, `string`, `symbol`, and `undefined`. Usually, we only see the first four as actual arguments. You can find out more by going to `developer.mozilla.org/en-US/docs/Glossary/Primitive`.

We're not aiming to produce the best-ever memoizing solution, but let's study the subject a bit and produce several variants of a memoizing HOF. First, we'll deal with functions with a single parameter and then consider functions with several parameters.

Simple memoization

We will work with the Fibonacci function we mentioned previously, which is a simple case: it receives a single numeric parameter. This function is as follows:

```
// fibonacci.ts

function fib(n: number): number {
  if (n == 0) {
    return 0;
  } else if (n == 1) {
    return 1;
  } else {
    return fib(n - 2) + fib(n - 1);
  }
}
```

The solution we previously created was general in concept but not particularly good in its implementation: we had to directly modify the function's code to take advantage of said memoization. Let's look into how to do this automatically, in the same fashion as other wrapped functions. The solution would be a `memoize()` function that wraps any other function to apply memoization. For clarity, let's work with JavaScript first and just for functions with a single numeric parameter:

```
// memoize.ts

const memoize = (fn) => {
  const cache = {};
  return (x) =>
    x in cache ? cache[x] : (cache[x] = fn(x));
};
```

How does this work? The returned function, for any given argument, checks whether the argument was already received; that is, whether it can be found as a key in the cache object. (See *Question 6.2* for an alternative implementation of the cache.) If so, there's no need for calculation, and the cached value is returned. Otherwise, we calculate the missing value and store it in the cache. (We use a closure to hide the cache from external access.) Here, we assume that the memoized function receives only one argument (`x`) and that it is a numeric value, which can then be directly used as a key value for the cache object; we'll consider other cases later.

We now need to go to TypeScript; here's the equivalent version of `memoize()`. The generic data typing is along the same lines as what we saw in the *Logging in a functional way* section, with the only difference being that now we work with functions that get a single numeric argument:

```
// continued...

const memoize = <T extends (x: number) => any>(
  fn: T
): ((x: number) => ReturnType<T>) => {
  const cache = {} as Record<number, ReturnType<T>>;
  return (x) =>
    x in cache ? cache[x] : (cache[x] = fn(x));
};
```

Is memoization working? We'll have to time it – and we happen to have a useful `addTiming()` function for that! First, we time the original `fib()` function. We want to time the complete calculation and not each recursive call, so we write an auxiliary `testFib()` function, which is the one we'll time.

We should repeat the timing operations and do an average, but since we just want to confirm that memoizing works, we'll tolerate differences:

```
const testFib = (n: number) => fib(n);
addTiming(testFib)(45); // 18,957 ms
addTiming(testFib)(40); //  1,691 ms
addTiming(testFib)(35); //    152 ms
```

Of course, your times will depend on your specific CPU, RAM, and so on. However, the results seem logical: the exponential growth we mentioned in *Chapter 4*, *Behaving Properly*, appears to be present, and times grow quickly. Now, let's memoize `fib()`. We should get shorter times... shouldn't we?

```
const testMemoFib = memoize((n: number) => fib(n));
addTiming(testMemoFib)(45); // 19,401 ms
addTiming(testMemoFib)(45); //  0.005 ms - good!
addTiming(testMemoFib)(40); //  2,467 ms  ???
addTiming(testMemoFib)(35); //    174 ms  ???
```

Something's wrong! The times should have gone down, but they are just about the same. This is because of a common error, which I've even seen in some articles and web pages. We are timing `testMemoFib()`, but nobody calls that function except for timing, which only happens once! Internally, all recursive calls are to `fib()`, which isn't memoized. If we called `testMemoFib(45)` again, *that* call would be cached, and it would return almost immediately, but that optimization doesn't apply to the internal `fib()` calls. This is the reason why the calls for `testMemoFib(40)` and `testMemoFib(35)` weren't optimized – when we did the calculation for `testMemoFib(45)`, that was the only value that got cached.

The correct solution is as follows:

```
fib = memoize(fib);
addTiming(testFib)(45); // 0.1481 ms
addTiming(testFib)(45); // 0.0022 ms
addTiming(testFib)(40); // 0.0019 ms
addTiming(testFib)(35); // 0.0029 ms
```

Now, when calculating `fib(45)`, all the intermediate Fibonacci values (from `fib(0)` to `fib(45)` itself) are stored, so the forthcoming calls have practically no work to do.

Now that we know how to memoize single-argument functions, let's look at functions with more arguments.

More complex memoization

What can we do if we have to work with a function that receives two or more arguments, or can receive arrays or objects as arguments? Of course, like in the problem that we looked at in *Chapter 2*, *Thinking Functionally*, about having a function do its job only once, we could simply ignore the question: if the function to be memoized is unary, we go through the memoization process; otherwise, we don't do anything!

On the length of functions

The number of parameters of a function is called the function's *arity,* or *valence*, and JavaScript provides it as the function's `length` attribute; see `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Function/length`. You may speak in three different ways: you can say a function has arity one, two, three, and so on; you can say that a function is unary, binary, ternary, and so on; or you can say it's monadic, dyadic, triadic, and so on. Take your pick!

Our first attempt could be just memoizing unary functions and leaving the rest alone, as in the following code:

```
// continued...

const memoize2 = <
  T extends (x: number, ...y: any[]) => any
>(
  fn: T
): ((x: number, ...y: any[]) => ReturnType<T>) => {
  if (fn.length === 1) {
    const cache = {} as Record<number, ReturnType<T>>;
    return (x) =>
      x in cache ? cache[x] : (cache[x] = fn(x));
  } else {
    return fn;
  }
};
```

Working more seriously, if we want to be able to memoize any function, we must find a way to generate cache keys. To do this, we must find a way to convert any argument into a string. We cannot use a non-primitive as a cache key directly. We could attempt to convert the value into a string with something such as `strX = String(x)`, but we'd have problems. With arrays, it seems this could work. However, take a look at the following three cases that involve different arrays but with a twist:

```
var a = [1, 5, 3, 8, 7, 4, 6];
String(a); // "1,5,3,8,7,4,6"

var b = [[1, 5], [3, 8, 7, 4, 6]];
String(b); // "1,5,3,8,7,4,6"
```

```
var c = [[1, 5, 3], [8, 7, 4, 6]];
String(c); // "1,5,3,8,7,4,6"
```

These three cases produce the same result. If we were only considering a single array argument, we'd be able to make do, but when different arrays produce the same key, that's a problem. Things become worse if we have to receive objects as arguments because the `String()` representation of any object is, invariably, `"[object Object]"`:

```
var d = {a: "fk"};
String(d); // "[object Object]"

var e = [{p: 1, q: 3}, {p: 2, q: 6}];
String(e); // "[object Object],[object Object]"
```

The simplest solution is to use `JSON.stringify()` to convert whatever arguments we have received into a useful, distinct string:

```
var a = [1, 5, 3, 8, 7, 4, 6];
JSON.stringify(a); // "[1,5,3,8,7,4,6]"

var b = [[1, 5], [3, 8, 7, 4, 6]];
JSON.stringify(b); // "[[1,5],[3,8,7,4,6]]"

var c = [[1, 5, 3], [8, 7, 4, 6]];
JSON.stringify(c); // "[[1,5,3],[8,7,4,6]]"

var d = {a: "fk"}; JSON.stringify(d); // "{"a":"fk"}"

var e = [{p: 1, q: 3}, {p: 2, q: 6}];
JSON.stringify(e); // "[{"p":1,"q":3},{"p":2,"q":6}]"
```

For performance, our logic should be as follows: if the function we are memoizing receives a single argument that's a primitive value, we can use that argument directly as a cache key. In other cases, we would use the result of `JSON.stringify()` that's applied to the array of arguments. Our enhanced memoizing HOF could be as follows:

```
// continued...

const memoize3 = <T extends (...x: any[]) => any>(
  fn: T
): ((...x: Parameters<T>) => ReturnType<T>) => {
  const cache = {} as Record<
    number | string,
    ReturnType<T>
  >;
  const PRIMITIVES = ["number", "string"];
  return (...args) => {
    const strX: number | string =
      args.length === 1 &&
      PRIMITIVES.includes(typeof args[0])
        ? args[0]
        : JSON.stringify(args);
    return strX in cache
      ? cache[strX]
      : (cache[strX] = fn(...args));
  };
};
```

In terms of universality, this is the safest version. If you are sure about the type of parameters in the function you will process, it's arguable that our first version was faster. On the other hand, if you want to have easier-to-understand code, even at the cost of some wasted CPU cycles, you could go with a simpler version:

```
// continued...

const memoize4 = <T extends (...x: any[]) => any>(
  fn: T
): ((...x: Parameters<T>) => ReturnType<T>) => {
  const cache = {} as Record<string, ReturnType<T>>;
  return (...args) => {
    const strX = JSON.stringify(args);
    return strX in cache
      ? cache[strX]
      : (cache[strX] = fn(...args));
  };
};
```

Birth of a speeder

If you want to learn about the development of a top-performance memoizing function, read Caio Gondim's *How I wrote the world's fastest JavaScript memoization library* article, available online at `blog.risingstack.com/the-worlds-fastest-javascript-memoization-library/`.

So far, we have achieved several interesting memoizing functions, but how will we write tests for them? Let's analyze this problem now.

Memoization testing

Testing the memoization HOF poses an interesting problem – how would you go about it? The first idea would be to look into the cache, but that's private and not visible. Then, of course, we could change `memoize()` so that it uses a global cache or somehow allows external access to the cache, but doing that sort of internal exam is frowned upon: you should try to do your tests based on external properties only.

Accepting that we shouldn't try to examine the cache, we could go for a time control: calling a function such as `fib(n)` for a large value of `n` should take longer if the function isn't memoized. This is certainly possible, but it's also prone to possible failures: something external to your tests could run at just the wrong time, and it could be possible that your memoized run would take longer than the original one. Okay, it's possible, but not probable – but your test isn't entirely reliable.

We could think about calculating some Fibonacci numbers and testing how many times the function was called – once directly and all the other times because of recursion. (See *Question 6.3* for more on this.) The preceding code is fairly straightforward: we are using the Fibonacci function we developed earlier and testing that it produces correct values. For instance, we can find out that calculating `fib(6)` requires 25 calls by revisiting the diagram we looked at in *Chapter 4*, *Behaving Properly*, and seeing that there are 25 nodes (each one representing a call to `fib()`) in it:

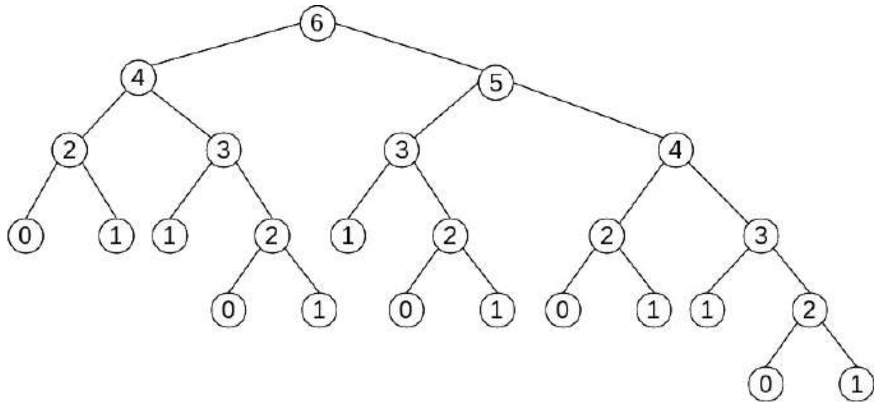


Figure 6.1 – 25 calls are needed for calculating fib(6)

The first idea would be counting calls, as shown here – but it won't work!

```
// memoize.test.ts

import { fib } from "./fibonacci";
import * as moduleFib from "./fibonacci";

describe("the original fib", function () {
  it("should repeat calculations", () => {
    jest.spyOn(moduleFib, "fib");
    expect(fib(6)).toBe(8);
    expect(fib).toHaveBeenCalledTimes(25);
  });
});
```

We first calculate `fib(6)` – which correctly returns `8` – and then we check that there should have been 25 calls to `fib()`, but only one was found; what's going on? The problem is in Jest: when you spy on a function, you are actually spying on a wrapper that calls the function you want to check. *This* wrapper function is called only once; our `fib()` function was called 25 times, but Jest doesn't see that!

We'll have to do something else in a very non-functional way! Let's test a modified `fib()` function that will update an external counter; we'll call it `fibM()`:

```
// continued...

describe("the modified fib", function () {
  it("should repeat calculations", () => {
    let count = 0;

    const fibM = (n: number): number => {
      count++;
      if (n == 0) {
        return 0;
      } else if (n == 1) {
        return 1;
      } else {
        return fibM(n - 2) + fibM(n - 1);
      }
    };
    expect(fibM(6)).toBe(8);
    expect(count).toBe(25);
  });
});
```

Now that the test works out, how about testing the memoized, modified version instead? In this case, the count of calls should be lower because of cached results. In fact, it should just be 7 because we'll need all values from `fib(6)` down to `fib(0)`:

```
// continued...

describe("the memoized, modified fib", function () {
  it("should repeat calculations", () => {
    let count = 0;

    const fibMM = memoize((n: number): number => {
      count++;
      if (n == 0) {
        return 0;
      } else if (n == 1) {
        return 1;
      } else {
        return fibMM(n - 2) + fibMM(n - 1);
      }
    });

    expect(fibMM(6)).toBe(8);
    expect(count).toBe(7);
  });
```

In this section, we've dealt with several examples that implied wrapping functions so that they keep working but with some extra features added in. Now, let's look at a different case where we want to change how a function works.

Memoizing promises

Let's go a bit further and consider memoizing `async` functions, which return promises. In a complex web application with many related components, it may very well be the case that redundant, repeated

API calls go out for no good reason, harming performance and producing a bad user experience. Imagine, for instance, a dashboard-style web page with several tabs. Whenever a user selects a tab, several API calls go out to get the data that the page needs. However, if the user selects a different tab but later returns to the first one, the very same API calls will go out again. For many applications, data is basically constant, meaning "not changing in real time." You don't then need to re-send API calls; re-using previously fetched data also works.

Some solutions are not practical: we could modify the server to enable caching, but what if that's not possible? Or we could work with a cache, checking before every call whether that data was already fetched, but that would entail hand-modifying every single API call to check the cache first! We want a solution that requires no code changes, and memoizing comes to mind.

Assume we call the API with an `async` function that returns a promise. Given the `memoize()` function we developed, we could memoize the `async` function, and it would be a start. The first time you call the function with some arguments, the API call will go out, and a promise will be returned (since that's what the function returns). If you call the function again with the same arguments, the memoized promise will be immediately returned. Great! Except there's a catch… what would happen if the API call failed? We need to add some error-catching logic:

```
// memoize.ts

const promiseMemoize = <
  A,
  T extends (...x: any[]) => Promise<A>
>(
  fn: T
): ((...x: Parameters<T>) => Promise<A>) => {
  const cache = {} as Record<string, Promise<A>>;
  return (...args) => {
    const strX = JSON.stringify(args);
    return strX in cache
      ? cache[strX]
      : (cache[strX] = fn(...args).catch((x) => {
          delete cache[strX];
          return x;
        }));
  };
};
```

All logic is as before, with a couple of additional details:

- We are now making explicit that the memoized function returns a promise (`Promise<A>`) of some generic type `A`
- If the promise is rejected, we add code to delete the cached promise, so a future call will go out again

Our new `promiseMemoize()` function can deal with errors, allowing future retries of rejected calls; good! Now let's look at a different case, where we want to change the way a function actually works.

Altering a function's behavior

In the previous section, we considered some ways of wrapping functions so that they maintain their original functionality, even though they've been enhanced in some way. Now, we'll turn to modifying what the functions do so that the new results will differ from their original ones.

We'll be covering the following topics:

- Revisiting the problem of having a function work, but just once
- Negating or inverting a function's result
- Changing the arity of a function
- Throttling and debouncing functions for performance

Let's get started!

Doing things once, revisited

In *Chapter 2*, *Thinking Functionally*, we went through an example of developing an FP-style solution for a simple problem: fixing things so that a given function works only once. We defined `once()` with an arrow function then; let's go with a standard function for variety:

```
// once.ts

function once<T extends (...args: any[]) => void>(
  f: T
): (...args: Parameters<T>) => void {
  let done = false;

  return ((...args: Parameters<T>) => {
    if (!done) {
      done = true;
```

```
        f(...args);
      }
    }) as T;
  }
```

This is a perfectly acceptable solution; it works well, and we have nothing to object to. We can, however, think of a variation. We could observe that the given function gets called once, but its return value gets lost. This is easy to fix: we need to add a `return` statement. However, that wouldn't be enough; what would the function return if it's called more than once? We can take a page from the memoizing solution and store the function's return value for future calls.

Let's store the function's value in a `result` variable so that we can return it later:

```
// continued...

function once2<T extends (...args: any[]) => any>(
  f: T
): (...args: Parameters<T>) => ReturnType<T> {
  let done = false;
  let result: ReturnType<T>;

  return ((...args: Parameters<T>): ReturnType<T> => {
    if (!done) {
      done = true;
      result = f(...args);
    }
    return result;
  }) as T;
}
```

The first time the function gets called, its value is stored in `result`; further calls just return that value with no further process. You could also think of making the function work only once but for each set of arguments. You wouldn't have to do any work for that – `memoize()` would be enough!

Back in the *Producing an even better solution* section of *Chapter 2*, *Thinking Functionally*, we considered a possible alternative to `once()`: another HOF that took two functions as parameters and allowed the first function to be called only once, calling the second function from that point on. Adding a `return` statement to the previous code and rewriting it as a standard function would result as follows:

```
// continued...
```

```
function onceAndAfter<T extends (...args: any[]) => any>(
  f: T,
  g: T
): (...args: Parameters<T>) => ReturnType<T> {
  let done = false;

  return ((...args: Parameters<T>): ReturnType<T> => {
    if (!done) {
      done = true;
      return f(...args);
    } else {
      return g(...args);
    }
  }) as T;
}
```

We can rewrite this if we remember that functions are first-order objects. Instead of using a flag to remember which function to call, we can use a `toCall` variable to directly store whichever function needs to be called. Logically, that variable will be initialized to the first function but will then change to the second one. The following code implements that change:

```
// continued...

function onceAndAfter2<T extends (...args: any[]) => any>(
  f: T,
  g: T
): (...args: Parameters<T>) => ReturnType<T> {
  let toCall = f;

  return ((...args: Parameters<T>): ReturnType<T> => {
    let result = toCall(...args);
    toCall = g;
    return result;
  }) as T;
}
```

The `toCall` variable is initialized with `f`, so `f()` will get called the first time, but then `toCall` gets the `g` value, implying that all future calls will execute `g()` instead. The very same example we looked at earlier in this book would still work:

```
const squeak = (x: string) => console.log(x, "squeak!!");
const creak = (x: string) => console.log(x, "creak!!");

const makeSound = onceAndAfter2(squeak, creak);

makeSound("door"); // "door squeak!!"
makeSound("door"); // "door creak!!"
makeSound("door"); // "door creak!!"
makeSound("door"); // "door creak!!"
```

In terms of performance, the difference may be negligible. The reason for showing this further variation is to show that you should keep in mind that, by storing functions, you can often produce results more simply. Using flags to store state is a common technique in procedural programming. However, here, we manage to skip that usage and produce the same result. Now, let's look at some new examples of wrapping functions to change their behaviors.

Logically negating a function

Let's consider the `filter()` method from *Chapter 5*, *Programming Declaratively*. Given a predicate, we can filter the array to only include those elements for which the predicate is true. But how would you do a reverse filter and exclude the elements for which the predicate is true?

The first solution should be pretty obvious: rework the predicate to return the opposite of whatever it originally returned. In the mentioned chapter, we looked at the following example:

```
// not.ts

const delinquent = serviceResult.accountsData.filter(
  (v) => v.balance < 0
);
```

(For the `serviceResult` object, see the *A filter() example* section in the previous chapter.)

So, we could write it the other way round, in either of these equivalent fashions. Note the different ways of writing the same predicate to test for non-negative values:

```
// continued...
```

```
const notDelinquent = serviceResult.accountsData.filter(
  (v) => v.balance >= 0
);

const notDelinquent2 = serviceResult.accountsData.filter(
  (v) => !(v.balance < 0)
);
```

That's perfectly fine, but we could also have had something like the following in our code:

```
// continued...

const isNegativeBalance = (v: AccountData) => v.balance < 0;


.
. many lines later
.

const delinquent2 = serviceResult.accountsData.filter(
  isNegativeBalance
);
```

In this case, rewriting the original `isNegativeBalance()` function isn't possible. (Another possibility: the function could be defined in a separate module, which you can't or shouldn't modify.) However, working in a functional way, we can write an HOF that will take any predicate, evaluate it, and then negate its result. A possible implementation would be pretty straightforward, thanks to modern JavaScript syntax – and for the TypeScript version, check *Question 6.5*:

```
// continued...

const not = (fn) => (...args) => !fn(...args);
```

Working in this way, we could have rewritten the preceding filter as follows; to test for non-negative balances, we use the original `isNegativeBalance()` function, which is negated via our `not()` HOF:

```
// continued...

const notDelinquent3 = serviceResult.accountsData.filter(
  not(isNegativeBalance)
);
```

There is an additional solution we might want to try out. Instead of reversing the condition (as we did), we could write a new filtering method (possibly `filterNot()`?) that would work in the opposite way to `filter()`. The following code shows how this new function would be written. Given an `arr` array of values and an `fn` predicate, we'd have the following:

```
// continued...

const filterNot =
  <A, T extends (x: A) => boolean>(arr: A[]) =>
  (fn: T): A[] =>
    arr.filter(not((y) => fn(y)));
```

This solution doesn't fully match `filter()` since you cannot use it as a method, but we could either add it to `Array.prototype` or apply some methods. We'll look at these ideas in *Chapter 8, Connecting Functions*. However, it's more interesting to note that we used the negated function, so `not()` is necessary for both solutions to the reverse filtering problem. In the upcoming *Demethodizing – turning methods into functions* section, we will see that we have yet another solution since we can decouple methods such as `filter()` from the objects they apply to, thereby changing them into common functions.

As for negating the function versus using a new `filterNot()` function, even though both possibilities are equally valid, I think using `not()` is clearer. If you already understand how filtering works, then you can practically read the code aloud, and it will be understandable: we want those accounts that don't have a negative balance, right? Now, let's consider a related problem: inverting the results of a function.

Inverting the results

In the same vein as the preceding filtering problem, let's revisit the sorting problem from the *Injection – sorting it out* section of *Chapter 3, Starting Out with Functions*. Here, we wanted to sort an array with a specific method. Therefore, we used `sort()`, providing it with a `comparison` function that basically pointed out which of the two strings should go first. To refresh your memory, given two strings, the function should do the following:

- Return a negative number if the first string should precede the second one
- Return `0` if the strings are the same
- Return a positive number if the first string should follow the second one

Let's go back to the code we looked at for sorting in Spanish. We had to write a specialized `comparison` function so that sorting would take into account the character-ordering rules from Spanish, such as placing the letter *ñ* between *n* and *o*, and more. The code for this was as follows:

```
const spanishComparison = (a: string, b: string) =>
```

```
  a.localeCompare(b, "es");

palabras.sort(spanishComparison);
// sorts the array according to Spanish rules
```

We are facing a similar problem: how can we sort in descending order? Given what we saw in the previous section, some options should immediately come to mind:

- Sort into ascending order, and afterward reverse the array. While this solves the problem, we still only sort into ascending order, and we would want to avoid the extra reversing step.
- Write a function that will invert the result from the comparing function. This will invert the result of all the decisions as to which string should precede, and the final result will be an array sorted in exactly the opposite way.
- Write a `sortDescending()` function or method that does its work in the opposite fashion to `sort()`.

Let's opt for the second option and write an `invert()` function that will change the comparison result. The code itself is quite similar to that of `not()`. Again, check *Question 6.5* for the TypeScript equivalent:

```
// invert.ts

const invert = (fn) => (...args) => -fn(...args);
```

Given this HOF, we can sort in descending order by providing a suitably inverted `comparison` function. Take a look at the last few lines, where we use `invert()` to change the result of the sorting comparison:

```
const spanishComparison = (a: string, b: string): number =>
  a.localeCompare(b, "es");

const palabras = [
  "ñandú",
  "oasis",
  "mano",
  "natural",
  "mítico",
  "musical",
];
palabras.sort(spanishComparison);
// "mano", "mítico", "musical", "natural", "ñandú", "oasis"
```

```
palabras.sort(invert(spanishComparison));
// "oasis", "ñandú", "natural", "musical", "mítico", "mano"
```

The output is as expected: when we `invert()` the `comparison` function, the results are in the opposite order. Writing unit tests would be quite easy, given that we already have some test cases with their expected results, wouldn't it?

Arity changing

Back in the *Parsing numbers tacitly* section of *Chapter 5*, *Programming Declaratively*, we saw that using `parseInt()` with `reduce()` produces problems because of the unexpected arity of that function, which took more than one argument—remember the example from earlier?

```
["123.45", "-67.8", "90"].map(parseInt);
// [123, NaN, NaN]
```

We have more than one way to solve this. In the mentioned chapter, we went with an arrow function. This was a simple solution, with the added advantage of being clear to understand. In *Chapter 7*, *Transforming Functions*, we will look at yet another, based on partial application. For now, let's go with an HOF We need a function that will take another function as a parameter and turn it into a unary function. Using JavaScript's spread operator and an arrow function, this is easy to manage:

```
const unary = fn => (...args) => fn(args[0]);
```

The following is the example in TypeScript:

```
// arity.ts

const unary =
  <T extends (...x: any[]) => any>(
    fn: T
  ): ((arg: Parameters<T>[0]) => ReturnType<T>) =>
 (x) => fn(x);
```

Our `unary()` function works with a generic `T` function. It produces a new function with just a single argument (the first one, `Parameters<T>[0]`) that returns the same type of result (`ReturnType<T>`) as the original function does.

Using this function, our number parsing problem goes away:

```
["123.45", "-67.8", "90"].map(unary(parseInt));
// [123, -67, 90]
```

It goes without saying that it would be equally simple to define further `binary()` or `ternary()` functions, and others that would turn any function into an equivalent but restricted-arity version. Let's not go overboard and just look at a couple of all the possible functions – see *Question 6.10* for more on this:

```
// continued...

const binary = fn => (...a) => fn(a[0], a[1]);

const ternary = fn => (...a) => fn(a[0], a[1], a[2]);
```

This works, but spelling out all the parameters can become tiresome. We can even go one better by using array operations and spreading and make a generic function to deal with all of these cases, as follows:

```
// continued...

const arity = (n, fn) => (...a) => fn(...a.slice(0, n));
```

With this generic `arity()` function, we can give alternative definitions for `unary()`, `binary()`, and so on. We could even rewrite the earlier functions as follows:

```
const unary = fn => arity(1, fn);
const binary = fn => arity(2, fn);
const ternary = fn => arity(3, fn);
```

You may think that there aren't many cases in which you would want to apply this kind of solution, but there are many more than you would expect. Going through all of JavaScript's functions and methods, you can quickly produce a list starting with `apply()`, `assign()`, `bind()`, `concat()`, `copyWithin()`, and many more! If you wanted to use any of those in a tacit way, you would probably need to fix their arity so that they would work with a fixed, non-variable number of parameters.

Everything under the sun

If you want a nice list of JavaScript functions and methods, check out `developer.mozilla.org/en-US/docs/Web/JavaScript/Guide/Functions` and `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Methods_Index`. As for tacit programming (or pointfree style), we'll return to it in *Chapter 8*, *Connecting Functions*.

There will be a problem with TypeScript, though. TypeScript deals with static typing, but the type of the result of a call to `arity()` is determined at runtime. The most we may manage is, by a series of overloads, to say that given a function with several parameters, the result of applying `arity()` to it will have zero, one, two, and so on different possibilities – but we won't be able to do more.

So far, we have learned how to wrap functions while keeping their original behavior or changing it in some fashion. Now, let's consider some other ways of modifying functions.

Throttling and debouncing

Let's finish this section with two techniques that limit when and how often a function "does its thing": **debouncing** and **throttling**. Both techniques share the same concept, so we'll tackle them together:

- *Debouncing* a function means we delay for some time, doing nothing *until* we actually call the function
- *Throttling* a function means we delay for some time, doing nothing *after* we actually call the function

These techniques are very efficient for web pages and allow for better performance. In a sense, they are related to memoizing. With memoization, you modify a function so it will get called only once (for some given arguments) but never more. With the techniques here, we do not go that far – we will allow a function to do its thing again, but in a restricted way, with some delays added in.

Debouncing functions

The idea of debouncing comes from electronics and involves waiting to do something until a stable state has been reached. For example, if you write an autocomplete component, every time the user types a letter, you could query an API to fetch the possible options. However, you wouldn't want to do this keypress by keypress because you'd be generating lots of calls, most of which you won't even use since you'll only care for the last one you made. Other usual examples involve mouse movement or page scrolling events; you don't want to run associated handlers too often since that will negatively impact the page's performance.

If you debounced the API-calling function, you could still call it for every keypress, but no API call would be made until some time elapsed without any more calls. See *Figure 6.2* for an example of this; events are shown as circles, and the actual call goes only given some event-less time after the last event:

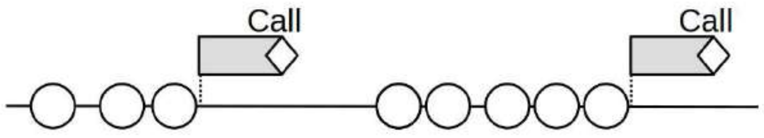


Figure 6.2 – A debounced function executes only after a pause in calls to it

We can implement this with a timeout as follows:

```
// debounce.ts
```

```
const debounce = <T extends (...args: any[]) => void>(
  fn: T,
  delay = 1000
) => {
  let timer: ReturnType<typeof setTimeout>;
  return (...args: Parameters<T>): void => {
    clearTimeout(timer);
    timer = setTimeout(() => fn(...args), timeDelay);
  };
};
```

A debounced function is a new one that can be called as often as desired but won't do anything until a `timer` has run. If you call the function once and then call it again, the timer will be reset and start running again. The only way for the function to actually do its thing is if a given `delay` period passes without any new calls.

Throttling functions

For the complementary throttling transformation, imagine a web form with a **FETCH**, **APPLY FILTERS**, or **RETRIEVE** button. When you click on it, an API call is made to get some data. However, if the user starts clicking again and again, too many calls will be made, even if they will get the same results. We want to throttle the calls so the first call will go through, but further calls will be disabled until some time has passed. A similar use case applies to *infinite scrolling*; as the user scrolls down the page, you want to fetch more data, but you neither want to do it very often for performance reasons nor wait until the user reaches the bottom (as would be the case with debouncing) because then scrolling would be stopped.

Throttling is similar to debouncing, but a throttled function runs but then waits until the next run, while a debounced function first waits and then runs. *Figure 6.3* shows how throttling works. As in the previous section, events are shown as circles. After a call to the API, no further calls are done unless some time has passed:

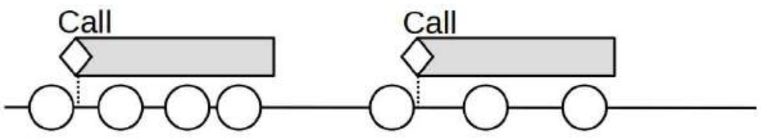


Figure 6.3 – A throttled function runs the first time it's called but then delays until running again

```
// throttle.ts
```

```
const throttle = <T extends (...args: any[]) => void>(
  fn: T,
  delay = 1000
) => {
  let timer: ReturnType<typeof setTimeout> | undefined;
  return (...args: Parameters<T>): void => {
    if (!timer) {
      timer = setTimeout(() => {
        timer = undefined;
      }, delay);
      fn(...args);
    }
  };
};
```

A throttled function is a new one, which you can call as often as desired, but it will "do its thing" the first time and not again until a certain `delay`. When you call the function, it first checks whether the `timer` is set; if so, it won't do anything. If the timer isn't set, a timeout will be set to clear the `timer` after some `delay`, and the function will be called. We are using the `timer` variable both for the timeout and as a flag ("are we waiting?").

So far, we have learned how to wrap functions while keeping their original behavior or by altering them in some fashion. Now, let's consider some other ways of modifying functions.

Changing functions in other ways

Let's end this chapter by considering other sundry functions that provide results, such as new finders, decoupling methods from objects, and more. Our examples will include the following:

- Turning operations (such as adding with the + operator) into functions
- Turning functions into promises
- Accessing objects to get the value of a property
- Turning methods into functions
- A better way of finding optimum values

Turning operations into functions

We have already seen several cases where we needed to write a function just to add or multiply a pair of numbers. For example, in the *Summing an array* section of *Chapter 5*, *Programming Declaratively*, we had to write code equivalent to the following:

```
const mySum = myArray.reduce(
  (x: number, y: number): number => x + y,
  0
);
```

In the *Working with ranges* section of *Chapter 5*, *Programming Declaratively*, we wrote this to calculate a factorial:

```
const factorialByRange = (n: number): number =>
  range(1, n + 1).reduce((x, y) => x * y, 1);
```

It would have been easier if we could just turn a binary operator into a function that calculates the same result. The preceding two examples could have been written more succinctly, as follows. Can you understand the change we made?

```
const mySum = myArray.reduce(binaryOp2("+"), 0);

const factorialByRange = (n: number): number =>
  range(1, n + 1).reduce(binaryOp2("*"), 1);
```

We haven't looked at how `binaryOp()` is implemented yet, but the key notion is that instead of an infix operator (like we use when we write `22+9`), we now have a function (as if we could write our sum like `+(22,9)`, which certainly isn't valid JavaScript). Let's see how we can make this work.

Implementing operations

How would we write this `binaryOp()` function? There are at least two ways of doing so: a safe but long one and a riskier and shorter alternative. The first would require listing each possible operator. The following code does this by using a longish switch:

```
// binaryOp.ts

const binaryOp1 = (op: string) => {
  switch (op) {
    case "+":
      return (x: number, y: number): number => x + y;
    case "-":
      return (x: number, y: number): number => x - y;
    case "*":
      return (x: number, y: number): number => x * y;
    //
    // etc.
    //
    default:
      throw new Error(`Unknown ${op} operator`);
  }
};
```

This solution is perfectly fine but requires too much work. By the way, we should have separate `binaryMathOp()` and `binaryLogicalOp()` functions; the first would be `(op: string) => ((x: number, y: number) => number)` while the second would be `(op: string) => ((x: boolean, y: boolean) => boolean)` because, as in the previous section, TypeScript cannot deduce the type of the returned function.

There's a second solution, which is shorter but more dangerous. Please consider this only as an example for learning purposes; using `eval()` isn't recommended for security reasons! Our second version would use `Function()` to create a new function that uses the desired operator, as follows:

```
// continued...

const binaryOp2 = (op) =>
  new Function("x", "y", `return x ${op} y;`);
```

Again, TypeScript cannot determine the type of the returned function because that will be determined only at runtime. So, we need to write the following:

```
// continued...

const binaryOp2 = (op: string) =>
  new Function("x", "y", `return x ${op} y;`) as (
    x: number,
    y: number
  ) => number;
```

We don't have to specify the type of `binaryOp2()` because TypeScript can work it out to be `(o: string) => (x: number, y: number) => number` by itself, given the cast that we applied to the result.

The (easier) way out

Some libraries, such as Lodash, already provide functions such as `_.multiply()` and `_.sum()`, so that's a more straightforward solution! You could quickly whip up your own and create your own mini-library of mathematical and logical essential functions.

If you follow this train of thought, you may also define a `unaryOp()` function, even though there are fewer applications for it. (I leave this implementation to you; it's similar to what we already wrote.) In *Chapter 7*, *Transforming Functions*, we will look at an alternative way of creating this unary function by using a partial application.

A handier implementation

Let's get ahead of ourselves. Doing FP doesn't always mean getting down to the simplest possible functions. For example, in an upcoming section of this book, we will need a function to check whether a number is negative, and we'll consider (see the *Converting to pointfree style* section of *Chapter 8, Connecting Functions*) using `binaryOp2()` to write it:

```
const isNegative = curry(binaryOp2(">"))(0);
```

Don't worry about the `curry()` function for now (we'll get to it soon, in the following chapter) – the idea is that it fixes the first argument to `0` so that our function will check for a given `n` number if `0>n`. The point is that the function we just wrote isn't very clear. We could do better if we defined a binary operation function that lets us specify one of its parameters – the left or the right one – in addition to the operator to be used. Here, we can write the following couple of functions, which define the functions where the left or right operators are missing:

```
// continued...

const binaryLeftOp =
  (x: number, op: string) => (y: number) =>
    binaryOp2(op)(x, y);

const binaryOpRight =
  (op: string, y: number) => (x: number) =>
    binaryOp2(op)(x, y);
```

With these new functions, we could write either of the following two definitions, though I think the second is clearer. I'd rather test whether a number is less than `0` than whether `0` is greater than the number:

```
const isNegative1 = binaryLeftOp(0, ">");
const isNegative2 = binaryOpRight("<", 0);
```

What is the point of this? Don't strive for some basic simplicity or go down to basics. We can transform an operator into a function, but if you can do better and simplify your coding by specifying one of the two parameters for the operation, just do it! The idea of FP is to help write better code, and creating artificial limitations won't help anybody.

Of course, for a simple function such as checking whether a number is negative, I would never want to complicate things with currying, binary operators, pointfree style, or anything else, and I'd write the following with no further ado:

```
const isNegative3 = (x: number): boolean => x < 0;
```

So far, we have seen several ways of solving the same problem. Keep in mind that FP doesn't force you to pick one way of doing things; instead, it allows you a lot of freedom in deciding which way to go!

Turning functions into promises

In Node.js, most asynchronous functions require a callback such as `(err,data)=>{...}`: if `err` is falsy, the function was successful, and `data` is its result; otherwise, the function failed, and `err` gives the cause. (See `nodejs.org/api/errors.html#error-first-callbacks` for more on this.)

However, you might prefer to work with promises instead. So, we can think of writing an HOF that will transform a function that requires a callback into a promise that lets you use the `then()` and `catch()` methods. (In *Chapter 12*, *Building Better Containers*, we will see that promises are actually *monads*, so this transformation is interesting in yet another way.) This will be an exercise for some developers because Node.js (since version 8) already provides the `util.promisify()` function, which turns an `async` function into a promise. See `nodejs.org/dist/latest-v8.x/docs/api/util.html#util_util_promisify_original` for more on that.

So, how can we manage this? The transformation is relatively simple. Given a function, we produce a new one: this will return a promise that, upon calling the original function with some parameters, will either `reject()` or `resolve()` the promise appropriately.

The `promisify()` function does precisely that. Its parameter is an `fn` function that returns either an `err` error of generic type `E`, or some `data` of generic type `D`. The arguments of `fn` may be any type, except that the last one must be a callback; this requires using *variadic* data types, available in TypeScript since version 4.0, from 2020:

```
// promisify.ts

const promisify =
  <E, T extends any[], D>(
    fn: (...args: [...T, (err: E, data: D) => void]) => void
  ) =>
  (...args: T): Promise<D> =>
    new Promise((resolve, reject) =>
      fn(...args, (err: E, data: D) =>
        err ? reject(err) : resolve(data)
      )
    );
```

The given `fn` function is turned into a promise. The promise calls `fn` with a special callback: if that callback gets a non-null `err` value, the promise is rejected with that error; otherwise, the promise is resolved with `data`.

When working in Node.js, the following style is fairly common:

```
const fs = require("fs");

const cb = (err, data) =>
  err
    ? console.log("ERROR", err)
    : console.log("SUCCESS", data);

fs.readFile("./exists.txt", cb);       // success, data
fs.readFile("./doesnt_exist.txt", cb); // fail, exception
```

You can use promises instead by using our `promisify()` function – or in current versions of Node.js, `util.promisify()` (but see the following, by the end of this section!):

```
const fspromise = promisify(fs.readFile.bind(fs));

const goodRead = (data) =>
  console.log("SUCCESSFUL PROMISE", data);
const badRead = (err) =>
  console.log("UNSUCCESSFUL PROMISE", err);

fspromise("./readme.txt")    // success
  .then(goodRead)
  .catch(badRead);

fspromise("./readmenot.txt") // failure
```

```
  .then(goodRead)
  .catch(badRead);
```

Now, you can use `fspromise()` instead of the original method. To do so, we had to bind `fs.readFile`, as we mentioned in the *An unnecessary mistake* section of *Chapter 3, Starting Out with Functions*.

By the way, when using Node.js, be aware that many modules already provide a promise-based API in addition to the older callback-based API; for example, see `nodejs.org/api/fs.html#promises-api` and compare it to `nodejs.org/api/fs.html#callback-api`.

Getting a property from an object

There is a simple function that we could also produce. Extracting an attribute from an object is a commonly required operation. For example, in *Chapter 5*, *Programming Declaratively*, we had to get latitudes and longitudes to calculate an average. The code for this was as follows:

```
// getField.ts

const markers = [
  { name: "UY", lat: -34.9, lon: -56.2 },
  { name: "AR", lat: -34.6, lon: -58.4 },
  { name: "BR", lat: -15.8, lon: -47.9 },
  // ...
  { name: "BO", lat: -16.5, lon: -68.1 },
];

let averageLat = average(markers.map(x => x.lat));
let averageLon = average(markers.map(x => x.lon));
```

We saw another example when we learned how to filter an array; in our example, we wanted to get the IDs for all the accounts with a negative balance. After filtering out all other accounts, we still needed to extract the `id` field:

```
const delinquent = serviceResult.accountsData.filter(
  (v) => v.balance < 0
);

const delinquentIds = delinquent.map((v) => v.id);
```

What do we need? We need an HOF that will receive the name of an attribute and produce a new function that can extract an attribute from an object. Using the arrow function syntax, this function is easy to write; `f` is the name of the field we want, and `obj` is the object from which to get the field:

```
// getField.ts

const getField = f => obj => obj[f];
```

The full TypeScript version is a bit longer, but not much; mainly, we need to specify that `f` must be a key of the object:

```
// continued...

const getField = <D>(f: keyof D) => (obj: D) => obj[f];
```

With this function, the coordinate extraction process could have been written as follows:

```
let averageLat = average(markers.map(getField("lat")));
let averageLon = average(markers.map(getField("lon")));
```

But that won't be accepted! The issue is that TypeScript cannot detect the type of the result of the call to `getField()` because that will be decided at runtime. We must help by informing it that our two calls will return numbers. We can define the type of a generic number-returning function as `NumFn`, and then write the following:

```
type NumFn = (...args: any[]) => number;

const averageLat2 = average(
  markers.map(getField("lat") as NumFn)
);

const averageLon2 = average(
  markers.map(getField("lon") as NumFn)
);
```

For variety, we could have used an auxiliary variable to get the delinquent IDs and avoid using an extra type similar to `NumFn`, as follows:

```
const getId = getField("id") as (...args: any[]) => string;

const delinquent = serviceResult.accountsData.filter(
  (v) => v.balance < 0
);

const delinquentIds = delinquent.map(getId);
```

Make sure that you fully understand what's going on here. The result of the `getField()` call is a function that will be used in further expressions. The `map()` method requires a mapping function and is what `getField()` produces.

Demethodizing – turning methods into functions

Methods such as `filter()` and `map()` are only available for arrays; however, you may want to apply them to, say, `NodeList` or `String`, and you'd be out of luck. Also, we are focusing on strings, so having to use these functions as methods is not exactly what we had in mind. Finally, whenever we create a new function (such as `none()`, which we saw in the *Checking negatives* section of *Chapter 5, Programming Declaratively*), it cannot be applied in the same way as its peers (`some()` and `every()`, in this case) unless you do some prototype trickery. This is rightly frowned upon and not recommended, but we'll look into it anyhow; another case of "do as I say, not as I do!"

Read the *Extending current data types* section of *Chapter 12*, *Building Better Containers*, where we will make `map()` available for most basic types.

So, what can we do? We can apply the old saying *If the mountain won't come to Muhammad, then Muhammad must go to the mountain*. Instead of worrying about not being able to create new methods, we will turn the existing methods into functions. We can do this if we convert each method into a function that will receive, as its first parameter, the object it will work on.

Decoupling methods from objects can help you because once you achieve this separation, everything turns out to be a function, and your code will be simpler. (Remember what we wrote in the *Logically negating a function* section, regarding a possible `filterNot()` function in comparison to the `filter()` method?) A decoupled method works similarly to generic functions in other languages since they can be applied to diverse data types.

An important ABC: apply, bind, call

Take a look at `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Function` for explanations on `apply()`, `call()`, and `bind()`. We are going to use these for our implementation. Back in *Chapter 1*, *Becoming Functional*, we saw the equivalence between `apply()` and `call()` when we used the spread operator.

There are three distinct but similar ways to implement this decoupling in JavaScript. The first argument in the list (`arg0`) will correspond to the object, and the other arguments (`...args`) to the actual ones for the called method. The three equivalent versions would be as follows, and any of them could be used as a `demethodize()` function; pick your favorite! Let's go with a plain JavaScript version to understand how they work; see *Question 6.15* for TypeScript versions:

```
// demethodize.ts

const demethodize1 =
  (fn) =>
  (arg0, ...args) =>
    fn.apply(arg0, args);

const demethodize2 =
  (fn) =>
  (arg0, ...args) =>
    fn.call(arg0, ...args);

const demethodize3 =
  (fn) =>
  (arg0, ...args) =>
    fn.bind(arg0, ...args)();
```

A fourth way

There's yet another way of doing this: `const demethodize = Function.prototype.bind.bind(Function.prototype.call)`. If you want to understand how this works, read Leland Richardson's *Clever Way to Demethodize Native JS Methods*, at `www.intelligiblebabble.com/clever-way-to-demethodize-native-js-methods`.

Let's look at some applications of these! Let's start with a simple one that will also serve as a warning. We can make the `sort()` method into a function – but don't think it will be made pure!

```
const sort = demethodize1(Array.prototype.sort);
const a = ["delta", "alfa", "beta", "gamma", "epsilon"];
const b = sort(a);
console.log(a, b);

// [ 'alfa', 'beta', 'delta', 'epsilon', 'gamma' ] twice!
```

Now we can use `sort()` as a function – but it still produces the same side effect; `a` and `b` are the same array since `sort()` keeps working "in place."

A more contrived case: we can use `map()` to loop over a string without converting it into an array of characters first. Say you wanted to separate a string into individual letters and make them uppercase; we could achieve this by using `split()` and `toUpperCase()`:

```
const name = "FUNCTIONAL";

const result = name.split("").map((x) => x.toUpperCase());
// ["F", "U", "N", "C", "T", "I", "O", "N", "A", "L"]
```

By demethodizing `map()` and `toUpperCase()`, we can simply write the following:

```
const map = demethodize1(Array.prototype.map);
const toUpperCase = demethodize2(
  String.prototype.toUpperCase
);

const result2 = map(name, toUpperCase);
// ["F", "U", "N", "C", "T", "I", "O", "N", "A", "L"]
```

Yes, of course, for this particular case, we could have turned the string into uppercase and then split it into separate letters, as in `name.toUpperCase().split("")`, but it wouldn't have been such a nice example, with two usages of demethodizing being used.

Similarly, we could convert an array of decimal amounts into properly formatted strings with thousands separators and decimal points:

```
const toLocaleString = demethodize3(
  Number.prototype.toLocaleString
);

const numbers = [2209.6, 124.56, 1048576];

const strings = numbers.map(toLocaleString);
console.log(strings);
/*
[ '2.209,6', '124,56', '1.048.576' ] // Uruguay Locale
*/
```

Alternatively, given the preceding demethodized `map()` function, we could have done the mapping with `map(numbers, toLocaleString)` instead.

The idea of demethodizing a method to turn it into a function will prove to be quite useful in diverse situations. We have already seen some examples where we could have applied it, and there will be more such cases in the rest of this book.

Methodizing – turning functions into methods

In the previous section, we saw how we could separate methods from objects to transform them into independent, standalone functions. Then, for fairness, let's consider the complementary transformation, adding a function (as a method) to objects. We should call this operation *methodizing*, shouldn't we?

We already saw something of this when we defined and worked with polyfills in the *Adding missing functions* section of *Chapter 3, Starting Out with Functions*. Modifying prototypes is usually frowned upon because of the possibility of clashes with different libraries, at the very least. However, it's an interesting technique, so let's study it anyway.

Reversing strings

Let's start with a simple example. Back in the *Folding left and right* section of *Chapter 5, Programming Declaratively,* we defined a `reverseString()` function to reverse a string. Since we already have a `reverse()` method that works with arrays, we could implement a `reverse()` method for strings. For variety, let's do a new implementation of the string-reversing logic. We'll add a Boolean parameter; if set to `true`, the function will add dashes between letters; this is just to show that methodizing also works with functions with more parameters. What we want to achieve is the following:

```
"ABCDE".reverse();     // "EDCBA"
"ABCDE".reverse(true); // "E-D-C-B-A"
```

The needed function is as follows (as a curiosity, note that we are using the array `reverse()` method to implement our `reverse()` string one!):

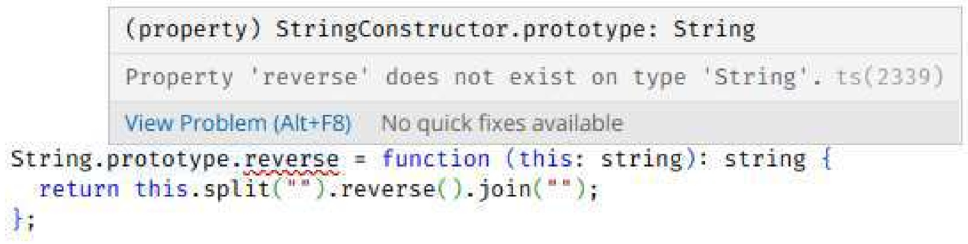
```
// methodize.ts

function reverse(x: string, y = false): string {
  return x
    .split("")
    .reverse()
    .join(y ? "-" : "");
}
```

We used a standard function (instead of an arrow one) because of the implicit handling of `this`, which wouldn't be bound otherwise. Another crucial detail: the first argument to the function must be the string with which it will operate.

Now, we must tell TypeScript that we'll be extending the `String.prototype` object with a new method (see `www.typescriptlang.org/docs/handbook/declaration-files/templates/global-modifying-module-d-ts.html` for more on this):

```
// continued...

declare global {
  interface String {
    reverse(y?: boolean): string;
  }
}
```

Without this definition (which could also have been in a separate `.d.ts` file), when we try to assign the new method, we'll get the error shown in *Figure 6.4*:



```
(property) StringConstructor.prototype: String
Property 'reverse' does not exist on type 'String'. ts(2339)
View Problem (Alt+F8)    No quick fixes available
String.prototype.reverse = function (this: string): string {
  return this.split("").reverse().join("");
};
```

Figure 6.4 – You cannot add new methods to an existing object without an extra definition

How do we add a new method to the `String.prototype` object? In essence, we want to achieve the following:

```
// continued...

String.prototype.reverse = function (
  this: string,
  y
): string {
  return reverse(this, y);
};
```

We add a function that calls our original one. Note that `this` (the current string object) is passed as the first argument. Other parameters are passed untouched. We can implement all this with a `methodize()` function; let's see it first in JavaScript and then get into typing details. We want to do the following to achieve this:

```
// continued...

function methodize(obj, fn) {
  obj.prototype[fn.name] = function (...args) {
    return fn(this, ...args);
  };
}
```

This is what we did before. We are using the function's name for the newly added method's name. In TypeScript, this is a bit more complex, but we need the data type checks, so let's do this:

```
function methodize<
  T extends any[],
  O extends { prototype: { [key: string]: any } },
  F extends (arg0: any, ...args: T) => any
>(obj: O, fn: F) {
  obj.prototype[fn.name] = function (
    this: Parameters<F>[0],
    ...args: T
  ): ReturnType<F> {
    return fn(this, ...args);
  };
}
```

Let's see the data types we added:

- `T` is the generic type of the parameters that we'll pass to our new methodized function
- `O` is the object's type to whose prototype we'll add the new method
- `F` is the function we'll be methodizing; the first argument (`arg0`) is key, and we'll be assigned the value of `this`. The other arguments (if any) are of a `T` type

How do we use this `methodize()` function? Simple, with just one line:

```
methodize(String, reverse);
```

With this, we can use our new method as planned:

```
console.log("MONTEVIDEO".reverse());
// OEDIVETNOM

console.log("MONTEVIDEO".reverse(true));
// O-E-D-I-V-E-T-N-O-M
```

Averaging arrays

Let's see one more example, to highlight a possible detail with typing. We'll take the `average()` function that we wrote in the *Calculating an average* section of *Chapter 5, Programming Declaratively,* and add it to `Array.prototype`:

```
// continued...

function average(x: number[]): number {
  return (
    x.reduce((x: number, y: number) => x + y, 0) / x.length
  );
}
```

The problem is that we want our function to only apply to arrays of numbers. We want TypeScript to detect and reject a line such as the following because of the wrong data type of the array:

```
const xx = ["FK", "ST", "JA", "MV"].average();
```

When writing the global declaration for the added method, an error will pop up:

```
// methodize.ts

declare global {
  // eslint-disable @typescript-eslint/no-unused-vars
  interface Array<T> {
    average(): number;
  }
}
```

The definition of `Array` must be bound to a generic `Array<T>`. However, our definition for `average()` doesn't depend on `T`. This means we have an unused definition to which ESLint objects. Since there's no way of including `T` in our function, we'll have to tell ESLint to let the error be; no other solution!

There's nothing more to this; we can now methodize the `average()` function and use it as a method:

```
methodize(Array, average);

const myAvg = [22, 9, 60, 12, 4, 56].average(); // 27.166667
```

You can now extend all base classes as desired – but remember our advice about being very, very careful!

Finding the optimum

Let's end this section by creating an extension of the `find()` method. Suppose we want to find the optimum value – let's suppose it's the maximum – of an array of numbers. We could make do with this:

```
// optimum.ts

const findOptimum = (arr: number[]): number =>
  Math.max(...arr);

const myArray = [22, 9, 60, 12, 4, 56];
console.log(findOptimum(myArray)); // 60
```

Now, is this sufficiently general? There are at least a pair of problems with this approach. First, are you sure that the optimum of a set will always be the maximum? If you were considering several mortgages, the one with the lowest interest rate would be the best, right? To assume that you always want the maximum of a set is too constrictive.

A negative maximum?

You could do a roundabout trick: if you change the signs of all the numbers in an array, find its maximum, and change its sign, you actually get the minimum of the array. In our case, `-findOptimum(myArray.map((x) => -x))` would correctly produce `4`, but it's not easily understandable code.

Second, this way of finding the maximum depends on each option having a numeric value. But how would you find the optimum if such a value didn't exist? The usual way depends on comparing elements with each other and picking the one that comes out on top:

1. Compare the first element with the second and keep the best of those two.
2. Then compare that value with the third element and keep the best.
3. Keep at it until you have finished going through all the elements.

The way to solve this problem with more generality is to assume the existence of a comparator function, which takes two elements as arguments and returns the best of those. If you could associate a numeric value with each element, the comparator function could simply compare those values. In other cases, it could do whatever logic is needed to decide what element comes out on top.

Let's try to create an appropriate HOF; our newer version will use `reduce()` as follows:

```
// continued...

const findOptimum2 =
  <T>(fn: (x: T, y: T) => T) =>
  (arr: T[]): T =>
    arr.reduce(fn);
```

This generic function takes a comparator that returns the best of two elements of a `T` type and then applies that function to an array of elements of a `T` type to produce the optimum.

With this, we can easily replicate the maximum- and minimum-finding functions; we only have to provide the appropriate reducing functions:

```
const findMaximum = findOptimum2(
  (x: number, y: number): number => (x > y ? x : y)
);

const findMinimum = findOptimum2(
  (x: number, y: number): number => (x < y ? x : y)
);

console.log(findMaximum(myArray)); // 60
console.log(findMinimum(myArray)); // 4
```

Let's go one better and compare non-numeric values. Let's imagine a superhero card game: each card represents a hero and has several numeric attributes, such as `strength`, `powers`, and `tech`. The corresponding class could be the following:

```
class Card {
  name: string;
  strength: number;
  powers: number;
  tech: number;
  constructor(n: string, s: number, p: number, t: number) {
    this.name = n;
    this.strength = s;
    this.powers = p;
    this.tech = t;
  }
}
```

When two heroes fight each other, the winner is the one with more categories with higher values than the other. Let's implement a comparator for this; a suitable `compareHeroes()` function could be as follows:

```
const compareHeroes = (card1: Card, card2: Card): Card => {
  const oneIfBigger = (x: number, y: number): number =>
    x > y ? 1 : 0;

  const wins1 =
    oneIfBigger(card1.strength, card2.strength) +
    oneIfBigger(card1.powers, card2.powers) +
    oneIfBigger(card1.tech, card2.tech);

  const wins2 =
    oneIfBigger(card2.strength, card1.strength) +
    oneIfBigger(card2.powers, card1.powers) +
    oneIfBigger(card2.tech, card1.tech);

  return wins1 > wins2 ? card1 : card2;
};
```

Then, we can apply this to our tournament of heroes. First, let's create our own league of heroes:

```
const codingLeagueOfAmerica = [
  new Card("Forceful", 20, 15, 2),
  new Card("Electrico", 12, 21, 8),
  new Card("Speediest", 8, 11, 4),
  new Card("TechWiz", 6, 16, 30),
];
```

With these definitions, we can write a `findBestHero()` function to get the top hero:

```
const findBestHero = findOptimum2(compareHeroes);

console.log(findBestHero(codingLeagueOfAmerica));
// Electrico is the top Card!
```

Order does matter

When you rank elements according to one-to-one comparisons, unexpected results may be produced. For instance, with our superheroes comparison rules, you could find three heroes where the results show that the first beats the second, the second beats the third, but the third beats the first! In mathematical terms, the comparison function is *not transitive*, and you don't have a *total ordering* for the set.

With this, we have seen several ways of modifying functions to produce newer variants with enhanced processing; think of particular cases you might be facing and consider whether an HOF might help you out.

Summary

In this chapter, we learned how to write HOFs of our own that can either wrap another function to provide some new feature, alter a function's objective so that it does something else, or even provide totally new features, such as decoupling methods from objects or creating better finders. The main takeaway from this chapter is that you have a way of modifying a function's behavior without actually having to modify its own code; HOFs can manage this in an orderly way.

In *Chapter 7*, *Transforming Functions*, we'll keep working with HOFs and learn how to produce specialized versions of existing functions with predefined arguments by using currying and partial application.

Questions

6.1 **Go with arrows**: We implemented `addLogging()` using a function, and its typing was not simple. Just to deal with a different syntax, can you provide an alternate implementation of `addLogging()` but using an arrow function?

6.2 **Mapping for memory**: We implemented our memoizing functions by using an object as a cache. However, using a map would be better; make the necessary changes.

6.3 **How many?** How many calls would be needed to calculate `fib(50)` without memoizing? For example, one call and no further recursion were needed to calculate `fib(0)` or `fib(1)`, and 25 calls were required for `fib(6)`. Can you find a formula to do this calculation?

6.4 **A randomizing balancer**: Write an HOF, that is, `randomizer(fn1, fn2, ...)`, that will receive a variable number of functions as arguments and return a new function that will, on each call, randomly call one of `fn1`, `fn2`, and so on. You could use this to balance calls to different services on a server if each function did an AJAX call. For bonus points, ensure that no function will be called twice in a row.

6.5 **Not in TypeScript**: Write the fully typed TypeScript version of our `not()` and `invert()` functions.

6.6 **Just say no!** In this chapter, we wrote a `not()` function that worked with Boolean functions and a `negate()` function that worked with numerical ones. Can you go one better and write a single `opposite()` function that will behave as `not()` or `negate()`, as needed?

6.7 **Invert tests**: Write some tests for `invert()`, as suggested.

6.8 **Why not shorter?** If we write the `filterNot()` function with a slight change, as shown here, TypeScript will object; why?

```
const filterNot2 =
  <A, T extends (x: A) => boolean>(arr: A[]) =>
  (fn: T): A[] =>
    arr.filter(not(fn));
```

6.9 **Wrong function length**: Our `arity()` function works well, but the produced functions don't have the correct `length` attribute. Can you write a different arity-changing function without this defect?

6.10 **Many arities!** Can you write TypeScript versions of `binary()` and `ternary()`?

6.11 **Throttling promises**: If you memoize an `async` function, every time you call it with the same arguments, you'll get the same promise as a result. But imagine we were calling a weather API, which updates its data every 5 minutes. We don't want to call it just once and never again (as with memoization), but we don't want to call it every time either. Can you add throttling behavior to our `promiseMemoize()` function so, after a given delay, a new call to the API will be made?

6.12 **All operators called**: When writing a full `binaryOp()` function that would work with numbers, what is the list of all the operators you should consider?

6.13 **Missing companion**: If we have a `getField()` function, we should also have a `setField()` function, so can you define it? We'll need both in *Chapter 10, Ensuring Purity*, when we work with getters, setters, and lenses. Note that `setField()` shouldn't directly modify an object; instead, it should return a new object with a changed value – it should be a pure function!

6.14 **A border case**: What happens with our `getField()` function if we apply it to a null object? What should its behavior be? If necessary, modify the function. This question has different answers in JavaScript and TypeScript; be careful!

6.15 **Typed demethodizing**: Provide TypeScript fully typed versions of our trio of `demethodize()` functions. A tip: once you get one of them right, the other two will be pretty similar!

6.16 **Not reinventing the wheel**: When we wrote `findMaximum()` and `findMinimum()`, we wrote our own functions to compare two values – but JavaScript already provides appropriate functions for that! Can you figure out alternative versions of our code based on that hint?

6.17 **Comparing heroes**: Why didn't we just write `const wins2 = 3 - wins1` in our `compareHeroes()` function? Wouldn't that have been faster? Or even better: avoid calculating `wins2` at all, and change the final line to `return wins1 >= 2`?

7
Transforming Functions – Currying and Partial Application

In *Chapter 6*, *Producing Functions*, we saw several ways of manipulating functions to get new versions with some changes in their functionality. In this chapter, we will go into a particular kind of transformation, a sort of **factory method** that lets you produce new versions of any given function.

We will be considering the following:

- **Currying**: A classic FP theoretical function that transforms a function with many parameters into a sequence of unary functions
- **Partial application**: Another time-honored FP transformation, which produces new versions of functions by fixing some of their arguments
- **Partial currying** (a name of my own): Can be seen as a mixture of the two previous transformations

The techniques in this chapter will provide you with a different way of producing functions from other functions. To be fair, we'll also see that some of these techniques can be emulated, possibly with greater clarity, by simple arrow functions. However, since you are liable to find currying and partial application in all sorts of texts and web pages on FP, it is important that you know their meaning and usage, even if you opt for a simpler way out. We'll look at several applications of the ideas in the following sections.

A bit of theory

The concepts we'll discuss in this chapter are in some ways very similar, and in other ways quite different. It's common to find confusion about their real meanings, and plenty of web pages misuse terms. You could even say that all the transformations in this chapter are roughly equivalent since they let you transform a function into another one that fixes some parameters, leaving other parameters free, and eventually leading to the same result. Okay, I agree; this isn't very clear! So, let's start by clearing the air and providing some short definitions, which we will expand on later. (If you feel your eyes are glazing over, please skip this section and return to it later!) Yes, you may find the following descriptions a bit perplexing, but bear with us—we'll go into more detail in just a bit:

- *Currying* is transforming an *m*-ary function (that is, a function of arity *m*) into a sequence of *m* unary functions, each receiving one argument of the original function, from left to right. (The first function receives the first argument of the original function and returns a second function, which receives the second argument and returns a third function, which receives the third argument, and so on.) Upon being called with an argument, each function produces the next one in the sequence, and the last one does the actual calculations.
- *Partial application* is providing *n* arguments to an *m*-ary function, with *n* less than or equal to *m*, to transform it into a function with (*m*-*n*) parameters. Each time you provide some arguments, a new function is produced, with smaller arity. When you provide the last arguments, the actual calculations are performed.
- *Partial currying* is a mixture of both preceding ideas: you provide *n* arguments (from left to right) to an *m*-ary function and produce a new function of arity (*m*-*n*). When this new function receives some other arguments, also from left to right, it will produce yet another function. When the last parameters are provided, the function produces the correct calculations.

In this chapter, we will see these three transformations, what they require, and ways of implementing them.

Currying

We already mentioned *currying* back in the *Arrow functions* section of *Chapter 1, Becoming Functional,* and in the *One argument or many?* section of *Chapter 3*, *Starting Out with Functions*, but let's be more thorough here. Currying is a technique that enables you to only work with single-variable functions, even if you need a multi-variable one.

Currying by any other name?

The idea of converting a multi-variable function into a series of single-variable functions (or, more rigorously, reducing operators with several operands to a sequence of applications of a single operand operator) was worked on by Moses Schönfinkel. Some authors suggest, not necessarily tongue-in-cheek, that currying would be more correctly named *Schönfinkeling*!

In the following sections, we will first see how to deal with functions with many parameters, and then move on to how to curry by hand or by using `bind()`.

Dealing with many parameters

The idea of currying, by itself, is simple. If you need a function with, say, three parameters, you could write something like the following by using arrow functions:

```
// curryByHand.ts

const make3 = (a: string, b: number, c: string): string =>
  `${a}:${b}:${c}`;
```

Alternatively, you can have a sequence of functions, each with a single parameter, as shown here:

```
// continued...

const make3curried =
  (a: string) => (b: number) => (c: string) =>
    `${a}:${b}:${c}`;
```

Alternatively, you might want to consider them as nested functions, like the following code snippet:

```
// continued...

const make3curried2 = function (a: string) {
  return function (b: number) {
    return function (c: string) {
      return `${a}:${b}:${c}`;
    };
  };
};
```

In terms of usage, there's an essential difference in how you'd use each function. While you would call the first in the usual fashion, such as `make3("A",2,"Z")`, that wouldn't work with the second definition. Let's work out why: `make3curried()` is a unary (single parameter), so we should write `make3curried("A")`. But what does this return? According to the preceding definition, this also returns a unary function—and that function also returns a unary function! So, the correct call to get the same result as with the ternary function would be `make3curried("A")(2)("Z")`! See *Figure 7.1*:

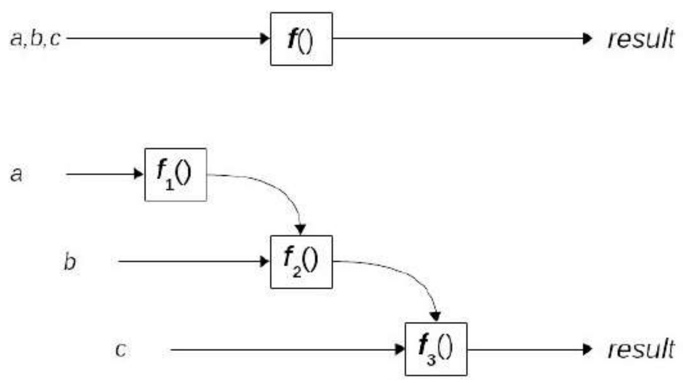


Figure 7.1 – The difference between a common function and a curried equivalent

Study this carefully—we have the first function, and when we apply an argument to it, we get a second function. Applying an argument to it produces a third function, and a final application produces the desired result. This can be seen as a needless exercise in theoretical computing, but it actually brings some advantages because you can then always work with unary functions, even if you need functions with more parameters.

Currying versus uncurrying

Since there is a currying transformation, there is also an uncurrying one! In our case, we would write `make3uncurried = (a, b, c) => make3curried(a)(b)(c)` to reverse the currying process and make it usable once again, to provide all parameters in one sitting.

In some languages, such as Haskell, functions are only allowed to take a single parameter—but then again, the language's syntax allows you to invoke functions as if multiple parameters were permitted. For our example, in Haskell, writing `make3curried "A" 2 "Z"` would have produced `"A:2:Z"` without anybody even needing to be aware that it involved three function calls, each with one of our arguments. Since you don't write parentheses around parameters and don't separate them with commas, you cannot tell that you are not providing a triplet of values instead of three singular ones.

Currying is basic in Scala or Haskell, which are fully functional languages, but JavaScript has enough features to allow us to define and use currying in our work. It won't be as easy since, after all, it's not built-in—but we'll be able to manage.

So, to review the basic concepts, the key differences between our original `make3()` and `make3curried()` functions are as follows:

- `make3()` is a ternary function, but `make3curried()` is unary
- `make3()` returns a string; `make3curried()` returns another function—which itself returns a second function, which returns yet a third function, which finally does return a string

- You can produce a string by writing something like `make3("A",2,"Z")`, which returns `"A:2:Z"`, but you'll have to write `make3curried("A")(2)("Z")` to get the same result

Why would you go to all this bother? Let's look at a simple example, and further on, we will look at more examples. Suppose you had a function that calculated the value-added tax (VAT) for an amount, as shown here:

```
// continued...

const addVAT = (rate: number, amount: number): number =>
  amount * (1 + rate / 100);

addVAT(20, 500); // 600 -- that is, 500 + 20%
addVAT(15, 200); // 230 -- 200 +15%
```

If you had to apply a single, constant rate, you could curry the `addVAT()` function to produce a more specialized version that always applied your given rate. For example, if your national rate was 6%, you could then have something like the following:

```
// continued...

const addVATcurried =
  (rate: number) =>
  (amount: number): number =>
    amount * (1 + rate / 100);

const addNationalVAT = addVATcurried(6);
addNationalVAT(1500); // 1590 -- 1500 + 6%
```

The first line defines a curried version of our VAT-calculating function. Given a tax rate, `addVATcurried()` returns a new function, which, when given an amount of money, finally adds the original tax rate to it. So, if the national tax rate were 6%, `addNationalVAT()` would be a function that added 6% to any amount given to it. For example, if we were to calculate `addNationalVAT(1500)`, as in the preceding code, the result would be `1590`: $1,500, plus 6% tax.

Of course, you are justified in saying that this currying thing is a bit too much just to add a 6% tax, but the simplification is what counts. Let's look at one more example. In your application, you may want to include some logging with a function such as the following:

```
// continued...

```

```
function myLog(severity: string, logText?: string) {
  // display logText in an appropriate way,
  // according to its severity
  // ("NORMAL", "WARNING", or "ERROR")
}
```

However, with this approach, every time you wanted to display a normal log message, you would write `myLog("NORMAL", "some normal text")`, and for warnings, you'd write `myLog("WARNING", "some warning text")`. You could simplify this a bit with currying, by fixing the first parameter of `myLog()` as follows, with a `curry()` function that we'll look at later. Our code could then be as follows:

```
// continued...

myLog = curry(myLog);

const myNormalLog = myLog("NORMAL");
const myWarningLog = myLog("WARNING");
const myErrorLog = myLog("ERROR");
```

What do you gain? Now, you can write `myNormalLog("some normal text")` or `myWarningLog("some warning text")` because you have curried `myLog()` and then fixed its argument, making for simpler, easier-to-read code!

By the way, if you prefer, you could have also achieved the same result in a single step, with the original uncurried `myLog()` function, by currying it case by case:

```
// continued...

const myNormalLog2 = curry(myLog)("NORMAL");
const myWarningLog2 = curry(myLog)("WARNING");
const myErrorLog2 = curry(myLog)("ERROR");
```

So, having a `curry()` function lets you fix some arguments while leaving others still open; let's see how to do this in three different ways.

Currying by hand

Before trying more complex things, we could curry a function by hand, without any special auxiliary functions or anything else. And, in fact, if we want to implement currying for a particular case, there's no need to do anything complex because we can manage with simple arrow functions. We saw that with both `make3curried()` and `addVATcurried()`, so there's no need to revisit that idea.

Instead, let's look into some ways of doing that automatically, so we can produce an equivalent curried version of any function, even without knowing its arity beforehand. Going further, we should code a more intelligent version of a function that could work differently depending on the number of received arguments. For example, we could have a `sum(x,y)` function that behaved as in the following examples:

```
sum(3, 5); // 8; did you expect otherwise?

const add3 = sum(3);
add3(5);   // 8

sum(3)(5); // 8
```

We can achieve that behavior by hand. Our function would be something like the following – and since we won't be using this style, let's stay with plain JavaScript, with no typing:

```
// continued...

const sum = (x, y) => {
  if (x !== undefined && y !== undefined) {
    return x + y;
  } else if (x !== undefined && y == undefined) {
    return (z) => sum(x, z);
  } else {  // x,y both undefined
    return sum;
  }
};
```

Let's recap what we did here. Our curried-by-hand function has this behavior:

- If we call it with two arguments, it adds them and returns the sum; this provides our first use case, as in `sum(3,5)===8`.
- If only one argument is provided, it returns a new function. This new function expects a single argument and will return the sum of that argument and the original one: this behavior is what we expected in the other two use cases, such as `add2(3)===5` or `sum(2)(7)===9`.
- Finally, if no arguments are provided, it returns itself. This means that we would be able to write `sum()(1)(2)` if we desired. (No, I cannot think of a reason for wanting to write that.)

So, we can incorporate currying in the definition itself of a function. However, you'll have to agree that dealing with all the special cases in each function could quickly become troublesome and error-prone. So, let's work out some generic ways of accomplishing the same result without any particular coding.

Currying with bind()

We can find a solution to currying by using the `bind()` method, which we have already applied in several places in this book. This allows us to fix one argument (or more, if need be; we won't need to do that here, but later on we will use it) and provide a function with that fixed argument. Of course, many libraries (such as Lodash, Underscore, Ramda, and others) provide this functionality, but we want to see how to implement that ourselves.

A plain JavaScript version

Our implementation is relatively short but will require some explanation. First, let's see a JavaScript version and deal with TypeScript later:

```
// curry.js

function curry(fn) {
  return fn.length === 0
    ? fn()
    : (x) => curryByBind(fn.bind(null, x));
}
```

Start by noticing that `curryByBind()` always returns a new function, which depends on the `fn` function given as its parameter. If the function has no (more) parameters left (when `fn.length===0`) because all parameters have already been bound, we can evaluate it by using `fn()`. Otherwise, the result of currying the function will be a new function that receives a single argument and produces a newly curried function with another fixed argument. Let's see this in action, with a detailed example, using the `make3()` function we saw at the beginning of this chapter once again:

```
// continued...

const make3 = (a, b, c) => `${a}:${b}:${c}`;

// f1 is the curried version of make3
const f1 = curry(make3);

// f2 is a function that will fix make3's 1st parameter
const f2 = f1("A");
```

```
// f3 is a function that will fix make3's 2nd parameter
const f3 = f2(2);

// "A2Z" will be now calculated, since we are providing
// the 3rd (last) make3's parameter
const f4 = f3("Z");

console.log(f4);
```

The explanation of this code is as follows:

- The first function, `f1()`, has yet to receive any arguments. When called with an argument, it will produce a curried version of `make3()`, with its first argument fixed.
- Calling `f1("A")` produces a new unary function, `f2()`, which will itself produce a curried version of `make3()`—but with its first argument set to `"A"`, so actually, the new function will end up fixing the second parameter of `make3()`.
- Similarly, calling `f2(2)` produces a third unary function, `f3()`, which will produce a version of `make3()`, but fixing its third argument, since the first two have already been fixed.
- Finally, when we calculate `f3("Z")`, this fixes the last parameter of `make3()` to `"Z"`, and since there are no more arguments left, the thrice-bound `make3()` function is called and the `"A:2:Z"` result is produced.

You can do other call sequences as well, such as the following:

```
// continued...

const f2b = f1("TEA")(4);
const f3b = f2b("TWO");
// "TEA:4:TWO"

const f1c = f1("IN")(10)("TION");
// "IN":10:"TION"
```

To curry the function by hand, you could use JavaScript's `.bind()` method. The sequence would be as follows:

```
// continued…

const step1 = make3.bind(null, "A");
const step2 = step1.bind(null, 2);
const step3 = step2.bind(null, "Z");

console.log(step3()); // "A:2:Z"
```

In each step, we provide an additional parameter. (The `null` value is required, to provide context. If it were a method attached to an object, we would provide that object as the first parameter to `.bind()`. Since that's not the case, `null` is expected.) This is equivalent to what our code does, except that the last time, `curryByBind()` does the actual calculation instead of making you do it, as in `step3()`.

A TypeScript version

Now that have implemented this in JavaScript, let's see how to define types for currying. We have to work recursively and consider two cases:

- If we curry a function with just one parameter, the function will directly produce the desired result
- If we curry a function with two or more parameters, we'll create a unary function (with the first parameter) that will return a (curried!) function that will deal with the rest of the parameters:

```
// curry.ts

type Curry<P, R> = P extends [infer H]
  ? (arg: H) => R // only 1 arg
  : P extends [infer H, ...infer T] // 2 or more args
  ? (arg: H) => Curry<[...T], R>
  : never;
```

We will have a generic type with two inputs: `P`, representing the parameters of the function to process, and `R`, standing for the result type of that function. If `P` has just one type, `H`, we return a function that, given an argument of the `H` type, returns a result of the `R` type. If `P` is formed by a first `H` type ("head") and some other `T` types ("tail"), we return a function that will return a (curried) function with `T` types as arguments.

Using this type has an added complexity. TypeScript cannot verify that our `curryByBind()` function works correctly because it cannot deduce that, for every function, we'll eventually produce a result instead of yet another curried function. There's a tricky solution involving an overloaded function with just *one* signature. The key is that the implementation is checked more loosely, and you can use `any` types to get by. Of course, working like this isn't precisely type-safe; it's up to you to ensure that the function is type-correct because you are essentially bypassing TypeScript's checks. We'll have to do this kind of trick more than once in this chapter:

```
// continued...

function curry<A extends any[], R>(
  fn: (...args: A) => R
): Curry<A, R>;
function curry(fn: (...args: any) => any) {
  return fn.length === 0
    ? fn()
    : (x: any) => curry(fn.bind(null, x));
}
```

Let's go back to our `make3()` example. Types work out perfectly well:

```
const f1 = curry(make3);
// (arg: string) => (arg: number) => (arg: string) => string
const f2 = f1("A");
// (arg: number) => (arg: string) => string
const f3 = f2(2);
// (arg: string) => string
const f4 = f3("Z");
// string
```

The type of `f1` is key; it shows that our recursive typing worked as expected. The types of `f2` and `f3` are shorter, and the type of `f4` is the type of the final result, `string`.

Currying tests

Testing this transformation is rather simple because there are not many possible ways of currying:

```
// curry.test.js

describe("with curry", function () {
  it("you fix arguments one by one", () => {
    const make3a = curry(make3);
    const make3b = make3a("A")(2);
    const make3c = make3b("Z");
    expect(make3c).toBe(make3("A", 2, "Z"));
  });
});
```

What else could you test? Maybe functions with just one parameter could be added, but there are no more to try.

Partial application

The second transformation we will be considering lets you fix some of the function's parameters, creating a new function that will receive the rest of them. Let's make this clear with a nonsense example. Imagine you have a function with five parameters. You might want to fix the second and fifth parameters, and partial application would produce a new version of the function that fixed those two parameters but left the other three open for new calls. If you called the resulting function with the three required arguments, it would produce the correct answer by using the original two fixed parameters plus the newly provided three.

Projecting parameters

The idea of specifying only some parameters in function application, producing a function of the remaining parameters, is called **projection**: you are said to be projecting the function onto the remaining arguments. We will not use this term, but I wanted to cite it in case you find it elsewhere.

Let's consider an example using the `fetch()` API, widely considered the modern way to go for Ajax calls. You might want to fetch several resources, always specifying the same parameters for the call (for example, request headers) and only changing the URL to search. By using partial application, you could create a new `myFetch()` function that would always provide fixed parameters.

On fetching

You can read more on `fetch()` at `developer.mozilla.org/en-US/docs/Web/API/Fetch_API/Using_Fetch`. According to `caniuse.com/#search=fetch`, you can use it in most browsers except for (oh, surprise!) Internet Explorer, but you can get around this limitation with a polyfill, such as the one found at `github.com/github/fetch`.

Let's assume we have a `partial()` function that implements this kind of application and let's see how we'd use that to produce our new, specialized version of `fetch()`:

```
const myFetch = partial(fetch, undefined, myParameters);
// undefined means the first argument for fetch
// is not yet defined; the second argument for
// fetch() is set to myParameters

myFetch("a/first/url")
  .then(/* do something */)
  .catch(/* on error */);

myFetch("a/second/url")
  .then(/* do something else */)
  .catch(/* on error */);
```

Currying would have worked if the request parameters had been the first argument for `fetch()`. (We'll have more to say about the order of parameters later.) With partial application, you can replace any arguments, no matter which, so in this case, `myFetch()` ends up as a unary function. This new function will get data from any URL you wish, always passing the same set of parameters for the `GET` operation.

Partial application with arrow functions

Trying to do partial application by hand, as we did with currying, is too complicated. For instance, for a function with 5 parameters, you would have to write code allowing the user to provide any of the 32 possible combinations of fixed and unfixed parameters – 32 being equal to 2 raised to the fifth power. Even if you could simplify the problem, it would still remain hard to write and maintain. See *Figure 7.2* for one of many possible combinations:

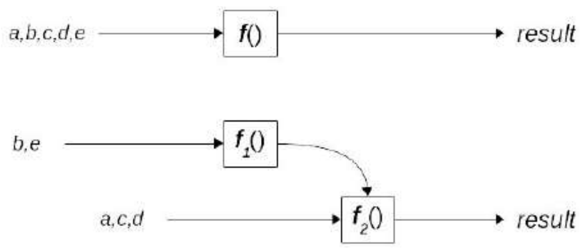


Figure 7.2 – Partial application may let you first provide some parameters, and then provide the rest, to finally get the result

Doing partial application with arrow functions, however, is much simpler. With the example we mentioned previously, we would have something like the following code. In this case, we will assume we want to fix the second parameter to `22` and the fifth parameter to `1960`:

```
const nonsense = (a, b, c, d, e) =>
  `${a}/${b}/${c}/${d}/${e}`;
const fix2and5 = (a, c, d) => nonsense(a, 22, c, d, 1960);
```

Doing partial application this way is quite simple, though we may want to find a more general solution. You can set any number of parameters, by creating a new function out of the previous one but fixing some more parameters. (Wrappers, as in *Chapter 6*, *Producing Functions*, could be used.) For instance, you might now want to also fix the last parameter of the new `fix2and5()` function to `9`, as shown in the following code; there's nothing easier:

```
const fixLast = (a, c) => fix2and5(a, c, 9);
```

You might also have written `nonsense(a, 22, c, 9, 1960)` if you wished to, but the fact remains that fixing parameters by using arrow functions is simple. Let's now consider, as we said, a more general solution.

Partial application with closures

If we want to be able to do partial application fixing of any combination of parameters, we must have a way to specify which arguments are to be left free and which will be fixed from that point on. Some libraries, such as Underscore and Lodash, use a special _ object to signify an omitted parameter. In this fashion, still using the same `nonsense()` function, we would write the following:

```
const fix2and5 = _.partial(nonsense)(_, 22, _, _, 1960);
```

We could do the same sort of thing by having a global variable that would represent a pending, not yet fixed argument, but let's make it simpler and just use `undefined` to represent a missing parameter.

Careful comparison

When checking for `undefined`, remember to always use the `===` operator; with `==`, it happens that `null==undefined`, and you don't want that. See `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/undefined` for more on this.

We want to write a function that will partially apply some arguments and leave the rest open for the future. We want to write code similar to the following and produce a new function in the same fashion as we did earlier with arrow functions:

```
const nonsense = (a, b, c, d, e) =>
  `${a}/${b}/${c}/${d}/${e}`;

const fix2and5 = partial(nonsense)(
  undefined,
  22,
  undefined,
  undefined,
  1960
);
```

```
// fix2and5 would become
//     (X0, X2, X3) => nonsense(X0, 22, X2, X3, 1960);
```

How will we do this? Our implementation will use closures. (You may want to review that topic in *Chapter 1*, *Becoming Functional*.) This way of doing partial application will behave in a fashion somewhat reminiscent of currying in the sense that each function will produce a new one with some more fixed parameters. Our new implementation would be as follows – and once again, let's start with plain JavaScript:

```
// partial.js

function partial(fn) {
  const partialize =
    (...args1) =>
    (...args2) => {
      for (
        let i = 0;
        i < args1.length && args2.length;
        i++
      ) {
        if (args1[i] === undefined) {
          args1[i] = args2.shift();
        }
      }
      const allParams = [...args1, ...args2];
      return allParams.includes(undefined) ||
        allParams.length < fn.length
        ? partialize(...allParams)
        : fn(...allParams);
    };

  return partialize();
}
```

Wow—a longish bit of code! The key is the inner `partialize()` function. Given a list of parameters (`args1`), it produces a function that receives a second list of parameters (`args2`):

- First, it replaces all possible `undefined` values in `args1` with values from `args2`

- Then, if any parameters are left in `args2`, it also appends them to those of `args1`, producing `allParams`
- Finally, if `allParams` does not include any more `undefined` values and is sufficiently long, it calls the original function
- Otherwise, it partializes itself to wait for more parameters

An example will make it more clear. Let's go back to our trusty `make3()` function and construct a partial version of it:

```
const make3 = (a: string, b: number, c: string): string =>
  `${a}:${b}:${c}`;

const f0 = partial(make3);
const f1 = f0(undefined, 2);
```

The `f1()` function gets `[undefined, 2]` as parameters. Now, let's create a new function:

```
const f2 = f1("A");
```

What happens? The previous list of parameters (`[undefined, 2]`) gets merged with the new list (a single element—in this case, `["A"]`), producing a function that now receives `"A"` and `2` as its first two arguments. However, this isn't yet ready, because the original function requires three arguments. We can write the following:

```
const f3 = f2("Z");
```

Then, the current list of arguments would be merged with the new argument, producing `["A",2,"Z"]`. Since the list is now complete, the original function will be evaluated, producing `"A:2:Z"` as the final result.

There are significant similarities between the structure of this code and the other higher-order function we wrote earlier in the *Currying with bind()* section:

- If all the arguments have been provided, the original function is called
- Otherwise, if some arguments are still required (when currying, it's just a matter of counting arguments by checking the function's `length` property; when doing partial application, you must also consider the possibility of having some `undefined` parameters), the higher-order function calls itself to produce a new version of the function, which will wait for the missing arguments

Let's get now to a TypeScript version with its data typing.

Partial data types

We'll use an auxiliary type, `Partialize<P,A>`. If `P` is the tuple of the parameter types for the function, and `A` is the tuple of the argument types for a function call, `Partialize<>` will return a tuple with the types in `P` for which there is an `undefined` type in `A`:

```
// partial.ts

type Partialize<
  P extends any[],
  A extends any[]
> = 0 extends P["length"]
  ? []
  : 0 extends A["length"]
  ? P
  : [P, A] extends [
      [infer PH, ...infer PT],
      [infer AH, ...infer AT]
    ]
  ? AH extends undefined
    ? [PH, ...Partialize<PT, AT>]
    : [...Partialize<PT, AT>]
  : never;
```

How does this work?

- If `P` is empty, the output is empty as well.
- If `A` is empty (there are no more arguments left), the output is `P`.
- If `P` is split in `PH` (head) and `PT` (tail), and `A` is similarly split in `AH` and `AT`, then if `AH` is `undefined`, we return a new type that includes `PH` (because no value was given for it) and `Partialize<PT,AT>`, to recursively process the rest of both tuples. Otherwise, if `AH` is not `undefined`, we provide a value for the corresponding parameter, so the result is `Partialize<PT,AT>`; we don't have to care about the parameter corresponding to `PH`.

Using recursion makes this harder to understand; let's see some examples:

```
// continued...

type p00 = Partialize<
```

```
  [boolean, number, string],
  [undefined, undefined, undefined]
>; // [boolean, number, string]

type p01 = Partialize<
  [boolean, number, string],
  [boolean, undefined, undefined]
>; // [number, string]

type p02 = Partialize<
  [boolean, number, string],
  [undefined, string, undefined]
>; // [boolean, string]

type p03 = Partialize<
  [boolean, number, string],
  [undefined, undefined, string]
>; // [boolean, number]

type p04 = Partialize<
  [boolean, number, string],
  [boolean, undefined, string]
>; // [number]

type p05 = Partialize<[boolean, number, string], [boolean]>;
// [number, string]

type p06 = Partialize<[boolean, number, string], []>;
// [boolean, number, string]
```

For instance, the `p04` type shows that if you have a function that expects three parameters – `boolean`, `number`, and `string` – and you call it with a `boolean`, an `undefined` value, and a `string`, the partialized function will have just a `number` parameter. The `p05` type shows that if you had called that function with just a `boolean`, the partialized function would have a `number` and a `string` as parameters.

This isn't totally right, however. Let's say we had written the following instead:

```
type p04 = Partialize<
  [boolean, number, string],
  [string, undefined, number]
>; // [number]
```

The result would have been the same; we are checking that we have the right number of arguments, but not their types. Let's have another auxiliary type check:

```
// continued...

type TypesMatch<
  P extends any[],
  A extends any[]
> = 0 extends P["length"]
  ? boolean
  : 0 extends A["length"]
  ? boolean
  : [P, A] extends [
      [infer PH, ...infer PT],
      [infer AH, ...infer AT]?
    ]
  ? AH extends undefined
    ? TypesMatch<PT, AT>
    : PH extends AH
    ? TypesMatch<PT, AT>
    : never
  : never;
```

`TypesMatch` gets two lists of types, `P` and `A`:

- If any of the lists is empty, that's OK.
- If both lists are not empty, it splits them in head and tail as `PH` and `PT`, and `AH` and `AT`. If `AH` is `undefined`, or if it matches `PH`, then `TypesMatch<>` keeps going to analyze both tails.
- If `AH` isn't `undefined` but doesn't match `PH`, `never` (which implies an error) is generated.

We can now write the `Partial<>` generic type using this auxiliary definition:

```
// continued...

type Partial<P extends any[], R> = <A extends any[]>(
  ...x: A
) => TypesMatch<P, A> extends never
  ? never
  : P extends any[]
  ? 0 extends Partialize<P, A>["length"]
    ? (...x: [...P]) => R
    : Partial<Partialize<P, A>, R>
  : never;
```

Here, `P` stands for the types of the function's parameters, `R` for its result type, and `A` for the types of the function's arguments. We first check whether `P` and `A` match types. If so, if `Partialize<P,A>` is empty, we return a `(...x: [...P]) => R` function; otherwise, we (recursively) return a function with `Partialize<P,A>` parameter types.

Finally, we have all we need for our TypeScript version of `partial()`:

```
// continued...

function partial<P extends any[], R>(
  fn: (...a: P) => R
): Partial<P, R>;
function partial(fn: (...a: any) => any) {
  const partialize =
    (...args1: any[]) =>
    (...args2: any[]) => {
      for (
        let i = 0;
        i < args1.length && args2.length;
        i++
      ) {
        if (args1[i] === undefined) {
          args1[i] = args2.shift();
        }
      }
      const allParams = [...args1, ...args2];
      return allParams.includes(undefined) ||
        allParams.length < fn.length
        ? partialize(...allParams)
        : fn(...allParams);
    };
  return partialize();
}
```

It's worth noting that, as in the currying examples, we use several `any` types because TypeScript isn't really very good at working with recursion. This implies that we must be extra careful with our code because there will be no way of detecting errors.

Partial testing

Let's finish this section by writing some tests. Here are some things we should consider:

- When we do partial application, the arity of the produced function should decrease
- The original function should be called when arguments are in the correct order

We could write something like the following, allowing the fixing of arguments in different places. Instead of using a spy or mock, we can directly work with the `nonsense()` function we had because it's quite efficient:

```
// partial.test.ts

function nonsense(
  a: number,
  b: number,
  c: number,
  d: number,
  e: number
) {
  return `${a}/${b}/${c}/${d}/${e}`;
}

describe("with partial()", function () {
  it("you could fix no arguments", () => {
    const nonsensePC0 = partial(nonsense);
    expect(nonsensePC0(0, 1, 2, 3, 4)).toBe(
      nonsense(0, 1, 2, 3, 4)
    );
  });

  it("you could fix only some initial arguments", () => {
    const nonsensePC1 = partial(nonsense)(1, 2, 3);
    expect(nonsensePC1(4, 5)).toBe(nonsense(1, 2, 3, 4,
      5));
  });

  it("you could skip some arguments", () => {
    const nonsensePC2 = partial(nonsense)(
      undefined,
      22,
      undefined,
      44
    );
    expect(nonsensePC2(11, 33, 55)).toBe(
      nonsense(11, 22, 33, 44, 55)
    );
  });

  it("you could fix only some last arguments", () => {
    const nonsensePC3 = partial(nonsense)(
      undefined,
      undefined,
      undefined,
      444,
      555
    );
    expect(nonsensePC3(111, 222, 333)).toBe(
      nonsense(111, 222, 333, 444, 555)
    );
  });
  it("you could fix ALL the arguments", () => {
    const nonsensePC4 = partial(nonsense)(6, 7, 8, 9, 0);
    expect(nonsensePC4).toBe(nonsense(6, 7, 8, 9, 0));
  });

  it("you could work in steps - (a)", () => {
    const nonsensePC5 = partial(nonsense);
    const nn = nonsensePC5(undefined, 2, 3);
    const oo = nn(undefined, undefined, 5);
    const pp = oo(1, undefined);
    const qq = pp(4);
    expect(qq).toBe(nonsense(1, 2, 3, 4, 5));
  });

  it("you could work in steps - (b)", () => {
    const nonsensePC6 = partial(nonsense)(undefined, 2, 3)(
      undefined,
      undefined,
      5
    )(
      1,
      undefined
    )(4);
    expect(nonsensePC6).toBe(nonsense(1, 2, 3, 4, 5));
  });
});
```

We have now seen currying and partial application; let's see our third and last transformation, a hybrid of our previous ones.

Partial currying

The last transformation we will look at is a mixture of currying and partial application. If you google it, in some places, you will find it called currying, and in others, partial application, but as it happens, it fits neither, so I'm sitting on the fence and calling it *partial currying*!

Given a function, the idea is to fix its first few arguments and produce a new function that will receive the rest of them. However, if that new function is given fewer arguments, it will fix whatever it was given and produce a newer function to receive the rest of them, until all the arguments are given and the final result can be calculated. See *Figure 7.3*:

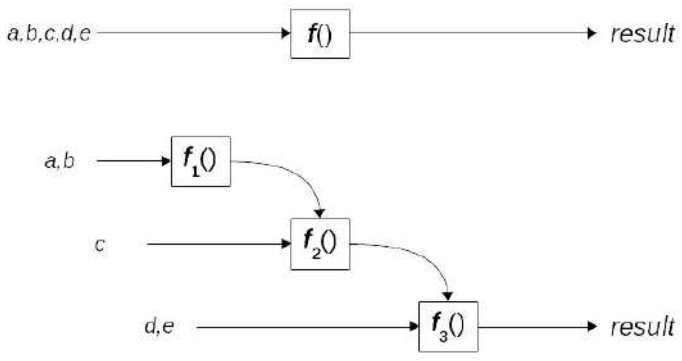


Figure 7.3 – Partial currying is a mixture of currying and partial application. You may provide arguments from the left, in any quantity, until all have been provided, and then the result is calculated

To look at an example, let's go back to the `nonsense()` function we have been using in previous sections, as follows. Assume we already have a `partialCurry()` function:

```
const nonsense = (a, b, c, d, e) =>
  `${a}/${b}/${c}/${d}/${e}`;

const pcNonsense = partialCurry(nonsense);

const fix1And2 = pcNonsense(9, 22);
// fix1And2 is now a ternary function

const fix3 = fix1And2(60);
// fix3 is a binary function

const fix4and5 = fix3(12, 4);
// fix4and5 === nonsense(9,22,60,12,4), "9/22/60/12/4"
```

The original function had an arity of `5`. When we partially curry that function and give it arguments of `9` and `22`, it becomes a ternary function, because out of the original five parameters, two have become fixed. If we take that ternary function and give it a single argument, `(60)`, the result is yet another function: in this case, a binary one, because now we have fixed the first three of the original five parameters. The final call, providing the last two arguments, then does the job of actually calculating the desired result.

There are some points in common with currying and partial application, but also some differences, as follows:

- The original function is transformed into a series of functions, each producing the next one until the last in the series actually carries out its calculations.
- You always provide parameters starting from the first one (the leftmost one), as in currying, but you can provide more than one, as in partial application.
- When currying a function, all the intermediate functions are unary, but with partial currying, that need not be so. However, if in each instance we were to provide a single argument, then the result would require as many steps as plain currying.

So, we have our definition—let's now see how we can implement our new higher-order function; we'll probably be reusing a few concepts from the previous sections in this chapter.

Partial currying with bind()

Similar to what we did with currying, there's a simple way to do partial currying. We will take advantage of the fact that `bind()` can actually fix many arguments at once, and we'll look at JavaScript code first for clarity:

```
// partialCurry.js

function partialCurry(fn) {
  return fn.length === 0
    ? fn()
    : (...x) => partialCurry(fn.bind(null, ...x));
}
```

Compare the code to the previous `curry()` function and you'll see the main, but very small, differences:

```
function curry(fn) {
  return fn.length === 0
    ? fn()
    : (x) => curry(fn.bind(null, x));
}
```

The mechanism is exactly the same. The only difference is that in our new function, we can bind many arguments simultaneously, while in `curry()`, we always bind just one.

In a sense, the TypeScript version is akin to the one for `partial()`. The provided arguments must match the types of the original function parameters, so we'll use again our `TypesMatch<>` type from the previous section. If the original function had several parameters, and we provide a few of them, we need to figure out the rest – our `Minus<>` type will do that:

```
// partialCurry.ts

type Minus<X, Y> = [X, Y] extends [
  [any, ...infer XT],
  [any, ...infer YT]
]
  ? Minus<XT, YT>
  : X;
```

Basically, if both types have more than one element, we ignore the first ones and process the tails of both types; otherwise, we return the first. With this, we can write the `PartialCurry<>` type:

```
// partialCurry.ts

type PartialCurry<P extends any[], R> = <A extends any[]>(
  ...x: A
) => TypesMatch<P, A> extends never
  ? never
  : P extends any[]
  ? A["length"] extends P["length"]
    ? R
    : PartialCurry<Minus<P, A>, R>
  : never;
```

If types don't match (a wrong type argument was provided), the result is an error, `never`. Otherwise, if we've provided enough arguments, the original `R` result type will be produced; if not, we'll produce a new function with fewer parameters by recursion and using `Minus<>`.

We can revisit our earlier example with the `make3()` function, and the only difference is that we can get results in fewer steps – or more, as in the little sensical `h7` example!

```
const h1 = partialCurryByBind(make3);

const h2 = h1("A");
const h3 = h2(2, "Z");
console.log(h3); // A:2:Z
```

```
const h5 = h1("BE", 4);
const h6 = h5("YOU");
console.log(h6); // BE:4:YOU

const h7 = h5()()()("ME");
console.log(h7); // B:4:ME
```

By the way, and just to be aware of the existing possibilities, you can fix some parameters when currying, as shown here:

```
const h8 = partialCurryByBind(make3)("I",8);
const h9 = h8("SOME");
console.log(h9); // I:8:SOME
```

Testing this function is easy, and the examples we provided are a very good starting point. Note, however, that since we allow fixing any number of arguments, we cannot test the arity of the intermediate functions. Our tests could be as follows, then:

```
// partialCurry.test.ts

describe("with partialCurryByBind", function () {
  it("you could fix arguments in several steps", () => {
    const make3a = partialCurryByBind(make3);
    const make3b = make3a("MAKE", 1);
    const make3c = make3b("TRY");
    expect(make3c).toBe(make3("MAKE", 1, "TRY"));
  });

  it("you could fix arguments in a single step", () => {
    const make3a = partialCurryByBind(make3);
    const make3b = make3a("SET", 2, "IT");
    expect(make3b).toBe(make3("SET", 2, "IT"));
  });

  it("you could fix ALL the arguments", () => {
    const make3all = partialCurryByBind(make3);
    expect(make3all("SOME", 1, "KNOWS")).toBe(
      make3("SOME", 1, "KNOWS")
    );
  });

  it("you could fix one argument at a time", () => {
    const make3one =
      partialCurryByBind(make3)("READY")(2)("GO");
    expect(make3one).toBe(make3("READY", 2, "GO"));
  });
});
```

Partial currying with closures

As with partial application, there's a solution that works with closures. Since we have gone over many of the required details, let's jump directly into the code, the JavaScript version first:

```
// partialCurry.js

const partialCurryByClosure = (fn) => {
  const curryize =
    (...args1) =>
    (...args2) => {
      const allParams = [...args1, ...args2];
      return allParams.length < fn.length
        ? curryize(...allParams)
        : fn(...allParams);
    };

  return curryize();
};
```

If you compare `partialCurryByClosure()` and `partial()`, the main difference is that with partial currying, since we are always providing arguments from the left and there is no way to skip some, you concatenate whatever arguments you had with the new ones, and check whether you got enough. If the new list of arguments has reached the expected arity of the original function, you can call it and get the final result. In other cases, you just use `curryize()` (in `partial()`, we had a similar `partialize()` function) to get a new intermediate function, which will wait for more arguments.

With TypeScript, we don't need any new types since the function just works (internally) in a different way, but produces the same results:

```
// partialCurry.ts

function partialByClosure<P extends any[], R>(
  fn: (...a: P) => R
): PartialCurry<P, R>;
function partialByClosure(fn: (...a: any) => any) {
  const curryize =
    (...args1: any[]) =>
    (...args2: any[]) => {
      const allParams = [...args1, ...args2];
      return allParams.length < fn.length
        ? curryize(...allParams)
        : fn(...allParams);
    };

  return curryize();
}
```

The results are exactly the same as in the previous section, so it's not worth repeating them. You can change the tests we wrote to use `partialCurryByClosure()` instead of `partialCurryByBind()`, and they will work.

Final thoughts

Let's finish this chapter with some short topics. First, we should consider how we'd apply the methods in this chapter to a function with a variable number of parameters – not a trivial point, as all the code we've seen strongly depends on the function's arity.

Then we'll finish with two more philosophical considerations regarding currying and partial application, which may cause a bit of a discussion:

- First, many libraries are just wrong about the order of their parameters, making them harder to use
- Second, I don't usually even use the higher-order functions in this chapter, going for simpler JavaScript code

That's probably not what you were expecting at this time, so let's first solve the problem with the functions with an unknown number of parameters, and then go over the last two points in more detail, so you'll see it's not a matter of *do as I say, not as I do*... or as the libraries do!

Variable number of parameters

How can we work with functions that allow for a variable (possibly undefined, indeterminate) number of parameters? This is a problem because all the code we developed in the chapter depends on `fn.length`, the arity of the function to be processed. You could want to curry the `reduce()` function, but you'd find that its arity is `1`, so the curried function would not accept a second argument. Another case: you could have a `sumAll()` function as follows, and you'd want to apply `partial()` to it and get a function with, say, three parameters, but `sumAll.length` is `0` because all its parameters are optional:

```
const sumAll = (...args: number[]): number =>
  args.reduce((x, y) => x + y, 0);
```

In the two previous editions of this book, I added an extra parameter to `curry()` and the rest so I could override the `length` attribute of the input function:

```
const curry = (fn, len = fn.length) =>
  len === 0
    ? fn()
    : (p) => curry(fn.bind(null, p), len - 1);
```

However, currently, I don't think this is best. First, TypeScript cannot understand how many arguments the function will have, and that's not very good. And, second, we don't really need this! Given the functions that we saw in the *Arity changing* section of the previous chapter, if you have an `fn()` function that you want to curry for just two parameters, you can do `curry(binary(fn))` – and that solves the issue!

I think combining functions is a better solution than twiddling with already good implementations, so from now on, I'm recommending this new approach. Check the *Being functional* section later in this chapter for more examples of this usage.

Parameter order

There's a problem that's common to not only functions such as Underscore's or Lodash's `_.map(list, mappingFunction)` or `_.reduce(list, reducingFunction, initialValue)` but also to some that we have produced in this book, such as the result of `demethodize()`, for example. (See the *Demethodizing – turning methods into functions* section of *Chapter 6, Producing Functions,* to review that higher-order function.) The problem is that the order of their parameters doesn't really help with currying.

When currying a function, you will probably want to store intermediate results. When we do something as in the code that follows, we assume that you are going to reuse the curried function with the fixed argument, and that means that the first argument to the original function is the least likely to change. Let's now consider a specific case. Answer this question: what's more likely—that you'll use `map()` to apply the same function to several different arrays or that you'll apply several different functions to the same array? With validations or transformations, the former is more likely, but that's not what we get!

We can write a simple function to flip the parameters for a binary function, as shown here:

```
const flip2 = fn => (p1, p2) => fn(p2, p1);
```

With this, you could then write code as follows:

```
const myMap = curry(flip2(demethodize(map)));
const makeString = (v) => String(v);

const stringify = myMap(makeString);
let x = stringify(anArray);
let y = stringify(anotherArray);
let z = stringify(yetAnotherArray);
```

The most common use case is that you'll want to apply the function to several different lists; neither the library functions nor our own de-methodized ones provide that. However, by using `flip2()`, we can work in the fashion we prefer.

(Yes, in this particular case, we might have solved our problem by using partial application instead of currying; with that, we could fix the second argument to `map()` without any further bother. However, flipping arguments to produce new functions that have a different order of parameters is also an often-used technique, and you must be aware of it.)

For situations such as with `reduce()`, which usually receives three arguments (the list, the function, and the initial value), we may opt for this:

```
const flip3 = (fn) => (p1, p2, p3) => fn(p2, p3, p1);

const myReduce = partialCurry(
  flip3(demethodize(Array.prototype.reduce))
);

const sum = (x, y) => x + y;
const sumAll = myReduce(sum, 0);
sumAll(anArray);
sumAll(anotherArray);
```

Here, we used partial currying to simplify the expression for `sumAll()`. The alternative would have been using common currying, and then we would have defined `sumAll = myReduce(sum)(0)`.

You can also go for more esoteric parameter rearranging functions if you want, but you usually won't need more than these two. For really complex situations, you may instead opt for using arrow functions (as we did when defining `flip2()` and `flip3()`) and make it clear what kind of reordering you need.

Being functional

Now that we are nearing the end of this chapter, a confession is in order: I do not always use currying and partial application, as shown previously! Don't misunderstand me, I do apply those techniques—but sometimes they make for longer, less clear, not necessarily better code. Let me show you what I'm talking about.

If I'm writing my own function and then I want to curry it to fix the first parameter, currying, partial application, or partial currying don't really make a difference compared to arrow functions. I'd have to write the following:

```
const myFunction = (a, b, c) => { ... };

const myCurriedFn = curry(myFunction)(fix1st);

// and later in the code...
myCurriedFn(set2nd)(set3rd);
```

Currying the function and giving it a first parameter, all in the same line, may be considered not so clear; the alternative calls for an added variable and one more line of code. Later, the future call isn't so good either; however, partial currying makes it more straightforward, with something like `myPartiallyCurriedFn(set2nd, set3rd)`.

In any case, when I compare the final code with the use of arrow functions, I think the other solutions aren't really any better; make your own evaluation of the sample that follows:

```
const myFunction = (a, b, c) => { ... };

const myFixedFirst = (b, c) => myFn(fix1st, b, c);

// and later...
myFixedFirst(set2nd, set3rd);
```

Where I do think that currying and partial application is quite good is in my small library of de-methodized, pre-curried, basic higher-order functions. I have my own set of functions, such as the following:

```
const _plainMap = demethodize(Array.prototype.map);
const myMap = curry(binary(_plainMap));
const myMapX = curry(flipTwo(_plainMap));

const _plainReduce = demethodize(Array.prototype.reduce);
const myReduce = curry(ternary(_plainReduce));
const myReduceX = curry(flip3(_plainReduce));

const _plainFilter = demethodize(Array.prototype.filter);
const myFilter = curry(binary(_plainFilter));
const myFilterX = curry(flipTwo(_plainFilter));

// ...and more functions in the same vein
```

Here are some points to note about the code:

- I have these functions in a separate module, and I only export the `myXXX()` named ones.
- The other functions are private, and I use the leading underscore to remind me of that.
- I use the `my...` prefix to remember that these are my functions, not the normal JavaScript ones. Some people would rather keep familiar names such as `map()` or `filter()`, but I prefer distinct names.
- Since most of the JavaScript methods have a variable arity, I fixed that as described in the *Variable number of parameters* section.
- I always provide the third argument (the initial value for reducing) to `reduce()`, so the arity I chose for that function is `3`.
- When currying flipped functions, you don't need to specify the number of parameters because flipping already does that for you.

Ultimately, it all comes down to a personal decision; experiment with the techniques we've looked at in this chapter and see which ones you prefer!

Summary

In this chapter, we have considered a new way of producing functions by fixing arguments to an existing function in several different ways: currying, which originally came from computer theory; partial application, which is more flexible; and partial currying, which combines good aspects from both of the previous methods. Using these transformations, you can simplify your coding because you can generate more specialized versions of general functions without any hassle.

In *Chapter 8*, *Connecting Functions*, we will turn back to some concepts we looked at in the chapter on pure functions, and we will consider ways of ensuring that functions cannot become impure by accident, by seeking ways to make their arguments immutable, making them impossible to mutate.

Questions

7.1 **Hard by hand**: With our "curried by hand" `sum()` function, we could write `sum()(3)(5)` and get `8`. But what happens if we write `sum(3)()(5)` instead?

7.2 **Sum as you will**: The following exercise will help you understand some of the concepts we dealt with in this chapter, even if you solve it without using any of the functions we looked at. Write a `sumMany()` function that lets you sum an indeterminate quantity of numbers in the following fashion. Note that when the function is called with no arguments, the sum is returned:

```
let result = sumMany(9)(2)(3)(1)(4)(3)();
// 22
```

7.3 **Curry with eval?** You could also produce a curried version of a function by using `eval()` – yes, the unsafe, dangerous `eval()`! If you are willing to avoid the potential security headaches that `eval()` can bring, you could use it to transform a function such as the following:

```
const make3 = (a: string, b: number, c: string): string =>
  `${a}:${b}:${c}`;
```

You could transform it into a curried equivalent:

```
const make3curried = x1 => x2 => x3 => make3(x1, x2, x3);
```

Give it a try! A tip: using the `range()` function we wrote back in the *Working with ranges* section of *Chapter 5*, *Programming Declaratively,* may shorten your code. Also, remember that `fn.length` tells you the arity of the `fn()` function.

7.4 **Uncurrying the curried**: Write an `unCurry(fn, arity)` function that receives as arguments a (curried) function and its expected arity, and returns an uncurried version of `fn()` – that is, a function that will receive all arguments at once and produce a result (providing the expected arity is needed because you have no way of determining it on your own):

```
const make3 = (a, b, c) => String(100 * a + 10 * b + c);

const make3c = curry(make3);
console.log(make3c(1)(2)(3)); // 123
```

```
const remake3 = uncurry(make3c, 3);
console.log(remake3(1, 2, 3)); // 123
```

7.5 **Let me count the ways**: If you curry a function with three parameters, there's only one way of using it: `(a) => (b) => (c) => result`. However, if you use partial curry, there are some more ways of using it: `(a,b) => (c) => result`, `(a) => (b,c) => result`, and even `(a,b,c) => result`. In how many ways can you use a partially curried function with *n* parameters?

7.6 **Currying by prototype**: Modify `Function.prototype` to provide a `curry()` method that will work like the `curry()` function we saw in the chapter. Completing the following code should produce the following results:

```
Function.prototype.curry = function () {
  // ...your code goes here...
};

const sum3 = (a, b, c) => 100 * a + 10 * b + c;
sum3.curry()(1)(2)(4); // 124

const sum3C = sum3.curry()(2)(2);
sum3C(9); // 229
```

7.7 **Shorter typing**: A reader commented that the `Curry<>` type could be written in an equivalent but shorter way if you first tested for two or more arguments. Can you implement this change?

7.8 **Counting arguments**: When we wrote the `Curry<>` type, we tested whether a single argument was provided by writing `P extends [infer H]` – can you rewrite the code to work with `["length"]` instead? A hint: we did this kind of thing when we defined the `Partial<>` type:

```
type Curry<P, R> = P extends [infer H]
  ? (arg: H) => R // only 1 arg
  : P extends [infer H, ...infer T] // 2 or more args
  ? (arg: H) => Curry<[...T], R>
  : never;
```

7.9 **Working stylishly**: Write an `applyStyle()` function that will let you apply basic styling to strings in the following way. Use either currying or partial application:

```
const makeBold = applyStyle("b");
document.getElementById("myCity").innerHTML =
  makeBold("Montevideo");
```

```
// <b>Montevideo</b>, to produce Montevideo

const makeUnderline = applyStyle("u");
document.getElementById("myCountry").innerHTML =
  makeUnderline("Uruguay");
// <u>Uruguay</u>, to produce Uruguay
```

7.10 **Mystery questions function**: What does the following function, purposefully written in an unhelpful way, actually do?

```
const what = (who) => (...why) => who.length <= why.length
  ? who(...why) : (...when) => what(who)(...why, ...when);
```

7.11 **Partial transformations**: Modify the prototype for functions, so both `partial()` and `partialCurry()` will be available as methods.

7.12 **Yet more curry!** Here is another proposal for a currying-style function: can you see why it works? A hint – the code is related to something we saw in the chapter:

```
const curryN =
  (fn) =>
  (...args) =>
    args.length >= fn.length
      ? fn(...args)
      : curryN(fn.bind(null, ...args));
```

8
Connecting Functions – Pipelining, Composition, and More

In *Chapter 7*, *Transforming Functions*, we looked at ways to build new functions by applying higher-order functions. In this chapter, we will go to the core of FP and learn how to create sequences of function calls and how to combine them to produce a more complex result out of several simpler components. To do this, we will cover the following topics:

- **Pipelining**: A way to join functions, similar to Unix/Linux pipes
- **Chaining**: A variant of pipelining, but restricted to objects
- **Composing**: A classic operation with its origins in basic computer theory
- **Transducing**: An optimized way to compose `map`, `filter`, or `reduce` operations

Along the way, we will be touching on related concepts, such as the following:

- **Pointfree style**, which is often used with pipelining and composition
- **Debugging** of composed or piped functions, for which we'll whip up some auxiliary tools
- **Testing** for these functions, which won't prove to be of high complexity

Armed with these techniques, you'll be able to combine small functions to create larger ones, which is a characteristic of FP and will help you develop better code.

Pipelining

Pipelining and composition are techniques that are used to set up functions to work in sequence so that the output of a function becomes the input for the following function. There are two ways of looking at this: from a computer point of view, and from a mathematical point of view. We'll look at both in this section. Most FP texts start with the latter, but since I assume that most of you will prefer computers over math, let's start with the former instead.

Piping in Unix/Linux

In Unix/Linux, executing a command and passing its output as input to a second command, whose output will yield the input of a third command, and so on, is called a pipeline. This is quite a common application of the philosophy of Unix, as explained in a Bell Laboratories article written by the creator of the pipelining concept himself, Doug McIlroy:

- Make each program do one thing well. To do a new job, build afresh rather than complicating old programs by adding new features.
- Expect the output of every program to become the input to another, so far unknown program.

A bit of history

Given the historical importance of Unix, I'd recommend reading some of the seminal articles describing the (then new) operating system in the Bell System Technical Journal, July 1978, at `emulator.pdp-11.org.ru/misc/1978.07_-_Bell_System_Technical_Journal.pdf`. The two quoted rules are in the *Style* section of the *Foreword* article.

Let's consider a simple example to get started. Suppose I want to know how many LibreOffice text documents there are in a directory. There are many ways to do this, but the following example will do. We will execute three commands, piping (that's the meaning of the | character) each command's output as input to the next one. Suppose we have `cd /home/fkereki/Documents` and then do the following (please ignore the dollar sign, which is just the console prompt):

```
$ ls -1 | grep "odt$" | wc -l
4
```

What does this mean? How does it work? We have to analyze this process step by step:

- The first part of the pipeline, `ls -1`, lists all the files in the current directory (`/home/fkereki/Documents`, as per our `cd` command) in a single column, with one filename per line
- The output from the first command is provided as input to `grep "odt$"`, which filters (only lets pass) lines that finish with `"odt"`, the standard file extension for LibreOffice Writer
- The filtered output is provided to the counting command, `wc -l`, which counts how many lines there are in its input

More on pipelining

You can find out more about pipelines in *Section 6.2*, *Filters*, of *The UNIX Time-Sharing System* by Dennis Ritchie and Ken Thompson, also in the issue of the Bell Laboratories journal that I mentioned previously.

From the point of view of FP, this is a key concept. We want to build more complex operations out of simple, single-purpose, shorter functions. Pipelining is what the Unix shell uses to apply that concept. It does this by simplifying the job of executing a command, taking its output, and providing it as input to yet another command. We will apply similar concepts in our own functional style in JavaScript later:

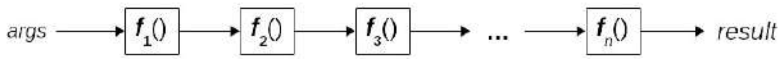


Figure 8.1 – Pipelines in JavaScript are similar to Unix/Linux pipelines. The output of each function becomes the input for the next

By the way (and no—rest assured, this isn't turning into a shell tutorial!), you can make pipelines accept parameters. For example, if I happened to want to count how many files I had with this or that extension, I could create a function such as `cfe`, standing for *count for extension*:

```
$ function cfe() {
ls -1 | grep "$1\$"| wc -l
}
```

Then, I could use `cfe` as a command, giving it the desired extension as an argument:

```
$ cfe odt
4
$ cfe pdf
6
```

`cfe` executes my pipeline and tells me I have four `odt` files (LibreOffice) and six `pdf` files; nice! We will also want to write similar parametric pipelines: we are not constrained to fixed functions in our flow; we have full liberty regarding what we want to include. Having worked in Linux, we can now go back to coding. Let's see how.

Revisiting an example

We can start tying ends together by revisiting a problem from a previous chapter. Remember when we had to calculate the average latitude and longitude for some geographic data that we looked at in the *Extracting data from objects* section of *Chapter 5, Programming Declaratively*? Basically, we started with some data such as the following, and the problem was to calculate the average latitude and longitude of the given points:

```
const markers = [
  { name: "AR", lat: -34.6, lon: -58.4 },
  { name: "BO", lat: -16.5, lon: -68.1 },
  { name: "BR", lat: -15.8, lon: -47.9 },
  { name: "CL", lat: -33.4, lon: -70.7 },
  { name: "CO", lat:   4.6, lon: -74.0 },
  { name: "EC", lat:  -0.3, lon: -78.6 },
  { name: "PE", lat: -12.0, lon: -77.0 },
  { name: "PY", lat: -25.2, lon: -57.5 },
  { name: "UY", lat: -34.9, lon: -56.2 },
  { name: "VE", lat:  10.5, lon: -66.9 },
];
```

With what we know, we can write a solution in terms of the following:

- Being able to extract the latitude (and afterward, the longitude) from each point
- Using that function to create an array of latitudes
- Pipelining the resulting array to the average function we wrote in the *Calculating an average* section of the aforementioned chapter

To do the first task, we can use the `myMap()` function from the *Parameter order* section of *Chapter 7, Transforming Functions*. For the second task, we can make do with the `getField()` function from the *Getting a property from an object* section of *Chapter 6, Producing Functions*. Finally, for the third task, we'll use the (yet unwritten) `pipeline()` function we'll develop soon! In full, our solution could look like this:

```
const sum = (x: number, y: number): number => x + y;

const average = (arr: number[]) =>
  arr.reduce(sum, 0) / arr.length;

const myMap = curry(
  flip2(demethodize(Array.prototype.map))
);

const getAllLats = myMap(getField("lat")) as (
  arg: any
) => number[];
```

```
const averageLat = pipeline(getAllLats, average)(markers);
// and similar code to average longitudes
```

We had to add some casting to `getAllLats` so that TypeScript would know to what we would apply that function.

Of course, you can always yield to the temptation of going for one-liners, but would it be much clearer or better?

```
const averageLat2 = pipeline(
  curry(flip2(demethodize(Array.prototype.map)))(
    getField("lat")
  ) as (arg: any) => number[],
  average
)(markers);
```

Whether this makes sense to you will depend on your experience with FP. In any case, no matter which solution you take, the fact remains that adding pipelining (and later on, composition) to your set of tools can help you write tighter, declarative, simpler-to-understand code.

Now, let's learn how to pipeline functions in the right way.

Creating pipelines

We want to be able to generate a pipeline of several functions. We can do this in two ways: by building the pipeline by hand, in a problem-specific way, or by using more generic constructs that can be applied with generality. Let's look at both.

Potential pipeline proposal

A new operator, |>, is being considered for JavaScript, but it's currently only at stage 2, which means it may be a while before it's accepted and available. You may read more about the proposal and its varied history at `github.com/tc39/proposal-pipeline-operator/blob/main/HISTORY.md`.

Building pipelines by hand

Let's go with a Node.js example, similar to the command-line pipeline we built earlier in this chapter. Here, we'll build the pipeline we need by hand. We need a function to read all the files in a directory. We can do that (although this isn't recommended because of the synchronous call, which is normally not good in a server environment) with something like this:

```
// pipeline.ts

function getDir(path) {
  const fs = require("fs");
  const files = fs.readdirSync(path);
  return files;
}
```

Selecting only `odt` files is quite simple. We start with the following function:

```
// continued...

const filterByText = (
  text: string,
  arr: string[]
): string[] => arr.filter((v) => v.endsWith(text));
```

This function takes an array of strings and filters out elements that do not end with the given text, so we can now write the following:

```
// continued...

const filterOdt = (arr: string[]): string[] =>
  filterByText(".odt", arr);
```

Better still, we can apply currying and go for pointfree style, as shown in the *An unnecessary mistake* section of *Chapter 3*, *Starting Out with Functions*, and write this, instead:

```
// continued...

const filterOdt = curry(filterByText)(".odt");
```

Both versions of the filtering function are equivalent; which one you use comes down to your tastes. Finally, we can write the following to count elements in an array. Since `length` is not a function, we cannot apply our demethodizing trick:

```
// continued...

const count = <T>(arr: T[]): number => arr.length;
```

With these functions, we could write something like this:

```
// continued...

const countOdtFiles = (path: string): number => {
  const files = getDir(path);
  const filteredFiles = filterOdt(files);
  const countOfFiles = count(filteredFiles);
  return countOfFiles;
};

countOdtFiles("/home/fkereki/Documents");
// 4, as with the command line solution
```

We are essentially doing the same process as in Linux: getting the files, keeping only the `odt` ones, and counting how many files result from this. If you wanted to get rid of all the intermediate variables, you could also go for a one-liner definition that does precisely the same job in the very same way, albeit with fewer lines:

```
const countOdtFiles2 = (path: string): number =>
  count(filterOdt(getDir(path)));

const c2 = countOdtFiles2("/home/fkereki/Documents");
// 4, again
```

This gets to the crux of the matter: both implementations of our file-counting function have disadvantages. The first definition uses several intermediate variables to hold the results and makes a multiline function out of what was a single line of code in the Linux shell. On the other hand, the second, much shorter definition is harder to understand, insofar as we are writing the steps of the computation in seemingly reverse order! Our pipeline has to read files first, then filter them, and finally count them, but those functions appear *the other way around* in our definition!

We can undoubtedly implement pipelining by hand, as we have seen, but it would be better if we went for a more declarative style.

Let's move on and try to build a better pipeline more clearly and more understandably by applying some of the concepts we've already seen.

Using other constructs

If we think in functional terms, what we have is a list of functions and we want to apply them sequentially, starting with the first, then applying the second to whatever the first function produced as its result, and then applying the third to the second function's results, and so on. If we were fixing a pipeline of two functions, we could use the following code:

```
// continued...

const pipeTwo =
  <AF extends any[], RF, RG>(
    f: (...args: AF[]) => RF,
    g: (arg: RF) => RG
  ) =>
  (...args: any[]) => g(f(...args));
```

This is the basic definition we provided earlier in this chapter: we evaluate the first function, and its output becomes the input for the second function; relatively straightforward! Typing is simple: the first function to apply (`f()`) may have any number of parameters, but the second function (`g()`) must have a single one, the same type that `f()` returns. The return type of the pipeline is the return type of `g()`.

You may object, though, that this pipeline of only two functions is a bit too limited! This is not as useless as it may seem because we can compose longer pipelines—though I'll admit that it requires too much writing! Suppose we wanted to write our three-function pipeline (from the previous section); we could do so in two different, equivalent ways:

```
// continued...

const countOdtFiles3 = (path: string): number =>
  pipeTwo(pipeTwo(getDir, filterOdt), count)(path);

const countOdtFiles4 = (path: string): number =>
  pipeTwo(getDir, pipeTwo(filterOdt, count))(path);
```

A touch of math

We are taking advantage of the fact that piping is an associative operation. In mathematics, the associative property is the one that says that we can compute 1+2+3 either by adding 1+2 first and then adding that result to 3 or by adding 1 to the result of first adding 2+3: in other terms, 1+2+3 is the same as (1+2)+3 or 1+(2+3).

How do they work? How is it that they are equivalent? Following the execution of a given call will be useful; it's quite easy to get confused with so many calls! The first implementation can be followed step by step until the final result, which matches what we already know:

```
countOdtFiles3(path) ===
  pipeTwo(pipeTwo(getDir, filterOdt), count)
  pipeTwo(filterOdt(getDir(path)), count)(path)
  pipeTwo(count(filterOdt(getDir(path))))
```

The second implementation also comes to the same final result:

```
countOdtFiles4(path) ===
  pipeTwo(getDir, pipeTwo(filterOdt, count))(path)
  pipeTwo(getDir(path), pipeTwo(filterOdt, count))
  pipeTwo(filterOdt, count)(getDir(path))
  pipeTwo(count(filterOdt(getDir(path))))
```

Both derivations arrived at the same final expression—the same we had written by hand earlier, in fact—so we now know that we can make do just with a basic *pipe of two* higher-order functions, but we'd really like to be able to work in a shorter, more compact way. A first implementation could be along the lines of the following, and let's look at typing later:

```
function pipeline(...fns) {
  return (...args) => {
    let result = fns[0](...args);
    for (let i = 1; i < fns.length; i++) {
      result = fns[i](result);
    }
    return result;
  };
}

pipeline(
  getDir,
  filterOdt,
  count
)("/home/fkereki/Documents"); // still 4
```

This does work—and specifying our file-counting pipeline is much clearer since the functions are given in their proper order. However, the implementation of the `pipeline()` function is not very functional and goes back to old, imperative, loop-by-hand methods. We can do better using `reduce()`, as in *Chapter 5*, *Programming Declaratively*.

The idea is to start the evaluation with the first function, pass the result to the second, then that result to the third, and so on. By doing this, we can pipeline with shorter code, and again we'll leave typing for later:

```
// continued...

function pipeline2(...fns) {
  return fns.reduce(
    (result, f) =>
      (...args) =>
        f(result(...args))
  );
}
```

This code is more declarative. However, you could have gone one better by writing it using our `pipeTwo()` function, which does the same thing but more concisely:

```
// continued...

function pipeline3(...fns) {
  return fns.reduce(pipeTwo);
}
```

(Using an arrow function would make for even shorter code.) You can understand this code by realizing that it uses the associative property we mentioned previously and pipes the first function to the second; then, it pipes this result to the third function, and so on.

Which version is better? I would say that the version that refers to the `pipeTwo()` function is clearer: if you know how `reduce()` works, you can readily understand that our pipeline goes through the functions two at a time, starting from the first—and that matches what you know about how pipes work. The other versions we wrote are more or less declarative, but not as simple to understand.

We didn't look at typing for all our pipelining functions, so let's do that now.

Typing

When we pipeline several functions, a function's output type should be the same as the following function's parameter type. Let's have an auxiliary `FnsMatchPipe<>` type to check whether two types satisfy this condition:

```
// continued…
```

```
type FN = (...args: any[]) => any;

type FnsMatchPipe<FNS extends FN[]> =
  1 extends FNS["length"]
    ? boolean
    : FNS extends [
        infer FN1st extends FN,
        infer FN2nd extends FN,
        ...infer FNRest extends FN[]
      ]
    ? Parameters<FN2nd> extends [ReturnType<FN1st>]
      ? FnsMatchPipe<[FN2nd, ...FNRest]>
      : never
    : never;
```

This works recursively. If we have a single function in the pipeline (the length of `FNS` is `1`), then we return `boolean` to signify success. If we have more than one function, we take the first and second functions, check that the parameter of the latter is the same type as the return type of the former, and apply recursion to check types from the second function onward. If there's no match in types, we return `never` to mark a failure.

Now, what's the type of the pipeline? The type of its arguments will match the first function's argument type, and the type of the result will match the last function's result type:

```
// continued...

type Pipeline<FNS extends FN[]> =
  boolean extends FnsMatchPipe<FNS>
    ? 1 extends FNS["length"]
      ? FNS[0]
      : FNS extends [
          infer FNFIRST extends FN,
          ...FN[],
          infer FNLAST extends FN
        ]
      ? (...args: Parameters<FNFIRST>) => ReturnType<FNLAST>
      : never
    : never;
```

We first verify that the function's types are correct, using `FnsMatchPipe<>`. If the types match, the type of the whole pipeline is that of a function that gets arguments of the same type as the first function in the pipeline and returns a value of the same type as the last pipelined function.

Now, our pipelines can be properly written – and we'll have to use the same "overloading" as in the previous chapter to help TypeScript work out types:

```
// continued...

function pipeline<FNS extends FN[]>(
  ...fns: FNS
): Pipeline<FNS>;
function pipeline<FNS extends FN[]>(...fns: FNS): FN {
  return (...args: Parameters<FNS[0]>) => {
    let result = fns[0](...args);
    for (let i = 1; i < fns.length; i++) {
      result = fns[i](result);
    }
    return result;
  };
}

function pipeline2<FNS extends FN[]>(
  ...fns: FNS
): Pipeline<FNS>;
function pipeline2<FNS extends FN[]>(...fns: FNS): FN {
  return fns.reduce(
    (result, f) =>
      (...args) =>
        f(result(...args))
  );
}

function pipeline3<FNS extends FN[]>(
  ...fns: FNS
): Pipeline<FNS>;
function pipeline3<FNS extends FN[]>(
  ...fns: FNS
): (...fns: FNS) => FN {
  return fns.reduce(pipeTwo);
}
```

Before we look at other ways to connect functions, let's consider how we would debug our pipelines.

Debugging pipelines

Now, let's turn to a practical question: how do you debug your code? With pipelining, you can't see what's passed on from function to function, so how do you do it? We have two answers for that: one (also) comes from the Unix/Linux world, and the other (the most appropriate for this book) uses wrappers to provide some logs.

Using tee

The first solution we'll use implies adding a function to the pipeline, which will just log its input. We want to implement something similar to the `tee` Linux command, which can intercept the standard data flow in a pipeline and send a copy to an alternate file or device. Remembering that `/dev/tty` is the usual console, we could execute something similar to the following and get an onscreen copy of everything that passes using the `tee` command:

```
$ ls -1 | grep "odt$" | tee /dev/tty | wc -l

...the list of files with names ending in odt...
4
```

We could write a similar function with ease:

```
// pipeline_debug.ts

const tee = <A>(arg: A) => {
  console.log(arg);
  return arg;
};
```

Comma power!

If you are aware of the uses of the comma operator, you can be more concise and write `const tee2 = <A>(arg: A) => (console.log(arg), arg)`—do you see why? Check out `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Operators/Comma_Operator` for the answer!

Our logging function is short and to the point: it will receive a single argument, list it, and pass it on to the following function in the pipe. We can see it working in the following code:

```
// continued...

console.log(
  pipeline3(
    getDir,
    tee,
    filterOdt,
    tee,
    count
  )("/home/fkereki/Documents")
);

...the list of all the files in the directory...
...the list of files with names ending in odt...
4
```

It would be even better if our `tee()` function could receive a logger function as a parameter, as in the *Logging in a functional way* section of *Chapter 6, Producing Functions*; it's just a matter of making the same kind of change we managed there. The same good design concepts are applied again!

```
// continued...

const tee2 = <A>(arg: A, logger = console.log) => {
  logger(arg);
  return arg;
};
```

This function works exactly in the same way as the previous `tee()`, although it will allow us to be more flexible when it comes to applying and testing. However, in our case, this would just be an extra enhancement to an already easily-testable function.

Let's consider an even more generic tapping function, with more possibilities than just doing a bit of logging.

Tapping into a flow

If you wish, you could write an enhanced `tee()` function to produce more debugging information, send the reported data to a file or remote service, and so on—there are many possibilities you can explore. You could also explore a more general solution, of which `tee()` would be a particular case and allow us to create personalized tapping functions. This can be seen in the following diagram:

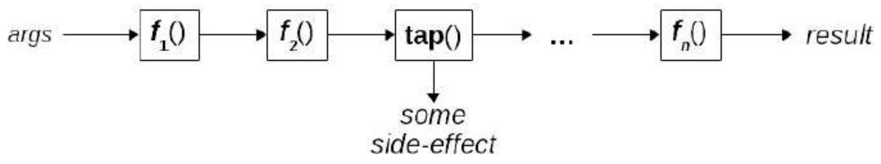


Figure 8.2 – Tapping allows you to apply a function so that you can inspect data as it flows through the pipeline

When working with pipelines, you may want to put a logging function in the middle of them, or you might want some other kind of *snooping* function—possibly for storing data somewhere, calling a service, or some other kind of side effect. We could have a generic `tap()` function to allow us to inspect data as it moves along our pipeline, which would behave in the following way:

```
// continued...

const tap = curry(<A>(fn: FN, x: A) => (fn(x), x));
```

This is a candidate for the *trickiest-looking code-in-the-book* award, so let's explain it. We want to produce a function that, given a function, `fn()`, and an argument, `x`, will evaluate `fn(x)` (to produce whatever sort of side effect we may be interested in) but return `x` (so the pipeline goes on without interference). The comma operator has exactly that behavior: if you write something similar to `(a, b, c)`, JavaScript will evaluate the three expressions in order and use the last value as the expression's value.

Here, we can use currying to produce several different tapping functions. The one we wrote in the previous section, `tee()`, could also be written in the following fashion:

```
// continued...

const tee3 = tap(console.log);
```

By the way, you could have also written `tap()` without currying, but you'll have to admit it loses some of its mystery! This is demonstrated here:

```
// continued...

const tap2 = (fn: FN) => <A>(x: A) => (fn(x), x);
```

This does exactly the same job, and you'll recognize this way of currying from the *Currying by hand* section of *Chapter 7, Transforming Functions*. Now that we have learned how to tap into a pipeline, let's move on to a different way of logging by revisiting some concepts we looked at in previous chapters.

Using a logging wrapper

The second idea we mentioned is based on the `addLogging()` function we wrote in the *Logging* section of *Chapter 6, Producing Functions*. The idea was to wrap a function with some logging functionality so that, on entry, the arguments would be printed and, on exit, the result of the function would be shown:

```
pipeline2(
  addLogging(getDir),
  addLogging(filterOdt),
  addLogging(count)
)("/home/fkereki/Documents");

entering getDir(/home/fkereki/Documents)
exiting  getDir=> ...list of files...
entering filterOdt(...list of files, again...)
exiting  => ...list of .odt files...
entering count(...list of .odt files ...)
exiting  count=>4
```

We can trivially verify that the `pipeline()` function is doing its thing correctly—whatever a function produces as a result is given as input to the next function in the line, and we can also understand what's happening with each call. Of course, you don't need to add logging to every function in the pipeline: you would probably do so in places where you suspected an error was occurring.

Now that we've looked at how to join functions, let's look at a common way of defining functions in FP, *pointfree style*, which you may encounter.

Pointfree style

When you join functions together, either in a pipeline or with composition, as we'll see later in this chapter, you don't need any intermediate variables to hold the results that will become arguments to the following function in line: they are implicit. Similarly, you can write functions without mentioning their parameters; this is called the *pointfree style*.

(By the way, pointfree style is also called *tacit* programming and *pointless* programming by detractors! The term point itself means a function parameter, while pointfree refers to not naming those parameters.)

Defining pointfree functions

You can easily recognize a pointfree function definition because it doesn't need the `function` keyword or the `=>` arrow. Let's revisit some of the previous functions we wrote in this chapter and check them out. For example, the definition of our original file-counting functions is as follows:

```
const countOdtFiles3 = (path: string): number =>
  pipeTwo(pipeTwo(getDir, filterOdt), count)(path);

const countOdtFiles4 = (path: string): number =>
  pipeTwo(getDir, pipeTwo(filterOdt, count))(path);
```

The preceding code could be rewritten as follows:

```
// pointfree.ts

const countOdtFiles3b = pipeTwo(
  pipeTwo(getDir, filterOdt),
  count
);
const countOdtFiles4b = pipeTwo(
  getDir,
  pipeTwo(filterOdt, count)
);
```

The new definitions don't reference the parameter for the newly defined functions.

You can deduce this by examining the first function in the pipeline (`getDir()`, in this case) and seeing what it receives as arguments. (Using type signatures, as we'll see in *Chapter 12*, *Building Better Containers*, is of great help in terms of documentation, and complements TypeScript types.) In our *Revisiting an example* section, we could have written a `getLat()` function to get the `lat` field out of an object in a pointfree fashion:

```
const getLat = curry(getField)("lat");
```

What should the equivalent full-style definition be? You'd have to examine the `getField()` function (we looked at this in the *Revisiting an example* section) to decide that it expects an object as an argument. However, making that need explicit by writing the following wouldn't make much sense:

```
const getLat = (obj) => curry(getField)("lat")(obj);
```

If you were willing to write all this, you might wish to stick with the following:

```
const getLat = (obj) => obj.lat;
```

Then, you simply wouldn't need to worry about currying!

Converting to pointfree style

On the other hand, you had better pause for a minute and try not to write everything in pointfree code, at any cost. For example, consider the `isNegativeBalance()` function we wrote back in *Chapter 6*, *Producing Functions*:

```
const isNegativeBalance = v => v.balance < 0;
```

Can we write this in a pointfree style? Yes, we can, and we'll see how—but I'm not sure we'd want to code this way! We can consider building a pipeline of two functions: one will extract the balance from the given object, while the other will check whether it's negative. Due to this, we will write our alternative version of the balance-checking function like so:

```
const isNegativeBalance2 = pipeline(getBalance,
  isNegative);
```

To extract the `balance` attribute from a given object, we can use `getField()` and a bit of currying, and write the following:

```
const getBalance = curry(getField)("balance");
```

For the second function, we could write the following code:

```
const isNegative = (x: number): boolean => x < 0;
```

There goes our pointfree goal! Instead, we can use the `binaryOp()` function, also from the same chapter we mentioned earlier, plus some more currying, to write the following:

```
const isNegative = curry(binaryOp(">"))(0);
```

I wrote the test the other way around (`0>x` instead of `x<0`) just for ease. An alternative would have been to use the enhanced functions I mentioned in the *A handier implementation* section of *Chapter 6*, *Producing Functions*, which is a bit less complex, as follows:

```
const isNegative = binaryOpRight("<", 0);
```

So, finally, we could write the following:

```
const isNegativeBalance2 = pipeline(
  curry(getField)("balance"),
  curry(binaryOp(">"))(0)
);
```

Alternatively, we could write the following:

```
const isNegativeBalance3 = pipeline(
  curry(getField)("balance"),
  binaryOpRight("<", 0)
);
```

Is that an improvement? Our new versions of `isNegativeBalance()` don't make a reference to their argument and are fully pointfree, but the idea of using pointfree style should be to help improve the clarity and readability of your code and not to produce obfuscation and opaqueness! I doubt anybody would look at our new versions of the function and consider them to be an advantage over the original.

If you find that your code is becoming harder to understand due to using pointfree programming, stop and roll back your changes. Remember our doctrine for this book: we want to do FP, but we don't want to go overboard with it—and using the pointfree style is not a requirement!

In this section, we've learned how to build pipelines of functions—this is a powerful technique. For objects and arrays, however, we have another special technique that you may have used already: *chaining*. Let's take a look at this now.

Chaining and fluent interfaces

When you work with objects or arrays, there is another way of linking the execution of several calls together: by applying *chaining*. For example, when you work with arrays, if you apply a `map()` or `filter()` method, the result is a new array, to which you can then apply another `map()` or `filter()` function, and so forth. We used these methods when we defined the `range()` function back in the *Working with ranges* section of *Chapter 5, Programming Declaratively*:

```
const range = (start: number, stop: number): number[] =>
  new Array(stop - start).fill(0).map((v, i) => start + i);
```

First, we created a new array; then, we applied the `fill()` method to it, which updated the array in place (side effect) and returned the updated array, to which we finally applied a `map()` method. The latter method generated a new array, to which we could have applied further mapping, filtering, or any other available method.

Let's take a look at a common example of fluent APIs, which work by chaining, and then consider how we can do this on our own.

An example of fluent APIs

This style of continuous chained operations is also used in fluent APIs or interfaces. To give just one example, the graphic `D3.js` library (see `d3js.org` for more on it) frequently uses this style. The following example, taken from `bl.ocks.org/mbostock/4063269`, shows it in action:

```
var node = svg
  .selectAll(".node")
  .data(pack(root).leaves())
  .enter()
  .append("g")
  .attr("class", "node")
  .attr("transform", function (d) {
    return "translate(" + d.x + "," + d.y + ")";
  });

node
  .append("circle")
  .attr("id", function (d) {
    return d.id;
  })
  .attr("r", function (d) {
    return d.r;
  })
  .style("fill", function (d) {
    return color(d.package);
  });
```

Each method works on the previous object and provides access to a new object to which future method calls will be applied (such as the `selectAll()` or `append()` methods) or updates the current one (as the `attr()` attribute setting calls do). This style is not unique, and several other well-known libraries (jQuery comes to mind) also apply it.

Can we automate this? In this case, the answer is "possibly, but I'd rather not." I think using `pipeline()` or `compose()` works just as well and achieves the same thing. With object chaining, you are limited to returning new objects or arrays or something that methods can be applied to. (Remember, if you are working with standard types, such as strings or numbers, you can't add methods to them unless you mess with their prototype, which isn't recommended!). With composition, however, you can return any value; the only restriction is that the next function in line must expect the data type you provide.

On the other hand, if you are writing your own API, you can provide a fluent interface by just having each method return `this`—unless it needs to return something else! If you were working with someone else's API, you could also do some trickery by using a proxy. However, be aware that there may be cases in which your proxied code might fail: maybe another proxy is being used, or there are some getters or setters that somehow cause problems, and so on.

On proxies

You may want to read up on proxy objects at `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/Proxy` – they are very powerful and allow for interesting metaprogramming functionalities. Still, they can trap you with technicalities and will cause an (albeit slight) slowdown in your proxied code.

Let's now look at how to chain calls so we can do this with any class.

Chaining method calls

Let's go for a basic example. We have a `City` class with `name`, latitude (`lat`), and longitude (`long`) attributes:

```
// chaining.ts

class City {
  name: string;
  lat: number;
  long: number;

  constructor(name: string, lat: number, long: number) {
    this.name = name;
    this.lat = lat;
    this.long = long;
  }

  getName() {
    return this.name;
  }

  setName(newName: string) {
    this.name = newName;
  }

  setLat(newLat: number) {
    this.lat = newLat;
  }
  setLong(newLong: number) {
    this.long = newLong;
  }

  getCoords() {
    return [this.lat, this.long];
  }
}
```

This is a common class with a few methods; everything's quite normal. We could use this class as follows and provide details about my native city, Montevideo, Uruguay:

```
const myCity = new City(
  "Montevideo, Uruguay",
  -34.9011,
  -56.1645
);
console.log(myCity.getCoords(), myCity.getName());
// [ -34.9011, -56.1645 ] 'Montevideo, Uruguay'
```

If we wanted the setters to be handled in a fluent manner, we could set up a proxy to detect these calls and provide the missing `return this`. How can we do that? If the original method doesn't return anything, JavaScript will include a `return undefined` statement by default so that we can detect whether that's what the method returns and substitute `return this` instead. Of course, this is a problem: what would we do if we had a method that could legally return `undefined` because of its semantics? We could have some kind of exceptions list to tell our proxy not to add anything in those cases, but let's not get into that.

The code for our handler is as follows. Whenever the method of an object is invoked, a `get()` is implicitly called, and we catch it. If we get a function, we wrap it with some code of our own that will call the original method and then decide whether to return its value or a reference to the proxied object instead. If we didn't get a function, we would return the requested property's value. Our `chainify()` function will take care of assigning the handler to an object and creating the needed proxy:

```
// chainify.ts

const chainify = <OBJ extends { [key: string]: any }>(
  obj: OBJ
): Chainify<OBJ> =>
  new Proxy(obj, {
    get(target, property, receiver) {
      if (typeof property === "string") {
        if (typeof target[property] === "function") {
          // requesting a method? return a wrapped version
          return (...args: any[]) => {
            const result = target[property](...args);
            return result === undefined ? receiver :
              result;
          };
        } else {
          // an attribute was requested - just return it
          return target[property];
        }
      } else {
        return Reflect.get(target, property, receiver);
      }
    },
  });
```

We must check whether the invoked `get()` was for a function or an attribute. In the first case, we wrap the method with extra code so that it will execute it and then return its results (if any) or a reference to the object itself. In the second case, we return the attribute, which is the expected behavior. (For the use of `Reflect.get()`, check out `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Reflect/get`.)

What's the type of a "chainified" object? Any property that isn't a function is the same. A property that is a function that returns some non-`void` value is also still the same. However, if a function returns `void`, we wrap it, so it returns the object itself. The `Chainify<>` type definition does that:

```
// continued...

type Chainify<A extends { [key: string]: any }> = {
  [key in keyof A]: A[key] extends (...args: any[]) => any
    ? void extends ReturnType<A[key]>
      ? (...args: Parameters<A[key]>) => Chainify<A>
      : (...args: Parameters<A[key]>) => ReturnType<A[key]>
    : A[key];
};
```

With this, we can chainify any object so that we can inspect any called method. As I'm writing this, I'm currently living in Pune, India, so let's reflect that change:

```
const myCity2 = chainify(myCity);

console.log(
  myCity2
    .setName("Pune, India")
    .setLat(18.5626)
    .setLong(73.8087)
    .getCoords(),
  myCity.getName()
);
// [ 18.5626, 73.8087 ] 'Pune, India'
```

Notice the following:

- The type of `myCity2` (which is chainified) is different from the type of `myCity`. For instance, `myCity2.setLong()` is now of the `setLong(newLong: number): Chainify<City>` type instead of `setLong(newLong: number): void` as before. (See *Question 8.8*.)
- We call several setters in a fluent manner, and they are working fine since our proxy is taking care of providing the value for the following call.
- The calls to `getCoords()` and `getName()` are intercepted, but nothing special is done because they already return a value.

Is working in a chained way worth it? That's up to you—but remember that there may be cases in which this approach fails, so be wary! Now, let's move on to composing, the other most common way of joining functions.

Composing

Composing is quite similar to pipelining, but has its roots in mathematical theory. The concept of composition is a sequence of function calls in which the output of one function is the input for the next one—but in the opposite order to when pipelining. So, if you have a series of functions, from left to right, when pipelining, the first function of the series to be applied is the leftmost one, but when you use composition, you start with the rightmost one.

Let's investigate this a bit more. When you define the composition of, say, three functions as (`f∘g∘h`) and apply this composition to `x`, this is equivalent to writing `f(g(h(x)))`.

It's important to note that, as with pipelining, the arity of the first function to be applied (actually the last one in the list) can be anything, but all the other functions must be unary. Also, besides the difference in the sequence of function evaluation, composing is an important tool in FP: it abstracts the implementation details (putting your focus on what you need to accomplish rather than on the specific details for achieving that), thereby letting you work in a more declarative fashion.

Tip for reading

If it helps, you can read ($f \circ g \circ h$) as "*f* after *g* after *h*" so that it becomes clear that *h* is the first function to be applied, while *f* is the last.

Given its similarity to pipelining, it will be no surprise that implementing composition isn't very hard. However, there are still some important and interesting details. Let's see some examples of composition before moving on to using higher-order functions and finishing with some considerations about testing composed functions.

Some examples of composition

It may not be a surprise to you, but we have already seen several examples of composition—or, at the very least, cases in which the solutions we achieved were functionally equivalent to using composition. Let's review some of these and work with some new examples too.

Unary operators

In the *Logically negating a function* section of *Chapter 6*, *Producing Functions*, we wrote a `not()` function that, given another function, would logically invert its result. We used that function to negate a check for negative balances; the sample code for this (and I'm going with plain JavaScript here, for clarity) could be as follows:

```
const not = (fn) => (...args) => !fn(...args);

const positiveBalance = not(isNegativeBalance);
```

In another section (*Turning operations into functions*) of that chapter, I left you with the challenge of writing a `unaryOp()` function that would provide unary functions equivalent to common JavaScript operators. If you met that challenge, you should be able to write something such as the following:

```
const logicalNot = unaryOp("!");
```

Assuming the existence of a `compose()` function, you could have also written the following:

```
const positiveBalance = compose(
  logicalNot,
  isNegativeBalance
);
```

Which one do you prefer? It's a matter of taste—but I think the second version clarifies what we are trying to do better. With the `not()` function, you must check what it does to understand the general code. With composition, you still need to know what `logicalNot()` is, but the global construct is open to see.

To look at just one more example in the same vein, you could have achieved the same results that we got in the *Inverting the results* section in the same chapter. Recall that we had a function that could compare strings according to the rules of Spanish, but we wanted to invert the result of the comparison so that it was sorted in descending order:

```
const changeSign = unaryOp("-");

palabras.sort(compose(changeSign, spanishComparison));
```

This code produces the same result that our previous sorting problem did, but the logic is expressed more clearly and with less code: a typical FP result! Let's look at some more examples of composing functions by reviewing another task we discussed earlier.

Counting files

We can also go back to our pipeline. We wrote a single-line function to count the `odt` files in a given path:

```
const countOdtFiles2 = (path: string): number =>
  count(filterOdt(getDir(path)));
```

Disregarding (at least for the moment) the observation that this code is not as clear as the pipeline version that we developed later, we could have also written this function with composition:

```
const countOdtFiles2b = (path: string): number =>
  compose(count, filterOdt, getDir)(path);

countOdtFiles2b("/home/fkereki/Documents");
// 4, no change here
```

We may also see this written in a one-liner fashion:

```
compose(count, filterOdt, getDir)("/home/fkereki/Documents");
```

Even if it's not as clear as the pipeline version (and that's just my opinion, which may be biased due to my liking of Linux!), this declarative implementation makes it clear that we depend on combining three distinct functions to get our result—this is easy to see and applies the idea of building large solutions out of simpler pieces of code.

Let's take a look at another example that's designed to compose as many functions as possible.

Finding unique words

Finally, let's go for another example, which, I agree, could have also been used for pipelining. Suppose you have some text and want to extract all the unique words from it: how would you go about doing so? If you think about it in steps (instead of trying to create a full solution in one go), you would probably come up with a solution similar to this:

1. Ignore all non-alphabetic characters.
2. Put everything in uppercase.
3. Split the text into words.
4. Create a set of words.

(Why a set? Because it automatically discards repeated values; check out `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/Set` for more on this. By the way, we will use the `Array.from()` method to produce an array out of our set; see `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Array/from` for more on this.)

Now, using FP, let's solve each problem:

```
const removeNonAlpha = (str: string): string =>
  str.replace(/[^a-z]/gi, " ");

const toUpperCase = demethodize(
  String.prototype.toUpperCase
);

const splitInWords = (str: string): string[] =>
  str.trim().split(/\s+/);

const arrayToSet = (arr: string[]): Set<string> =>
  new Set(arr);

const setToList = (set: Set<string>): string[] =>
  Array.from(set).sort();
```

With these functions, the result can be written as follows:

```
const getUniqueWords = compose(
  setToList,
  arrayToSet,
  splitInWords,
  toUpperCase,
  removeNonAlpha
);
```

Since you don't get to see the arguments of any of the composed functions, you don't need to show the parameter for `getUniqueWords()` either, so the pointfree style is natural in this case.

Now, let's test our function. To do this, let's apply this function to the first two sentences of Abraham Lincoln's address at Gettysburg (which we already used in an example back in the *Mapping and flattening – flatMap* section of *Chapter 5, Programming Declaratively*) and print out the 43 different words (trust me, I counted them!) in it:

```
const GETTYSBURG_1_2 = `Four score and seven years ago
our fathers brought forth on this continent, a new nation,
conceived in liberty, and dedicated to the proposition that all
men are created equal. Now we are engaged in a great civil war,
testing whether that nation, or any nation so conceived and so
dedicated, can long
endure.`;

console.log(getUniqueWords(GETTYSBURG_1_2));
// Output: 43 words, namely
  'A',           'AGO',        'ALL',
  'AND',         'ANY',        'ARE',
  'BROUGHT',     'CAN',        'CIVIL',
  'CONCEIVED',   'CONTINENT', 'CREATED',
  'DEDICATED',   'ENDURE',     'ENGAGED',
  'EQUAL',       'FATHERS',    'FORTH',
  'FOUR',        'GREAT',      'IN',
  'LIBERTY',     'LONG',       'MEN',
  'NATION',      'NEW',        'NOW',
  'ON',          'OR',         'OUR',
  'PROPOSITION', 'SCORE',      'SEVEN',
  'SO',          'TESTING',    'THAT',
  'THE',         'THIS',       'TO',
  'WAR',         'WE',         'WHETHER',
  'YEARS'
```

Of course, you could have written `getUniqueWords()` more succinctly, but the point I'm making is that by composing your solution out of several shorter steps, your code is clearer and easier to grasp. However, if you wish to say that a pipelined solution seems better, it's just a matter of opinion!

We have looked at many examples of function composition at this point, but there's another way to manage this—by using higher-order functions.

Composing with higher-order functions

Evidently, composing by hand can be done similarly to pipelining. For example, the unique word-counting function that we wrote previously could be written in simple JavaScript style:

```
const getUniqueWords1 = (str: string): string[] => {
  const str1 = removeNonAlpha(str);
  const str2 = toUpperCase(str1);
  const arr1 = splitInWords(str2);
  const set1 = arrayToSet(arr1);
  const arr2 = setToList(set1);
  return arr2;
};

console.log(getUniqueWords1(GETTYSBURG_1_2));
// Output: the same 43 words
```

Alternatively, it could be written more concisely (but more obscurely!) in a one-liner style:

```
const getUniqueWords2 = (str: string): string[] =>
  setToList(
    arrayToSet(
      splitInWords(toUpperCase(removeNonAlpha(str)))
    )
  );

console.log(getUniqueWords2(GETTYSBURG_1_2));
// Output: the same 43 words
```

This works fine, but as when we studied pipelining, let's look for a more general solution that won't require writing a new particular function every time we want to compose some other functions.

Composing two functions is relatively easy and requires making a small change to our `pipeTwo()` function, which we looked at earlier in this chapter. We just have to exchange `f` and `g` to get the new definition!

```
// compose.ts

const pipeTwo =
  <F extends FN, G extends FN>(f: F, g: G) =>
  (...args: Parameters<F>): ReturnType<G> =>
    g(f(...args));

const composeTwo =
  <F extends FN, G extends FN>(f: F, g: G) =>
  (...args: Parameters<G>): ReturnType<F> =>
    f(g(...args));
```

The only difference is that, with piping, you apply the leftmost function first, while with composing, you start with the rightmost function first. This variation suggests that we could have used the `flipTwo()` higher-order function from the *Parameter order* section of *Chapter 7, Transforming Functions*. Is it clearer? Here is the code:

```
// continued...

const composeTwoByFlipping = flipTwo(pipeTwo);
```

In any case, if we want to compose more than two functions, we can take advantage of the associative property and write something like the following:

```
const getUniqueWords3 = composeTwo(
  setToList,
  composeTwo(
    arrayToSet,
    composeTwo(
      splitInWords,
      composeTwo(toUpperCase, removeNonAlpha)
    )
  )
);
```

Even though this works, let's go for a better solution—we can provide several. We could use a loop like when we wrote our first pipelining function:

```
// continued...

function compose(...fns) {
  return (...args) => {
    let result = fns[fns.length - 1](...args);
    for (let i = fns.length - 2; i >= 0; i--) {
      result = fns[i](result);
    }
    return result;
  };
}

console.log(
  compose(
    setToList,
    arrayToSet,
    splitInWords,
    toUpperCase,
    removeNonAlpha
  )(GETTYSBURG_1_2)
);
// same output as earlier
```

We could also note that pipelining and composing work in opposite directions. We apply functions from left to right when pipelining, and from right to left when composing. Thus, we can achieve the same result we achieved with composition by reversing the order of the functions and doing pipelining instead; a very functional solution, which I really like! This is as follows:

```
// continued...

function compose1(...fns) {
  return pipeline(...fns.reverse());
}
```

The only tricky part is the usage of the spread operator before calling `pipeline()`. After reversing the `fns` array, we must spread its elements to call `pipeline()` correctly.

Yet another solution, less declarative, is to use `reduceRight()` so that instead of reversing the list of functions, we reverse the order of processing them:

```
// continued...

function compose2(...fns) {
  return fns.reduceRight(
    (f, g) => (...args) => g(f(...args))
  );
}

console.log(
  compose2(
    setToList,
    arrayToSet,
    splitInWords,
    toUpperCase,
    removeNonAlpha
  )(GETTYSBURG_1_2)
);
// still same output
```

Why and how does this work? Let's look at the inner workings of this call:

- Since no initial value is provided, `f()` is `removeNonAlpha()` and `g()` is `toUpperCase()`, so the first intermediate result is a function, `(...args) => toUpperCase(removeNonAlpha(...args))`; let's call it `step1()`.
- The second time, `f()` is `step1()` from the previous step, while `g()` is `splitInWords()`, so the new result is a function, `(...args) => splitInWords(step1(...args)))`, which we can call `step2()`.
- The third time around, in the same fashion, we get `(...args) => arrayToSet(step2(...args))))`, which we call `step3()`.
- Finally, the result is `(...args) => setToList(step3(...args))`, a function; let's call it `step4()`.

The final result turns out to be a function that receives `(...args)` and starts by applying `removeNonAlpha()` to it, then `toUpperCase()`, and so on, before finishing by applying `setToList()`.

It may come as a surprise that we can also make this work with `reduce()`—can you see why? The reasoning is similar to what we did previously, so we'll leave this as an exercise for you:

```
// continued...

function compose3(...fns) {
  return fns.reduceRight(pipeTwo);
}
```

A symmetric challenge!

After working out how `compose3()` works, you might want to write a version of `pipeline()` that uses `reduceRight()`, just for symmetry, to round things out!

Data typing for composition

Given what we did for pipelining, data typing for composition is very much the same, and we'll follow what we did in parallel. First, we'll have an auxiliary type to check whether our functions' types can be composed correctly:

```
// compose.ts

type FnsMatchComp<FNS extends FN[]> =
  1 extends FNS["length"]
    ? boolean
    : FNS extends [
        ...infer FNInit extends FN[],
        infer FNPrev extends FN,
        infer FNLast extends FN
      ]
    ? Parameters<FNPrev> extends [ReturnType<FNLast>]
      ? FnsMatchComp<[...FNInit, FNPrev]>
      : never
    : never;
```

This is essentially the same as what we wrote for pipelining, except that we process functions from right to left. With this done, we can now write our `Compose<>` type:

```
// continued...

type Compose<FNS extends FN[]> =
  boolean extends FnsMatchComp<FNS>
    ? 1 extends FNS["length"]
      ? FNS[0]
      : FNS extends [
          infer FNFIRST extends FN,
          ...FN[],
          infer FNLAST extends FN
        ]
      ? (...args: Parameters<FNLAST>) =>
        ReturnType<FNFIRST>
      : never
    : never;
```

This is also what we had for pipelining, except for the type of the result, which is symmetrical. Finally, we can apply types to our composing functions; let's see just one example, because (logically!) typing is the same for all the versions of our code!

```
function compose<FNS extends FN[]>(
  ...fns: FNS
): Compose<FNS>;
function compose<FNS extends FN[]>(...fns: FNS): FN {
  return (...args: Parameters<FNS[0]>) => {
    let result = fns[fns.length - 1](...args);
    for (let i = fns.length - 2; i >= 0; i--) {
      result = fns[i](result);
    }
    return result;
  };
}
```

So far, we have looked at the important methods we can use to connect functions using pipelining, chaining, and composition. All this works very well, but we'll see that there's a particular case in which the performance of your code can be affected and that will require a new way to handle composition: *transducing*.

Transducing

Let's consider a performance problem in JavaScript that happens when we're dealing with large arrays and applying several `map()`, `filter()`, or `reduce()` operations. If you start with an array and apply these operations (via chaining, as we saw earlier in this chapter), you get the desired result. However, many intermediate arrays are created, processed, and discarded—and that causes delays. If you are dealing with small arrays, the extra time won't make an impact, but with larger arrays (as in a big data process, maybe in Node.js, where you're working with the results of a large database query), then you will probably have to need some optimization. We'll do this by learning about a new tool for composing functions: *transducing*.

First, let's create some functions and data. We'll make do with a nonsensical example since we aren't focusing on the actual operations but on the general process. We'll start with some filtering functions and some mapping:

```
// transducing.ts

const testOdd = (x: number): boolean => x % 2 === 1;

const testUnderFifty = (x: number): boolean => x < 50;

const duplicate = (x: number): number => x + x;

const addThree = (x: number): number => x + 3;
```

Now, let's apply those maps and filters to an array. First, we drop the even numbers, duplicate the odd numbers, drop results over 50, and end by adding 3 to all the results:

```
// continued...

const myArray = [22, 9, 60, 24, 11, 63];

const a0 = myArray
  .filter(testOdd)
  .map(duplicate)
  .filter(testUnderFifty)
  .map(addThree);
```

```
console.log(a0);
// Output: [ 21, 25 ]
```

The following diagram shows how this sequence of operations works:

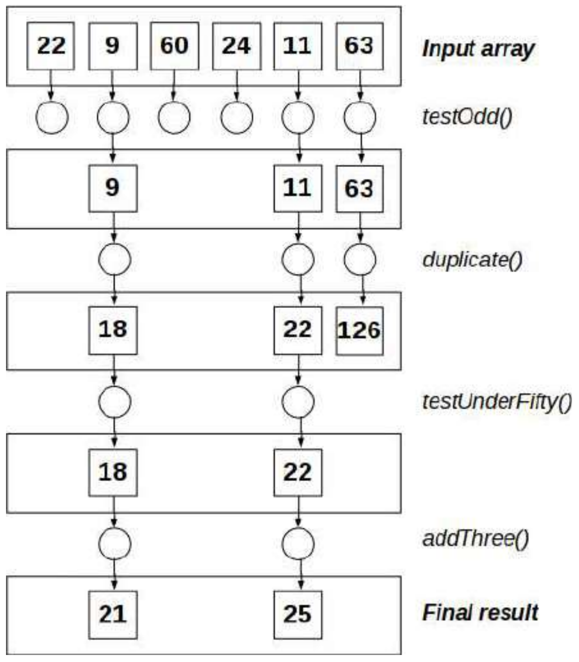


Figure 8.3 – Chaining map/filter/reduce operations causes intermediate arrays to be created and later discarded

Here, we can see that chaining together several `map()`, `filter()`, and `reduce()` operations causes intermediate arrays (three, in this case) to be created and later discarded—and for large arrays, that can become cumbersome.

How can we optimize this? The problem here is that processing applies the first transformation to the input array; then, the second transformation is applied to the resulting array; then the third, and so on. An alternative solution would be to take the first element of the input array and apply all the transformations in sequence to it. Then, you would need to take the second element of the input array and apply all the transformations to it, then take the third, and so on. In pseudocode, the difference is between this:

```
for each transformation to be applied:
    for each element in the input list:
        apply the transformation to the element
```

And then this approach:

```
for each element in the input list:
    for each transformation to be applied:
        apply the transformation to the element
```

With the first logic, we go transformation by transformation, applying it to each list and generating a new one. This requires several intermediate lists to be produced. With the second logic, we go element by element and apply all the transformations to each one in sequence to arrive at the final output list without any intermediate lists being created.

Now, the problem is being able to transpose the transformations; how can we do this? We saw this key concept in *Chapter 5*, *Programming Declaratively*, and we can define `map()` and `filter()` in terms of `reduce()`. Using those definitions, instead of a sequence of different functions, we will apply the same operation (`reduce()`) at each step, and here is the secret! As shown in the following diagram, we change the order of evaluation by composing all the transformations so that they can be applied in a single pass with no intermediate arrays whatsoever:

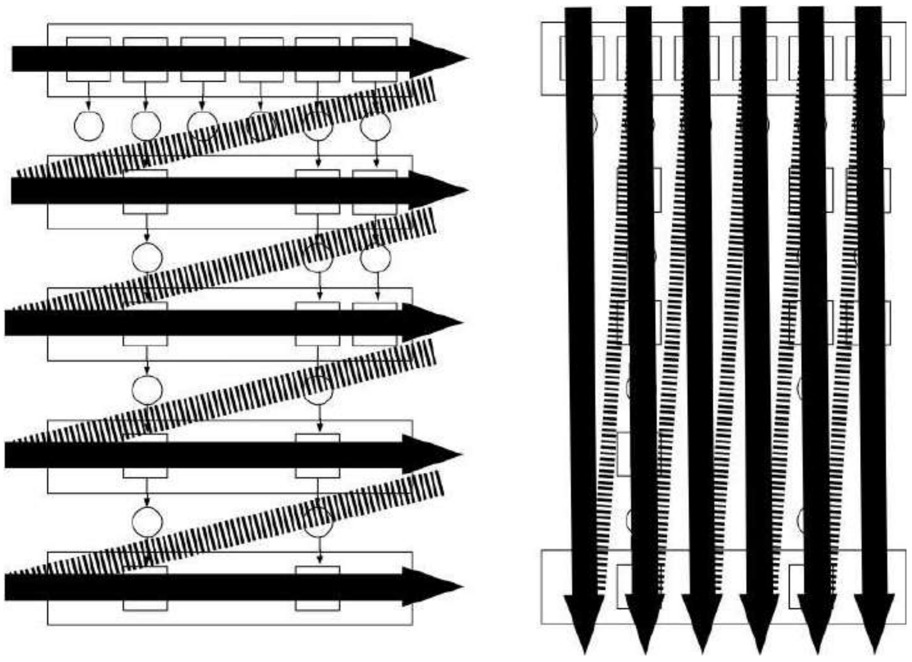


Figure 8.4 – By applying transducers, we will change the order of evaluation but get the same result

Instead of applying a first `reduce()` operation, passing its result to a second, its result to a third, and so on, we will compose all the reducing functions into a single one! Let's analyze this.

Composing reducers

Essentially, what we want is to transform each function (`testOdd()`, `duplicate()`, and so on) into a reducing operation that will call the following reducer. A couple of higher-order functions will help; one for mapping functions and another for filtering ones. With this idea, the result of an operation will be passed to the next one, avoiding intermediate arrays:

```
// continued...

const mapTR =
  <V, W>(fn: (x: V) => W) =>
  <A>(reducer: (am: A, wm: W) => A) =>
  (accum: A, value: V): A =>
    reducer(accum, fn(value));

const filterTR =
  <V>(fn: (x: V) => boolean) =>
  <A>(reducer: (af: A, wf: V) => A) =>
  (accum: A, value: V): A =>
    fn(value) ? reducer(accum, value) : accum;
```

These two transforming functions are *transducers*: functions that accept a reducing function and return a new reducing function. (Some trivia: the word *transduce* comes from Latin, meaning transform, transport, convert, change over, and is applied in many different fields, including biology, psychology, machine learning, physics, electronics, and more.)

Typing is not too hard. For mapping, we assume a mapping function that gets a value of type `V` and produces a result of type `W`. The generic reducer takes an accumulator of type `A` and a value of type `W` and produces a new accumulator, also of type `A`. For filtering, the filtering function gets a value of type `V` and produces a `Boolean` value, and the reducer gets an accumulator of type `A` and a value of type `V`, returning a type `A` result.

How do we use these transducers? We can write code such as the following, although we'll want a more abstract, generic version later:

```
// continued...

const testOddR = filterTR(testOdd);

const testUnderFiftyR = filterTR(testUnderFifty);
const duplicateR = mapTR(duplicate);

const addThreeR = mapTR(addThree);
```

Each of our original four functions is transformed, so they will calculate their result and call a reducer to deal with this further. As an example, `addThreeR()` will add three to its input and pass the incremented value to the next reducer, which in this case is `addToArray()`.

This will build up the final resulting array. Now, we can write our whole transformation in a single step:

```
// continued...

const addToArray = (a: any[], v: any): any[] => {
  a.push(v);
  return a;
};

const a1 = myArray.reduce(
  testOddR(
    duplicateR(testUnderFiftyR(addThreeR(addToArray)))
  ),
  []
);

console.log(a1);
// Output: [ 21, 25 ], again
```

This is quite a mouthful, but it works! However, we can simplify our code by using the `compose()` function:

```
// continued...

const transduce = <A>(arr: A[], fns: FN[]) =>
  arr.reduce(compose(...fns)(addToArray), []);

console.log(
  transduce(myArray, [
    testOddR,
    duplicateR,
    testUnderFiftyR,
    addThreeR,
  ])
);
// Output: [ 21, 25 ], yet again
```

The code is the same, but pay particular attention to the `compose(...fns)(addToArray)` expression: we compose all the mapping and filtering functions—with the last one being `addToArray`—to build up the output. However, this is not as general as we may want it to be: why do we have to create an array? Why can't we have a different final reducing function? We can go one better by generalizing a bit more.

Generalizing for all reducers

To be able to work with all kinds of reducers and produce whatever kind of result they build, we'll need to make a small change. The idea is simple: let's modify our `transduce()` function so that it will accept a final reducer and a starting value for the accumulator:

```
// continued...

const transduce2 = <A>(
  arr: A[],
  fns: FN[],
  reducer: FN = addToArray,
  initial: any = []
) => arr.reduce(compose(...fns)(reducer), initial);

console.log(
  transduce2(myArray, [
    testOddR,
    duplicateR,
    testUnderFiftyR,
    addThreeR,
  ])
);
// Output: [ 21, 25 ], always
```

To make this function more usable, we specified our array-building function (and an empty array as a starting accumulator value) so that if you skip those two parameters, you'll get a reducer that produces an array. Now, let's look at the other option: instead of an array, let's calculate the sum of the resulting numbers after all the mapping and filtering:

```
// continued...

console.log(
  transduce2(
    myArray,
    [testOddR, duplicateR, testUnderFiftyR, addThreeR],
    (acc, value) => acc + value,
    0
  )
);
// 46
```

By using transducers, we have been able to optimize a sequence of `map`, `filter`, and `reduce` operations so that the input array is processed once and directly produces the output result (whether an array or a single value) without creating any intermediate arrays; a good gain!

We've seen several ways of connecting functions; to round this off, let's see how to write unit tests for connected functions.

Testing connected functions

Let's finish by considering testing for functions connected in all the ways we've seen in this chapter. Given that the mechanisms for pipelining and composition are similar, we will look at examples of both. They won't differ, other than their logical differences due to the left-to-right or right-to-left order of function evaluation.

Testing pipelined functions

When it comes to pipelining, we can start by looking at how to test the `pipeTwo()` function since the setup will be similar to `pipeline()`. We need to create some mocks and check whether they were called the correct number of times and whether they received the correct arguments each time. We will set them to provide a known answer to a call.

By doing this, we can check whether the output of a function becomes the input of the next function in the pipeline:

```
// pipetwo.test.ts

describe("pipeTwo", function () {
  it("works with single arguments", () => {
    const fn1 = jest.fn().mockReturnValue(1);
    const fn2 = jest.fn().mockReturnValue(2);

    const pipe = pipeTwo(fn1, fn2);
    const result = pipe(22);

    expect(fn1).toHaveBeenCalledTimes(1);
    expect(fn2).toHaveBeenCalledTimes(1);
    expect(fn1).toHaveBeenCalledWith(22);
    expect(fn2).toHaveBeenCalledWith(1);
    expect(result).toBe(2);
  });

  it("works with multiple arguments", () => {
    const fn1 = jest.fn().mockReturnValue(11);
    const fn2 = jest.fn().mockReturnValue(22);

    const pipe = pipeTwo(fn1, fn2);
    const result = pipe(12, 4, 56);

    expect(fn1).toHaveBeenCalledTimes(1);
    expect(fn2).toHaveBeenCalledTimes(1);
    expect(fn1).toHaveBeenCalledWith(12, 4, 56);

    expect(fn2).toHaveBeenCalledWith(11);
    expect(result).toBe(22);
  });
});
```

There is little to test given that our function always receives two functions as parameters. The only difference between the tests is that one shows a pipeline applied to a single argument, while the other shows it applied to several arguments.

Moving on to `pipeline()`, the tests would be quite similar. However, we can add a test for a single-function pipeline (a border case!) and another with four functions:

```
// pipeline.test.ts
```

```
describe("pipeline", function () {
  it("works with a single function", () => {
    const fn1 = jest.fn().mockReturnValue(11);

    const pipe = pipeline(fn1);
    const result = pipe(60);

    expect(fn1).toHaveBeenCalledTimes(1);
    expect(fn1).toHaveBeenCalledWith(60);
    expect(result).toBe(11);
  });

  it("works with single arguments", () => {
    const fn1 = jest.fn().mockReturnValue(1);
    const fn2 = jest.fn().mockReturnValue(2);

    const pipe = pipeline(fn1, fn2);
    const result = pipe(22);

    expect(fn1).toHaveBeenCalledTimes(1);
    expect(fn2).toHaveBeenCalledTimes(1);
    expect(fn1).toHaveBeenCalledWith(22);
    expect(fn2).toHaveBeenCalledWith(1);
    expect(result).toBe(2);
  });

  it("works with multiple arguments", () => {
    const fn1 = jest.fn().mockReturnValue(11);
    const fn2 = jest.fn().mockReturnValue(22);

    const pipe = pipeline(fn1, fn2);
    const result = pipe(12, 4, 56);

    expect(fn1).toHaveBeenCalledTimes(1);
    expect(fn2).toHaveBeenCalledTimes(1);
    expect(fn1).toHaveBeenCalledWith(12, 4, 56);

    expect(fn2).toHaveBeenCalledWith(11);
    expect(result).toBe(22);
  });

  it("works with 4 functions, multiple arguments", () => {
    const fn1 = jest.fn().mockReturnValue(111);
    const fn2 = jest.fn().mockReturnValue(222);
    const fn3 = jest.fn().mockReturnValue(333);
    const fn4 = jest.fn().mockReturnValue(444);

    const pipe = pipeline(fn1, fn2, fn3, fn4);
    const result = pipe(24, 11, 63);

    expect(fn1).toHaveBeenCalledTimes(1);
    expect(fn2).toHaveBeenCalledTimes(1);
    expect(fn3).toHaveBeenCalledTimes(1);
    expect(fn4).toHaveBeenCalledTimes(1);
    expect(fn1).toHaveBeenCalledWith(24, 11, 63);

    expect(fn2).toHaveBeenCalledWith(111);
    expect(fn3).toHaveBeenCalledWith(222);
    expect(fn4).toHaveBeenCalledWith(333);
    expect(result).toBe(444);
  });
});
```

Testing composed functions

For composition, the style is the same (except that the order of function evaluation is reversed), so let's take a look at a single test—here, I simply changed the order of the functions in the preceding test:

```
// compose.test.ts

describe("compose", function () {

  // other tests, omitted here
  it("works with 4 functions, multiple arguments", () => {
    const fn1 = jest.fn().mockReturnValue(111);
    const fn2 = jest.fn().mockReturnValue(222);
    const fn3 = jest.fn().mockReturnValue(333);
    const fn4 = jest.fn().mockReturnValue(444);

    const comp = compose(fn4, fn3, fn2, fn1);
    const result = comp(24, 11, 63);

    expect(fn1).toHaveBeenCalledTimes(1);
    expect(fn2).toHaveBeenCalledTimes(1);
    expect(fn3).toHaveBeenCalledTimes(1);
    expect(fn4).toHaveBeenCalledTimes(1);
    expect(fn1).toHaveBeenCalledWith(24, 11, 63);

    expect(fn2).toHaveBeenCalledWith(111);
    expect(fn3).toHaveBeenCalledWith(222);
    expect(fn4).toHaveBeenCalledWith(333);
    expect(result).toBe(444);
  });
});
```

Testing chained functions

To test the `chainify()` function, I opted to use the preceding `City` object I created—I didn't want to mess with mocks, stubs, spies, and the like; I wanted to ensure that the code worked under normal conditions:

```
// chaining.test.ts

class City {
// as above
}

let myCity: City;
let myCity2: Chainify<City>;
```

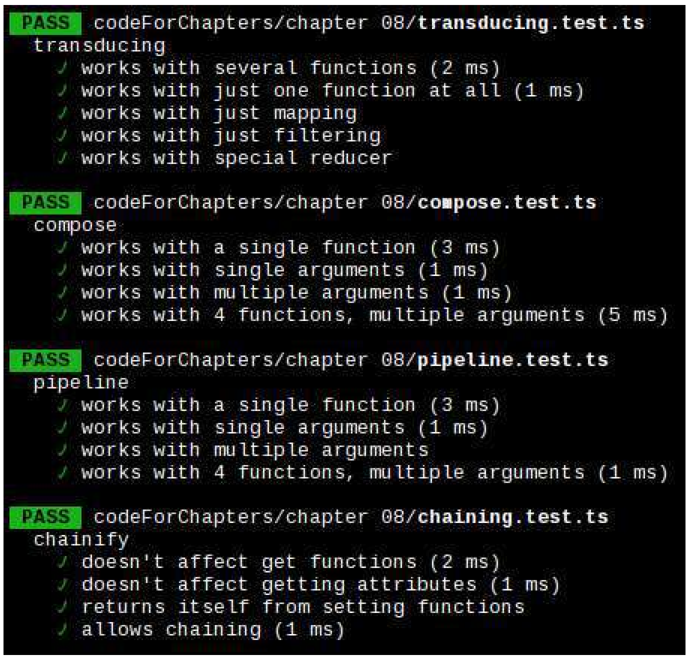
```
describe("chainify", function () {
  beforeEach(() => {
    myCity = new City(
      "Montevideo, Uruguay",
      -34.9011,
      -56.1645
    );
    myCity2 = chainify(myCity);
  });

  it("doesn't affect get functions", () => {
    expect(myCity2.getName()).toBe("Montevideo, Uruguay");
    expect(myCity2.getCoords()[0]).toBe(-34.9011);
    expect(myCity2.getCoords()[1]).toBe(-56.1645);
  });

  it("doesn't affect getting attributes", () => {
    expect(myCity2.name).toBe("Montevideo, Uruguay");
    expect(myCity2.lat).toBe(-34.9011);
    expect(myCity2.long).toBe(-56.1645);
  });

  it("returns itself from setting functions", () => {
    //    expect(myCity2.setName("Other
      name")).toBe(myCity2);
    expect(myCity2.setLat(11)).toBe(myCity2);
    expect(myCity2.setLong(22)).toBe(myCity2);
  });

  it("allows chaining", () => {
    const newCoords = myCity2
      .setName("Pune, India")
      .setLat(18.5626)
      .setLong(73.8087)
      .getCoords();
    expect(myCity2.name).toBe("Pune, India");
    expect(newCoords[0]).toBe(18.5626);
    expect(newCoords[1]).toBe(73.8087);
  });
});
```

Testing transduced functions

We tried several examples earlier in the chapter, and it's easy to turn them into tests. We'll also add new tests for border cases (for instance, just one function, only mapping functions, etc.) for more generality. For simplicity, I kept using the same data array and mapping and filtering functions I used before:

```
// transducing.test.ts

describe("transducing", () => {
  it("works with several functions", () => {
    expect(
      transduce(myArray, [
        testOddR,
        duplicateR,
        testUnderFiftyR,
        addThreeR,
      ])
    ).toEqual([21, 25]);
  });

  it("works with just one function at all", () => {
    expect(transduce(myArray, [testOddR])).toEqual([
      9, 11, 63,
    ]);

    expect(transduce(myArray, [addThreeR])).toEqual([
      25, 12, 63, 27, 14, 66,
    ]);
  });
  it("works with just mapping", () => {
    expect(
      transduce(myArray, [addThreeR, duplicateR])
    ).toEqual([50, 24, 126, 54, 28, 132]);
  });

  it("works with just filtering", () => {
    expect(
      transduce(myArray, [testOddR, testUnderFiftyR])
    ).toEqual([9, 11]);
  });

  it("works with special reducer", () => {
    expect(
      transduce2(
        myArray,
        [testOddR, duplicateR, testUnderFiftyR, addThreeR],
        (acc, value) => acc + value,
        0
      )
    ).toBe(46);
  });
});
```

The final result of all of these tests can be seen in the following screenshot:



```
 PASS  codeForChapters/chapter 08/transducing.test.ts
  transducing
    ✓ works with several functions (2 ms)
    ✓ works with just one function at all (1 ms)
    ✓ works with just mapping
    ✓ works with just filtering
    ✓ works with special reducer

 PASS  codeForChapters/chapter 08/compose.test.ts
  compose
    ✓ works with a single function (3 ms)
    ✓ works with single arguments (1 ms)
    ✓ works with multiple arguments (1 ms)
    ✓ works with 4 functions, multiple arguments (5 ms)

 PASS  codeForChapters/chapter 08/pipeline.test.ts
  pipeline
    ✓ works with a single function (3 ms)
    ✓ works with single arguments (1 ms)
    ✓ works with multiple arguments
    ✓ works with 4 functions, multiple arguments (1 ms)

 PASS  codeForChapters/chapter 08/chaining.test.ts
  chainify
    ✓ doesn't affect get functions (2 ms)
    ✓ doesn't affect getting attributes (1 ms)
    ✓ returns itself from setting functions
    ✓ allows chaining (1 ms)
```

Figure 8.5 – A successful run of testing for connected functions

As we can see, all our tests passed successfully; good!

Summary

In this chapter, we learned how to create new functions by joining several other functions in different ways using pipelining and composition. We also looked at fluent interfaces, which apply chaining, and transducing, a way to compose reducers to get higher-speed sequences of transformations. With these methods, you'll be able to create new functions out of existing ones and keep programming in the declarative way we favor.

In *Chapter 9*, *Designing Functions*, we will move on to function design and study the usage of recursion, which is a basic tool in FP and allows for very clean algorithm designs.

Questions

8.1 **Headline capitalization**: Let's define headline-style capitalization, so ensure that a sentence is all written in lowercase, except the first letter of each word. (The real definition of this style is more complicated, so let's simplify it for this question.) Write a `headline(sentence)` function that will receive a string as an argument and return an appropriately capitalized version. Spaces separate words. Build this function by connecting smaller functions:

```
console.log(headline("Alice's ADVENTURES in WoNdErLaNd"));
// Alice's Adventures In Wonderland
```

8.2 **Pending tasks**: A web service returns a result such as the following, showing all assigned tasks person by person. Tasks may be finished (`done===true`) or pending (`done===false`). Your goal is to produce an array with the IDs of the pending tasks for a given person, identified by name, which should match the responsible field. Solve this by using composition or pipelining:

```
const allTasks = {
  date: "2017-09-22",
  byPerson: [
    {
      responsible: "EG",
      tasks: [
        { id: 111, desc: "task 111", done: false },
        { id: 222, desc: "task 222", done: false },
      ],
    },
    {
      responsible: "FK",
      tasks: [
        { id: 555, desc: "task 555", done: false },
        { id: 777, desc: "task 777", done: true },
        { id: 999, desc: "task 999", done: false },
      ],
    },
    {
      responsible: "ST",
      tasks: [{ id: 444, desc: "task 444", done: true }],
    },
  ],
};
```

Ensure your code doesn't throw an exception if, for example, the person you are looking for doesn't appear in the web service result!

8.3 **Thinking in abstract terms**: Suppose you are looking through somewhat old code and find a function that looks like the following one. (I'm keeping the names vague and abstract so that you can focus on the structure and not on the actual functionality). Can you transform this into pointfree style?

```
function getSomeResults(things) {
  return sort(group(filter(select(things))));
}
```

8.4 **Reversing types**: You can define the `Compose<>` type using the `Pipeline<>` type plus a new `Reverse<>` type. What should that new type be?

8.5 **Empty pipeline?** Do our pipelining functions work with an empty array of functions? Can you fix that?

8.6 **Undetected impurity?**: Did you notice that the `addToArray()` function we wrote is actually impure? (Check out the *Argument mutation* section of *Chapter 4, Behaving Properly,* if you aren't convinced!) Would it be better if we wrote it as follows? Should we go for it?

```
const addToArray = (a, v) => [...a, v];
```

8.7 **Needless transducing?** We used transducers to simplify any sequence of mapping and filtering operations. Would you have needed this if you only had `map()` operations? What if you only had `filter()` operations?

8.8 **What type?** In the *Chaining method calls* section, I explained that the type of the (chainified) `myCity2` object was not the same as the type of the original `myCity` one. What is its type exactly?

9
Designing Functions – Recursion

In *Chapter 8*, *Connecting Functions*, we considered yet more ways to create new functions out of combining previous existing ones. Here, we will get into a different theme: how to design and write functions in a typically functional way, by applying recursive techniques.

We will be covering the following topics:

- Understanding what recursion is and how to think in order to produce recursive solutions
- Applying recursion to some well-known problems, such as making a change or the Tower of Hanoi
- Using recursion instead of iteration to re-implement some higher-order functions from earlier chapters
- Writing search and backtrack algorithms with ease
- Traversing data structures, such as trees, to work with filesystem directories or with the browser DOM
- Understanding mutual recursion and applying it to problems such as correctly evaluating arithmetical expressions
- Getting around some limitations caused by browser JavaScript engine considerations

Using recursion

Recursion is a key technique in FP, to the degree that some languages do not provide for iterations or loops, and work exclusively with recursion (Haskell, which we already mentioned, is a prime example of that). A fundamental fact of computer science is that whatever you can do with recursion, you can do with iteration (loops), and vice versa. The key concept is that there are many algorithms whose definition is far easier if you work recursively. On the other hand, recursion is not always taught, and many programmers, even after knowing about it, prefer not to use it. Therefore, in this section, we shall see several examples of recursive thinking so that you can adapt it for your functional coding.

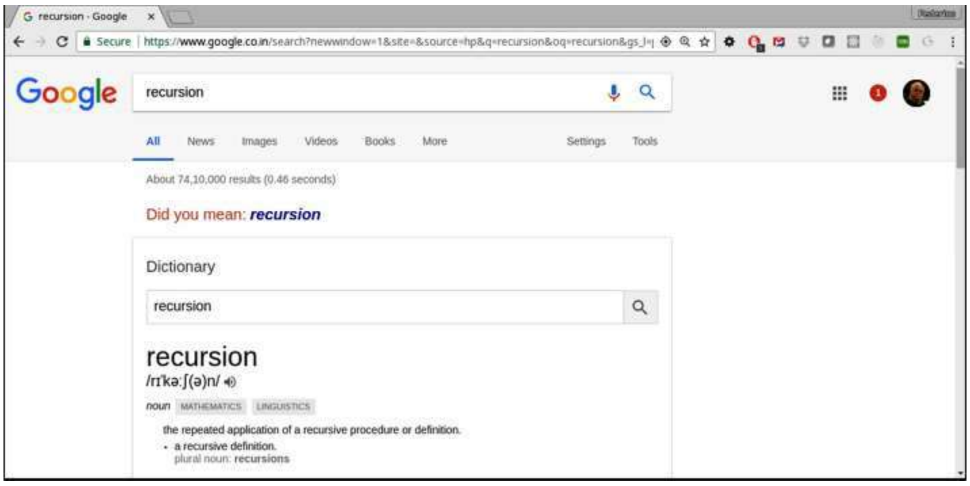
A typical, oft-quoted, and very old computer joke!
Dictionary definition: **recursion**: *(n) see* **recursion**

But what is recursion? There are many ways to define what recursion is, but the simplest one I've seen runs along the lines of *a function calling itself again and again until it doesn't*. A more complex case is mutual recursion, the simplest example of which is when we have two functions, `A()` and `B()`, each of which calls the other, over and over, until they are done.

Recursion is a natural technique for several kinds of problems, such as the following:

- Mathematical definitions, such as the Fibonacci sequence or the factorial of a number
- Data-structure-related algorithms with recursively defined structures, such as lists (a list is either empty or consists of a head node followed by a list of nodes) or trees (a tree might be defined as a special node, called the root, linked to zero or more trees)
- Syntax analysis for compilers based on grammar rules, which themselves depend on other rules, which also depend on other rules, and so on

And many more! It even appears in art and humor, as shown in *Figure 9.1*:


recursion - Google
Secure | https://www.google.co.in/search?newwindow=1&site=&source=hp&q=recursion&oq=recursion&gs_l=
Google
recursion
All
News
Images
Videos
Books
More
Settings
Tools

About 74,10,000 results (0.46 seconds)

Did you mean: ***recursion***

Dictionary

recursion

recursion
/rɪˈkəːʃ(ə)n/

noun MATHEMATICS LINGUISTICS

the repeated application of a recursive procedure or definition.
- a recursive definition.
  plural noun: recursions

Figure 9.1 – Google itself jokes about it: if you ask about recursion, it answers, "Did you mean: recursion"

Apart from some easy base cases in which no further computation is required, a recursive function must call itself one or more times to perform part of the required calculations. This concept may not be very clear at this point, so in the following sections, we will see how we can think recursively and solve several common problems by applying this technique.

Thinking recursively

The key to solving problems recursively is assuming that you already have a function that does whatever you need and just calling it. (Doesn't this sound weird? Actually, it is quite appropriate: if you want to solve a problem with recursion, you must first have solved it before...) On the other hand, if you attempt to work out in your head how the recursive calls work and try to follow the flow, you'll probably just get lost. So, what you need to do is the following:

1. Assume you already have an appropriate function to solve your problem.
2. See how the big problem can be solved by solving one (or more) smaller problems.
3. Solve those problems by using the imagined function from *step 1*.
4. Decide what your base cases are. Make sure they are simple enough that they are solved directly, without requiring more calls.

With these points in mind, you can solve problems by recursion because you'll have the basic structure for your recursive solution.

There are three usual methods for solving problems by applying recursion:

- **Decrease and conquer** is the simplest case, in which solving a problem directly depends on solving a single, simpler case of itself.
- **Divide and conquer** is a more general approach. The idea is to try to divide your problem into two or more smaller versions, solve them recursively, and use these solutions to solve the original problem. The only difference between this technique and *decrease and conquer* is that you have to solve two or more other problems instead of only one.
- **Dynamic programming** can be seen as a variant of *divide and conquer*: basically, you solve a complex problem by breaking it into a set of somewhat simpler versions of the same problem and solving each in order; however, a key idea in this strategy is to store previously found solutions, so that whenever you find yourself needing the solution to a simpler case again, you won't directly apply recursion but, instead, use the stored result and avoid unnecessary repeated calculations.

In this section, we shall look at a few problems and solve them by thinking recursively. Of course, we shall see more applications of recursion in the rest of the chapter; here, we'll focus on the key decisions and questions needed to create such an algorithm.

Decrease and conquer – searching

The most usual case of recursion involves just a single, simple case. We have already seen some examples of this, such as the ubiquitous factorial calculation: to calculate the factorial of *n*, you previously needed to calculate the factorial of *n*-1. (See *Chapter 1*, *Becoming Functional*.) Let's turn now to a non-mathematical example.

You would also use this decrease-and-conquer strategy to search for an element in an array. If the array is empty, then obviously the searched-for value isn't there; otherwise, the result is in the array if, and only if, it's the array's first element or if it's in the rest of the array. The following code does just that:

```
// search.ts

const search = <A>(arr: A[], key: A): boolean => {
  if (arr.length === 0) {
    return false;
  } else if (arr[0] === key) {
    return true;
  } else {
    return search(arr.slice(1), key);
  }
};
```

This implementation directly mirrors our explanation, and verifying its correctness is easy.

By the way, just as a precaution, let's look at two further implementations of the same concept. You can shorten the search function a bit—is it still clear?

We are using a ternary operator to detect whether the array is empty, and a Boolean `||` operator to return `true` if the first element is the sought one or else return the result of the recursive search:

```
// continued...

const search2 = <A>(arr: A[], key: A): boolean =>
  arr.length === 0
    ? false
    : arr[0] === key || search2(arr.slice(1), key);
```

Sparseness can go even further! Using `&&` as a shortcut is a common idiom:

```
// continued...

const search3 = <A>(arr: A[], key: A): boolean =>
  !!arr.length &&
  (arr[0] === key || search3(arr.slice(1), key));
```

I'm not really suggesting that you code the function in this way—instead, consider it a warning against the tendency that some FP developers have to try to go for the tightest, shortest possible solution and never mind clarity!

Decrease and conquer – doing powers

Another classic example has to do with efficiently calculating powers of numbers. If you want to calculate, say, 2 to the 13th power (2^{13}), then you can do this with 12 multiplications; however, you can do much better by writing 2^{13} as the following:

= 2 times 2^{12}

= 2 times 4^{6}

= 2 times 16^{3}

= 2 times 16 times 16^{2}

= 2 times 16 times 256^{1}

= 8192

This reduction in the total number of multiplications may not look very impressive, but in terms of algorithmic complexity, it allows us to bring down the order of the calculations from O(*n*) to O(*log n*). In some cryptographic-related methods, which have to raise numbers to really high exponents, this makes a significant difference. We can implement this recursive algorithm in a few lines of code, as shown in the following code:

```
// power.ts

const powerN = (base: number, power: number): number => {
  if (power === 0) {
    return 1;
  } else if (power % 2) {
    // odd power?
    return base * powerN(base, power - 1);
  } else {
    // even power?
    return powerN(base * base, power / 2);
  }
};
```

Extra speed

When implemented for production, bit operations are used instead of modulus and divisions. Checking whether a number is odd can be written as `power & 1`, and division by 2 is achieved with `power >> 1`. These alternative calculations are way faster than the replaced operations.

Calculating a power is simple when the base case is reached (raising something to the zeroth power) or based on a previously calculated power for a smaller exponent. (If you wanted to, you could add another base case for raising something to the power of one.) These observations show that we are seeing a textbook case for the decrease and conquer recursive strategy.

Finally, some of our higher-order functions, such as `map()`, `reduce()`, and `filter()`, also apply this technique; we'll look into this later on in this chapter.

Divide and conquer – the Tower of Hanoi

With the divide-and-conquer strategy, solving a problem requires two or more recursive solutions. For starters, let's consider a classic puzzle invented by a French mathematician, Édouard Lucas, in the 19th century. The puzzle involves a temple in India, with 3 posts, the first of them with 64 golden disks of decreasing diameter. The priests have to move the disks from the first post to the last one following two rules: only one disk can be moved at a time, and a larger disk can never be placed on top of a smaller disk. According to the legend, when the 64 disks are moved, the world will end. This puzzle is usually marketed under the *Tower of Hanoi* name (yes, they changed countries!) with fewer than 10 disks. See *Figure 9.2*:

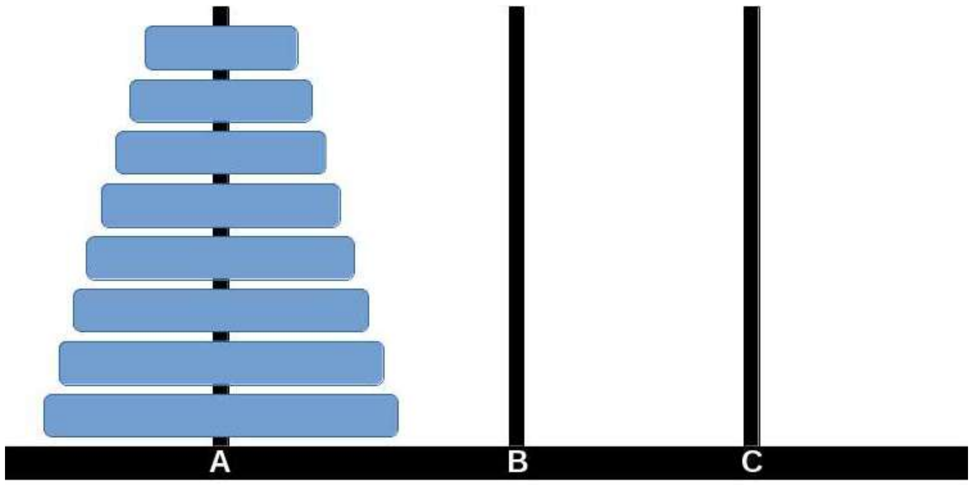


Figure 9.2 – The classic Tower of Hanoi puzzle has a simple recursive solution

A long, long time…

The solution for *n* disks requires 2^n-1 movements. The original puzzle, requiring 2^{64}-1 movements, at one movement per second, would take more than 584 billion years to finish – a very long time, considering that the universe's age is evaluated to only be 13.8 billion years!

Suppose we already have a function that solves the problem of moving any number of disks from a source post to a destination post using the remaining post as an extra aid. Think about solving the general problem if you already had a function to solve that problem: `hanoi(disks, from, to, extra)`. If you wanted to move several disks from one post to another, then you could solve it using this (still unwritten!) function by carrying out the following steps:

1. Moving all of the disks but the last one to the extra post.
2. Moving the last disk to the destination post.
3. Moving all the disks from the extra post (where you had placed them earlier) to the destination.

But what about our base cases? We could decide that to move a single disk, you don't need the function; you just go ahead and move the disk. When coded, it becomes the following:

```
// hanoi.ts

const hanoi = (
  disks: number,
  from: Post,
  to: Post,
  extra: Post
) => {
  if (disks === 1) {
    console.log(
      `Move disk 1 from post ${from} to post ${to}`
    );
  } else {
    hanoi(disks - 1, from, extra, to);
    console.log(
      `Move disk ${disks} from post ${from} to post ${to}`
    );
    hanoi(disks - 1, extra, to, from);
  }
};
```

Using the `Post` type is possibly not needed, but good practice anyway. We can quickly verify that this code works:

```
hanoi (4, "A", "B", "C");
// move all disks from A to B
Move disk 1 from post A to post C
Move disk 2 from post A to post B
Move disk 1 from post C to post B
Move disk 3 from post A to post C
Move disk 1 from post B to post A
Move disk 2 from post B to post C
Move disk 1 from post A to post C
Move disk 4 from post A to post B
Move disk 1 from post C to post B
Move disk 2 from post C to post A
Move disk 1 from post B to post A
Move disk 3 from post C to post B
Move disk 1 from post A to post C
Move disk 2 from post A to post B
Move disk 1 from post C to post B
```

There's only a small detail to consider, which can simplify the function further. In this code, our base case (the one that needs no further recursion) is when `disks` equals one. You could also solve this differently by letting the disks go down to zero and simply not doing anything—after all, moving zero disks from one post to another is achieved by doing nothing at all! The revised code would be as follows:

```
// continued...

const hanoi2 = (
  disks: number,
  from: Post,
  to: Post,
  extra: Post
) => {
  if (disks > 0) {
    hanoi(disks - 1, from, extra, to);
    console.log(
      `Move disk ${disks} from post ${from} to post ${to}`
    );
    hanoi(disks - 1, extra, to, from);
  }
};
```

Instead of checking whether there are any disks to move before doing the recursive call, we can just skip the check and have the function test, at the next level, whether there's something to be done.

Hanoi by hand

If you are doing the puzzle by hand, there's a simple solution for that: on odd turns, always move the smaller disk to the next post (if the total number of disks is odd) or to the previous post (if the total number of disks is even). On even turns, make the only possible move that doesn't involve the smaller disk.

So, the principle for recursive algorithm design works: assume you already have your desired function and use it to build itself!

Divide and conquer – sorting

We can see another example of the divide-and-conquer strategy with sorting. A way to sort arrays, called Quicksort, is based upon the following steps:

1. If your array has 0 or 1 element(s), do nothing; it's already sorted (this is the base case).
2. Pick an element of the array (called the pivot) and split the rest of the array into two subarrays: the elements smaller than your chosen element and the elements greater than or equal to your chosen element.
3. Recursively sort each subarray.
4. To produce the sorted version of the original array, concatenate both sorted results, with the pivot in between.

Let's see a simple version of this (there are some better-optimized implementations, but we are interested in the recursive logic now). Usually, picking a random element of the array is suggested to avoid some bad performance border cases, but for our example, let's just take the first one:

```
// quicksort.ts

const quicksort = <A>(arr: A[]): A[] => {
  if (arr.length < 2) {
    return arr;
  } else {
    const pivot = arr[0];
    const smaller = arr.slice(1).filter((x) => x < pivot);
    const greaterEqual = arr
      .slice(1)
      .filter((x) => x >= pivot);
    return [
      ...quicksort(smaller),
      pivot,
      ...quicksort(greaterEqual),
    ];
  }
};

console.log(quicksort([22, 9, 60, 12, 4, 56]));
// [4, 9, 12, 22, 56, 60]
```

We can see how this works in *Figure 9.3*: the pivot for each array and subarray is underlined. Splitting is shown with dotted arrows and is joined with full lines:

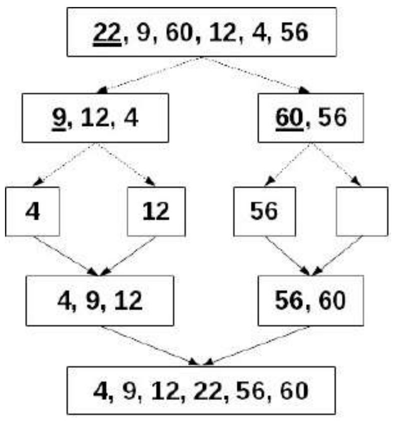


Figure 9.3 – Quicksort sorts an array recursively, applying the divide-and-conquer strategy to reduce the original problem to smaller ones

Easy-to-get bug!

Writing Quicksort correctly is not trivial; see *Question 9.8* at the end of this chapter for an alternative version that is *almost* right, but not totally correct!

We have already seen the basic strategies to reduce a problem to simpler versions of itself. Let's now look at an important optimization, a key for many algorithms.

Dynamic programming – making change

The third general strategy, *dynamic programming*, assumes that you will have to solve many smaller problems, but instead of using recursion every time, it depends on you having stored the previously found solutions – *memoization*, in other words! In *Chapter 4*, *Behaving Properly*, and later, in a better fashion, in *Chapter 6*, *Producing Functions*, we already saw how to optimize the calculations of the usual Fibonacci series, avoiding unnecessary repeated calls. Let's now consider another problem.

Given a certain number of dollars and the list of existing bill values, calculate how many different ways we can pay that amount of dollars with different combinations of bills. It is assumed that you have access to an unlimited number of each bill. How can we go about solving this? Let's start by considering the base cases where no further computation is needed. They are as follows:

- Paying negative values is not possible, so in such cases, we should return `0`
- Paying zero dollars is only possible in a single way (by giving no bills), so in this case, we should return `1`
- Paying any positive amount of dollars isn't possible if no bills are provided, so in this case, also return `0`

Finally, we can answer the question: in how many ways can we pay *N* dollars with a given set of bills? We can consider two cases: we do not use the larger bill at all and pay the amount using only smaller denomination bills, or we can take one bill of the larger amount and reconsider the question. (Let's forget the avoidance of repeated calculations for now.)

In the first case, we should invoke our supposedly existing function with the same value of *N* but prune the largest bill denomination from the list of available bills.

In the second case, we should invoke our function with *N* minus the largest bill denomination, keeping the list of bills the same, as shown in the following code:

```
// makeChange.ts

const makeChange = (n: number, bills: number[]): number => {
  if (n < 0) {
    return 0; // no way of paying negative amounts
  } else if (n == 0) {
    return 1; // one single way of paying $0: with no bills
  } else if (bills.length == 0) {
    // here, n>0
    return 0; // no bills? no way of paying
  } else {
    return (
      makeChange(n, bills.slice(1)) +
      makeChange(n - bills[0], bills)
    );
  }
};

console.log(makeChange(64, [100, 50, 20, 10, 5, 2, 1]));
// 969 ways of paying $64
```

Now, let's do some optimization. This algorithm often needs to recalculate the same values over and over. (To verify this, add `console.log(n, bills.length)` as the first line in `makeChange()`—but be ready for plenty of output!) However, we already have a solution for this: memoization! Since we are applying this technique to a binary function, we'll need a version of the memoization algorithm that deals with more than one parameter. We saw that in *Chapter 6, Producing Functions*:

```
// continued...

const memoize4 = <T extends (...x: any[]) => any>(
  fn: T
): ((...x: Parameters<T>) => ReturnType<T>) => {
  const cache = {} as Record<string, ReturnType<T>>;
  return (...args) => {
    const strX = JSON.stringify(args);
    return strX in cache
      ? cache[strX]
      : (cache[strX] = fn(...args));
  };
};

const makeChange = memoize4((n, bills) => {
// ...same as above
});
```

The memoized version of `makeChange()` is far more efficient, and you can verify it with logging. While it is certainly possible to deal with the repetitions by yourself (for example, by keeping an array of already computed values), the memoization solution is, in my opinion, better because it composes two functions to produce a better solution for the given problem.

Higher-order functions revisited

Classic FP techniques do not use iteration at all but work exclusively with recursion as the only way to do some looping. Let's revisit some of the functions that we have already seen in *Chapter 5, Programming Declaratively*, such as `map()`, `reduce()`, `find()`, and `filter()`, to see how we can make do with just recursion.

We are not planning to exchange the basic JavaScript functions for ours, though: it's likely that performance will be worse for our recursive polyfills, and we won't derive any advantages just from having the functions use recursion. Instead, we want to study how iterations are performed in a recursive way so that our efforts are more pedagogical than practical, OK?

Mapping and filtering

Mapping and filtering are quite similar insofar as both imply going through all the elements in an array and applying a callback to each to produce output. Let's first work out the mapping logic, which will have several points to solve, and then we should see that filtering has become almost trivially easy, requiring just small changes.

For mapping, given how we are developing recursive functions, we need a base case. Fortunately, that's easy: mapping an empty array produces a new empty array. Mapping a non-empty array can be done by first applying the mapping function to the first element of the array, then recursively mapping the rest of the array, and finally, producing a single array accumulating both results.

Based on this idea, we can work out a simple initial version: let's call it `mapR()`, just to remember that we are dealing with our own, recursive version of `map()`; however, be careful – our polyfill has some bugs! We'll deal with them one at a time. Here's our first attempt at writing our own mapping code:

```
// map.ts

const mapR = <A, B>(arr: A[], cb: (x: A) => B): B[] =>
  arr.length === 0
    ? []
    : [cb(arr[0])].concat(mapR(arr.slice(1), cb));
```

Let's test it out:

```
const aaa = [1, 2, 4, 5, 7];
const timesTen = (x: number): number => x * 10;
```

```
console.log(aaa.map(timesTen));   // [10, 20, 40, 50, 70]
console.log(mapR(aaa, timesTen)); // [10, 20, 40, 50, 70]
```

Great! Our `mapR()` function seemingly produces the same results as `map()`. However, shouldn't our callback function receive a couple more parameters, specifically the index at the array and the original array itself? (Check out the definition for the callback function for `map()` at `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/Array/map`.)

Our implementation isn't quite ready yet. Let's first see how it fails by using a simple example:

```
const timesTenPlusI = (v: number, i: number) => 10 * v + i;

console.log(aaa.map(timesTenPlusI)); // [10, 21, 42, 53,
  74]
console.log(mapR(aaa, timesTenPlusI));
```

If you were working with JavaScript, the last call would produce `[NaN, NaN, NaN, NaN, NaN]` – TypeScript detects the error because the type of `timesTenPlusI()` is wrong:

```
Argument of type '(v: number, i: number) => number' is not
assignable to parameter of type '(x: number) => number'.
```

Generating the appropriate index position will require an extra parameter for the recursion. Still, it is basically simple: when we start out, we have `index=0`, and when we call our function recursively, it's with the `index+1` position. Accessing the original array requires yet another parameter, which will never change, and now we have a better mapping function:

```
// continued...

const mapR2 = <A, B>(
  arr: A[],
  cb: (x: A, i: number, arr: A[]) => B,
  i = 0,
  orig = arr
): B[] =>
  arr.length == 0
    ? []
    : [cb(arr[0], i, orig)].concat(
        mapR2(arr.slice(1), cb, i + 1, orig)
      );
```

```
const senseless = (
  x: number,
  i: number,
  a: number[]
): number => x * 10 + i + a[i] / 10;

console.log(aaa.map(senseless));
// [10.1, 21.2, 42.4, 53.5, 74.7]
console.log(mapR2(aaa, senseless));
// [10.1, 21.2, 42.4, 53.5, 74.7]
```

Great! When you do recursion instead of iteration, you don't have access to an index, so if you need it (as in our case), you'll have to generate it on your own. This is an often-used technique, so working out our `map()` substitute was a good idea.

However, having extra arguments in the function is not so good; a developer might accidentally provide them and the results would be unpredictable. So, using another usual technique, let's define an inner function, `mapLoop()`, to handle looping. This is, in fact, the usual way in which looping is achieved when you only use recursion; look at the following code, in which the extra function isn't accessible from outside:

```
// continued...

const mapR3 = <A, B>(
  orig: A[],
  cb: (x: A, i: number, a: A[]) => B
): B[] => {
  const mapLoop = (arr: A[], i: number): B[] =>
    arr.length == 0
      ? []
      : [cb(arr[0], i, orig)].concat(
          mapLoop(arr.slice(1), i + 1)
        );
  return mapLoop(orig, 0);
};
console.log(mapR3(aaa, senseless));
// [10.1, 21.2, 42.4, 53.5, 74.7], again
```

There's only one pending issue: if the original array has some missing elements, they should be skipped during the loop. Let's look at an example, in plain JavaScript:

```
[1, 2, , , 5].map(tenTimes)
// [10, 20, undefined × 2, 50]
```

(Why just JavaScript? TypeScript would object because the array to be processed had `number | undefined` types, but `timesTen()` expects an array with just `number` types. By the way, I also had to disable ESLint's `no-sparse-array` rule, which catches accidental extra commas in arrays.)

Fortunately, fixing this is simple—and be glad that all the experience gained here will help us write the other functions in this section! Can you understand the fix in the following code, apart from the obvious changes to allow values in arrays to be `undefined`, for which I used an auxiliary `Opt<>` type definition?

```
// continued...


type Opt<X> = X | undefined;

const mapR4 = <A, B>(
  orig: Opt<A>[],
  cb: (x: A, i: number, a: Opt<A>[]) => B
): Opt<B>[] => {
  const mapLoop = (arr: Opt<A>[], i: number): Opt<B>[] =>
    arr.length == 0
      ? []
      : !(0 in arr) || arr[0] === undefined
      ? ([,] as Opt<B>[]).concat(
          mapLoop(arr.slice(1), i + 1)
        )
      : ([cb(arr[0] as A, i, orig)] as Opt<B>[]).concat(
          mapLoop(arr.slice(1), i + 1)
        );

  return mapLoop(orig, 0);
};
```

Wow! This was more than we bargained for, but we saw several techniques: how to replace iteration with recursion, how to accumulate a result across iterations, and how to generate and provide the index value—good tips! Furthermore, writing filtering code will prove much easier since we'll be able to apply very much the same logic as we did for mapping. The main difference is that we use the callback function to decide whether an element goes into the output array, so the inner loop function is a tad longer:

```
// filter.ts

type Opt<X> = X | undefined;

const filterR = <A>(
  orig: Opt<A>[],
  cb: (x: A, i: number, a: Opt<A>[]) => boolean
): A[] => {
  const filterLoop = (arr: Opt<A>[], i: number): A[] =>
    arr.length == 0
      ? []
      : !(0 in arr) ||
        arr[0] === undefined ||
        !cb(arr[0] as A, i, orig)
      ? filterLoop(arr.slice(1), i + 1)
      : ([arr[0]] as A[]).concat(
          filterLoop(arr.slice(1), i + 1) as A[]
        );

  return filterLoop(orig, 0);
};
```

Okay, we managed to implement two of our basic higher-order functions with similar recursive functions. What about the others?

Other higher-order functions

Programming `reduce()` is, from the outset, a bit trickier, since you can decide to omit the initial value for the accumulator. Since we mentioned earlier that providing that value is generally better, let's work here under the assumption that it will be given; dealing with the other possibility won't be too hard.

The base case is simple: if the array is empty, the result is the accumulator; otherwise, we must apply the `reduce` function to the current element and the accumulator, update the latter, and then continue working with the rest of the array. This can be a bit confusing because of the ternary operators, but it should be clear enough after all we've seen. Look at the following code for the details:

```
// reduce.ts

const reduceR = <A, B>(
  orig: A[],
  cb: (acc: B, x: A, i: number, a: A[]) => B,
  accum: B
) => {
  const reduceLoop = (arr: A[], accum: B, i: number): B =>
    arr.length == 0
      ? accum
      : !(0 in arr) || arr[0] === undefined
      ? reduceLoop(arr.slice(1), accum, i + 1)
      : reduceLoop(
          arr.slice(1),
          cb(accum, arr[0], i, orig),
          i + 1
        );

  return reduceLoop(orig, accum, 0);
};

let bbb = [1, 2, , 5, 7, 8, 10, 21, 40];
console.log(bbb.reduce((x, y) => x + y, 0));   // 94
console.log(reduce2(bbb, (x, y) => x + y, 0)); // 94
```

On the other hand, `find()` is particularly apt for recursive logic since the very definition of how you (attempt to) find something is recursive in itself:

- You look at the first place you think of, and if you find what you were seeking, you are done
- Alternatively, you look at the other places to see whether what you seek is there

We are only missing the base case, but that's simple, and we already saw this earlier in the chapter – if you have no places left to search, then you know you won't be successful in your search:

```
// find.ts

const findR = <A>(
  arr: A[],
  cb: (x: A) => boolean
): Opt<A> =>
  arr.length === 0
    ? undefined
    : cb(arr[0])
    ? arr[0]
    : findR(arr.slice(1), cb);
```

We can quickly verify whether this works:

```
let aaa = [1, 12, , , 5, 22, 9, 60];

const isTwentySomething = x => 20 <= x && x <= 29; console.
log(findR(aaa, isTwentySomething)); // 22

const isThirtySomething = x => 30 <= x && x <= 39; console.
log(findR(aaa, isThirtySomething)); // undefined
```

Let's finish with our pipelining function. The definition of a pipeline lends itself to quick implementation:

- If we want to pipeline a single function, then that's the result of the pipeline
- If we want to pipeline several functions, we must first apply the initial function and then pass that result as input to the pipeline of the other functions

We can directly turn this into code:

```
function pipelineR<FNS extends FN[]>(
  ...fns: FNS
): Pipeline<FNS>;
function pipelineR<FNS extends FN[]>(...fns: FNS): FN {
  return fns.length === 1
    ? fns[0]
    : (...args) =>
        pipelineR(...fns.slice(1))(fns[0](...args));
}
```

We can verify its correctness with a simple example. Let's pipeline several calls to a couple of functions, one of which just adds 1 to its argument and the other of which multiplies by 10:

```
const plus1 = (x: number): number => x + 1;
const by10 = (x: number): number => x * 10;
```

```
pipelineR(
  by10,
  plus1,
  plus1,
  plus1,
  by10,
  plus1,
  by10,
  by10,
  plus1,
  plus1,
  plus1
)(2);
// 23103
```

If you follow the math, you'll be able to check that the pipelining is working fine. We could have a slightly different recursive call if we take the base case to be when no functions are provided:

```
// continued...

function pipelineR2<FNS extends FN[]>(
  ...fns: FNS
): Pipeline<FNS>;
function pipelineR2<FNS extends FN[]>(...fns: FNS): FN {
  return fns.length === 0
    ? (...args) => args[0]
    : (...args) =>
        pipelineR2(...fns.slice(1))(fns[0](...args));
}
```

In any case, these pipelines won't work in TypeScript because our `Pipeline<>` type definition won't allow for an empty set of functions – can you fix that?

Doing the same for composition is easy, except that you cannot use the spread operator to simplify the function definition, and you'll have to work with array indices—work it out!

Searching and backtracking

Searching for solutions to problems, especially when there is no direct algorithm and you must resort to trial and error, is particularly appropriate for recursion. Many of these algorithms fall into a scheme such as the following:

- Out of many choices available, pick one. If no options are available, you've failed.
- If you could pick one, apply the same algorithm, but find a solution to the rest.
- If you succeed, you are done. Otherwise, try another choice.

You can apply similar logic with minor variations to find a good—or possibly, optimum—solution to a given problem. Each time you find a possible solution, you match it with previous ones that you might have found and decide which to keep. This may continue until all possible solutions are evaluated or until a good enough solution has been found.

There are many problems to which this logic applies. They are as follows:

- *Finding a way out of mazes*—pick any path, mark it as already followed, and try to find a way out of the maze that won't reuse that path: if you succeed, you are done, and if you do not, go back to pick a different path
- *Filling out Sudoku puzzles*—if an empty cell can contain only a single number, then assign it; otherwise, run through all of the possible assignments, and for each one, recursively try to see whether the rest of the puzzle can be filled out
- *Playing chess*—where you aren't likely to be able to follow through all possible move sequences, so you opt for the best-estimated position instead

Let's apply these techniques to two problems: solving the eight queens puzzle and traversing a complete file directory.

The eight queens puzzle

The eight queens puzzle was invented in the 19th century and involves placing eight chess queens on a standard chessboard. The restriction is that no queen should be able to attack another—implying that no pair of queens may share a row, column, or diagonal line. The puzzle may ask for any solution or the total number of distinct solutions, which we will attempt to find.

The *n* queens variation

The puzzle may also be generalized to *n* queens by working on an *nxn* square board. It is known that there are solutions for all values of *n*, except *n*=2 (pretty simple to see why: after placing one queen, all of the board is threatened) and *n*=3 (if you place a queen in the center, all of the board is threatened, and if you place a queen on a side, only two squares are not threatened, but they threaten each other, making it impossible to place queens on them).

Let's start our solution with top-level logic. Because of the given rules, there will be a single queen in each column, so we use a `places` array to take note of each queen's row within the given column. The `SIZE` constant could be modified to solve a more general problem. We'll count each found distribution of queens in the `solutions` variable. Finally, the `finder()` function will perform the recursive search for solutions. The basic skeleton for the code would be as follows:

```
// queens.ts

const SIZE = 8;
const places = Array(SIZE);
let solutions = 0;

finder();

console.log(`Solutions found: ${solutions}`);
```

Let's get into the required logic. When we want to place a queen in a given row and column, we must check whether any of the previously placed queens were placed on the same row or in a diagonal leading from the row. See *Figure 9.4*:

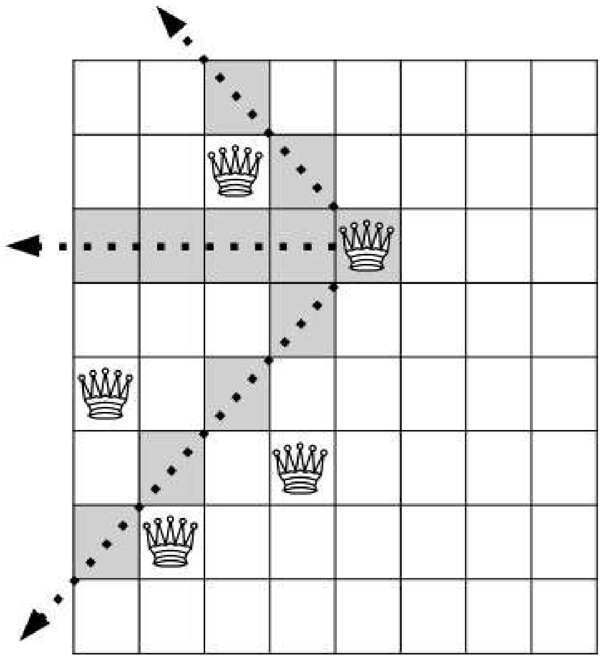


Figure 9.4 – Before placing a queen in a column, we must check the previously placed queens' positions

Let's write a `checkPlace(column, row)` function to verify whether a queen can be safely placed in the given square. The most straightforward way is by using `every()`, as shown in the following code:

```
// continued...

const checkPlace = (column: number, row: number): boolean =>
  places
    .slice(0, column)
    .every(
      (v, i) =>
        v !== row && Math.abs(v - row) !== column - i
    );
```

This declarative fashion seems best: when we place a queen in a position, we want to ensure that every other previously placed queen is in a different row and diagonal. A recursive solution would have been possible too, so let's see that. How do we know that a square is safe?

- A base case is when there are no more columns to check, the square is safe
- If the square is in the same row or diagonal as any other queen, it's not safe
- If we have checked a column and found no problem, we can now recursively check the following one

The required alternative code to check whether a position in a column can be occupied by a queen is, therefore, as follows:

```
// continued...

const checkR = (column: number, row: number): boolean => {
  const checkColumn = (i: number): boolean => {
    if (i == column) {
      return true;
    } else if (
      places[i] == row ||
      Math.abs(places[i] - row) == column - i
    ) {
      return false;
    } else {
      return checkColumn(i + 1);
    }
    };
    return checkColumn(0);
  };
```

The code works, but I wouldn't use it since the declarative version is clearer. Anyway, having worked out this check, we can pay attention to the main `finder()` logic, which will do the recursive search. The process proceeds as we described at the beginning: try out a possible placement for a queen, and if that is acceptable, use the same search procedure to try and place the remaining queens. We start at column 0, and our base case is when we reach the last column, meaning that all queens have been successfully placed: we can print out the solution, count it, and go back to search for a new configuration.

Getting nice output

Check out how we use `map()` and a simple arrow function to print the rows of the queens, column by column, as numbers between 1 and 8, instead of 0 and 7. In chess, rows are numbered from 1 to 8 (and columns from a to h, but that doesn't matter here).

Check out the following code, which applies the logic that we described previously:

```
// continued...

const finder = (column = 0) => {
  if (column === SIZE) {
    // all columns tried out?
    // if so, print and count solution
    console.log(JSON.stringify(places.map((x) => x + 1)));
    solutions++;
  } else {
    const testRowsInColumn = (j: number) => {
      if (j < SIZE) {
        if (checkR(column, j)) {
          places[column] = j;
          finder(column + 1);
        }
        testRowsInColumn(j + 1);
      }
    };
    testRowsInColumn(0);
  }
};
```

The inner `testRowsInColumn()` function also fulfills an iterative role, but recursively. The idea is to attempt placing a queen in every possible row, starting at zero: if the square is safe, `finder()` is called to start searching from the next column onward. No matter whether a solution was or wasn't found, all rows in the column are tried out because we are interested in the total number of solutions. In other search problems, you might be content with finding any solution, and you would stop your search there.

We have come this far, so let's find the answer to our problem!

```
[1,5,8,6,3,7,2,4]
[1,6,8,3,7,4,2,5]
[1,7,4,6,8,2,5,3]
[1,7,5,8,2,4,6,3]
[2,4,6,8,3,1,7,5]
[2,5,7,1,3,8,6,4]
[2,5,7,4,1,8,6,3]
[2,6,1,7,4,8,3,5]
   ...
   ... 70 lines snipped out
   ...
[8,2,4,1,7,5,3,6]
[8,2,5,3,1,7,4,6]
[8,3,1,6,2,5,7,4]
[8,4,1,3,6,2,7,5]
Solutions found: 92
```

Each solution is given as the row positions for the queens, column by column, and there are 92 solutions in all.

Traversing a tree structure

Data structures, which include recursion in their definition, are naturally appropriate for recursive techniques. Let's consider, for example, how to traverse a complete filesystem directory, listing all of its contents. Where's the recursion? The answer is straightforward if you consider that each directory can do either of the following:

- Be empty—a base case in which there's nothing to do
- Include one or more entries, each of which is either a file or a directory itself

Let's work out a full recursive directory listing—meaning that when we encounter a directory, we also list its contents, and if those include more directories, we also list them, and so on. We'll be using the same node functions as in `getDir()` (from the *Building pipelines by hand* section in *Chapter 8, Connecting Functions*), plus a few more to test whether a directory entry is a symbolic link (which we won't follow to avoid possible infinite loops), a directory (which will require a recursive listing), or a common file:

```
// directory.ts

import * as fs from "fs";

const recursiveDir = (path: string) => {
  console.log(path);
  fs.readdirSync(path).forEach((entry) => {
    if (entry.startsWith(".")) {
      // skip it!
    } else {
      const full = path + "/" + entry;
      const stats = fs.lstatSync(full);
      if (stats.isSymbolicLink()) {
        console.log("L ", full); // symlink, don't follow
      } else if (stats.isDirectory()) {
        console.log("D ", full);
        recursiveDir(full);
      } else {
        console.log("  ", full);
      }
    }
  });
};
```

The listing is long but correct. I opted to list the `/boot` directory in my own openSUSE Linux laptop, and this was produced:

```
recursiveDir("/boot");
/boot
/boot/System.map-4.11.8-1-default
/boot/boot.readme
/boot/config-4.11.8-1-default D  /boot/efi
D    /boot/efi/EFI
```

```
D    /boot/efi/EFI/boot
/boot/efi/EFI/boot/bootx64.efi
/boot/efi/EFI/boot/fallback.efi
...
... many omitted lines
...
L    /boot/initrd
/boot/initrd-4.11.8-1-default
/boot/message
/boot/symtypes-4.11.8-1-default.gz
/boot/symvers-4.11.8-1-default.gz
/boot/sysctl.conf-4.11.8-1-default
/boot/vmlinux-4.11.8-1-default.gz  L  /boot/vmlinuz
/boot/vmlinuz-4.11.8-1-default
```

We can apply the same structure to a similar problem: traversing a DOM structure. We could list all of the tags, starting from a given element, using the same approach: we list a node and (by applying the same algorithm) all of its children. The base case is the same as before: when a node has no children, no more recursive calls are made. You can see this in the following code:

```
// dom.ts

const traverseDom = (node: Element, depth = 0) => {
  console.log(
    `${"| ".repeat(depth)}<${node.nodeName.toLowerCase()}>`
  );
  for (let i = 0; i < node.children.length; i++) {
    traverseDom(node.children[i], depth + 1);
  }
};
```

We are using the `depth` variable to know how many levels below the original element we are. We could also use it to make the traversing logic stop at a certain level; in our case, we are using it only to add some bars and spaces to appropriately indent each element according to its place in the DOM hierarchy. The result of this function is shown in the following code. It would be easy to list more information and not just the element tag, but I wanted to focus on the recursive process:

```
traverseDom(document.body);
<body>
```

```
| <script>
| <div>
| | <div>
| | | <a>
| | | <div>
| | | | <ul>
| | | | | <li>
| | | | | | <a>
| | | | | | | <div>
| | | | | | | | <div>
| | | | | | | <div>
| | | | | | | | <br>
| | | | | | | <div>
| | | | | | <ul>
| | | | | | | <li>
| | | | | | | | <a>
| | | | | | | <li>
...etc.!
```

However, there's an ugly point there: why are we making a loop to go through all of the children? We should know better! The problem is that the structure we get from the DOM isn't really an array. However, there's a way out – we can use `Array.from()` to create a real array out of it and then write a more declarative solution. The following code solves the problem in a better way:

```
// continued...

const traverseDom2 = (node: Element, depth = 0) => {
  console.log(
    `${"| ".repeat(depth)}<${node.nodeName.toLowerCase()}>`
  );
  Array.from(node.children).forEach((child) =>
    traverseDom2(child, depth + 1)
  );
};
```

Writing `[...node.children].forEach()` would have worked as well but using `Array.from()` makes it more apparent to any reader that we are trying to make an array out of something that looks like one, but really isn't.

We have now seen many ideas about the usage of recursion, and we've seen many applications of it; however, there are some cases in which you may run into problems, so let's now consider some tweaks that may come in handy for specific problems.

Mutual recursion

Recursion need not be as "simple" and "direct" as having a function that calls itself. We can have more complex situations as a set of functions, each of which calls one or more of the others but not necessarily calling itself. (However, note that this is also allowed.)

Thinking in terms of mutual recursion is harder. For simple recursion, you had to imagine you already had a function to do something, and then you used it (in itself!) to do that. In mutual recursion, you have to think of a set of functions, each of which does its own part by simultaneously depending on all the set of functions: the others, and possibly itself as well.

Let's examine a simple case to get our feet wet, and then go for a "real-life" application.

Odds and evens

How can you determine whether a (not negative) integer number is odd or even? This a trivial problem, to be sure (but see *Question 9.11*) but we can get an interesting solution if we realize the following:

- Zero is even
- If a number is even, when you subtract 1 from it, you get an odd number
- A number is odd if it's not even:

```
function isEven(n: number): boolean {
  if (n === 0) {
    return true;
  } else {
    return isOdd(n - 1);
  }
}

function isOdd(n: number): boolean {
  return !isEven(n);
}

console.log("22.. isEven?", isEven(22));
console.log("9... isOdd?", isOdd(5));
console.log("60... isOdd?", isOdd(10));
```

How does this work? Each function (`isEven()` and `isOdd()`) depends on the other to produce a result. How do we know that 9 is odd? The calculations are as follows:

```
is 9 odd?
Is 9 not even?
Is 8 odd?
Is 8 not even?
Is 7 odd?
Is 7 not even?
   ...
   ... several lines skipped
   ...
Is 1 odd?
Is 1 not even?
Is 0 odd?
Is 0 not even?
```

And after the last call, the whole tower of calls gets resolved; 9 is reported to be odd (fortunately!)

You could say that this actually isn't a great example of mutual recursion, because you could easily replace the code for `isOdd()` in `isEven()` to get single recursion versions:

```
// continued…

function isEven2(n: number): boolean {
  if (n === 0) {
    return true;
  } else {
    return !isEven2(n - 1);
  }
}

function isOdd2(n: number): boolean {
  return !isEven2(n);
}
```

However, we can go about this in another way that will also include mutual recursion:

```
// continued...
```

```
function isEven3(n: number): boolean {
  if (n === 0) {
    return true;
  } else {
    return isOdd3(n - 1);
  }
}

function isOdd3(n: number): boolean {
  if (n === 0) {
    return false;
  } else {
    return isEven3(n - 1);
  }
}
```

So, don't get to think that mutual recursion can always be simplified away; sometimes, that's not really possible or practical.

Going back to the code, it should be evident that no one would implement a parity test this way. Still, this example paves the way to implementing a more complex function: parsing and evaluating an arithmetic expression, which will involve multiple mutually recursive functions, as we'll see next.

Doing arithmetic

Let's see a more complete problem, which also happens to (frequently!) appear online, with puzzles as in *Figure 9.5*. We'll implement a set of mutually recursive functions that can correctly evaluate an arithmetic expression according to standard precedence rules for operators.

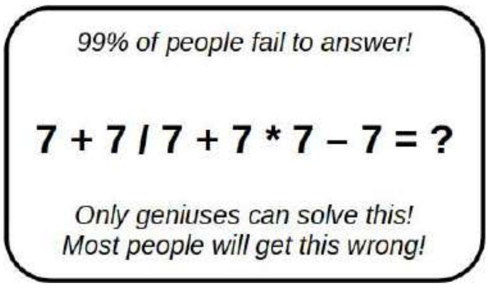

99% of people fail to answer!
7 + 7 / 7 + 7 * 7 – 7 = ?
Only geniuses can solve this!
Most people will get this wrong!

Figure 9.5 – Common puzzles call for evaluating arithmetic expressions

To solve this, we'll first see a tool that lets us correctly process operations: *railroad diagrams*. We want to evaluate an expression, and we can say that an expression is either one single term, or several terms added or subtracted. *Figure 9.6* shows this graphically. Imagine the arrows are railroad tracks, and any path you follow that starts at the left and eventually ends at the right represents a possible expression.

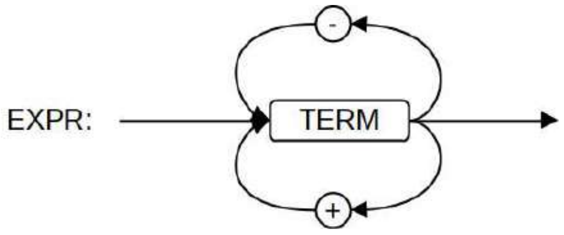


Figure 9.6 – A railroad syntax diagram for arithmetic expressions

Now, what's a term? A term is either a single factor, or the result of multiplying, dividing, or using modulus operations on several factors, as shown in *Figure 9.7*. Note that with these two rules, *2*3+5* is correctly evaluated as *(2*3)+5*, because *2*3* and *5* are terms.

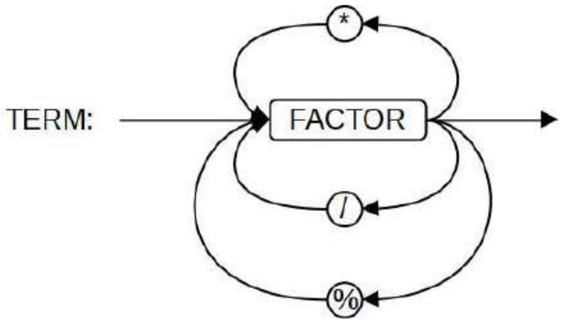


Figure 9.7 – A railroad syntax for terms: multiplication, division, and modulus are performed before addition or subtraction

We need one more diagram, for factors. A factor can be a single number or an expression between parentheses. We'll allow an optional minus sign at the beginning, so -3 is accepted. *Figure 9.8* shows the needed diagram.

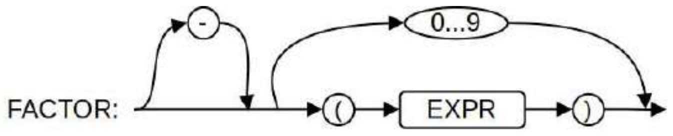


Figure 9.8 – A factor starts with an optional minus sign, and can be a number or an expression within parentheses

We'll implement the needed evaluation with three functions, one for each diagram. In the usual compiler or interpreter code, we have a first phase that reads the input and splits it into *tokens*, and a second phase that processes those tokens to do whatever's needed. In our case, the tokens will be numbers (single digits, for simplicity), operators, and parentheses. The code we'll write is as follows:

```
function evaluate(str: string) {
  const PLUS = "+";
  const MINUS = "-";
  const TIMES = "*";
  const DIVIDES = "/";
  const MODULUS = "%";
  const LPARENS = "(";
  const RPARENS = ")";

  let curr = 0;
  const tokens = str
    .split("")
    .map((x) => (Number.isNaN(Number(x)) ? x : Number(x)));

  return expression();

  function expression(): number { ... }

  function term(): number { ... }

  function factor(): number { ... }
}
```

We define some constants (`PLUS`, `MINUS`, etc.) for clarity. Given a string such as `"7+7/7+7*7-7"`, we split it into the tokens array; we take care to evaluate digits. Finally, we have a `curr` variable pointing to the token being processed right now. The evaluation of the input expression will be done by three functions that will use mutual recursion:

```
  function expression(): number {
  let accum = term();

  while (
    tokens[curr] === PLUS ||
    tokens[curr] === MINUS
  ) {
    if (tokens[curr] === PLUS) {
      curr++;
      accum += term();
    } else if (tokens[curr] === MINUS) {
      curr++;
      accum -= term();
    }
  }

  return accum;
}
```

The `expression()` function first calls `term()` to get the value of the first term and then loops if an addition or subtraction is found. In our case, this means that the function would first evaluate a 7, then add 7/7, then also add 7*7, and finally subtract the last 7. (And yes, the result is 50.) After a token is processed, `curr` is incremented to continue with the rest of the tokens.

The code for `term()` is similar in style; the only difference is how it works with multiplication, and so on:

```
function term(): number {
  let accum = factor();

  while (
    tokens[curr] === TIMES ||
    tokens[curr] === DIVIDES ||
    tokens[curr] === MODULUS
  ) {
    if (tokens[curr] === TIMES) {
      curr++;
      accum *= factor();
    } else if (tokens[curr] === DIVIDES) {
      curr++;
      accum /= factor();
    } else if (tokens[curr] === MODULUS) {
      curr++;
```

```
        accum %= factor();
      }
    }

    return accum;
  }
```

This function would be called to evaluate 7, then 7/7, then 7*7, and finally another 7.

Finally, `factor()` is a tad different:

```
function factor(): number {
  let mult = 1;
  if (tokens[curr] === MINUS) {
    mult = -1;
    curr++; // skip MINUS
  }
  let result = 0;

  if (tokens[curr] === LPARENS) {
    curr++; // skip LPARENS
    result = expression();
    curr++; // skip RPARENS
  } else {
    result = tokens[curr] as number;
    curr++;
  }

  return mult * result;
}
```

The `mult` variable will be `-1` if an initial minus sign was present, or `+1` otherwise. We have no loops here, and just an alternative: if a left parenthesis is seen, we skip it, recursively evaluate the included expression, skip the right parenthesis, and return the value of the expression. The alternative is that we have a number, which we return. Whatever we return, we'll multiply by the `mult` value to produce the correct result.

If you analyze the recursive calls, we have `expression()` calling `term()`, which calls `factor()`, which calls `recursive()` – a cycle of three! Mutual recursion is harder to understand and to get right because to plan such code, you must foresee what several functions will do. However, for the right problems (as shown here), it's a very powerful technique.

Recursion techniques

While recursion is a very good technique, you may face some problems because of the way it is internally implemented. Each function call, recursive or not, requires an entry in the internal JavaScript stack. When you are working with recursion, each recursive call itself counts as another call, and you might find that there are some situations in which your code will crash and throw an error because it ran out of memory, just because of multiple calls. On the other hand, with most current JavaScript engines, you can probably have several thousand pending recursive calls without a problem – but with earlier browsers and smaller machines, the number could drop into the hundreds and feasibly go even lower. Thus, it could be argued that, at present, you are not likely to suffer from any particular memory problems.

In any case, let's review the problem and go over some possible solutions in the following sections. Even if you don't get to actually apply them, they represent valid FP ideas for which you may find a place in yet other problems. We will be looking at the following solutions:

- **Tail call optimization**, a technique that speeds up recursion **continuation-passing style** (**CPS**), an important FP technique that can help with recursion
- A couple of interestingly named techniques, **trampolines** and **thunks**, which are also standard FP tools
- **Recursion elimination**, a technique beyond this book's scope, but which may still be applied

Tail call optimization

When is a recursive call not a recursive call? Put this way, the question may make little sense, but there's a common optimization—for other languages, alas, but not JavaScript!—that explains the answer. If the recursive call is the very last thing a function will do, then the call could be transformed into a simple jump to the start of the function without needing to create a new stack entry. (Why? The stack entry wouldn't be required: after the recursive call is done, the function would have nothing else to do, so there is no need to further save any of the elements that have been pushed into the stack upon entering the function.) The original stack entry would then no longer be needed and could be replaced by a new one, corresponding to the recent call.

Implementation irony

The fact that a recursive call, a quintessential FP technique, is being implemented by a base imperative `GO TO` statement can be considered an ultimate irony!

These calls are known as **tail calls** (for obvious reasons) and have higher efficiency, not only because of the saved stack space but also because a jump is quite a bit faster than any alternative. If the browser implements this enhancement, it uses **tail call optimization** (**TCO**); however, a glance at the compatibility tables at `kangax.github.io/compat-table/es6/` shows that at the time of writing (at the end of 2022), the only browser that provides TCO is Safari.

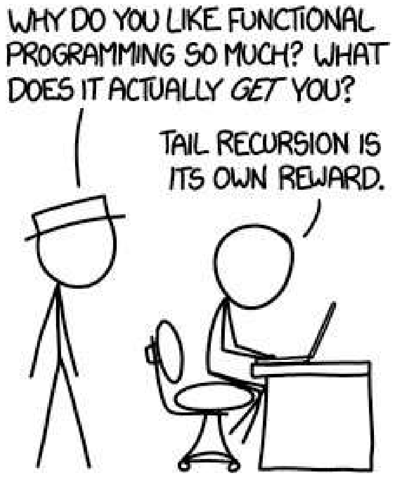

WHY DO YOU LIKE FUNCTIONAL PROGRAMMING SO MUCH? WHAT DOES IT ACTUALLY *GET* YOU?
TAIL RECURSION IS ITS OWN REWARD.

Figure 9.9 – To understand this joke, you must have previously understood it!

A simple (though non-standard) test lets you verify whether your browser provides TCO. I found this snippet of code in several places on the web, but I'm sorry to say, I cannot attest to the original author, although I believe it is Csaba Hellinger from Hungary. Calling `detectTCO()` lets you know whether your browser does or does not use TCO:

```
// tailRecursion.ts

function detectTCO() {
  const outerStackLen = new Error().stack!.length;
  return (function inner() {
    const innerStackLen = new Error().stack!.length;
    return innerStackLen <= outerStackLen;
  })();
}
```

The `Error().stack` result is not a JavaScript standard, but modern browsers support it, albeit in somewhat different ways. (I had to add the "`!`" symbol so TypeScript would accept that `stack` would be present.) In any case, the idea is that when a function with a long name calls another function with a shorter name, the stack trace should do the following:

- It should get shorter if the browser implements TCO, since the old entry for the longer-named function would be replaced with the entry for the shorter-named one
- It should get longer without TCO, since a completely new stack entry would be created without doing away with the original one

I'm using Chrome on my Linux laptop, and I added a `console.log()` statement to show `Error().stack`. You can see that both stack entries (for `inner()` and `detectTCO()`) are *live*, so there's no TCO:

```
Error
at inner (<anonymous>:6:13)
at detectTCO (<anonymous>:9:6) at <anonymous>:1:1
```

Of course, there's another way of learning whether your environment includes TCO: try out the following function (which does nothing!) with large enough numbers. If you manage to run it with numbers such as, say, 100,000 or 1,000,000, you can be reasonably sure that your JavaScript engine is doing TCO! A possible such function could be the following:

```
// continued...

function justLoop(n: number): void {
  n && justLoop(n - 1); // until n is zero
}
```

Let's finish this section with a very short quiz to ensure we understand what tail calls are. Is the recursive call in the factorial function we saw in *Chapter 1*, *Becoming Functional*, (but here written in TypeScript) a tail call?

```
function fact(n: number): number {
  if (n === 0) {
    return 1;
  } else {
    return n * fact(n - 1);
  }
}
```

Think about it, because the answer is important! You might be tempted to answer in the affirmative, but the correct answer is *no*. There's a good reason for this, and it's a key point: after the recursive call is done and the value for `fact(n-1)` has been calculated, the function still has work to do. (So doing the recursive call wasn't actually the last thing that the function would do.) You can see it more clearly if you write the function in this equivalent way:

```
function fact2(n: number): number {
  if (n === 0) {
    return 1;
  } else {
    const aux = fact2(n - 1);
    return n * aux;
  }
}
```

There should be two takeaways from this section: TCO isn't usually offered by browsers, and even if it were, you cannot take advantage of it if your calls aren't actual tail calls. Now that we know what the problem is, let's see some FP ways of working around it!

Continuation-passing style

We already know that our logic will fail if we have recursive calls stacked too high. On the other hand, we know that tail calls should alleviate that problem, but they don't because of browser implementations! However, there's a way out of this. Let's first consider how we can transform recursive calls into tail calls by using a well-known FP concept—**continuations**—and we'll leave the problem of solving TCO limitations for the next section. (We mentioned continuations in *Chapter 3*, *Starting Out with Functions*, but we didn't go into detail.)

In FP parlance, a continuation represents the state of a process and allows processing to continue. This may be too abstract, so let's see what this means. The key idea is that when you call a function, you also provide it with a continuation (in reality, a simple function) that will be called at return time.

Let's look at a trivial example. Suppose you have a function that returns the time of the day, and you want to show this on the console. The usual way to do this could be as follows:

```
function getTime(): string {
  return new Date().toTimeString();
}
console.log(getTime()); // "21:00:24 GMT+0530 (IST)"
```

If you were doing CPS, you would pass a continuation to the `getTime()` function. Instead of returning a calculated value, the function would invoke the continuation, giving it the value as a parameter:

```
function getTime2(cont: FN) {
  return cont(new Date().toTimeString());
}
getTime2(console.log); // similar result as above
```

What's the difference? The key is that we can apply this mechanism to make a recursive call into a tail call because all of the code that comes after will be provided in the recursive call itself. To make this clear, let's revisit the factorial function in the version that made it explicit that we weren't doing tail calls:

```
function fact2(n: number): number {
  if (n === 0) {
    return 1;
  } else {
    const aux = fact2(n - 1);
    return n * aux;
  }
}
```

We will add a new parameter to the function for the continuation. What do we do with the result of the `fact(n-1)` call? We multiply it by `n`, so let's provide a continuation that will do just that. I'll rename the factorial function as `factC()` to make it clear that we are working with continuations, as shown in the following code:

```
// continued...

function factC(
  n: number,
  cont: (x: number) => number
): number {
  if (n === 0) {
    return cont(1);
  } else {
    return factC(n - 1, (x) => cont(n * x));
  }
}
```

How would we get the final result? Easy – we can call `factC()` with a continuation that will return whatever it's given:

```
console.log(factC(7, x => x)); // 5040, correctly
factC(7, console.log);         // same result
```

Identity combinator

In FP, a function that returns its argument as a result is usually called `identity()` for obvious reasons. In combinatory logic (which we won't be using), we would speak of the **I combinator**.

Can you understand how it worked? Then let's try out a more complex case with the Fibonacci function, which has two recursive calls in it, as shown in the following highlighted code:

```
// continued...

const fibC = (n: number, cont: FN): number => {
  if (n <= 1) {
    return cont(n);
  } else {
    return fibC(n - 2, (p) =>
      fibC(n - 1, (q) => cont(p + q))
    );
  }
};
```

This is trickier: we call `fibC()` with `n-2` and a continuation that says that whatever that call returned, call `fibC()` with `n-1`, and when *that* call returns, sum the results of both calls and pass that result to the original continuation.

Let's see just one more example, involving a loop with an undefined number of recursive calls. By then, you should have some idea about how to apply CPS to your code—though I'll readily admit it can become really complex!

Earlier in this chapter, we saw this function in the *Traversing a tree structure* section. The idea was to print out the DOM structure, like this:

```
<body>
| <script>
| <div>
| | <div>
| | | <a>
| | | <div>
| | | | <ul>
| | | | | <li>
| | | | | | <a>
| | | | | | | <div>
| | | | | | | | <div>
| | | | | | | <div>
| | | | | | | | <br>
| | | | | | | <div>
| | | | | | <ul>
| | | | | | | <li>
| | | | | | | | <a>
| | | | | | | <li>
...etc.!
```

The function we ended up designing back then was the following:

```
// dom.ts

const traverseDom2 = (node: Element, depth = 0) => {
  console.log(
    `${"| ".repeat(depth)}<${node.nodeName.toLowerCase()}>`
  );
  Array.from(node.children).forEach((child) =>
    traverseDom2(child, depth + 1)
  );
};
```

Let's start by making this fully recursive, getting rid of the `forEach()` loop. We have seen this technique before, so we can move on to the following result; note how the following code forms its loops by using recursion. Also, note we added lots of `return` statements, even if they are not really needed; we'll see the reason for this soon:

```
// continued...

const traverseDom3 = (node: Element, depth = 0): void => {
  console.log(
    `${"| ".repeat(depth)}<${node.nodeName.toLowerCase()}>`
  );
  const traverseChildren = (
    children: Element[],
    i = 0
  ): void => {
    if (i < children.length) {
      traverseDom3(children[i], depth + 1);
      return traverseChildren(children, i + 1); // loop
    }
    return;
  };
  return traverseChildren(Array.from(node.children));
};
```

Now, we have to add a continuation to `traverseDom3()`. The only difference from the previous cases is that the function doesn't return anything, so we won't pass any arguments to the continuation. It's also important to remember the implicit return at the end of the `traverseChildren()` loop; we must call the continuation:

```
// continued...

const traverseDom3C = (
  node: Element,
  depth = 0,
  cont: FN = () => {
    /*  nothing */
  }
): void => {
  console.log(
    `${"| ".repeat(depth)}<${node.nodeName.toLowerCase()}>`
  );
  const traverseChildren = (
    children: Element[],
    i = 0
  ): void => {
    if (i < children.length) {
      return traverseDom3C(children[i], depth + 1, () =>
        traverseChildren(children, i + 1)
      );
    }
    return cont();
  };
  return traverseChildren(Array.from(node.children));
};
```

We opted to give a default value to `cont`, so we can call `traverseDom3C(document.body)` as before. If we try out this logic, it works, but the problem of the potentially high number of pending calls hasn't been solved; let's look for a solution to this in the following section.

Trampolines and thunks

For the last solution to our problem, we shall have to think about the cause of the problem. Each pending recursive call creates a new entry stack. Whenever the stack gets too empty, the program crashes, and our algorithm is history. So, if we can work out a way to avoid stack growth, we should be free. The solution, in this case, is quite imposing and requires *thunks* and a *trampoline*—let's see what these are!

First, a **thunk** is really quite simple: it's just a nullary function (so, with no parameters) that helps delay a computation, providing a form of **lazy evaluation**. If you have a thunk, then you won't get its value unless you call the thunk. For example, if you want to get the current date and time in ISO format, you could get it with `new Date().toISOString()`; however, if you provide a thunk that calculates that, you won't get the value until you actually invoke it:

```
// trampoline.ts

const getIsoDT = () => new Date().toISOString(); // a thunk

const isoDT = getIsoDT(); // getting the thunk's value
```

What's the use of this? The problem with recursion is that a function calls itself, and calls itself, and calls itself, and so on until the stack blows over. Instead of directly calling itself, we will have the function return a thunk, which, when executed, will actually recursively call the function. So, instead of having the stack grow more and more, it will actually be quite flat since the function will never get to actually call itself; the stack will grow by one position when you call the function, and then get back to its size as soon as the function returns its thunk.

But who gets to do the recursion? That's where the concept of a **trampoline** comes in. A trampoline is just a loop that calls a function, gets its return, and if it is a thunk, then it calls it so that recursion will proceed, but in a flat, linear way! The loop is exited when the thunk evaluation returns an actual value instead of a new function. Look at the following code:

```
// continued...

const trampoline = (fn: FN): any => {
  while (typeof fn === "function") {
    fn = fn();
  }
  return fn;
};
```

How can we apply this to an actual function? Let's start with a simple one that sums all numbers from 1 to *n*, but in a recursive, guaranteed-to-cause-a-stack-crash fashion. Our simple `sumAll()` function could be the following:

```
// continued...

const sumAll = (n: number): number =>
  n == 0 ? 0 : n + sumAll(n - 1);
```

However, if we start trying this function out, we'll eventually stumble and crash, as you can see in the following examples:

```
console.log(sumAll(10));
console.log(sumAll(100));
console.log(sumAll(1_000));
console.log(sumAll(10_000));
console.log(sumAll(100_000));

// Output:
55
5050
500500
50005000
RangeError: Maximum call stack size exceeded
```

The stack problem will come up sooner or later depending on your machine, its memory size, and so on – but it will come, no doubt. Let's rewrite the function in CPS so that it will become tail-recursive. We will apply the same technique that we saw earlier, as shown in the following code:

```
// continued...

const sumAllC = (n: number, cont: FN): number =>
  n === 0 ? cont(0) : sumAllC(n - 1, (v) => cont(v + n));
```

This, however, crashes as before; eventually, the stack grows too much. Let's apply a simple rule to the code: whenever you are going to return from a call, instead, return a thunk that will, when executed, do the call that you actually wanted to do. The following code implements that change:

```
// continued...

const sumAllT = (n: number, cont: FN): (() => number) =>
  n === 0
    ? () => cont(0)
    : () => sumAllT(n - 1, (v) => () => cont(v + n));
```

Whenever there would have been a call to a function, we now return a thunk. How do we get to run this function? This is the missing detail. You need an initial call that will invoke `sumAllT()` the first time, and (unless the function was called with a zero argument) a thunk will be immediately returned. The `trampoline` function will call the thunk, and that will cause a new call, and so on until we eventually get a thunk that just returns a value, and then the calculation will be ended:

```
// continued...

const sumAll2 = n => trampoline(sumAllT(n, x => x));

console.log(sumAll2(1_000_000)); // no problem now!
```

In fact, you probably wouldn't want a separate `sumAllT()` function, so you'd go for something like this:

```
const sumAll3 = (n: number): number => {
  const sumAllT = (n: number, cont: FN) =>
    n === 0
      ? () => cont(0)
      : () => sumAllT(n - 1, (v) => () => cont(v + n));

  return trampoline(sumAllT(n, (x) => x));
};

console.log(sumAll3(1_000_000)); // no stack crash
```

There's only one problem left: what would we do if the result of our recursive function wasn't a value but rather a function? The problem there would be on the `trampoline()` code that, as long as the result of the thunk evaluation is a function, goes back again and again to evaluate it. The simplest solution would be to return a thunk, but wrapped in an object, as shown in the following code:

```
// continued...

class Thunk {
  fn: FN;
  constructor(fn: FN) {
    this.fn = fn;
  }
}

const trampoline2 = (thk: Thunk) => {
  while (
    typeof thk === "object" &&
    thk.constructor.name === "Thunk"
  ) {
    thk = thk.fn();
  }
  return thk;
};
```

The difference now would be that, instead of returning a thunk, you'd return a `Thunk` object, so our new trampolining function can now distinguish an actual thunk (which is meant to be invoked and executed) from any other kind of result (which is meant to be returned).

So, if you happen to have a recursive algorithm, but it won't run because of stack limits, you can fix it reasonably by going through the following steps:

1. Change all recursive calls to tail recursion using continuations.
2. Replace all `return` statements so that they'll return thunks.
3. Replace the call to the original function with a `trampoline` call to start the calculations.

Of course, this doesn't come for free. You'll notice that, when using this mechanism, there's extra work involving returning thunks, evaluating them, and so on, so you can expect the total time to go up. Nonetheless, this is a low price to pay if the alternative is having a non-working solution to a problem!

Recursion elimination

There's yet one other possibility that you might want to explore, but that falls beyond the realm of FP and into algorithm design. It's a computer science fact that any algorithm implemented using recursion has an equivalent version that doesn't use recursion at all, and instead depends on a stack. There are ways to systematically transform recursive algorithms into iterative ones, so if you run out of all options (that is, if not even continuations or thunks can help you), then you'd have a final opportunity to achieve your goals by replacing all recursion with iteration. We won't be getting into this—as I said, this elimination has little to do with FP—but it's important to know that the tool exists and that you might be able to use it.

Summary

In this chapter, we saw how we can use recursion, a basic tool in FP, as a powerful technique to create algorithms for problems that would probably require far more complex solutions otherwise. We started by considering what recursion is and how to think recursively in order to solve problems, then moved on to see some recursive solutions to several problems in different areas, and ended by analyzing potential problems with deep recursion and how to solve them.

In *Chapter 10*, *Ensuring Purity*, we shall get back to a concept we saw earlier in the book, function purity, and see some techniques that will help us guarantee that a function won't have any side effects by ensuring the immutability of arguments and data structures.

Questions

9.1 **Into reverse**: Can you program a `reverse(str: string)` function but implement it in a recursive fashion? The best way to do this would be using the standard string `reverse()` method, as detailed in `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Array/reverse`, but that wouldn't do for a question on recursion, would it?

9.2 **Climbing steps**: Suppose you want to climb up a ladder with *n* steps. Each time you raise your foot, you may climb up one or two rungs. In how many different ways can you climb up that ladder? For example, you can climb a four-rung ladder in five different ways:

- Always take one step at a time
- Always take two steps at a time
- Take two steps first, then one, and then one
- Take one step first, then two, and then one
- Take one step first, then another one, and finish with two

9.3 **Sorting recursively**: Many sorting algorithms can be described with recursion; can you implement them?

- **Selection sort**: Find the maximum element of the array, remove it, recursively sort the rest, and then push the maximum element to the end of the sorted rest
- **Insertion sort**: Take the first element of the array, sort the rest, and finish by inserting the removed element into its correct place in the sorted rest

- **Merge sort**: Divide the array into two parts, sort each one, and finish by merging the two sorted parts into a sorted list

9.4 **What could go wrong?** A developer decided that he could write a shorter version of Quicksort. He reasoned that the pivot didn't need special handling since it would be set into its correct place when sorting `greaterEqual`. Can you foresee any possible problems with this? The following code highlights the changes that the developer made with regard to the original version we saw earlier:

```
const quicksort = <A>(arr: A[]): A[] => {
  if (arr.length < 2) {
    return arr;
  } else {
    const pivot = arr[0];
    const smaller = arr.filter((x) => x < pivot);
    const greaterEqual = arr.filter((x) => x >= pivot);
    return [
      ...quicksort(smaller),
      ...quicksort(greaterEqual),
    ];
  }
};
```

9.5 **More efficiency**: Let's make `quicksort()` more efficient by avoiding having to call `filter()` twice. Along the lines of what we saw in the *Calculating several values at once* section in *Chapter 5*, *Programming Declaratively*, write a `partition(arr, pr)` function that, given an `arr` array and an `fn()` predicate, will return two arrays: the values of `arr` for which `fn` is true in the first one, and the rest of the values of `arr` in the second one:

```
const partition = <A>(
  arr: A[],
  fn: (x: A) => boolean
): [A[], A[]] => { … };

const quicksort = <A>(arr: A[]): A[] => {
  if (arr.length < 2) {
    return arr;
  } else {
    const pivot = arr[0];
    const [smaller, greaterEqual] = partition(
      arr.slice(1),
      (x) => x < pivot
    );
    return [
      ...quicksort(smaller),
      pivot,
      ...quicksort(greaterEqual),
    ];
  }
};
```

9.6 **Completing callbacks**: In our `findR()` function, we did not provide all possible parameters to the `cb()` callback. Can you fix that? Your solution should be along the lines of what we did for `map()` and other functions. (And yes, if you can also allow for empty places in the array, it would be even better.)

9.7 **Recursive logic**: We didn't get to code `every()` and `some()` using recursion: can you do that?

9.8 **Symmetrical queens**: In the eight queens puzzle we previously solved, only one solution shows symmetry in the placement of the queens. Can you modify your algorithm to find it?

9.9 **Longest common subsequence**: A classic dynamic programming problem is as follows: given two strings, find the length of the longest subsequence present in both of them. Be careful: we define a subsequence as a sequence of characters that appear in the same relative order but not necessarily next to each other. For example, the longest common subsequence of `INTERNATIONAL` and `CONTRACTOR` is `N...T...R...A...T...O`. Try it out with and without memoizing and see the difference!

9.10 **At odds with JavaScript**: This may not be a functional programming question, but in how many ways (not necessarily recursive!) can you implement `isOdd()`? There are quite a few!

9.11 **Odds and evens trampolining**: Implement `isOdd()` and `isEven()` using a trampoline to avoid stack overflow problems.

9.12 **Mutual problem?** One version I coded for `isEven()/isOdd()` was as follows, but it had a serious bug; can you find it?

```
function isEven(n: number): boolean {
  if (n === 0) {
    return true;
  } else {
    return isOdd(n - 1);
  }
}
```

```
function isOdd(n: number): boolean {
  if (n === 1) {
    return true;
  } else {
    return isEven(n - 1);
  }
}
```

9.13 **Say no to whiles?** Alternative (shorter) implementations of `expression()` and `term()`, which don't use `while`, follow – are they correct?

```
function expression(): number {
  for (let accum = term(); ; ) {
    if (tokens[curr] === PLUS) {
      curr++; // skip PLUS
      accum += term();
    } else if (tokens[curr] === MINUS) {
      curr++; // skip MINUS
      accum -= term();
    } else {
      return accum;
    }
  }
}

function term(): number {
  for (let accum = factor(); ; ) {
    if (tokens[curr] === TIMES) {
      curr++; // skip TIMES
      accum *= factor();
    } else if (tokens[curr] === DIVIDES) {
      curr++; // skip DIVIDES
      accum /= factor();
    } else if (tokens[curr] === MODULUS) {
      curr++; // skip MODULUS
      accum %= factor();
      } else {
        return accum;
      }
    }
  }
```

9.14 **Power, more power!** Add the exponentiation operator, `"^"`, to our arithmetic expression evaluator. (Yes, the exponentiation operator in JavaScript is `"**"`, not `"^"`, but I wanted to have single-character tokens for simplicity.) Be sure to implement priorities correctly, and also to make the operator right-associative: `2^3^4` should be evaluated as `(2^(3^4))`, not `((2^3)^4)`.

9.15 **Error-prone evaluation**: Our evaluation algorithm is prone to errors because it expects expressions to be syntactically valid. How can you enhance it?

10
Ensuring Purity – Immutability

In *Chapter 4*, *Behaving Properly*, when we considered pure functions and their advantages, we saw that side effects such as modifying a received argument or a global variable were frequent causes of impurity. Now, after several chapters dealing with many aspects and tools of FP, let's talk about the concept of *immutability* – how to work with objects in such a way that accidentally modifying them will become harder or, even better, impossible.

We cannot force developers to work in a safe, guarded way. Still, if we find some way to make data structures immutable (meaning that they cannot be directly changed, except through some interface that never allows us to modify the original data and produces new objects instead), then we'll have an enforceable solution. In this chapter, we will look at two distinct approaches to working with such immutable objects and data structures:

- *Basic JavaScript ways*, such as freezing objects, plus cloning to create new ones instead of modifying existing objects
- *Persistent data structures*, with methods that allow us to update them without changing the original and without the need to clone everything either, for higher performance

Warning!

The code in this chapter isn't production-ready; I wanted to focus on the main points and not on all the myriad details concerning properties, getters, setters, lenses, prototypes, and so on that you should take into account for a full, bulletproof solution. For actual development, I recommend going with a third-party library, but only after checking that it really applies to your situation. We'll be recommending several such libraries, but of course, there are many more that you could use.

Going the straightforward JavaScript way

One of the biggest causes of side effects was the possibility of a function modifying its arguments or global objects. All non-primitive objects are passed as references, so if/when you modify them, the original objects will be changed. If we want to stop this (without just depending on the goodwill and clean coding of our developers), we may want to consider some straightforward JavaScript techniques to prohibit those side effects:

- Avoiding mutator functions that directly modify the object that they are applied to
- Using `const` declarations to prevent variables from being changed
- Freezing objects so that they can't be modified in any way
- Creating (changed) clones of objects to avoid modifying the original
- Using getters and setters to control what is changed and how
- Using a functional concept – *lenses* – to access and set attributes

Let's take a look at each technique in more detail.

Mutator functions

A common source of unexpected problems is that several JavaScript methods are mutators that modify the underlying object. (Refer to `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Array#Mutator_methods` for more on mutators.) In this case, by merely using these methods, you will be causing a side effect that you may not even be aware of. Arrays are the most basic sources of problems, and the list of troublesome methods isn't short:

- `copyWithin()` lets you copy elements within an array
- `fill()` fills an array with a given value
- `push()` and `pop()` let you add or delete elements at the end of an array
- `shift()` and `unshift()` work in the same way as `push()` and `pop()` but at the beginning of an array
- `splice()` lets you add or delete elements anywhere within an array
- `reverse()` and `sort()` modify an array in place, reversing or sorting its elements

Let's take a look at an example we saw in the *Argument mutation* section of *Chapter 4, Behaving Properly*:

```
// maxStrings.ts

const maxStrings = (a: string[]) => a.sort().pop();
const countries = [
  "Argentina",
  "Uruguay",
  "Brasil",
  "Paraguay",
];

console.log(maxStrings(countries)); // "Uruguay"
```

Our `maxStrings()` function returns the highest value in an array, but also modifies the original array; this is a side effect of the `sort()` and `pop()` mutator functions. In this case and others, you might generate a copy of the array and then work with that; both the spread operator and `.slice()` are useful:

```
const maxStrings2 = (a: string[]): string =>
  [...a].sort().pop() as string;

const maxStrings3 = (a: string[]): string =>
  a.slice().sort().pop() as string;

console.log(maxStrings2(countries)); // "Uruguay"
console.log(maxStrings3(countries)); // "Uruguay"

console.log(countries);
// ["Argentina", "Uruguay", "Brasil", "Paraguay"]
// unchanged
```

Both new versions of our `maxStrings()` functions are now functional, without side effects, because the mutator methods have been applied to copies of the original argument. By the way, if you are wondering about the `as string` part in both new functions, it's because TypeScript warns you that the array might be empty, and I'm telling it that I guarantee the array won't be so.

Of course, setter methods are also mutators and will logically produce side effects because they can do just about anything. If this is the case, you'll have to go for some of the other solutions described later in this chapter.

Constants

If the mutations don't happen because of the use of some JavaScript methods, then we might want to attempt to use `const` definitions, but unfortunately, that just won't work. In JavaScript, `const` means that the *reference* to the object or array cannot change (you cannot assign a different object to it), but you can still modify its properties. We can see this in the following code:

```
const myObj = { d: 22, m: 9 };
console.log(myObj);

// {d: 22, m: 9}

myObj = { d: 12, m: 4 };
// Uncaught TypeError: Assignment to constant variable.

myObj.d = 12; // but this is fine!
myObj.m = 4;
console.log(myObj);
// {d: 12, m: 4}
```

You cannot modify the value of `myObj` by assigning it a new value, but you can modify its current value so that only the reference to an object is constant, not the object's values themselves. (By the way, this would have also happened with arrays.) So, if you use `const` everywhere, you will only be safe against direct assignments to objects and arrays. More modest side effects, such as changing an attribute or an array element, will still be possible, so this is not a solution.

Two methods can work – *freezing* to provide unmodifiable structures, and *cloning* to produce modified new ones. These are probably not the best ways to go about forbidding objects from being changed, but they can be used as a makeshift solution. Let's look at them in more detail, starting with freezing.

Freezing

If we want to avoid the possibility of a programmer accidentally or willingly modifying an object, freezing it is a valid solution. After an object has been frozen, any attempts at modifying it will silently fail – JavaScript won't report an error or throw an exception, but it won't alter the object either.

In the following example, if we attempt to make the same changes we made in the previous section, they won't have any effect, and `myObj` will be unchanged:

```
const myObj2 = { d: 22, m: 9 };
console.log(myObj2);

// {d: 22, m: 9}

Object.freeze(myObj2);
```

```
myObj2.d = 12; // won't have effect...
myObj2.m = 4;

console.log(myObj2);
// Object {d: 22, m: 9}
```

Sealing or freezing?

Don't confuse freezing with sealing – `Object.seal()`, when applied to an object, prohibits you from adding or deleting properties to it. This means that the object's structure is immutable, but the attributes themselves can be changed. `Object.freeze()` covers not only sealing properties but also making them unchangeable. See `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/Object/seal` and `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/Object/freeze` for more on this.

There is only one problem with this solution – freezing an object is a shallow operation that freezes the attributes themselves, similar to what a `const` declaration does. If any of the attributes are objects or arrays themselves they can still be modified. We will only be considering data here; you may also want to freeze, say, functions, but for most use cases, it's data you want to protect:

```
const myObj3 = {
  d: 22,
  m: 9,
  o: { c: "MVD", i: "UY", f: { a: 56 } },
};

Object.freeze(myObj3);

console.log(myObj3);
// {d:22, m:9, o:{c:"MVD", i:"UY", f:{ a:56}}}
```

This is only partially successful, as we can see when we try changing some attributes:

```
myObj3.d = 8888;     // won't work, as earlier

myObj3.o.f.a = 9999; // oops, does work!!

console.log(myObj3);
// {d:22, m:9, o:{c:"MVD", i:"UY", f:{ a:9999 }}}
```

Modifying `myObj3.d` doesn't work because the object is frozen, but that doesn't extend to objects within `myObj3`, so changing `myObj3.o.f.a` does work.

If we want to achieve real immutability for our object, we need to write a routine that will freeze all the levels of an object. Fortunately, it's easy to achieve this by applying recursion. (We saw similar applications of recursion in the *Traversing a tree structure* section of the previous chapter.) Mainly, the idea is to freeze the object itself and then recursively freeze each of its properties. We must ensure that we only freeze the object's own properties; we shouldn't mess with the prototype of the object, for example:

```
// deepFreeze.ts

const deepFreeze = <O extends OBJ>(obj: O): O => {
  if (
    obj &&
    typeof obj === "object" &&
    !Object.isFrozen(obj)
  ) {
    Object.freeze(obj);
    Object.getOwnPropertyNames(obj).forEach((prop) =>
      deepFreeze(obj[prop])
    );
  }

  return obj;
};
```

Note that, in the same way that `Object.freeze()` works, `deepFreeze()` also freezes the object in place. I wanted to keep the original semantics of the operation so that the returned object would always be the original one. If we wanted to work in a purer fashion, we should make a copy of the original object first (we'll learn how to do this in the next section) and then freeze that. As for TypeScript, the returned value is the same type as the input; the object being frozen makes no difference with regard to types.

A small possible problem remains, but with a very bad result – what would happen if an object included a reference to itself? We can avoid this if we skip freezing already frozen objects; backward circular references would be ignored, since the objects they refer to would already be frozen. So, the logic we wrote took care of that problem, and there's nothing more to be done!

If we apply `deepFreeze()` to an object, we can safely pass it to any function, knowing there is no way in which it can be modified. You can also use this property to test whether a function modifies its arguments – deep-freeze them, call the function, and if the function depends on modifying its arguments, it won't work because the changes will be silently ignored. So, how can we return a result from a function if it involves a received object? This can be solved in many ways. A simple one uses cloning, as we'll see.

In this section, we dealt with one of the methods we can use to avoid changes in objects. (Check the *Questions* section at the end of this chapter for another way of freezing objects by means of proxies.) Now, let's look at an alternative involving cloning.

Cloning and mutating

If mutating an object isn't allowed, you must create a new one. For example, if you use Redux, a reducer is a function that receives the current state and an action (essentially, an object with new data) and produces the new state. Modifying the current state is totally forbidden, and we could avoid this error by always working with frozen objects, as we saw in the previous section. To fulfill the reducer's requirements, we have to be able to clone the original state, as well as mutate it according to the received action. The resulting object will become the new state.

To round things off, we should also freeze the returned object, just like we did with the original state. But let's start at the beginning – how do we clone an object? Of course, you can always do this by hand, but that's not something you'd want to consider when working with large, complex objects. (You may want to revisit the *More general looping* section of *Chapter 5*, *Programming Declaratively*, where we wrote a basic `objCopy()` function that provides a different approach from the one we'll show here.) For example, if you wanted to clone `oldObject` to produce `newObject`, doing it by hand would imply a lot of code:

```
const oldObject = {
  d: 22,
  m: 9,
  o: { c: "MVD", i: "UY", f: { a: 56 } },
};

const newObject = {
  d: oldObject.d,
  m: oldObject.m,
  o: {
    c: oldObject.o.c,
    i: oldObject.o.i,
    f: { a: oldObject.o.f.a },
  },
};
```

This manual solution is obviously a lot of work, and error-prone as well; you could easily forget an attribute! Going for more automatic solutions, there are a couple of straightforward ways of copying arrays or objects in JavaScript, but they have the same shallowness problem. You can make a (shallow) copy of an object with `Object.assign()` or by spreading:

```
const myObj = { d: 22, m: 9 };

const newObj1 = Object.assign({}, myObj);

const newObj2 = { ...myObj };
```

To create a (shallow) copy of an array, you can either use `slice()` or spreading, as we saw in the *Mutator functions* section earlier in this chapter:

```
const myArray = [1, 2, 3, 4];

const newArray1 = myArray.slice();

const newArray2 = [...myArray];
```

What's the problem with these solutions? If an object or array includes objects (which may themselves include objects), we get the same problem that we had when freezing – objects are copied by reference, which means that a change in the new object will also change the old object:

```
const oldObject = {
  d: 22,
  m: 9,
  o: { c: "MVD", i: "UY", f: { a: 56 } },
};

const newObject2 = Object.assign({}, oldObject);

newObject2.d = 8888;
newObject2.o.f.a = 9999;

console.log(newObject2);
// {d:8888, m:9, o: {c:"MVD", i:"UY", f: {a:9999}}} -- ok

console.log(oldObject);
// {d:22, m:9, o: {c:"MVD", i:"UY", f: {a:9999}}} -- oops!!
```

In this case, note what happened when we changed some properties of `newObject`. Changing `newObject.d` worked fine, but changing `newObject.o.f.a` also impacted `oldObject`, since `newObject.o` and `oldObject.o` actually refer to the very same object.

New age, old section

Since 2022, a new `structuredClone()` function has been available, so if your browser supports it, the code on these pages won't be needed. For more information, check out `developer.mozilla.org/en-US/docs/Web/API/structuredClone`.

There is a simple solution to this, based on JSON. If we `stringify()` the original object and then `parse()` the result, we'll get a new object that's totally separate from the old one:

```
// deepCopy.ts

const jsonCopy = <O extends OBJ>(obj: O): O =>
  JSON.parse(JSON.stringify(obj));
```

By using `JSON.stringify()`, we can convert our object into a string. Then, `JSON.parse()` creates a (new) object out of that string – simple! This works with both arrays and objects, but there's a problem. If any object's properties have a constructor, they won't be invoked; the result will always be composed of plain JavaScript objects. (This is not the only problem with `jsonCopy()`; see *Question 10.2*.) We can see this very simply with `Date()`:

```
const myDate = new Date();

const newDate = jsonCopy(myDate);

console.log(typeof myDate, typeof newDate);
// object string
```

While `myDate` is an object, `newDate` turns out to be a string with a value, the date and time at the moment we did the conversion, "`2023-01-15T09:23:55.125Z`".

We could do a recursive solution, just like we did with deep freezing, and the logic is quite similar. Whenever we find a property that is really an object, we invoke the appropriate constructor:

```
// continued...

const deepCopy = <O extends OBJ>(obj: O): O => {
  let aux: O = obj;
  if (obj && typeof obj === "object") {
    aux = new (obj as any).constructor(); // TS hack!

    Object.getOwnPropertyNames(obj).forEach((prop) => {
      aux[prop as keyof O] = deepCopy(obj[prop]);
    });
  }

  return aux;
};
```

Whenever we find that a property of an object is actually another object, we invoke its constructor before continuing. This solves the problem we found with dates or, in fact, with any object! If we run the preceding code but use `deepCopy()` instead of `jsonCopy()`, we'll get `object object` as output, as it should be. If we check the types and constructors, everything will match.

There's a need for a minor hack because TypeScript works better with classes than with constructor functions – writing `obj as any` gets type checking to work, but it's not very nice. Also, we need to write `prop as keyof O` because, otherwise, TypeScript would protest that `prop` could be anything, not necessarily a key of the original type.

The data-changing experiment will also work fine now:

```
let oldObject = {
  d: 22,
  m: 9,
  o: { c: "MVD", i: "UY", f: { a: 56 } },
};

let newObject = deepCopy(oldObject);
newObject.d = 8888;
newObject.o.f.a = 9999;

console.log(newObject);
// {d:8888, m:9, o:{c:"MVD", i:"UY", f:{a:9999}}}

console.log(oldObject);
// {d:22, m:9, o:{c:"MVD", i:"UY", f:{a:56}}} -- unchanged!
```

Let's check out the last few lines. Modifying `newObject` had no impact on `oldObject`, so both objects are completely separate.

Now that we know how to copy an object, we can follow these steps:

1. Receive a (frozen) object as an argument.
2. Make a copy of it, which won't be frozen.
3. Take values from that copy that we can use in our code.
4. Modify the copy at will.
5. Freeze it.
6. Return it as the result of the function.

All of this is viable, though a bit cumbersome. Also, there are some limitations – we won't be able to duplicate private properties or properties that involve symbols, we won't duplicate getters and setters, and metadata-related features will also be missing. Let's accept that, and add a couple of functions that will help bring everything together.

Getters and setters

When following the steps provided at the end of the previous section, you may have noticed that every time you want to update a field, things become troublesome and prone to errors. Let's use a common technique to add a pair of functions: getters and setters. They are as follows:

- *Getters* can be used to get values from a frozen object by unfreezing them so that they can be used.
- *Setters* allow you to modify any property of an object. You can do this by creating a new and updated version, leaving the original untouched.

Let's build our getters and setters.

Getting a property

In the *Getting a property from an object* section in *Chapter 6*, *Producing Functions*, we wrote a simple `getField()` function that could handle getting a single attribute from an object. (See *Question 6.13* in that chapter for the missing companion `setField()` function.) Let's take a look at how we can code this. We can have a straightforward version as follows:

```
// getByPath.ts

const getField =
  <O extends OBJ>(f: keyof O) =>
  (obj: O) =>
    obj[f];
```

We can even go one better by applying currying so that we have a more general version:

```
// continued...

const getField2 = curry(getField);
```

We could get a deep attribute from an object by composing a series of `getField()` applications, but that would be rather cumbersome. Instead, let's create a function that will receive a path – an array of field names – and return the corresponding part of the object, or be undefined if the path doesn't exist. Using recursion is appropriate here and simplifies coding! Observe the following code:

```
// continued...

const getByPath = <O extends OBJ>(
  arr: string[],
  obj: O
): any => {
  if (arr[0] in obj) {
    return arr.length > 1
      ? getByPath(arr.slice(1), obj[arr[0]])
      : deepCopy(obj[arr[0]]);
  } else {
    return undefined;
  }
};
```

Basically, we look for the first string in the path to see whether it exists in the object. If it doesn't, the operation fails, so we return `undefined`. If successful, and we still have more strings in the path, we use recursion to keep digging into the object; otherwise, we return a deep copy of the attribute's value.

Once an object has been frozen, we cannot defrost it, so we must resort to making a new copy of it; `deepCopy()` is appropriate for doing this. Let's try out our new function:

```
const myObj4 = deepFreeze({
  d: 22,
  m: 9,
  o: { c: "MVD", i: "UY", f: { a: 56 } },
});

console.log(getByPath(["d"], myObj4));
```

```
// 22

console.log(getByPath(["o"], myObj4));
// {c: "MVD", i: "UY", f: {a: 56}}

console.log(getByPath(["o", "c"], myObj4));
// "MVD"

console.log(getByPath(["o", "f", "a"], myObj4));
// 56
```

We can also check that returned objects are not frozen:

```
const fObj = getByPath(["o", "f"], myObj4);
console.log(fObj);
// {a: 56}

fObj.a = 9999;
console.log(fObj);
// {a: 9999} -- it's not frozen
```

Here, we can see that we could directly update the `fObj` object, which means it wasn't frozen. Now that we've written our getter, we can create a setter.

Setting a property by path

Now, we can code a similar `setByPath()` function that will take a path, a value, and an object and update an object. This is not a pure function, but we'll use it to write a pure one – wait and see! Here is the code:

```
// setByPath.ts

const setByPath = <O extends OBJ>(
  arr: string[],
  value: any,
  obj: O
): O => {
  if (!(arr[0] in obj)) {
    (obj as any)[arr[0]] =
        arr.length === 1
          ? null
          : Number.isInteger(arr[1])
          ? []
          : {};
    }

    if (arr.length > 1) {
      return setByPath(arr.slice(1), value, obj[arr[0]]);
    } else {
      obj[arr[0] as keyof O] = value;
      return obj;
    }
  };
```

Here, we are using recursion to get into the object, creating new attributes if needed, until we have traveled the entire length of the path. One crucial detail when creating attributes is whether we need an array or an object. (And why the `as any` cast for `obj`? That's an issue with TypeScript, which objects to `obj[arr[0]]`, so we must "trick" it. Weirdly, using `Reflect.set()` also works!) We can determine that by checking the next element in the path – if it's a number, then we need an array; otherwise, an object will do.

When we get to the end of the path, we assign the new given value.

Seamless, immutable objects

If you like this way of doing things, check out the `seamless-immutable` library, which works in this fashion. The seamless part of the name alludes to the fact that you still work with normal objects – albeit frozen – which means you can use `map()`, `reduce()`, and so on. You can read more about this at `github.com/rtfeldman/seamless-immutable`.

Now, you can write a function that will be able to take a frozen object and update an attribute within it, returning a new, also frozen, object:

```
// continued...

const updateObject = <O extends OBJ>(
  arr: string[],
  obj: O,
  value: any
) => {
  const newObj = deepCopy(obj);
  setByPath(arr, value, newObj);
  return deepFreeze(newObj);
};
```

Let's check out how it works. To do this, we'll run several updates on the `myObj3` object we have been using:

```
const myObj3 = {
  d: 22,
  m: 9,
  o: { c: "MVD", i: "UY", f: { a: 56 } },
};

const new1 = updateObject(["m"], myObj3, "sep");
console.log(new1);
// {d: 22, m: "sep", o: {c: "MVD", i: "UY", f: {a: 56}}};

const new2 = updateObject(["b"], myObj3, 220960);
console.log(new2);
// {d: 22, m: 9, o: {c: "MVD", i: "UY", f: {a: 56}}, b:
  220960};

const new3 = updateObject(["o", "f", "a"], myObj3, 9999);
console.log(new3);
// {d: 22, m: 9, o: {c: "MVD", i: "UY", f: {a: 9999}}};

const new4 = updateObject(
  ["o", "f", "j", "k", "l"],
  myObj3,
  "deep"
);
console.log(new4);
// {d: 22, m: 9, o: {c: "MVD", i: "UY", f: {a: 56, j: {k:
  "deep"}}}};
```

Given this pair of functions, we have finally gotten ourselves a way to keep immutability:

- Objects must be frozen from the beginning
- Getting data from objects is done with `getByPath()`
- Setting data is done with `updateObject()`, which internally uses `setByPath()`

In this section, we learned how to get and set values from an object in a way that keeps objects immutable. Let's now look at a variation of this concept – **lenses** – that will allow us to not only get and set values but also apply a function to the data.

Lenses

There's another way to get and set values, which goes by the name of *optics*, and includes *lenses* (which we'll study now) and *prisms* (which we'll look at later in this chapter). What are lenses? They are functional ways of focusing (another optical term!) on a given spot in an object so that we can access or modify its value in a non-mutating way. In this section, we'll look at some examples of the usage of lenses and consider two implementations – first, a simple one based on objects, and then a more complete one that's interesting because of some of the techniques we will be using.

Working with lenses

Both implementations will share basic functionality, so let's start by skipping what lenses are or how they are built and look at some examples of their usage instead. First, let's create a sample object that we will work with – some data about a writer (his name sounds familiar...) and his books:

```
const author = {
  user: "fkereki",
  name: {
    first: "Federico",
    middle: "",
    last: "Kereki",
  },
  books: [
    { name: "Google Web Toolkit", year: 2010 },
    { name: "Functional Programming", year: 2017 },
    { name: "Javascript Cookbook", year: 2018 },
  ],
};
```

We shall assume that several functions exist; we'll see how they are implemented in upcoming sections. A lens depends on having a getter and a setter for a given attribute, and we can build one by directly using `lens()`, or `lensProp()` for briefer coding. Let's create a lens for the `user` attribute:

```
const lens1 = lens(getField("user"), setField("user"));
```

This defines a lens that focuses on the `user` attribute. Since this is a common operation, it can also be written more compactly:

```
const lens1 = lensProp("user");
```

Both these lenses allow us to focus on the `user` attribute of whatever object we use them with. With lenses, there are three basic operations, and we'll follow tradition by using the names that most (if not all) libraries follow:

- `view()`: Used to access the value of an attribute
- `set()`: Used to modify the value of an attribute
- `over()`: Used to apply a function to an attribute and change its value

Let's assume the functions are curried, as we saw in the previous chapter. So, to access the `user` attribute, we can write the following:

```
console.log(view(lens1)(author));
// fkereki
```

The `view()` function takes a lens as its first parameter. When applied to an object, it produces the value of whatever the lens focuses on – in our case, the `user` attribute. Of course, you could apply sequences of `view()` functions to get to deeper parts of the object:

```
console.log(
  view(lensProp("last"))(view(lensProp("name"))(author))
);
// Kereki
```

In this section on optics, we'll always go with fully curried functions, not only for variety but because that's usually how those functions are applied, as you'll see in any textbook.

Instead of writing such a series of `view()` calls, we'll compose lenses so that we can focus more deeply on an object. Let's take a look at one final example, which shows how we access an array:

```
const lensBooks = lensProp("books");
console.log(
  "The author wrote " +
    view(lensBooks)(author).length +
    " book(s)"
);
// The author wrote 3 book(s)
```

In the future, should there be any change in the author structure, a simple change in the `lensBooks` definition would be enough to keep the rest of the code unchanged.

Lenses elsewhere?

You can also use lenses to access other structures; refer to *Question 10.8* for a way to use lenses with arrays, and *Question 10.9* for how to use lenses so that they work with maps.

Moving on, the `set()` function allows us to set the value of the focus of the lens:

```
console.log(set(lens1)("FEFK")(author));
/*
{
  user: 'FEFK',
  name: { first: 'Federico', middle: '', last: 'Kereki' },
  books: [
    { name: 'Google Web Toolkit', year: 2010 },
    { name: 'Functional Programming', year: 2017 },
    { name: 'Javascript Cookbook', year: 2018 }
  ]
}
*/
```

The result of `set()` is a new object with a changed value. Using this function in a fully curried style may be surprising, but if we used our `curry()` or `partialCurry()` function from earlier chapters, we could write `set(lens1, "FEFK", author)` as well.

Using `over()` is similar in that a new object is returned, but in this case, the value is changed by applying a mapping function to it:

```
const triple = (x: string): string => x + x + x;
const newAuthor = over(lens1)(triple)(author);
console.log(newAuthor);
/*
{
  user: 'fkerekifkerekifkereki',
  name: { first: 'Federico', middle: '', last: 'Kereki' },
  books: [
    { name: 'Google Web Toolkit', year: 2010 },
    { name: 'Functional Programming', year: 2017 },
    { name: 'Javascript Cookbook', year: 2018 }
  ]
}
*/
```

A fundamental question is, why is `user` equal to `"fkerekifkerekifkereki"` and not `"FEFKFEFKFEFK"`? Our lens does not modify an object when using the setter but instead provides a new one, so we're applying `triple()` to the original object's user attribute.

There are more functions you can do with lenses, but we'll just go with these three for now. (Here's a suggestion – take a look at *Question 10.7* for an interesting idea on how to use lenses to access virtual attributes that don't actually exist in an object.)

To finish this section, I'd recommend looking at some third-party optics libraries (`github.com/stoeffel/awesome-fp-js#lenses` and `tinyurl.com/jslenses` have several suggestions) to get a glimpse into all the available functionality. Now that we have an idea of what to expect when using lenses, let's learn how to implement them.

Implementing lenses with objects

The simplest way to implement a lens is by representing it with an object with just two properties – a getter and a setter. In this case, we'd have something like this:

```
// lensesWithObjects.ts

const getField =
  <O extends OBJ>(attr: string) =>
  (obj: O) =>
    obj[attr];

const setField =
  <O extends OBJ>(attr: string) =>
  (value: any) =>
  (obj: O): O => ({ ...obj, [attr]: value });
```

We've already seen similar `getField()` and `setField()` functions; the former gets a specific attribute from an object, and the latter returns a new object with a single changed attribute. We can now define our `lens`:

```
// continued...

type GET<O extends OBJ> = ReturnType<typeof getField<O>>;

type SET<O extends OBJ> = ReturnType<typeof setField<O>>;

const lens = <O extends OBJ>(
  getter: GET<O>,
  setter: SET<O>
) => ({
  getter,
  setter,
});

const lens = (getter: GET, setter: SET): LENS => ({
  getter,
  setter,
});

const lensProp = (attr: string) =>
  lens((getField as any)(attr), setField(attr));
```

This is easy to understand – given a getter and a setter, `lens()` creates an object with those two attributes, and `lensProp()` creates a getter/setter pair by using `getField()` and `setField()` with `lens()`, which is very straightforward. Now that we have our lens, how do we implement the three basic functions we saw in the previous section? Viewing an attribute requires applying the getter; to maintain a curried style, let's do currying by hand:

```
// continued...

type LENS<O extends OBJ> = ReturnType<typeof lens<O>>;

const view =
  <O extends OBJ>(someLens: LENS<O>) =>
  (someObj: O) =>
    someLens.getter(someObj);
```

The generic `LENS<>` type is the type of whatever the `lens()` function returns.

Similarly, setting an attribute is a matter of applying the setter:

```
// continued...

const set =
  <O extends OBJ>(someLens: LENS<O>) =>
  (newVal: any) =>
  (someObj: O) =>
    someLens.setter(newVal)(someObj);
```

Finally, applying a mapping function to an attribute is a *two-for-one* operation – we use the getter to get the current value of the attribute, we apply the function to it, and we use the setter to store the calculated result:

```
// continued...

const over =
  <O extends OBJ>(someLens: LENS<O>) =>
  (mapFn: (arg: any) => any) =>
  (someObj: O) =>
    someLens.setter(mapFn(someLens.getter(someObj)))(
      someObj
    );
```

This needs to be studied carefully. We use the lens's `getter()` function to get some attribute from the input object, we apply the mapping function to the obtained value, and we use the lens's `setter()` function to produce a new object with the changed attribute.

Now that we can do all three operations, we have working lenses! What about composition? Lenses have a peculiar characteristic – they're composed backward, left to right, so you start with the most generic and end with the most specific. That certainly goes against intuition; we'll learn about this in more detail in the next section, but for now, we'll keep with tradition:

```
// continued...

const composeTwoLenses = <O extends OBJ>(
  lens1: LENS<O>,
  lens2: LENS<O>
) => ({
  getter: (obj: O) => lens2.getter(lens1.getter(obj)),
  setter: (newVal: any) => (obj: O) =>
    lens1.setter(lens2.setter(newVal)(lens1.getter(obj)))(
      obj
    ),
});
```

The code is sort of impressive but not too hard to understand. The getter for the composition of two lenses is the result of using the first lens's getter and then applying the second lens's getter to that result. The setter for the composition is a tad more complex, but follows along the same lines; can you see how it works? Now, we can compose lenses easily; let's start with an invented nonsensical object:

```
const deepObject = {
  a: 1,
  b: 2,
  c: {
    d: 3,
    e: {
      f: 6,
      g: { i: 9, j: { k: 11 } },
      h: 8,
    },
  },
};
```

Now, we can define a few lenses:

```
const lC = lensProp("c");
const lE = lensProp("e");
const lG = lensProp("g");
const lJ = lensProp("j");
const lK = lensProp("k");
```

We can try composing our new lens in a couple of ways, just for variety, to check that everything works:

```
const lJK = composeTwoLenses(lJ, lK);
const lGJK = composeTwoLenses(lG, lJK);
const lEGJK = composeTwoLenses(lE, lGJK);
const lCEGJK1 = composeTwoLenses(lC, lEGJK);
console.log(view(lCEGJK1)(deepObject));

const lCE = composeTwoLenses(lC, lE);
const lCEG = composeTwoLenses(lCE, lG);
const lCEGJ = composeTwoLenses(lCEG, lJ);
const lCEGJK2 = composeTwoLenses(lCEGJ, lK);
console.log(view(lCEGJK2)(deepObject));

/*
11 both times
*/
```

With `lCEGJ1`, we composed some lenses, starting with the latter ones. With `lCEGJ2`, we started with the lenses at the beginning, but the results are the same. Now, let's try setting some values. We want to get down to the `k` attribute and set it to `60`. We can do this by using the same lens we just applied:

```
const setTo60 = set(lCEGJK1)(60)(deepObject);
/*
{
  a: 1,
  b: 2,
  c: {
    d: 3,
    e: {
      f: 6,
      g: { i: 9, j: { k: 60 } },
      h: 8,
    },
  },
};
*/
```

The composed lens worked perfectly, and the value was changed. (Also, a new object was returned; the original is unmodified, as we wanted.) To finish, let's verify that we can use `over()` with our lens and try to duplicate the `k` value so that it becomes `22`. Just for variety, let's use the other composed lens, even though we know that it works in the same way:

```
const setToDouble = over(lCEGJK2)((x) => x * 2)(deepObject);
/*
{
  a: 1,
  b: 2,
  c: {
    d: 3,
    e: {
      f: 6,
      g: { i: 9, j: { k: 22 } },
      h: 8,
    },
  },
};
*/
```

Now, we have learned how to implement lenses in a simple fashion. However, let's consider a different way of achieving the same objective by using actual functions to represent a lens. This will allow us to do composition in the standard way, without needing any special lens function.

Implementing lenses with functions

The previous implementation of lenses with objects works well, but we want to look at a different way of doing things that will let us work with more advanced functional ideas. This will involve some concepts we'll be analyzing in more detail in *Chapter 12*, *Building Better Containers*, but here, we'll use just what we need so that you don't have to go and read that chapter now! Our lenses will work the same way the preceding ones did, except that since they will be functions, we'll be able to compose them with no special composing code.

What's the key concept here? A lens will be a function, based on a getter and a setter pair, that will construct a *container* (actually an object, but let's go with the container name) with a `value` attribute and a `map` method (in *Chapter 12*, *Building Better Containers*, we'll see that this is a *functor*, but you don't need to know that now). By having specific mapping methods, we'll implement our `view()`, `set()`, and `over()` functions.

Our `lens()` function is as follows. We'll explain the details of this later:

```
// lensesWithFunctions.ts

const lens =
  <O extends OBJ>(getter: GET<O>, setter: SET<O>) =>
  (fn: FN) =>
  (obj: O) =>
    fn(getter(obj)).map((value: any) =>
      setter(value)(obj));
```

Let's consider its parameters:

- The `getter` and `setter` parameters are the same as before.
- The `fn` function is the "magic sauce" that makes everything work; depending on what we want to do with the lens, we'll provide a specific function. There'll be more on this later!
- The `obj` parameter is the object we want to apply the lens to.

Let's code our `view()` function. For this, we'll need an auxiliary class, `Constant`, that, given a value, `v`, produces a container with that value and a `map` function that returns the very same container:

```
// continued...

class Constant<V> {
  private value: V;
  map: FN;

  constructor(v: V) {
    this.value = v;
    this.map = () => this;
  }
}
```

With this, we can now code `view()`:

```
// continued...

const view =
  <O extends OBJ, V>(someLens: LENS<O>) =>
  (obj: O) =>
    someLens((x: V) => new Constant(x))(obj).value;

const user = view(lensProp("user"), author);
/*
fkereki
*/
```

What happens here? Let's follow this step by step; it's a bit tricky!

1. We use `lensProp()` to create a lens focusing on the `user` attribute.
2. Our `view()` function passes the constant-building function to `lens()`.
3. Our `lens()` function uses the getter to access the user attribute in the `author` object.
4. Then, the value we receive is used to create a constant container.
5. The `map()` method is invoked, which returns the very same container.
6. The `value` attribute of the container is accessed, and that's the value that the getter retrieved in *step 3*. Wow!

With that under our belt, let's move on to `set()` and `over()`, which will require a different auxiliary function to create a container whose value may vary:

```
// continued...

class Variable<V> {
  private value: V;
  map: FN;

  constructor(v: V) {
    this.value = v;
    this.map = (fn) => new Variable(fn(v));
  }
}
```

In this case (as opposed to `Constant` objects), the `map()` method really does something – when provided with a function, it applies it to the value of the container and returns a new `Variable` object, with the resulting value. The `set()` function can be implemented now:

```
// continued...

const set =
  <O extends OBJ, V>(someLens: LENS<O>) =>
  (newVal: V) =>
  (obj: O) =>
    someLens(() => new Variable(newVal))(obj).value;

const changedUser = set(lensProp("user"))("FEFK")(author);
```

```
/*
{
  user: 'FEFK',
  name: { first: 'Federico', middle: '', last: 'Kereki' },
  books: [
    { name: 'Google Web Toolkit', year: 2010 },
    { name: 'Functional Programming', year: 2017 },
    { name: 'Javascript Cookbook', year: 2018 }
  ]
}
*/
```

In this case, when the lens invokes the container's `map()` method, it will produce a new container with a new value, which makes all the difference. To understand how this works, follow the same six steps we saw for `get()` – the only difference will be in *step 5*, where a new, different container is produced.

Now that we've survived this (tricky indeed!) code, the `over()` function is simple, and the only difference is that instead of mapping to a given value, you use the mapping `mapfn` function provided to compute the new value for the container:

```
// continued...

const over =
  <O extends OBJ, V>(someLens: LENS<O>) =>
  (mapfn: FN) =>
  (obj: O) =>
    someLens((x: V) => new Variable(mapfn(x)))(obj).value;

const newAuthor = over(lensProp("user"))(triple)(author);
/*
{
  user: 'fkerekifkerekifkereki',
  name: { first: 'Federico', middle: '', last: 'Kereki' },
  books: [
    { name: 'Google Web Toolkit', year: 2010 },
    { name: 'Functional Programming', year: 2017 },
    { name: 'Javascript Cookbook', year: 2018 }
  ]
}
*/
```

As you can see, the difference between `set()` and `over()` is that, in the former case, you provide a value to replace the original one, while in the latter case, you provide a function to calculate the new value. Other than that, both are similar.

To finish, let's verify that `compose()` can be applied to our functor-based lenses:

```
// continued...

const lastName = view(
  compose(lensProp("name"), lensProp("last"))
)(author);
/*
Kereki
*/
```

Here, we created two individual lenses for `name` and `last`, and we composed them with the very same `compose()` function that we developed back in *Chapter 8*, *Connecting Functions*. Using this composite lens, we focused on the author's last name without any problem, so everything worked as expected.

Wrong direction?

It seems to go against logic that lenses should be composed from left to right; this appears to be backward. This is something that troubles developers, and if you google for an explanation, you'll find many. To answer this question on your own, I suggest spelling out how `compose()` works in full – two functions will be enough – and then substitute the definitions of lenses; you'll see why and how everything works out.

Now that we've looked at lenses, we can move on and look at **prisms**, another optics tool.

Prisms

As we saw in the previous section, lenses are useful for working with product types. However, prisms are useful for working with *sum* types. But what are they? (We'll look at products and unions in more detail in the last chapter of the book.) Whereas a product type is always built out of the same options, such as an object from a class, a sum type will likely have different structures – extra or missing attributes, for example. When you use a lens, you assume that the object you'll be applying it to has a known structure with no variations, but what do you use if the object has different structures? The answer is prisms. Let's look at how they are used first; then, we'll examine their implementation.

Working with prisms

Working with prisms is similar to using lenses, except for what happens when an attribute is not present. Let's take a look at an example from the previous section:

```
const author = {
  user: "fkereki",
  name: {
    first: "Federico",
    middle: "",
    last: "Kereki",
  },
  books: [
    { name: "Google Web Toolkit", year: 2010 },
    { name: "Functional Programming", year: 2017 },
    { name: "Javascript Cookbook", year: 2018 },
  ],
};
```

If we wanted to access the `user` attribute using prisms, we would write something like the following (and don't worry about the details now):

```
const pUser = prismProp("user");
console.log(preview(pUser, author).toString());
/*
fkereki
*/
```

Here, we define a prism using a `prismProp()` function, which parallels our previous `lensProp()`. Then, we use the prism with the `preview()` function, which is analogous to `get()` with lenses, and the result is the same as if we had used lenses – no surprises there. What would have happened if we had asked for a non-existing pseudonym attribute? Let's see:

```
const pPseudonym = prismProp("pseudonym");

console.log(preview(pPseudonym, author).toString());
/*
undefined
*/
```

So far, we may not see any differences, but let's see what happens if we try to compose lenses or prisms with several missing attributes. Say you wanted to access a (missing!) `pseudonym.usedSince` attribute with lenses, without taking precautions and checking that the attributes exist. Here, you would get the following output:

```
const lPseudonym = lensProp("pseudonym");
const lUsedSince = lensProp("usedSince");

console.log(
  "PSEUDONYM, USED SINCE",
  view(compose(lPseudonym, lUsedSince))(author)
);
/*
TypeError: Cannot read property 'usedSince' of undefined
.
. many more error lines, snipped out
.
*/
```

On the other hand, since prisms already take missing values into account, this would cause no problems, and we'd get an `undefined` result; that's why `preview()` is sometimes called `getOptional()`:

```
const pUsedSince = prismProp("usedSince");
console.log(
  preview(compose(pPseudonym, pUsedSince))(
    author
  ).toString()
);
/*
undefined
*/
```

What happens if we want to set a value? The analogous function to `set()` is `review()`; let's look at how it would work. The idea is that whatever attribute we specify will be set if, and only if, the attribute already exists. So, if we attempt to change the `user.name` attribute, this will work:

```
const fullAuthor2 = review(
  compose(prismProp("name"), prismProp("first")),
  "FREDERICK",
  author
);
```

However, if we try to modify the (non-existent) `pseudonym` attribute, the original, unchanged object will be returned:

```
const fullAuthor3 = review(pPseudonym, "NEW ALIAS", author);

// returns author, unchanged
```

So, using prisms takes care of all possible missing or optional fields. How do we implement this new optics type? New names are used (`preview()` and `review()` instead of `get()` and `set()`), but that difference is minor. Let's take a look.

Implementing prisms

How do we implement prisms? We will take our cue from our lens implementation and make a few changes. When getting an attribute, we must check whether the object we are processing is not `null` or `undefined` and whether the attribute we want is in the object. We can make do with small changes to our original `getField()` function:

```
// prisms.ts

const getFieldP =
  <O extends OBJ>(attr: string) =>
  (obj: O) =>
    obj && attr in obj ? obj[attr] : undefined;
```

Here, we're checking for the existence of the object and the attribute – if everything's okay, we return `obj[attr]`; otherwise, we return `undefined`. The changes for `setField()` are very similar:

```
// continued...

const setFieldP =
  <O extends OBJ>(attr: string) =>
  (value: any) =>
  (obj: O): O =>
    obj && attr in obj
      ? { ...obj, [attr]: value }
      : { ...obj };
```

If the object and the attribute both exist, we return a new object by changing the attribute's value; otherwise, we return a copy of the object. That's all there is to it! Defining the other functions is directly based on `lens()`, `lensProp()`, and so on, so we'll skip that.

Now that we've learned how to access objects in functional ways, let's analyze persistent data structures that can be modified very efficiently without the need for a full copy of the original object.

Creating persistent data structures

If you want to change something in a data structure and you just go and change it, your code will be full of side effects. On the other hand, copying complete structures every time is a waste of time and space. There's a middle ground to this that has to do with persistent data structures, which, if handled correctly, let you apply changes while creating new structures efficiently.

Given that there are many possible data structures you could work with, let's just take a look at a few examples:

- Working with lists, one of the simplest data structures
- Working with objects, a very common necessity in JavaScript programs
- Dealing with arrays, which will prove to be harder to work with

Let's get started!

Working with lists

Let's consider a simple procedure – suppose you have a list and want to add a new element to it. How would you do this? Here, we can assume that each node is a `NodeList` object:

```
// lists.ts

class ListNode<T> {
  value: T;
  next: ListNode<T> | null;

  constructor(value: any, next = null) {
    this.value = value;
    this.next = next;
  }
}
```

A possible list would be as shown in the following figure – a `list` variable would point to the first element. Look at the following diagram; can you tell what is missing in the list, and where?

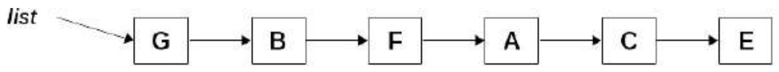


Figure 10.1 – The initial list

If you wanted to add D between B and F (the sample list represents a concept that musicians will understand, the *Circle of Thirds*, but with the D note missing), the simplest solution would be to add a new node and change an existing one. This would result in the following:

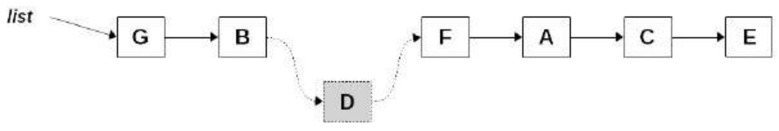


Figure 10.2 – The list now has a new element – we had to modify an existing one to perform the addition

However, working in this way is obviously non-functional, and we are clearly modifying data. There is a different way of working – creating a persistent data structure in which all the alterations (insertions, deletions, and modifications) are done separately, being careful not to modify existing data. On the other hand, if some parts of the structure can be reused, this is done to gain performance. Doing a persistent update would return a new list, with some nodes that are duplicates of some previous ones but no changes whatsoever to the original list. This can be seen in the following diagram:

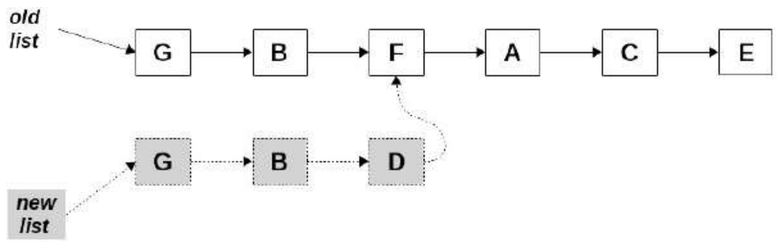


Figure 10.3 – The dotted elements show the newly returned list, which shares some elements with the old one

Updating a structure this way requires duplicating some elements to avoid modifying the original structure, but part of the list is shared.

Of course, we will also deal with updates or deletions. Starting again with the list shown in the following diagram, if we wanted to update its fourth element, the solution would imply creating a new subset of the list, up to and including the fourth element, while keeping the rest unchanged:

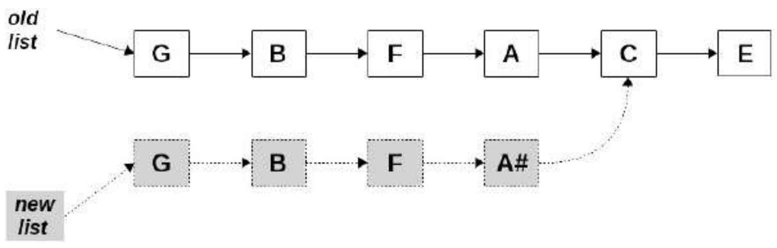


Figure 10.4 – Our list, with a changed element

Removing an element would also be similar. Let's do away with the third element, F, in the original list, as follows:

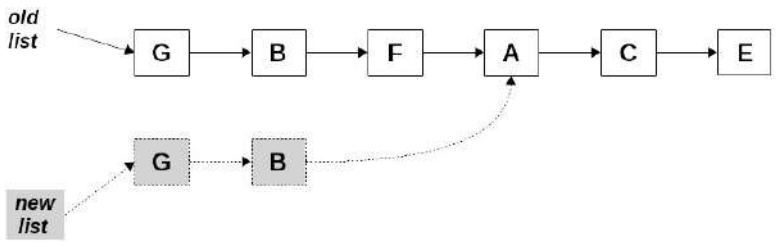


Figure 10.5 — The original list, after removing the third element in a persistent way

Working with lists or other structures can always be solved to provide data persistence. For now, focus on what will probably be the most important kind of work for us – dealing with simple JavaScript objects. After all, all data structures are JavaScript objects, so if we can work with objects, we can work with other structures.

Updating objects

This method can also be applied to more common requirements, such as modifying an object. This is a very good idea for, say, Redux users – a reducer can be programmed to receive the old state as a parameter and produce an updated version with the minimum needed changes, without altering the original state in any way.

Imagine you had the following object:

```
myObj = {
    a: ...,
    b: ...,
    c: ...,
    d: {
            e: ...,
            f: ...,
            g: {
                h: ...,
                i: ...
            }
        }
    };
```

Let's assume you wanted to modify the value of the `myObj.d.f` attribute but in a persistent way. Instead of copying the entire object (with the `deepCopy()` function we wrote earlier), we could create a new object, with several attributes in common with the previous object but new ones for the modified ones. This can be seen in the following diagram:

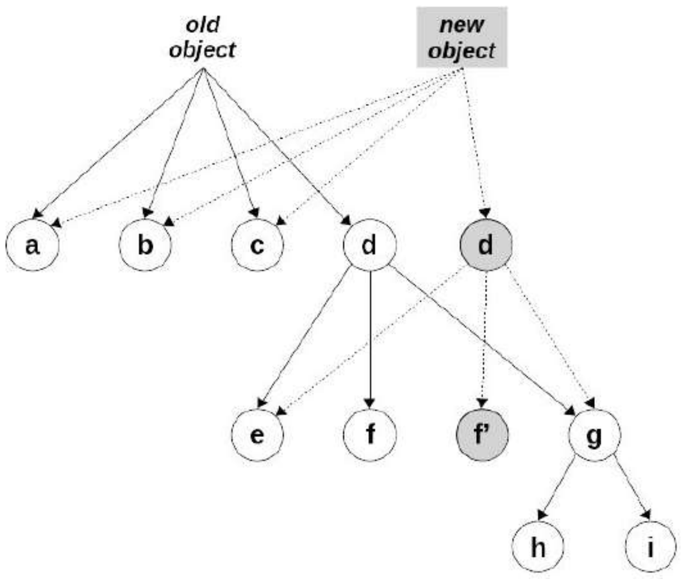


Figure 10.6 – A persistent way of editing an object – that is, by sharing some attributes and creating others

The old and new objects share most of the attributes, but there are new `d` and `f` attributes, so you managed to minimize the changes when creating the new object.

If you want to do this by hand, you would have to write, in a very cumbersome way, something like the following. Most attributes are taken from the original object, but `d` and `d.f` are new:

```
newObj = {
  a: myObj.a,
  b: myObj.b,
  c: myObj.c,
  d: {
    e: myObj.d.e,
    f: the new value,
    g: myObj.d.g,
  },
};
```

We saw some similar code earlier in this chapter when we decided to work on a cloning function. Here, let's go for a different type of solution. In fact, this kind of update can be automated:

```
// objects.ts

const setIn = <O extends OBJ>(
  arr: (string | number)[],
  value: any,
  obj: O
): O => {
  const newObj = Number.isInteger(arr[0]) ? [] : {};

  Object.keys(obj).forEach((k) => {
    (newObj as any)[k] = k !== arr[0] ? obj[k] : null;
  });

  (newObj as any)[arr[0]] =
    arr.length > 1
      ? setIn(arr.slice(1), value, obj[arr[0]])
      : value;

  return newObj as O;
};
```

The logic is recursive, but not too complex. First, we figure out, at the current level, what kind of object we need – an array or an object. Then, we copy all the attributes from the original object to the new one, except the property we are changing. Finally, we set that property to the given value (if we have finished with the path of property names), or we use recursion to go deeper with the copy.

Ordering parameters

Note the order of the parameters – first, the path, then the value, and finally, the object. We are applying the concept of putting the most stable parameters first and the most variable last. If you curry this function, you can apply the same path to several different values and objects, and if you fix the path and the value, you can still use the function with different objects.

Let's give this logic a try. We'll start with a nonsensical object but with several levels, and even an array of objects for variety:

```
const myObj1 = {
  a: 111,
  b: 222,
  c: 333,
  d: {
    e: 444,
    f: 555,
    g: {
      h: 666,
      i: 777,
    },
    j: [{ k: 100 }, { k: 200 }, { k: 300 }],
  },
};
```

We can test this by changing `myObj.d.f` to a new value:

```
let myObj2 = setIn(["d", "f"], 88888, myObj1);

/*
{
  a: 111,
  b: 222,
  c: 333,
  d: {
    e: 444,
    f: 88888,
    g: { h: 666, i: 777 },
    j: [{ k: 100 }, { k: 200 }, { k: 300 }],
  }
}
*/

console.log(myObj1.d === myObj2.d);      // false
console.log(myObj1.d.f === myObj2.d.f); // false
console.log(myObj1.d.g === myObj2.d.g); // true
```

The logs at the bottom verify that the algorithm is working correctly – `myObj2.d` is a new object, but `myObj2.d.g` is reusing the value from `myObj1`.

Updating the array in the second object lets us test how the logic works in those cases:

```
const myObj3 = setIn(["d", "j", 1, "k"], 99999, myObj2);

/*
{
  a: 111,
  b: 222,
  c: 333,
  d: {
    e: 444,
    f: 88888,
    g: { h: 666, i: 777 },
    j: [{ k: 100 }, { k: 99999 }, { k: 300 }],
  }
}
*/

console.log(myObj1.d.j === myObj3.d.j);       // false
console.log(myObj1.d.j[0] === myObj3.d.j[0]); // true
console.log(myObj1.d.j[1] === myObj3.d.j[1]); // false
console.log(myObj1.d.j[2] === myObj3.d.j[2]); // true
```

We can compare the elements in the `myObj1.d.j` array with the ones in the newly created object. You will see that the array is a new one, but two of the elements (the ones that weren't updated) are still the same objects that were in `myObj1`.

This obviously isn't enough to get by. Our logic can update an existing field or even add it if it wasn't there, but you'd also need to eliminate an old attribute. Libraries usually provide many more functions, but let's work on the deletion of an attribute for now so that we can look at some of the other important structural changes we can make to an object:

```
// continued...

const deleteIn = <O extends OBJ>(
  arr: (string | number)[],
  obj: O
): O => {
  const newObj = Number.isInteger(arr[0]) ? [] : {};

  Object.keys(obj).forEach((k) => {
    if (k !== arr[0]) {
      (newObj as any)[k] = obj[k];
    }
  });

  if (arr.length > 1) {
    (newObj as any)[arr[0]] = deleteIn(
      arr.slice(1),
      obj[arr[0]]
    );
  }

  return newObj as O;
};
```

The logic here is similar to that of `setIn()`. The difference is that we don't always copy all the attributes from the original object to the new one; we only do that if we haven't arrived at the end of the array of path properties. Continuing with the series of tests after the updates, we get the following:

```
const myObj4 = deleteIn(["d", "g"], myObj3);
const myObj5 = deleteIn(["d", "j"], myObj4);

console.log(myObj5);
// { a: 111, b: 222, c: 333, d: { e: 444, f: 88888 } }
```

With this pair of functions, we can manage to work with persistent objects by making changes, additions, and deletions in an efficient way that won't create new objects needlessly.

A tip

The most well-known library for working with immutable objects is the appropriately named `immutable.js`, which can be found at `immutable-js.com/`. The only weak point about it is its notoriously obscure documentation. However, there's an easy solution – check out *The Missing Immutable.js Manual* with all the examples you'll ever need at `untangled.io/the-missing-immutable-js-manual/`, and you won't have any trouble!

A final caveat

Working with persistent data structures requires some cloning, but how would you implement a persistent array? If you think about this, you'll realize that, in that case, there would be no way out apart from cloning the whole array after each operation. This would mean that an operation such as updating an element in an array, which took a constant time, would now take a length of time proportional to the size of the array.

Complexity concerns

In algorithm complexity terms, updates went from being O(1) operations to O(n) ones. Similarly, access to an element may become an O($log\ n$) operation, and similar slowdowns might be observed for other operations, such as mapping and reducing.

How do we avoid this? There's no easy solution. For example, you may find that an array is internally represented as a binary search tree (or even more complex data structures) and that the persistence library provides the necessary interface so that you'll still be able to use it as an array, not noticing the internal difference.

When using this kind of library, the advantages of having immutable updates without cloning may be partially offset by some operations that may become slower. If this becomes a bottleneck in your application, you might have to go so far as changing the way you implement immutability or even work out how to change your basic data structures to avoid the time loss, or at least minimize it.

Summary

In this chapter, we looked at two different approaches (used by commonly available immutability libraries) to avoiding side effects by working with immutable objects and data structures – one based on using JavaScript's object freezing, plus some special logic for cloning, and the other based on applying the concept of persistent data structures with methods that allow all kinds of updates, without changing the original or requiring full cloning.

In *Chapter 11*, *Implementing Design Patterns*, we will focus on a question often asked by object-oriented programmers – how are design patterns used in FP? Are they required, available, or usable? Are they still practiced but with a new focus on functions rather than on objects? We'll answer these questions with several examples, showing where and how they are equivalent or how they differ from the usual OOP practices.

Questions

10.1 **Not just date problems**: We saw that our `jsonCopy()` function has problems with dates, but that's not all. What happens if we try to copy objects that include maps? Sets? Regular expressions? Functions?

10.2 **The mote in jsonCopy's eye…**: The previous question pointed out some problems of `jsonCopy()`; how does `deepCopy()` fare with the same kind of objects? Can it be enhanced?

10.3 **Going in circles**: Objects may have circular references that point to themselves, and `JSON.stringify()` will protest if dealing with such. How could you fix our `deepCopy()` function to avoid that problem? We did deal with that issue in the `deepFreeze()` function, but that solution cannot be used here; something different is required.

10.4 **Freezing by proxying**: In the *Chaining and fluent interfaces* section of *Chapter 8*, *Connecting Functions*, we used a proxy to get operations to provide automatic chaining. By using a proxy for setting and deleting operations, you can do your own freezing (if, instead of setting an object's property, you'd rather throw an exception). Implement a `freezeByProxy(obj)` function that will apply this idea to forbid all kinds of updates (adding, modifying, or deleting properties) for an object. Remember to work recursively if an object has other objects as properties!

10.5 **Inserting into a list, persistently**: In the *Working with lists* section, we described how an algorithm could add a new node to a list, but in a persistent way, by creating a new list. Implement an `insertAfter(list, newKey, oldKey)` function that will create a new list, but add a new node with `newKey` just after the node with `oldKey`. Here, you'll need to assume that the nodes in the list were created by the following logic:

```
type MUSICAL_KEY = string;

class Node {
  key: MUSICAL_KEY;
  next: Node | null;

  constructor(key: MUSICAL_KEY, next: Node | null) {
    this.key = key;
    this.next = next;
  }
}

const c3 =
  new Node("G",
    new Node("B",
      new Node("F",
        new Node("A",
          new Node("C",
            new Node("E", null)
          )
        )
      )
    )
  );
```

10.6 **Composing many lenses**: Write a `composeLenses()` function that will allow you to compose as many simple lenses as you want, instead of only two, as in `composeTwoLenses()`, along the same lines as what we did in *Chapter 8, Connecting Functions*, when we moved from `composeTwo()` to a generic `compose()` function.

10.7 **Lenses by path**: In this chapter, we created lenses using `getField()` and `setField()`. Then, we used composition to access deeper attributes. Can you create a lens by giving a path, allowing shorter code?

10.8 **Accessing virtual attributes**: By using lenses, you can view (and even set) attributes that don't actually exist in an object. Here are some tips to let you develop that. First, can you write a getter that will access an object such as `author` and return the author's full name in LAST NAME, FIRST NAME format? Second, can you write a setter that, given a full name, will split it in half and set its first and last names? With those two functions, you could write the following:

```
const fullNameLens = lens(
...your getter...,
...your setter...
);

console.log(view(fullNameLens, author));
/*
Kereki, Federico
*/
```

```
console.log(set(fullNameLens, "Doe, John", author));
/*
{
  user: 'fkereki',
  name: { first: ' John', middle: '', last: 'Doe' },
…
}
*/
```

10.9 **Lenses for arrays?** What would happen if you created a lens like in the following code and applied it to an array? If there's a problem, could you fix it?

```
const getArray = curry((ind, arr) => arr[ind]);

const setArray = curry((ind, value, arr) => {
  arr[ind] = value;
  return arr;
});

const lensArray = (ind) =>
  lens(getArray(ind), setArray(ind));
```

10.10 **Lenses into maps**: Write a `lensMap()` function to create a lens you can use to access and modify maps. You may want to look at the following for more information about cloning maps: `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Map`. Your function should be declared as follows. You'll have to write a couple of auxiliary functions as well:

```
const lensMap = key => lens(getMap(key), setMap(key));
```

11
Implementing Design Patterns – The Functional Way

In *Chapter 10*, *Ensuring Purity*, we saw several functional techniques to solve different problems. However, programmers used to employing OOP may find that we have missed some well-known formulas and solutions often used in imperative coding. Since design patterns are well known, and programmers will likely already be aware of how they are applied in other languages, it's important to look at how a functional implementation would be done.

In this chapter, we shall consider the solutions provided by **design patterns** that are common in OOP, to see their equivalent in FP. This will help you transition from OOP to a more functional approach and learn more about FP's power and methods, by seeing alternative solutions to problems.

In particular, we will study the following topics:

- The concept of *design patterns* and what they apply to
- A few OOP standard patterns and what alternatives we have in FP if we need one
- The *Observer* pattern, which leads to *reactive programming*, a declarative way of dealing with events
- FP design patterns, not related to the OOP ones

In this chapter, we won't be worrying much about typing and TypeScript because we'll want to focus on the patterns, minimizing and abstracting everything else.

Understanding design patterns

One of the most relevant books in software engineering is *Design Patterns: Elements of Reusable Object-Oriented Software* (1994), written by the **Gang of Four** (**GoF**) – Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides. This book presented about two dozen OOP patterns and has been recognized as highly important in computer science.

Patterns are actually a concept in architectural design, originally defined by an architect, Christopher Alexander. Still, in software terms, a *design pattern* is a generally applicable, reusable solution to a commonly-seen problem in software design. Rather than a specific finished and coded design, it's a description of a solution (the word *template* is also used) that can solve a given problem that appears in many contexts. Given their advantages, design patterns are best practices that can be used by developers working with different kinds of systems, programming languages, and environments.

The GoF book obviously focused on OOP, and some patterns within cannot be recommended for or applied in FP. Other patterns are unnecessary or irrelevant because functional languages already provide standard solutions to the corresponding object-oriented problems. Even given this difficulty, since most programmers have been exposed to OOP design patterns and usually try to apply them even in other contexts such as FP, it makes sense to consider the original problems and then take a look at how a new solution can be produced. The standard object-based solutions may not apply, but the problems can still stand, so seeing how to solve them is still valid.

Patterns are often described in terms of four essential, basic elements:

- A simple, short *name,* used to describe the problem, its solutions, and its consequences. The name helps when talking with colleagues, explaining a design decision, or describing a specific implementation.
- The *context* to which the pattern applies – specific situations that require a solution, possibly with additional conditions that must be met.
- A *solution* that lists the elements (classes, objects, functions, relationships, and so on) that you'll need to solve the given situation.
- The *consequences* (results and trade-offs) if you apply the pattern. You may derive some gains from the solution, but it may also imply some losses.

In this chapter, we will assume that you are already aware of the design patterns we will describe and use, so we will only provide a few details about them. Rather, we will focus on how FP either makes a problem irrelevant (because there is an obvious way of applying functional techniques to solve it) or solves it in some fashion.

Also, we won't be going over all of the GoF patterns; we'll just focus on the ones that are the most interesting, that is, those that bring out more differences when FP is applied compared to when OOP is applied.

Design pattern categories

According to their focus, design patterns are usually grouped into several distinct categories. The first three in the following list are the ones that appeared in the original GoF book, but more categories have since been added. They are as follows:

- **Behavioral design patterns** have to do with interactions and communications between objects. Rather than focusing on how objects are created or built, the key consideration is how to connect them so that they can cooperate when performing a complex task, preferably in a way that provides well-known advantages, such as diminished coupling or enhanced cohesiveness.

- **Creational design patterns** deal with ways to create objects in a manner suitable for the current problem. With them, you can decide between several alternative objects, so the program can work differently, depending on parameters that may be known at compilation time or runtime.
- **Structural design patterns** have to do with the composition of objects, forming larger structures from many individual parts and implementing relationships between objects. Some of the patterns imply inheritance or implementation of interfaces, whereas others use different mechanisms, all geared toward being able to dynamically change the way objects are composed at runtime.
- **Concurrency patterns** deal with multithreaded programming. Although FP is generally quite appropriate for this (given, for example, the lack of assignments and side effects), since we are working with JavaScript, these patterns are not very relevant to us.
- **Architectural patterns** are more high-level oriented, with a broader scope than the previous patterns we've listed, and provide general solutions to software architecture problems. As is, we aren't considering such problems in this book, so we won't deal with these either.

The categories are not really fixed or set in stone. Fifteen years after the original GoF book, three of its authors (see the *Design Patterns 15 Years Later: An Interview with Erich Gamma, Richard Helm, and Ralph Johnson* article at `www.informit.com/articles/article.aspx?p=1404056`) suggested a new list of categories – *Core*, *Creational* (similar to the original category, but adding the *Dependency Injection* pattern, which we'll study later on), *Peripheral*, and *Other*.

Old good practices

Coupling and cohesiveness are terms that were in use even before OOP came into vogue; they date back to the late 1960s when the *Structured Design* book by Larry Constantine came out. Coupling measures the interdependence between any two modules, and cohesiveness has to do with the degree to which all module components really belong together. Low coupling and high cohesiveness are worthy goals for software design because they imply that related things are nearby and unrelated ones are separate.

Following along these lines, you could also classify design patterns as *object patterns* (which concern the dynamic relationships between objects) and *class patterns* that deal with the relationships between classes and subclasses (which are defined statically at compile time). We won't be worrying much about this classification because our point of view has more to do with behaviors and functions, rather than classes and objects.

As mentioned earlier, we can now readily observe that these categories are heavily oriented toward OOP, and the first three directly mention objects. However, without the loss of generality, we will look beyond the definitions, remember what problem we were trying to solve, and then look into analogous solutions with FP, which, if not 100% equivalent to the OOP ones, will in spirit solve the same problem in a parallel way. Let's move on and start by considering why we want to deal with patterns at all!

Do we need design patterns?

An interesting point of view says that design patterns are only needed to patch the shortcomings of programming languages. The rationale is that if you can solve a problem with a given programming language in a simple, direct, and straightforward way, then you may not need a design pattern at all. (For example, if your language doesn't provide recursion, you would have to implement it on your own; otherwise, you can just use it without further ado.) However, studying patterns lets you think about different ways of solving problems, so that's a point in their favor.

In any case, it's interesting for OOP developers to understand why FP helps solve some problems without needing further tools. In the next section, we shall consider several well-known design patterns and examine why we don't need them or how we can easily implement them. It's also a fact that we have already applied several patterns earlier in the text, so we'll also point out those examples.

We won't try, however, to express or convert all design patterns into FP terms. For example, the Singleton pattern basically requires a single, global object, which is sort of opposed to everything that functional programmers are used to. Given our approach to FP (remember *Sorta Functional Programming* (SFP), from the first chapter of this book?), we won't mind either, and if a Singleton is required, we may consider using it, even though FP doesn't have an appropriate equivalent. (And, as we'll see soon enough, every time you import from a module you're using a Singleton!)

Finally, it must be said that our point of view may affect what is considered a pattern and what isn't. What may be a pattern to some may be considered a trivial detail for others. We will find some such situations, given that FP lets us solve some particular problems in easy ways, and we have already seen examples of that in previous chapters.

Object-oriented design patterns

In this section, we'll review some of the GoF design patterns, check whether they are pertinent to FP, and study how to implement them. Of course, some design patterns don't get an FP solution. As an example, there's no equivalent for a Singleton, which implies the foreign concept of a globally accessed object. Additionally, while it's true that you may no longer need OOP-specific patterns, developers will still think in terms of those. Also, since we're not going fully functional, if some OOP pattern fits, why not use it even if it's not fully functional?

We will be considering the following:

- **Façade** and **Adapter** to provide new interfaces to other code
- **Decorator** (also known as **Wrapper**) to add new functionality to existing code
- **Strategy**, **Template**, and **Command** to let you fine-tune algorithms by passing functions as parameters
- **Dependency Injection** to help in decoupling components and simplify testing

- **Observer**, which leads to reactive programming, a declarative way of dealing with events
- Other patterns that do not so fully match the corresponding OOP ones

Let's begin our study by analyzing a couple of similar patterns that let you use your code in somewhat different ways.

Facade and Adapter

Out of these two patterns, let's start with the Facade or, more correctly, Façade. This is meant to solve the problem of providing a different interface to the methods of a class or to a library. The idea is to provide a new interface to a system that makes it easier to use. You might say that a Façade provides a better control panel to access certain functionalities, removing difficulties for the user.

S or K?

Façade or *facade*? The original word is an architectural term meaning *the front of a building* and comes from the French language. According to this source and the usual sound of the cedilla (ç) character, its pronunciation is a bit like *fuh-sahd*. The other spelling probably has to do with the lack of international characters in keyboards and poses the following problem – shouldn't you read it as *fah-Kade*? You may see this problem as the reverse of *Celtic*, which is pronounced as *Keltic*, changing the *s* sound to a *k* sound.

The main problem we want to solve is using external code more easily. (Of course, if it were your code, you could handle such problems directly; we must assume you cannot – or shouldn't – Insert space try to modify that other code. This would be the case when you use any library available over the web, for example.) The key is to implement a module that will provide an interface that better suits your needs. Your code will use your module and won't directly interact with the original code.

Suppose that you want to do Ajax calls, and your only possibility is using some hard library with a really complex interface. With modules, you might write something like the following, working with an imagined, hard-to-use Ajax library:

```
// simpleAjax.js

import * as hard from "hardajaxlibrary";
// import the other library that does Ajax calls
// but in a hard, difficult way, requiring complex code

const convertParamsToHardStyle = (params) => {
  // do some internal steps to convert params
  // into whatever the hard library may require
};

const makeStandardUrl = (url) => {
  // make sure the URL is in the standard
  // way for the hard library
};

const getUrl = (url, params, callback) => {
  const xhr = hard.createAnXmlHttpRequestObject();
  hard.initializeAjaxCall(xhr);
  const standardUrl = makeStandardUrl(url);
  hard.setUrl(xhr, standardUrl);
  const convertedParams = convertParamsToHardStyle(params);
  hard.setAdditionalParameters(params);
  hard.setCallback(callback);
  if (hard.everythingOk(xhr)) {
    hard.doAjaxCall(xhr);
  } else {
    throw new Error("ajax failure");
  }
};

const postUrl = (url, params, callback) => {
  // some similarly complex code
  // to do a POST using the hard library
};

export { getUrl, postUrl };
// the only methods that will be seen
```

Now, if you need to do `GET` or `POST`, instead of having to go through all of the complications of the provided complex Ajax library, you can use the new façade that provides a simpler way of working. Developers would write `import {getUrl, postUrl} from "simpleAjax"` and work more reasonably.

Nowadays, with `import`/`export` support in browsers, code will work as shown previously. Before that (or for backward-compatibility reasons) the implementation would require the usage of an **Immediately Invoked Function Expression** (**IIFE**), as covered in the *Immediate invocation* section of *Chapter 3*, *Starting Out with Functions*, using a **revealing module** pattern. The way to implement the pattern would then be as follows:

```
const simpleAjax = (function () {
  const hard = require("hardajaxlibrary");

  const convertParamsToHardStyle = (params) => {
    // ...
  };

  const makeStandardUrl = (url) => {
    // ...
  };

  const getUrl = (url, params, callback) => {
    // ...
  };

  const postUrl = (url, params, callback) => {
    // ...
  };

  return { getUrl, postUrl };
})();
```

The reason for the *revealing module* name should now be apparent. With the preceding code, because of the JavaScript scope rules, the only visible attributes of `simpleAjax` will be `simpleAjax.getUrl` and `simpleAjax.postUrl`; using an IIFE lets us implement the module (and, hence, the façade) safely, making implementation details private.

Of modules and singletons

In modern JavaScript, modules are a case of the Singleton pattern. (In math, a "singleton" is a set with just one element.) If you import a module in several different places of your code, all references will be to the same object, precisely as the Singleton pattern requires in object-oriented code.

Now, the Adapter pattern is similar, insofar as it is also meant to define a new interface. However, while Façade defines a new interface to old code, Adapter is used when you need to implement an old interface for new code, so it will match what you already have. If you are working with modules, it's clear that the same type of solution that worked for Façade will work here, so we don't have to study it in detail. Now, let's continue with a well-known pattern, which we saw earlier in this book!

Decorator or Wrapper

The Decorator pattern (also known as Wrapper) is useful when you want to add additional responsibilities or functionalities to an object in a dynamic way. Let's consider a simple example, which we will illustrate with some React code. (Don't worry if you do not know this framework; the example will be easy to understand. The idea of using React is because it can take advantage of this pattern very well. Also, we have already seen pure JavaScript higher-order function examples, so it's good to see something new.) Suppose we want to show some elements on the screen, and for debugging purposes, we want to show a thin red border around an object. How can you do it?

If you were using OOP, you would have to create a new subclass with the extended functionality. For this particular example, you might provide some attribute with the name of some CSS class that would provide the required style, but let's keep our focus on OOP; using CSS won't always solve this software design problem, so we want a more general solution. The new subclass would know how to show itself with a border, and you'd use this subclass whenever you wanted an object's border to be visible.

With our experience with higher-order functions, we can solve this differently by *wrapping* the original function within another one, which would provide extra functionality.

Note that we have already seen some examples of wrapping in the *Wrapping functions – keeping behavior* section of *Chapter 6, Producing Functions*. For example, in that section, we saw how to wrap functions to produce new versions that could log their input and output, provide timing information, or even memorize calls to avoid future delays. On this occasion, we are applying the concept to decorate a visual component, but the principle remains the same.

Let's define a simple React component, `ListOfNames`, that can display a heading and a list of people, and for the latter, we will use a `FullNameDisplay` component. The code for those elements would be as shown in the following fragment:

```
const FullNameDisplay = ({ first, last }) => {
  return (
    <div>
      First Name: <b>{first}</b>
      <br />
      Last Name: <b>{last}</b>
    </div>
  );
};
```

```
const ListOfNames = ({ people, heading }) => {
  return (
    <div>
      <h1>{heading}</h1>
      <ul>
        {people.map((v) => (
          <FullNameDisplay first={v.first} last={v.last} />
        ))}
      </ul>
    </div>
  );
};
```

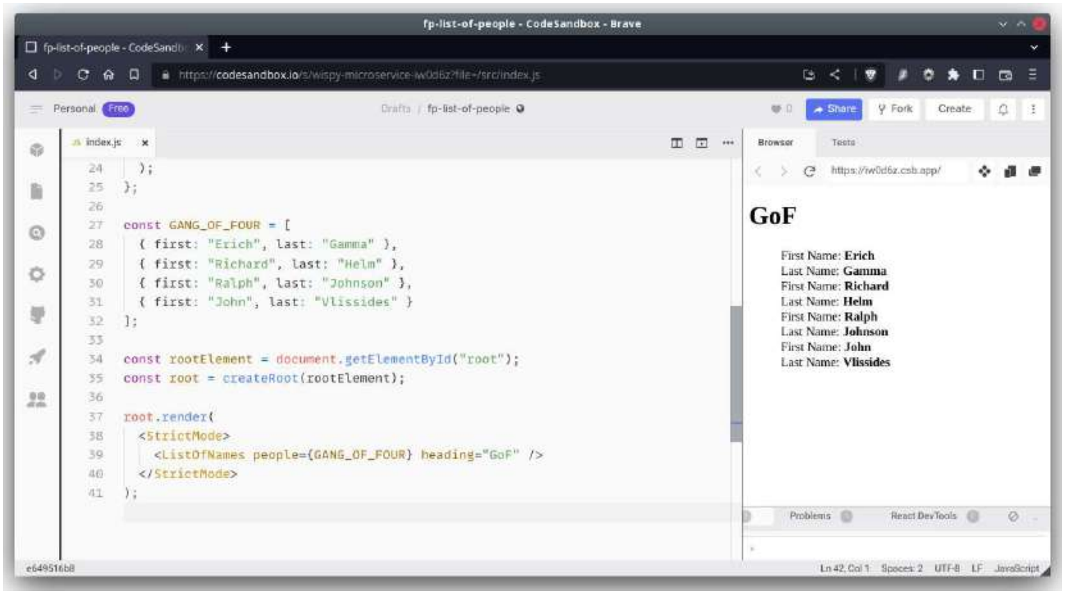
The `ListOfNames` component uses mapping to create a `FullNameDisplay` component to show data for each person. The logic for our application could then be the following:

```
import { createRoot } from "react-dom/client";

const GANG_OF_FOUR = [
  { first: "Erich", last: "Gamma" },
  { first: "Richard", last: "Helm" },
  { first: "Ralph", last: "Johnson" },
  { first: "John", last: "Vlissides" }
];

const FullNameDisplay = ...

const ListOfNames = ...

const rootElement = document.getElementById("root");
const root = createRoot(rootElement);
root.render(
  <ListOfNames people={GANG_OF_FOUR} heading="GoF" />
);
```

Do as I say...

In real life, you wouldn't put all the code for every component in the same single source code file – and you would probably have a few CSS files. However, for our example, having everything in one place and using inline styles is enough, so bear with me and keep in mind the saying *"Do as I say, not as I do."*

We can quickly test the result in the online React sandbox at `codesandbox.io/`; google `react online sandbox` if you want other options. The interface design isn't much to talk about (so please don't criticize my poor web page!) because we are interested in design patterns right now; refer to *Figure 11.1*, given as follows:



```
  );
};

const GANG_OF_FOUR = [
  { first: "Erich", last: "Gamma" },
  { first: "Richard", last: "Helm" },
  { first: "Ralph", last: "Johnson" },
  { first: "John", last: "Vlissides" }
];

const rootElement = document.getElementById("root");
const root = createRoot(rootElement);

root.render(
  <StrictMode>
    <ListOfNames people={GANG_OF_FOUR} heading="GoF" />
  </StrictMode>
);
```

```
GoF

First Name: Erich
Last Name: Gamma
First Name: Richard
Last Name: Helm
First Name: Ralph
Last Name: Johnson
First Name: John
Last Name: Vlissides
```

Figure 11.1 – The original version of our components shows a (not much to speak about) list of names

In React, inline components are written in JSX (inline HTML style) and compiled into objects, which are later transformed into HTML code to be displayed. Whenever the `render()` method is called, it returns a structure of objects. So, we will write a function that will take a component as a parameter and return a new JSX, a wrapped object. In our case, we'd like to wrap the original component within `<div>` with the required border:

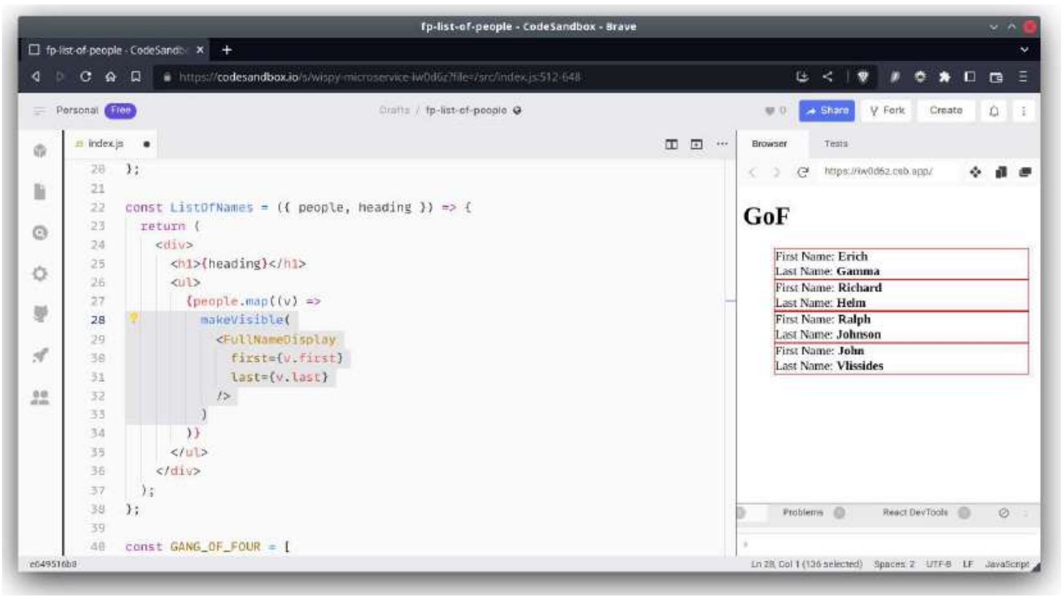
```
const makeVisible = (component) => {
  return (
    <div style={{ border: "1px solid red" }}>
      {component}
    </div>
  );
};
```

If you wish, you can make this function aware of whether it's executing in development mode or production; in the latter case, it would simply return the original component argument without any change, but let's not worry about that now.

We now have to change `ListOfNames` to use wrapped components; the new version would be as follows:

```
const ListOfNames = ({ people, heading }) => {
  return (
    <div>
      <h1>{heading}</h1>
      <ul>
        {people.map((v) =>
          makeVisible(<FullNameDisplay
            first={v.first}
            last={v.last} />)
        )}
      </ul>
    </div>
  );
};
```

The decorated version of the code works as expected: each of the `ListOfNames` components is now wrapped in another component that adds the desired border to them; refer to *Figure 11.2*, given as follows:



```
};

const ListOfNames = ({ people, heading }) => {
  return (
    <div>
      <h1>{heading}</h1>
      <ul>
        {people.map((v) =>
          makeVisible(
            <FullNameDisplay
              first={v.first}
              last={v.last}
            />
          )
        )}
      </ul>
    </div>
  );
};

const GANG_OF_FOUR = [
```

```
GoF

First Name: Erich
Last Name: Gamma
First Name: Richard
Last Name: Helm
First Name: Ralph
Last Name: Johnson
First Name: John
Last Name: Vlissides
```

Figure 11.2 – The decorated ListOfNames component is still nothing much to look at, but now it shows an added border

In earlier chapters, we saw how to decorate a function, wrapping it inside of another function, so it would perform extra code and add a few functionalities. Here, we saw how to apply the same solution style to provide a *higher-order component* (as it's called in React parlance), wrapped in an extra `<div>` to provide some visually distinctive details.

A Redux decorator

If you have used Redux and the `react-redux` package, you may note that the latter's `connect()` method is also a decorator in the same sense; it receives a component class, and returns a new component class, connected to the store, for usage in your forms. Refer to `github.com/reduxjs/react-redux` for more details.

Let's move to a different set of patterns that will let us change how functions perform.

Strategy, Template, and Command

The Strategy pattern applies whenever you want to have the ability to change a class, method, or function, possibly in a dynamic way, by changing the way it actually does whatever it's expected to do. For example, a GPS application might want to find a route between two places by applying different strategies if the person is on foot, rides a bicycle, or goes by car. In that case, the fastest or the shortest routes might be desired. The problem is the same, but different algorithms must be applied, depending on the given condition.

Does this sound familiar? If so, it is because we have already met a similar problem. When we wanted to sort a set of strings in different ways, in *Chapter 3*, *Starting Out with Functions*, we needed a way to specify how the ordering was to be applied or, equivalently, how to compare two given strings and determine which had to go first. Depending on the language, we had to sort applying different comparison methods.

Before trying an FP solution, let's consider more ways of implementing our routing function. You could make do by having a big enough piece of code, which would receive an argument declaring which algorithm to use, plus the starting and ending points. With these arguments, the function could do a switch or something similar to apply the correct path-finding logic. The code would be roughly equivalent to the following fragment:

```
function findRoute(byMeans, fromPoint, toPoint) {
  switch (byMeans) {
    case "foot":
    /*
    find the shortest road for a walking person
    */

    case "bicycle":
    /*
    find a route apt for a cyclist
    */

    case "car-fastest":
    /*
    find the fastest route for a car driver
    */

    case "car-shortest":
    /*
    find the shortest route for a car driver
    */

    default:
    /*
    plot a straight line, or throw an error,
    or whatever suits you
```

```
      */
    }
  }
```

This kind of solution is not desirable, and your function is the sum of many distinct other functions, which doesn't offer a high level of cohesion. If your language doesn't support lambda functions (as was the case with Java, for example, until Java 8 came out in 2014), the OOP solution for this requires defining classes that implement the different strategies you may want, creating an appropriate object, and passing it around.

With FP in JavaScript, implementing strategies is trivial; instead of using a variable such as `byMeans` to switch, you provide a route-finding function (`routeAlgorithm()` in the following code) that will implement the desired path logic:

```
function findRoute(routeAlgorithm, fromPoint, toPoint) {
  return routeAlgorithm(fromPoint, toPoint);
}
```

You would still have to implement all of the desired strategies (there's no way around that) and decide which function to pass to `findRoute()`, but now that function is independent of the routing logic, and if you wanted to add new routing algorithms, you wouldn't touch `findRoute()`.

If you consider the Template pattern, the difference is that Strategy allows you to use completely different ways of achieving an outcome, while Template provides an overarching algorithm (or template) in which some implementation details are left to methods to be specified. In the same way, you can provide functions to implement the Strategy pattern; you can also provide them for a Template pattern.

Finally, the Command pattern also benefits from the ability to be able to pass functions as arguments. This pattern is meant to be enabled to encapsulate a request as an object, so for different requests, you have differently parameterized objects. Given that we can pass functions as arguments to other functions, there's no need for the enclosing object.

We also saw a similar use of this pattern back in the *A React-Redux reducer* section of *Chapter 3, Starting Out with Functions*. There, we defined a table, each of whose entries was a callback that was called whenever needed. We could directly say that the Command pattern is just an **object-oriented** (OO) replacement for plain functions working as callbacks.

Let's now consider a related pattern, Dependency Injection, that will also let us change how a method or function works.

Dependency Injection

In basic terms, Dependency Injection is a pattern in which an object or function receives any other objects or functions that it needs to do its job, leading to less coupling and more flexibility. With this technique, a service can work in multiple environments or with different configurations, and changing it may be achieved without having to modify its code.

To make things clearer, let's consider a service, implemented in Node plus Express, that gets a request, interacts with other entities (maybe it queries a database, accesses some file buckets, posts a message to a message queue, calls some other services, etc.) and eventually builds a response to send back. What's wrong with this? A quick answer would be "*Nothing!*" because it works, and it's how many services are implemented. However, digging a bit further, we may decide the answer should be "*Everything*!" Why?

With any piece of code, there always are three primary concerns:

- *Is it understandable?* Our service's code may be hard to follow because it mixes business logic concerns with implementation details, concerning secondary matters such as how to query the database and access the buckets.
- *Is it maintainable?* If we wonder how simple it may be to change our service's code, the question is how many reasons for change there may be. A change in business logic is always a possibility; that's essential. However, other changes (using Redis instead of MySQL or adding records to a database table instead of sending messages to a queue) that aren't related to the service's business objectives would also require changes in code.
- *Is it testable?* We may or may not need to maintain the code (and, indeed, if any changes are needed, that would be in the future), but we have to test our code today. How would we go about it? Would it be easy?

The last item is the one we care about now. All the interactions with other entities are clearly impure functions, so we could set up our tests in three ways.

- We could work with separate, special environments. Each developer would need to have a complete environment (with databases, queues, servers, etc.) so code can run as in reality. To do a test, the developer should first set everything up in a known fashion and then check whether the database got modified correctly, if the right messages were sent, and so on. All this is possible but costly, hard to set up, and mainly slow – before each test, you have to reset everything, and after each test, you have to check everything.
- We could work with fully mocked external entities. Tools such as Jest or Jasmine allow us to mock entities, so our code, instead of dealing with actual databases, queues, services, and so on would (transparently) interact with mocks that mimic the needed behaviors. This is much more efficient (because no real environments are needed, no actual databases get updated, no messages are really sent, and so on), but simulating all the required behaviors is still a lot of work.
- We can make the service less impure first! We saw this approach back in *Chapter 4*, *Behaving Properly*, which allows us to easily write tests.

Let's now get to actual details and consider a possible service.

Implementing a service

Imagine we have an endpoint that responds to `GET /client/:id` requests by searching for the client in a database and posting a message to a queue after the search.

We'll code our service in terms of *ports* (interfaces) and *adapters* (interface implementations) that it will receive. In our case, ports will (abstractly) define how our service is meant to interact with other entities, and adapters will (concretely) implement the needed functionality. With this in mind, we will be able to provide different adapters, allowing flexibility for different environments. In a production environment, we'll provide adapters that work, access databases, post messages, and so on, but for testing, we'll be able to inject mock adapters with trivial "do nothing" fake implementations.

An architecture by any other name

This architectural style is naturally known as "Ports and Adapters," but it also goes by "Hexagonal Architecture" – a much catchier name! Don't try to figure out why the word "hexagonal" is used; it just refers to hexagons being used to represent services in diagrams, and nothing else!

Let's see how this would work. If our service needs to look for a client by its ID in a database, we must define a suitable interface, a "find client" port. We could define the following:

```
type FindClientPort = (
  id: number
) => Promise<ClientType | null>;
```

This definition says that our port will receive a numerical ID as an argument and return a promise that will either resolve to a `ClientType` object or `null`. (We cannot specify semantic aspects, but it sounds likely that the returned object will be the client, if found; `null` would represent a failed search.) We also require an actual implementation:

```
const findClientFromDBAdapter: FindClientPort = async (
  id: number
) => {
  // access the database, do the search, etc., and
  // return a promise to get the client from DB
};
```

Naming is important; the port definition does not say where the client will come from, but the adapter does. We could have different adapters that would look for clients in other places (a key store, a spreadsheet, or the filesystem), but they would all implement the same interface.

Of course, given our service definition, we'll also need a port and adapter for sending messages. How would we now write our service? The code would be as follows:

```
function getClientService(id: number,
  { findClient, sendMsg } =
  { findClient: findClientFromDBAdapter,
    sendMsg: sendMsgToMQAdapter }) {
  ...
}
```

What are we doing? Our service receives `id` and an optional object providing two adapters. If this object is omitted, our service will use default adapters that work with a database and a message queue. In our server, the code dealing with the `/client/:id` endpoint would use `getClientService(req.params.id)` and, thus, work with an actual database and a message queue. But how will we test our service? That's what we need to see now.

Testing a service

In the previous section, we saw how to call our service in production. However, for testing, we would do things differently, such as the following:

```
findClientMock = jest.fn().mockResolvedValue(...);
sendMsgMock = jest.fn().mockReturnValue(...);

result = await getClientService(22,
  { findClient: findClientMock,
    sendMsg: sendMsgMock });

expect(findClientMock).toHaveBeenCalledWith(22);
expect(sendMsgMock).toHaveBeenCalledWith(...);
expect(result).toMatchObject(...);
```

We would first define a couple of mock functions; `findClientMock` would simulate a search in the database, and `sendMsgMock` would return whatever a successful message-sending operation would return. We can now call our `getClientService()` with the mocks, and we would then verify that the (mock) adapters were used properly and that the service returns the correct answer.

Let's now move on to a classic pattern that implies a new term, *reactive programming*, which is being thrown around a lot these days.

Observers and reactive programming

The idea of the Observer pattern is to define a link between entities so that when one changes, all dependent entities are updated automatically. An *observable* can publish changes to its state, and its observer (which subscribed to the observable) will be notified of such changes.

No observables for now

There is a proposal for adding observables to JavaScript (see `github.com/tc39/proposal-observable`), but as of January 2023, it's still stuck at stage one, with no activity since late 2020. Hence, for the time being, using a library will still be mandatory.

There's an extension to this concept called **reactive programming**, which involves asynchronous streams of events (such as mouse clicks or keypresses) or data (from APIs or WebSockets), and different parts of the application subscribing to observe such streams by passing callbacks that will get called whenever something new appears.

We won't be implementing reactive programming on our own; instead, we'll use RxJS, a JavaScript implementation of Reactive Extensions (*ReactiveX*), initially developed by Microsoft. RxJS is widely used in the Angular framework and can also be used in other frontend frameworks, such as React or Vue, or the backend with Node.js. Learn more about RxJS at `rxjs-dev.firebaseapp.com` and `www.learnrxjs.io`.

The techniques we will be showing in these sections are, confusingly, called both **functional reactive programming** (**FRP**) and **reactive functional programming** (**RFP**); pick whichever you want! There is also a suggestion that FRP shouldn't be applied to discrete streams (so the name is wrong) but the expression is seen all over the web, which gives it some standing. But what makes this functional, and why should we be interested in it? The key is that we will be using similar methods to `map()`, `filter()`, and `reduce()` to process those streams and pick which events to process and how. Okay, this may be confusing now, so bear with me and let's see some concepts first, and after that, some examples of FRP – or whatever you want to call it! We will be seeing the following:

- Several basic concepts and terms you'll need to work with FRP
- Some of the many available operators you'll use
- A couple of examples – detecting multi-clicks and providing typeahead searches

Let's proceed to analyze each item, starting with the basic ideas you need to know.

Basic concepts and terms

Using FRP requires getting used to several new terms, so let's begin with a short glossary:

- **Observable**: This represents a stream of (present or future) values and can be connected to an observer. You can create observables from practically anything, but the most common case is from events. By convention, observable variable names end with `$`; see `angular.io/guide/rx-library#naming-conventions`.
- **Observer**: This is either a callback that is executed whenever the observable it's subscribed to produces a new value, or an object with three methods, `next()`, `error()`, and `complete()`, which will be called by the observable when a value is available, when there's an error, and when the stream is ended respectively.

- **Operators**: These are pure functions (similar to `map()`, `filter()`, and so on, from *Chapter 5*, *Programming Declaratively*) that let you apply transformations to a stream in a declarative way.
- **Pipe**: This is a way to define a pipeline of operators that will be applied to a stream. This is similar to the `pipeline()` function we developed in *Chapter 8*, *Connecting Functions*.
- **Subscription**: This is the connection to an observable. An observable doesn't do anything until you call the `subscribe()` method, providing an observer.

An interesting way of looking at observables is that they complete the lower row of this table – check it out. You will probably be quite familiar with the *Single* column, but maybe not with the *Multiple* one:

	Single	**Multiple**
Pull	`Function`	`Iterator`
Push	`Promise`	`Observable`

How do we interpret this table? The rows distinguish between pull (you call something) and push (you get called), and the columns represent how many values you get – one or many. With these descriptions, we can see the following:

- A `function` is called and returns a single value
- A `promise` calls your code (a callback in the `then()` method), also with a single value
- An `iterator` returns a new value each time it's called – at least until the sequence is over
- An `observable` calls your code (provided you `subscribe()` to the observable) for each value in the stream

Observables and promises can be compared a bit more:

- They are both mostly `async` in nature, and your callback will be called at an indefinite future time
- Promises cannot be canceled, but you can `unsubscribe()` from an observable
- Promises start executing the moment you create them; observables are lazy, and nothing happens until an observer does `subscribe()` to them

The real power of observables derives from the variety of operators you can use; let's see some of them.

Operators for observables

Basically, operators are just functions. Creation operators can be used to create observables out of many different sources, and pipeable operators can be applied to modify a stream, producing a new observable; we'll see many families of these, but for complete lists and descriptions, you should access `www.learnrxjs.io/learn-rxjs/operators` and `rxjs.dev/guide/operators`.

Also, we won't be covering how to install RxJS; see `rxjs.dev/guide/installation` for all the possibilities. In particular, in our examples, meant for a browser, we'll be installing RxJS from a CDN, which creates a global `rxjs` variable, similar to jQuery's `$` or Lodash's `_` variables.

Let's begin by creating observables, and then move on to transforming them. For creation, some of the several operators you can use are explained in the following table:

Operator	Usage
`Ajax`	Creates an observable for an Ajax request, for which we'll emit the response that is returned
`from`	Produces an observable out of an array, an iterable, or a promise
`fromEvent`	Turns events (for example, mouse clicks) into an observable sequence
`interval`	Emits values at periodic intervals
`of`	Generates a sequence out of a given set of values
`range`	Produces a sequence of values in a range
`timer`	After an initial delay, emits values periodically

To give an elementary example, the following three observables will all produce a sequence of values from 1 to 10, and we'll be seeing more practical examples a bit later in this chapter:

```
const obs1$ = from([1, 2, 3, 4, 5, 6, 7, 8, 9, 10]);
const obs2$ = of(1, 2, 3, 4, 5, 6, 7, 8, 9, 10);
const obs3$ = range(1, 10);
```

The available pipeable operators are way too many for this section, so we'll just go over some families and describe their basic idea, with one or two particular mentions. The following table lists the most common families, with their most often used operators:

Family	Description
Combination	These operators allow us to join information from several distinct observables, including the following: • `concat()` to put observables in a queue one after the other • `merge()` to create a single observable out of many • `pairWise()` to emit the previous value and the current one as an array • `startWith()` to inject a value in an observable

Family	Description
Conditional	These produce values depending on conditions and include the following: • `defaultIfEmpty()` emits a value if an observable doesn't emit anything before completing • `every()` emits true if all values satisfy a predicate and emits false otherwise • `iif()` subscribes to one of two observables, depending on a condition, such as the ternary `?` operator
Error handling	These (obviously!) apply to error conditions and include the following: • `catchError()` to gracefully process an error from an observable • `retry()` and `retryWhen()` to retry an observable sequence (most likely, one linked to HTTP requests)
Filtering	Probably the most important family, providing many operators to process sequences by selecting which elements will get processed or dismissed, by applying different types of conditions for your selection. Some of the more common ones include the following: • `debounce()` and `debounceTime()` to deal with values too close together in time • `distinctUntilChanged()` to only emit when the new value is different from the last • `filter()` to only emit values that satisfy a given predicate • `find()` to emit only the first value that satisfies a condition • `first()` and `last()` to pick only the first or last values of a sequence • `skip()` plus `skipUntil()` and `skipWhile()` to discard values • `take()` and `takeLast()` to pick a given number of values from the beginning or end of a sequence • `takeUntil()` and `takeWhile()` to pick values and more

Family	Description
Transforming	The other very commonly used family, which includes operators to transform the values in a sequence. Some of the many possibilities include these: • `buffer()` and `bufferTime()` to collect values and emit them as an array • `groupBy()` to group values together based on some property • `map()` to apply a given mapping function to every element in the sequence • `partition()` to split an observable into two, based on a given predicate • `pluck()` to pick only some attributes from each element • `reduce()` to reduce a sequence of values to a single one • `scan()` works like `reduce()` but emits all intermediate values • `toArray()` collects all values and emits them as a single array
Utilities	A sundry collection of operators with different functions, including the following: • `tap()` to perform a side effect, similar to what we saw in the *Tapping into a flow* section in *Chapter 8*, *Connecting Functions* • `delay()` to delay sequence values for some time • `finalize()` to call a function when an observable completes or produces an error • `repeat()` is just like `retry()` but for normal (that is, non-error) cases • `timeout()` to produce an error if no value is produced before a given duration

Wow, that's a lot of operators! We have excluded many, and you could even write your own, so be sure to look at the documentation. By the way, understanding operators is easier with marble diagrams; we won't be using them here, but read `reactivex.io/documentation/observable.html` for a basic explanation, and then check out `rxmarbles.com` for many interactive examples of operators and how they function.

Let's finish this section with a couple of examples of the possibility of application for your own coding.

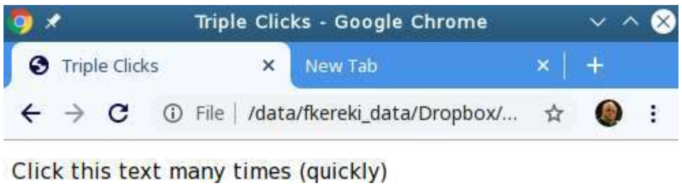
Detecting multi-clicks

Suppose you decided, for some reason or another, that users should be able to triple-click or four-click on something, and the number of clicks would somehow be meaningful and produce some kind of result. Browsers do very well detecting single- or double-clicks and letting you respond to them, but triple- (or more) clicks aren't available so easily.

However, we can make do with a bit of FRP. Let's start with a truly basic layout, including a text span that the user should click. The code is given here:

```
<html>
  <head>
    <title>Multiple click example</title>
    <script
      type="text/javascript"
      src="rxjs.umd.js"
    ></script>
  </head>
  <body>
    <span id="mySpan"
      >Click this text many times (quickly)</span
    >
    <script>
      // our code goes here...
    </script>
  </body>
</html>
```

This is as plain as can be; you just get a text on screen, urging you to multi-click it. See *Figure 11.3*:



Click this text many times (quickly)

Figure 11.3 – A very plain screen to test detecting triple-clicks

To detect these multi-clicks, we'll need some RxJS functions, so let's start with those:

```
const { fromEvent, pipe } = rxjs;
const { buffer, filter } = rxjs.operators;
```

We will use these functions soon enough. How do we detect triple- (or more) clicks? Let's go straight on to the code given here:

```
const spanClick$ = fromEvent(
  document.getElementById("mySpan"),
  "click"
);

spanClick$
  .pipe(
    buffer(spanClick$.pipe(debounceTime(250))),
    map((list) => list.length),
    filter((x) => x >= 3)
  )
  .subscribe((e) => {
    console.log(`${e} clicks at ${new Date()}`);
  });

/*
5 clicks at Fri Feb 03 2023 18:08:42 GMT-0300
3 clicks at Fri Feb 03 2023 18:08:45 GMT-0300
6 clicks at Fri Feb 03 2023 18:08:47 GMT-0300
4 clicks at Fri Feb 03 2023 18:08:51 GMT-0300
*/
```

The logic is simple:

1. We create an observable with `fromEvent()` to listen to mouse clicks on our span.
2. Now, a tricky point – we use `buffer()` to join together many events, which come from applying `debounceTime()` to the sequence of clicks, so all clicks that happen within an interval of 250 milliseconds will get grouped into a single array.
3. We then apply `map()` to transform each array of clicks into just its length – after all, we care about how many clicks there were, not their specific details.
4. We finish by filtering out values under `3`, so only longer sequences of clicks will be processed.
5. The subscription just logs the clicks, but in your application, it should do something more relevant.

If you wanted, you could detect multi-clicks by hand, writing your own code; see *Question 11.3* in the *Questions* section. Let's finish with a longer example and do some typeahead searches, invoking some external API.

Providing typeahead searches

Let's do another web example: typeahead searches. The usual setup is that there is some sort of textbox, the user types in it, and the web page queries an API to provide ways of completing the search. The important thing is when and how to do the search, and try to avoid unnecessary calls to the backend server whenever possible. A (totally basic) HTML page could be as follows (see *Figure 11.4* later in this section):

```
<html>
  <head>
    <title>Cities search</title>
    <script
      type="text/javascript"
      src="rxjs.umd.js"
    ></script>
  </head>
  <body>
    Find cities:
    <input type="text" id="myText" />
    <br />
    <h4>Some cities...</h4>
    <div id="myResults"></div>
    <script>
      // typeahead code goes here...
    </script>
  </body>
</html>
```

We now have a single textbox in which the user will type and an area below that in which we'll show whatever the API provides. We'll use the GeoDB Cities API (see `geodb-cities-api.wirefreethought.com`), which provides many search options, to search for cities starting with whatever the user has typed. To get it out of our way, let's look at the `getCitiesOrNull()` function, which will return a promise for search results (if something was typed in) or `null` (no cities, if nothing was typed in). The results of this promise will be used to fill the `myResults` division on the page. Let's see how this works out in code:

```
const URL = `http://` +
  `geodb-free-service.wirefreethought.com/v1/geo/cities`;

const getCitiesOrNull = (text) => {
  if (text) {
    const citySearchUrl =
      `${URL}?` +
      `hateoasMode=false&` +
      `sort=-population&` +
      `namePrefix=${encodeURIComponent(text)}`;
    return;
    fetch(citySearchUrl);
  } else {
    return Promise.resolve(null);
  }
};
```

The code is simple – if some text was provided, we generate the URL for the cities' search and use `fetch()` to get the API data. With this done, let's see how to generate the needed observable. We will need some RxJS functions, so first, let's have some definitions:

```
const { fromEvent, pipe } = rxjs;
const {
  debounceTime,
  distinctUntilChanged,
  filter,
  map,
  reduce,
  switchMap,
} = rxjs.operators;
```

We will be using all of these functions later. Now, we can write the code to do the typeahead:

```
const textInput$ = fromEvent(
  document.getElementById("myText"),
  "input"
).pipe(
  map((e) => e.target.value),
  debounceTime(200),
  filter((w) => w.length === 0 || w.length > 3),
  distinctUntilChanged(),
  switchMap((w) => getCitiesOrNull(w))
);
```

This requires going step by step:

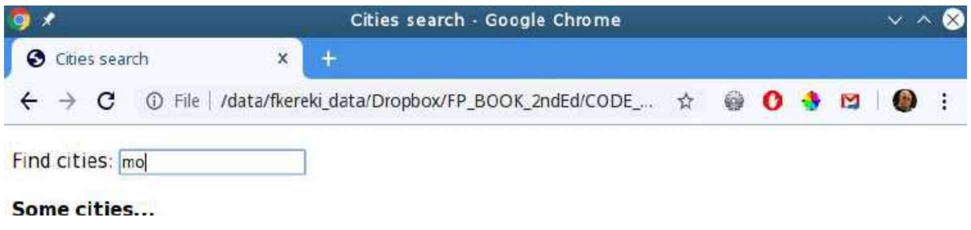
1. We use the `fromEvent()` constructor to observe input events (every time the user types something) from the `myText` input field.
2. We use `map()` to get the event's target value, the complete text of the input field.
3. We use `debounceTime(200)` so that the observable won't emit until the user has been 0.2 seconds (200 milliseconds) without typing – what's the use of calling the API if the user isn't done with their query?
4. We then use `filter()` to discard the input if it was only one, two, or three characters long because that's not long enough for our search. We accept empty strings (so we'll empty the results area) and strings four or more characters long.
5. Then, we use `distinctUntilChanged()`, so if the search string is the same as before (the user possibly added a character but quickly backspaced, deleting it), nothing will be emitted.
6. Finally, we change `switchMap()` to cancel the previous subscription to the observable and create a new one using `getCitiesOrNull()`.

How do we use this? We subscribe to the observable, and when we get results, we use them to display values. A possible sample code follows:

```
textInput$.subscribe(async (fetchResult) => {
  domElem = document.getElementById("myResults");

  if (fetchResult !== null) {
    result = await fetchResult.json();
    domElem.innerHTML = result.data
      .map((x) => `${x.city}, ${x.region}, ${x.country}`)
      .join("<br />");
  } else {
    domElem.innerHTML = "";
  }
});
```

An important point – the promise is resolved, and the final value of the sequence is, hence, whatever the promise produced. If the result isn't `null`, we get an array of cities, and we use `map()` and `join()` to produce the (very basic!) HTML output; otherwise, we empty the results area.

Let's try it out. If you start typing, nothing will happen until you reach at least four characters and pause a bit (see *Figure 11.4*, as follows):

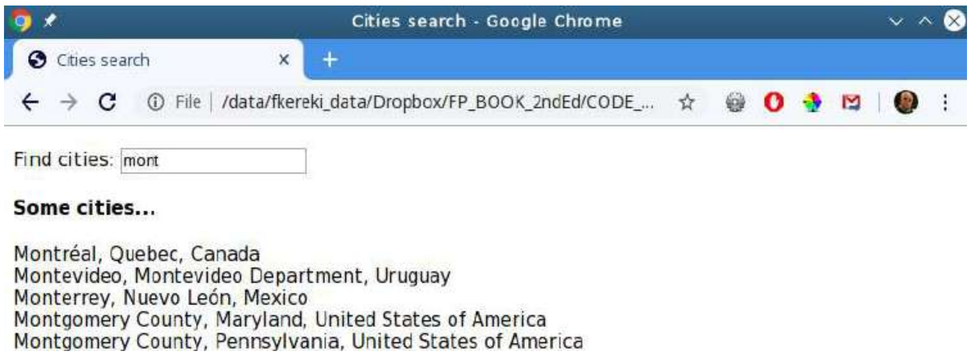

Cities search - Google Chrome
Cities search
File | /data/fkereki_data/Dropbox/FP_BOOK_2ndEd/CODE_...

Find cities: mo

Some cities...

Figure 11.4 – Our search for cities doesn't trigger for less than four characters

When you reach four characters and pause for a moment, the observable will emit an event, and we'll do a first search – in this case, for cities with names starting with `MONT` (see *Figure 11.5*):


Cities search - Google Chrome
Cities search
File | /data/fkereki_data/Dropbox/FP_BOOK_2ndEd/CODE_...

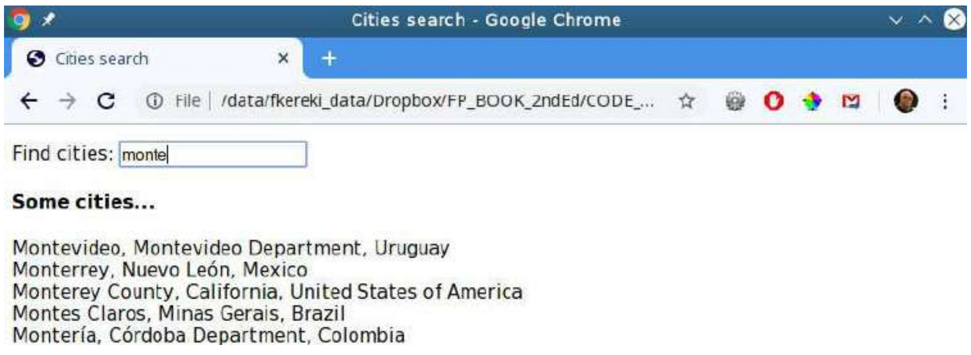
Find cities: mont

Some cities...

Montréal, Quebec, Canada
Montevideo, Montevideo Department, Uruguay
Monterrey, Nuevo León, Mexico
Montgomery County, Maryland, United States of America
Montgomery County, Pennsylvania, United States of America

Figure 11.5 – After reaching four characters, searches will be fired

Finally, as you add more characters, new API calls will be made, refining the search (see *Figure 11.6*).


Cities search - Google Chrome
Cities search
File | /data/fkereki_data/Dropbox/FP_BOOK_2ndEd/CODE_...

Find cities: monte

Some cities...

Montevideo, Montevideo Department, Uruguay
Monterrey, Nuevo León, Mexico
Monterey County, California, United States of America
Montes Claros, Minas Gerais, Brazil
Montería, Córdoba Department, Colombia

Figure 11.6 – Further characters are used to refine the search

What can we learn from these examples? Using observables for events lets us achieve a good separation of concerns regarding event production and event consumption, and the declarative style of the stream process makes the data flow clearer. Note that even the HTML code has no reference to click methods or anything like that; the complete code is separate from that.

We have now seen most of the interesting patterns; let's finish with some other ones, which may or may not be exactly equivalent to their classic OOP partners.

Other patterns

Let's end this section by glancing at some other patterns where the equivalence may or may not be so good:

- **Currying and partial application** (which we saw in *Chapter 7*, *Transforming Functions*: This can be seen as approximately equivalent to a *Factory* for functions. Given a general function, you can produce specialized cases by fixing one or more arguments, which is, in essence, what a Factory does – speak about functions and not objects.
- **Declarative functions** (such as `map()` or `reduce()`): These can be considered an application of the Iterator pattern. The traversal of the container's elements is decoupled from the container itself. You can also provide different `map()` methods for different objects to traverse all kinds of data structures.
- **Persistent data structures**: As mentioned in *Chapter 10*, *Ensuring Purity*, these allow for the implementation of the Memento pattern. The central idea is, given an object, to be able to go back to a previous state. As we saw, each updated version of a data structure doesn't affect the previous one(s), so you could easily add a mechanism to provide an earlier state and *roll back* to it.
- A **Chain of Responsibility** pattern: In this pattern, there is a potentially variable number of request processors and a stream of requests to be handled, which may be implemented using `find()` to determine which processor will handle the request (the desired one is the first in the list that accepts the request) and then simply doing the required process.

Remember the warning at the beginning – with these patterns, the match with FP techniques may not be as perfect as with others that we have previously seen. However, the idea is to show that some common FP patterns can be applied and will produce the same results as the OOP solutions, despite having different implementations.

Now, after having seen several OOP equivalent patterns, let's move on to more specific FP ones.

Functional design patterns

Having seen several OOP design patterns, it may seem a cheat to say that there's no approved, official, or even remotely generally accepted similar list of patterns for FP. There are, however, several problems for which there are standard FP solutions, which can be considered design patterns on their own, and we have already covered most of them in this book.

What are the candidates for a possible list of patterns? Let's attempt to prepare one – but remember that it's just a personal view. Also, I'll admit that I'm not trying to mimic the usual style of pattern definition; I'll just be mentioning a general problem and refer to the way FP in JavaScript can solve it, and I won't be aiming for nice, short, and memorable names for the patterns either:

- **Processing collections using filter/map/reduce**: Whenever you have to process a data collection, using declarative higher-order functions such as `filter()`, `map()`, and `reduce()`, as we saw in this chapter and previously in *Chapter 5*, *Programming Declaratively*, is a way to remove complexity from the problem. (The usual `MapReduce` web framework is an extension of this concept, which allows for distributed processing among several servers, even if the implementation and details aren't exactly the same.) Instead of performing looping and processing as a single step, you should think about the problem as a sequence of steps, applied in order, and doing transformations until obtaining the final, desired result.

Looping in other ways

JavaScript also includes *iterators*, another way of looping through a collection. Using iterators isn't particularly functional, but you may want to look at them, since they may be able to simplify some situations. Read more at `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Iteration_protocols`.

- **Lazy evaluation with thunks**: The idea of lazy evaluation is not doing any calculations until they are actually needed. In some programming languages, this is built in. However, in JavaScript (and most imperative languages), *eager evaluation* is applied, in which an expression is evaluated as soon as it is bound to some variable. (Another way of saying this is that JavaScript is a *strict programming language*, with a *strict paradigm*, which only allows calling a function if all of its parameters have been completely evaluated.) This sort of evaluation is required when you need to specify the order of evaluation with precision, mainly because such evaluations may have side effects.

  In FP, which is more declarative and pure, you can delay such evaluation with *thunks* (which we used in the *Trampolines and thunks* section of *Chapter 9, Designing Functions*) by passing a thunk that will calculate the needed value only when it's needed, but not earlier.

Generating more results

You may also want to look at JavaScript generators, another way of delaying evaluation, though not particularly related to FP. Read more about them at `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Generator`. The combination of generators and promises is called an `async` function, which may be of interest to you; refer to `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Statements/async_function`.

- **Persistent data structures for immutability**: Having immutable data structures, as we saw in *Chapter 10*, *Ensuring Purity*, is mandatory when working with certain frameworks, and in general, it is recommended because it helps to reason about a program or to debug it. (Earlier in this chapter, we also mentioned how the *Memento* OOP pattern can be implemented in this fashion.) Whenever you have to represent structured data, the FP solution of using a persistent data structure helps in many ways.
- **Wrapped values for checks and operations**: If you directly work with variables or data structures, you can modify them at will (possibly violating any restrictions), or you may need to do many checks before using them (such as verifying that a value is not `null` before trying to access the corresponding object). This pattern aims to wrap a value within an object or function, so direct manipulation won't be possible, and checks can be managed more functionally. We'll refer to more of this in *Chapter 12*, *Building Better Containers*.

As we have said, the power of FP is such that, instead of having a couple of dozen standard design patterns (and that's only in the GoF book; if you read other texts, the list grows!), there isn't yet a standard or acknowledged list of functional patterns.

Summary

In this chapter, we have made a bridge from the OO way of thinking and the usual patterns we use when coding that way to the FP style, by showing how we can solve the same basic problems but relatively more easily than with classes and objects. We have seen several common design patterns, and we've seen that the same concepts apply in FP, even if implementations may vary, so now you have a way to apply those well-known solution structures to your JavaScript coding.

In *Chapter 12*, *Building Better Containers*, we will be working with a potpourri of FP concepts, giving you even more ideas about tools you can use. I promised that this book wouldn't be deeply theoretical but, rather, more practical, and we'll try to keep it this way, even if some of the presented concepts may seem abstruse or remote.

Questions

11.1 **Decorating methods, the future way**: In *Chapter 6*, *Producing Functions*, we wrote a decorator to enable logging for any function. Currently, method decorators are being considered for upcoming versions of JavaScript: refer to `tc39.github.io/proposal-decorators` for more information on that. (A Stage 2 Draft means that inclusion of this feature in the standard is likely, although there may be some additions or small changes. TypeScript provides decorators today, but warns that *"Decorators are an experimental feature that may change in future releases"*; see more at `www.typescriptlang.org/docs/handbook/decorators.html`.) Study the following code and take a look at what makes the next code tick:

```
const logging = (target, name, descriptor) => {
  const savedMethod = descriptor.value;
  descriptor.value = function (...args) {
    console.log(`entering ${name}: ${args}`);
    try {
      const valueToReturn = savedMethod.bind(this)(...args);
      console.log(`exiting ${name}: ${valueToReturn}`);
      return valueToReturn;
    } catch (thrownError) {
      console.log(`exiting ${name}: threw ${thrownError}`);
      throw thrownError;
    }
  };
  return descriptor;
};
```

A working example would be as follows:

```
class SumThree {
  constructor(z) {
    this.z = z;
  }
  @logging
  sum(x, y) {
    return x + y + this.z;
  }
}

new SumThree(100).sum(20, 8);
// entering sum: 20,8
// exiting sum: 128
```

The following are some questions about the code for `logging()`:

- What's the need for the `savedMethod` variable?
- Why do we use `function()` when assigning a new `descriptor.value`, instead of an arrow function?

- Why is `.bind()` used?
- What is `descriptor`?

11.2 **Decorator with mixins**: In the *Questions* section of *Chapter 1*, *Becoming Functional*, we saw that classes are first-class objects. Taking advantage of this, complete the following `addBar()` function, which will add some mixins to the `Foo` class so that the code will run as shown. The created `fooBar` object should have two attributes (`fooValue` and `barValue`) and two methods (`doSomething()` and `doSomethingElse()`) that simply show some text and properties, as shown here:

```
class Foo {
  constructor(fooValue) {
    this.fooValue = fooValue;
  }
  doSomething() {
    console.log("something: foo... ", this.fooValue);
  }
}

const addBar = (BaseClass) => {
  /*
  your code goes here
  */
};

const fooBar = new (addBar(Foo))(22, 9);
fooBar.doSomething();
// something: foo... 22

fooBar.somethingElse();
// something else: bar... 9

console.log(Object.keys(fooBar));
// ["fooValue", "barValue"]
```

Could you include a third mixin, `addBazAndQux()`, so that `addBazAndQux(addBar(Foo))` would add even more attributes and methods to `Foo`?

11.3 **Multi-clicking by hand**: Can you write your own multi-click detection code, which should work exactly as in our example?

11.4 **Sorting logically**: In *Chapter 3*, *Starting Out with Functions*, we saw how to sort numbers and strings by injecting a sorting function, an application of the Strategy pattern. What comparison function would you use to sort an array with Boolean values, with `false` values first and `true` values last?

11.5 **Finding routes, objectively**: Working in an object-oriented fashion, the route-finding problem would have been solved in another way, involving classes and subclasses. How? (Tip: the answer to this question is a pattern we have mentioned in this chapter.)

12
Building Better Containers – Functional Data Types

In *Chapter 11*, *Implementing Design Patterns*, we went over how to use functions to achieve different results. In this chapter, we will look at data types from a functional point of view. We'll be considering how we can implement our own data types, along with several features that can help us compose operations or ensure their purity so that our FP coding will become simpler and shorter.

We'll be touching on several topics:

- **Data types** from a functional point of view. Even though JavaScript is not a typed language, a better understanding of types and functions is needed, to complement our usage of TypeScript.
- **Containers**, including functors and the mystifying monads, to structure a data flow.
- **Functions as structures**, in which we'll see yet another way of using functions to represent data types, with immutability thrown in as an extra.

With that, let's get started!

Specifying data types

Even though JavaScript is a dynamic language, without static or explicit typing declarations and controls, it doesn't mean you can simply ignore types. Even if the language doesn't allow you to specify the types of your variables or functions, you still work—even if only in your head—with types. Specifying types has advantages, as follows:

- TypeScript can detect compile-time errors, avoiding many bugs.
- It will help if you move from JavaScript to a more functional language, such as Elm (see `elm-lang.org`).

- It serves as documentation that lets future developers understand what type of arguments they must pass to the function and what type it will return. All the functions in the Ramda library are documented in this way.
- It will also help us with the functional data structures we will cover later in this section, where we will examine a way of dealing with structures, similar to what you do in fully functional languages such as Haskell.

Why are we discussing types again, after using TypeScript throughout the whole book? The reason is that in most FP texts, a different style is used. TypeScript definitions are just, well, TypeScript, but the definitions we'll see here can be applied to any other language. Let's forget TypeScript for a minute and start thinking about a new type system. We'll start with functions, the most relevant type, and then consider other definitions.

Signatures for functions

The specification of a function's arguments and the result are given by a signature. Type signatures are based on a type system called **Hindley–Milner** (**HM**), which influenced several (mostly functional) languages, including Haskell, though the notation has changed from that of the original paper. This system can even deduce types that are not directly given, in the same way that TypeScript or Flow does. Instead of providing a dry, formal explanation about the rules for writing correct signatures, let's work with examples. We only need to know the following:

- We will be writing the type declaration as a comment
- The function name is written first, and then `::`, which can be read as *is of type* or *has type*
- Optional constraints may follow, with a double (fat) arrow ⇒ (or `=>` in basic ASCII fashion, if you cannot type in the arrow) afterward
- The input type of the function follows, with a → (or `->`, depending on your keyboard)
- The result type of the function comes last

Careful with arrows!

An advance warning: check out the arrow styles we'll use; they are not what TypeScript uses! A "thin" arrow will be used instead of `=>`, and a "fat" arrow will be used to specify a generic constraint; be careful!

Now, we can begin with some examples. Let's define the type for a simple function that capitalizes a word, and do the same for the `Math.random` function:

```
// firstToUpper :: String → String

const firstToUpper = (s: string): string =>
```

```
  s[0].toUpperCase() + s.substring(1).toLowerCase();

// Math.random :: () → Number
```

These are simple cases—only take the signatures into account here; we are not interested in the actual functions. The arrows denote functions. The first function receives a string as an argument and returns a new string. The second one receives no arguments (as indicated by the empty parentheses) and returns a floating-point number. So, we can read the first signature as `firstToUpper()` *is a function of the type that receives a string and returns a string*. We can speak similarly about the maligned (impurity-wise) `Math.random()` function, the only difference being that it doesn't receive arguments.

Comparing the new type definition with TypeScript, it's clear that they are very much alike. However, the new style is clearer. You could have also defined `firstToUpper()` in the following way, without specifying the result type (because TypeScript can work it out), but with HM types, you have to provide all the details, providing more clarity:

```
// firstToUpper :: String → String

const firstToUpper = (s: string) =>
  s[0].toUpperCase() + s.substring(1).toLowerCase();
```

Another detail is that in this new way of specifying types, the type descriptions stand on their own, without being mixed with the details of the programming language—you don't need to understand JavaScript, TypeScript, or any other language to figure out what types are involved in a function.

We've already looked at functions with zero or one parameter, but what about functions with more than one? There are two answers to this. If we are working in a strict functional style, we would always be currying (as we saw in *Chapter 7*, *Transforming Functions*), so all the functions would be unary. The other solution is enclosing a list of argument types in parentheses. We can see both of these solutions in the following code:

```
// sum3C :: Number → Number → Number → Number

const sum3C = curry(
  (a: number, b: number, c: number): number => a + b + c
);

// sum3 :: (Number, Number, Number) → Number

const sum3 = (a: number, b: number, c: number) => a + b +
  c;
```

Remember that `sum3c()` is actually `(a) => (b) => (c) => a + b + c`; this explains the first signature, which can also be read as follows:

```
// sum3C :: Number → (Number → (Number → (Number)))

const sum3C = curry(
  (a: number, b: number, c: number): number => a + b + c
);
```

After you provide the first argument to the function, you are left with a new function, which also expects an argument and returns a third function, which, when given an argument, will produce the final result. We won't be using parentheses because we'll always assume this grouping from right to left.

Now, what about higher-order functions, which receive functions as arguments? The `map()` function poses a problem: it works with arrays of any type. Also, the mapping function can produce any type of result. For these cases, we can specify generic types, identified by lowercase letters. These generic types can stand for any possible type. For arrays themselves, we use brackets. So, we would have the following:

```
// map :: [a] → (a → b) → [b]

const map = curry(<A, B>(arr: A[], fn: (x: A) => B) =>
  arr.map(fn)
);
```

It's perfectly valid to have `a` and `b` represent the same type, as in a mapping that's applied to an array of numbers, which produces another array of numbers. The point is that, in principle, `a` and `b` may stand for different types, which we described previously. This definition requires using generic types in TypeScript, `A` and `B` in our case.

Note that if we weren't currying, the signature would have been `([a], (a → b)) → [b]`, showing a function that receives two arguments (an array of elements of type `a` and a function that maps from type `a` to type `b`) and produces an array of elements of type `b` as its result.

We can similarly write the following:

```
// filter :: [a] → (a → Boolean) → [a]

const filter = curry(<A>(arr: A[], fn: (x: A) => B) =>
  arr.filter(fn)
);
```

And now the big one: what's the signature for `reduce()`? Be sure to read it carefully and see whether you can work out why it's written that way. You may prefer thinking about the second part of the signature as if it were `((b, a) → b)`:

```
// reduce :: [a] → (b → a → b) → b → b

const reduce = curry(
  <A, B>(arr: A[], fn: (a: B, v: A) => B, acc: B) =>
    arr.reduce(fn, acc)
);
```

Finally, if you are defining a method instead of a function, you use a squiggly arrow such as ~>:

```
// String.repeat :: String ⇝ Number → String
```

So far, we have defined data types for functions, but we aren't done with this subject. Let's consider some other cases.

Other data type options

What else are we missing? Let's look at some other options that you might use. *Product types* are a sets of values that are always together and are commonly used with objects. For *tuples* (that is, arrays with a fixed number of elements of (probably) different types), we can write something like the following:

```
// getWeekAndDay :: String → (Number × String)

const getWeekAndDay = (
  yyyy_mm_dd: string
): [number, string] => {
  let weekNumber: number;
  let dayOfWeekName: string;
  .
  .
  .
  return [weekNumber, dayOfWeekName];
};
```

For objects, we can go with a definition very similar to what JavaScript already uses. Let's imagine we have a `getPerson()` function that receives an ID and returns an object with data about a person:

```
// getPerson :: Number → { id:Number × name:String }
```

```
const getPerson = (
  personId: number
): { id: number; name: string } => {
  .
  .
  .
  return { id: personId, name: personName };
};
```

Sum types (also known as *union types*) are defined as a list of possible values. For example, our `getField()` function from *Chapter 6*, *Producing Functions*, returns either the value of an attribute or `undefined`. For this, we can write the following signature:

```
// getField :: String → Object → a | undefined

const getField =
  <A>(attr: string) =>
  (obj: { [key: string]: A }) =>
    obj[attr];
```

We could also define a type (union or otherwise) and use it in further definitions. For instance, the data types that can be directly compared and sorted are numbers, strings, and Booleans, so we could write the following definitions:

```
// Sortable :: Number | String | Boolean
```

Afterward, we could specify that a comparison function can be defined in terms of the `Sortable` type, but be careful: there's a hidden problem here!

```
// compareFunction :: (Sortable, Sortable) → Number
```

The previous definition would allow us to write a function that received, say, a `number` and a `Boolean`. It doesn't say that both types should be the same. However, there's a way out. If you have constraints for some data types, you can express them before the actual signature, using a fat arrow, as shown in the following code:

```
// compareFunction :: Sortable a ⇒ (a, a) → Number
```

The definition is now correct because all occurrences of the same type (denoted by the same letter, in this case, `a`) must be exactly the same. An alternative, but one that requires much more typing, would have been to write all three possibilities with a union:

```
// compareFunction ::
//     ((Number, Number) |
//     (String, String)  |
//     (Boolean, Boolean)) → Number
```

Actually, this definition isn't very precise because you can compare any type, even if it doesn't make much sense. However, bear with me for the sake of this example! If you want to refresh your memory about sorting and comparison functions, see `developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/Array/sort`.

So far, we have been using the standard type definitions. However, when working with JavaScript, we have to consider other possibilities, such as functions with optional parameters, or even with an undetermined number of parameters. We can use `...` to stand for any number of arguments and add `?` to represent an optional type, as follows:

```
// unary :: ((b, ...) → a) → (b → a)
```

The `unary()` higher-order function we defined in the same chapter we cited previously took any function as a parameter and returned a unary function as its result. We can show that the original function can receive any number of arguments but that the result used only the first. The data type definition for this would be as follows:

```
// parseInt :: (String, Number?) → Number
```

The standard `parseInt()` function provides an example of optional arguments, though it's highly recommended that you don't omit the second parameter (the base radix); you can, in fact, skip it.

Fantastic definitions?

Check out `github.com/fantasyland/fantasy-land/` and `sanctuary.js.org/#types` for a more formal definition and description of types, as applied to JavaScript.

From now on, throughout this chapter, we'll not only be using TypeScript, but we will also be adding HM signatures to methods and functions, so you can get used to them. Let's now change track and cover a highly important topic: *containers*.

Building containers

Back in *Chapter 5*, *Programming Declaratively*, and later, in *Chapter 8*, *Connecting Functions*, we saw that the ability to apply a mapping to all the elements of an array—and even better, being able to chain a sequence of similar operations—was an excellent way to produce better, more understandable code.

However, there is a problem: the `map()` method (or the equivalent, demethodized one, which we looked at in *Chapter 6*, *Producing Functions*) is only available for arrays, and we might want to be able to apply mappings and chaining to other data types. So, what can we do?

Let's consider different ways of doing this, which will give us several new tools for better functional coding. Basically, there are only two possible ways of solving this: we can either add new methods to existing types (though that will be limited because we can only apply that to basic JavaScript types) or wrap types in some type of container, which will allow mapping and chaining.

Let's start by extending current types before moving on to using wrappers, which will lead us into the deep functional territory with entities such as functors and monads.

Extending current data types

If we want to add mapping to basic JavaScript data types, we need to start by considering our options:

- With `null`, `undefined`, and `Symbol`, applying maps doesn't sound too interesting
- We have some interesting possibilities with `Boolean`, `Number`, and `String` data types, so we can examine some of those
- Applying mapping to an object is trivial: we just have to add a `map()` method, which must return a new object
- Finally, despite not being basic data types, we could also consider special cases, such as dates or functions, to which we could also add `map()` methods

As in the rest of this book, we are sticking to plain JavaScript and TypeScript, but you should look into libraries such as Lodash, Underscore, or Ramda, which already provide functionalities similar to the ones we are developing here.

A key point to consider in all these mapping operations should be that the returned value is of the same type as the original one. When we use `Array.map()`, the result is also an array, and similar considerations must apply to any other `map()` method implementations (you could observe that the resulting array may have different element types to the original one, but it is still an array).

What could we do with a Boolean? First, let's accept that Booleans are not containers, so they don't really behave in the same way as an array. Trivially, a Boolean can only have a Boolean value, while an array may contain any type of element. However, accepting that difference, we can extend `Boolean.prototype` (though, as I've already mentioned, that's not usually recommended) by adding a new `map()` method to it and making sure that whatever the mapping function returns is turned into a new Boolean value. For the latter, the solution will be similar to the following:

```
// Boolean.map :: Boolean ⇝ (Boolean → a) → Boolean

Boolean.prototype.map = function (
  this: boolean,
  fn: (x: boolean) => any
) {
  return !!fn(this);
};
```

We already saw examples of adding a (fake) `this` parameter to a method, to let TypeScript know what type `this` will be—in this case, a Boolean. The `!!` operator forces the result to be a Boolean. `Boolean(fn(this))` could also have been used. This kind of solution can also be applied to numbers and strings, as shown in the following code:

```
// Number.map :: Number ⇝ (Number → a) → Number

Number.prototype.map = function (
  this: number,
  fn: (x: number) => number
) {
  return Number(fn(this));
};

// String.map :: String ⇝ (String → a) → String

String.prototype.map = function (
  this: string,
  fn: (x: string) => string
) {
  return String(fn(this));
};
```

As with Boolean values, we are forcing the results of the mapping operations to the correct data types. By the way, TypeScript won't directly accept any of these new `map()` definitions; see *Question 12.1* to fix this.

Finally, if we wanted to apply mappings to a function, what would that mean? Mapping a function should produce a function. The logical interpretation for `f.map(g)` would be applying `f()`, and then applying `g()` to the result. So, `f.map(g)` should be the same as writing `x => g(f(x))` or, equivalently, `pipe(f,g)`. The definition is more complex than it was for the previous examples (but, in my opinion, simpler in HM than with TypeScript), so study it carefully:

```
// Function.map :: (a → b) ⇝ (b → c) → (a → c)
```

```
Function.prototype.map = function <A, B, C>(
  this: (x: A) => B,
  fn: (y: B) => C
): (x: A) => C {
  return (x: A) => fn(this(x));
};
```

Verifying that this works is simple, and the following code is an easy example of how to do this. The `times10()` mapping function is applied to the result of calculating `plus1(3)`, so the result is 40:

```
const plus1 = (x) => x + 1;
const times10 = (y) => 10 * y;

console.log(plus1.map(by10)(3));
// 40: first add 1 to 3, then multiply by 10
```

With this, we are done talking about what we can achieve with basic JavaScript types, but we need a more general solution if we want to apply this to other data types. We'd like to be able to apply mapping to any kind of value, and for that, we'll need to create a container. We'll do this in the next section.

Containers and functors

What we did in the previous section works and can be used without problems. However, we would like to consider a more general solution that we can apply to any data type. Since not all things in JavaScript provide the desired `map()` method, we will have to either extend the type (as we did in the previous section) or apply a design pattern that we considered in *Chapter 11*, *Implementing Design Patterns*: wrapping our data types with a wrapper that will provide the required `map()` operations.

In particular, we will do the following:

- Start by seeing how to build a basic container, wrapping a value
- Convert the container into something more powerful—a functor
- Study how to deal with missing values using a special functor, `Maybe`

Wrapping a value – a basic container

Let's pause for a minute and consider what we need from this wrapper. There are two basic requirements:

- We must have a `map()` method
- We need a simple way to wrap a value

To get started, let's create a basic container. Any object containing just a value would do, but we want some additions, so our object won't be that trivial; we'll explain the differences after the code:

```
// container.ts

class Container<A> {
  protected x: A;

  constructor(x: A) {
    this.x = x;
  }

  map(fn: (_: A) => any) {
    return fn(this.x);
  }
}
```

Some primary considerations that we need to keep in mind are as follows:

- We want to be able to store some value in a container, so the constructor takes care of that.
- Using a `protected` attribute avoids "tinkering" from the outside, but allows access to subclasses. (See *Question 12.2* for some JavaScript considerations.)
- We need to be able to `map()`, so a method is provided for that.

Our barebones container is ready, but we can also add some other methods for convenience, as follows:

- To get the value of a container, we could use `map((x) => x)`, but that won't work with more complex containers, so we'll add a `valueOf()` method to get the contained value.
- Being able to list a container can undoubtedly help with debugging. The `toString()` method will come in handy for this.
- Because we don't need to write `new Container()` all the time, we can add a static `of()` method to do the same job.

A functional sin?

Working with classes to represent containers (and later, functors and monads) when living in a FP world may seem like heresy or sin... but remember that we don't want to be dogmatic, and using classes simplifies our coding. Similarly, it could be argued that you must never take a value out of the container—but using a `valueOf()` method is sometimes too handy, so we won't be that restrictive.

By taking all of this into account, our container is as follows:

```
// continued...

class Container<A> {
  protected x: A;

  constructor(x: A) {
    this.x = x;
  }

  static of<B>(x: B): Container<B> {
    return new Container(x);
  }

  map(fn: (_: A) => any) {
    return fn(this.x);
  }

  toString() {
    return `${this.constructor.name}(${this.x})`;
  }

  valueOf() {
    return this.x;
  }
}
```

Now, we can use this container to store a value, and `map()` to apply any function to that value, but this isn't very different from what we could do with a variable! Let's enhance this a bit.

Enhancing our container – functors

We want to have wrapped values, so what exactly should `map()` return? If we want to be able to chain operations, the only logical answer is that it should return a new wrapped object. In true functional style, when we apply a mapping to a wrapped value, the result will be another wrapped value that we can keep working on.

A map by any other name

Instead of `map()`, this operation is sometimes called `fmap()`, standing for *functorial map*. The rationale for the name change was to avoid expanding the meaning of `map()`. However, since we are working in a language that supports reusing the name, we can keep it.

We can extend our `Container` class to implement this change and get ourselves an enhanced container: a *functor*. The `of()` and `map()` methods will require a small change. For this, we'll be creating a new class, as shown in the following code:

```
// functor.ts

class Functor<A> extends Container<A> {
  static of<B>(x: B) {
    return new Functor(x);
  }

  map<B>(fn: (_: A) => B): Functor<B> {
    return Functor.of(fn(this.x));
  }
}
```

Here, the `of()` method produces a `Functor` object, and so does the `map()` method. With these changes, we have just defined what a *functor* is in category theory! (Or, if you want to get really technical, a *pointed functor* because of the `of()` method—but let's keep it simple.) We won't go into the theoretical details, but roughly speaking, a functor is some container that allows us to apply `map()` to its contents, producing a new container of the same type. If this sounds familiar, it's because you already know a functor: arrays! When you apply `map()` to an array, the result is a new array containing transformed (mapped) values.

Extra requirements

There are more requirements for functors. First, the contained values may be polymorphic (of any type), just like arrays. Second, a function must exist whose mapping produces the same contained value— `(x) => x` does this for us. Finally, applying two consecutive mappings must produce the same result as applying their composition. This means that `container.map(f).map(g)` must be the same as `container.map(compose(g,f))`.

Let's pause for a moment and consider the signatures for our function and methods:

```
// of :: Functor f ⇒ a → f a
// Functor.toString :: Functor f ⇒ f a ⇝ String
// Functor.valueOf :: Functor f ⇒ f a ⇝ a
// Functor.map :: Functor f ⇒ f a ⇝ (a → b) → f b
```

The first function, `of()`, is the simplest: given a value of any type, it produces a functor of that type. The following two are also relatively simple to understand: given a functor, `toString()` always returns a string (no surprise there!), and if the functor-contained value is of a given type, `valueOf()` produces a result of that same type. The third one, `map()`, is more interesting. Given a function that takes an argument of type `a` and produces a result of type `b`, applying it to a functor that contains a value of type `a` produces a functor containing a value of type `b`. This is precisely what we described previously.

Promises and Functors

You could compare functors to promises, at least in one aspect. With functors, instead of acting on its value directly, you have to apply a function with `map()`. In promises, you do exactly the same, but using `then()` instead! In fact, there are more analogies, as we'll be seeing soon.

As is, functors are not allowed or expected to produce side effects, throw exceptions, or exhibit any other behavior outside of producing a container-ed result. Their main usage is to provide us with a way to manipulate a value, apply operations to it, compose results, and so on, without changing the original value—in this sense, we are once again coming back to immutability.

However, you could reasonably say that this isn't enough since, in everyday programming, it's pretty common to have to deal with exceptions, undefined or null values, and so on. So, let's start by looking at more examples of functors. After that, we'll enter the realm of monads to look at even more sophisticated processing. Let's experiment a bit!

Dealing with missing values with Maybe

A common problem in programming is dealing with missing values. There are many possible causes for this situation: a web service Ajax call may have returned an empty result, a dataset could be empty, an optional attribute might be missing from an object, and so on. In a normal imperative fashion, dealing with this kind of situation requires adding `if` statements or ternary operators everywhere to catch the possible missing value to avoid a certain runtime error. We can do better by implementing a `Maybe` functor to represent a value that may (or may *not*) be present! We will use two classes, `Just` (as in *just some value*) and `Nothing`, both of which are functors. The `Nothing` functor is particularly simple, with trivial methods:

```
// maybe.ts

class Nothing extends Maybe<any> {
  constructor() {
    super(null);
  }

  isNothing() {
    return true;
  }

  toString() {
    return "Nothing()";
  }

  map(_fn: FN) {
    return this;
  }
}
```

The `isNothing()` method returns `true`, `toString()` returns constant text, and `map()` always returns itself, no matter what function it's given.

Moving forward, the `Just` functor is also a basic one, with the added `isNothing()` method (which always returns `false`, since a `Just` object isn't `Nothing`), and a `map()` method that now returns `Maybe`:

```
// continued...

class Just<A> extends Maybe<A> {
  static of<B>(x: B): Maybe<B> {
    if (x === null || x === undefined) {
      throw new Error("Just should have a value");
    } else {
      return new Just(x);
    }
  }

  isNothing() {
    return false;
  }

  map<B>(fn: (_: A) => B): Just<B> {
    return new Just(fn(this.x));
  }
}
```

Finally, our `Maybe` class packs the logic needed to construct either `Nothing` or `Just`. If it receives an `undefined` or `null` value, `Nothing` will be constructed; in other cases, `Just` will be the result. The `of()` method has exactly the same behavior:

```
// continued...

abstract class Maybe<A> extends Functor<A> {
  static of<B>(x: B): Maybe<B> {
    return x === null || x === undefined
      ? new Nothing()
      : new Just(x);
  }

  isNothing() {
    /* abstract */
  }

  map<B>(fn: (_: A) => B): Maybe<B> {
    return Maybe.of(fn(this.x));
  }
}
```

We are using an `abstract` class because you shouldn't directly write `new Maybe(...)`; you should use `Maybe.of()` or directly build `Just` or `Nothing`. (If you are wondering how to do this in JavaScript, see *Question 12.3*.) We can quickly verify that this works by trying to apply an operation to either a valid value or a missing one. Let's look at two examples of this:

```
const plus1 = x => x + 1;

Maybe.of(2209).map(plus1).map(plus1).toString();
// "Just(2211)"

Maybe.of(null).map(plus1).map(plus1).toString();
// "Nothing()"
```

When we applied `plus1()` (twice) to `Maybe.of(2209)`, everything worked fine, and we ended up with a `Just(2011)` value. On the other hand, when we applied the same sequence of operations to a `Maybe.of(null)` value, the end result was `Nothing`, but there were no errors, even if we tried to do math with a `null` value. A `Maybe` functor can deal with mapping a missing value by just skipping the operation and returning a wrapped `null` value instead. This means that this functor includes an abstracted check, which won't let an error happen.

(Later in this chapter, we'll see that `Maybe` can actually be a monad instead of a functor, and we'll also examine more examples of monads.)

Let's look at a more realistic example of its usage.

Dealing with varying API results

Suppose we are writing a small server-side service in Node.js to get the weather alerts for a city and produce a not-very-fashionable HTML `<table>` with them, to be part of some server-side-produced web page. (Yes, I know you should try to avoid tables in your pages, but I want a short example of HTML generation, and the actual results aren't significant.) If we used the *Dark Sky* API (see `darksky.net` for more on this API and how to register with it) to get the alarms, our code would be something like the following, all quite normal. Note the callback in case of an error; you'll see why in the following code:

```
import request from "superagent";

const getAlerts = (
  lat: number,
  long: number,
  callback: FN
) => {
  const SERVER = "https://api.darksky.net/forecast";
  const UNITS = "units=si";
  const EXCLUSIONS = "exclude=minutely,hourly,daily,flags";
  const API_KEY = "you.need.to.get.your.own.api.key";
```

```
    request
      .get(
        `${SERVER}/${API_
          KEY}/${lat},${long}?${UNITS}&${EXCLUSIONS}`
      )
      .end(function (err, res) {
        if (err) {
          callback({});
        } else {
          callback(JSON.parse(res.text));
        }
      });
  };
```

The (heavily edited and reduced in size) output of such a call might be something like this:

```
  {
    latitude: 29.76,
    longitude: -95.37,
    timezone: "America/Chicago",
    offset: -5,
    currently: {
      time: 1503660334,
      summary: "Drizzle",
      icon: "rain",
      temperature: 24.97,
      .
      .
      .
      uvIndex: 0,
    },
    alerts: [
      {
        title: "Tropical Storm Warning",
        regions: ["Harris"],
        severity: "warning",
        time: 1503653400,
      expires: 1503682200,
      description:
        "TROPICAL STORM WARNING REMAINS IN EFFECT... WIND -
        LATEST LOCAL FORECAST: Below tropical storm force wind
        ... CURRENT THREAT TO LIFE AND PROPERTY: Moderate ...
        Locations could realize roofs peeled off buildings,
        chimneys toppled, mobile homes pushed off foundations
        or overturned ...",
      uri: "https://alerts.weather.gov/cap/wwacapget.php?x=
      TX125862DD4F88.TropicalStormWarning.125862DE8808TX.
      HGXTCVHGX.73ee697556fc6f3af7649812391a38b3",
    },
    .
    .
    .
    {
      title: "Hurricane Local Statement",
      regions: ["Austin", ... , "Wharton"],
      severity: "advisory",
      time: 1503748800,
      expires: 1503683100,
      description:
        "This product covers Southeast Texas **HURRICANE
        HARVEY DANGEROUSLY APPROACHING THE TEXAS COAST** ...
        The next local statement will be issued by the National
        Weather Service in Houston/Galveston TX around 1030 AM
        CDT, or sooner if conditions warrant.\n",
      uri: "https://alerts.weather.gov/...",
    },
  ],
};
```

I got this information for Houston, TX, US, on a day when Hurricane Harvey was approaching the state. If you called the API on a normal day, the data would not include the `alerts:[...]` part. Here, we can use a `Maybe` functor to process the received data without any problems, with or without any alerts:

```
import os from "os";

const produceAlertsTable = (weatherObj: typeof resp) =>
```

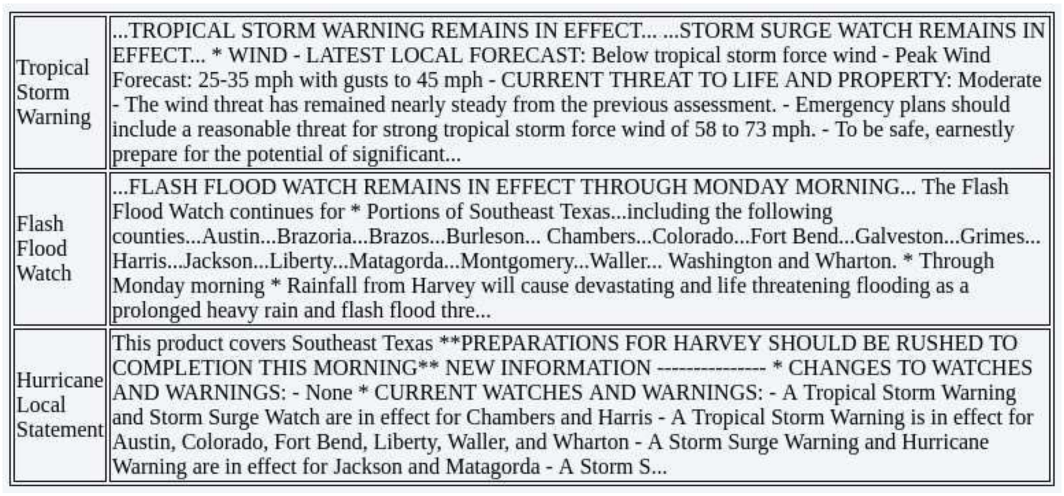
```
  Maybe.of(weatherObj)
    .map((w: typeof resp) => w.alerts)
    .map((a) =>
      a.map(
        (x) =>
          `<tr><td>${x.title}</td>` +
          `<td>${x.description.substr(0,
            500)}...</td></tr>`
      )
    )
    .map((a) => a.join(os.EOL))
    .map((s) => `<table>${s}</table>`);

getAlerts(29.76, -95.37, (x) =>
  console.log(produceAlertsTable(x).valueOf())
);
```

Of course, you would probably do something more interesting than just logging the value of the contained result of `produceAlertsTable()`! The most likely option would be to use `map()` again with a function that would output the table, send it to a client, or do whatever you needed to do. In any case, the resulting output would look something like this:

```
<table><tr><td>Tropical Storm Warning</td><td>...TROPICAL STORM
WARNING REMAINS IN EFFECT... ...STORM SURGE WATCH REMAINS IN
EFFECT... * WIND -
LATEST LOCAL FORECAST: Below tropical storm force wind - Peak
Wind Forecast: 25-35 mph with gusts to 45 mph - CURRENT THREAT
TO LIFE AND PROPERTY: Moderate - The wind threat has remained
nearly steady from the previous assessment. - Emergency plans
should include a reasonable threat for strong tropical storm
force wind of 58 to 73 mph. - To be safe, earnestly prepare for
the potential of significant...</td></tr>
<tr><td>Flash Flood Watch</td><td>...FLASH FLOOD WATCH REMAINS
IN EFFECT
THROUGH MONDAY MORNING... The Flash Flood Watch continues
for * Portions of Southeast Texas...including the following
counties...Austin...Brazoria...Brazos...Burleson...
Chambers...Colorado...Fort Bend...Galveston...Grimes...
Harris...Jackson...Liberty...Matagorda...Montgomery...Waller...
Washington and Wharton. * Through Monday morning * Rainfall
```

```
from Harvey will cause devastating and life threatening
flooding as a prolonged heavy rain and flash flood thre...</
td></tr>
<tr><td>Hurricane Local Statement</td><td>This product covers
Southeast
Texas **PREPARATIONS FOR HARVEY SHOULD BE RUSHED TO COMPLETION
THIS MORNING** NEW INFORMATION --------------- * CHANGES TO
WATCHES AND
WARNINGS: - None * CURRENT WATCHES AND WARNINGS: - A Tropical
Storm Warning and Storm Surge Watch are in effect for Chambers
and Harris - A Tropical Storm Warning is in effect for Austin,
Colorado, Fort Bend, Liberty, Waller, and Wharton - A Storm
Surge Warning and Hurricane Warning are in effect for Jackson
and Matagorda - A Storm S...</td></tr></table>
```

The output of the preceding code can be seen in the following screenshot:



Tropical Storm Warning	...TROPICAL STORM WARNING REMAINS IN EFFECT... ...STORM SURGE WATCH REMAINS IN EFFECT... * WIND - LATEST LOCAL FORECAST: Below tropical storm force wind - Peak Wind Forecast: 25-35 mph with gusts to 45 mph - CURRENT THREAT TO LIFE AND PROPERTY: Moderate - The wind threat has remained nearly steady from the previous assessment. - Emergency plans should include a reasonable threat for strong tropical storm force wind of 58 to 73 mph. - To be safe, earnestly prepare for the potential of significant...
Flash Flood Watch	...FLASH FLOOD WATCH REMAINS IN EFFECT THROUGH MONDAY MORNING... The Flash Flood Watch continues for * Portions of Southeast Texas...including the following counties...Austin...Brazoria...Brazos...Burleson... Chambers...Colorado...Fort Bend...Galveston...Grimes... Harris...Jackson...Liberty...Matagorda...Montgomery...Waller... Washington and Wharton. * Through Monday morning * Rainfall from Harvey will cause devastating and life threatening flooding as a prolonged heavy rain and flash flood thre...
Hurricane Local Statement	This product covers Southeast Texas **PREPARATIONS FOR HARVEY SHOULD BE RUSHED TO COMPLETION THIS MORNING** NEW INFORMATION --------------- * CHANGES TO WATCHES AND WARNINGS: - None * CURRENT WATCHES AND WARNINGS: - A Tropical Storm Warning and Storm Surge Watch are in effect for Chambers and Harris - A Tropical Storm Warning is in effect for Austin, Colorado, Fort Bend, Liberty, Waller, and Wharton - A Storm Surge Warning and Hurricane Warning are in effect for Jackson and Matagorda - A Storm S...

Figure 12.1 – The output table is not much to look at, but the logic that produced it didn't require a single if statement

If we had called `getAlerts(-34.9, -54.60, ...)` with the coordinates for Montevideo, Uruguay, instead, since there were no alerts for that city, the `getField("alerts")` function would have returned `undefined`—and since that value is recognized by the `Maybe` functor, and even though all the following `map()` operations would still be executed, no one would actually do anything, and a `null` value would be the final result.

We took advantage of this behavior when we coded the error logic. If an error occurs when calling the service, we would still call the original callback to produce a table but provide an empty object. Even if this result is unexpected, we would be safe because the same guards would avoid causing a runtime error.

As a final enhancement, we can add an `orElse()` method to provide a default value when no value is provided. The added method will return the default value if `Maybe` is `Nothing`, or the `Maybe` value itself otherwise:

```
// continued...

class Maybe<A> extends Functor<A> {
  .
  .
  .
  orElse(v: any) {
    /* abstract */
  }
}

class Nothing extends Functor<any> {
  .
  .
  .
  orElse(v: any) {
    return v;
  }
}

class Just<A> extends Functor<A> {
  .
  .
  .
  orElse(v: any) {
    return this.x;
  }
}
```

Using this new method instead of `valueOf()`, trying to get the alerts for someplace without weather warnings would just return a default result. In the case we mentioned previously, attempting to get the alerts for Montevideo, instead of a `null` value, we would get the following appropriate result:

```
getAlerts(-34.9, -54.6, (x) =>
  console.log(
    produceAlertsTable(x).orElse(
      "<span>No alerts today.</span>"
    )
  )
);
```

With this, we have looked at an example of dealing with different situations when working with an API. Let's quickly revisit another topic from a previous chapter and look at a better implementation of prisms.

Implementing prisms

The more common implementations of prisms (which we first met in the *Prisms* section of *Chapter 10, Ensuring Purity*), instead of returning either some value or `undefined` and leaving it up to the caller to check what happened, opt to return `Maybe`, which already provides us with easy ways to deal with missing values. In our new implementation (which we'll look at soon), our example from the aforementioned chapter would look like this:

```
const author = {
  user: "fkereki",
  name: {
    first: "Federico",
    middle: "",
    last: "Kereki",
  },
  books: [
    { name: "Google Web Toolkit", year: 2010 },
    { name: "Functional Programming", year: 2017 },
    { name: "Javascript Cookbook", year: 2018 },
  ],
};
```

If we wanted to access the `author.user` attribute, the result would be different:

```
const pUser = prismProp("user");
```

```
console.log(review(pUser, author).toString());
/*
Just("fkereki")
*/
```

Similarly, if we asked for a non-existent pseudonym attribute, instead of `undefined` (as in our previous version of `Prism`), we would get `Nothing`:

```
const pPseudonym = prismProp("pseudonym"); console.
log(review(pPseudonym, author).toString());
/*
Nothing()
*/
```

So, this new version of `Prism` is better to work with if you are already used to dealing with `Maybe` values. What do we need to implement this? We need just a single change; our `Constant` class now needs to return `Maybe` instead of a value, so we'll have a new `ConstantP` (`P` for `Prism`) class:

```
class ConstantP<V> {
  private value: Maybe<V>;
  map: FN;

  constructor(v: V) {
    this.value = Maybe.of(v);
    this.map = () => this;
  }
}
```

We will have to rewrite `preview()` to use the new class, and that finishes the change:

```
const preview = curry(
  (prismAttr, obj) =>
    prismAttr((x) => new ConstantP(x))(obj).value
);
```

So, getting `Prism` to work with `Maybe` wasn't that hard, and now we have a consistent way of dealing with possibly missing attributes. Working in this fashion, we can simplify our coding and avoid many tests for nulls and other similar situations. However, we may want to go beyond this; for instance, we may want to know why there were no alerts: was it a service error? Or just a normal situation? Just getting null at the end isn't enough, and to work with these new requirements, we will need to add some extra functionality to our functors (as we'll see in the next section) and enter the domain of *monads*.

Monads

Monads have weird fame among programmers. Well-known developer Douglas Crockford has famously spoken of a curse, maintaining that "*Once you happen to finally understand monads, you immediately lose the ability to explain them to other people!*" On a different note, if you decide to go back to the basics and read *Categories for the Working Mathematician* by Saunders Mac Lane (one of the creators of category theory), you may find a somewhat disconcerting explanation—which is not too illuminating!

A monad in X is just a monoid in the category of endofunctors of X, with product × replaced by composition of endofunctors and unit set by the identity endofunctor.

The difference between monads and functors is that the former adds some extra functionality; we'll see what functionality they add soon. Let's start by looking at the new requirements before moving on and considering some common, useful monads. As with functors, we will have a basic monad, which you could consider an *abstract* version, and specific *monadic types*, which are *concrete* implementations geared to solve specific cases.

All you could want to read

To read a precise and careful description of functors, monads, and their family (but leaning heavily to the theoretical side, with plenty of algebraic definitions to go around), try the *Fantasy Land Specification* at `github.com/fantasyland/fantasy-land/`. Please don't say we didn't warn you: the alternative name for that page is *Algebraic JavaScript Specification*!

Adding operations

Let's consider a simple problem. Suppose you have the following pair of functions, working with `Maybe` functors: the first function tries to search for something (say, a client or a product) given its key, and the second attempts to extract some attribute from whatever we found (I'm being purposefully vague because the problem does not have anything to do with whatever objects or things we may be working with). Both functions produce `Maybe` results to avoid possible errors. We are using a mocked search function just to help us see the problem. For even keys, it returns fake data, and for odd keys, it throws an exception. The code for this search is very simple:

```
const fakeSearchForSomething = (key: number) => {
  if (key % 2 === 0) {
    return { key, some: "whatever", other: "more data" };
  } else {
    throw new Error("Not found");
  }
};
```

Using this search, our `findSomething()` function will try to do a search and return `Maybe.of()` (a `Just`) for a successful call, or `Maybe.of(null)` (a `Nothing`) in case of an error:

```
const findSomething = (key: number) => {
  try {
    const something = fakeSearchForSomething(key);
    return Maybe.of(something);
  } catch (e) {
    return Maybe.of(null);
  }
};
```

With this, we could think of writing these two functions to do some searching, but not everything would be fine; can you see the problem here?

```
const getSome = (something: any) =>
  Maybe.of(something.map((x: any) => x.some));

const getSomeFromSomething = (key: number) =>
  getSome(findSomething(key));
```

The problem in this sequence is that the output from `getSome()` is a `Maybe` value, which itself contains a `Maybe` value, so the result we want is double-wrapped, as we can see by executing a couple of calls, for an even number (which will return `"whatever"`) and for an odd number (which will be an error), as follows:

```
const xxx = getSomeFromSomething(2222).valueOf().valueOf();
// "whatever"

const yyy = getSomeFromSomething(9999).valueOf().valueOf();
// undefined
```

This problem can be easily solved in this toy problem if we avoid using `Maybe.of()` in `getSome()`, but this kind of issue can arise in many more complex ways. For instance, you could be building a `Maybe` out of an object, one of whose attributes happened to be a `Maybe`, and you'd end up in the same situation when accessing that attribute: you would end up with a double-wrapped value.

Now, we are going to look into monads. A monad should provide the following operations:

- A constructor.
- A function that inserts a value into a monad: our `of()` method.

- A function that allows us to chain operations: our `map()` method.
- A function that can remove extra wrappers: we will call it `unwrap()`. It will solve our preceding multiple wrapper problems. Sometimes, this function is called `flatten()`.

To simplify our coding, we will also have a function to chain calls and another function to apply functions, but we'll get to those later. Let's see what a monad looks like in actual JavaScript code. Data type specifications are very much like those for functors, so we won't repeat them here:

```
// monad.ts

class Monad<A> extends Functor<A> {
  static of<B>(x: B): Monad<B> {
    return new Monad(x);
  }

  map<B>(fn: (_: A) => B): Monad<B> {
    return new Monad(fn(this.x));
  }

  unwrap(): any {
    const myValue = this.x;
    return myValue instanceof Monad
      ? myValue.unwrap()
      : this;
  }
}
```

We use recursion to successively remove wrappers until the wrapped value isn't a container anymore. Using this method, we could avoid double wrapping easily, and we could rewrite our previous troublesome function like this:

```
const getSomeFromSomething = key =>
getSome(findSomething(key)).unwrap();
```

However, this sort of problem could reoccur at different levels. For example, if we were doing a series of `map()` operations, any intermediate results may end up double-wrapped. You could solve this by remembering to call `unwrap()` after each `map()`—note that you could do this even if it is not actually needed since the result of `unwrap()` would be the very same object (can you see why?). But we can do better! Let's define a `chain()` operation (sometimes named `flatMap()` instead, which is a bit confusing since we already have another meaning for that; see *Chapter 5*, *Programming Declaratively*, for more on this) that will do both things for us:

```
// continued...

class Monad<A> extends Functor<A> {
  .
  .
  .
  chain<B>(fn: (_: A) => B) {
    return this.map(fn).unwrap();
  }
}
```

There's only one operation left. Suppose you have a curried function with two parameters—nothing outlandish! What would happen if you provided that function to a `map()` operation?

```
const add = (x: number) => (y: number) => x + y;
// or curry((x,y) => x+y)

const something = Monad.of(2).map(add);
```

What would `something` be? Given that we have only provided one argument to add, the result of that application will be a function—not just any function, though, but a wrapped one! (Since functions are first-class objects, there's no logical obstacle to wrapping a function in a monad, is there?) What would we want to do with such a function? To be able to apply this wrapped function to a value, we'll need a new method: `ap()`. What could its value be? In this case, it could either be a plain number or a number wrapped in a monad as a result of other operations. Since we can always map a plain number into a wrapped one with `Map.of()`, let's have `ap()` work with a monad as its parameter; the new method would be as follows:

```
// continued...

class Monad<A> extends Functor<A> {
  .
  .
  .
  ap<B, C extends FN>(this: Monad<C>, m: Monad<B>) {
    return m.map(this.x);
  }
}
```

With this, you could then do the following:

```
const monad5 = something.ap(Monad.of(3));
console.log(monad5.toString())
// Monad(5)
```

You can use monads to hold values or functions and to interact with other monads and chaining operations as you wish. So, as you can see, there's no big trick to monads, which are just functors with some extra methods. Now, let's look at how we can apply them to our original problem and handle errors in a better way.

Handling alternatives – the Either monad

Knowing that a value was missing may be enough in some cases, but in others, you'll want to be able to provide an explanation. We can get such an explanation if we use a different functor, which will take one of two possible values—one associated with a problem, error, or failure, and another associated with normal execution, or success:

- A *left* value, which should be null, but if present, then it represents some special value (for example, an error message or a thrown exception) that cannot be mapped over
- A *right* value, which represents the normal value of the functor and can be mapped over

We can construct this monad similarly to what we did for `Maybe` (actually, the added operations make it better for `Maybe` to extend `Monad` as well). The constructor will receive a left and a right value. If the left value is present, it will become the value of the `Either` monad; otherwise, the right value will be used. Since we have provided `of()` methods for all our functors, we need one for `Either` too. The `Left` monad is very similar to our previous `Nothing`:

```
// either.ts

class Left extends Monad<any> {
  isLeft() {
    return true;
  }

  map(_: any) {
    return this;
  }
}
```

Similarly, `Right` resembles our previous `Just`:

```
// continued...

class Right<A> extends Monad<A> {
  isLeft() {
    return false;
  }

  map(fn: (_: A) => any) {
    return Either.of(null, fn(this.x));
  }
}
```

And with these two monads under our belt, we can write our `Either` monad. It shouldn't be surprising that this resembles our previous `Maybe`, should it?

```
// continued...

abstract class Either<A, B> extends Monad<A | B> {
  static of<C, D>(left: C, right?: D): Left | Right<D> {
    return right === undefined || right === null
      ? new Left(left)
      : new Right(right);
  }

  isLeft() {
    /* */
  }
}
```

The `map()` method is key. If this functor has got a left value, it won't be processed any further; in other cases, the mapping will be applied to the right value, and the result will be wrapped. Now, how can we enhance our code with this? The key idea is for every involved method to return an `Either` monad; `chain()` will be used to execute operations one after another. Getting the alerts would be the first step—we invoke the callback either with an `AJAX FAILURE` message or with the result from the API call, as follows:

```
const getAlerts2 = (lat, long, callback) => {
  const SERVER = "https://api.darksky.net/forecast";
  const UNITS = "units=si";
  const EXCLUSIONS = "exclude=minutely,hourly,daily,flags";
  const API_KEY = "you.have.to.get.your.own.key";

  request
    .get(
      `${SERVER}/${API_KEY}/${lat},${long}` +
        `?${UNITS}&${EXCLUSIONS}`
    )
    .end((err, res) =>
      callback(
        err
          ? Either.of("AJAX FAILURE", null)
          : Either.of(null, JSON.parse(res.text))
      )
    );
};
```

Then, the general process would be as follows. We use an `Either` monad again. If there are no alerts, instead of an array, we will return a `"NO ALERTS"` message:

```
const produceAlertsTable2 = (weatherObj: typeof resp) => {
  return weatherObj
    .chain((obj: typeof resp) => {
      const alerts = getField("alerts")(obj);
      return alerts
        ? Either.of(null, alerts)
        : Either.of("NO ALERTS", null);
    })
    .chain((a) =>
      a.map(
        (x) =>
          `<tr><td>${x.title}</td>` +
          `<td>${x.description.substr(0,
            500)}...</td></tr>`
      )
    )
    .chain((a) => a.join(os.EOL))
    .chain((s) => `<table>${s}</table>`);
};
```

Note how we used `chain()` so that multiple wrappers would be no problem. Now, we can test multiple situations and get appropriate results—or at least, for the current weather situation around the world!

- For Houston, TX, we still get an HTML table
- For Montevideo, UY, we get a text saying there were no alerts
- For a point with wrong coordinates, we learn that the AJAX call failed: nice!

```
// Houston, TX, US:
getAlerts2(29.76, -95.37, (x) =>
  console.log(produceAlertsTable2(x).toString())
);
// Right("...a table with alerts: lots of HTML code...");

// Montevideo, UY
getAlerts2(-34.9, -54.6, (x) =>
  console.log(produceAlertsTable2(x).toString())
);
// Left("NO ALERTS");

// A point with wrong coordinates
getAlerts2(444, 555, (x) =>
  console.log(produceAlertsTable2(x).toString())
);
// Left("AJAX FAILURE");
```

We are not done with the `Either` monad. It's likely that much of your code will involve calling functions. Let's look at a better way of achieving this by using a variant of this monad.

Calling a function – the Try monad

If we are calling functions that may throw exceptions and we want to do so in a functional way, we could use the `Try` monad to encapsulate the function result or the exception. The idea is basically the same as the `Either` monad. The only difference is in the constructor, which receives a function and calls it:

- If there are no problems, the returned value becomes the `right` value for the monad
- If there's an exception, it will become the `left` value

This can be seen in the following code:

```
// try.ts

class Try<A> extends Either<A, string> {
  // @ts-expect-error Call to super() not needed
  constructor(fn: () => A, msg?: string) {
    try {
      return Either.of(null, fn()) as Either<A, string>;
    } catch (e: any) {
      return Either.of(msg || e.message, null) as Either<
        string,
        string
      >;
    }
  }
}
```

Why the `@ts-expect-error` notation? A constructor should either call `super()` or return a fully constructed method, but TypeScript always expects the former, so we have to tell it that we know what we're doing here.

Now, we can invoke any function, catching exceptions in a good way. For example, the `getField()` function that we have been using would crash if it were called with a `null` argument:

```
const getField = attr => obj => obj[attr];
```

In the *Implementing prisms* section of *Chapter 10*, *Ensuring Purity*, we wrote a `getFieldP()` function that could deal with `null` values, but here, we will rewrite it using the `Try` monad, so, in addition, it will play nice with other composed functions. The alternative implementation of our getter would be as follows:

```
const getField2 = (attr: string) => (obj: OBJ | null) =>
  new Try(() => obj![attr], "NULL OBJECT");
```

We can check that this works by trying to apply our new function to a null value:

```
const x = getField2("somefield")(null);

console.log(x.isLeft()); // true
console.log(x.toString()); // Left(NULL OBJECT)
```

There are many more monads, and, of course, you can even define your own, so we couldn't possibly go over all of them. However, let's visit just one more—one you have been using already, without being aware of its monad-ness!

Unexpected monads – promises

Let's finish this section on monads by mentioning yet another one that you may have used, though under a different name: promises! Previously, we mentioned that functors (and, remember, monads are functors) had at least something in common with promises: using a method to access the value. However, the similarities are greater than that!

- `Promise.resolve()` corresponds with `Monad.of()`—if you pass a value to `.resolve()`, you'll get a promise resolved to that value, and if you provide a promise, you will get a new promise, the value of which will be that of the original one (see `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Promise/resolve` for more on this). This is an unwrapping behavior!
- `Promise.then()` stands for `Monad.map()` as well as `Monad.chain()`, given the mentioned unwrapping.

We don't have a direct match to `Monad.ap()`, but we could add something like the following code (this will be rejected by TypeScript, but we've seen how to solve this):

```
Promise.prototype.ap = function (promise2) {
  return this.then((x) => promise2.map(x));
};
```

Promises – never gone

Even if you opt for the modern `async` and `await` features, internally, they are based on promises. Furthermore, in some situations, you may still need `Promise.race()` and `Promise.all()`, so you will likely keep using promises, even if you opt for full ES8 coding.

This is an appropriate ending for this section. Earlier, you found that ordinary arrays were, in fact, functors. Now, in the same way that Monsieur Jourdain (a character in Molière's play *Le Bourgeois Gentilhomme*, *The Bourgeois Gentleman*) discovered that all his life he had been speaking in prose, you now know you had already been using monads without even knowing it! So far, we have learned how to build different types of containers. Now, let's learn how functions can also make do as containers, as well as for all kinds of data structures!

Functions as data structures

So far, we have learned how to use functions to work with or transform other functions to process data structures or to create data types. Now, we'll finish this chapter by showing you how a function can implement a data type, becoming a container of its own. In fact, this is a fundamental theoretical point of lambda calculus (if you want to learn more, look up *Church encoding* and *Scott encoding*), so we may very well say that we have come back to where we began this book, to the origins of FP! We will start with a detour that considers binary trees in a different functional language, Haskell, and then move on to implementing trees as functions, but in JavaScript. This experience will help you work out how to deal with other data structures.

Binary trees in Haskell

Consider a binary tree. Such a tree may either be empty or consist of a node (the tree *root*) with two children: a *left* binary tree and a *right* one. A node that has no children is called a *leaf*.

Of many types of trees

In *Chapter 9*, *Designing Functions*, we worked with more general tree structures, such as a filesystem or the browser DOM itself, which allow a node to have any number of children. In the case of the trees in this section, each node always has two children, although each of them may be empty. The difference may seem minor, but allowing for empty subtrees lets you define that all nodes are binary.

Let's make a digression with the Haskell language. In it, we might write something like the following; `a` would be the type of whatever value we hold in the nodes:

```
data Tree a = Nil | Node a (Tree a) (Tree a)
```

In the Haskell language, pattern matching is often used for coding. For example, we could define an empty function as follows:

```
empty :: Tree a -> Bool empty Nil = True
empty (Node root left right) = False
```

What does this mean? Apart from the data type definition, the logic is simple: if the tree is `Nil` (the first possibility in the definition of the type), then the tree is certainly empty; otherwise, the tree isn't empty. The last line would probably be written as `empty _ = False`, using _ as a placeholder because you don't actually care about the components of the tree; the mere fact that it's not `Nil` suffices.

Searching for a value in a binary search tree (in which the root is greater than all the values of its left subtree and less than all the values of its right subtree) would be written similarly:

```
contains :: (Ord a) => (Tree a)
     -> a -> Bool contains Nil _ = False

contains (Node root left right) x
```

```
| x == root = True
| x   < root = contains left x
| x   > root = contains right x
```

What patterns are matched here? We have four patterns now, which must be considered in order:

1. An empty tree (`Nil`—it doesn't matter what we are looking for, so just write _) doesn't contain the searched value.
2. If the tree isn't empty, and the root matches the searched value (`x`), we are done.
3. If the root doesn't match and is greater than the searched value, the answer is found while searching in the left subtree.
4. Otherwise, the answer is found by searching in the right subtree.

There's an important point to remember: for this data type, which is a union of two possible types, we have to provide two conditions, and pattern matching will be used to decide which one will be applied. Keep this in mind!

Functions as binary trees

Can we do something similar with functions? The answer is yes: we will represent a tree (or any other structure) with a function itself—not with a data structure that is processed by a set of functions, nor with an object with some methods, but by just a function. Furthermore, we will get a functional data structure that's 100% immutable, which, if updated, produces a new copy of itself. We will do all this without using objects; here, closures will provide the desired results.

How can this work? We shall be applying similar concepts to the ones we looked at earlier in this chapter, so the function will act as a container and produce, as its result, a mapping of its contained values. Let's walk backward and start by looking at how we'll use the new data type. Then, we'll go through the implementation details.

Creating a tree can be done by using two functions: `EmptyTree()` and `Tree(value, leftTree, rightTree)`. For example, let's say we wish to create a tree similar to the one shown in the following diagram:

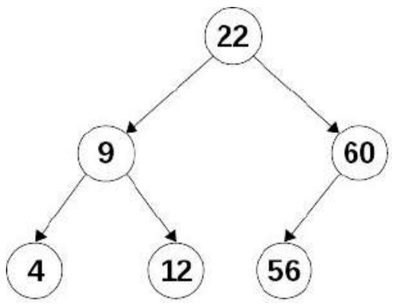


Figure 12.2 – A binary search tree

We can create this using the following code:

```
// functionAsTree.ts

const myTree: TREE = NewTree(
  22,
  NewTree(
    9,
    NewTree(4, EmptyTree(), EmptyTree()),
    NewTree(12, EmptyTree(), EmptyTree())
  ),
  NewTree(
    60,
    NewTree(56, EmptyTree(), EmptyTree()),
    EmptyTree()
  )
);
```

How do you work with this structure? According to the data type description, whenever you work with a tree, you must consider two cases: a non-empty tree and an empty one. In the preceding code, `myTree()` is a function that receives two functions as arguments, one for each of the two data type cases. The first function will be called with the node value and left and right trees as arguments, while the second function will receive none:

```
// continued...

type TREE<A> = (
  _nonEmptyTree: (
    _x: A,
    _left: TREE<A>,
    _right: TREE<A>
  ) => any,
  _emptyTree: () => any
) => any;
```

To get the root of a tree, we could write something similar to the following:

```
const myRoot = myTree(
  (value) => value,
    () => null
);
```

If we were dealing with a non-empty tree, we would expect the first function to be called and return the value of the root. With an empty tree, the second function should be called, and then a `null` value would be returned.

Similarly, if we wanted to count how many nodes there are in a tree, we would write the following:

```
// continued...

const treeCount = <A>(tree: TREE<A>): number =>
  tree(
    (value, left, right) =>
      1 + treeCount(left) + treeCount(right),
    () => 0
  );

console.log(treeCount(myTree));
```

For non-empty trees, the first function would return `1` (for the root), plus the node count from both the root's subtrees. For empty trees, the count is simply `0`. Get the idea?

Now, we can show the `NewTree()` and `EmptyTree()` functions. They are as follows:

```
// continued...

const NewTree =
  <A>(value: A, left: TREE<A>, right: TREE<A>): TREE<A> =>
  (destructure, _) =>
    destructure(value, left, right);

const EmptyTree =
  <A>(): TREE<A> =>
  (_, destructure) =>
    destructure();
```

The `destructure()` function is what you will pass as an argument (the name comes from the destructuring statement in JavaScript, which lets you separate an object attribute into distinct variables). You will have to provide two versions of this function. If the tree is non-empty, the first function will be executed; for an empty tree, the second one will be run (this mimics the case selection in the Haskell code, except we are placing the non-empty tree case first and the empty tree last). The underscore-named variable is used as a placeholder that stands for an otherwise-ignored argument but shows that two arguments are assumed; an initial underscore is usually meant to imply some parameter isn't used.

This can be hard to understand, so let's look at more examples. If we need to access specific elements of a tree, we have the following three functions:

```
// continued...

const treeRoot = <A>(tree: TREE<A>): A | null =>
  tree(
    (value, _left, _right) => value,
    () => null
  );
```

How can we decide whether a tree is empty? See whether you can figure out why the following short line of code works:

```
// continued...

const treeIsEmpty = <A>(tree: TREE<A>): boolean =>
  tree(
    () => false,
    () => true
  );
```

Let's go over a few more examples of this. For example, we can build an object out of a tree, which would help with debugging. I added logic to avoid including left or right empty subtrees, so the produced object would be more compact; check out the two `if` statements in the following code:

```
// continued...

const treeToObject = <A>(tree: TREE<A>): OBJ =>
  tree(
    (value, left, right) => {
      const leftBranch = treeToObject(left);
      const rightBranch = treeToObject(right);
      const result: OBJ = { value };
      if (leftBranch) {
        result.left = leftBranch;
      }
      if (rightBranch) {
        result.right = rightBranch;
      }
      return result;
    },
    () => null
  );
```

Note the usage of recursion, as in the *Traversing a tree structure* section of *Chapter 9*, *Designing Functions*, to produce the object equivalents of the left and right subtrees. An example of this function is as follows; I edited the output to make it clearer:

```
console.log(treeToObject(myTree));
/*
{
  value: 22,
  left: {
    value: 9,
    left: {
      value: 4,
    },
    right: { value: 12 },
  },
  right: {
    value: 60,
    left: {
      value: 56,
    },
  },
};
*/
```

Can we search for a node? Of course, and the logic closely follows the definition we saw in the previous section. (We could have shortened the code a bit, but I wanted to parallel the Haskell version; for a leaner version, see *Question 12.6*.) Our `treeSearch()` function could be as follows:

```
// continued...
```

```
const treeSearch = <A>(
  findValue: A,
  tree: TREE<A>
): boolean =>
  tree(
    (value, left, right) =>
      findValue === value
        ? true
        : findValue < value
        ? treeSearch(findValue, left)
        : treeSearch(findValue, right),
    () => false
  );
```

If the value we want is the root, we found it; if it's smaller than the root, we recursively search the left subtree, and if greater, the right subtree.

To round off this section, let's also look at how to add new nodes to a tree. Study the code carefully; you'll notice how the current tree isn't modified and that a new one is produced instead. Of course, given that we are using functions to represent our tree data type, it should be evident that we wouldn't have been able to modify the old structure: it's immutable by default. The tree insertion function would be as follows:

```
// continued...

const treeInsert = <A>(
  newValue: A,
  tree: TREE<A>
): TREE<A> =>
  tree(
    (value, left, right) =>
      newValue <= value
        ? NewTree(value, treeInsert(newValue, left), right)
        : NewTree(value, left, treeInsert(newValue,
          right)),
    () => NewTree(newValue, EmptyTree(), EmptyTree())
  );
```

When trying to insert a new key, if its value is less than or equal to the root of the tree, we produce a new tree that has the current root as its own root, maintains the old right subtree, but changes its left subtree to incorporate the new value (which will be done recursively). If the key was greater than the root, the changes wouldn't have been symmetrical; they would have been analogous. If we try to insert a new key and find ourselves with an empty tree, we replace that empty structure with a new tree having the new value at its root, and empty left and right subtrees.

We can test out this logic easily, but the simplest way is to verify that the binary tree that we showed earlier (*Figure 12.2*) is generated by the following sequence of operations:

```
let myTree = EmptyTree();
myTree = treeInsert(22, myTree);
myTree = treeInsert(9, myTree);
myTree = treeInsert(60, myTree);
myTree = treeInsert(12, myTree);
myTree = treeInsert(4, myTree);
myTree = treeInsert(56, myTree);

// The resulting tree is:
{
  value: 22,
  left: {
    value: 9,
    left: { value: 4 },
    right: { value: 12 },
  },
  right: { value: 60, left: { value: 56 } },
}
```

We could make this insertion function even more general by providing the comparator function that would be used to compare values. In this fashion, we could easily adapt a binary tree to represent a generic map. The value of a node would actually be an object such as `{key:... , data:...}` and the provided function would compare `newValue.key` and `value.key` to decide where to add the new node. Of course, if the two keys were equal, we would change the root of the current tree. The new tree insertion code would be as follows. Let's start with types and comparisons:

```
// continued...

type NODE<K, D> = { key: K; data: D };
```

```
const compare = <K, D>(
  obj1: NODE<K, D>,
  obj2: NODE<K, D>
) =>
  obj1.key === obj2.key ? 0 : obj1.key < obj2.key ? -1 : 1;
```

The tree insertion code is now the following:

```
// continued...

const treeInsert2 = <K, D>(
  comparator: typeof compare<K, D>,
  newValue: NODE<K, D>,
  tree: TREE<NODE<K, D>>
): TREE<NODE<K, D>> =>
  tree(
    (value, left, right) =>
      comparator(newValue, value) === 0
        ? NewTree(newValue, left, right)
        : comparator(newValue, value) < 0
        ? NewTree(
            value,
            treeInsert2(comparator, newValue, left),
            right
          )
        : NewTree(
            value,
            left,
            treeInsert2(comparator, newValue, right)
          ),
    () => NewTree(newValue, EmptyTree(), EmptyTree())
  );
```

What else do we need? Of course, we can program diverse functions: deleting a node, counting nodes, determining a tree's height, comparing two trees, and so on. However, in order to gain more usability, we should really turn the structure into a functor by implementing a `map()` function. Fortunately, using recursion, this proves to be easy—we apply the mapping function to the tree root and use `map()` recursively on the left and right subtrees, as follows:

```
// continued...

const treeMap = <A, B>(
  fn: (_x: A) => B,
  tree: TREE<A>
): TREE<B> =>
  tree(
    (value, left, right) =>
      NewTree(
        fn(value),
        treeMap(fn, left),
        treeMap(fn, right)
      ),
    () => EmptyTree()
  );
```

We could go on with more examples, but that wouldn't change the important conclusions we can derive from this work:

- We are handling a data structure (a recursive one, at that) and representing it with a function
- We aren't using external variables or objects for the data: closures are used instead
- The data structure satisfies all the requirements we analyzed in *Chapter 10*, *Ensuring Purity*, insofar that it is immutable and all the changes always produce new structures
- The tree is a functor, providing all the corresponding advantages

In this section, we have looked at one more application of FP as well as how a function can actually become a structure by itself, which isn't what we are usually accustomed to!

Summary

In this chapter, we looked at the theory of data types and learned how to use and implement them from a functional point of view. We started with defining function signatures to help us understand the transformations implied by the multiple operations we looked at later, with a syntax independent from TypeScript's. Then, we went on to define several containers, including functors and monads, and saw how they can be used to enhance function composition. Finally, we learned how functions can be directly used by themselves, with no extra baggage, to implement functional data structures to simplify dealing with errors.

In this book, we have looked at several features of FP for JavaScript and TypeScript. We started with some definitions, and a practical example, then moved on to important considerations such as pure functions, avoiding side effects, immutability, testability, building new functions out of other ones, and implementing a data flow based upon function connections and data containers. We have looked at a lot of concepts, but I'm confident that you'll be able to put them to practice and start writing even higher-quality code—give it a try, and thank you very much for reading this book!

Questions

12.1 **Extending prototypes**: Whenever we added to a prototype, TypeScript would object because of a missing `global` declaration; can you add that declaration?

12.2 **No protection?** For all our containers, we use classes with a (TypeScript-only) protected attribute that didn't allow accessing it from the "outside." However, in the previous editions, we worked with plain JavaScript; how could we manage hiding the attribute from outsiders? A hint may help: think of a `Symbol`!

12.3 **No abstract classes?** We used abstract classes for the `Maybe` and `Either` monads, but those types of classes are only available in TypeScript. Can you figure out an alternative way of working, but in JavaScript?

12.4 **Maybe tasks?** In the *Questions* section of *Chapter 8*, *Connecting Functions*, a question (*Question 8.2*) had to do with getting the pending tasks for a person while taking errors or border situations into account, such as the possibility that the selected person might not even exist. Redo that exercise but using a `Maybe` or `Either` monad to simplify that code.

12.5 **Extending your trees**: To get a more complete implementation of our functional binary search trees, implement the following functions:

- Calculate the tree's height or, equivalently, the maximum distance from the root to any other node
- List all the tree's keys, in ascending order
- Delete a key from a tree

12.6 **Code shortening**: We mentioned that the `treeSearch()` function could be shortened—can you do that? Yes, this is more of a JavaScript problem than a functional one, and I'm not saying that shorter code is necessarily better, but many programmers act as if it were, so it's good to be aware of such a style if only because you're likely to find it.

12.7 **Functional lists**: In the same spirit as binary trees, implement functional lists. Since a list is defined to be either empty or a node (*head*), followed by another list (*tail*), you might want to start with the following, quite similar to our binary search tree:

```
type LIST<A> = (
  _nonEmptyList: (_head: A, _tail: LIST<A>) => any,
  _emptyList: LIST<A>
) => any;

const NewList =
  <A>(head: A, tail: LIST<A>): LIST<A> =>
  (f: FN, _g: FN) =>
    f(head, tail);

const EmptyList =
  <A>(): LIST<A> =>
  (f: FN, g: FN) =>
    g();
```

Here are some easy one-line operations to get you started; note they are very similar in style to what we wrote for binary trees:

```
const listHead = <A>(list: LIST<A>): A | null =>
  list(
    (head: A, _tail: LIST<A>) => head,
    () => null
  );

const listTail = <A>(list: LIST): LIST<A> | null =>
  list(
    (head: A, tail: LIST<A>) => tail,
    () => null
  );

const listIsEmpty = <A>(list: LIST<A>): boolean =>
  list(
    (_head: A, _tail: LIST<A>) => false,
    () => true
  );

const listSize = <A>(list: LIST<A>): number =>
  list(
    (head: A, tail: LIST<A>) => 1 + listSize(tail),
      () => 0
    );
```

You could consider having these operations:

- Transforming a list into an array and vice versa
- Reversing a list
- Appending one list to the end of another list
- Concatenating two lists

Don't forget a `listMap()` function! Also, the `listReduce()` and `listFilter()` functions will come in handy.

12.8 **No Boolean operators?** Imagine we had the `true` and `false` Boolean values, but we didn't have any operators such as `&&`, `||`, or `!`. While we could make up for their absence with some (possibly repetitive) coding, we can have functions produce the same results; can you see how? Think along the same lines as for binary trees. We could represent a Boolean value by a function that takes a pair of functions as arguments and applies the first if the Boolean is true, and the second otherwise.

Answers to Questions

Here are the solutions (partial, or worked out in full) to the questions that were contained within the chapters in this book. In many cases, there are extra questions so that you can do further work if you choose to.

Chapter 1, Becoming Functional – Several Questions

1.1 **TypeScript, please!** The following are the fully annotated versions of the code in the chapter. This is the code for the factorial functions:

```
// question_01_typescript_please.ts

function fact(n: number): number {
  if (n === 0) {
    return 1;
  } else {
    return n * fact(n - 1);
  }
}

const fact2 = (n: number): number => {
  if (n === 0) {
    return 1;
  } else {
    return n * fact2(n - 1);
  }
};

const fact3 = (n: number): number =>
  n === 0 ? 1 : n * fact3(n - 1);
```

This is the code for the spreading examples:

```
// continued...
```

```
function sum3(a: number, b: number, c: number): number {
  return a + b + c;
}

const x: [number, number, number] = [1, 2, 3];
const y = sum3(...x); // equivalent to sum3(1,2,3)

const f = [1, 2, 3];
const g = [4, ...f, 5];
const h = [...f, ...g];

const p = { some: 3, data: 5 };
const q = { more: 8, ...p };

const numbers = [2, 2, 9, 6, 0, 1, 2, 4, 5, 6];
const minA = Math.min(...numbers); // 0

const maxArray = (arr: number[]) => Math.max(...arr);
const maxA = maxArray(numbers); // 9
```

Why do we need to specify the type of `x`, but not those of `f`, `g`, `h`, `p`, and `q`? The issue is that TypeScript checks the call to `sum3()`, and for that, it needs to be sure that `x` is defined to be an array with three numbers.

TypeScript would be able to deduce that `sum3()` returns a number, but it's best if you specify it, to prevent possible future bugs where you would return something that isn't a number.

The `newCounter()` function needs no type definitions; TypeScript is able to work types out. (See *Question 1.7* further on.)

1.2 **Classes as first-class objects**: As you may recall, a class is basically a function that can be used with `new`. Therefore, it stands to reason that we should be able to pass classes as parameters to other functions. `makeSaluteClass()` creates a class (that is, a special function) that uses a closure to remember the value of `term`. We have looked at more examples like this throughout this book.

The TypeScript code for the class is as follows:

```
// question_01_classes_as_1st_class.ts

const makeSaluteClass = (term: string) =>
```

```
  class {
    x: string;

    constructor(x: string) {
      this.x = x;
    }

    salute(y: string) {
      console.log(`${this.x} says "${term}" to ${y}`);
    }
  };

const Spanish = makeSaluteClass("HOLA");
new Spanish("ALFA").salute("BETA");
// ALFA says "HOLA" to BETA

new (makeSaluteClass("HELLO"))("GAMMA").salute("DELTA");
// GAMMA says "HELLO" to DELTA

const fullSalute = (
  c: ReturnType<typeof makeSaluteClass>,
  x: string,
  y: string
) => new c(x).salute(y);

const French = makeSaluteClass("BON JOUR");
fullSalute(French, "EPSILON", "ZETA");
// EPSILON says "BON JOUR" to ZETA
```

Note the usage of TypeScript's `ReturnType<>` utility type to specify that `c` will be something created by calling `makeSaluteClass()`.

1.3 **Climbing factorial**: The following code does the trick. We add an auxiliary variable, `f`, and we make it climb from `1` to `n`. We must be careful so that `factUp(0) === 1`:

```
// question_01_climbing_factorial.ts
```

```
const factUp = (n: number, f = 1): number =>
  n <= f ? f : f * factUp(n, f + 1);
```

You don't need to specify that `f` is of type `number`; TypeScript automatically works that out.

This solution may worry you because nobody prevents calling `factUp()` with two arguments – but we need the second parameter to be omitted, so it will be initialized to `1`. We can solve this defect as follows:

```
// continued...

const factUp2 = (n: number): number => {
  const factAux = (f: number): number =>
    n <= f ? f : f * factAux(f + 1);
  return factAux(1);
};
```

The internal `factAux()` function is basically our previous `factUp()` function, except that it doesn't need the `n` parameter, because it's available in its scope. Our new `factUp2()` function calls `factAux()`, providing its needed default value of `1`.

If you like having a default value, you can go with the following code:

```
// continued...

const factUp3 = (n: number): number => {
  const factAux = (f = 1): number =>
    n <= f ? f : f * factAux(f + 1);
  return factAux();
};
```

To test these functions, the tests (for correct values) in *Question 1.5* will do.

1.4 **Factorial errors**: The key to avoiding repeating tests is to write a function that will check the value of the argument to ensure it's valid, and if so, call an inner function to do the factorial itself, without worrying about erroneous arguments:

```
// question_01_factorial_errors.ts

const carefulFact = (n: number): number | never => {
  if (
    typeof n === "number" &&
    n >= 0 &&
    n === Math.floor(n)
  ) {
    const innerFact = (n: number): number =>
      n === 0 ? 1 : n * innerFact(n - 1);
    return innerFact(n);
  } else {
    throw new Error("Wrong parameter for carefulFact2");
  }
};
```

In order, we check that `n` must be a number, not negative, and an integer. When an incorrect argument is recognized, we throw an error. By the way, that's the reason for the `number | never` type specification; the user of this function directly recognizes that sometimes (namely, when an exception is thrown) no value will be returned.

1.5 **Factorial testing**: The following tests do the trick:

```
// question_01_factorial_testing.test.ts

import { carefulFact } from "./question_1.4";

describe("Correct cases", () => {
  test("5! = 120", () => expect(carefulFact(5)).toBe(120));

  test("0! = 1", () => expect(carefulFact(0)).toBe(1));
});

describe("Errors", () => {
  test("Should reject 3.1", () => {
    expect(() => carefulFact(3.1)).toThrow();
  });

  test("Should reject -4", () => {
    expect(() => carefulFact(-3)).toThrow();
  });

  test("Should reject -5.2", () => {
    expect(() => carefulFact(-3)).toThrow();
  });
});
```

Running the suite shows we achieved 100% coverage.

1.6 **Code squeezing**: Using arrow functions, as suggested, as well as the prefix ++ operator (for more information, see `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Operators/Increment`), you can condense `newCounter()` down to the following:

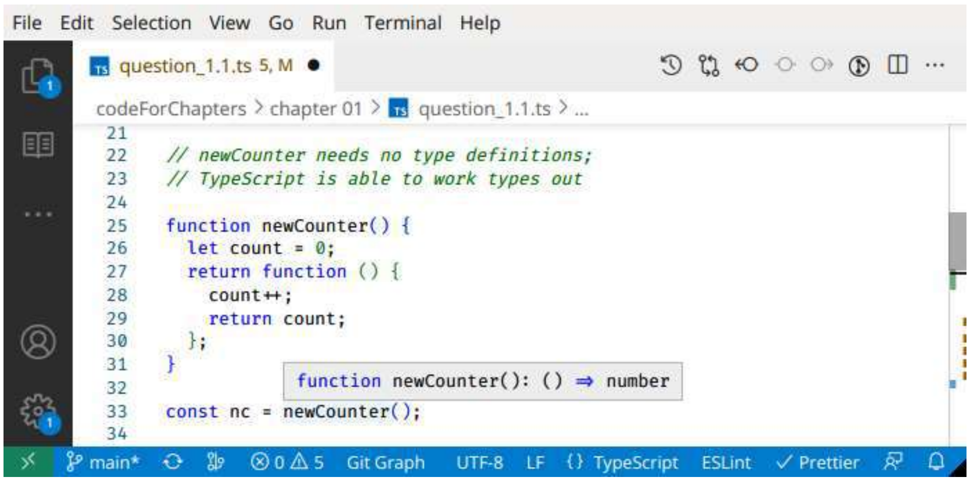
```
// question_01_code_squeezing.ts

const shorterCounter = () => {
  let count = 0;
  return () => ++count;
};
```

Using arrow functions isn't hard to understand, but be aware that many developers may have questions or doubts about using ++ as a prefix operator, so this version could prove to be harder to understand.

ESLint has a `no-plusplus` rule that disallows both ++ and `--`. Since I do approve of using them, I had to disable the rule; see `eslint.org/docs/latest/user-guide/configuring/rules` for more on this.

1.7 **What type is it?** As `newCounter()` takes no arguments and returns a number, the answer is `() => number`.

If you are working with Visual Studio Code, there's a quicker way of doing this: hovering will provide the answer, as in *Figure 1*.


File Edit Selection View Go Run Terminal Help
question_1.1.ts 5, M
codeForChapters > chapter 01 > question_1.1.ts > ...
main* ⊗ 0 ⚠ 5 Git Graph UTF-8 LF {} TypeScript ESLint ✓ Prettier

```
// newCounter needs no type definitions;
// TypeScript is able to work types out

function newCounter() {
  let count = 0;
  return function () {
    count++;
    return count;
  };
}
                  function newCounter(): () => number
const nc = newCounter();
```

Figure 1 – Visual Studio Code helps with typing

Chapter 2, Thinking Functionally – A First Example

2.1 **No extra variables**: We can make do by using the `fn` variable itself as a flag. After calling `fn()`, we set the variable to `null`. Before calling `fn()`, we check that it's not `null` by using the short-circuit `&&` operator:

```
// question_02_no_extra_variables.ts

const once = <FNType extends (...args: any[]) => any>(
  fn: FNType | null
) =>
  ((...args: Parameters<FNType>) => {
    fn && fn(...args);
    fn = null;
  }) as FNType;
```

We need a small change to let TypeScript know that `fn` could be `null`; otherwise, it would object to the `fn = null` assignment.

2.2 **Alternating functions**: Like what we did in the previous question, we swap functions, and then we do the call. Here, we use a destructuring assignment to write the swap more compactly. For more information, refer to `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Operators/Destructuring_assignment#swapping_variables`:

```
// question_02_alternating_fns.ts

const alternator = <FNType extends (...args: any[]) =>
  any>(
  fn1: FNType,
  fn2: FNType
) =>
  ((...args: Parameters<FNType>) => {
    [fn1, fn2] = [fn2, fn1];
    return fn2(...args);
  }) as FNType;
```

We can write a test as follows:

```
// question_02_alternating_fns.test.ts

import { alternator } from "./question_2.2";

describe("alternator", () => {
  it("calls the two functions alternatively", () => {
    const funcA = jest.fn().mockReturnValue("A");
    const funcB = jest.fn().mockReturnValue("B");
    const testFn = jest.fn(alternator(funcA, funcB));

    expect(testFn()).toEqual("A");
    expect(testFn()).toEqual("B");
    expect(testFn()).toEqual("A");
    expect(testFn()).toEqual("B");
    expect(testFn()).toEqual("A");
    expect(testFn()).toEqual("B");

    expect(testFn).toHaveBeenCalledTimes(6);
    expect(funcA).toHaveBeenCalledTimes(3);
    expect(funcB).toHaveBeenCalledTimes(3);
  });
});
```

We set up two mock functions, one will return `"A"` and the other `"B"`, and then we test that successive calls alternate between those two values.

2.3 **Everything has a limit!** We simply check whether `limit` is greater than `0`. If so, we decrement it by 1 and call the original function; otherwise, we do nothing:

```
// question_02_everything_has_a_limit.ts

const thisManyTimes =
  <FNType extends (...args: any[]) => any>(
    fn: FNType,
    limit: number
  ) =>
  (...args: Parameters<FNType>) => {
    if (limit > 0) {
      limit--;
      return fn(...args);
    }
  };
```

We can write a test for it as follows:

```
// question_02_everything_has_a_limit.test.ts

import { thisManyTimes } from "./question_2.3";

describe("thisManyTimes", () => {
  it("calls the function 2 times, nothing after", () => {
    const fn = jest.fn();
    const testFn = jest.fn(thisManyTimes(fn, 2));

    testFn(); // works
    testFn(); // works
    testFn(); // nothing now
    testFn(); // nothing now
    testFn(); // nothing now
    testFn(); // nothing now
    expect(testFn).toHaveBeenCalledTimes(6);
    expect(fn).toHaveBeenCalledTimes(2);
  });
});
```

Our `testFn()` function is set to call `fn()` twice, no more; the tests confirm that behavior.

2.4 **Allow for crashing**: We just have to modify `once()`, so if `fn()` crashes, we'll reset `done` to `false` to allow a new attempt:

```
// question_02_allow_for_crashing.ts

const onceIfSuccess = <
  FNType extends (...args: any[]) => any
>(
  fn: FNType
) => {
  let done = false;

  return ((...args: Parameters<FNType>) => {
    if (!done) {
      done = true;
      try {
        return fn(...args);
      } catch {
        done = false;
      }
    }
  }) as FNType;
};
```

We can see this works with a simple example; our `crashTwice()` function will throw an error twice and work fine afterward:

```
// question_02_allow_for_crashing.manual.ts

import { onceIfSuccess } from "./question_2.4";
```

```
let count = 0;

const crashTwice = () => {
  count++;
  if (count <= 2) {
    console.log("CRASH!");
    throw new Error("Crashing...");
  } else {
    console.log("OK NOW");
  }
};

const doIt = onceIfSuccess(crashTwice);

doIt(); // CRASH!
doIt(); // CRASH!
doIt(); // OK NOW
doIt(); // nothing
doIt(); // nothing
doIt(); // nothing
```

We can write tests as follows:

```
// question_02_allow_for_crashing.test.ts

import { onceIfSuccess } from "./question_2.4";

describe("onceIfSuccess", () => {
  it("should run once if no errors", () => {
    const myFn = jest.fn();
    const onceFn = jest.fn(onceIfSuccess(myFn));

    onceFn();
    onceFn();
    onceFn();
    expect(onceFn).toHaveBeenCalledTimes(3);
    expect(myFn).toHaveBeenCalledTimes(1);
  });

  it("should run again if an exception", () => {
    const myFn = jest.fn()
      .mockImplementationOnce(() => {
        throw new Error("ERROR 1");
      })
      .mockImplementationOnce(() => {
        throw new Error("ERROR 2");
      })
      .mockReturnValue(22);

    const onceFn = jest.fn(onceIfSuccess(myFn));

    expect(onceFn).toThrow();
    expect(onceFn).toThrow();
    expect(onceFn()).toBe(22); // OK now (returns 22)
    onceFn(); // nothing
    onceFn(); // nothing
    onceFn(); // nothing

    expect(onceFn).toHaveBeenCalledTimes(6);
    expect(myFn).toHaveBeenCalledTimes(3);
  });
});
```

We need to check two cases: when the called function works normally and when it crashes at least once. The first case is just like the test we wrote for `once()`, so nothing is new here. For the second case, we set up a mock `myFn()` function that throws errors twice and returns a regular value afterward; the test verifies the expected behavior.

2.5 **Say no to arrows**: The code is essentially the same, but the placement of type information varies:

```
// question_02_say_no_to_arrows.ts
```

```
function once<FNType extends (...args: any[]) => any>(
  fn: FNType
): FNType {
  let done = false;

  return function (...args: Parameters<FNType>) {
    if (!done) {
      done = true;
      return fn(...args);
    }
  } as FNType;
}
```

Chapter 3, Starting Out with Functions – A Core Concept

3.1 **Uninitialized object?** The key is that we didn't wrap the returned object in parentheses, so JavaScript thinks the braces enclose the code to be executed. In this case, `type` is considered to be labeling a statement, which doesn't really do anything: it's a `(t)` expression that isn't used. Due to this, the code is considered valid, and since it doesn't have an explicit `return` statement, the implicit returned value is `undefined`.

The corrected code is as follows:

```
const simpleAction = (t:string) => ({
  type: t;
});
```

See `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Statements/label` for more on labels, and `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Functions/Arrow_functions#Returning_object_literals` for more on returning objects.

3.2 **Are arrows allowed?** There would be no problems with `useArguments2()`, but with `useArguments()`, you would get an error since arguments are not defined for arrow functions:

```
useArguments(22,9,60);
Uncaught ReferenceError: arguments is not defined
```

3.3 **Three more types**: We have the following:

- `fn1` is `(y: number) => (z: number) => number`
- `fn2` is `(z: number) => number`
- `fn3` is just `number`

3.4 **One-liner**: It works! (Yes, a one-line answer is appropriate in this case!)

3.5 **Reducing types**: Let's see all the types that we'll need. For `State`, we'd have an object with all the fields needed for your application. For a generic version, we could write the following, but a specific description would be much better:

```
type State = Record<string, unknown>;
```

We would define all the possible action types with something like the following:

```
type ActionType = "CREATE" | "DELETE" | "UPDATE";
```

We'd have an object with `type` and an optional `payload` for actions:

```
type Action = {
  type: ActionType;
  payload: Record<string, unknown> | null;
};
```

(It would be much better if you defined in detail what possible payloads you could have, instead of going with a generic definition as in the preceding code.)

Our `doAction()` function would be as follows:

```
function doAction(state: State, action: Action) {
  const newState: State = {};
  switch (action?.type) {
    …
  }
}
```

For `dispatchTable`, we'd have the following:

```
const dispatchTable: Record<
```

```
  ActionType,
  (state: State, action: Action) => State
> = {
  CREATE: (state, action) => {
    // update state, generating newState,
    // depending on the action data
    // to create a new item
    const NewState: State = {
      /* updated State */
    };
    return NewState;
  },
  …
};
```

Finally, we would write the following:

```
function doAction2(state: State, action: Action) {
  return dispatchTable[action.type]
    ? dispatchTable[action.type](state, action)
    : state;
}
```

3.6 **Spot the bug!** Initially, many people look at the weird (`console(...), window.store.set(...)`) code, but the bug isn't there: because of how the comma operator works, JavaScript does the logging first, and then the setting. The real problem is that `oldSet()` is not bound to the `window.store` object, so the second line should be as follows instead:

```
const oldSet = window.store.set.bind(window.store);
```

Reread the *Working with methods* section for more on this, and see *Question 11.1* for another way of doing logging – that is, with decorators.

3.7 **Bindless binding**: If `bind()` wasn't available, you could use a closure, the `that` trick (which we saw in the *Handling the this value* section), and the `apply()` method, as follows:

```
// question_03_bindless_binding.ts
```

```
function bind(context) {
  var that = this;
  return function() {
    return that.apply(context, arguments);
  };
}
```

We could do something similar to what we did in the *Adding missing functions* section.

Alternatively, just for variety, we could use a common idiom based on the `||` operator: if `Function.prototype.bind` exists, evaluation stops right there, and the existing `bind()` method is used; otherwise, our new function is applied:

```
Function.prototype.bind =
  Function.prototype.bind || function(context) {
  var that = this;
  return function() {
    return that.apply(context, arguments);
  };
};
```

3.8 **Mystery sort**: The `compare(a,b)` comparison function must return a positive number if `a>b`, a negative number if `a<b`, or `0` if `a` equals `b`. When you subtract `ab`, you get that result, so it works. (Of course, this assumes that no number is either `Infinity` or `NaN`.) For more on this, check `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Array/sort#description`.

3.9 **Negative sort**: All negative numbers get sorted first because of the initial "`-`", so that's kind of right, but the numbers themselves are still sorted as strings, so the result is wrong anyway. In the following example, the lowest number is `-666`, which should have been the first element after sorting:

```
let someNumbers = [3, 20, 100, -44, -5, -666];

someNumbers.sort();  // [-44, -5, -666, 100, 20, 3]
```

3.10 **Lexicographic sorting**: Let's suppose we have an array of strings. To sort it lexicographically in an efficient way, a solution would be as follows:

1. Transform the array of strings into an array of objects with an added `sortBy` field.
2. For each string, generate the corresponding string to sort by, and put the value in the `sortBy` field.
3. Sort the array by `sortBy`.
4. Drop the added field to convert the sorted array into an array of strings as originally.

3.11 **Stubbed logging**: The `console.log()` method can accept any number of arguments of any type, and won't return anything, so its type is `(...args: any[]): void`.

Chapter 4, Behaving Properly – Pure Functions

4.1 **Must return?** If a pure function doesn't return anything, it means that the function doesn't do anything since it can't modify its inputs and doesn't have any other side effect.

4.2 **Well-specified return**: TypeScript would have objected because the result of the function would be `string | undefined`, because the `.pop()` method returns `undefined` if the input array is empty.

4.3 **Go for a closure**: We just have to wrap the definition of `fib2()` in an IIFE; `fibC()` is equivalent to `fib2()` but with an internal `cache`:

```
// question_04_go_for_a_closure.ts

const fibC = (() => {
  const cache: number[] = [];

  const fib2 = (n: number): number => {
    if (cache[n] === undefined) {
      if (n === 0) {
        cache[0] = 0;
      } else if (n === 1) {
        cache[1] = 1;
      } else {
        cache[n] = fib2(n - 2) + fib2(n - 1);
      }
      }

      return cache[n];
    };

  return fib2;
})();
```

4.4 **Minimalistic function**: It works because fib(0)=0 and fib(1)=1, so it's true that for n<2, fib(n) equals n.

4.5 **A cheap way**: This algorithm works the same way as you'd calculate a Fibonacci number by hand. You'd start by writing down fib(0)=0 and fib(1)=1, adding them to get fib(2)=1, adding the last two to get fib(3)=2, and so on. In this version of the algorithm, `a` and `b` stand for two consecutive Fibonacci numbers. This implementation is quite efficient!

4.6 **Rounding type**: The full definition, including the result type, would be as follows:

```
const roundFix2 = (
  accum: number,
  n: number
): {
  accum: number;
  nRounded: number;
} => ...
```

4.7 **Tuples to go**: In this case, we would return an array with two numbers, so we may write the following:

```
// question_04_tuples_to_go.ts

type AccumRoundedType = [number, number];

const roundFix2a = (
  accum: number,
  n: number
): AccumRoundedType => {
  const nRounded = accum > 0 ? Math.ceil(n) :
    Math.floor(n);
  accum += n - nRounded;
  return [accum, nRounded];
};

const roundFix2b = ([
  accum,
  n,
]: AccumRoundedType): AccumRoundedType => {
  const nRounded = accum > 0 ? Math.ceil(n) :
    Math.floor(n);
  accum += n - nRounded;
  return [accum, nRounded];
};
```

The tests are very similar to what we already wrote; here, we have abridged versions of our previous code, highlighting the needed changes:

```
// question_04_tuples_to_go.test.ts

describe("roundFix2a", function () {
  it("rounds 3.14159->3 if differences are 0", () => {
    const [accum, nRounded] = roundFix2a(0.0, 3.14159);
    expect(accum).toBeCloseTo(0.14159);
    expect(nRounded).toBe(3);
  });

  it("rounds 2.71828->3 if differences are 0.14159", () =>
    {
    const [accum, nRounded] = roundFix2a(0.14159, 2.71828);
    expect(accum).toBeCloseTo(-0.14013);
    expect(nRounded).toBe(3);
  });
});
```

```
describe("roundFix2b", function () {
  it("rounds 2.71828->2 if differences are -0.14013", () =>
    {
    const [accum, nRounded] = roundFix2b([
      -0.14013, 2.71828,
    ]);
    expect(accum).toBeCloseTo(0.57815);
    expect(nRounded).toBe(2);
  });

  it("rounds 3.14159->4 if differences are 0.57815", () =>
    {
    const [accum, nRounded] = roundFix2b([
      0.57815, 3.14159,
    ]);
    expect(accum).toBeCloseTo(-0.28026);
    expect(nRounded).toBe(4);
  });
});
```

4.8 **One injection or two?** Having two optional injected functions would allow specifying one but omitting the other, and then `calculateDeb2()` would still attempt to call the API. Providing an object with the dependencies makes injection an *all-or-nothing* option.

4.9 **JavaScript does math?** If you run the code, you'll (unexpectedly) get the `"Math failure?"` message. The problem has to do with the fact that JavaScript internally uses binary instead of decimal, and floating-point precision is limited. In decimal, 0.1, 0.2, and 0.3 have a fixed, short representation, but in binary, they have infinite representation, much like 1/3=0.33333... has in decimal. If you write out the value of `a+b` after the test, you'll get 0.30000000000000004 – and that's why you must be very careful when testing for equality in JavaScript.

4.10 **Breaking laws**: Some of the properties are no longer always valid. To simplify our examples, let's assume two numbers are close to each other if they differ by no more than 0.1. If this is the case, then we have the following:

- 0.5 is close to 0.6, and 0.6 is close to 0.7, but 0.5 is not close to 0.7
- 0.5 is close to 0.6, and 0.7 is close to 0.8, but *0.5+0.7=1.2* is not close to *0.6+0.8=1.4*, and *0.5*0.7=0.35* is not close to *0.6*0.8=0.48* either
- 0.5 is close to 0.4, and 0.2 is close to 0.3, but *0.5-0.2=0.3* is not close to *0.4-0.3=0.1*, and *0.5/0.2=2.5* is not close to *0.4/0.3=1.333*

The other cited properties are always valid.

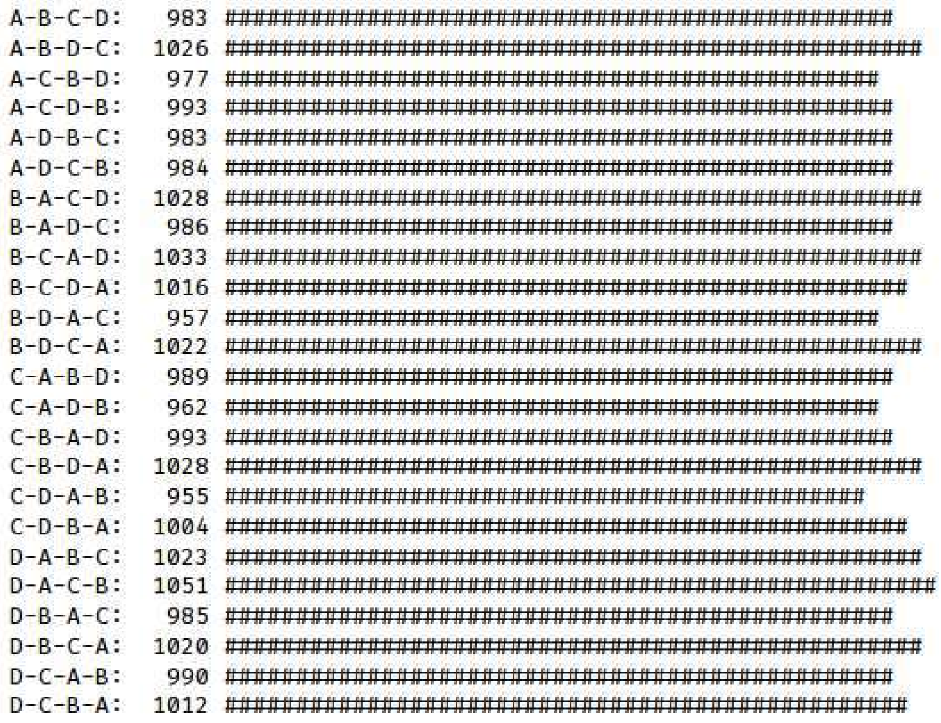
4.11 **Shuffling kinds**: This type definition allows our function to work with arrays of any type (strings, numbers, objects, etc.) and says that the type of the output array will be the same as the type of the input array.

4.12 **No return needed**: If no data is returned, we then write `<T>(arr: T[]) => void`. See `www.typescriptlang.org/docs/handbook/2/functions.html` for more.

4.13 **A shuffle test**: Before shuffling the array, sort a copy of it, use `JSON.stringify()` on it, and save the result. After shuffling, sort a copy of the shuffled array and use `JSON.stringify()` on it too. Those two JSON strings should be equal. This does away with all the other tests since it ensures that the array doesn't change its length or elements, and it would also work for arrays with repeated elements:

```
// question_04_a_shuffle_test.test.ts

describe("shuffleTest", function () {
  it("doesn't change the array length or elements", () => {
    const a = [22, 9, 60, 22, 12, 4, 56, 22, 60];
    const oldA = JSON.stringify([...a].sort());
    shuffle(a);
    const newA = JSON.stringify([...a].sort());
    expect(oldA).toBe(newA);
  });
});
```

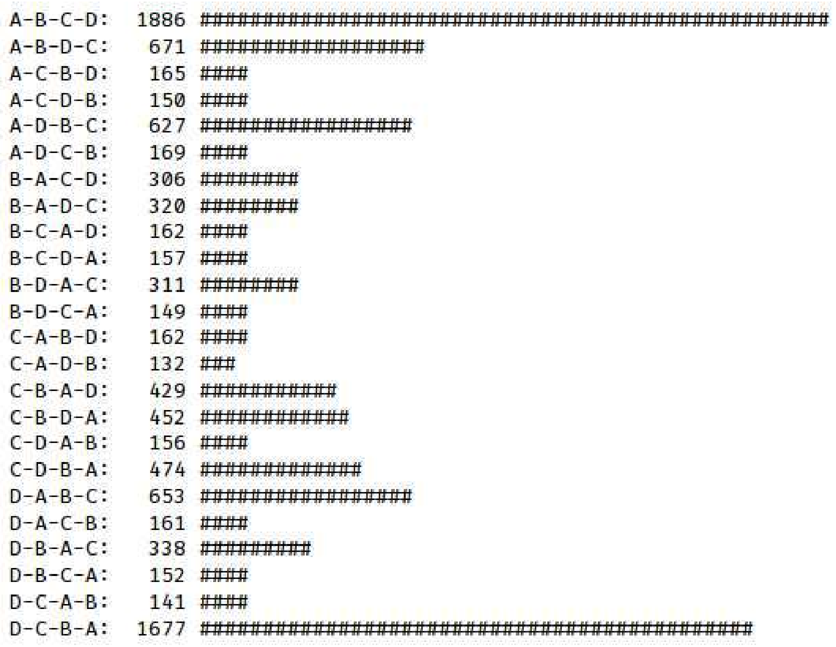
4.14 **Popular, but wrong!** To test that a `shuffle` function works well, an idea is to shuffle a small array many times, and count how many possible outputs come up; the final counts should be similar, though not necessarily (because of the random aspects) equal. In my article at `blog.openreplay.com/forever-functional-shuffling-an-array-not-as-trivial-as-it-sounds/`, I tested the Fisher–Yates algorithm by shuffling a four-letter (A to D) array 24,000 times, and got this:



```
A-B-C-D:   983 ################################################
A-B-D-C:  1026 ##################################################
A-C-B-D:   977 ###############################################
A-C-D-B:   993 ################################################
A-D-B-C:   983 ################################################
A-D-C-B:   984 ################################################
B-A-C-D:  1028 ##################################################
B-A-D-C:   986 ################################################
B-C-A-D:  1033 ##################################################
B-C-D-A:  1016 #################################################
B-D-A-C:   957 ###############################################
B-D-C-A:  1022 ##################################################
C-A-B-D:   989 ################################################
C-A-D-B:   962 ###############################################
C-B-A-D:   993 ################################################
C-B-D-A:  1028 ##################################################
C-D-A-B:   955 ##############################################
C-D-B-A:  1004 #################################################
D-A-B-C:  1023 ##################################################
D-A-C-B:  1051 ###################################################
D-B-A-C:   985 ################################################
D-B-C-A:  1020 ##################################################
D-C-A-B:   990 ################################################
D-C-B-A:  1012 #################################################
```

All 24 possible orderings were produced (see the *Recursion* section in *Chapter 1, Becoming Functional*), and the results were all pretty close to 1,000; the difference between the highest and lowest counts is only around 10%. This is not a thorough statistical confirmation – for that, we'd have to apply statistical frequency tests such as χ^2 (Chi-squared), Kolmogorov–Smirnov, or Anderson–Darling – but at least we get a notion that shuffling is not working very badly.

When I applied the (supposedly good!) algorithm, the counts were more lopsided:



```
A-B-C-D:  1886 ######################################################
A-B-D-C:   671 ###################
A-C-B-D:   165 ####
A-C-D-B:   150 ####
A-D-B-C:   627 ##################
A-D-C-B:   169 ####
B-A-C-D:   306 ########
B-A-D-C:   320 ########
B-C-A-D:   162 ####
B-C-D-A:   157 ####
B-D-A-C:   311 ########
B-D-C-A:   149 ####
C-A-B-D:   162 ####
C-A-D-B:   132 ###
C-B-A-D:   429 ############
C-B-D-A:   452 #############
C-D-A-B:   156 ####
C-D-B-A:   474 ##############
D-A-B-C:   653 ##################
D-A-C-B:   161 ####
D-B-A-C:   338 #########
D-B-C-A:   152 ####
D-C-A-B:   141 ####
D-C-B-A:  1677 ###############################################
```

The highest count is more than 14 times the lowest; we can definitely conclude that not all arrangements are equally likely, so the popular shuffling algorithm is simply not good enough.

4.15 **Shuffling by sorting**: To get a random sequence, we can assign to each array element a random number and sort by that number; the result will be a totally random shuffling:

```
// question_04_shuffling_by_sorting.ts

const sortingShuffle = <T>(arr: T[]): T[] =>
  arr
    .map((v) => ({ val: v, key: Math.random() }))
    .sort((a, b) => a.key - b.key)
    .map((o) => o.val);
```

The first `.map()` transforms each array element into an object, with the original value at `val` and a random value at `key`. We then sort the array by the `key` value, using the technique shown in *Question 3.8*. Finally, we undo the first mapping to get just the original values.

A final comment: this code is truly functional, and returns a new array instead of modifying the original argument in place.

Chapter 5, Programming Declaratively – A Better Style

5.1 **Generating HTML code, with restrictions**: In real life, you wouldn't limit yourself to using only `filter()`, `map()`, and `reduce()`, but the objective of this question was to make you think about how to manage with only those. Using `join()` or other extra string functions would make the problem easier. For instance, finding out a way to add the enclosing `<div><ul> ... </ul></div>` tags is tricky, so we had to make the first `reduce()` operation produce an array so that we could keep on working on it:

```
const characters = [
  { name: "Fred", plays: "bowling" },
  { name: "Barney", plays: "chess" },
  { name: "Wilma", plays: "bridge" },
  { name: "Betty", plays: "checkers" },
  { name: "Pebbles", plays: "chess" },
];

const list = characters
  .filter(
    (x) => x.plays === "chess" || x.plays == "checkers"
  )
  .map((x) => `<li>${x.name}</li>`)
  .reduce((a, x) => [a[0] + x], [""])
  .map((x) => `<div><ul>${x}</ul></div>`)
  .reduce((a, x) => x);

console.log(list);
/* Output is a single line; here output is wrapped
<div><ul><li>Barney</li><li>Betty</li><li>Pebbles</li>
</ul></div>
*/
```

Accessing the array and index arguments for the `map()` or `reduce()` callbacks would also provide solutions:

```
const list2 = characters
  .filter(
    (x) => x.plays === "chess" || x.plays == "checkers"
  )
  .map(
    (x, i, t) =>
      `${i === 0 ? "<div><ul>" : ""}` +
      `<li>${x.name}</li>` +
      `${i == t.length - 1 ? "</ul></div>" : ""}`
  )
  .reduce((a, x) => a + x, "");

// exact same result
```

We could also do the following:

```
const list3 = characters
  .filter(
    (x) => x.plays === "chess" || x.plays == "checkers"
  )
  .map((x) => `<li>${x.name}</li>`)
  .reduce(
    (a, x, i, t) =>
      a + x + (i === t.length - 1 ? "</ul></div>" : ""),
    "<div><ul>"
  );

// again, the same result
```

Study the three examples: they will help you gain insight into these higher-order functions and provide you with ideas so that you can do independent work.

5.2 **More formal testing**: Use an idea from *Question 4.13*; select an array and a function, find the result of mapping using both the standard `map()` method and the new `myMap()` function, but instead of using `JSON.stringify()`, use Jest's `toEqual()` method to compare the results. See the answer to *Question 5.5* for more.

5.3 **Reverse by summing**: This works, but we need to define an overloaded `sum()` function so TypeScript won't object. Overloading isn't available for arrow functions, so we have to change how we define `sum()`:

```
function sum(x: number, y: number): number;
function sum(x: string, y: string): string;
function sum(x: any, y: any): string | number {
  return x + y;
}
```

Now `reverseString2()` works and summing an array of numbers also works:

```
const reverseString2 = (str: string): string =>
  str.split("").reduceRight(sum, "");

console.log(reverseString2("MONTEVIDEO"));
// OEDIVETNOM

const myArray = [22, 9, 60, 12, 4, 56];

console.log(myArray.reduce(sum, 0));
// 163
```

If you try to do something as `sum(22,"X")` or `sum(false,{a:1})`, TypeScript will reject it because it won't match the defined overloads:

```
describe("myMap", () => {
  const myArray = [22, 9, 60, 12, 4, 56];

  it("duplicates values", () => {
    const dup = (x: number): number => 2 * x;
    expect(myArray.map(dup)).toEqual(myMap(myArray, dup));
  });

  it("add dashes", () => {
    const addDashes = (x: number): string => `-${x}-`;
    expect(myArray.map(addDashes)).toEqual(
      myMap(myArray, addDashes)
    );
  });
});
```

5.4 **Reversed reverse?** In this case, it would return the same input string as the output; check it out!

5.5 **Ranging far and wide**: This requires a bit of careful arithmetic, but shouldn't be much trouble. Here, we need to distinguish two cases: upward and downward ranges. The default step is `1` for the former and `-1` for the latter. We used `Math.sign()` for this:

```
const range2 = (
  from: number,
  to: number,
  step = Math.sign(to - from)
): number[] => {
  const arr = [];
  do {
    arr.push(from);
    from += step;
  } while (
    (step > 0 && to > from) ||
    (step < 0 && to < from)
  );
  return arr;
};
```

A different implementation starts by calculating how big an array is needed and then filling it using `fill()` and `map()`. We must be careful if `start` and `stop` are equal to avoid a division by zero:

```
const range2b = (
  start: number,
  stop: number,
  step: number = Math.sign(stop - start)
): number[] =>
  new Array(
    step === 0 ? 1 : Math.ceil((stop - start) / step)
  )
    .fill(0)
    .map((v, i) => start + i * step);
```

A few examples of calculated ranges show the diversity in terms of the options we have:

```
range2(1, 10);         // [1, 2, 3, 4, 5, 6, 7, 8, 9]
range2(1, 10, 2);      // [1, 3, 5, 7, 9]
range2(1, 10, 3);      // [1, 4, 7]
range2(1, 10, 6);      // [1, 7]
range2(1, 10, 11);     // [1]
range2(21, 10);        // [21, 20, 19, ... 13, 12, 11]
range2(21, 10, -3);    // [21, 18, 15, 12]
range2(21, 10, -4);    // [21, 17, 13]
range2(21, 10, -7);    // [21, 14]
range2(21, 10, -12);   // [21]
```

Writing Jest tests is straightforward; the following code shows just three cases of the preceding code:

```
describe("range2()", () => {
  it("works from 1 to 10", () =>
    expect(range2(1, 10)).toEqual([
      1, 2, 3, 4, 5, 6, 7, 8, 9,
    ]));

  it("works from 1 to 10 by 2", () =>
    expect(range2(1, 10, 2)).toEqual([1, 3, 5, 7, 9]));

  it("works from 21 down to 10 by -4", () =>
    expect(range2(21, 10, -4)).toEqual([21, 17, 13]));
});
```

Using this new `range2()` function means you can write a greater variety of loops in a functional way, with no need for `for(...)` statements.

5.6 **Range generators**: The following does the job and works for all sorts of ranges, ascending or descending. The first time it is called, it returns the initial value (`from`) and then updates it (by summing the `step` value) until the resulting value is outside the range:

```
function* range4(
  from: number,
  to: number,
  step: number = Math.sign(to - from)
): Generator<number> {
  do {
    yield from;
    from += step;
  } while (
    (step > 0 && to >= from) ||
    (step < 0 && to <= from)
  );
}
```

We can write tests for this function in several different ways: manually calling the generator several times, using the spread operator to get all the values at once, or using the `for..of` construct:

```
describe("range4", () => {
  it("generates 2..5", () => {
    const range = range4(2, 5);
    expect(range.next().value).toBe(2);
    expect(range.next().value).toBe(3);
    expect(range.next().value).toBe(4);
    expect(range.next().value).toBe(5);
    expect(range.next().value).toBe(undefined);
  });

  it("generates 5..2", () => {
    const range = range4(5, 2);
    expect([...range]).toEqual([5, 4, 3, 2]);
  });

  it("generates 1..10 by 2", () => {
    const numbers = [];
    for (const i of range4(1, 10, 2)) {
      numbers.push(i);
    }
    expect(numbers).toEqual([1, 3, 5, 7, 9]);
  });
});
```

5.7 **Doing the alphabet**: The problem is that `String.fromCharCode()` is not unary; it may receive any number of arguments. When you write `map(String.fromCharCode)`, the callback gets called with three parameters (the current value, the index, and the array) and that causes unexpected results. Using `unary()` from the *Arity changing* section of *Chapter 6, Producing Functions,* would also work. To find out more, go to `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/String/fromCharCode`.

5.8 **Producing a CSV**: A first solution, along with some auxiliary functions, is as follows; can you understand what each function does?

```
const myData = [
  [1, 2, 3, 4],
  [5, 6, 7, 8],
  [9, 10, 11, 12],
];

const concatNumbers = (a: string, b: number): string =>
  !a ? `${b}` : `${a},${b}`;

const concatLines = (c: string, d: string): string =>
  c + "\n" + d;

const makeCSV = (data: number[][]) =>
  data
    .map((x) => x.reduce(concatNumbers, ""))
    .reduce(concatLines, "");

console.log(makeCSV(myData));
/*
1,2,3,4
5,6,7,8
9,10,11,12
*/
```

An alternative one-liner is possible, but not as clear – do you agree?

```
const makeCSV2 = (data: number[][]) =>
  data
```

```
     .map((x: number[]) =>
       x.reduce(
         (a: string, b: number): string =>
           !a ? `${b}` : `${a},${b}`,
         ""
       )
     )
     .reduce((c: string, d: string) => c + "\n" + d, "");
```

5.9 **An empty question?** Both `flat1()` and `flat2()` depend on `flatOne()`. If that function (in any of its two provided implementations) finds an empty array position, it doesn't `concat()` anything to its output.

5.10 **Producing better output**: For this, you'll have to do some extra mapping, as follows:

```
const better = apiAnswer
  .flatMap((c) =>
    c.states.map((s) => ({ ...s, country: c.name }))
  )
  .flatMap((s) =>
    s.cities.map((t) => ({
      ...t,
      state: s.name,
      country: s.country,
    }))
  )
  .map((t) => `${t.name}, ${t.state}, ${t.country}`);

console.log(better);

/*
[
  'Lincoln, Buenos Aires, Argentine',
  'Lincoln, England, Great Britain',
  'Lincoln, California, United States of America',
  'Lincoln, Rhode Island, United States of America',
  'Lincolnia, Virginia, United States of America',
  'Lincoln Park, Michigan, United States of America',
  'Lincoln, Nebraska, United States of America',
  'Lincoln Park, Illinois, United States of America',
  'Lincoln Square, Illinois, United States of America'
]
*/
```

5.11 **Old-style code only!** One way of doing this is by using `join()` to build a single long string out of the individual sentences, using `split()` to separate that string into words, and finally, looking at the length of the resulting array:

```
const words = gettysburg.join(" ").split(" ").length; // 270
```

5.12 **Filtering…but what?** `Boolean(x)` is the same as `!!x`, turning an expression from `truthy` or `falsy` into `true` or `false`, respectively. Thus, the `filter()` operation removes all `falsy` elements from the array.

5.13 **Yet another factorial question**: Yes, it works, and `fact4(0)` returns `1` as expected. The `range(1,1)` call produces an empty array, so the original value of `result` (`1`) is returned without further change.

5.14 **Async chaining**: An article by Valeri Karpov, which can be found at `thecodebarbarian.com/basic-functional-programming-with-async-await.html`, provides polyfills for methods such as `forEach()`, `map()`, and so on, and also develops a class for `async` arrays that allows chaining.

5.15 **Missing equivalents**: Start by using `mapAsync()` to get the async values and apply the original function to the returned array. An example for `some()` would be as follows:

```
const someAsync = <T>(
  arr: T[],
  fn: (x: T) => Promise<boolean>
) =>
  mapAsync(arr, fn).then((mapped) => mapped.some(Boolean));
```

We can write tests for this in two different fashions: awaiting the result of a call, or using Jest's `.resolves` for shorter code:

```
describe("someAsync", () => {
  it("succeeds if sometimes OK", async () => {
    const someEven = await someAsync(
      [1, 2, 3, 4],
      fakeFilter
    );
    expect(someEven).toBeTruthy();
  });

  it("fails if never OK", () => {
    expect(
      someAsync([1, 3, 5, 7, 9], fakeFilter)
    ).resolves.toBeFalsy();
  });
});
```

5.16 **Emptying the pool**: The provided suggestion is good: we could do the check either at the top of `workerCall()` or when we reset a worker to be not in use. Let's go with the second solution, to make the call as fast as possible. We will add a `MAX_NOT_IN_USE` constant with the threshold of number of workers not in use and a `notInUse()` predicate as a refactor:

```
const notInUse = (p: PoolEntry): boolean => !p.inUse;

const MAX_NOT_IN_USE = 10;
```

Then, we'll change the last part of the `workerCall()` function as follows:

```
  return new Promise((resolve) => {
    available!.inUse = true;
    available!.worker.on("message", (x) => {
      resolve(x);
      available!.inUse = false;

      while (
        pool.filter(notInUse).length > MAX_NOT_IN_USE
      ) {
        const notUsed = pool.findIndex(notInUse);
        pool[notUsed].worker.terminate();
        pool.splice(notUsed, 1);
      }
    });
    available!.worker.postMessage(value);
  });
```

While the count of workers not in use is higher than our limit, we find one worker to remove, `terminate()` it, and remove it from the pool of workers.

5.17 **Queueing for the pool**: This question has an interesting way of handling a promise to act as a barrier, initially denying but eventually allowing procedures to go through. The idea is to check that there are not too many running workers before adding a worker to the pool. If so, proceed as before, but if not, add something to the queue (we'll see what), so we can run the worker later. Whenever a worker responds, we'll check whether there's anything in the queue to allow it to run.

We'll first add three things:

```
const queue: ((v?: any) => void)[] = [];
let running = 0;
const MAX_TO_USE = 5;
```

The way we'll handle waiting is by creating a promise, which we'll eventually resolve at a later time. That explains the weird `queue` data type, which contains resolving functions. The `running` variable will count how many workers are running, and `MAX_TO_USE` is the maximum possible value for `running`.

To work with the queue, we'll have two functions:

```
const enqueue = (resolve2: (v?: any) => void) => {
  if (running < MAX_TO_USE) {
    running++;
    resolve2();
  } else {
    queue.push(resolve2);
  }
};

const dequeue = () => {
  const resolve2 = queue.shift();
  resolve2 && resolve2();
};
```

The `enqueue()` function checks how many workers are running; if there are less than `MAX_TO_USE`, it increments `running` (because a worker will run) and then calls `resolve2()` to allow the corresponding request to go forward. If there are too many running workers, the function to call is instead pushed into the queue. The `dequeue()` function just tries to get the front element from the queue, and if there's something, it calls the dequeued value to allow a queued request to proceed.

The modified `workerCall()` function is now as follows:

```
export const workerCall = (
  filename: string,
  value: any
): Promise<any> => {
  return new Promise((resolve) => {
    new Promise((resolve2) => enqueue(resolve2)).then(
      () => {
        let available = pool
          .filter(notInUse)
          .find((x) => x.filename === filename);

        if (available === undefined) {
          available = {
            worker: new Worker(filename),
            filename,
            value,
            inUse: true,
          } as PoolEntry;

          pool.push(available);
        }

        available!.inUse = true;
        available!.worker.on("message", (x) => {
          resolve(x);
          available!.inUse = false;
          dequeue();
        });
        available!.worker.postMessage(value);
      }
    );
  });
};
```

The `new Promise((resolve2) => …)` line is the barrier we mentioned; it will allow work to go on (at `then()`) only when its `resolve2()` function is called – which will be done either by `enqueue()` (if there were few running workers) or `dequeue()` (when some previously running worker ends).

5.18 **Showing results**: Basically, given a string, it returns a logging function that expects a single parameter and lists both the string and the argument. We'll see other ways of achieving similar results in *Chapter 6*, *Producing Functions*.

5.19 **Double filtering?** This is not optimal; `filter()` goes through all the workers, and then `find()` goes through the filtered ones. This could be achieved in a single pass as follows:

```
  let available = pool
    .find((v) => !v.inUse && v.filename === filename);
```

5.20 **Wishful thinking**: At the very least, you should listen to the `"error"` event, which fires if an error occurs in the worker. In this case, the worker should be marked as not in use (because it has ended its job) and the promise should be rejected. The final part of the `workerCall()` function should look something like this:

```
  return new Promise((resolve, reject) => {
    available!.inUse = true;
    available!.worker.on("message", (x) => {
      resolve(x);
      available!.inUse = false;
    });
    available!.worker.on("error", (x) => {
      reject(x);
```

```
        available!.inUse = false;
      });
      available!.worker.postMessage(value);
    });
```

For an "industrial-strength" level library, you should deal with all possible events; check `developer.mozilla.org/en-US/docs/Web/API/Worker#events` and `nodejs.org/api/worker_threads.html#class-worker` for more on this.

Chapter 6, Producing Functions – Higher-Order Functions

6.1 **Go with arrows**: Just minor changes are needed:

```
const addLogging = <T extends (...args: any[]) => any>(
  fn: T
): ((...args: Parameters<T>) => ReturnType<T>) => {
  return (...args: Parameters<T>): ReturnType<T> => {
    console.log(`entering ${fn.name}(${args})`);
    const valueToReturn = fn(...args);
    console.log(`exiting  ${fn.name}=>${valueToReturn}`);
    return valueToReturn;
  };
};
```

6.2 **Mapping for memory**: Let's do this for the most complete memoizing function we wrote, `memoize4()`. Instead of using an object for `cache`, we create a map. We check whether the map has the searched `strX` key, we set new values after calling the original function, and we get the return value from the cache. The `as` part in `return` is to let TypeScript know that `get()` will succeed because the search won't fail:

```
const memoize4 = <T extends (...x: any[]) => any>(
  fn: T
): ((...x: Parameters<T>) => ReturnType<T>) => {
  const cache = new Map() as Map<string, ReturnType<T>>;
  return (...args) => {
    const strX = JSON.stringify(args);
    if (!cache.has(strX)) {
      cache.set(strX, fn(...args));
    }
    return cache.get(strX) as ReturnType<T>;
  };
};
```

6.3 **How many?** Let's call `calc(n)` the number of calls needed to evaluate `fib(n)`. Analyzing the tree that shows all the needed calculations, we get the following:

- calc(0)=1
- calc(1)=1
- For n>1, calc(n)=1 + calc(n-1) + calc(n-2)

The last line follows from the fact that when we call `fib(n)`, we have one call, plus calls to `fib(n-1)` and `fib(n-2)`. A spreadsheet shows that `calc(50)` is 40,730,022,147 – rather high!

If you care for some algebra, it can be shown that calc(n)=5fib(n-1)+fib(n-4)-1, or that as n grows, calc(n) becomes approximately (1+√5)=3.236 times the value of fib(n) – but since this is not a math book, I won't even mention those results!

6.4 **A randomizing balancer**: Using our `shuffle()` function from *Chapter 4*, *Behaving Properly*, we can write the following code. We remove the first function from the list before shuffling the rest, and we add it back at the end of the array to avoid repeating any calls:

```
const randomizer =
  <T extends (...x: any[]) => any>(...fns: T[]) =>
  (
    ...args: Parameters<T>
  ): ((...args: Parameters<T>) => ReturnType<T>) => {
    const first: T = fns.shift() as T;
    fns = shuffle(fns);
    fns.push(first);
    return fns[0](...args);
  };
```

We need to add `as T` when assigning a value to `first`; otherwise, TypeScript will object because `fns.shift()` returns `undefined` if `fns` is empty. It wouldn't be a bad idea to check that `fns` is not empty; can you add it?

A quick verification shows it fulfills all our requirements:

```
const say1 = () => console.log(1);
const say22 = () => console.log(22);
const say333 = () => console.log(333);
const say4444 = () => console.log(4444);

const rrr = randomizer(say1, say22, say333, say4444);
rrr(); // 333
rrr(); // 4444
rrr(); // 333
rrr(); // 22
rrr(); // 333
rrr(); // 22
rrr(); // 333
rrr(); // 4444
rrr(); // 1
rrr(); // 4444
```

A minor consideration: the first function in the list can never be called the first time around because of the way `randomizer()` is written. Can you provide a better version that won't have this slight defect so that all the functions in the list have the same chance of being called the first time?

6.5 **Not in TypeScript**: The following code does the job. The only difference between the functions is that one works with Boolean-returning functions and the other with number-returning ones:

```
const not =
  <T extends (...args: any[]) => boolean>(fn: T) =>
  (...args: Parameters<T>): boolean =>
    !fn(...args);

const invert =
  <T extends (...args: any[]) => number>(fn: T) =>
  (...args: Parameters<T>): number =>
    -fn(...args);
```

6.6 **Just say no!** Call the original function and then use `typeof` to check whether the returned value is numeric or Boolean before deciding what to return. We must declare that the input function is either a Boolean-returning or a number-returning function:

```
const opposite =
  <T extends (...args: any[]) => number | boolean>(fn: T)
    =>
  (…args: Parameters<T>): ReturnType<T> => {
    const result = fn(...args);
    return (
      typeof result === "boolean" ? !result : -result
    ) as any;
  };
```

6.7 **Invert tests**: We can quickly transform the example shown in the text into a real test; we'll leave it up to you to write more tests:

```
import { invert } from "../invert";

describe("invert", () => {
  it("can be used to sort Spanish words", () => {
    const spanishComparison = (
      a: string,
      b: string
    ): number => a.localeCompare(b, "es");

    const palabras = [
   "  "ñandú",
   "  "oasis",
   "  "mano",
   "  "natural",
   "  "mítico",
   "  "musical",
    ];

    expect(
      palabras.sort(invert(spanishComparison))
    ).toEqual([
   "  "oasis",
   "  "ñandú",
   "  "natural",
   "  "musical",
   "  "mítico",
   "  "mano",
    ]);
  });
});
```

6.8 **Why not shorter?** The reason is that `filter()` expects to receive a function with three parameters (the `A`, `number`, and `A[]` types), and the type of `not(fn)` doesn't match that.

6.9 **Wrong function length**: We can solve this problem by using `eval()` – which, in general, isn't such a good idea! If you persist and insist, though, we can write a `function.length` preserving version of `arity()` as follows; let'scall it `arityL()`:

```
import { range } from "../../chapter 05/range";

function arityL<T extends (...args: any[]) => any>(
  n: number,
  fn: T
): (...x: Parameters<T>) => ReturnType<T> {
  const args1n = range(0, n)
    .map((i) => `x${i}`)
    .join(",");

  return eval(`(${args1n}) => ${fn.name}(${args1n})`);
}
```

If you were to apply `arityL()` to `Number.parseInt`, the results would be as follows. The produced functions have the right `length` property, and their actual implementation is given in the comments:

```
const parseInt1 = arityL(parseInt, 1);
// (x0) => parseInt(x0,x1) parseInt1.length === 1
```

```
const parseInt2 = arity(Number.parseInt,2)
// (x0,x1) => parseInt(x0,x1) parseInt2.length === 2
```

Do note, however, that TypeScript cannot determine the type of the resulting functions because that will be known at runtime.

6.10 **Many arities!** If we were working just with JavaScript, the following would do:

```
const binary = (fn) => (...a) => fn(a[0], a[1]);
const ternary = (fn) => (...a) => fn(a[0], a[1], a[2]);
```

Adding data types, we get the following:

```
const binary =
  <T extends (...x: any[]) => any>(
    fn: T
  ): ((
    arg0: Parameters<T>[0],
    arg1: Parameters<T>[1]
  ) => ReturnType<T>) =>
  (x, y) =>
    fn(x, y);

const ternary =
  <T extends (...x: any[]) => any>(
    fn: T
  ): ((
    arg0: Parameters<T>[0],
    arg1: Parameters<T>[1],
    arg2: Parameters<T>[2]
  ) => ReturnType<T>) =>
  (x, y, z) =>
    fn(x, y, z);
```

6.11 **Throttling promises**: Every time we actually do a call, we'll set up a timer that will, in time, remove the promise from the cache. By default, let's have a delay of 5 minutes. We'll have a pool of timers, one per promise. In case of an error when calling the API, we'll remove both the rejected promise and its corresponding timer:

```
const promiseThrottle = <
  A,
  T extends (...x: any[]) => Promise<A>
>(
  fn: T,
  delay = 300_000  /* 5 minutes */
): ((...x: Parameters<T>) => Promise<A>) => {
  const cache = {} as Record<string, Promise<A>>;
  const timers = {} as Record<
    string,
    ReturnType<typeof setTimeout>
  >;
  return (...args) => {
    const strX = JSON.stringify(args);
    if (!(strX in timers)) {
      timers[strX] = setTimeout(() => {
        delete cache[strX];
        delete timers[strX];
      }, delay);
    }
    return strX in cache
      ? cache[strX]
      : (cache[strX] = fn(...args).catch((x) => {
          delete cache[strX];
          delete timers[strX];
          return x;
        }));
  };
};
```

6.12 **All operators called**: You would have all math operators (`+`, `-`, `*`, `/`, `**`, and `%`), all bitwise operators (`&`, `|`, and `^`), all logical operators (`&&` and `||`), all shift operators (`<<`, `>>`, and `>>>`), all comparisons (`>`, `>=`, `<`, `<=`, `==`, `===`, `!=`, and `!==`), and the new nullish coalescing operator (`??`).

The comma operator could be included as well. Check out `developer.mozilla.org/en-US/docs/Web/JavaScript/Guide/Expressions_and_Operators` for more on this topic.

6.13 **Missing companion**: A simple one-line version could be as follows. Here, we use spreading to get a shallow copy of the original object and then set the specified attribute to its new value by using a computed property name. See `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Operators/Object_initializer` for more details:

```
const setField = <D>(
  attr: keyof D,
  value: any,
  obj: D
) => ({
  ...obj,
  [attr]: value,
});
```

In *Chapter 10*, *Ensuring Purity*, we wrote `deepCopy()`, which would be better than spreading when it comes to creating a totally new object instead of a shallow copy. By using this, we would have the following:

```
const setField2 = <D>(
  attr: keyof D,
  value: any,
  obj: D
) => ({
  ...deepCopy(obj),
  [attr]: value,
});
```

Finally, you could also look into modifying the `updateObject()` function, also from *Chapter 10*, *Ensuring Purity*, by removing the freezing code; I'll leave it up to you.

6.14 **A border case**: With plain JavaScript, applying the function to a `null` object would throw an error:

```
const getField = attr => obj => obj[attr];
getField("someField")(null);
// Uncaught TypeError: Cannot read property 'a' of null
```

With TypeScript, the code won't compile because first, `"someField"` isn't the name of an attribute, and second, `null` is not a valid object:

```
const getField =
  <D>(f: keyof D) =>
  (obj: D) =>
    obj[f];
```

However, it's still possible to do things "behind TypeScript's back" and get the code accepted and the exception thrown. Having functions throw exceptions is not usually good in FP. You may opt to produce `undefined` instead, or work with monads, just like in *Chapter 12*, *Building Better Containers*. A safer version of `getField()` would add a safeguard and return `obj && obj[f]` instead.

6.15 **Typed demethodizing**: The three full definitions are as follows:

```
const demethodize1 =
  <T extends (arg0: any, ...args: any[]) => any>(fn: T) =>
  (arg0: any, ...args: Parameters<T>) =>
    fn.apply(arg0, args);

const demethodize2 =
  <T extends (arg0: any, ...args: any[]) => any>(fn: T) =>
  (arg0: any, ...args: Parameters<T>): ReturnType<T> =>
    fn.call(arg0, ...args);

const demethodize3 =
  <T extends (arg0: any, ...args: any[]) => any>(fn: T) =>
  (arg0: any, ...args: Parameters<T>): ReturnType<T> =>
    fn.bind(arg0, ...args)();
```

6.16 **Not reinventing the wheel**: We can use `Math.max()` and `Math.min()` as follows:

```
const findMaximum2 = findOptimum2((x, y) => Math.max(x,
  y));

const findMinimum2 = findOptimum2((x, y) => Math.min(x,
  y));
```

Another way of writing this could be achieved by defining the following first:

```
const max = (...arr: number[]): number => Math.max(...arr);

const min = (...arr: number[]): number => Math.min(...arr);
```

Then, we could write in a pointfree style:

```
const findMaximum3 = findOptimum2(max);

const findMinimum3 = findOptimum2(min);
```

6.17 **Comparing heroes**: The first suggested change wouldn't allow for ties in some features, where no hero beats the other. And, in fact, this points out a problem in our logic; if the first hero doesn't beat the second one, we assume that the latter beat the former, not allowing for ties between heroes.

Chapter 7, Transforming Functions – Currying and Partial Application

7.1 **Hard by hand**: It would work; `sum(3)` returns a function with `3` already bound; `sum(3)()` returns the same, and `sum(3)()(5)` produces the result.

7.2 **Sum as you will**: The following `sumMany()` function does the job:

```
const sumMany = (total: number) => (value?: number) =>
  value === undefined ? total : sumMany(total + value);

sumMany(2)(2)(9)(6)(0)(-3)(); // 16
```

In JavaScript, the function poses no problem; with TypeScript, we'll get an objection because it cannot determine that `sumMany(2)` is a function, not a number.

A small detail: can you fix the function so `sumMany()` will return `0`?

7.3 **Curry with eval?** Let's see this in JavaScript first:

```
// curryByEval.js
```

```
function curryByEval(fn) {
  return eval(`${range(0, fn.length)
    .map((i) => `x${i}`)
    .join("=>")} => ${fn.name}(${range(0, fn.length)
    .map((i) => `x${i}`)
    .join(",")})`);
}
```

This is quite a chunk of code to digest, and, in fact, it should instead be coded in several separate lines to make it more understandable. Let's see how this works when applied to the `make3()` function as input:

1. The `range()` function produces an array with the `[0,1,2]` values.
2. We use `map()` to generate a new array with the `["x0","x1","x2"]` values.
3. We use `join()` on the values in that array to produce `x0=>x1=>x2`, which will be the beginning of the code that we will evaluate.
4. We then add an arrow, the function's name, and an opening parenthesis, to make the middle part of our newly generated code: `=> make3(`.
5. We use `range()`, `map()`, and `join()` again, but this time, to generate a list of arguments: `x0,x1,x2`.
6. We finally add a closing parenthesis, and after applying `eval()`, we get the curried version of `make3()`.

After following all these steps, in our case, the resulting function would be as follows:

```
curryByEval(make3); // x0=>x1=>x2 => make3(x0,x1,x2)
```

Typing is essentially the same as for our `curry()` function since we are getting the same parameter and producing the same output. Note, however, that we're definitely "lying" to TypeScript because it wouldn't be able to deduce what `eval()` was returning; it's really up to us not to mess up! Without further ado, we can write the following:

```
function curryByEval<A extends any[], R>(
  fn: (...args: A) => R
): Curry<A, R>;
function curryByEval(fn: (...args: any) => any) {
  const pp = `${range(0, fn.length)
    .map((i) => `x${i}`)
```

```
     .join("=>")} => ${fn.name}(${range(0, fn.length)
     .map((i) => `x${i}`)
     .join(",")})`;
}
```

We see we can do currying by using `eval()` – but there's one remaining problem: if the original function didn't have a name, the transformation wouldn't work. We can work around the function name problem by including the actual code of the function to be curried:

```
function curryByEval2<A extends any[], R>(
  fn: (...args: A) => R
): Curry<A, R>;
function curryByEval2(fn: (...args: any) => any) {
  return eval(`${range(0, fn.length)
    .map((i) => `x${i}`)
    .join("=>")} =>
    (${fn.toString()})
    (${range(0, fn.length)
      .map((i) => `x${i}`)
      .join(",")})`);
}
```

The only change is that instead of including the original function name, we substitute its actual code:

```
curryByEval2(make3);
// x0=>x1=>x2=> ((a, b, c) => `${a}:${b}:${c}`)(x0,x1,x2)
```

7.4 **Uncurrying the curried**: We can work similarly to what we did in the previous question:

```
const uncurry = (fn, len) =>
  eval(
    `(${range(0, len)
      .map((i) => `x${i}`)
      .join(",")}) => ${fn.name}${range(0, len)
      .map((i) => `(x${i})`)
      .join("")}`
  );
```

Earlier, when currying, given an `fn()` function with an arity of `3`, we would have generated the following:

```
x0=>x1=>x2=> make3(x0,x1,x2)
```

Now, to uncurry a function (say, `curriedFn()`), we want to do something very similar: the only difference is the placement of the parentheses:

```
(x0,x1,x2) => curriedFn(x0)(x1)(x2)
```

The expected behavior is as follows – and let's use the last result from the previous question:

```
const curriedMake3 = (x0) => (x1) => (x2) =>
  ((a, b, c) => `${a}:${b}:${c}`)(x0, x1, x2);

console.log(uncurry(curriedMake3, 3).toString());
// (x0,x1,x2) => curriedMake3(x0)(x1)(x2)
```

If you want to consider a case in which the function to "uncurry" has no name, you can apply the same change we did in the previous question and include `fn.toString()` in the output.

7.5 **Let me count the ways**: If the function has *n* parameters, there are 2^{n-1} ways of calling it. This means that our three-parameter function could be called in 2^2=4 ways (correct!), a function with two parameters would allow 2^1=2 ways, and a function with just one parameter would allow only 2^0=1 way.

7.6 **Currying by prototype**: Basically, we are just transforming the `curry()` version so that it uses this:

```
Function.prototype.curry = function () {
  return this.length === 0
    ? this()
    : (p) => this.bind(this, p).curry();
};
```

7.7 **Shorter typing**: The suggested earlier test shortens the code. We are essentially saying "*if there's at least one argument, return a curried function; otherwise, return a value*":

```
type Curry2<P, R> = P extends [infer H, ...infer T]
  ? (arg: H) => Curry2<[...T], R>
  : R;
```

7.8 **Counting arguments**: We can check whether `P` has a single type by checking `P["length"]` as follows – and to access that single type, we'll have to write `P[0]`:

```
type Curry<P extends any[], R> = 1 extends P["length"]
  ? (arg: P[0]) => R // only 1 arg
  : P extends [infer H, ...infer T] // 2 or more args
  ? (arg: H) => Curry<[...T], R>
  : never;
```

7.9 **Working stylishly**: We can do currying by hand for `applyStyle()` or by using our `curry()` function – let's see both ways:

```
const applyStyle =
  (style: string) =>
  (text: string): string =>
    `<${style}>${text}</${style}>`;

const makeBold = applyStyle("b");
console.log(makeBold("Montevideo"));
// <b>Montevideo</b>

const applyStyle2 = (style: string, text: string): string
  =>
  `<${style}>${text}</${style}>`;

const makeUnderline = curry(applyStyle2)("u");
console.log(makeUnderline("Uruguay"));
// <u>Uruguay</u>
```

7.10 **Mystery questions function**: It implements partial currying; a more understandable and better-named version of the `what()` function is as follows:

```
const partial =
  (fn) =>
  (...params) =>
    fn.length <= params.length
```

```
        ? fn(...params)
        : (...otherParams) =>
            partial(fn)(...params, ...otherParams);
```

7.11 **Partial transformations**: Just apply the same transformation as in *Question 7.6* – take the original code we wrote, and replace all references to the function with references to `this`.

7.12 **Yet more curry!** The `curryN()` function is an alternative version of our `partialCurry()`. The only difference is that if you provide all the arguments to a function, this new `curryN()` function directly calls the curried function, while `partialCurry()` would first bind the function to all its arguments and then recursively call it to return the final result – but the result would be precisely the same.

Chapter 8, Connecting Functions – Pipelining, Composition, and More

8.1 **Headline capitalization**: We can make use of several functional equivalents of different methods, such as `split()`, `map()`, and `join()`. Using `demethodize()` from *Chapter 6*, *Producing Functions*, and `flipTwo()` from *Chapter 7*, *Transforming Functions*, would have also been possible:

```
const split = (str: string) => (text: string) =>
  text.split(str);

const map =
  (fn: (x: string) => string) => (arr: string[]) =>
    arr.map(fn);

const firstToUpper = (word: string): string =>
  word[0].toUpperCase() + word.substring(1).toLowerCase();

const join = (str: string) => (arr: string[]) =>
  arr.join(str);

const headline = pipeline(
  split(" "),
  map(firstToUpper),
  join(" ")
);
```

The pipeline works as expected: we split the string into words, we map each word to make its first letter uppercase, and we join the array elements to form a string again. We could have used `reduce()` for the last step, but `join()` already does what we need, so why reinvent the wheel?

```
console.log(headline("Alice's ADVENTURES in WoNdErLaNd"));
// Alice's Adventures In Wonderland
```

8.2 **Pending tasks**: The following pipeline does the job:

```
const getField = attr => obj => obj[attr]; const filter =
  fn => arr => arr.filter(fn); const map = fn => arr =>
  arr.map(fn);
const reduce = (fn, init) => arr => arr.reduce(fn, init);

const pending = (listOfTasks, name) => pipeline(
getField("byPerson"),
filter(t => t.responsible === name), map(t => t.tasks),
reduce((y, x) => x, []), filter(t => t && !t.done),
  map(getField("id"))
)(allTasks || {byPerson: []}); //
```

The `reduce()` call may be mystifying. By that time, we are handling an array with a single element – an object – and we want the object in the pipeline, not the array. This code works even if the responsible person doesn't exist, or if all the tasks have been completed; can you see why? Also, note that if `allTasks` is `null`, an object must be provided with the `byPerson` property so that future functions won't crash! For an even better solution, I think monads are better: see *Question 12.1* for more.

8.3 **Thinking in abstract terms**: The simple solution implies composing. I preferred it to pipelining in order to keep the list of functions in the same order:

```
const getSomeResults2 = compose(sort, group, filter, select);
```

8.4 **Reversing types**: We can apply recursion to reverse a list of types:

```
type Reverse<FNS extends FN[]> = 1 extends FNS["length"]
  ? [FNS[0]]
  : FNS extends [
      infer FN1st extends FN,
      ...infer FNRest extends FN[]
    ]
  ? [...Reverse<FNRest>, FN1st]
  : never;
```

With this, we can define `Compose<>` in terms of `Pipeline<>`:

```
type Compose<FNS extends FN[]> = Pipeline<Reverse<FNS>>;

function compose1<FNS extends FN[]>(
  ...fns: FNS
): Compose<FNS> {
  return pipeline(...fns.reverse()) as Compose<FNS>;
}
```

Instead of an overload, we're using a cast here to let TypeScript know what types we are working with.

8.5 **Empty pipeline?** The `pipeline()` function we wrote accesses `fns[0]` without checking whether the `fns` array is empty, so it won't work. The `pipeline1()` and `pipeline2()` functions use `reduce()` without an initial value, so they will also fail. We must add an initial test, so if no functions are provided (`fns.length===0`), we'll simply return the input value as the result.

8.6 **Undetected impurity?** Yes, the function is impure, but using it as-is would fall squarely under the **Sorta Functional Programming** (**SFP**) style we mentioned back in the *Theory versus practice* section of *Chapter 1, Becoming Functional*. The version we used is not pure, but in the way we use it, the final results are pure: we modify an array in place, but it's a new array that we are creating. The alternate implementation is pure and also works, but will be slower since it creates a completely new array every time we call it. So, accepting this bit of impurity helps us get a function that performs better; we can accept that!

8.7 **Needless transducing?** If you only had a sequence of `map()` operations, you could apply a single `map()` by pipelining all the mapping functions into a single one. For `filter()` operations, it becomes a bit harder, but here's a tip: use `reduce()` to apply all the filters in sequence with a carefully thought-out accumulating function.

8.8 **What type?** According to the definition of `chainify()`, the type of `myCity2` is `Chainify<City>`. Attributes have the same types as before, but the `void`-returning methods now return an object of the same `Chainify<City>` type:

```
{
    name: string;
    lat: number;
    long: number;
    extra: boolean;
    getName: () => string;
    setName: (newName: string) => Chainify<City>;
    setLat: (newLat: number) => Chainify<City>;
    setLong: (newLong: number) => Chainify<City>;
    getCoords: () => number[];
}
```

Chapter 9, Designing Functions – Recursion

9.1 **Into reverse**: An empty string is reversed by simply doing nothing. To reverse a non-empty string, remove its first character, reverse the rest, and append the removed character at the end. For example, `reverse("MONTEVIDEO")` can be found by doing `reverse("ONTEVIDEO")+"M"`. In the same way, `reverse("ONTEVIDEO")` would be equal to `reverse("NTEVIDEO")+"O"`, and so on:

```
const reverse = (str: string): string =>
  str.length === 0 ? "" : reverse(str.slice(1)) + str[0];
```

9.2 **Climbing steps**: To climb a ladder with *n* steps, we can act in two ways:

- Climb one single step and then climb an (*n*-1) steps ladder
- Climb two steps at once and then climb an (*n*-2) steps ladder

So, if we call ladder(*n*) the number of ways to climb a steps ladder, we know that ladder(n)= ladder(*n*-1) + ladder(*n*-2). Adding the fact that ladder(0)=1 (there's only one way to climb a ladder with no steps: do nothing) and ladder(1)=1, the solution is that ladder(*n*) equals the (*n*-1)th Fibonacci number! Check it out: ladder(2)=2, ladder(3)=3, ladder(4)=5, and so on.

9.3 **Sorting recursively**: Let's look at the first of these algorithms; many of the techniques here will help you write the other sorts. If the array is empty, sorting it produces a (new) empty array. Otherwise, we find the maximum value of the array (`max`), create a new copy of the array but without that element, sort the copy, and then return the sorted copy with `max` added at the end. Take a look at how we dealt with the mutator functions to avoid modifying the original array and note that this sorting code only works with numbers because of the way we find `max`:

```
const selectionSort = (arr: number[]): number[] => {
  if (arr.length === 0) {
    return [];
  } else {
    const max = Math.max(...arr);
    const rest = [...arr];
    rest.splice(arr.indexOf(max), 1);
    return [...selectionSort(rest), max];
  }
};

selectionSort([2, 2, 0, 9, 1, 9, 6, 0]);
// [0, 0, 1, 2, 2, 6, 9, 9]
```

9.4 **What could go wrong?** This would fail if, at any time, the array (or subarray) to be sorted consisted of all equal values. In that case, `smaller` would be an empty array, and `greaterEqual` would be equal to the whole array to sort, so the logic would enter an infinite loop.

The original code can never enter a loop because every pass removes one element (the pivot) so you're guaranteed to reach a state with nothing left to sort.

9.5 **More efficiency**: The following code does the work for us. Here, we use a ternary operator to decide where to push the new item:

```
const partition = <A>(
  arr: A[],
  fn: (x: A) => boolean
): [A[], A[]] =>
  arr.reduce(
    (result: [A[], A[]], elem: A) => {
      result[fn(elem) ? 0 : 1].push(elem);
      return result;
    },
    [[], []]
  );
```

9.6 **Completing callbacks**: Code is very much along the same lines as `mapR()`, so I'll skip repeating explanations – the only difference is in the `return` value, which is now a value from the array (`arr[0]` in `findLoop()`) instead of a mapped whole array as in `mapR()`:

```
type Opt<X> = X | undefined;

const findR = <A>(
  orig: Opt<A>[],
  cb: (x: A, i: number, a: Opt<A>[]) => boolean
): Opt<A> => {
  const findLoop = (arr: Opt<A>[], i: number): Opt<A> =>
    arr.length === 0
      ? undefined
      : !(0 in arr) || arr[0] === undefined
      ? findLoop(arr.slice(1), I + 1)
      : cb(arr[0], i, orig)
      ? arr[0]
      : findLoop(arr.slice(1), i + 1);

  return findLoop(orig, 0);
};
```

9.7 **Recursive logic**: Again, we can take inspiration from our `mapR()` example, so I won't comment on the looping, types, and so on. When programming `everyR()`, we must be careful what to do with empty arrays or missing places; the standard `every()` method considers them to return `true`, so we'll do the same:

```
type Opt<X> = X | undefined;

const everyR = <A>(
  orig: Opt<A>[],
  cb: (x: A, i: number, a: Opt<A>[]) => boolean
): boolean => {
  const everyLoop = (arr: Opt<A>[], i: number): boolean =>
    arr.length === 0
      ? true
      : !(0 in arr) || arr[0] === undefined
      ? true
      : !cb(arr[0], i, orig)
      ? false
      : everyLoop(arr.slice(1), i + 1);

  return everyLoop(orig, 0);
};
```

When programming `someR()`, an empty array means a false result, but empty places are skipped:

```
type Opt<X> = X | undefined;

const someR = <A>(
  orig: Opt<A>[],
  cb: (x: A, i: number, a: Opt<A>[]) => boolean
): boolean => {
  const someLoop = (arr: Opt<A>[], i: number): boolean =>
    arr.length === 0
      ? false
      : !(0 in arr) || arr[0] === undefined
      ? someLoop(arr.slice(1), i + 1)
      : cb(arr[0], i, orig)
      ? true
      : someLoop(arr.slice(1), i + 1);

  return someLoop(orig, 0);
};
```

9.8 **Symmetrical queens**: The key to finding only symmetric solutions is as follows. After the first four queens have been (tentatively) placed on the first half of the board, we don't have to try all the possible positions for the other queens; they are automatically determined with regard to the first ones:

```
const SIZE = 8;

const places = Array(SIZE);

const checkPlace = (column: number, row: number): boolean
  =>
  places
    .slice(0, column)
    .every(
      (v, i) =>
        v !== row && Math.abs(v - row) !== column - i
    );

const symmetricFinder = (column = 0): void => {
  if (column === SIZE) {
    console.log(JSON.stringify(places.map((x) => x + 1)));
  } else if (column <= SIZE / 2) {
    // first half of the board?
    const testRowsInColumn = (j: number): void => {
      if (j < SIZE) {
        if (checkPlace(column, j)) {
          places[column] = j;
          symmetricFinder(column + 1);
        }
        testRowsInColumn(j + 1);
      }
    };
    testRowsInColumn(0);
  } else {
    // second half of the board
    const symmetric = SIZE - 1 - places[SIZE - 1 - column];
    if (checkPlace(column, symmetric)) {
      places[column] = symmetric;
```

```
        symmetricFinder(column + 1);
      }
    }
  };
```

Calling `symmetricFinder()` produces four solutions, which are essentially the same. Make drawings and check them to make sure the solution is correct!

```
[3,5,2,8,1,7,4,6]
[4,6,8,2,7,1,3,5]
[5,3,1,7,2,8,6,4]
[6,4,7,1,8,2,5,3]
```

9.9 **Longest common subsequence**: The length of the **longest common sequence** (**LCS**) of two strings, `a` and `b`, can be found with recursion as follows:

- If the length of `a` is zero, or if the length of `b` is zero, return zero
- If the first characters of `a` and `b` match, the answer is 1 plus the LCS of `a` and `b`, both minus their initial characters
- If the first characters of `a` and `b` do not match, the answer is the largest of the following two results:
  - The LCS of `a` minus its initial character, and `b`
  - The LCS of `a`, and `b` minus its initial character

We can implement this as follows. We do memoization "by hand" to avoid repeating calculations; we could have also used our memoization function:

```
const LCS = (strA: string, strB: string): number => {
  // memoization "by hand"
  const cache: { [k: string]: number } = {};

  const innerLCS = (strA: string, strB: string): number =>
    {
    const key = strA + "/" + strB;
    let ret: number;

    if (!(key in cache)) {
      if (strA.length === 0 || strB.length === 0) {
        ret = 0;
      } else if (strA[0] === strB[0]) {
        ret = 1 + innerLCS(strA.substr(1), strB.substr(1));
      } else {
        ret = Math.max(
          innerLCS(strA, strB.substr(1)),
          innerLCS(strA.substr(1), strB)
        );
      }

      cache[key] = ret;
    }

    return cache[key];
  };

  return innerLCS(strA, strB);
};

console.log(LCS("INTERNATIONAL", "CONTRACTOR"));
// 6, as in the text
```

As an extra exercise, you could produce not only the length of the LCS but also the characters that are involved.

9.10 **At odds with JavaScript**: I'll show over a dozen solutions, but I'm certain there are even more. The first solution is the obvious one: divide by `2` and check whether the remainder is `1`:

```
function isOdd1(n: number): boolean {
  return n % 2 === 1;
}
```

You could have another solution by doing `return Boolean(n % 2)` instead:

```
function isOdd2(n: number): boolean {
  return Boolean(n % 2);  // or !!(n % 2) instead
}
```

Another way is to divide the number by 2 and check whether it has a fractional part:

```
function isOdd3(n: number): boolean {
  return Math.floor(n / 2) !== n / 2;
}
```

If a number is odd, dividing it by 2 and dividing its predecessor by 2, both results have the same integer part (for instance, 9/2 and 8/2 both have integer part 4):

```
function isOdd4(n: number): boolean {
  return Math.floor(n / 2) === Math.floor((n - 1) / 2);
}
```

Using bit operations is fast; an odd number will have its least significant bit set to `1`:

```
function isOdd5(n: number): boolean {
  return (n & 1) === 1;
}
```

As in `isOdd1()`, you get another variation by doing `return Boolean(n & 1)` instead:

```
function isOdd6(n: number): boolean {
  return Boolean(n & 1); // or !!(n & 1) instead
}
```

Shifting in binary also works; if we shift the number one bit to the right (dropping its least significant bit) and then shift the number back one bit to the left, for an odd number, we don't get the same result:

```
function isOdd7(n: number): boolean {
  return (n >> 1) << 1 !== n;
}
```

Shifting to the right is the same as dividing by 2 and keeping the integer part, so this solution is basically the same as the third one:

```
function isOdd8(n: number): boolean {
  return n >> 1 === (n - 1) >> 1;
}
```

Odd numbers end in 1, 3, 5, 7, or 9, so we can also look at the string representation of the number and check its value:

```
function isOdd9(n: number): boolean {
  return "13579".includes(String(n).at(-1)!);
}
```

We could work with the string by using `find()` or `indexOf()`; I'll leave these versions to you.

9.11 **Odds and evens trampolining**: We must first change our mutually recursive functions to work with continuations, and return calls to `trampoline()`:

```
function isEven(n: number, cont: FN): () => boolean {
  if (n === 0) {
    return trampoline(() => cont(true));
  } else {
    return trampoline(() => isOdd(n - 1, (v) => cont(v)));
  }
}

function isOdd(n: number, cont: FN): () => boolean {
  return trampoline(() => isEven(n, (v) => cont(!v)));
}
```

For instance, the first `return` in `isEven()` used to be `return true`; now we trampoline a thunk that will call a continuation with `true`. We can now finish the job by providing an appropriate continuation that just returns the calculated value:

```
function isEvenT(n: number): boolean {
  return trampoline(isEven(n, (x) => x));
}

function isOddT(n: number): boolean {
  return trampoline(isOdd(n, (x) => x));
}

console.log("22.. isEven?", isEvenT(22));  // true
console.log("9... isOdd?", isOddT(5));     // true
console.log("63... isEven?", isEvenT(63)); // false
console.log("60... isOdd?", isOddT(60));   // false
```

9.12 **Mutual problem?** If you do `isEven(1)` or `isOdd(2)`, you get an infinite loop; can you see why? (The same will happen if you replace `1` and `2` with any odd or even number, respectively.) A hint: the problem is with the base cases for recursion.

9.13 **Say no to whiles?** Yes, the code is equivalent. We are replacing `while()` with a `for(;;)` loop and breaking out with a `return`.

9.14 **Power, more power!** We'll need to add a new `power()` function, sitting between `term()` and `factor()`, so its priority will be correctly placed.

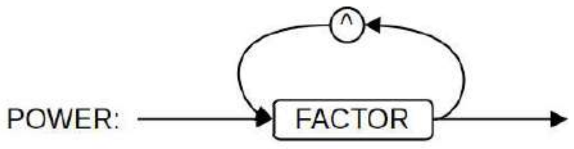


Figure 2 – Power represents a sequence of exponentiations

We'll change `term()` to call `power()` instead of `factor()`:

```
function term(): number {
  let accum = power();

  while (
    tokens[curr] === TIMES ||
    tokens[curr] === DIVIDES ||
    tokens[curr] === MODULUS
  ) {
    if (tokens[curr] === TIMES) {
      curr++;
      accum *= power();
    } else if (tokens[curr] === DIVIDES) {
      curr++;
      accum /= power();
    } else if (tokens[curr] === MODULUS) {
      curr++;
      accum %= power();
      }
    }

    return accum;
  }
```

To properly calculate "towers" such as 2^3^4, we'll store `2`, `3`, and `4` in an array, and then reduce it from right to left: we'll first calculate 3^4, and then 2^(the calculated result for 3^4):

```
function power(): number {
  const tower = [factor()];
  while (tokens[curr] === POWER) {
    curr++;
    tower.push(factor());
  }

  while (tower.length > 1) {
    tower[tower.length - 2] **= tower[tower.length - 1];
    tower.pop();
  }
  return tower[0];
}
```

9.15 **Error-prone evaluation**: Here are some ideas:

- When skipping a token, check if it's correct anyway; for instance, `factor()` skips the second parenthesis without actually checking whether it is, so it would evaluate "(1+2]" as 3, even though it's wrong.
- Add a special end-of-string (EOS) token, to check whether the evaluation finishes at that token.
- Check you do not go beyond the end of the `tokens` array whenever you advance to the next token.

Chapter 10, Ensuring Purity – Immutability

10.1 **Not just date problems**: We can see more limitations of `jsonCopy()` in the following example, but don't assume there aren't any more problems:

```
const agent = {
  error: new Error("It's stirred; I ordered it shaken"),
  map: new Map([["James", "Bond"]]),
  set: new Set([0, 0, 7]),
  regex: /007/,
  useLicense() {
    console.log("Bang! Bang!");
  },
};

console.log(jsonCopy(agent));
/*
{ error: {}, map: {}, set: {}, regex: {} }
*/
```

Four of the properties got transformed into an empty object, and the function was ignored.

10.2 **The mote in jsonCopy's eye…** Our `deepCopy()` function does marginally better; with the same agent object as in the previous question, copying produces the following:

```
/*
{
  error: Error: It's stirred; I ordered it shaken
    ...many lines snipped out
  map: Map(0) {},
  set: Set(0) {},
  regex: /(?:)/,
  useLicense: [Function: useLicense]
}
*/
```

The error and the function got converted OK. The map and the set were converted into the right types, but they are empty; this could be fixed by adding logic that would scan the original objects and insert copies of them into the new ones. (*Question 10.10* may help.) Finally, cloning a regular expression is a tad harder, but google "*clone regexp in JavaScript*" and you'll find several implementations for this.

10.3 **Going in circles**: We may fix this by using a memoizing-style solution, as in *Chapter 4, Behaving Properly*. After we copy an object, we'll store a reference in a map. Before we try to copy any object, we'll first see whether we copied it earlier (by looking for it in the map) and if so, we won't do any new copying and will just use what we found in the map. Our new `deepCopy2()` function is as follows:

```
const deepCopy2 = <O extends OBJ>(obj: O): O => {
  const mapped = new Map<O, O>();

  const deepCopy = (obj: O): O => {
    let aux: O = obj;
    if (obj && typeof obj === "object") {
      if (mapped.has(obj)) {
        return mapped.get(obj) as O;
      }

      aux = new (obj as any).constructor();
      mapped.set(obj, aux);

      Object.getOwnPropertyNames(obj).forEach((prop) => {
        (aux as any)[prop as keyof O] =
          deepCopy(obj[prop]);
      });
    }

    return aux;
  };

  return deepCopy(obj);
};
```

We'll use the `mapped` variable for our map. When we find that we have to clone an `obj` object, we first check (`mapped.has(obj)`) whether we have already done that, and if so, we return the value from the map. If this was a new, not yet copied object, we add it and its `aux` copy to the map (`mapped.set(obj,aux)`) for future reference.

We can verify how this work with a simple example:

```
const circular = {
  a: 1,
  b: { c: 3, d: { e: 5, f: null } }
};
circular.b.d.f = circular.b as any;

console.log(deepCopy2(circular));

/*
{
  a: 1,
  b: <ref *1> { c: 3, d: { e: 5, f: [Circular *1] } }
}
*/
```

If we use `deepCopy()` on `circular`, we'll get a `RangeError: Maximum call stack size exceeded` exception. However, with our new `deepCopy2()` function, the circular reference is tackled with no problem.

10.4 **Freezing by proxying**: As requested, a proxy allows you to intercept changes on an object. (See `developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Proxy` for more on this.) We use recursion to apply the proxy all the way down in case some attributes are objects themselves:

```
const proxySetAll = (obj: OBJ): OBJ => {
  Object.keys(obj).forEach((v) => {
    if (typeof obj[v] === "object") {
      obj[v] = proxySetAll(obj[v]);
    }
  });

  return new Proxy(obj, {
    set() {
      throw new Error("DON'T MODIFY ANYTHING IN ME");
    },
    deleteProperty() {
      throw new Error("DON'T DELETE ANYTHING IN ME");
    },
  }) as OBJ;
};
```

The following is the output of the preceding code. For real-life implementations, you'd probably require something other than a `DON'T MODIFY ANYTHING IN ME` message, of course!

```
const myObj = proxySetAll({
  a: 5,
  b: 6,
  c: { d: 7, e: 8 },
});

myObj.a = 777;
// Uncaught Error: DON'T MODIFY ANYTHING IN ME

myObj.f = 888;
// Uncaught Error: DON'T MODIFY ANYTHING IN ME

delete myObj.b;
// Uncaught Error: DON'T DELETE ANYTHING IN ME
```

10.5 **Inserting into a list, persistently**: Using recursion helps out as follows:

- If the list is empty, we cannot insert the new key.
- If we are at a node whose key is `oldKey`, we create a clone of that node that points at a list that starts with a new node with `newKey` as its value and a pointer to the rest of the original node's list.
- If we are at a node whose key isn't `oldKey`, we create a clone of the node and (recursively) insert the new key somewhere in the rest of the original node's list:

```
type NODE_PTR = Node | null;

const insertAfter = (
  list: NODE_PTR,
  newKey: string,
  oldKey: string
): NODE_PTR => {
  if (list === null) {
    return null;
  } else if (list.key === oldKey) {
      return new Node(list.key, new Node(newKey, list.next));
    } else {
      return new Node(
        list.key,
        insertAfter(list.next, newKey, oldKey)
      );
    }
  };
```

In the following code, we can see this working. The new list is similar to the one shown in *Figure 10.2*. However, printing out the lists (`c3` and `newList`) wouldn't be enough; you wouldn't be able to distinguish new or old nodes, so I've included several comparisons:

```
const c3 =
  new Node("G",
    new Node("B",
      new Node("F",
        new Node("A",
          new Node("C",
            new Node("E", null))))));

const newList = insertAfter(c3, "D", "B");

console.log(c3 === newList);
// false

console.log(c3!.key === newList!.key);
// true (both are "G")

console.log(c3!.next === newList!.next);
// false

console.log(c3!.next!.key === newList!.next!.key);
// true (both are "B")

console.log(c3!.next!.next === newList!.next!.next);
// false
```

```
console.log(c3!.next!.next!.key === "F");
// true

console.log(newList!.next!.next!.key === "D");
// true

console.log(
  c3!.next!.next!.next === newList!.next!.next!.next!.next
);
// true - after F, the list is the old one
```

A lot of `!` non-null assertions were needed to inform TypeScript that no `null` values were around.

A new question: In the preceding logic, nothing is inserted if `oldKey` isn't found. Can you change the logic so, in that case, the new node is added at the end of the list?

10.6 **Composing many lenses**: We want to compose lenses from left to right so we can directly use `reduce()`. Let's write the `composeManyLenses()` function and apply it to the same example that was shown in the text:

```
const composeManyLenses = <O extends OBJ>(
  ...lenses: LENS<O>[]
) =>
  lenses.reduce((acc, lens) => composeTwoLenses(acc,
    lens));
```

With the `deepObject` example seen earlier, plus all the lenses to get `c`, `e`, `g`, and so on, we get the following:

```
const deepObject = {
  a: 1,
  b: 2,
  c: {
    d: 3,
    e: {
      f: 6,
      g: { i: 9, j: { k: 11 } },
      h: 8,
    },
  },
};

console.log(
  view(composeManyLenses(lC, lE, lG, lJ, lK), deepObject)
);

// 11, same as earlier
```

10.7 **Lenses by path**: Hint – the needed changes would be similar to what we did when we went from `getField()` to `getByPath()`.

10.8 **Accessing virtual attributes**: Using a getter is always viable, and for this question, you'd write something like the following, and you'd have a getter for the virtual `fullName` attribute:

```
const lastNameLens = composeTwoLenses(
  lensProp("name"),
  lensProp("last")
);

const firstNameLens = composeTwoLenses(
  lensProp("name"),
  lensProp("first")
);

const fullNameGetter = <O extends OBJ>(obj: O): string =>
  `${view(lastNameLens)(obj)},
    ${view(firstNameLens)(obj)}`;
```

Being able to set several attributes based on a single value isn't always possible, but if we assume the incoming name is in the `LAST,FIRST` format, we can split it by the comma and assign the two parts to the first and last names, respectively:

```
const fullNameSetter =
  <O extends OBJ>(fullName: string) =>
  (obj: O): O => {
    const parts = fullName.split(",");
    return set(firstNameLens)(parts[1])(
      set(lastNameLens)(parts[0])(obj)
    ) as O;
  };

const fullNameLens = lens(fullNameGetter, fullNameSetter);
```

10.9 **Lenses for arrays?** The `view()` function would work well, but `set()` and `over()` wouldn't work in a pure way since `setArray()` doesn't return a new array; instead, it modifies the current one in place. Take a look at the following question for a related problem.

10.10 **Lenses into maps**: Getting a value from the map poses no problem, but for setting, we need to clone the map:

```
const getMap =
  <K, V>(key: K) =>
  (map: Map<K, V>) =>
    map.get(key);

const setMap =
  <K, V>(key: K) =>
  (value: V) =>
  (map: Map<K, V>) =>
    new Map(map).set(key, value);

const lensMap = <K, V>(key: K) =>
  lens(getMap<K, V>(key), setMap<K, V>(key));
```

Chapter 11, Implementing Design Patterns – The Functional Way

11.1 **Decorating methods, the future way**: As we've already mentioned, decorators aren't a fixed, definitive feature at the moment. However, by following `tc39.github.io/proposal-decorators/`, we can write the following:

```
const logging = (target, name, descriptor) => {
  const savedMethod = descriptor.value;
  descriptor.value = function (...args) {
    console.log(`entering ${name}: ${args}`);

    try {
      const valueToReturn =
        savedMethod.bind(this)(...args);
      console.log(`exiting ${name}: ${valueToReturn}`);
      return valueToReturn;
    } catch (thrownError) {
      console.log(`exiting ${name}: threw ${thrownError}`);
      throw thrownError;
    }
  };

  return descriptor;
};
```

We want to add a `@logging` decoration to a method. We save the original method in `savedMethod` and substitute a new method that will log the received arguments, call the original method to save its return value, log that, and finally return it. If the original method throws an exception, we catch it, report it, and throw it again so that it can be processed as expected. A simple example of this is as follows:

```
class SumThree {
  constructor(z) {
    this.z = z;
  }
  @logging
  sum(x, y) {
    return x + y + this.z;
  }
}

new SumThree(100).sum(20, 8);
// entering sum: 20,8
// exiting sum: 128
```

11.2 **Decorator with mixins**: We write an `addBar()` function that receives a `Base` class and extends it. In this case, I decided to add a new attribute and a new method. The constructor for the extended class calls the original constructor and creates the `barValue` attribute. The new class has both the original's `doSomething()` method and the new `somethingElse()` method:

```
const addBar = (Base) =>
  class extends Base {
    constructor(fooValue, barValue) {
      super(fooValue);
      this.barValue = barValue;
    }

    somethingElse() {
      console.log(
        "something added: bar... ",
        this.barValue
      );
    }
  };
```

11.3 **Multi-clicking by hand**: There are various ways to achieve this with timers and counting, but make sure that you don't interfere with single- or double-click detection! You can also use a common listener and look at `event.detail`; you can find out more at `developer.mozilla.org/en-US/docs/Web/API/UIEvent/detail`.

11.4 **Sorting logically**: If you have, say, a `flags` array with Boolean values, you don't need any special comparison function; `flags.sort()` works "out of the box" and will place `false` values first and `true` values last. This is because the standard sort works by converting values into strings, and then comparing them; when you do this, Boolean values become `"false"` and `"true"`, and as `"false" < "true"`, everything turns out well!

11.5 **Finding routes, objectively**: The standard solution would be to have an abstract `RouteFinder` class with several subclasses, such as `ByFootRouteFinder`, `BicycleRouteFinder`, and so on, each implementing a `findRouteAlgorithm()` method in a different way, and a factory that chooses what subclass to instantiate.

Chapter 12, Building Better Containers – Functional Data Types

12.1 **Extending prototypes**: Here are the needed definitions to add a `map()` method to Booleans, numbers, and strings:

```
declare global {
  interface Boolean {
    map(_f: (_x: boolean) => boolean): boolean;
  }
}

declare global {
  interface Number {
    map(_f: (_x: number) => number): number;
  }
}

declare global {
  interface String {
    map(_f: (_x: string) => string): string;
  }
}
```

Some examples are as follows:

```
Boolean.prototype.map = function (
  this: boolean,
  fn: (_x: boolean) => any
) {
  return !!fn(this);
};

const t = true;
const f = false;
const negate = (x: boolean) => !x;

console.log(t.map(negate), f.map(negate));
```

```
// false true

Number.prototype.map = function (
  this: number,
  fn: (_x: number) => number
) {
  return Number(fn(this));
};

const n = 22;
const add1 = (n: number) => n + 1;
console.log(n.map(add1));
// 23

String.prototype.map = function (
  this: string,
  fn: (_x: string) => string
) {
  return String(fn(this));
};

const s = "Montevideo";
const addBangs = (s: string): string => s + "!!!";

console.log(s.map(addBangs));
// Montevideo!!!
```

12.2 **No protection?** In previous editions of the book, I used a `Symbol`, whose value was defined inside a module and not exported, so nobody could access the corresponding attribute:

```
const VALUE = Symbol("Value");

class Container {
  constructor(x) {
    this[VALUE] = x;
  }
  map(fn) {
    return fn(this[VALUE]);
  }
  .
  . other methods
  .
}
```

Using a `Symbol` helps hide the field: the property key won't show up in `Object.keys()` or in `for...in` or `for...of` loops, making them more meddle-proof. (If you haven't worked with JavaScript symbols, possibly the least known of its primitive data types, you might want to check out `developer.mozilla.org/en-US/docs/Glossary/symbol`.)

The `map()` method could access the "protected" attribute because it had access to the `VALUE` symbol, but without that, you cannot get at the attribute.

12.3 **No abstract classes?** You have to add a check at the constructor. If you want the `XXX` class to be abstract, it should start like this:

```
class XXX {
  constructor(...) {
    if (this.constructor === XXX) {
      throw new Error("Cannot initialize XXX class")
    }
    .
    . rest of the constructor
    .
  }


  .
  . other methods
  .
}
```

12.4 **Maybe tasks?** The following code shows a simpler solution than the one we looked at earlier:

```
const pending = Maybe.of(listOfTasks)
  .map(getField("byPerson"))
  .map(filter((t) => t.responsible === name))
  .map((t) => tasks)
  .map((t) => t[0])
  .map(filter((t) => !t.done))
  .map(getField("id"))
  .valueOf();
```

Here, we apply one function after the other, secure in the knowledge that if any of these functions produces an empty result (or even if the original `listOfTasks` is null), the sequence of calls will go on. In the end, you will either get an array of task IDs or a `null` value.

12.5 **Extending your trees**: Calculating the tree's height is simple if you do this in a recursive fashion. The height of an empty tree is zero, while the height of a non-empty tree is one (for the root) plus the maximum height of its left and right subtrees:

```
const treeHeight = <A>(tree: TREE<A>): number =>
  tree(
    (val, left, right) =>
      1 + Math.max(treeHeight(left), treeHeight(right)),
    () => 0
  );
```

Listing the keys in order is a well-known requirement. Because of the way that the tree is built, you list the left subtree's keys first, then the root, and finally the right subtree's keys, all in a recursive fashion:

```
const treeList = <A>(tree: TREE<A>): void =>
  tree(
    (value, left, right) => {
      treeList(left);
      console.log(value);
      treeList(right);
    },
    () => {
      // nothing
    }
  );
```

Finally, deleting a key from a binary search tree is a bit more complex. First, you must locate the node that is going to be removed, and then there are several cases:

- If the node has no subtrees, deletion is simple.
- If the node has only one subtree, you just replace the node with its subtree
- If the node has two subtrees, then you have to do the following:
    - Find the minimum key in the tree with a greater key
    - Place it in the node's place

Since this algorithm is well covered in all computer science textbooks, I won't go into more detail about this here:

```
const treeRemove = <A>(
  toRemove: A,
  tree: TREE<A>
): TREE<A> =>
  tree(
    (val, left, right) => {
      const findMinimumAndRemove = (
        tree: TREE<A> /* never empty */
      ): { min: A; tree: TREE<A> } =>
        tree(
          (value, left, right) => {
            if (treeIsEmpty(left)) {
              return { min: value, tree: right };
            } else {
              const result = findMinimumAndRemove(left);
              return {
                min: result.min,
                tree: Tree(value, result.tree, right),
              };
            }
          },
          () => {
            /* not needed */
          }
        );
      if (toRemove < val) {
        return Tree(val, treeRemove(toRemove, left),
          right);
      } else if (toRemove > val) {
        return Tree(val, left, treeRemove(toRemove,
          right));
      } else if (treeIsEmpty(left) && treeIsEmpty(right)) {
        return EmptyTree();
      } else if (treeIsEmpty(left) !== treeIsEmpty(right))
        {
        return tree(
          (val, left, right) =>
            left(
              () => left,
              () => right
            ),
          () => {
            /* not needed */
          }
        );
      } else {
        const result = findMinimumAndRemove(right);
        return Tree(result.min, left, result.tree);
      }
    },
    () => tree
  );
```

12.6 **Code shortening**: The first thing you would do is get rid of the first ternary operator by taking advantage of the short-circuit evaluation of the || operator:

```
const treeSearch2 = <A>(
  findValue: A,
  tree: TREE<A>
): boolean =>
  tree(
    (value, left, right) =>
      findValue === value ||
      (findValue < value
        ? treeSearch2(findValue, left)
        : treeSearch2(findValue, right)),
    () => false
  );
```

Also, seeing that both alternatives in the second ternary operator are very similar, you could also do some shortening there:

```
const treeSearch3 = <A>(
  findValue: A,
  tree: TREE<A>
): boolean =>
  tree(
    (value, left, right) =>
      findValue === value ||
      treeSearch3(
        findValue,
        findValue < value ? left : right
      ),
    () => false
  );
```

Remember: shorter doesn't imply better! However, I've found many examples of this kind of code tightening, and it's better if you have been exposed to it, too.

12.7 **Functional lists**: Let's add to the samples that have already been provided. We can simplify working with lists if we can transform a list into an array, and vice versa:

```
const listToArray = <A>(list: LIST<A>): A[] =>
  list(
    (head, tail) => [head, ...listToArray(tail)],
    () => []
  );
```

```
const listFromArray = <A>(arr: A[]): LIST<A> =>
  arr.length
    ? NewList(arr[0], listFromArray(arr.slice(1)))
    : EmptyList();
```

Concatenating two lists together and appending a value to a list have simple recursive implementations. We can also reverse a list by using the appending function:

```
const listConcat = <A>(list1: LIST<A>, list2: LIST<A>) =>
  list1(
    (head, tail) => NewList(head, listConcat(tail, list2)),
    () => list2
  );

const listAppend = <A>(list: LIST<A>, value: A): LIST<A> =>
  list(
    (head, tail) => NewList(head, listAppend(tail, value)),
    () => NewList(value, EmptyList())
  );

const listReverse = <A>(list: LIST<A>): LIST<A> =>
  list(
    (head, tail) => listAppend(listReverse(tail), head),
    () => EmptyList()
  );
```

Finally, the basic `map()`, `filter()`, and `reduce()` operations are good to have:

```
const listMap = <A, B>(
  list: LIST<A>,
  fn: (_x: A) => B
): LIST<B> =>
  list(
    (head, tail) => NewList(fn(head), listMap(tail, fn)),
    EmptyList
  );
```

```
const listFilter = <A>(
  list: LIST<A>,
  fn: (_x: A) => boolean
): LIST<A> =>
  list(
    (head, tail) =>
      fn(head)
        ? NewList(head, listFilter(tail, fn))
        : listFilter(tail, fn),
    EmptyList
  );

const listReduce = <A, B>(
  list: LIST<A>,
  fn: (_acc: B, _val: A) => B,
  accum: B
): B =>
  list(
    (head, tail) => listReduce(tail, fn, fn(accum, head)),
    () => accum
  );
```

The following are some exercises that have been left for you to tackle. Generate a printable version of a list:

- Compare two lists to see whether they have the same values, in the same order
- Search a list for a value
- Get, update, or remove the value at the *n*th position of a list

12.8 **No Boolean operators?** Let's start by defining a `BOOLEAN` type and two special functions, `TRUE` and `FALSE`, which will stand for the usual `true` and `false` values:

```
type BOOLEAN = (_true: any, _false: any) => any;

const TRUE: BOOLEAN = (trueValue: any, __: any) =>
  trueValue;
```

```
const FALSE: BOOLEAN = (__: any, falseValue: any) =>
  falseValue;
```

The BOOLEAN type receives two values and returns one of those. A TRUE Boolean returns the first of those two values; a FALSE Boolean returns the second. We can construct and check variables like this:

```
const MakeBool = (value: boolean) => (value ? TRUE :
  FALSE);

const valueOf = (boolValue: BOOLEAN): boolean =>
  boolValue(true, false);



console.log("LOG T  ", valueOf(TRUE));
console.log("LOG F  ", valueOf(FALSE));
// true false

console.log("VAL T  ", valueOf(MakeBool(true)));
console.log("VAL F  ", valueOf(MakeBool(false)));
// true false
```

We can now define operators:

```
const NOT = (boolValue: BOOLEAN): BOOLEAN =>
  boolValue(FALSE, TRUE);

const AND = (
  boolLeft: BOOLEAN,
  boolRight: BOOLEAN
): BOOLEAN => boolLeft(boolRight, FALSE);

const OR = (
  boolLeft: BOOLEAN,
  boolRight: BOOLEAN
): BOOLEAN => boolLeft(TRUE, boolRight);

const XOR = (
  boolLeft: BOOLEAN,
  boolRight: BOOLEAN
): BOOLEAN => boolLeft(NOT(boolRight), boolRight);

const EQU = (
  boolLeft: BOOLEAN,
  boolRight: BOOLEAN
): BOOLEAN => boolLeft(boolRight, NOT(boolRight));

const IMP = (
  boolLeft: BOOLEAN,
  boolRight: BOOLEAN
): BOOLEAN => boolLeft(boolRight, TRUE);
```

These are not the only possibilities, but I'll leave you to discover alternatives. Finally, we could have an `ifElse()` function to work with these `BOOLEAN` values and thunks:

```
const ifElse = (
  boolValue: BOOLEAN,
  fnTRUE: FN,
  fnFALSE: FN
) => boolValue(fnTRUE, fnFALSE)();

ifElse(
  TRUE,
  () => console.log("I'm true"),
  () => console.log("I'm false")
);
// true

ifElse(
  FALSE,
  () => console.log("I'm true"),
  () => console.log("I'm false")
);
// false
```

A final comment: this code goes to show more things that you *could* do with functions, but it doesn't mean you *should* do them this way! You can read the following at `www.usrsb.in/Building-Data-Structures-from-Functions.html`:

> *In the end, this might strike you as nothing more than a useless programming trick. In a sense that's right. I'd never use this in my own code. What makes this technique so valuable is that it actually fits into the broader context of lambda calculus, which is a mathematical abstraction of computation.*

Couldn't say it better myself!

Bibliography

The following texts are freely available online:

- *ECMA-262: ECMAScript 2022 Language Specification*, latest edition (currently the 13th) at `www.ecma-international.org/ecma-262/`. This provides the official standard for the current version of JavaScript.
- *Eloquent JavaScript*, Second Edition, by *Marijn Haverbeke*, at `eloquentjavascript.net/`
- *JavaScript for Impatient Programmers (ES2022 edition)*, by *Dr. Axel Rauschmayer*, at `exploringjs.com/impatient-js/`
- *Functional-Light JavaScript*, by *Kyle Simpson*, at `github.com/getify/Functional-Light-JS`
- *JavaScript Allongé (the "six" edition)*, by *Reginald Braithwaite*, at `leanpub.com/javascriptallongesix/read`
- *Professor Frisby's Mostly Adequate Guide to Functional Programming*, by *Dr. Boolean* (*Brian Lonsdorf*), at `github.com/MostlyAdequate/mostly-adequate-guide`

If you prefer printed books, you can go with this list:

- *Beginning Functional JavaScript*, by *Anto Aravinth*, *Apress*, 2017
- *Discover Functional JavaScript*, by *Cristian Salcescu*, (independently published), 2019
- *Functional JavaScript*, by *Michael Fogus*, *O'Reilly Media*, 2013
- *Functional Programming in JavaScript*, by *Dan Mantyla*, *Packt Publishing*, 2015
- *Functional Programming in JavaScript*, by *Luis Atencio*, *Manning Publications*, 2016
- *Grokking Simplicity – Taming complex software with functional thinking*, by *Eric Normand*, *Manning Publications*, 2021
- *Hands-on Functional Programming with TypeScript*, by *Remo Jansen*, *Packt Publishing*, 2019
- *Introduction to Functional Programming*, by *Richard Bird and Philip Wadler*, *Prentice Hall International*, 1988. A more theoretical point of view, not dealing specifically with JavaScript
- *Pro JavaScript Design Patterns*, by *Ross Harmes and Dustin Díaz*, *Apress*, 2008
- *Secrets of the JavaScript Ninja*, by John Resig and Bear Bibeault, *Manning Publications*, 2012
- *TypeScript 4 Design Patterns and Best Practices*, by *Theo Despoudis*, *Packt Publishing*, 2021

Also interesting, though with a lesser focus on functional programming, are the following:

- *High-Performance JavaScript*, by *Nicholas Zakas*, *O'Reilly Media*, 2010
- *JavaScript Patterns*, by *Stoyan Stefanov*, *O'Reilly Media*, 2010
- *JavaScript: The Good Parts*, by *Douglas Crockford*, *O'Reilly Media*, 2008
- *JavaScript with Promises*, by *Daniel Parker*, *O'Reilly Media*, 2015
- *Learning JavaScript Design Patterns*, by *Addy Osmani*, *O'Reilly Media*, 2012
- *Mastering JavaScript Design Patterns, Second Edition*, by *Simon Timms*, *Packt Publishing*, 2016
- *Mastering JavaScript High Performance*, by *Chad Adams*, *Packt Publishing*, 2015
- *Pro JavaScript Performance*, by *Tom Barker*, *Apress*, 2012

These titles are on the subject of reactive functional programming:

- *Mastering Reactive JavaScript*, by *Erich de Souza Oliveira*, *Packt Publishing*, 2017
- *Reactive Programming with Node.js*, by *Fernando Doglio*, *Apress*, 2016
- *Reactive Programming with RxJS*, by *Sergi Mansilla*, *The Pragmatic Programmers*, 2015

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