Eloquent JavaScript

THIRD EDITION

A Modern Introduction to Programming

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no starch press

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3rd edition

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The illustrations are contributed by various artists: Cover and chapter illustrations by Madalina Tantareanu. Pixel art in Chapters 7 and 16 by Antonio Perdomo Pastor. Regular expression diagrams in Chapter 9 generated with regexper.com by Jeff Avallone. Village photograph in Chapter 11 by Fabrice Creuzot. Game concept for Chapter 16 by Thomas Palef.

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Contents

> *"We think we are creating the system for our own purposes. We believe we are making it in our own image... But the computer is not really like us. It is a projection of a very slim part of ourselves: that portion devoted to logic, order, rule, and clarity."*
>
> —Ellen Ullman, Close to the Machine: Technophilia and its Discontents

Introduction

This is a book about instructing computers. Computers are about as common as screwdrivers today, but they are quite a bit more complex, and making them do what you want them to do isn't always easy.

If the task you have for your computer is a common, well-understood one, such as showing you your email or acting like a calculator, you can open the appropriate application and get to work. But for unique or open-ended tasks, there probably is no application.

That is where programming may come in. *Programming* is the act of constructing a *program*—a set of precise instructions telling a computer what to do. Because computers are dumb, pedantic beasts, programming is fundamentally tedious and frustrating.

Fortunately, if you can get over that fact, and maybe even enjoy the rigor of thinking in terms that dumb machines can deal with, programming can be rewarding. It allows you to do things in seconds that would take *forever* by hand. It is a way to make your computer tool do things that it couldn't do before. And it provides a wonderful exercise in abstract thinking.

Most programming is done with programming languages. A *programming language* is an artificially constructed language used to instruct computers. It is interesting that the most effective way we've found to communicate with a computer borrows so heavily from the way we communicate with each other. Like human languages, computer languages allow words and phrases to be combined in new ways, making it possible to express ever new concepts.

At one point language-based interfaces, such as the BASIC and DOS prompts of the 1980s and 1990s, were the main method of interacting with computers. They have largely been replaced with visual interfaces, which are easier to learn but offer less freedom. Computer languages are still there, if you know where to look. One such language, JavaScript, is built into every modern web browser and is thus available on almost every device.

This book will try to make you familiar enough with this language to do useful and amusing things with it.

On programming

Besides explaining JavaScript, I will introduce the basic principles of programming. Programming, it turns out, is hard. The fundamental rules are simple and clear, but programs built on top of these rules tend to become complex enough to introduce their own rules and complexity. You're building your own maze, in a way, and you might just get lost in it.

There will be times when reading this book feels terribly frustrating. If you are new to programming, there will be a lot of new material to digest. Much of this material will then be *combined* in ways that require you to make additional connections.

It is up to you to make the necessary effort. When you are struggling to follow the book, do not jump to any conclusions about your own capabilities. You are fine—you just need to keep at it. Take a break, reread some material, and make sure you read and understand the example programs and exercises. Learning is hard work, but everything you learn is yours and will make subsequent learning easier.

> When action grows unprofitable, gather information; when information grows unprofitable, sleep.
>
> —Ursula K. Le Guin, The Left Hand of Darkness

A program is many things. It is a piece of text typed by a programmer, it is the directing force that makes the computer do what it does, it is data in the computer's memory, yet it controls the actions performed on this same memory. Analogies that try to compare programs to objects we are familiar with tend to fall short. A superficially fitting one is that of a machine—lots of separate parts tend to be involved, and to make the whole thing tick, we have to consider the ways in which these parts interconnect and contribute to the operation of the whole.

A computer is a physical machine that acts as a host for these immaterial machines. Computers themselves can do only stupidly straightforward things. The reason they are so useful is that they do these things at an incredibly high speed. A program can ingeniously combine an enormous number of these simple actions to do very complicated things.

A program is a building of thought. It is costless to build, it is weightless, and it grows easily under our typing hands.

But without care, a program's size and complexity will grow out of control, confusing even the person who created it. Keeping programs under control is the main problem of programming. When a program works, it is beautiful. The

art of programming is the skill of controlling complexity. The great program is subdued—made simple in its complexity.

Some programmers believe that this complexity is best managed by using only a small set of well-understood techniques in their programs. They have composed strict rules ("best practices") prescribing the form programs should have and carefully stay within their safe little zone.

This is not only boring, it is ineffective. New problems often require new solutions. The field of programming is young and still developing rapidly, and it is varied enough to have room for wildly different approaches. There are many terrible mistakes to make in program design, and you should go ahead and make them so that you understand them. A sense of what a good program looks like is developed in practice, not learned from a list of rules.

Why language matters

In the beginning, at the birth of computing, there were no programming languages. Programs looked something like this:

```
00110001 00000000 00000000
00110001 00000001 00000001
00110011 00000001 00000010
01010001 00001011 00000010
00100010 00000010 00001000
01000011 00000001 00000000
01000001 00000001 00000001
00010000 00000010 00000000
01100010 00000000 00000000
```

That is a program to add the numbers from 1 to 10 together and print out the result: `1 + 2 + ... + 10 = 55`. It could run on a simple, hypothetical machine. To program early computers, it was necessary to set large arrays of switches in the right position or punch holes in strips of cardboard and feed them to the computer. You can probably imagine how tedious and error-prone this procedure was. Even writing simple programs required much cleverness and discipline. Complex ones were nearly inconceivable.

Of course, manually entering these arcane patterns of bits (the ones and zeros) did give the programmer a profound sense of being a mighty wizard. And that has to be worth something in terms of job satisfaction.

Each line of the previous program contains a single instruction. It could be written in English like this:

1. Store the number 0 in memory location 0.
2. Store the number 1 in memory location 1.
3. Store the value of memory location 1 in memory location 2.
4. Subtract the number 11 from the value in memory location 2.
5. If the value in memory location 2 is the number 0, continue with instruction 9.
6. Add the value of memory location 1 to memory location 0.
7. Add the number 1 to the value of memory location 1.
8. Continue with instruction 3.
9. Output the value of memory location 0.

Although that is already more readable than the soup of bits, it is still rather obscure. Using names instead of numbers for the instructions and memory locations helps.

```
  Set “total” to 0.
  Set “count” to 1.
 [loop]
  Set “compare” to “count”.
  Subtract 11 from “compare”.
  If “compare” is zero, continue at [end].
  Add “count” to “total”.
  Add 1 to “count”.
  Continue at [loop].
 [end]
  Output “total”.
```

Can you see how the program works at this point? The first two lines give two memory locations their starting values: `total` will be used to build up the result of the computation, and `count` will keep track of the number that we are currently looking at. The lines using `compare` are probably the weirdest ones. The program wants to see whether `count` is equal to 11 to decide whether it can stop running. Because our hypothetical machine is rather primitive, it can only test whether a number is zero and make a decision based on that. So it uses the memory location labeled `compare` to compute the value of `count - 11` and makes a decision based on that value. The next two lines add the value

of `count` to the result and increment `count` by 1 every time the program has decided that `count` is not 11 yet.

Here is the same program in JavaScript:

```
let total = 0, count = 1;
while (count <= 10) {
  total += count;
  count += 1;
}
console.log(total);
// → 55
```

This version gives us a few more improvements. Most important, there is no need to specify the way we want the program to jump back and forth anymore. The `while` construct takes care of that. It continues executing the block (wrapped in braces) below it as long as the condition it was given holds. That condition is `count <= 10`, which means "*count* is less than or equal to 10". We no longer have to create a temporary value and compare that to zero, which was just an uninteresting detail. Part of the power of programming languages is that they can take care of uninteresting details for us.

At the end of the program, after the `while` construct has finished, the `console.log` operation is used to write out the result.

Finally, here is what the program could look like if we happened to have the convenient operations `range` and `sum` available, which respectively create a collection of numbers within a range and compute the sum of a collection of numbers:

```
console.log(sum(range(1, 10)));
// → 55
```

The moral of this story is that the same program can be expressed in both long and short, unreadable and readable ways. The first version of the program was extremely obscure, whereas this last one is almost English: `log` the `sum` of the `range` of numbers from 1 to 10. (We will see in later chapters how to define operations like `sum` and `range`.)

A good programming language helps the programmer by allowing them to talk about the actions that the computer has to perform on a higher level. It helps omit details, provides convenient building blocks (such as `while` and `console.log`), allows you to define your own building blocks (such as `sum` and `range`), and makes those blocks easy to compose.

What is JavaScript?

JavaScript was introduced in 1995 as a way to add programs to web pages in the Netscape Navigator browser. The language has since been adopted by all other major graphical web browsers. It has made modern web applications possible—applications with which you can interact directly without doing a page reload for every action. JavaScript is also used in more traditional websites to provide various forms of interactivity and cleverness.

It is important to note that JavaScript has almost nothing to do with the programming language named Java. The similar name was inspired by marketing considerations rather than good judgment. When JavaScript was being introduced, the Java language was being heavily marketed and was gaining popularity. Someone thought it was a good idea to try to ride along on this success. Now we are stuck with the name.

After its adoption outside of Netscape, a standard document was written to describe the way the JavaScript language should work so that the various pieces of software that claimed to support JavaScript were actually talking about the same language. This is called the ECMAScript standard, after the Ecma International organization that did the standardization. In practice, the terms ECMAScript and JavaScript can be used interchangeably—they are two names for the same language.

There are those who will say *terrible* things about JavaScript. Many of these things are true. When I was required to write something in JavaScript for the first time, I quickly came to despise it. It would accept almost anything I typed but interpret it in a way that was completely different from what I meant. This had a lot to do with the fact that I did not have a clue what I was doing, of course, but there is a real issue here: JavaScript is ridiculously liberal in what it allows. The idea behind this design was that it would make programming in JavaScript easier for beginners. In actuality, it mostly makes finding problems in your programs harder because the system will not point them out to you.

This flexibility also has its advantages, though. It leaves space for a lot of techniques that are impossible in more rigid languages, and as you will see (for example in Chapter 10), it can be used to overcome some of JavaScript's shortcomings. After learning the language properly and working with it for a while, I have learned to actually *like* JavaScript.

There have been several versions of JavaScript. ECMAScript version 3 was the widely supported version in the time of JavaScript's ascent to dominance, roughly between 2000 and 2010. During this time, work was underway on an ambitious version 4, which planned a number of radical improvements and extensions to the language. Changing a living, widely used language in such a

radical way turned out to be politically difficult, and work on the version 4 was abandoned in 2008, leading to a much less ambitious version 5, which made only some uncontroversial improvements, coming out in 2009. Then in 2015 version 6 came out, a major update that included some of the ideas planned for version 4. Since then we've had new, small updates every year.

The fact that the language is evolving means that browsers have to constantly keep up, and if you're using an older browser, it may not support every feature. The language designers are careful to not make any changes that could break existing programs, so new browsers can still run old programs. In this book, I'm using the 2017 version of JavaScript.

Web browsers are not the only platforms on which JavaScript is used. Some databases, such as MongoDB and CouchDB, use JavaScript as their scripting and query language. Several platforms for desktop and server programming, most notably the Node.js project (the subject of Chapter 20), provide an environment for programming JavaScript outside of the browser.

Code, and what to do with it

Code is the text that makes up programs. Most chapters in this book contain quite a lot of code. I believe reading code and writing code are indispensable parts of learning to program. Try to not just glance over the examples—read them attentively and understand them. This may be slow and confusing at first, but I promise that you'll quickly get the hang of it. The same goes for the exercises. Don't assume you understand them until you've actually written a working solution.

I recommend you try your solutions to exercises in an actual JavaScript interpreter. That way, you'll get immediate feedback on whether what you are doing is working, and, I hope, you'll be tempted to experiment and go beyond the exercises.

The easiest way to run the example code in the book, and to experiment with it, is to look it up in the online version of the book at *https://eloquentjavascript.net*. There, you can click any code example to edit and run it and to see the output it produces. To work on the exercises, go to *https://eloquentjavascript.net/code*, which provides starting code for each coding exercise and allows you to look at the solutions.

If you want to run the programs defined in this book outside of the book's website, some care will be required. Many examples stand on their own and should work in any JavaScript environment. But code in later chapters is often written for a specific environment (the browser or Node.js) and can run

only there. In addition, many chapters define bigger programs, and the pieces of code that appear in them depend on each other or on external files. The sandbox on the website provides links to Zip files containing all the scripts and data files necessary to run the code for a given chapter.

Overview of this book

This book contains roughly three parts. The first 12 chapters discuss the JavaScript language. The next seven chapters are about web browsers and the way JavaScript is used to program them. Finally, two chapters are devoted to Node.js, another environment to program JavaScript in.

Throughout the book, there are five *project chapters*, which describe larger example programs to give you a taste of actual programming. In order of appearance, we will work through building a delivery robot, a programming language, a platform game, a pixel paint program, and a dynamic website.

The language part of the book starts with four chapters that introduce the basic structure of the JavaScript language. They introduce control structures (such as the `while` word you saw in this introduction), functions (writing your own building blocks), and data structures. After these, you will be able to write basic programs. Next, Chapters 5 and 6 introduce techniques to use functions and objects to write more *abstract* code and keep complexity under control.

After a first project chapter, the language part of the book continues with chapters on error handling and bug fixing, regular expressions (an important tool for working with text), modularity (another defense against complexity), and asynchronous programming (dealing with events that take time). The second project chapter concludes the first part of the book.

The second part, Chapters 13 to 19, describes the tools that browser JavaScript has access to. You'll learn to display things on the screen (Chapters 14 and 17), respond to user input (Chapter 15), and communicate over the network (Chapter 18). There are again two project chapters in this part.

After that, Chapter 20 describes Node.js, and Chapter 21 builds a small website using that tool.

Typographic conventions

In this book, text written in a `monospaced` font will represent elements of programs—sometimes they are self-sufficient fragments, and sometimes they just refer to part of a nearby program. Programs (of which you have already seen a few) are written as follows:

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

Sometimes, to show the output that a program produces, the expected output is written after it, with two slashes and an arrow in front.

```
console.log(factorial(8));
// → 40320
```

Good luck!

> *"Below the surface of the machine, the program moves. Without effort, it expands and contracts. In great harmony, electrons scatter and regroup. The forms on the monitor are but ripples on the water. The essence stays invisibly below."*
>
> —Master Yuan-Ma, The Book of Programming

CHAPTER 1

VALUES, TYPES, AND OPERATORS

Inside the computer's world, there is only data. You can read data, modify data, create new data—but that which isn't data cannot be mentioned. All this data is stored as long sequences of bits and is thus fundamentally alike.

Bits are any kind of two-valued things, usually described as zeros and ones. Inside the computer, they take forms such as a high or low electrical charge, a strong or weak signal, or a shiny or dull spot on the surface of a CD. Any piece of discrete information can be reduced to a sequence of zeros and ones and thus represented in bits.

For example, we can express the number 13 in bits. It works the same way as a decimal number, but instead of 10 different digits, you have only 2, and the weight of each increases by a factor of 2 from right to left. Here are the bits that make up the number 13, with the weights of the digits shown below them:

```
  0   0   0   0   1   1   0   1
128  64  32  16   8   4   2   1
```

So that's the binary number 00001101. Its non-zero digits stand for 8, 4, and 1, and add up to 13.

VALUES

Imagine a sea of bits—an ocean of them. A typical modern computer has more than 30 billion bits in its volatile data storage (working memory). Nonvolatile storage (the hard disk or equivalent) tends to have yet a few orders of magnitude more.

To be able to work with such quantities of bits without getting lost, we must separate them into chunks that represent pieces of information. In a JavaScript environment, those chunks are called *values*. Though all values are made of bits, they play different roles. Every value has a type that determines its role. Some

values are numbers, some values are pieces of text, some values are functions, and so on.

To create a value, you must merely invoke its name. This is convenient. You don't have to gather building material for your values or pay for them. You just call for one, and *whoosh*, you have it. They are not really created from thin air, of course. Every value has to be stored somewhere, and if you want to use a gigantic amount of them at the same time, you might run out of memory. Fortunately, this is a problem only if you need them all simultaneously. As soon as you no longer use a value, it will dissipate, leaving behind its bits to be recycled as building material for the next generation of values.

This chapter introduces the atomic elements of JavaScript programs, that is, the simple value types and the operators that can act on such values.

Numbers

Values of the *number* type are, unsurprisingly, numeric values. In a JavaScript program, they are written as follows:

```
13
```

Use that in a program, and it will cause the bit pattern for the number 13 to come into existence inside the computer's memory.

JavaScript uses a fixed number of bits, 64 of them, to store a single number value. There are only so many patterns you can make with 64 bits, which means that the number of different numbers that can be represented is limited. With N decimal digits, you can represent 10^N numbers. Similarly, given 64 binary digits, you can represent 2^{64} different numbers, which is about 18 quintillion (an 18 with 18 zeros after it). That's a lot.

Computer memory used to be much smaller, and people tended to use groups of 8 or 16 bits to represent their numbers. It was easy to accidentally *overflow* such small numbers—to end up with a number that did not fit into the given number of bits. Today, even computers that fit in your pocket have plenty of memory, so you are free to use 64-bit chunks, and you need to worry about overflow only when dealing with truly astronomical numbers.

Not all whole numbers less than 18 quintillion fit in a JavaScript number, though. Those bits also store negative numbers, so one bit indicates the sign of the number. A bigger issue is that nonwhole numbers must also be represented. To do this, some of the bits are used to store the position of the decimal point. The actual maximum whole number that can be stored is more in the range of

9 quadrillion (15 zeros)—which is still pleasantly huge.

Fractional numbers are written by using a dot.

```
9.81
```

For very big or very small numbers, you may also use scientific notation by adding an *e* (for *exponent*), followed by the exponent of the number.

```
2.998e8
```

That is $2.998 \times 10^8 = 299{,}800{,}000$.

Calculations with whole numbers (also called *integers*) smaller than the aforementioned 9 quadrillion are guaranteed to always be precise. Unfortunately, calculations with fractional numbers are generally not. Just as π (pi) cannot be precisely expressed by a finite number of decimal digits, many numbers lose some precision when only 64 bits are available to store them. This is a shame, but it causes practical problems only in specific situations. The important thing is to be aware of it and treat fractional digital numbers as approximations, not as precise values.

Arithmetic

The main thing to do with numbers is arithmetic. Arithmetic operations such as addition or multiplication take two number values and produce a new number from them. Here is what they look like in JavaScript:

```
100 + 4 * 11
```

The `+` and `*` symbols are called *operators*. The first stands for addition, and the second stands for multiplication. Putting an operator between two values will apply it to those values and produce a new value.

But does the example mean "add 4 and 100, and multiply the result by 11," or is the multiplication done before the adding? As you might have guessed, the multiplication happens first. But as in mathematics, you can change this by wrapping the addition in parentheses.

```
(100 + 4) * 11
```

For subtraction, there is the `-` operator, and division can be done with the `/` operator.

When operators appear together without parentheses, the order in which they are applied is determined by the *precedence* of the operators. The example shows that multiplication comes before addition. The `/` operator has the same precedence as `*`. Likewise for `+` and `-`. When multiple operators with the same precedence appear next to each other, as in `1 - 2 + 1`, they are applied left to right: `(1 - 2)+ 1`.

These rules of precedence are not something you should worry about. When in doubt, just add parentheses.

There is one more arithmetic operator, which you might not immediately recognize. The `%` symbol is used to represent the *remainder* operation. `X % Y` is the remainder of dividing `X` by `Y`. For example, `314 % 100` produces `14`, and `144 % 12` gives `0`. The remainder operator's precedence is the same as that of multiplication and division. You'll also often see this operator referred to as *modulo*.

Special numbers

There are three special values in JavaScript that are considered numbers but don't behave like normal numbers.

The first two are `Infinity` and `-Infinity`, which represent the positive and negative infinities. `Infinity - 1` is still `Infinity`, and so on. Don't put too much trust in infinity-based computation, though. It isn't mathematically sound, and it will quickly lead to the next special number: `NaN`.

`NaN` stands for "not a number", even though it *is* a value of the number type. You'll get this result when you, for example, try to calculate `0 / 0` (zero divided by zero), `Infinity - Infinity`, or any number of other numeric operations that don't yield a meaningful result.

Strings

The next basic data type is the *string*. Strings are used to represent text. They are written by enclosing their content in quotes.

```
`Down on the sea`
"Lie on the ocean"
'Float on the ocean'
```

You can use single quotes, double quotes, or backticks to mark strings, as long as the quotes at the start and the end of the string match.

Almost anything can be put between quotes, and JavaScript will make a string value out of it. But a few characters are more difficult. You can imagine how putting quotes between quotes might be hard. *Newlines* (the characters you get when you press ENTER) can be included without escaping only when the string is quoted with backticks (\`).

To make it possible to include such characters in a string, the following notation is used: whenever a backslash (\) is found inside quoted text, it indicates that the character after it has a special meaning. This is called *escaping* the character. A quote that is preceded by a backslash will not end the string but be part of it. When an `n` character occurs after a backslash, it is interpreted as a newline. Similarly, a `t` after a backslash means a tab character. Take the following string:

```
"This is the first line\nAnd this is the second"
```

The actual text contained is this:

```
This is the first line
And this is the second
```

There are, of course, situations where you want a backslash in a string to be just a backslash, not a special code. If two backslashes follow each other, they will collapse together, and only one will be left in the resulting string value. This is how the string "*A newline character is written like* "\n"." can be expressed:

```
"A newline character is written like \"\\n\"."
```

Strings, too, have to be modeled as a series of bits to be able to exist inside the computer. The way JavaScript does this is based on the *Unicode* standard. This standard assigns a number to virtually every character you would ever need, including characters from Greek, Arabic, Japanese, Armenian, and so on. If we have a number for every character, a string can be described by a sequence of numbers.

And that's what JavaScript does. But there's a complication: JavaScript's representation uses 16 bits per string element, which can describe up to 2^{16} different characters. But Unicode defines more characters than that—about twice as many, at this point. So some characters, such as many emoji, take up two "character positions" in JavaScript strings. We'll come back to this in

Chapter 5.

Strings cannot be divided, multiplied, or subtracted, but the `+` operator *can* be used on them. It does not add, but it *concatenates*—it glues two strings together. The following line will produce the string `"concatenate"`:

```
"con" + "cat" + "e" + "nate"
```

String values have a number of associated functions (*methods*) that can be used to perform other operations on them. I'll say more about these in Chapter 4.

Strings written with single or double quotes behave very much the same—the only difference is in which type of quote you need to escape inside of them. Backtick-quoted strings, usually called *template literals*, can do a few more tricks. Apart from being able to span lines, they can also embed other values.

```
`half of 100 is ${100 / 2}`
```

When you write something inside `${}` in a template literal, its result will be computed, converted to a string, and included at that position. The example produces "*half of 100 is 50*".

Unary operators

Not all operators are symbols. Some are written as words. One example is the `typeof` operator, which produces a string value naming the type of the value you give it.

```
console.log(typeof 4.5)
// → number
console.log(typeof "x")
// → string
```

We will use `console.log` in example code to indicate that we want to see the result of evaluating something. More about that in the next chapter.

The other operators shown all operated on two values, but `typeof` takes only one. Operators that use two values are called *binary* operators, while those that take one are called *unary* operators. The minus operator can be used both as a binary operator and as a unary operator.

```
console.log(- (10 - 2))
```

```
// → -8
```

Boolean values

It is often useful to have a value that distinguishes between only two possibilities, like "yes" and "no" or "on" and "off". For this purpose, JavaScript has a *Boolean* type, which has just two values, true and false, which are written as those words.

Comparison

Here is one way to produce Boolean values:

```
console.log(3 > 2)
// → true
console.log(3 < 2)
// → false
```

The `>` and `<` signs are the traditional symbols for "is greater than" and "is less than", respectively. They are binary operators. Applying them results in a Boolean value that indicates whether they hold true in this case.

Strings can be compared in the same way.

```
console.log("Aardvark" < "Zoroaster")
// → true
```

The way strings are ordered is roughly alphabetic but not really what you'd expect to see in a dictionary: uppercase letters are always "less" than lowercase ones, so `"Z" < "a"`, and nonalphabetic characters (!, -, and so on) are also included in the ordering. When comparing strings, JavaScript goes over the characters from left to right, comparing the Unicode codes one by one.

Other similar operators are `>=` (greater than or equal to), `<=` (less than or equal to), `==` (equal to), and `!=` (not equal to).

```
console.log("Itchy" != "Scratchy")
// → true
console.log("Apple" == "Orange")
// → false
```

There is only one value in JavaScript that is not equal to itself, and that is `NaN` ("not a number").

```
console.log(NaN == NaN)
// → false
```

`NaN` is supposed to denote the result of a nonsensical computation, and as such, it isn't equal to the result of any *other* nonsensical computations.

Logical operators

There are also some operations that can be applied to Boolean values themselves. JavaScript supports three logical operators: *and*, *or*, and *not*. These can be used to "reason" about Booleans.

The `&&` operator represents logical *and*. It is a binary operator, and its result is true only if both the values given to it are true.

```
console.log(true && false)
// → false
console.log(true && true)
// → true
```

The `||` operator denotes logical *or*. It produces true if either of the values given to it is true.

```
console.log(false || true)
// → true
console.log(false || false)
// → false
```

Not is written as an exclamation mark (`!`). It is a unary operator that flips the value given to it—`!true` produces `false`, and `!false` gives `true`.

When mixing these Boolean operators with arithmetic and other operators, it is not always obvious when parentheses are needed. In practice, you can usually get by with knowing that of the operators we have seen so far, `||` has the lowest precedence, then comes `&&`, then the comparison operators (`>`, `==`, and so on), and then the rest. This order has been chosen such that, in typical expressions like the following one, as few parentheses as possible are necessary:

```
1 + 1 == 2 && 10 * 10 > 50
```

The last logical operator I will discuss is not unary, not binary, but *ternary*, operating on three values. It is written with a question mark and a colon, like this:

```
console.log(true ? 1 : 2);
// → 1
console.log(false ? 1 : 2);
// → 2
```

This one is called the *conditional* operator (or sometimes just the *ternary* operator since it is the only such operator in the language). The value on the left of the question mark "picks" which of the other two values will come out. When it is true, it chooses the middle value, and when it is false, it chooses the value on the right.

Empty values

There are two special values, written `null` and `undefined`, that are used to denote the absence of a *meaningful* value. They are themselves values, but they carry no information.

Many operations in the language that don't produce a meaningful value (you'll see some later) yield `undefined` simply because they have to yield *some* value.

The difference in meaning between `undefined` and `null` is an accident of JavaScript's design, and it doesn't matter most of the time. In cases where you actually have to concern yourself with these values, I recommend treating them as mostly interchangeable.

Automatic type conversion

In the Introduction, I mentioned that JavaScript goes out of its way to accept almost any program you give it, even programs that do odd things. This is nicely demonstrated by the following expressions:

```
console.log(8 * null)
// → 0
console.log("5" - 1)
// → 4
console.log("5" + 1)
// → 51
console.log("five" * 2)
```

```
// → NaN
console.log(false == 0)
// → true
```

When an operator is applied to the "wrong" type of value, JavaScript will quietly convert that value to the type it needs, using a set of rules that often aren't what you want or expect. This is called *type coercion*. The `null` in the first expression becomes `0`, and the `"5"` in the second expression becomes `5` (from string to number). Yet in the third expression, `+` tries string concatenation before numeric addition, so the `1` is converted to `"1"` (from number to string).

When something that doesn't map to a number in an obvious way (such as `"five"` or `undefined`) is converted to a number, you get the value `NaN`. Further arithmetic operations on `NaN` keep producing `NaN`, so if you find yourself getting one of those in an unexpected place, look for accidental type conversions.

When comparing values of the same type using `==`, the outcome is easy to predict: you should get true when both values are the same, except in the case of `NaN`. But when the types differ, JavaScript uses a complicated and confusing set of rules to determine what to do. In most cases, it just tries to convert one of the values to the other value's type. However, when `null` or `undefined` occurs on either side of the operator, it produces true only if both sides are one of `null` or `undefined`.

```
console.log(null == undefined);
// → true
console.log(null == 0);
// → false
```

That behavior is often useful. When you want to test whether a value has a real value instead of `null` or `undefined`, you can compare it to `null` with the `==` (or `!=`) operator.

But what if you want to test whether something refers to the precise value `false`? Expressions like `0 == false` and `"" == false` are also true because of automatic type conversion. When you do *not* want any type conversions to happen, there are two additional operators: `===` and `!==`. The first tests whether a value is *precisely* equal to the other, and the second tests whether it is not precisely equal. So `"" === false` is false as expected.

I recommend using the three-character comparison operators defensively to prevent unexpected type conversions from tripping you up. But when you're certain the types on both sides will be the same, there is no problem with using

the shorter operators.

Short-circuiting of logical operators

The logical operators `&&` and `||` handle values of different types in a peculiar way. They will convert the value on their left side to Boolean type in order to decide what to do, but depending on the operator and the result of that conversion, they will return either the *original* left-hand value or the right-hand value.

The `||` operator, for example, will return the value to its left when that can be converted to true and will return the value on its right otherwise. This has the expected effect when the values are Boolean and does something analogous for values of other types.

```
console.log(null || "user")
// → user
console.log("Agnes" || "user")
// → Agnes
```

We can use this functionality as a way to fall back on a default value. If you have a value that might be empty, you can put `||` after it with a replacement value. If the initial value can be converted to false, you'll get the replacement instead. The rules for converting strings and numbers to Boolean values state that `0`, `NaN`, and the empty string (`""`) count as `false`, while all the other values count as `true`. So `0 || -1` produces `-1`, and `"" || "!?"` yields `"!?"`.

The `&&` operator works similarly but the other way around. When the value to its left is something that converts to false, it returns that value, and otherwise it returns the value on its right.

Another important property of these two operators is that the part to their right is evaluated only when necessary. In the case of `true || X`, no matter what `X` is—even if it's a piece of program that does something *terrible*—the result will be true, and `X` is never evaluated. The same goes for `false && X`, which is false and will ignore `X`. This is called *short-circuit evaluation*.

The conditional operator works in a similar way. Of the second and third values, only the one that is selected is evaluated.

Summary

We looked at four types of JavaScript values in this chapter: numbers, strings, Booleans, and undefined values.

Such values are created by typing in their name (`true`, `null`) or value (`13`, `"abc"`). You can combine and transform values with operators. We saw binary operators for arithmetic (`+`, `-`, `*`, `/`, and `%`), string concatenation (`+`), comparison (`==`, `!=`, `===`, `!==`, `<`, `>`, `<=`, `>=`), and logic (`&&`, `||`), as well as several unary operators (`-` to negate a number, `!` to negate logically, and `typeof` to find a value's type) and a ternary operator (`?:`) to pick one of two values based on a third value.

This gives you enough information to use JavaScript as a pocket calculator but not much more. The next chapter will start tying these expressions together into basic programs.

> *"And my heart glows bright red under my filmy, translucent skin and they have to administer 10cc of JavaScript to get me to come back. (I respond well to toxins in the blood.) Man, that stuff will kick the peaches right out your gills!"*
>
> —_why, Why's (Poignant) Guide to Ruby

CHAPTER 2

Program Structure

In this chapter, we will start to do things that can actually be called *programming*. We will expand our command of the JavaScript language beyond the nouns and sentence fragments we've seen so far, to the point where we can express meaningful prose.

Expressions and statements

In Chapter 1, we made values and applied operators to them to get new values. Creating values like this is the main substance of any JavaScript program. But that substance has to be framed in a larger structure to be useful. So that's what we'll cover next.

A fragment of code that produces a value is called an *expression*. Every value that is written literally (such as `22` or `"psychoanalysis"`) is an expression. An expression between parentheses is also an expression, as is a binary operator applied to two expressions or a unary operator applied to one.

This shows part of the beauty of a language-based interface. Expressions can contain other expressions in a way similar to how subsentences in human languages are nested—a subsentence can contain its own subsentences, and so on. This allows us to build expressions that describe arbitrarily complex computations.

If an expression corresponds to a sentence fragment, a JavaScript *statement* corresponds to a full sentence. A program is a list of statements.

The simplest kind of statement is an expression with a semicolon after it. This is a program:

```
1;
!false;
```

It is a useless program, though. An expression can be content to just produce a value, which can then be used by the enclosing code. A statement stands on

its own, so it amounts to something only if it affects the world. It could display something on the screen—that counts as changing the world—or it could change the internal state of the machine in a way that will affect the statements that come after it. These changes are called *side effects*. The statements in the previous example just produce the values `1` and `true` and then immediately throw them away. This leaves no impression on the world at all. When you run this program, nothing observable happens.

In some cases, JavaScript allows you to omit the semicolon at the end of a statement. In other cases, it has to be there, or the next line will be treated as part of the same statement. The rules for when it can be safely omitted are somewhat complex and error-prone. So in this book, every statement that needs a semicolon will always get one. I recommend you do the same, at least until you've learned more about the subtleties of missing semicolons.

Bindings

How does a program keep an internal state? How does it remember things? We have seen how to produce new values from old values, but this does not change the old values, and the new value has to be immediately used or it will dissipate again. To catch and hold values, JavaScript provides a thing called a *binding*, or *variable*:

```
let caught = 5 * 5;
```

That's a second kind of statement. The special word (*keyword*) `let` indicates that this sentence is going to define a binding. It is followed by the name of the binding and, if we want to immediately give it a value, by an `=` operator and an expression.

The previous statement creates a binding called `caught` and uses it to grab hold of the number that is produced by multiplying 5 by 5.

After a binding has been defined, its name can be used as an expression. The value of such an expression is the value the binding currently holds. Here's an example:

```
let ten = 10;
console.log(ten * ten);
// → 100
```

When a binding points at a value, that does not mean it is tied to that

value forever. The = operator can be used at any time on existing bindings to disconnect them from their current value and have them point to a new one.

```
let mood = "light";
console.log(mood);
// → light
mood = "dark";
console.log(mood);
// → dark
```

You should imagine bindings as tentacles, rather than boxes. They do not *contain* values; they *grasp* them—two bindings can refer to the same value. A program can access only the values that it still has a reference to. When you need to remember something, you grow a tentacle to hold on to it or you reattach one of your existing tentacles to it.

Let's look at another example. To remember the number of dollars that Luigi still owes you, you create a binding. And then when he pays back $35, you give this binding a new value.

```
let luigisDebt = 140;
luigisDebt = luigisDebt - 35;
console.log(luigisDebt);
// → 105
```

When you define a binding without giving it a value, the tentacle has nothing to grasp, so it ends in thin air. If you ask for the value of an empty binding, you'll get the value `undefined`.

A single `let` statement may define multiple bindings. The definitions must be separated by commas.

```
let one = 1, two = 2;
console.log(one + two);
// → 3
```

The words `var` and `const` can also be used to create bindings, in a way similar to `let`.

```
var name = "Ayda";
const greeting = "Hello ";
console.log(greeting + name);
// → Hello Ayda
```

The first, `var` (short for "variable"), is the way bindings were declared in pre-2015 JavaScript. I'll get back to the precise way it differs from `let` in the next chapter. For now, remember that it mostly does the same thing, but we'll rarely use it in this book because it has some confusing properties.

The word `const` stands for *constant*. It defines a constant binding, which points at the same value for as long as it lives. This is useful for bindings that give a name to a value so that you can easily refer to it later.

Binding names

Binding names can be any word. Digits can be part of binding names—`catch22` is a valid name, for example—but the name must not start with a digit. A binding name may include dollar signs (`$`) or underscores (`_`) but no other punctuation or special characters.

Words with a special meaning, such as `let`, are *keywords*, and they may not be used as binding names. There are also a number of words that are "reserved for use" in future versions of JavaScript, which also can't be used as binding names. The full list of keywords and reserved words is rather long.

```
break case catch class const continue debugger default
delete do else enum export extends false finally for
function if implements import interface in instanceof let
new package private protected public return static super
switch this throw true try typeof var void while with yield
```

Don't worry about memorizing this list. When creating a binding produces an unexpected syntax error, see whether you're trying to define a reserved word.

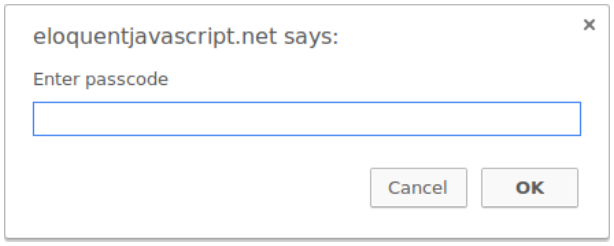
The environment

The collection of bindings and their values that exist at a given time is called the *environment*. When a program starts up, this environment is not empty. It always contains bindings that are part of the language standard, and most of the time, it also has bindings that provide ways to interact with the surrounding system. For example, in a browser, there are functions to interact with the currently loaded website and to read mouse and keyboard input.

Functions

A lot of the values provided in the default environment have the type *function*. A function is a piece of program wrapped in a value. Such values can be *applied* in order to run the wrapped program. For example, in a browser environment, the binding `prompt` holds a function that shows a little dialog box asking for user input. It is used like this:

```
prompt("Enter passcode");
```



Executing a function is called *invoking*, *calling*, or *applying* it. You can call a function by putting parentheses after an expression that produces a function value. Usually you'll directly use the name of the binding that holds the function. The values between the parentheses are given to the program inside the function. In the example, the `prompt` function uses the string that we give it as the text to show in the dialog box. Values given to functions are called *arguments*. Different functions might need a different number or different types of arguments.

The `prompt` function isn't used much in modern web programming, mostly because you have no control over the way the resulting dialog looks, but can be helpful in toy programs and experiments.

The console.log function

In the examples, I used `console.log` to output values. Most JavaScript systems (including all modern web browsers and Node.js) provide a `console.log` function that writes out its arguments to *some* text output device. In browsers, the output lands in the JavaScript console. This part of the browser interface is hidden by default, but most browsers open it when you press F12 or, on a Mac, COMMAND-OPTION-I. If that does not work, search through the menus for an item named Developer Tools or similar.

Though binding names cannot contain period characters, `console.log` does have one. This is because `console.log` isn't a simple binding. It is actually an

expression that retrieves the `log` property from the value held by the `console` binding. We'll find out exactly what this means in Chapter 4.

Return values

Showing a dialog box or writing text to the screen is a *side effect*. A lot of functions are useful because of the side effects they produce. Functions may also produce values, in which case they don't need to have a side effect to be useful. For example, the function `Math.max` takes any amount of number arguments and gives back the greatest.

```
console.log(Math.max(2, 4));
// → 4
```

When a function produces a value, it is said to *return* that value. Anything that produces a value is an expression in JavaScript, which means function calls can be used within larger expressions. Here a call to `Math.min`, which is the opposite of `Math.max`, is used as part of a plus expression:

```
console.log(Math.min(2, 4) + 100);
// → 102
```

The next chapter explains how to write your own functions.

Control flow

When your program contains more than one statement, the statements are executed as if they are a story, from top to bottom. This example program has two statements. The first one asks the user for a number, and the second, which is executed after the first, shows the square of that number.

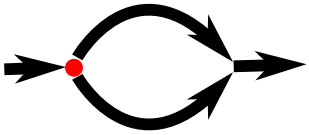
```
let theNumber = Number(prompt("Pick a number"));
console.log("Your number is the square root of " +
            theNumber * theNumber);
```

The function `Number` converts a value to a number. We need that conversion because the result of `prompt` is a string value, and we want a number. There are similar functions called `String` and `Boolean` that convert values to those types.

Here is the rather trivial schematic representation of straight-line control flow:

Conditional execution

Not all programs are straight roads. We may, for example, want to create a branching road, where the program takes the proper branch based on the situation at hand. This is called *conditional execution*.



Conditional execution is created with the `if` keyword in JavaScript. In the simple case, we want some code to be executed if, and only if, a certain condition holds. We might, for example, want to show the square of the input only if the input is actually a number.

```
let theNumber = Number(prompt("Pick a number"));
if (!Number.isNaN(theNumber)) {
  console.log("Your number is the square root of " +
              theNumber * theNumber);
}
```

With this modification, if you enter "parrot", no output is shown.

The `if` keyword executes or skips a statement depending on the value of a Boolean expression. The deciding expression is written after the keyword, between parentheses, followed by the statement to execute.

The `Number.isNaN` function is a standard JavaScript function that returns `true` only if the argument it is given is `NaN`. The `Number` function happens to return `NaN` when you give it a string that doesn't represent a valid number. Thus, the condition translates to "unless `theNumber` is not-a-number, do this".

The statement after the `if` is wrapped in braces (`{` and `}`) in this example. The braces can be used to group any number of statements into a single statement, called a *block*. You could also have omitted them in this case, since they hold only a single statement, but to avoid having to think about whether they are needed, most JavaScript programmers use them in every wrapped statement like this. We'll mostly follow that convention in this book, except for the occasional one-liner.

```
if (1 + 1 == 2) console.log("It's true");
// → It's true
```

You often won't just have code that executes when a condition holds true, but also code that handles the other case. This alternate path is represented by the second arrow in the diagram. You can use the `else` keyword, together with `if`, to create two separate, alternative execution paths.

```
let theNumber = Number(prompt("Pick a number"));
if (!Number.isNaN(theNumber)) {
  console.log("Your number is the square root of " +
              theNumber * theNumber);
} else {
  console.log("Hey. Why didn't you give me a number?");
}
```

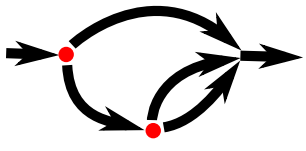
If you have more than two paths to choose from, you can "chain" multiple `if`/`else` pairs together. Here's an example:

```
let num = Number(prompt("Pick a number"));

if (num < 10) {
  console.log("Small");
} else if (num < 100) {
  console.log("Medium");
} else {
  console.log("Large");
}
```

The program will first check whether `num` is less than 10. If it is, it chooses that branch, shows `"Small"`, and is done. If it isn't, it takes the `else` branch, which itself contains a second `if`. If the second condition (`< 100`) holds, that means the number is between 10 and 100, and `"Medium"` is shown. If it doesn't, the second and last `else` branch is chosen.

The schema for this program looks something like this:

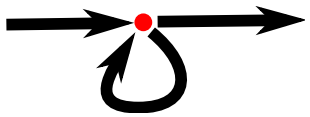


WHILE AND DO LOOPS

Consider a program that outputs all even numbers from 0 to 12. One way to write this is as follows:

```
console.log(0);
console.log(2);
console.log(4);
console.log(6);
console.log(8);
console.log(10);
console.log(12);
```

That works, but the idea of writing a program is to make something *less* work, not more. If we needed all even numbers less than 1,000, this approach would be unworkable. What we need is a way to run a piece of code multiple times. This form of control flow is called a *loop*.



Looping control flow allows us to go back to some point in the program where we were before and repeat it with our current program state. If we combine this with a binding that counts, we can do something like this:

```
let number = 0;
while (number <= 12) {
  console.log(number);
  number = number + 2;
}
// → 0
// → 2
// …   etcetera
```

A statement starting with the keyword `while` creates a loop. The word `while` is followed by an expression in parentheses and then a statement, much like `if`. The loop keeps entering that statement as long as the expression produces a value that gives `true` when converted to Boolean.

The `number` binding demonstrates the way a binding can track the progress of a program. Every time the loop repeats, `number` gets a value that is 2 more than its previous value. At the beginning of every repetition, it is compared

with the number 12 to decide whether the program's work is finished.

As an example that actually does something useful, we can now write a program that calculates and shows the value of 2^{10} (2 to the 10th power). We use two bindings: one to keep track of our result and one to count how often we have multiplied this result by 2. The loop tests whether the second binding has reached 10 yet and, if not, updates both bindings.

```
let result = 1;
let counter = 0;
while (counter < 10) {
  result = result * 2;
  counter = counter + 1;
}
console.log(result);
// → 1024
```

The counter could also have started at `1` and checked for `<= 10`, but for reasons that will become apparent in Chapter 4, it is a good idea to get used to counting from 0.

A `do` loop is a control structure similar to a `while` loop. It differs only on one point: a `do` loop always executes its body at least once, and it starts testing whether it should stop only after that first execution. To reflect this, the test appears after the body of the loop.

```
let yourName;
do {
  yourName = prompt("Who are you?");
} while (!yourName);
console.log(yourName);
```

This program will force you to enter a name. It will ask again and again until it gets something that is not an empty string. Applying the `!` operator will convert a value to Boolean type before negating it, and all strings except `""` convert to `true`. This means the loop continues going round until you provide a non-empty name.

Indenting Code

In the examples, I've been adding spaces in front of statements that are part of some larger statement. These spaces are not required—the computer will accept the program just fine without them. In fact, even the line breaks in

programs are optional. You could write a program as a single long line if you felt like it.

The role of this indentation inside blocks is to make the structure of the code stand out. In code where new blocks are opened inside other blocks, it can become hard to see where one block ends and another begins. With proper indentation, the visual shape of a program corresponds to the shape of the blocks inside it. I like to use two spaces for every open block, but tastes differ—some people use four spaces, and some people use tab characters. The important thing is that each new block adds the same amount of space.

```
if (false != true) {
  console.log("That makes sense.");
  if (1 < 2) {
    console.log("No surprise there.");
  }
}
```

Most code editor programs will help by automatically indenting new lines the proper amount.

FOR LOOPS

Many loops follow the pattern shown in the `while` examples. First a "counter" binding is created to track the progress of the loop. Then comes a `while` loop, usually with a test expression that checks whether the counter has reached its end value. At the end of the loop body, the counter is updated to track progress.

Because this pattern is so common, JavaScript and similar languages provide a slightly shorter and more comprehensive form, the `for` loop.

```
for (let number = 0; number <= 12; number = number + 2) {
  console.log(number);
}
// → 0
// → 2
// …   etcetera
```

This program is exactly equivalent to the earlier even-number-printing example. The only change is that all the statements that are related to the "state" of the loop are grouped together after `for`.

The parentheses after a `for` keyword must contain two semicolons. The part before the first semicolon *initializes* the loop, usually by defining a binding. The second part is the expression that *checks* whether the loop must continue. The final part *updates* the state of the loop after every iteration. In most cases, this is shorter and clearer than a `while` construct.

This is the code that computes 2^{10} using `for` instead of `while`:

```
let result = 1;
for (let counter = 0; counter < 10; counter = counter + 1) {
  result = result * 2;
}
console.log(result);
// → 1024
```

Breaking Out of a Loop

Having the looping condition produce `false` is not the only way a loop can finish. There is a special statement called `break` that has the effect of immediately jumping out of the enclosing loop.

This program illustrates the `break` statement. It finds the first number that is both greater than or equal to 20 and divisible by 7.

```
for (let current = 20; ; current = current + 1) {
  if (current % 7 == 0) {
    console.log(current);
    break;
  }
}
// → 21
```

Using the remainder (`%`) operator is an easy way to test whether a number is divisible by another number. If it is, the remainder of their division is zero.

The `for` construct in the example does not have a part that checks for the end of the loop. This means that the loop will never stop unless the `break` statement inside is executed.

If you were to remove that `break` statement or you accidentally write an end condition that always produces `true`, your program would get stuck in an *infinite loop*. A program stuck in an infinite loop will never finish running, which is usually a bad thing.

The `continue` keyword is similar to `break`, in that it influences the progress of a loop. When `continue` is encountered in a loop body, control jumps out of the body and continues with the loop's next iteration.

Updating bindings succinctly

Especially when looping, a program often needs to "update" a binding to hold a value based on that binding's previous value.

```
counter = counter + 1;
```

JavaScript provides a shortcut for this.

```
counter += 1;
```

Similar shortcuts work for many other operators, such as `result *= 2` to double `result` or `counter -= 1` to count downward.

This allows us to shorten our counting example a little more.

```
for (let number = 0; number <= 12; number += 2) {
  console.log(number);
}
```

For `counter += 1` and `counter -= 1`, there are even shorter equivalents: `counter++` and `counter--`.

Dispatching on a value with switch

It is not uncommon for code to look like this:

```
if (x == "value1") action1();
else if (x == "value2") action2();
else if (x == "value3") action3();
else defaultAction();
```

There is a construct called `switch` that is intended to express such a "dispatch" in a more direct way. Unfortunately, the syntax JavaScript uses for this (which it inherited from the C/Java line of programming languages) is somewhat awkward—a chain of `if` statements may look better. Here is an example:

```
switch (prompt("What is the weather like?")) {
  case "rainy":
    console.log("Remember to bring an umbrella.");
    break;
  case "sunny":
    console.log("Dress lightly.");
  case "cloudy":
    console.log("Go outside.");
    break;
  default:
    console.log("Unknown weather type!");
    break;
}
```

You may put any number of `case` labels inside the block opened by `switch`. The program will start executing at the label that corresponds to the value that `switch` was given, or at `default` if no matching value is found. It will continue executing, even across other labels, until it reaches a `break` statement. In some cases, such as the `"sunny"` case in the example, this can be used to share some code between cases (it recommends going outside for both sunny and cloudy weather). But be careful—it is easy to forget such a `break`, which will cause the program to execute code you do not want executed.

Capitalization

Binding names may not contain spaces, yet it is often helpful to use multiple words to clearly describe what the binding represents. These are pretty much your choices for writing a binding name with several words in it:

```
fuzzylittleturtle
fuzzy_little_turtle
FuzzyLittleTurtle
fuzzyLittleTurtle
```

The first style can be hard to read. I rather like the look of the underscores, though that style is a little painful to type. The standard JavaScript functions, and most JavaScript programmers, follow the bottom style—they capitalize every word except the first. It is not hard to get used to little things like that, and code with mixed naming styles can be jarring to read, so we follow this convention.

In a few cases, such as the `Number` function, the first letter of a binding is

also capitalized. This was done to mark this function as a constructor. What a constructor is will become clear in Chapter 6. For now, the important thing is not to be bothered by this apparent lack of consistency.

Comments

Often, raw code does not convey all the information you want a program to convey to human readers, or it conveys it in such a cryptic way that people might not understand it. At other times, you might just want to include some related thoughts as part of your program. This is what *comments* are for.

A comment is a piece of text that is part of a program but is completely ignored by the computer. JavaScript has two ways of writing comments. To write a single-line comment, you can use two slash characters (`//`) and then the comment text after it.

```
let accountBalance = calculateBalance(account);
// It's a green hollow where a river sings
accountBalance.adjust();
// Madly catching white tatters in the grass.
let report = new Report();
// Where the sun on the proud mountain rings:
addToReport(accountBalance, report);
// It's a little valley, foaming like light in a glass.
```

A `//` comment goes only to the end of the line. A section of text between `/*` and `*/` will be ignored in its entirety, regardless of whether it contains line breaks. This is useful for adding blocks of information about a file or a chunk of program.

```
/*
  I first found this number scrawled on the back of an old notebook.
  Since then, it has often dropped by, showing up in phone numbers
  and the serial numbers of products that I've bought. It obviously
  likes me, so I've decided to keep it.
*/
const myNumber = 11213;
```

Summary

You now know that a program is built out of statements, which themselves sometimes contain more statements. Statements tend to contain expressions, which themselves can be built out of smaller expressions.

Putting statements after one another gives you a program that is executed from top to bottom. You can introduce disturbances in the flow of control by using conditional (`if`, `else`, and `switch`) and looping (`while`, `do`, and `for`) statements.

Bindings can be used to file pieces of data under a name, and they are useful for tracking state in your program. The environment is the set of bindings that are defined. JavaScript systems always put a number of useful standard bindings into your environment.

Functions are special values that encapsulate a piece of program. You can invoke them by writing `functionName(argument1, argument2)`. Such a function call is an expression and may produce a value.

Exercises

If you are unsure how to test your solutions to the exercises, refer to the Introduction.

Each exercise starts with a problem description. Read this description and try to solve the exercise. If you run into problems, consider reading the hints at the end of the book. Full solutions to the exercises are not included in this book, but you can find them online at *https://eloquentjavascript.net/code*. If you want to learn something from the exercises, I recommend looking at the solutions only after you've solved the exercise, or at least after you've attacked it long and hard enough to have a slight headache.

Looping a triangle

Write a loop that makes seven calls to `console.log` to output the following triangle:

```
#
##
###
####
#####
######
#######
```

It may be useful to know that you can find the length of a string by writing `.length` after it.

```
let abc = "abc";
console.log(abc.length);
// → 3
```

FizzBuzz

Write a program that uses `console.log` to print all the numbers from 1 to 100, with two exceptions. For numbers divisible by 3, print `"Fizz"` instead of the number, and for numbers divisible by 5 (and not 3), print `"Buzz"` instead.

When you have that working, modify your program to print `"FizzBuzz"` for numbers that are divisible by both 3 and 5 (and still print `"Fizz"` or `"Buzz"` for numbers divisible by only one of those).

(This is actually an interview question that has been claimed to weed out a significant percentage of programmer candidates. So if you solved it, your labor market value just went up.)

Chessboard

Write a program that creates a string that represents an 8×8 grid, using newline characters to separate lines. At each position of the grid there is either a space or a "#" character. The characters should form a chessboard.

Passing this string to `console.log` should show something like this:

```
 # # # #
# # # #
 # # # #
# # # #
 # # # #
# # # #
 # # # #
# # # #
```

When you have a program that generates this pattern, define a binding `size = 8` and change the program so that it works for any `size`, outputting a grid of the given width and height.

> *"People think that computer science is the art of geniuses but the actual reality is the opposite, just many people doing things that build on each other, like a wall of mini stones."*
>
> —Donald Knuth

CHAPTER 3

Functions

Functions are the bread and butter of JavaScript programming. The concept of wrapping a piece of program in a value has many uses. It gives us a way to structure larger programs, to reduce repetition, to associate names with subprograms, and to isolate these subprograms from each other.

The most obvious application of functions is defining new vocabulary. Creating new words in prose is usually bad style. But in programming, it is indispensable.

Typical adult English speakers have some 20,000 words in their vocabulary. Few programming languages come with 20,000 commands built in. And the vocabulary that *is* available tends to be more precisely defined, and thus less flexible, than in human language. Therefore, we usually *have* to introduce new concepts to avoid repeating ourselves too much.

Defining a function

A function definition is a regular binding where the value of the binding is a function. For example, this code defines `square` to refer to a function that produces the square of a given number:

```
const square = function(x) {
  return x * x;
};

console.log(square(12));
// → 144
```

A function is created with an expression that starts with the keyword `function`. Functions have a set of *parameters* (in this case, only `x`) and a *body*, which contains the statements that are to be executed when the function is called. The function body of a function created this way must always be wrapped in braces, even when it consists of only a single statement.

A function can have multiple parameters or no parameters at all. In the following example, `makeNoise` does not list any parameter names, whereas `power` lists two:

```
const makeNoise = function() {
  console.log("Pling!");
};

makeNoise();
// → Pling!

const power = function(base, exponent) {
  let result = 1;
  for (let count = 0; count < exponent; count++) {
    result *= base;
  }
  return result;
};

console.log(power(2, 10));
// → 1024
```

Some functions produce a value, such as `power` and `square`, and some don't, such as `makeNoise`, whose only result is a side effect. A `return` statement determines the value the function returns. When control comes across such a statement, it immediately jumps out of the current function and gives the returned value to the code that called the function. A `return` keyword without an expression after it will cause the function to return `undefined`. Functions that don't have a `return` statement at all, such as `makeNoise`, similarly return `undefined`.

Parameters to a function behave like regular bindings, but their initial values are given by the *caller* of the function, not the code in the function itself.

Bindings and scopes

Each binding has a *scope*, which is the part of the program in which the binding is visible. For bindings defined outside of any function or block, the scope is the whole program—you can refer to such bindings wherever you want. These are called *global*.

But bindings created for function parameters or declared inside a function can be referenced only in that function, so they are known as *local* bindings.

Every time the function is called, new instances of these bindings are created. This provides some isolation between functions—each function call acts in its own little world (its local environment) and can often be understood without knowing a lot about what's going on in the global environment.

Bindings declared with `let` and `const` are in fact local to the *block* that they are declared in, so if you create one of those inside of a loop, the code before and after the loop cannot "see" it. In pre-2015 JavaScript, only functions created new scopes, so old-style bindings, created with the `var` keyword, are visible throughout the whole function that they appear in—or throughout the global scope, if they are not in a function.

```
let x = 10;
if (true) {
  let y = 20;
  var z = 30;
  console.log(x + y + z);
  // → 60
}
// y is not visible here
console.log(x + z);
// → 40
```

Each scope can "look out" into the scope around it, so `x` is visible inside the block in the example. The exception is when multiple bindings have the same name—in that case, code can see only the innermost one. For example, when the code inside the `halve` function refers to `n`, it is seeing its *own* `n`, not the global `n`.

```
const halve = function(n) {
  return n / 2;
};

let n = 10;
console.log(halve(100));
// → 50
console.log(n);
// → 10
```

Nested scope

JavaScript distinguishes not just *global* and *local* bindings. Blocks and functions can be created inside other blocks and functions, producing multiple degrees of locality.

For example, this function—which outputs the ingredients needed to make a batch of hummus—has another function inside it:

```
const hummus = function(factor) {
  const ingredient = function(amount, unit, name) {
    let ingredientAmount = amount * factor;
    if (ingredientAmount > 1) {
      unit += "s";
    }
    console.log(`${ingredientAmount} ${unit} ${name}`);
  };
  ingredient(1, "can", "chickpeas");
  ingredient(0.25, "cup", "tahini");
  ingredient(0.25, "cup", "lemon juice");
  ingredient(1, "clove", "garlic");
  ingredient(2, "tablespoon", "olive oil");
  ingredient(0.5, "teaspoon", "cumin");
};
```

The code inside the `ingredient` function can see the `factor` binding from the outer function. But its local bindings, such as `unit` or `ingredientAmount`, are not visible in the outer function.

The set of bindings visible inside a block is determined by the place of that block in the program text. Each local scope can also see all the local scopes that contain it, and all scopes can see the global scope. This approach to binding visibility is called *lexical scoping*.

Functions as values

A function binding usually simply acts as a name for a specific piece of the program. Such a binding is defined once and never changed. This makes it easy to confuse the function and its name.

But the two are different. A function value can do all the things that other values can do—you can use it in arbitrary expressions, not just call it. It is possible to store a function value in a new binding, pass it as an argument to a function, and so on. Similarly, a binding that holds a function is still just a regular binding and can, if not constant, be assigned a new value, like so:

```
let launchMissiles = function() {
  missileSystem.launch("now");
};
if (safeMode) {
  launchMissiles = function() {/* do nothing */};
}
```

In Chapter 5, we will discuss the interesting things that can be done by passing around function values to other functions.

Declaration notation

There is a slightly shorter way to create a function binding. When the `function` keyword is used at the start of a statement, it works differently.

```
function square(x) {
  return x * x;
}
```

This is a function *declaration*. The statement defines the binding `square` and points it at the given function. It is slightly easier to write and doesn't require a semicolon after the function.

There is one subtlety with this form of function definition.

```
console.log("The future says:", future());

function future() {
  return "You'll never have flying cars";
}
```

The preceding code works, even though the function is defined *below* the code that uses it. Function declarations are not part of the regular top-to-bottom flow of control. They are conceptually moved to the top of their scope and can be used by all the code in that scope. This is sometimes useful because it offers the freedom to order code in a way that seems meaningful, without worrying about having to define all functions before they are used.

Arrow functions

There's a third notation for functions, which looks very different from the others. Instead of the `function` keyword, it uses an arrow (`=>`) made up of an equal sign and a greater-than character (not to be confused with the greater-than-or-equal operator, which is written `>=`).

```
const power = (base, exponent) => {
  let result = 1;
  for (let count = 0; count < exponent; count++) {
    result *= base;
  }
  return result;
};
```

The arrow comes *after* the list of parameters and is followed by the function's body. It expresses something like "this input (the parameters) produces this result (the body)".

When there is only one parameter name, you can omit the parentheses around the parameter list. If the body is a single expression, rather than a block in braces, that expression will be returned from the function. So, these two definitions of `square` do the same thing:

```
const square1 = (x) => { return x * x; };
const square2 = x => x * x;
```

When an arrow function has no parameters at all, its parameter list is just an empty set of parentheses.

```
const horn = () => {
  console.log("Toot");
};
```

There's no deep reason to have both arrow functions and `function` expressions in the language. Apart from a minor detail, which we'll discuss in Chapter 6, they do the same thing. Arrow functions were added in 2015, mostly to make it possible to write small function expressions in a less verbose way. We'll be using them a lot in Chapter 5.

THE CALL STACK

The way control flows through functions is somewhat involved. Let's take a closer look at it. Here is a simple program that makes a few function calls:

```
function greet(who) {
  console.log("Hello " + who);
}
greet("Harry");
console.log("Bye");
```

A run through this program goes roughly like this: the call to `greet` causes control to jump to the start of that function (line 2). The function calls `console.log`, which takes control, does its job, and then returns control to line 2. There it reaches the end of the `greet` function, so it returns to the place that called it, which is line 4. The line after that calls `console.log` again. After that returns, the program reaches its end.

We could show the flow of control schematically like this:

```
not in function
   in greet
        in console.log
   in greet
not in function
   in console.log
not in function
```

Because a function has to jump back to the place that called it when it returns, the computer must remember the context from which the call happened. In one case, `console.log` has to return to the `greet` function when it is done. In the other case, it returns to the end of the program.

The place where the computer stores this context is the *call stack*. Every time a function is called, the current context is stored on top of this stack. When a function returns, it removes the top context from the stack and uses that context to continue execution.

Storing this stack requires space in the computer's memory. When the stack grows too big, the computer will fail with a message like "out of stack space" or "too much recursion". The following code illustrates this by asking the computer a really hard question that causes an infinite back-and-forth between two functions. Rather, it *would* be infinite, if the computer had an infinite stack. As it is, we will run out of space, or "blow the stack".

```
function chicken() {
  return egg();
}
function egg() {
  return chicken();
}
console.log(chicken() + " came first.");
// → ??
```

Optional Arguments

The following code is allowed and executes without any problem:

```
function square(x) { return x * x; }
console.log(square(4, true, "hedgehog"));
// → 16
```

We defined `square` with only one parameter. Yet when we call it with three, the language doesn't complain. It ignores the extra arguments and computes the square of the first one.

JavaScript is extremely broad-minded about the number of arguments you pass to a function. If you pass too many, the extra ones are ignored. If you pass too few, the missing parameters get assigned the value `undefined`.

The downside of this is that it is possible—likely, even—that you'll accidentally pass the wrong number of arguments to functions. And no one will tell you about it.

The upside is that this behavior can be used to allow a function to be called with different numbers of arguments. For example, this `minus` function tries to imitate the `-` operator by acting on either one or two arguments:

```
function minus(a, b) {
  if (b === undefined) return -a;
  else return a - b;
}

console.log(minus(10));
// → -10
console.log(minus(10, 5));
// → 5
```

If you write an `=` operator after a parameter, followed by an expression, the value of that expression will replace the argument when it is not given.

For example, this version of `power` makes its second argument optional. If you don't provide it or pass the value `undefined`, it will default to two, and the function will behave like `square`.

```
function power(base, exponent = 2) {
  let result = 1;
  for (let count = 0; count < exponent; count++) {
    result *= base;
  }
  return result;
}

console.log(power(4));
// → 16
console.log(power(2, 6));
// → 64
```

In the next chapter, we will see a way in which a function body can get at the whole list of arguments it was passed. This is helpful because it makes it possible for a function to accept any number of arguments. For example, `console.log` does this—it outputs all of the values it is given.

```
console.log("C", "O", 2);
// → C O 2
```

Closure

The ability to treat functions as values, combined with the fact that local bindings are re-created every time a function is called, brings up an interesting question. What happens to local bindings when the function call that created them is no longer active?

The following code shows an example of this. It defines a function, `wrapValue`, that creates a local binding. It then returns a function that accesses and returns this local binding.

```
function wrapValue(n) {
  let local = n;
  return () => local;
}
```

```
let wrap1 = wrapValue(1);
let wrap2 = wrapValue(2);
console.log(wrap1());
// → 1
console.log(wrap2());
// → 2
```

This is allowed and works as you'd hope—both instances of the binding can still be accessed. This situation is a good demonstration of the fact that local bindings are created anew for every call, and different calls can't trample on one another's local bindings.

This feature—being able to reference a specific instance of a local binding in an enclosing scope—is called *closure*. A function that references bindings from local scopes around it is called *a* closure. This behavior not only frees you from having to worry about lifetimes of bindings but also makes it possible to use function values in some creative ways.

With a slight change, we can turn the previous example into a way to create functions that multiply by an arbitrary amount.

```
function multiplier(factor) {
  return number => number * factor;
}

let twice = multiplier(2);
console.log(twice(5));
// → 10
```

The explicit `local` binding from the `wrapValue` example isn't really needed since a parameter is itself a local binding.

Thinking about programs like this takes some practice. A good mental model is to think of function values as containing both the code in their body and the environment in which they are created. When called, the function body sees the environment in which it was created, not the environment in which it is called.

In the example, `multiplier` is called and creates an environment in which its `factor` parameter is bound to 2. The function value it returns, which is stored in `twice`, remembers this environment. So when that is called, it multiplies its argument by 2.

Recursion

It is perfectly okay for a function to call itself, as long as it doesn't do it so often that it overflows the stack. A function that calls itself is called *recursive*. Recursion allows some functions to be written in a different style. Take, for example, this alternative implementation of `power`:

```
function power(base, exponent) {
  if (exponent == 0) {
    return 1;
  } else {
    return base * power(base, exponent - 1);
  }
}

console.log(power(2, 3));
// → 8
```

This is rather close to the way mathematicians define exponentiation and arguably describes the concept more clearly than the looping variant. The function calls itself multiple times with ever smaller exponents to achieve the repeated multiplication.

But this implementation has one problem: in typical JavaScript implementations, it's about three times slower than the looping version. Running through a simple loop is generally cheaper than calling a function multiple times.

The dilemma of speed versus elegance is an interesting one. You can see it as a kind of continuum between human-friendliness and machine-friendliness. Almost any program can be made faster by making it bigger and more convoluted. The programmer has to decide on an appropriate balance.

In the case of the `power` function, the inelegant (looping) version is still fairly simple and easy to read. It doesn't make much sense to replace it with the recursive version. Often, though, a program deals with such complex concepts that giving up some efficiency in order to make the program more straightforward is helpful.

Worrying about efficiency can be a distraction. It's yet another factor that complicates program design, and when you're doing something that's already difficult, that extra thing to worry about can be paralyzing.

Therefore, always start by writing something that's correct and easy to understand. If you're worried that it's too slow—which it usually isn't since most code simply isn't executed often enough to take any significant amount of time—you can measure afterward and improve it if necessary.

Recursion is not always just an inefficient alternative to looping. Some problems really are easier to solve with recursion than with loops. Most often these are problems that require exploring or processing several "branches", each of which might branch out again into even more branches.

Consider this puzzle: by starting from the number 1 and repeatedly either adding 5 or multiplying by 3, an infinite set of numbers can be produced. How would you write a function that, given a number, tries to find a sequence of such additions and multiplications that produces that number?

For example, the number 13 could be reached by first multiplying by 3 and then adding 5 twice, whereas the number 15 cannot be reached at all.

Here is a recursive solution:

```
function findSolution(target) {
  function find(current, history) {
    if (current == target) {
      return history;
    } else if (current > target) {
      return null;
    } else {
      return find(current + 5, `(${history} + 5)`) ||
             find(current * 3, `(${history} * 3)`);
    }
  }
  return find(1, "1");
}

console.log(findSolution(24));
// → (((1 * 3) + 5) * 3)
```

Note that this program doesn't necessarily find the *shortest* sequence of operations. It is satisfied when it finds any sequence at all.

It is okay if you don't see how it works right away. Let's work through it, since it makes for a great exercise in recursive thinking.

The inner function `find` does the actual recursing. It takes two arguments: the current number and a string that records how we reached this number. If it finds a solution, it returns a string that shows how to get to the target. If no solution can be found starting from this number, it returns `null`.

To do this, the function performs one of three actions. If the current number is the target number, the current history is a way to reach that target, so it is returned. If the current number is greater than the target, there's no sense in further exploring this branch because both adding and multiplying will only

make the number bigger, so it returns `null`. Finally, if we're still below the target number, the function tries both possible paths that start from the current number by calling itself twice, once for addition and once for multiplication. If the first call returns something that is not `null`, it is returned. Otherwise, the second call is returned, regardless of whether it produces a string or `null`.

To better understand how this function produces the effect we're looking for, let's look at all the calls to `find` that are made when searching for a solution for the number 13.

```
find(1, "1")
  find(6, "(1 + 5)")
    find(11, "((1 + 5) + 5)")
      find(16, "(((1 + 5) + 5) + 5)")
        too big
      find(33, "(((1 + 5) + 5) * 3)")
        too big
    find(18, "((1 + 5) * 3)")
      too big
  find(3, "(1 * 3)")
    find(8, "((1 * 3) + 5)")
      find(13, "(((1 * 3) + 5) + 5)")
        found!
```

The indentation indicates the depth of the call stack. The first time `find` is called, it starts by calling itself to explore the solution that starts with `(1 + 5)`. That call will further recurse to explore *every* continued solution that yields a number less than or equal to the target number. Since it doesn't find one that hits the target, it returns `null` back to the first call. There the `||` operator causes the call that explores `(1 * 3)` to happen. This search has more luck—its first recursive call, through yet *another* recursive call, hits upon the target number. That innermost call returns a string, and each of the `||` operators in the intermediate calls passes that string along, ultimately returning the solution.

Growing functions

There are two more or less natural ways for functions to be introduced into programs.

The first is that you find yourself writing similar code multiple times. You'd prefer not to do that. Having more code means more space for mistakes to hide and more material to read for people trying to understand the program.

So you take the repeated functionality, find a good name for it, and put it into a function.

The second way is that you find you need some functionality that you haven't written yet and that sounds like it deserves its own function. You'll start by naming the function, and then you'll write its body. You might even start writing code that uses the function before you actually define the function itself.

How difficult it is to find a good name for a function is a good indication of how clear a concept it is that you're trying to wrap. Let's go through an example.

We want to write a program that prints two numbers: the numbers of cows and chickens on a farm, with the words `Cows` and `Chickens` after them and zeros padded before both numbers so that they are always three digits long.

```
007 Cows
011 Chickens
```

This asks for a function of two arguments—the number of cows and the number of chickens. Let's get coding.

```
function printFarmInventory(cows, chickens) {
  let cowString = String(cows);
  while (cowString.length < 3) {
    cowString = "0" + cowString;
  }
  console.log(`${cowString} Cows`);
  let chickenString = String(chickens);
  while (chickenString.length < 3) {
    chickenString = "0" + chickenString;
  }
  console.log(`${chickenString} Chickens`);
}
printFarmInventory(7, 11);
```

Writing `.length` after a string expression will give us the length of that string. Thus, the `while` loops keep adding zeros in front of the number strings until they are at least three characters long.

Mission accomplished! But just as we are about to send the farmer the code (along with a hefty invoice), she calls and tells us she's also started keeping pigs, and couldn't we please extend the software to also print pigs?

We sure can. But just as we're in the process of copying and pasting those

four lines one more time, we stop and reconsider. There has to be a better way. Here's a first attempt:

```
function printZeroPaddedWithLabel(number, label) {
  let numberString = String(number);
  while (numberString.length < 3) {
    numberString = "0" + numberString;
  }
  console.log(`${numberString} ${label}`);
}

function printFarmInventory(cows, chickens, pigs) {
  printZeroPaddedWithLabel(cows, "Cows");
  printZeroPaddedWithLabel(chickens, "Chickens");
  printZeroPaddedWithLabel(pigs, "Pigs");
}

printFarmInventory(7, 11, 3);
```

It works! But that name, `printZeroPaddedWithLabel`, is a little awkward. It conflates three things—printing, zero-padding, and adding a label—into a single function.

Instead of lifting out the repeated part of our program wholesale, let's try to pick out a single *concept*.

```
function zeroPad(number, width) {
  let string = String(number);
  while (string.length < width) {
    string = "0" + string;
  }
  return string;
}

function printFarmInventory(cows, chickens, pigs) {
  console.log(`${zeroPad(cows, 3)} Cows`);
  console.log(`${zeroPad(chickens, 3)} Chickens`);
  console.log(`${zeroPad(pigs, 3)} Pigs`);
}

printFarmInventory(7, 16, 3);
```

A function with a nice, obvious name like `zeroPad` makes it easier for someone who reads the code to figure out what it does. And such a function is useful in

more situations than just this specific program. For example, you could use it to help print nicely aligned tables of numbers.

How smart and versatile *should* our function be? We could write anything, from a terribly simple function that can only pad a number to be three characters wide to a complicated generalized number-formatting system that handles fractional numbers, negative numbers, alignment of decimal dots, padding with different characters, and so on.

A useful principle is to not add cleverness unless you are absolutely sure you're going to need it. It can be tempting to write general "frameworks" for every bit of functionality you come across. Resist that urge. You won't get any real work done—you'll just be writing code that you never use.

Functions and side effects

Functions can be roughly divided into those that are called for their side effects and those that are called for their return value. (Though it is definitely also possible to both have side effects and return a value.)

The first helper function in the farm example, `printZeroPaddedWithLabel`, is called for its side effect: it prints a line. The second version, `zeroPad`, is called for its return value. It is no coincidence that the second is useful in more situations than the first. Functions that create values are easier to combine in new ways than functions that directly perform side effects.

A *pure* function is a specific kind of value-producing function that not only has no side effects but also doesn't rely on side effects from other code—for example, it doesn't read global bindings whose value might change. A pure function has the pleasant property that, when called with the same arguments, it always produces the same value (and doesn't do anything else). A call to such a function can be substituted by its return value without changing the meaning of the code. When you are not sure that a pure function is working correctly, you can test it by simply calling it and know that if it works in that context, it will work in any context. Nonpure functions tend to require more scaffolding to test.

Still, there's no need to feel bad when writing functions that are not pure or to wage a holy war to purge them from your code. Side effects are often useful. There'd be no way to write a pure version of `console.log`, for example, and `console.log` is good to have. Some operations are also easier to express in an efficient way when we use side effects, so computing speed can be a reason to avoid purity.

Summary

This chapter taught you how to write your own functions. The `function` keyword, when used as an expression, can create a function value. When used as a statement, it can be used to declare a binding and give it a function as its value. Arrow functions are yet another way to create functions.

```
// Define f to hold a function value
const f = function(a) {
  console.log(a + 2);
};

// Declare g to be a function
function g(a, b) {
  return a * b * 3.5;
}

// A less verbose function value
let h = a => a % 3;
```

A key aspect in understanding functions is understanding scopes. Each block creates a new scope. Parameters and bindings declared in a given scope are local and not visible from the outside. Bindings declared with `var` behave differently—they end up in the nearest function scope or the global scope.

Separating the tasks your program performs into different functions is helpful. You won't have to repeat yourself as much, and functions can help organize a program by grouping code into pieces that do specific things.

Exercises

Minimum

The previous chapter introduced the standard function `Math.min` that returns its smallest argument. We can build something like that now. Write a function `min` that takes two arguments and returns their minimum.

Recursion

We've seen that `%` (the remainder operator) can be used to test whether a number is even or odd by using `% 2` to see whether it's divisible by two. Here's another way to define whether a positive whole number is even or odd:

- Zero is even.
- One is odd.
- For any other number N, its evenness is the same as N - 2.

Define a recursive function `isEven` corresponding to this description. The function should accept a single parameter (a positive, whole number) and return a Boolean.

Test it on 50 and 75. See how it behaves on -1. Why? Can you think of a way to fix this?

Bean counting

You can get the Nth character, or letter, from a string by writing `"string"[N]`. The returned value will be a string containing only one character (for example, `"b"`). The first character has position 0, which causes the last one to be found at position `string.length - 1`. In other words, a two-character string has length 2, and its characters have positions 0 and 1.

Write a function `countBs` that takes a string as its only argument and returns a number that indicates how many uppercase "B" characters there are in the string.

Next, write a function called `countChar` that behaves like `countBs`, except it takes a second argument that indicates the character that is to be counted (rather than counting only uppercase "B" characters). Rewrite `countBs` to make use of this new function.

> *"On two occasions I have been asked, 'Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?' [...] I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question."*
>
> —Charles Babbage, Passages from the Life of a Philosopher (1864)

CHAPTER 4

Data Structures: Objects and Arrays

Numbers, Booleans, and strings are the atoms that data structures are built from. Many types of information require more than one atom, though. *Objects* allow us to group values—including other objects—to build more complex structures.

The programs we have built so far have been limited by the fact that they were operating only on simple data types. This chapter will introduce basic data structures. By the end of it, you'll know enough to start writing useful programs.

The chapter will work through a more or less realistic programming example, introducing concepts as they apply to the problem at hand. The example code will often build on functions and bindings that were introduced earlier in the text.

The online coding sandbox for the book (*https://eloquentjavascript.net/code*) provides a way to run code in the context of a specific chapter. If you decide to work through the examples in another environment, be sure to first download the full code for this chapter from the sandbox page.

The weresquirrel

Every now and then, usually between 8 p.m. and 10 p.m., Jacques finds himself transforming into a small furry rodent with a bushy tail.

On one hand, Jacques is quite glad that he doesn't have classic lycanthropy. Turning into a squirrel does cause fewer problems than turning into a wolf. Instead of having to worry about accidentally eating the neighbor (*that* would be awkward), he worries about being eaten by the neighbor's cat. After two occasions where he woke up on a precariously thin branch in the crown of an oak, naked and disoriented, he has taken to locking the doors and windows of his room at night and putting a few walnuts on the floor to keep himself busy.

That takes care of the cat and tree problems. But Jacques would prefer to get rid of his condition entirely. The irregular occurrences of the transformation

make him suspect that they might be triggered by something. For a while, he believed that it happened only on days when he had been near oak trees. But avoiding oak trees did not stop the problem.

Switching to a more scientific approach, Jacques has started keeping a daily log of everything he does on a given day and whether he changed form. With this data he hopes to narrow down the conditions that trigger the transformations.

The first thing he needs is a data structure to store this information.

DATA SETS

To work with a chunk of digital data, we'll first have to find a way to represent it in our machine's memory. Say, for example, that we want to represent a collection of the numbers 2, 3, 5, 7, and 11.

We could get creative with strings—after all, strings can have any length, so we can put a lot of data into them—and use `"2 3 5 7 11"` as our representation. But this is awkward. You'd have to somehow extract the digits and convert them back to numbers to access them.

Fortunately, JavaScript provides a data type specifically for storing sequences of values. It is called an *array* and is written as a list of values between square brackets, separated by commas.

```
let listOfNumbers = [2, 3, 5, 7, 11];
console.log(listOfNumbers[2]);
// → 5
console.log(listOfNumbers[0]);
// → 2
console.log(listOfNumbers[2 - 1]);
// → 3
```

The notation for getting at the elements inside an array also uses square brackets. A pair of square brackets immediately after an expression, with another expression inside of them, will look up the element in the left-hand expression that corresponds to the *index* given by the expression in the brackets.

The first index of an array is zero, not one. So the first element is retrieved with `listOfNumbers[0]`. Zero-based counting has a long tradition in technology and in certain ways makes a lot of sense, but it takes some getting used to. Think of the index as the amount of items to skip, counting from the start of the array.

PROPERTIES

We've seen a few suspicious-looking expressions like `myString.length` (to get the length of a string) and `Math.max` (the maximum function) in past chapters. These are expressions that access a *property* of some value. In the first case, we access the `length` property of the value in `myString`. In the second, we access the property named `max` in the `Math` object (which is a collection of mathematics-related constants and functions).

Almost all JavaScript values have properties. The exceptions are `null` and `undefined`. If you try to access a property on one of these nonvalues, you get an error.

```
null.length;
// → TypeError: null has no properties
```

The two main ways to access properties in JavaScript are with a dot and with square brackets. Both `value.x` and `value[x]` access a property on `value`—but not necessarily the same property. The difference is in how `x` is interpreted. When using a dot, the word after the dot is the literal name of the property. When using square brackets, the expression between the brackets is *evaluated* to get the property name. Whereas `value.x` fetches the property of `value` named "x", `value[x]` tries to evaluate the expression `x` and uses the result, converted to a string, as the property name.

So if you know that the property you are interested in is called *color*, you say `value.color`. If you want to extract the property named by the value held in the binding `i`, you say `value[i]`. Property names are strings. They can be any string, but the dot notation works only with names that look like valid binding names. So if you want to access a property named *2* or *John Doe*, you must use square brackets: `value[2]` or `value["John Doe"]`.

The elements in an array are stored as the array's properties, using numbers as property names. Because you can't use the dot notation with numbers and usually want to use a binding that holds the index anyway, you have to use the bracket notation to get at them.

The `length` property of an array tells us how many elements it has. This property name is a valid binding name, and we know its name in advance, so to find the length of an array, you typically write `array.length` because that's easier to write than `array["length"]`.

Methods

Both string and array values contain, in addition to the `length` property, a number of properties that hold function values.

```
let doh = "Doh";
console.log(typeof doh.toUpperCase);
// → function
console.log(doh.toUpperCase());
// → DOH
```

Every string has a `toUpperCase` property. When called, it will return a copy of the string in which all letters have been converted to uppercase. There is also `toLowerCase`, going the other way.

Interestingly, even though the call to `toUpperCase` does not pass any arguments, the function somehow has access to the string `"Doh"`, the value whose property we called. How this works is described in Chapter 6.

Properties that contain functions are generally called *methods* of the value they belong to, as in "`toUpperCase` is a method of a string".

This example demonstrates two methods you can use to manipulate arrays:

```
let sequence = [1, 2, 3];
sequence.push(4);
sequence.push(5);
console.log(sequence);
// → [1, 2, 3, 4, 5]
console.log(sequence.pop());
// → 5
console.log(sequence);
// → [1, 2, 3, 4]
```

The `push` method adds values to the end of an array, and the `pop` method does the opposite, removing the last value in the array and returning it.

These somewhat silly names are the traditional terms for operations on a *stack*. A stack, in programming, is a data structure that allows you to push values into it and pop them out again in the opposite order so that the thing that was added last is removed first. These are common in programming—you might remember the function call stack from the previous chapter, which is an instance of the same idea.

OBJECTS

Back to the weresquirrel. A set of daily log entries can be represented as an array. But the entries do not consist of just a number or a string—each entry needs to store a list of activities and a Boolean value that indicates whether Jacques turned into a squirrel or not. Ideally, we would like to group these together into a single value and then put those grouped values into an array of log entries.

Values of the type *object* are arbitrary collections of properties. One way to create an object is by using braces as an expression.

```
let day1 = {
  squirrel: false,
  events: ["work", "touched tree", "pizza", "running"]
};
console.log(day1.squirrel);
// → false
console.log(day1.wolf);
// → undefined
day1.wolf = false;
console.log(day1.wolf);
// → false
```

Inside the braces, there is a list of properties separated by commas. Each property has a name followed by a colon and a value. When an object is written over multiple lines, indenting it like in the example helps with readability. Properties whose names aren't valid binding names or valid numbers have to be quoted.

```
let descriptions = {
  work: "Went to work",
  "touched tree": "Touched a tree"
};
```

This means that braces have *two* meanings in JavaScript. At the start of a statement, they start a block of statements. In any other position, they describe an object. Fortunately, it is rarely useful to start a statement with an object in braces, so the ambiguity between these two is not much of a problem.

Reading a property that doesn't exist will give you the value `undefined`.

It is possible to assign a value to a property expression with the `=` operator. This will replace the property's value if it already existed or create a new

property on the object if it didn't.

To briefly return to our tentacle model of bindings—property bindings are similar. They *grasp* values, but other bindings and properties might be holding onto those same values. You may think of objects as octopuses with any number of tentacles, each of which has a name tattooed on it.

The `delete` operator cuts off a tentacle from such an octopus. It is a unary operator that, when applied to an object property, will remove the named property from the object. This is not a common thing to do, but it is possible.

```
let anObject = {left: 1, right: 2};
console.log(anObject.left);
// → 1
delete anObject.left;
console.log(anObject.left);
// → undefined
console.log("left" in anObject);
// → false
console.log("right" in anObject);
// → true
```

The binary `in` operator, when applied to a string and an object, tells you whether that object has a property with that name. The difference between setting a property to `undefined` and actually deleting it is that, in the first case, the object still *has* the property (it just doesn't have a very interesting value), whereas in the second case the property is no longer present and `in` will return `false`.

To find out what properties an object has, you can use the `Object.keys` function. You give it an object, and it returns an array of strings—the object's property names.

```
console.log(Object.keys({x: 0, y: 0, z: 2}));
// → ["x", "y", "z"]
```

There's an `Object.assign` function that copies all properties from one object into another.

```
let objectA = {a: 1, b: 2};
Object.assign(objectA, {b: 3, c: 4});
console.log(objectA);
// → {a: 1, b: 3, c: 4}
```

Arrays, then, are just a kind of object specialized for storing sequences of things. If you evaluate `typeof []`, it produces `"object"`. You can see them as long, flat octopuses with all their tentacles in a neat row, labeled with numbers.

We will represent the journal that Jacques keeps as an array of objects.

```
let journal = [
  {events: ["work", "touched tree", "pizza",
            "running", "television"],
   squirrel: false},
  {events: ["work", "ice cream", "cauliflower",
            "lasagna", "touched tree", "brushed teeth"],
   squirrel: false},
  {events: ["weekend", "cycling", "break", "peanuts",
            "beer"],
   squirrel: true},
  /* and so on... */
];
```

Mutability

We will get to actual programming *real* soon now. First there's one more piece of theory to understand.

We saw that object values can be modified. The types of values discussed in earlier chapters, such as numbers, strings, and Booleans, are all *immutable*—it is impossible to change values of those types. You can combine them and derive new values from them, but when you take a specific string value, that value will always remain the same. The text inside it cannot be changed. If you have a string that contains `"cat"`, it is not possible for other code to change a character in your string to make it spell `"rat"`.

Objects work differently. You *can* change their properties, causing a single object value to have different content at different times.

When we have two numbers, 120 and 120, we can consider them precisely the same number, whether or not they refer to the same physical bits. With objects, there is a difference between having two references to the same object and having two different objects that contain the same properties. Consider the following code:

```
let object1 = {value: 10};
let object2 = object1;
let object3 = {value: 10};
```

```
console.log(object1 == object2);
// → true
console.log(object1 == object3);
// → false

object1.value = 15;
console.log(object2.value);
// → 15
console.log(object3.value);
// → 10
```

The `object1` and `object2` bindings grasp the *same* object, which is why changing `object1` also changes the value of `object2`. They are said to have the same *identity*. The binding `object3` points to a different object, which initially contains the same properties as `object1` but lives a separate life.

Bindings can also be changeable or constant, but this is separate from the way their values behave. Even though number values don't change, you can use a `let` binding to keep track of a changing number by changing the value the binding points at. Similarly, though a `const` binding to an object can itself not be changed and will continue to point at the same object, the *contents* of that object might change.

```
const score = {visitors: 0, home: 0};
// This is okay
score.visitors = 1;
// This isn't allowed
score = {visitors: 1, home: 1};
```

When you compare objects with JavaScript's `==` operator, it compares by identity: it will produce `true` only if both objects are precisely the same value. Comparing different objects will return `false`, even if they have identical properties. There is no "deep" comparison operation built into JavaScript, which compares objects by contents, but it is possible to write it yourself (which is one of the exercises at the end of this chapter).

The lycanthrope's log

So, Jacques starts up his JavaScript interpreter and sets up the environment he needs to keep his journal.

```
let journal = [];
```

```
function addEntry(events, squirrel) {
  journal.push({events, squirrel});
}
```

Note that the object added to the journal looks a little odd. Instead of declaring properties like `events: events`, it just gives a property name. This is shorthand that means the same thing—if a property name in brace notation isn't followed by a value, its value is taken from the binding with the same name.

So then, every evening at 10 p.m.—or sometimes the next morning, after climbing down from the top shelf of his bookcase—Jacques records the day.

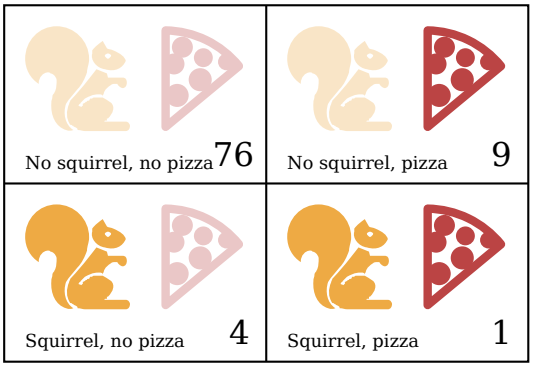
```
addEntry(["work", "touched tree", "pizza", "running",
          "television"], false);
addEntry(["work", "ice cream", "cauliflower", "lasagna",
          "touched tree", "brushed teeth"], false);
addEntry(["weekend", "cycling", "break", "peanuts",
          "beer"], true);
```

Once he has enough data points, he intends to use statistics to find out which of these events may be related to the squirrelifications.

Correlation is a measure of dependence between statistical variables. A statistical variable is not quite the same as a programming variable. In statistics you typically have a set of *measurements*, and each variable is measured for every measurement. Correlation between variables is usually expressed as a value that ranges from -1 to 1. Zero correlation means the variables are not related. A correlation of one indicates that the two are perfectly related—if you know one, you also know the other. Negative one also means that the variables are perfectly related but that they are opposites—when one is true, the other is false.

To compute the measure of correlation between two Boolean variables, we can use the *phi coefficient* (φ). This is a formula whose input is a frequency table containing the number of times the different combinations of the variables were observed. The output of the formula is a number between -1 and 1 that describes the correlation.

We could take the event of eating pizza and put that in a frequency table like this, where each number indicates the amount of times that combination occurred in our measurements:



If we call that table n, we can compute φ using the following formula:

$$\varphi = \frac{n_{11}n_{00} - n_{10}n_{01}}{\sqrt{n_{1\bullet}n_{0\bullet}n_{\bullet 1}n_{\bullet 0}}} \tag{4.1}$$

(If at this point you're putting the book down to focus on a terrible flashback to 10th grade math class—hold on! I do not intend to torture you with endless pages of cryptic notation—it's just this one formula for now. And even with this one, all we do is turn it into JavaScript.)

The notation n_{01} indicates the number of measurements where the first variable (squirrelness) is false (0) and the second variable (pizza) is true (1). In the pizza table, n_{01} is 9.

The value $n_{1\bullet}$ refers to the sum of all measurements where the first variable is true, which is 5 in the example table. Likewise, $n_{\bullet 0}$ refers to the sum of the measurements where the second variable is false.

So for the pizza table, the part above the division line (the dividend) would be $1\times76-4\times9 = 40$, and the part below it (the divisor) would be the square root of $5\times85\times10\times80$, or $\sqrt{340000}$. This comes out to $\varphi \approx 0.069$, which is tiny. Eating pizza does not appear to have influence on the transformations.

Computing correlation

We can represent a two-by-two table in JavaScript with a four-element array (`[76, 9, 4, 1]`). We could also use other representations, such as an array containing two two-element arrays (`[[76, 9], [4, 1]]`) or an object with property names like `"11"` and `"01"`, but the flat array is simple and makes the expressions that access the table pleasantly short. We'll interpret the indices to the array as two-bit binary numbers, where the leftmost (most significant) digit refers to the squirrel variable and the rightmost (least significant) digit refers to the event variable. For example, the binary number `10` refers to the case

where Jacques did turn into a squirrel, but the event (say, "pizza") didn't occur. This happened four times. And since binary `10` is 2 in decimal notation, we will store this number at index 2 of the array.

This is the function that computes the φ coefficient from such an array:

```
function phi(table) {
  return (table[3] * table[0] - table[2] * table[1]) /
    Math.sqrt((table[2] + table[3]) *
              (table[0] + table[1]) *
              (table[1] + table[3]) *
              (table[0] + table[2]));
}

console.log(phi([76, 9, 4, 1]));
// → 0.068599434
```

This is a direct translation of the φ formula into JavaScript. `Math.sqrt` is the square root function, as provided by the `Math` object in a standard JavaScript environment. We have to add two fields from the table to get fields like $n_{1\bullet}$ because the sums of rows or columns are not stored directly in our data structure.

Jacques kept his journal for three months. The resulting data set is available in the coding sandbox for this chapter (*https://eloquentjavascript.net/code#4*), where it is stored in the `JOURNAL` binding and in a downloadable file.

To extract a two-by-two table for a specific event from the journal, we must loop over all the entries and tally how many times the event occurs in relation to squirrel transformations.

```
function tableFor(event, journal) {
  let table = [0, 0, 0, 0];
  for (let i = 0; i < journal.length; i++) {
    let entry = journal[i], index = 0;
    if (entry.events.includes(event)) index += 1;
    if (entry.squirrel) index += 2;
    table[index] += 1;
  }
  return table;
}

console.log(tableFor("pizza", JOURNAL));
// → [76, 9, 4, 1]
```

Arrays have an `includes` method that checks whether a given value exists in the array. The function uses that to determine whether the event name it is interested in is part of the event list for a given day.

The body of the loop in `tableFor` figures out which box in the table each journal entry falls into by checking whether the entry contains the specific event it's interested in and whether the event happens alongside a squirrel incident. The loop then adds one to the correct box in the table.

We now have the tools we need to compute individual correlations. The only step remaining is to find a correlation for every type of event that was recorded and see whether anything stands out.

Array loops

In the `tableFor` function, there's a loop like this:

```
for (let i = 0; i < JOURNAL.length; i++) {
  let entry = JOURNAL[i];
  // Do something with entry
}
```

This kind of loop is common in classical JavaScript—going over arrays one element at a time is something that comes up a lot, and to do that you'd run a counter over the length of the array and pick out each element in turn.

There is a simpler way to write such loops in modern JavaScript.

```
for (let entry of JOURNAL) {
  console.log(`${entry.events.length} events.`);
}
```

When a `for` loop looks like this, with the word `of` after a variable definition, it will loop over the elements of the value given after `of`. This works not only for arrays but also for strings and some other data structures. We'll discuss *how* it works in Chapter 6.

The final analysis

We need to compute a correlation for every type of event that occurs in the data set. To do that, we first need to *find* every type of event.

```
function journalEvents(journal) {
```

```
  let events = [];
  for (let entry of journal) {
    for (let event of entry.events) {
      if (!events.includes(event)) {
        events.push(event);
      }
    }
  }
  return events;
}

console.log(journalEvents(JOURNAL));
// → ["carrot", "exercise", "weekend", "bread", …]
```

By going over all the events and adding those that aren't already in there to the `events` array, the function collects every type of event.

Using that, we can see all the correlations.

```
for (let event of journalEvents(JOURNAL)) {
  console.log(event + ":", phi(tableFor(event, JOURNAL)));
}
// → carrot:   0.0140970969
// → exercise: 0.0685994341
// → weekend:  0.1371988681
// → bread:   -0.0757554019
// → pudding: -0.0648203724
// and so on...
```

Most correlations seem to lie close to zero. Eating carrots, bread, or pudding apparently does not trigger squirrel-lycanthropy. It *does* seem to occur somewhat more often on weekends. Let's filter the results to show only correlations greater than 0.1 or less than -0.1.

```
for (let event of journalEvents(JOURNAL)) {
  let correlation = phi(tableFor(event, JOURNAL));
  if (correlation > 0.1 || correlation < -0.1) {
    console.log(event + ":", correlation);
  }
}
// → weekend:        0.1371988681
// → brushed teeth: -0.3805211953
// → candy:          0.1296407447
// → work:          -0.1371988681
```

```
// → spaghetti:      0.2425356250
// → reading:        0.1106828054
// → peanuts:        0.5902679812
```

Aha! There are two factors with a correlation that's clearly stronger than the others. Eating peanuts has a strong positive effect on the chance of turning into a squirrel, whereas brushing his teeth has a significant negative effect.

Interesting. Let's try something.

```
for (let entry of JOURNAL) {
  if (entry.events.includes("peanuts") &&
     !entry.events.includes("brushed teeth")) {
    entry.events.push("peanut teeth");
  }
}
console.log(phi(tableFor("peanut teeth", JOURNAL)));
// → 1
```

That's a strong result. The phenomenon occurs precisely when Jacques eats peanuts and fails to brush his teeth. If only he weren't such a slob about dental hygiene, he'd have never even noticed his affliction.

Knowing this, Jacques stops eating peanuts altogether and finds that his transformations don't come back.

For a few years, things go great for Jacques. But at some point he loses his job. Because he lives in a nasty country where having no job means having no medical services, he is forced to take employment with a circus where he performs as *The Incredible Squirrelman*, stuffing his mouth with peanut butter before every show.

One day, fed up with this pitiful existence, Jacques fails to change back into his human form, hops through a crack in the circus tent, and vanishes into the forest. He is never seen again.

Further arrayology

Before finishing the chapter, I want to introduce you to a few more object-related concepts. I'll start by introducing some generally useful array methods.

We saw `push` and `pop`, which add and remove elements at the end of an array, earlier in this chapter. The corresponding methods for adding and removing things at the start of an array are called `unshift` and `shift`.

```
let todoList = [];
function remember(task) {
  todoList.push(task);
}
function getTask() {
  return todoList.shift();
}
function rememberUrgently(task) {
  todoList.unshift(task);
}
```

That program manages a queue of tasks. You add tasks to the end of the queue by calling `remember("groceries")`, and when you're ready to do something, you call `getTask()` to get (and remove) the front item from the queue. The `rememberUrgently` function also adds a task but adds it to the front instead of the back of the queue.

To search for a specific value, arrays provide an `indexOf` method. The method searches through the array from the start to the end and returns the index at which the requested value was found—or -1 if it wasn't found. To search from the end instead of the start, there's a similar method called `lastIndexOf`.

```
console.log([1, 2, 3, 2, 1].indexOf(2));
// → 1
console.log([1, 2, 3, 2, 1].lastIndexOf(2));
// → 3
```

Both `indexOf` and `lastIndexOf` take an optional second argument that indicates where to start searching.

Another fundamental array method is `slice`, which takes start and end indices and returns an array that has only the elements between them. The start index is inclusive, the end index exclusive.

```
console.log([0, 1, 2, 3, 4].slice(2, 4));
// → [2, 3]
console.log([0, 1, 2, 3, 4].slice(2));
// → [2, 3, 4]
```

When the end index is not given, `slice` will take all of the elements after the start index. You can also omit the start index to copy the entire array.

The `concat` method can be used to glue arrays together to create a new array, similar to what the `+` operator does for strings.

The following example shows both `concat` and `slice` in action. It takes an array and an index, and it returns a new array that is a copy of the original array with the element at the given index removed.

```
function remove(array, index) {
  return array.slice(0, index)
    .concat(array.slice(index + 1));
}
console.log(remove(["a", "b", "c", "d", "e"], 2));
// → ["a", "b", "d", "e"]
```

If you pass `concat` an argument that is not an array, that value will be added to the new array as if it were a one-element array.

Strings and their properties

We can read properties like `length` and `toUpperCase` from string values. But if you try to add a new property, it doesn't stick.

```
let kim = "Kim";
kim.age = 88;
console.log(kim.age);
// → undefined
```

Values of type string, number, and Boolean are not objects, and though the language doesn't complain if you try to set new properties on them, it doesn't actually store those properties. As mentioned earlier, such values are immutable and cannot be changed.

But these types do have built-in properties. Every string value has a number of methods. Some very useful ones are `slice` and `indexOf`, which resemble the array methods of the same name.

```
console.log("coconuts".slice(4, 7));
// → nut
console.log("coconut".indexOf("u"));
// → 5
```

One difference is that a string's `indexOf` can search for a string containing more than one character, whereas the corresponding array method looks only for a single element.

```
console.log("one two three".indexOf("ee"));
// → 11
```

The `trim` method removes whitespace (spaces, newlines, tabs, and similar characters) from the start and end of a string.

```
console.log("  okay \n ".trim());
// → okay
```

The `zeroPad` function from the previous chapter also exists as a method. It is called `padStart` and takes the desired length and padding character as arguments.

```
console.log(String(6).padStart(3, "0"));
// → 006
```

You can split a string on every occurrence of another string with `split` and join it again with `join`.

```
let sentence = "Secretarybirds specialize in stomping";
let words = sentence.split(" ");
console.log(words);
// → ["Secretarybirds", "specialize", "in", "stomping"]
console.log(words.join(". "));
// → Secretarybirds. specialize. in. stomping
```

A string can be repeated with the `repeat` method, which creates a new string containing multiple copies of the original string, glued together.

```
console.log("LA".repeat(3));
// → LALALA
```

We have already seen the string type's `length` property. Accessing the individual characters in a string looks like accessing array elements (with a caveat that we'll discuss in Chapter 5).

```
let string = "abc";
console.log(string.length);
// → 3
console.log(string[1]);
// → b
```

Rest parameters

It can be useful for a function to accept any number of arguments. For example, `Math.max` computes the maximum of *all* the arguments it is given.

To write such a function, you put three dots before the function's last parameter, like this:

```
function max(...numbers) {
  let result = -Infinity;
  for (let number of numbers) {
    if (number > result) result = number;
  }
  return result;
}
console.log(max(4, 1, 9, -2));
// → 9
```

When such a function is called, the *rest parameter* is bound to an array containing all further arguments. If there are other parameters before it, their values aren't part of that array. When, as in `max`, it is the only parameter, it will hold all arguments.

You can use a similar three-dot notation to *call* a function with an array of arguments.

```
let numbers = [5, 1, 7];
console.log(max(...numbers));
// → 7
```

This "spreads" out the array into the function call, passing its elements as separate arguments. It is possible to include an array like that along with other arguments, as in `max(9, ...numbers, 2)`.

Square bracket array notation similarly allows the triple-dot operator to spread another array into the new array.

```
let words = ["never", "fully"];
console.log(["will", ...words, "understand"]);
// → ["will", "never", "fully", "understand"]
```

The Math object

As we've seen, `Math` is a grab bag of number-related utility functions, such as `Math.max` (maximum), `Math.min` (minimum), and `Math.sqrt` (square root).

The `Math` object is used as a container to group a bunch of related functionality. There is only one `Math` object, and it is almost never useful as a value. Rather, it provides a *namespace* so that all these functions and values do not have to be global bindings.

Having too many global bindings "pollutes" the namespace. The more names have been taken, the more likely you are to accidentally overwrite the value of some existing binding. For example, it's not unlikely to want to name something `max` in one of your programs. Since JavaScript's built-in `max` function is tucked safely inside the `Math` object, we don't have to worry about overwriting it.

Many languages will stop you, or at least warn you, when you are defining a binding with a name that is already taken. JavaScript does this for bindings you declared with `let` or `const` but—perversely—not for standard bindings nor for bindings declared with `var` or `function`.

Back to the `Math` object. If you need to do trigonometry, `Math` can help. It contains `cos` (cosine), `sin` (sine), and `tan` (tangent), as well as their inverse functions, `acos`, `asin`, and `atan`, respectively. The number π (pi)—or at least the closest approximation that fits in a JavaScript number—is available as `Math.PI`. There is an old programming tradition of writing the names of constant values in all caps.

```
function randomPointOnCircle(radius) {
  let angle = Math.random() * 2 * Math.PI;
  return {x: radius * Math.cos(angle),
          y: radius * Math.sin(angle)};
}
console.log(randomPointOnCircle(2));
// → {x: 0.3667, y: 1.966}
```

If sines and cosines are not something you are familiar with, don't worry. When they are used in this book, in Chapter 14, I'll explain them.

The previous example used `Math.random`. This is a function that returns a new pseudorandom number between zero (inclusive) and one (exclusive) every time you call it.

```
console.log(Math.random());
// → 0.36993729369714856
```

```
console.log(Math.random());
// → 0.727367032552138
console.log(Math.random());
// → 0.40180766698904335
```

Though computers are deterministic machines—they always react the same way if given the same input—it is possible to have them produce numbers that appear random. To do that, the machine keeps some hidden value, and whenever you ask for a new random number, it performs complicated computations on this hidden value to create a new value. It stores a new value and returns some number derived from it. That way, it can produce ever new, hard-to-predict numbers in a way that *seems* random.

If we want a whole random number instead of a fractional one, we can use `Math.floor` (which rounds down to the nearest whole number) on the result of `Math.random`.

```
console.log(Math.floor(Math.random() * 10));
// → 2
```

Multiplying the random number by 10 gives us a number greater than or equal to 0 and below 10. Since `Math.floor` rounds down, this expression will produce, with equal chance, any number from 0 through 9.

There are also the functions `Math.ceil` (for "ceiling", which rounds up to a whole number), `Math.round` (to the nearest whole number), and `Math.abs`, which takes the absolute value of a number, meaning it negates negative values but leaves positive ones as they are.

Destructuring

Let's go back to the `phi` function for a moment.

```
function phi(table) {
  return (table[3] * table[0] - table[2] * table[1]) /
    Math.sqrt((table[2] + table[3]) *
              (table[0] + table[1]) *
              (table[1] + table[3]) *
              (table[0] + table[2]));
}
```

One of the reasons this function is awkward to read is that we have a binding

pointing at our array, but we'd much prefer to have bindings for the *elements* of the array, that is, `let n00 = table[0]` and so on. Fortunately, there is a succinct way to do this in JavaScript.

```
function phi([n00, n01, n10, n11]) {
  return (n11 * n00 - n10 * n01) /
    Math.sqrt((n10 + n11) * (n00 + n01) *
              (n01 + n11) * (n00 + n10));
}
```

This also works for bindings created with `let`, `var`, or `const`. If you know the value you are binding is an array, you can use square brackets to "look inside" of the value, binding its contents.

A similar trick works for objects, using braces instead of square brackets.

```
let {name} = {name: "Faraji", age: 23};
console.log(name);
// → Faraji
```

Note that if you try to destructure `null` or `undefined`, you get an error, much as you would if you directly try to access a property of those values.

JSON

Because properties only grasp their value, rather than contain it, objects and arrays are stored in the computer's memory as sequences of bits holding the *addresses*—the place in memory—of their contents. So an array with another array inside of it consists of (at least) one memory region for the inner array, and another for the outer array, containing (among other things) a binary number that represents the position of the inner array.

If you want to save data in a file for later or send it to another computer over the network, you have to somehow convert these tangles of memory addresses to a description that can be stored or sent. You *could* send over your entire computer memory along with the address of the value you're interested in, I suppose, but that doesn't seem like the best approach.

What we can do is *serialize* the data. That means it is converted into a flat description. A popular serialization format is called *JSON* (pronounced "Jason"), which stands for JavaScript Object Notation. It is widely used as a data storage and communication format on the Web, even in languages other than JavaScript.

JSON looks similar to JavaScript's way of writing arrays and objects, with a few restrictions. All property names have to be surrounded by double quotes, and only simple data expressions are allowed—no function calls, bindings, or anything that involves actual computation. Comments are not allowed in JSON.

A journal entry might look like this when represented as JSON data:

```
{
  "squirrel": false,
  "events": ["work", "touched tree", "pizza", "running"]
}
```

JavaScript gives us the functions `JSON.stringify` and `JSON.parse` to convert data to and from this format. The first takes a JavaScript value and returns a JSON-encoded string. The second takes such a string and converts it to the value it encodes.

```
let string = JSON.stringify({squirrel: false,
                             events: ["weekend"]});
console.log(string);
// → {"squirrel":false,"events":["weekend"]}
console.log(JSON.parse(string).events);
// → ["weekend"]
```

Summary

Objects and arrays (which are a specific kind of object) provide ways to group several values into a single value. Conceptually, this allows us to put a bunch of related things in a bag and run around with the bag, instead of wrapping our arms around all of the individual things and trying to hold on to them separately.

Most values in JavaScript have properties, the exceptions being `null` and `undefined`. Properties are accessed using `value.prop` or `value["prop"]`. Objects tend to use names for their properties and store more or less a fixed set of them. Arrays, on the other hand, usually contain varying amounts of conceptually identical values and use numbers (starting from 0) as the names of their properties.

There *are* some named properties in arrays, such as `length` and a number of methods. Methods are functions that live in properties and (usually) act on

the value they are a property of.

You can iterate over arrays using a special kind of `for` loop—`for (let element of array)`.

Exercises

The sum of a range

The introduction of this book alluded to the following as a nice way to compute the sum of a range of numbers:

```
console.log(sum(range(1, 10)));
```

Write a `range` function that takes two arguments, `start` and `end`, and returns an array containing all the numbers from `start` up to (and including) `end`.

Next, write a `sum` function that takes an array of numbers and returns the sum of these numbers. Run the example program and see whether it does indeed return 55.

As a bonus assignment, modify your `range` function to take an optional third argument that indicates the "step" value used when building the array. If no step is given, the elements go up by increments of one, corresponding to the old behavior. The function call `range(1, 10, 2)` should return `[1, 3, 5, 7, 9]`. Make sure it also works with negative step values so that `range(5, 2, -1)` produces `[5, 4, 3, 2]`.

Reversing an array

Arrays have a `reverse` method that changes the array by inverting the order in which its elements appear. For this exercise, write two functions, `reverseArray` and `reverseArrayInPlace`. The first, `reverseArray`, takes an array as argument and produces a *new* array that has the same elements in the inverse order. The second, `reverseArrayInPlace`, does what the `reverse` method does: it *modifies* the array given as argument by reversing its elements. Neither may use the standard `reverse` method.

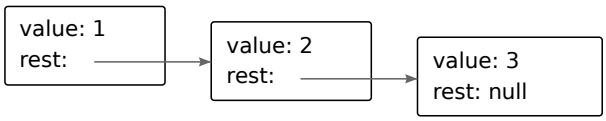
Thinking back to the notes about side effects and pure functions in the previous chapter, which variant do you expect to be useful in more situations? Which one runs faster?

A list

Objects, as generic blobs of values, can be used to build all sorts of data structures. A common data structure is the *list* (not to be confused with array). A list is a nested set of objects, with the first object holding a reference to the second, the second to the third, and so on.

```
let list = {
  value: 1,
  rest: {
    value: 2,
    rest: {
      value: 3,
      rest: null
    }
  }
};
```

The resulting objects form a chain, like this:



A nice thing about lists is that they can share parts of their structure. For example, if I create two new values `{value: 0, rest: list}` and `{value: -1, rest: list}` (with `list` referring to the binding defined earlier), they are both independent lists, but they share the structure that makes up their last three elements. The original list is also still a valid three-element list.

Write a function `arrayToList` that builds up a list structure like the one shown when given `[1, 2, 3]` as argument. Also write a `listToArray` function that produces an array from a list. Then add a helper function `prepend`, which takes an element and a list and creates a new list that adds the element to the front of the input list, and `nth`, which takes a list and a number and returns the element at the given position in the list (with zero referring to the first element) or `undefined` when there is no such element.

If you haven't already, also write a recursive version of `nth`.

Deep comparison

The `==` operator compares objects by identity. But sometimes you'd prefer to compare the values of their actual properties.

Write a function `deepEqual` that takes two values and returns true only if they are the same value or are objects with the same properties, where the values of the properties are equal when compared with a recursive call to `deepEqual`.

To find out whether values should be compared directly (use the `===` operator for that) or have their properties compared, you can use the `typeof` operator. If it produces `"object"` for both values, you should do a deep comparison. But you have to take one silly exception into account: because of a historical accident, `typeof null` also produces `"object"`.

The `Object.keys` function will be useful when you need to go over the properties of objects to compare them.

> *"There are two ways of constructing a software design: One way is to make it so simple that there are obviously no deficiencies, and the other way is to make it so complicated that there are no obvious deficiencies."*
>
> —C.A.R. Hoare, 1980 ACM Turing Award Lecture

CHAPTER 5

Higher-Order Functions

A large program is a costly program, and not just because of the time it takes to build. Size almost always involves complexity, and complexity confuses programmers. Confused programmers, in turn, introduce mistakes (*bugs*) into programs. A large program then provides a lot of space for these bugs to hide, making them hard to find.

Let's briefly go back to the final two example programs in the introduction. The first is self-contained and six lines long.

```
let total = 0, count = 1;
while (count <= 10) {
  total += count;
  count += 1;
}
console.log(total);
```

The second relies on two external functions and is one line long.

```
console.log(sum(range(1, 10)));
```

Which one is more likely to contain a bug?

If we count the size of the definitions of `sum` and `range`, the second program is also big—even bigger than the first. But still, I'd argue that it is more likely to be correct.

It is more likely to be correct because the solution is expressed in a vocabulary that corresponds to the problem being solved. Summing a range of numbers isn't about loops and counters. It is about ranges and sums.

The definitions of this vocabulary (the functions `sum` and `range`) will still involve loops, counters, and other incidental details. But because they are expressing simpler concepts than the program as a whole, they are easier to get right.

Abstraction

In the context of programming, these kinds of vocabularies are usually called *abstractions*. Abstractions hide details and give us the ability to talk about problems at a higher (or more abstract) level.

As an analogy, compare these two recipes for pea soup. The first one goes like this:

> Put 1 cup of dried peas per person into a container. Add water until the peas are well covered. Leave the peas in water for at least 12 hours. Take the peas out of the water and put them in a cooking pan. Add 4 cups of water per person. Cover the pan and keep the peas simmering for two hours. Take half an onion per person. Cut it into pieces with a knife. Add it to the peas. Take a stalk of celery per person. Cut it into pieces with a knife. Add it to the peas. Take a carrot per person. Cut it into pieces. With a knife! Add it to the peas. Cook for 10 more minutes.

And this is the second recipe:

> Per person: 1 cup dried split peas, half a chopped onion, a stalk of celery, and a carrot.
>
> Soak peas for 12 hours. Simmer for 2 hours in 4 cups of water (per person). Chop and add vegetables. Cook for 10 more minutes.

The second is shorter and easier to interpret. But you do need to understand a few more cooking-related words such as *soak*, *simmer*, *chop*, and, I guess, *vegetable*.

When programming, we can't rely on all the words we need to be waiting for us in the dictionary. Thus, we might fall into the pattern of the first recipe—work out the precise steps the computer has to perform, one by one, blind to the higher-level concepts that they express.

It is a useful skill, in programming, to notice when you are working at too low a level of abstraction.

Abstracting repetition

Plain functions, as we've seen them so far, are a good way to build abstractions. But sometimes they fall short.

It is common for a program to do something a given number of times. You can write a `for` loop for that, like this:

```
for (let i = 0; i < 10; i++) {
  console.log(i);
}
```

Can we abstract "doing something N times" as a function? Well, it's easy to write a function that calls `console.log` N times.

```
function repeatLog(n) {
  for (let i = 0; i < n; i++) {
    console.log(i);
  }
}
```

But what if we want to do something other than logging the numbers? Since "doing something" can be represented as a function and functions are just values, we can pass our action as a function value.

```
function repeat(n, action) {
  for (let i = 0; i < n; i++) {
    action(i);
  }
}

repeat(3, console.log);
// → 0
// → 1
// → 2
```

We don't have to pass a predefined function to `repeat`. Often, it is easier to create a function value on the spot instead.

```
let labels = [];
repeat(5, i => {
  labels.push(`Unit ${i + 1}`);
});
console.log(labels);
// → ["Unit 1", "Unit 2", "Unit 3", "Unit 4", "Unit 5"]
```

This is structured a little like a `for` loop—it first describes the kind of loop and then provides a body. However, the body is now written as a function value, which is wrapped in the parentheses of the call to `repeat`. This is why it has to be closed with the closing brace *and* closing parenthesis. In cases like

this example, where the body is a single small expression, you could also omit the braces and write the loop on a single line.

Higher-order functions

Functions that operate on other functions, either by taking them as arguments or by returning them, are called *higher-order functions*. Since we have already seen that functions are regular values, there is nothing particularly remarkable about the fact that such functions exist. The term comes from mathematics, where the distinction between functions and other values is taken more seriously.

Higher-order functions allow us to abstract over *actions*, not just values. They come in several forms. For example, we can have functions that create new functions.

```
function greaterThan(n) {
  return m => m > n;
}
let greaterThan10 = greaterThan(10);
console.log(greaterThan10(11));
// → true
```

And we can have functions that change other functions.

```
function noisy(f) {
  return (...args) => {
    console.log("calling with", args);
    let result = f(...args);
    console.log("called with", args, ", returned", result);
    return result;
  };
}
noisy(Math.min)(3, 2, 1);
// → calling with [3, 2, 1]
// → called with [3, 2, 1] , returned 1
```

We can even write functions that provide new types of control flow.

```
function unless(test, then) {
  if (!test) then();
}
```

```
repeat(3, n => {
  unless(n % 2 == 1, () => {
    console.log(n, "is even");
  });
});
// → 0 is even
// → 2 is even
```

There is a built-in array method, `forEach`, that provides something like a `for/of` loop as a higher-order function.

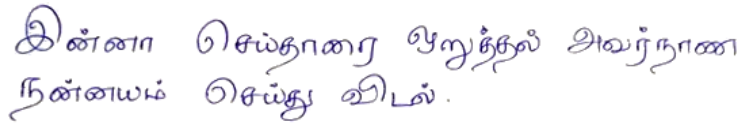
```
["A", "B"].forEach(l => console.log(l));
// → A
// → B
```

Script data set

One area where higher-order functions shine is data processing. To process data, we'll need some actual data. This chapter will use a data set about scripts—writing systems such as Latin, Cyrillic, or Arabic.

Remember Unicode from Chapter 1, the system that assigns a number to each character in written language? Most of these characters are associated with a specific script. The standard contains 140 different scripts—81 are still in use today, and 59 are historic.

Though I can fluently read only Latin characters, I appreciate the fact that people are writing texts in at least 80 other writing systems, many of which I wouldn't even recognize. For example, here's a sample of Tamil handwriting:



The example data set contains some pieces of information about the 140 scripts defined in Unicode. It is available in the coding sandbox for this chapter (*https://eloquentjavascript.net/code#5*) as the `SCRIPTS` binding. The binding contains an array of objects, each of which describes a script.

```
{
  name: "Coptic",
  ranges: [[994, 1008], [11392, 11508], [11513, 11520]],
```

```
  direction: "ltr",
  year: -200,
  living: false,
  link: "https://en.wikipedia.org/wiki/Coptic_alphabet"
}
```

Such an object tells us the name of the script, the Unicode ranges assigned to it, the direction in which it is written, the (approximate) origin time, whether it is still in use, and a link to more information. The direction may be `"ltr"` for left to right, `"rtl"` for right to left (the way Arabic and Hebrew text are written), or `"ttb"` for top to bottom (as with Mongolian writing).

The `ranges` property contains an array of Unicode character ranges, each of which is a two-element array containing a lower bound and an upper bound. Any character codes within these ranges are assigned to the script. The lower bound is inclusive (code 994 is a Coptic character), and the upper bound is non-inclusive (code 1008 isn't).

Filtering arrays

To find the scripts in the data set that are still in use, the following function might be helpful. It filters out the elements in an array that don't pass a test.

```
function filter(array, test) {
  let passed = [];
  for (let element of array) {
    if (test(element)) {
      passed.push(element);
    }
  }
  return passed;
}

console.log(filter(SCRIPTS, script => script.living));
// → [{name: "Adlam", …}, …]
```

The function uses the argument named `test`, a function value, to fill a "gap" in the computation—the process of deciding which elements to collect.

Note how the `filter` function, rather than deleting elements from the existing array, builds up a new array with only the elements that pass the test. This function is *pure*. It does not modify the array it is given.

Like `forEach`, `filter` is a standard array method. The example defined the