UNIT – II

DATA STRUCTURES :

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 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.

edit & run code by clicking it

```
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:

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

(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 1×76−4×9 = 40, and the part below it (the divisor) would be the square root of 5×85×10×80, or √340000. This comes out to $\phi \approx 0.069$, 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, 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.

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.

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"]
```

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.

edit & run code by clicking it

```
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.

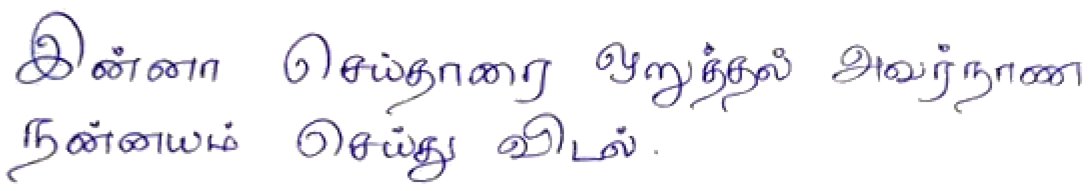
```
["A", "B"].forEach(l => console.log(l));
// → A
// → B
```

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:


இன்னா செய்தாரை ஒறுத்தல் அவர்நாண
நன்னயம் செய்து விடல்.

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 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 function only to show what it does internally. From now on, we’ll use it like this instead:

```
console.log(SCRIPTS.filter(s => s.direction == "ttb"));
// → [{name: "Mongolian", …}, …]
```

Transforming with map

Say we have an array of objects representing scripts, produced by filtering the SCRIPTS array somehow. But we want an array of names, which is easier to inspect.

The map method transforms an array by applying a function to all of its elements and building a new array from the returned values. The new array will have the same length as the input array, but its content will have been *mapped* to a new form by the function.

```
function map(array, transform) {
  let mapped = [];
  for (let element of array) {
    mapped.push(transform(element));
  }
  return mapped;
}

let rtlScripts = SCRIPTS.filter(s => s.direction == "rtl");
console.log(map(rtlScripts, s => s.name));
// → ["Adlam", "Arabic", "Imperial Aramaic", …]
```

Like forEach and filter, map is a standard array method.

Summarizing with reduce

Another common thing to do with arrays is to compute a single value from them. Our recurring example, summing a collection of numbers, is an instance of this. Another example is finding the script with the most characters.

The higher-order operation that represents this pattern is called *reduce* (sometimes also called *fold*). It builds a value by repeatedly taking a single element from the array and combining it with the current value. When summing numbers, you'd start with the number zero and, for each element, add that to the sum.

The parameters to reduce are, apart from the array, a combining function and a start value. This function is a little less straightforward than filter and map, so take a close look at it:

```
function reduce(array, combine, start) {
  let current = start;
  for (let element of array) {
    current = combine(current, element);
  }
  return current;
}

console.log(reduce([1, 2, 3, 4], (a, b) => a + b, 0));
// → 10
```

The standard array method reduce, which of course corresponds to this function, has an added convenience. If your array contains at least one element, you are allowed to leave off the start argument. The method will take the first element of the array as its start value and start reducing at the second element.

```
console.log([1, 2, 3, 4].reduce((a, b) => a + b));
// → 10
```

To use reduce (twice) to find the script with the most characters, we can write something like this:

```
function characterCount(script) {
  return script.ranges.reduce((count, [from, to]) => {
    return count + (to - from);
  }, 0);
}

console.log(SCRIPTS.reduce((a, b) => {
  return characterCount(a) < characterCount(b) ? b : a;
}));
// → {name: "Han", …}
```

The characterCount function reduces the ranges assigned to a script by summing their sizes. Note the use of destructuring in the parameter list of the reducer function. The second call to reduce then uses this to find the largest script by repeatedly comparing two scripts and returning the larger one.

The Han script has more than 89,000 characters assigned to it in the Unicode standard, making it by far the biggest writing system in the data set. Han is a script (sometimes) used for Chinese, Japanese, and Korean text. Those languages share a lot of characters, though they tend to write them differently. The (U.S.-based) Unicode Consortium decided to treat them as a single writing system to save character codes. This is called *Han unification* and still makes some people very angry.

Composability

Consider how we would have written the previous example (finding the biggest script) without higher-order functions. The code is not that much worse.

```
let biggest = null;
for (let script of SCRIPTS) {
  if (biggest == null ||
      characterCount(biggest) < characterCount(script)) {
    biggest = script;
  }
}
console.log(biggest);
// → {name: "Han", …}
```

There are a few more bindings, and the program is four lines longer. But it is still very readable.

Higher-order functions start to shine when you need to *compose* operations. As an example, let's write code that finds the average year of origin for living and dead scripts in the data set.

```
function average(array) {
  return array.reduce((a, b) => a + b) / array.length;
}
```

```
console.log(Math.round(average(
  SCRIPTS.filter(s => s.living).map(s => s.year))));
// → 1165
console.log(Math.round(average(
  SCRIPTS.filter(s => !s.living).map(s => s.year))));
// → 204
```

So the dead scripts in Unicode are, on average, older than the living ones. This is not a terribly meaningful or surprising statistic. But I hope you’ll agree that the code used to compute it isn’t hard to read. You can see it as a pipeline: we start with all scripts, filter out the living (or dead) ones, take the years from those, average them, and round the result.

You could definitely also write this computation as one big loop.

```
let total = 0, count = 0;
for (let script of SCRIPTS) {
  if (script.living) {
    total += script.year;
    count += 1;
  }
}
console.log(Math.round(total / count));
// → 1165
```

But it is harder to see what was being computed and how. And because intermediate results aren't represented as coherent values, it'd be a lot more work to extract something like average into a separate function.

In terms of what the computer is actually doing, these two approaches are also quite different. The first will build up new arrays when running filter and map, whereas the second computes only some numbers, doing less work. You can usually afford the readable approach, but if you're processing huge arrays, and doing so many times, the less abstract style might be worth the extra speed.

Strings and character codes

One use of the data set would be figuring out what script a piece of text is using. Let's go through a program that does this.

Remember that each script has an array of character code ranges associated with it. So given a character code, we could use a function like this to find the corresponding script (if any):

```
function characterScript(code) {
  for (let script of SCRIPTS) {
    if (script.ranges.some(([from, to]) => {
      return code >= from && code < to;
    })) {
      return script;
    }
  }
  return null;
}

console.log(characterScript(121));
// → {name: "Latin", …}
```

The some method is another higher-order function. It takes a test function and tells you whether that function returns true for any of the elements in the array.

But how do we get the character codes in a string?

In Chapter 1 I mentioned that JavaScript strings are encoded as a sequence of 16-bit numbers. These are called *code units*. A Unicode character code was initially supposed to fit within such a unit (which gives you a little over 65,000 characters). When it became clear that wasn't going to be enough, many people balked at the need to use more memory per character. To address these concerns, UTF-16, the format used by JavaScript strings, was invented. It describes most common characters using a single 16-bit code unit but uses a pair of two such units for others.

UTF-16 is generally considered a bad idea today. It seems almost intentionally designed to invite mistakes. It's easy to write programs that pretend code units and characters are the same thing. And if your language doesn’t use two-unit characters, that will appear to work just fine. But as soon as someone tries to use such a program with some less common Chinese characters, it breaks. Fortunately, with the advent of emoji, everybody has started using two-unit characters, and the burden of dealing with such problems is more fairly distributed.

Unfortunately, obvious operations on JavaScript strings, such as getting their length through the length property and accessing their content using square brackets, deal only with code units.

```
// Two emoji characters, horse and shoe
let horseShoe = "🐴👟";
console.log(horseShoe.length);
// → 4
console.log(horseShoe[0]);
// → (Invalid half-character)
console.log(horseShoe.charCodeAt(0));
// → 55357 (Code of the half-character)
console.log(horseShoe.codePointAt(0));
// → 128052 (Actual code for horse emoji)
```

JavaScript’s charCodeAt method gives you a code unit, not a full character code. The codePointAt method, added later, does give a full Unicode character. So we could use that to get characters from a string. But the argument passed to codePointAt is still an index into the sequence of code units. So to run over all characters in a string, we’d still need to deal with the question of whether a character takes up one or two code units.

In the previous chapter, I mentioned that a for/of loop can also be used on strings. Like codePointAt, this type of loop was introduced at a time where people were acutely aware of the problems with UTF-16. When you use it to loop over a string, it gives you real characters, not code units.

```
let roseDragon = "🌹🐉";
for (let char of roseDragon) {
  console.log(char);
}
// → 🌹
// → 🐉
```

If you have a character (which will be a string of one or two code units), you can use codePointAt(0) to get its code.

Recognizing text

We have a characterScript function and a way to correctly loop over characters. The next step is to count the characters that belong to each script. The following counting abstraction will be useful there:

```
function countBy(items, groupName) {
  let counts = [];
  for (let item of items) {
    let name = groupName(item);
    let known = counts.findIndex(c => c.name == name);
    if (known == -1) {
      counts.push({name, count: 1});
    } else {
      counts[known].count++;
    }
  }
  return counts;
}

console.log(countBy([1, 2, 3, 4, 5], n => n > 2));
// → [{name: false, count: 2}, {name: true, count: 3}]
```

The countBy function expects a collection (anything that we can loop over with for/of) and a function that computes a group name for a given element. It returns an array of objects, each of which names a group and tells you the number of elements that were found in that group.

It uses another array method—findIndex. This method is somewhat like indexOf, but instead of looking for a specific value, it finds the first value for which the given function returns true. Like indexOf, it returns -1 when no such element is found.

Using countBy, we can write the function that tells us which scripts are used in a piece of text.

```
function textScripts(text) {
  let scripts = countBy(text, char => {
    let script = characterScript(char.codePointAt(0));
    return script ? script.name : "none";
  }).filter(({name}) => name != "none");

  let total = scripts.reduce((n, {count}) => n + count, 0);
  if (total == 0) return "No scripts found";

  return scripts.map(({name, count}) => {
    return `${Math.round(count * 100 / total)}% ${name}`;
  }).join(", ");
}

console.log(textScripts('英国的狗说"woof", 俄罗斯的狗说"тяв"'));
// → 61% Han, 22% Latin, 17% Cyrillic
```

The function first counts the characters by name,
using characterScript to assign them a name and falling back to the string "none" for characters that aren’t part of any script. The filter call drops the entry for "none" from the resulting array since we aren’t interested in those characters.

To be able to compute percentages, we first need the total number of characters that belong to a script, which we can compute with reduce. If no such characters are found, the function returns a specific string. Otherwise, it transforms the counting entries into readable strings with map and then combines them with join.

Summary

Being able to pass function values to other functions is a deeply useful aspect of JavaScript. It allows us to write functions that model computations with "gaps" in them. The code that calls these functions can fill in the gaps by providing function values.

Arrays provide a number of useful higher-order methods. You can use forEach to loop over the elements in an array. The filter method returns a new array containing only the elements that pass the predicate function. Transforming an array by putting each element through a function is done with map. You can use reduce to combine all the elements in an array into a single value. The some method tests whether any element matches a given predicate function.
And findIndex finds the position of the first element that matches a predicate.

Exercises

Flattening

Use the reduce method in combination with the concat method to "flatten" an array of arrays into a single array that has all the elements of the original arrays.

```
let arrays = [[1, 2, 3], [4, 5], [6]];
// Your code here.
// → [1, 2, 3, 4, 5, 6]
```

Your own loop

Write a higher-order function loop that provides something like a for loop statement. It takes a value, a test function, an update function, and a body function. Each iteration, it first runs the test function on the current loop value and stops if that returns false. Then it calls the body function, giving it the current value. Finally, it calls the update function to create a new value and starts from the beginning.

When defining the function, you can use a regular loop to do the actual looping.

```
// Your code here.

loop(3, n => n > 0, n => n - 1, console.log);
// → 3
// → 2
// → 1
```

Everything

Analogous to the some method, arrays also have an every method. This one returns true when the given function returns true for *every* element in the array. In a way, some is a version of the || operator that acts on arrays, and every is like the && operator.

Implement every as a function that takes an array and a predicate function as parameters. Write two versions, one using a loop and one using the some method.

```
function every(array, test) {
  // Your code here.
}

console.log(every([1, 3, 5], n => n < 10));
// → true
console.log(every([2, 4, 16], n => n < 10));
// → false
console.log(every([], n => n < 10));
// → true
```

Dominant writing direction

Write a function that computes the dominant writing direction in a string of text. Remember that each script object has a direction property that can be "ltr" (left to right), "rtl" (right to left), or "ttb" (top to bottom).

The dominant direction is the direction of a majority of the characters that have a script associated with them.
The characterScript and countBy functions defined earlier in the chapter are probably useful here.

```
function dominantDirection(text) {
  // Your code here.
}

console.log(dominantDirection("Hello!"));
// → ltr
console.log(dominantDirection("Hey, مساء الخير"));
// → rtl
```