The Pragmatic Programmers

# Reactive Programming with RxJS

Untangle Your Asynchronous JavaScript Code

Sergi Mansilla

edited by Rebecca Gulick

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**by Sergi Mansilla**

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*Per a tu, Pipus*

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Every significant shift in software development demands rethinking our approaches. Real-time and asynchronous web applications pose a huge challenge in web development today. This book does an excellent job explaining how RxJS addresses those challenges and teaches you how to rethink your world in terms of Observables.

→Zef Hemel
VP engineering, STX Next

This book is as hot as reactive programming itself! With great writing, clear explanations, and practical examples, this is a fantastic resource for learning RxJS.

→Fred Daoud
Software-development contractor

Be proactive and learn reactive programming with this book before it’s too late.
Rx.Observable.fromBook(book).subscribe(function(value) {...do amazing stuff...});

→Javier Collado Cabeza
Senior software developer, NowSecure, Inc.

A very readable book with great content. This book is eminently useful and provides a clear roadmap for learning reactive programming with RxJS with practical examples.

→ Ramaninder Singh Jhajj
Software engineer, Area Services & Development, Know-Center, Austria

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Sergi Mansilla

Barcelona, December 2015

# Preface

Reactive programming is taking the software world by storm. This book combines the reactive programming philosophy with the possibilities of JavaScript, and you'll learn how to apply reactive techniques to your own projects. We'll focus on reactive programming to manage and combine streams of events. In fact, we'll cover how to make entire real-world, concurrent applications just by declaring transformations on our program's events.

Most software today deals with data that's available only over time: websites load remote resources and respond to complex user interactions, servers are distributed across multiple physical locations, and people have mobile devices that they expect to work at all times, whether on high-speed Wi-Fi or spotty cellular networks. Any serious application involves many moving asynchronous parts that need to be efficiently coordinated, and that's very hard with today's programming techniques. On top of that, we have what's always been there: servers crashing, slow networks, and software bugs we have to deal with.

We can’t afford to keep programming applications the way we always have. It worked for a while, but now it’s time for a new approach.

## New World, Old Methods

In recent years JavaScript has become the most ubiquitous language in the world and now powers the mission-critical infrastructure of businesses such as Walmart and Netflix,[1] mobile operating systems such as Firefox OS, and complex popular applications such as Google Docs.

And yet we're still using good ol' imperative-style programming to deal with problems that are essentially asynchronous. This is very hard.

JavaScript developers see the language's lack of threads as a feature, and we usually write asynchronous code using callbacks, promises, and events. But as we keep adding more concurrency to our applications, the code to coordinate asynchronous flows becomes unwieldy. Current mechanisms all have serious shortcomings that hinder the developer's productivity and make for fragile applications.

Here's a quick rundown of the current mechanisms for handling asynchronous operations, along with their problems.

### Callback Functions

A *callback* is a function *(A)* passed as a parameter to another function *(B)* that performs an asynchronous operation. When *(B)* is done, it *calls back (A)* with the results of the operation. Callbacks are used to manage asynchronous flows such as network I/O, database access, or user input.

intro/callback_example.js

```
function B(callback) {
  // Do operation that takes some time
  callback('Done!');
}

function A(message) {
  console.log(message);
}

// Execute `B` with `A` as a callback
B(A);
```

Callbacks are easy to grasp and have become the default way of handling asynchronous data flows in JavaScript. But this simplicity comes at a price. Callbacks have the following drawbacks:

- *Callback hell*. It's easy to end up with lots of nested callbacks when handling highly asynchronous code. When that happens, code stops being linear and becomes hard to reason about. Whole applications end up passed around in callbacks, and they become difficult to maintain and debug.
- *Callbacks can run more than once*. There's no guarantee the same callback will be called only once. Multiple invocations can be hard to detect and can result in errors and general mayhem in your application.
- *Callbacks change error semantics*. Callbacks break the traditional *try/catch* mechanism and rely on the programmer to check for errors and pass them around.
- *Concurrency gets increasingly complicated*. Combining interdependent results of multiple asynchronous operations becomes difficult. It requires us to keep track of the state of each operation in temporal variables, and then delegate them to the final combination operation in the proper order.

### Promises

Promises came to save us from callbacks. A promise represents the result of an asynchronous operation. In promise-based code, calling an asynchronous function immediately returns a "promise" that will eventually be either *resolved* with the result of the operation or *rejected* with an error. In the meantime, the *pending* promise can be used as a placeholder for the final value.

Promises usually make programs more clear by being closer to synchronous code, reducing the need for nesting blocks and keeping track of less state.

Unfortunately, promises are not a silver bullet. They're an improvement over callbacks, but they have a major shortcoming: they only ever yield a single value. That makes them useless for handling recurrent events such as mouse clicks or streams of data coming from the server, because we would have to create a promise for each separate event instead of creating a promise that handles the stream of events as it comes.

### Event Emitters

When we emit an event, event listeners that are subscribed to it will fire. Using events is a great way to decouple functionality, and in JavaScript, event programming is common and generally a good practice.

But, you guessed it, event listeners come with their own set of problems, too:

- *Events force side effects*. Event listener functions always ignore their return values, which forces the listener to have side effects if it wants to have any impact in the world.
- *Events are not first-class values*. For example, a series of `click` events can't be passed as a parameter or manipulated as the sequence it actually is. We're limited to handling each event individually, and only after the event happens.
- *It is easy to miss events if we start listening too late*. An infamous example of that is the first version of the *streams* interface in Node.js, which would often emit its `data` event before listeners had time to listen to it, losing it forever.

Since these mechanisms are what we've always used to manage concurrency, it might be hard to think of a better way. But in this book I'll show you one: reactive programming and RxJS try to solve all these problems with some new concepts and mechanisms to make asynchronous programming a breeze—and much more fun.

## What Is Reactive Programming?

Reactive programming is a programming paradigm that encompasses many concepts and techniques. In this book I'll focus particularly on creating, transforming, and reacting to streams of data. Mouse clicks, network requests, arrays of strings—all these can be expressed as streams to which we can "react" as they publish new values, using the same interfaces regardless of their source.

Reactive programming focuses on propagating changes without our having to explicitly specify how the propagation happens. This allows us to state what our code should do, without having to code every step to do it. This results in a more reliable and maintainable approach to building software.

## What Is RxJS?

RxJS is a JavaScript implementation of the Reactive Extensions, or Rx.[2] Rx is a reactive programming model originally created at Microsoft that allows developers to easily compose asynchronous streams of data. It provides a common interface to combine and transform data from wildly different sources, such as filesystem operations, user interaction, and social-network updates.

Rx started with an implementation for .NET, but today it has a well-maintained open source implementation in every major language (and some minor ones). It is becoming the standard to program reactive applications, and Rx's main data type, the Observable, is being proposed for inclusion in ECMAScript 7 as an integral part of JavaScript.

## Who This Book Is For

This book is for developers with some experience with JavaScript. You should be comfortable with closures and higher-order functions, and you should understand the scope rules in JavaScript. That being said, I try to explain the most complex language concepts we go through in this book.

## What's in This Book

This book is a practical introduction to reactive programming using RxJS. The objective is to get you to think reactively by building small real-world applications, so you can learn how to introduce reactive programming in your day-to-day programming and make your programs more robust. This is not a theoretical book about reactive programming, and it is not an exhaustive reference book for the RxJS API. You can find these kinds of resources online.

We'll be developing mostly for the browser, but we'll see some examples in Node.js, too. We'll get deep into the subject early on, and we'll build applications along the way to keep it real. Here are the chapters:

Unless you have used RxJS before, start with Chapter 1, *The Reactive Way*. In this chapter we introduce Observables, the main data type of RxJS, which we'll use extensively throughout the book.

With the basics of Observables established, we move on to Chapter 2, *Deep in the Sequence*. There you see that in reactive programming it's all about sequences of events. We visit some important sequence operators and we build our first application, a real-time earthquake visualizer.

In Chapter 3, *Building Concurrent Programs*, we look at how to write concurrent code with minimal side effects. After covering the Observable pipeline, we build a cool spaceship video game in about 200 lines of code and with almost no global state.

In Chapter 4, *Building a Complete Web Application*, we get deeper into reactive app development and enhance the earthquake application we made previously in Chapter 2, *Deep in the Sequence* by making a server part in Node.js that shows tweets related to earthquakes happening right now.

We get into some more advanced concepts of RxJS with Chapter 5, *Bending Time with Schedulers*, where we talk about the useful concept RxJS provides to handle concurrency at a more fine-grained level: Schedulers.

With the knowledge of Schedulers under our hats, we explore how they help us with testing. We'll see how to simulate time in our tests to accurately test asynchronous programs.

Finally, in Chapter 6, *Reactive Web Applications with Cycle.js*, we'll use Cycle.js, a UI framework built on top of RxJS, to build a simple application. Cycle.js draws concepts from modern frameworks such as React.js to create a reactive framework that uses the advantages of Observables to help us create fast user interfaces in a simple and reliable way.

## Running the Code Examples

The code examples in this book are made for either the browser or Node.js. The context of the code should clarify in what environment to run the code.

### Running RxJS Code in the Browser

If the code is meant to run in the browser, we'll use the file `rx.all.js`, which you can find in the RxJS GitHub repository.[3] `rx.all.js` includes all the operators in RxJS, and it's the easiest way to be sure all examples will work. Just load the script in the `<head>` section of your HTML document:

```
<html>
  <head>
    <script src="rx.all.js"></script>
  </head>
  ...
</html>
```

Keep in mind that it is a relatively big file and you may want to consider a smaller file, such as `rx.js` or `rx.lite.js`, for your projects if you're not using all the functionality in RxJS.

### Running RxJS Code in Node.js

Running code examples in Node.js is easy. Just make sure you install the RxJS dependency in your project using `npm`:

```
$ npm install rx
rx@4.0.0 node_modules/rx
```

After that, you can import the RxJS library in your JavaScript files:

```
var Rx = require('rx');

Rx.Observable.just('Hello World!').subscribe(
function(value) {
  console.log(value);
});
```

And you can run it by simply invoking `node` and the name of the file:

```
$ node test.js
Hello World!
```

## RxJS Version

All the examples are made for RxJS 4.x. You can download the latest version in the RxJS online repository.[4]

## Resources

RxJS is gaining adoption very quickly, and there are more and more resources about it every day. At times it might be hard to find resources about it online, though. These are my favorite ones:

- RxJS official source code repository[5]
- ReactiveX, a collection of resources related to the Reactive Extensions[6]
- RxMarbles, an interactive tool to visualize Observables[7]

# Download Sample Code

This book's website has links to an interactive discussion forum as well as a place to submit errata.[8] You'll also find the source code for all the projects we build. Readers of the ebook can interact with the box above each code snippet to view that snippet directly.

---

**FOOTNOTES**

[1] http://venturebeat.com/2012/01/24/why-walmart-is-using-node-js/, http://techblog.netflix.com/2014/06/scale-and-performance-of-large.html

[2] https://rx.codeplex.com/

[3] https://github.com/Reactive-Extensions/RxJS/tree/master/dist

[4] https://github.com/Reactive-Extensions/RxJS/releases/latest

[5] https://github.com/Reactive-Extensions/RxJS

[6] http://reactivex.io

[7] http://rxmarbles.com/

[8] http://pragprog.com/titles/smreactjs

Chapter 1

# The Reactive Way

The real world is pretty messy: events happen in random order, applications crash, and networks fail. Few applications are completely synchronous, and writing asynchronous code is necessary to keep applications responsive. Most of the time it's downright painful, but it really doesn't have to be.

Modern applications need super-fast responses and the ability to process data from different sources at the same time without missing a beat. Current techniques won't get us there because they don't scale—code becomes exponentially more complex as we add concurrency and application state. They get the job done only at the expense of a considerable mental load on the developer, and that leads to bugs and complexity in our code.

This chapter introduces you to reactive programming, a natural, easier way to think about asynchronous code. I'll show you how streams of events—which we call *Observables*—are a beautiful way to handle asynchronous code. Then we'll create an Observable and see how reactive thinking and RxJS dramatically improve on existing techniques and make you a happier, more productive programmer.

## What's Reactive?

Let's start by looking at a little reactive RxJS program. This program needs to retrieve data from different sources with the click of a button, and it has the following requirements:

- It must unify data from two different locations that use different JSON structures.
- The final result should not contain any duplicates.
- To avoid requesting data too many times, the user should not be able to click the button more than once per second.

Using RxJS, we would write something like this:

```
var button = document.getElementById(
'retrieveDataBtn');
var source1 = Rx.DOM.getJSON('/resource1').pluck(
'name');
var source2 = Rx.DOM.getJSON('/resource2').pluck(
'props', 'name');

function getResults(amount) {
    return source1.merge(source2)
      .pluck('names')
      .flatMap(function(array) { return
```

```
Rx.Observable.from(array); })
       .distinct()
       .take(amount);
}

var clicks = Rx.Observable.fromEvent(button,
'click');
clicks.debounce(1000)
   .flatMap(getResults(5))
   .subscribe(
     function(value) { console.log('Received value'
, value); },
     function(err) { console.error(err); },
     function() { console.log('All values
retrieved!'); }
   );
```

Don’t worry about understanding what’s going on here; let’s focus on the 10,000-foot view for now. The first thing you see is that we express more with fewer lines of code. We accomplish this by using Observables.

An Observable represents a stream of data. Programs can be expressed largely as streams of data. In the preceding example, both remote sources are Observables, and so are the mouse clicks from the user. In fact, our program is essentially a single Observable made from a button's `click` event that we transform to get the results we want.

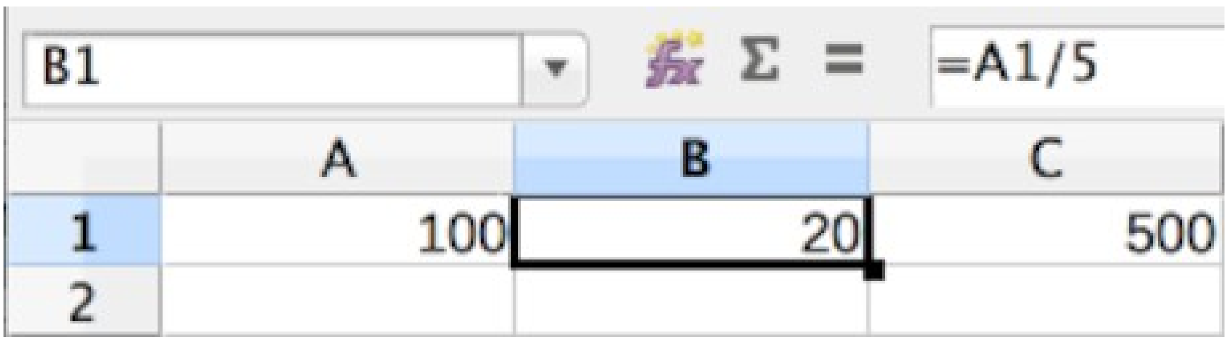
Reactive programming is expressive. Take, for instance, throttling mouse clicks in our example. Imagine how complex it would be to do that using callbacks or promises: we'd need to reset a timer every second and keep state of whether a second has passed since the last time the user clicked the button. It's a lot of complexity for so little functionality, and the code for it is not even related to your program's actual functionality. In bigger applications, these little complexities add up very quickly to make for a tangled code base.

With the reactive approach, we use the method `debounce` to throttle the stream of clicks. This ensures that there is at least a second between each click, and discards any clicks in between. We don't care how this happens internally; we just express *what* we want our code to do, not *how* to do it.

It gets much more interesting. Next you'll see how reactive programming can help us make our programs more efficient and expressive.

## Spreadsheets Are Reactive

Let’s start by considering the quintessential example of a reactive system: the spreadsheet. We all have used them, but we rarely stop and think how shockingly intuitive they are. Let’s say we have a value in cell A1 of the spreadsheet. We can then reference it in other cells in the spreadsheet, and whenever we change A1, every cell depending on A1 will automatically update its own value.




That behavior feels natural to us. We didn’t have to tell the computer to update cells that depend on A1 or how to do it; these cells just *reacted* to the change. In a spreadsheet, we simply *declare* our problem, and we don’t worry about how the computer calculates the results.

This is what reactive programming aims for. We declare relationships between players, and the program evolves as these entities change or come up with new values.

## The Mouse as a Stream of Values

To understand how to see events as streams of values, let's think of the program from the beginning of this chapter. There we used mouse clicks as an infinite sequence of events generated in real time as the user clicks. This is an idea by Erik Meijer—the inventor of RxJS—proposed in his paper "Your Mouse Is a Database."[9]

In reactive programming, we see mouse clicks as a continuous stream of events that we can query and manipulate. Thinking of streams instead of isolated values opens up a whole new way to program, one in which we can manipulate entire sequences of values that haven't been created yet.

Let that thought sink in for a moment. This is different from what we're used to, which is having values stored somewhere such as a database or an array and waiting for them to be available before we use them. If they are not available yet (for instance, a network request), we wait for them and use them only when they become available.


We can think of our streaming sequence as an array in which elements are separated by *time* instead of by memory. With either time or memory, we have sequences of elements:


Seeing your program as flowing sequences of data is key to understanding RxJS programming. It takes a bit of practice, but it is not hard. In fact, most data we use in any application can be expressed as a sequence. We'll look at sequences more in depth in Chapter 2, *Deep in the Sequence*.

## Querying the Sequence

Let's implement a simple version of that mouse stream using traditional event listeners in JavaScript. To log the x- and y-coordinates of mouse clicks, we could write something like this:

ch1/thinking_sequences.js

```
document.body.addEventListener('click', function
(e) {
  console.log(e.clientX, e.clientY);
});
```

This code will print the x- and y-coordinates of every mouse click in order. The output looks like this:

```
<= 252 183
   211 232
   153 323
   ...
```

Looks like a sequence, doesn't it? The problem, of course, is that manipulating events is not as easy as manipulating arrays. For example, if we want to change the preceding code so it logs only the first 10 clicks on the right side of the screen (quite a random goal, but bear with me here), we would write something like this:

```
var clicks = 0;
document.addEventListener('click', function
registerClicks(e) {
  if (clicks < 10) {
    if (e.clientX > window.innerWidth / 2) {
      console.log(e.clientX, e.clientY);
      clicks += 1;
    }
  } else {
    document.removeEventListener('click',
registerClicks);
  }
});
```

To meet our requirements, we introduced external state through a global variable `clicks` that counts clicks made so far. We also need to check for two different conditions and use nested conditional blocks. And when we're done, we have to tidy up and unregister the event to not leak memory.

---

**Side Effects and External State**

If an action has impact outside of the scope where it happens, we call this a *side effect*. Changing a variable external to our function, printing to the console, or updating a value in a database are examples of side effects.

For example, changing the value of a variable that exists *inside* our function is safe. But if that variable is *outside* the scope of our function then other functions can change its value. That means our function is not in control anymore and it can't assume that external variable contains the value we expect. We'd need to track it and add checks to ensure its value is what we expect. At that point we'd be adding code that is not relevant to our program, making it more complex and error prone.

Although side effects are necessary to build any interesting program, we should strive for having as few as possible in our code. That's especially important in reactive programs, where we have many moving pieces that change over time. Throughout this book, we'll pursue an approach that avoids external state and side effects. In fact, in Chapter 3, *Building Concurrent Programs*, we'll build an entire video game with no side effects.

---

We managed to meet our easy requirements, but ended up with pretty complicated code for such a simple goal. It's difficult code to maintain and not obvious for a developer who looks at it for the first time. More importantly, we made it prone to develop subtle bugs in the future because we need to keep state.

All we want in that situation is to query the “database” of clicks. If we were dealing with a relational database, we’d use the declarative language SQL:

```
SELECT x, y FROM clicks LIMIT 10
```

What if we treated that stream of `click` events as a data source that can be queried and transformed? After all, it’s no different from a database, one that emits values in real time. All we need is a data type that abstracts the concept for us.

Enter RxJS and its Observable data type:

```
Rx.Observable.fromEvent(document, 'click')
  .filter(function(c) { return c.clientX >
window.innerWidth / 2; })
  .take(10)
  .subscribe(function(c) { console.log(c.clientX,
c.clientY) })
```

This code does the same as the code, and it reads like this:

> *Create an Observable of `click` events and filter out the clicks that happen on the left side of the screen. Then print the coordinates of only the first 10 clicks to the console as they happen.*

Notice how the code is easy to read even if you're not familiar with it. Also, there's no need to create external variables to keep state, which makes the code self-contained and makes it harder to introduce bugs. There's no need to clean up after yourself either, so no chance of introducing memory leaks by forgetting about unregistering event handlers.

In the preceding code we created an Observable from a DOM event. An Observable provides us with a sequence or stream of events that we can manipulate as a whole instead of a single isolated event each time. Dealing with sequences gives us enormous power; we can merge, transform, or pass around Observables easily. We've turned events we can't get a handle on into a tangible data structure that's as easy to use as an array, but much more flexible.

In the next section we'll see the principles that make Observables such a great tool.

# Of Observers and Iterators

To understand where Observables come from we need to look at their foundations: the Observer and Iterator software patterns. In this section we'll take a quick look at them, and then we'll see how Observables combine concepts of both in a simple but powerful way.

## The Observer Pattern

For a software developer, it's hard to hear about Observables and not think of the venerable Observer pattern. In it we have an object called *Producer* that keeps an internal list of *Listeners* subscribed to it. Listeners are notified—by calling their `update` method—whenever the state of the Producer changes. (In most explanations of the Observer pattern, this entity is called *Subject*, but to avoid confusion with RxJS's own *Subject* type, we call it *Producer*.)

It's easy to implement a rudimentary version of the pattern in a few lines:

ch1/observer_pattern.js

```
function Producer() {
  this.listeners = [];
}
```

```
Producer.prototype.add = function(listener) {
  this.listeners.push(listener);
};

Producer.prototype.remove = function(listener) {
  var index = this.listeners.indexOf(listener);
  this.listeners.splice(index, 1);
};

Producer.prototype.notify = function(message) {
  this.listeners.forEach(function(listener) {
    listener.update(message);
  });
};
```

The Producer object keeps a dynamic list of Listeners in the instance's `listeners` array that will all be updated whenever the Producer calls its `notify` method. In the following code we create two objects that listen to `notifier`, an instance of `Producer`:

ch1/observer_pattern.js

```
// Any object with an 'update' method would work.
var listener1 = {
  update: function(message) {
```

```
    console.log('Listener 1 received:', message);
  }
};

var listener2 = {
  update: function(message) {
    console.log('Listener 2 received:', message);
  }
};

var notifier = new Producer();
notifier.add(listener1);
notifier.add(listener2);
notifier.notify('Hello there!');
```

When we run the program

```
<= Listener 1 received: Hello there!
   Listener 2 received: Hello there!
```

`listener1` and `listener2` are notified whenever the Producer `notifier` updates its internal state, without us having to check for it.

Our implementation is simple, but it illustrates how the Observer pattern allows decoupling between the events and the listener objects that react to them.

## The Iterator Pattern

The other piece in the Observable puzzle comes from the Iterator pattern. An Iterator is an object that provides a consumer with an easy way to traverse its contents, hiding the implementation from the consumer.

The Iterator interface is simple. It requires only two methods: `next()` to get the next item in the sequence, and `hasNext()` to check if there are items left in the sequence.

Here's how we'd write an iterator that operates on an array of numbers and yields only elements that are multiples of the `divisor` parameter:

ch1/iterator.js

```
function iterateOnMultiples(arr, divisor) {
  this.cursor = 0;
  this.array = arr;
  this.divisor = divisor || 1;
}

iterateOnMultiples.prototype.next = function() {
  while (this.cursor < this.array.length) {
```

```
    var value = this.array[this.cursor++];
    if (value % this.divisor === 0) {
      return value;
    }
  }
};

iterateOnMultiples.prototype.hasNext = function()
{
  var cur = this.cursor;
  while (cur < this.array.length) {
    if (this.array[cur++] % this.divisor === 0) {
      return true;
    }
  }
  return false;
};
```

We can use this iterator like this:

ch1/iterator.js

```
var consumer = new iterateOnMultiples([1, 2, 3, 4,
5, 6, 7, 8, 9, 10], 3);

console.log(consumer.next(), consumer.hasNext());
```

```
// 3 true
console.log(consumer.next(), consumer.hasNext());
// 6 true
console.log(consumer.next(), consumer.hasNext());
// 9 false
```

Iterators are great to encapsulate traversing logic for any kind of data structure. As we saw in the preceding example, iterators get interesting when made generic to handle different types of data, or when they can be configured in runtime, like we did in our example with the `divisor` parameter.

## The Rx Pattern and the Observable

While the Observer and the Iterator patterns are powerful in their own right, the combination of both is even better. We call this the Rx pattern, named after the Reactive Extensions libraries.[10] We'll be using this pattern for the rest of the book.

The *Observable sequence*, or simply *Observable* is central to the Rx pattern. An Observable emits its values in order—like an iterator—but instead of its consumers requesting the next value, the Observable "pushes" values to consumers as they become available. It has a similar role to the Producer's in the Observer pattern: emitting values and pushing them to its listeners.

**Pulling vs. Pushing**

In programming, *push-based behavior* means that the server component of an application sends updates to its clients instead of the clients having to poll the server for these updates. It's like the saying, "Don't call us; we'll call you."

RxJS is push-based, so the source of events (the Observable) will push new values to the consumer (the Observer), without the consumer requesting the next value.

Put more simply, an Observable is a sequence whose items become available over time. The consumers of Observables, Observers, are the equivalent of *listeners* in the Observer pattern. When an Observer is subscribed to an Observable, it will receive the values in the sequence as they become available, without having to request them.

So far it seems there's not much of a difference from the traditional Observer pattern. But actually there are two essential differences:

- An Observable doesn't start streaming items until it has at least one Observer subscribed to it.
- Like iterators, an Observable can signal when the sequence is completed.

Using Observables, we can declare how to react to the sequence of elements they emit, instead of reacting to individual items. We can efficiently copy, transform, and query the sequence, and these operations will apply to all the elements of the sequence.

## Creating Observables

There are several ways to create Observables, the `create` operator being the most obvious one. The `create` operator in the `Rx.Observable` object takes a callback that accepts an Observer as a parameter. That function defines how the Observable will emit values. Here's how we create a simple Observable:

```
var observable = Rx.Observable.create(function
(observer) {
  observer.onNext('Simon');
  observer.onNext('Jen');
  observer.onNext('Sergi');
  observer.onCompleted(); // We are done
});
```

When we subscribe to this Observable, it emits three strings by calling the `onNext` method on its listeners. It then calls `onCompleted` to signal that the sequence is finished. But how exactly do we subscribe to an Observable? We use Observers.

### First Contact with Observers

*Observers* listen to Observables. Whenever an event happens in an Observable, it calls the related method in all of its Observers.

Observers have three methods: `onNext`, `onCompleted`, and `onError`:

*onNext*
The equivalent of `Update` in the Observer pattern. It is called when the Observable emits a new value. Notice how the name reflects the fact that we're subscribed to sequences, not only to discrete values.

*onCompleted*
Signals that there is no more data available. After `onCompleted` is called, further calls to `onNext` will have no effect.

*onError*
Called when an error occurs in the Observable. After it is called, further calls to `onNext` will have no effect.

Here's how we create a basic Observer:

```
var observer = Rx.Observer.create(
  function onNext(x) { console.log('Next: ' + x);
},
  function onError(err) { console.log('Error: ' +
err); },
  function onCompleted() { console.log('Completed'
); }
);
```

The `create` method in the `Rx.Observer` object takes functions for the `onNext`, `onCompleted`, and `onError` cases and returns an Observer instance. These three functions are optional, and you can decide which ones to include. For example, if we are subscribing to an infinite sequence such as clicks on a button (the user could keep clicking forever), the `onCompleted` handler will never be called. If we're confident that the sequence can't error (for example, by making an Observable from an array of numbers), we don't need the `onError` method.

## Making Ajax Calls with an Observable

We haven't done anything really useful with Observables yet. How about creating an Observable that retrieves remote content? To do this, we'll wrap the XMLHttpRequest object using `Rx.Observable.create`:

```
function get(url) {
  return Rx.Observable.create(function(observer) {
    // Make a traditional Ajax request
    var req = new XMLHttpRequest();
    req.open('GET', url);

    req.onload = function() {
      if (req.status == 200) {
```

```
        // If the status is 200, meaning there
have been no problems,
        // Yield the result to listeners and
complete the sequence
        observer.onNext(req.response);
        observer.onCompleted();
      }
      else {
        // Otherwise, signal to listeners that
there has been an error
        observer.onError(new
Error(req.statusText));
      }
    };

    req.onerror = function() {
      observer.onError(new Error("Unknown Error"
));
    };

    req.send();
  });
}
```

```
// Create an Ajax Observable
var test = get('/api/contents.json');
```

In the preceding code, the `get` function uses `create` to wrap `XMLHttpRequest`. If the HTTP *GET* request is successful, we emit its contents and complete the sequence (our Observable will only ever emit one result). Otherwise, we emit an error. On the last line we call the function with a particular URL to retrieve. This will create the Observable, but it won't make any request yet. This is important: Observables don't do anything until at least one Observer subscribes to them. So let's take care of that:

```
// Subscribe an Observer to it
test.subscribe(
  function onNext(x) { console.log('Result: ' + x); },
  function onError(err) { console.log('Error: ' + err); },
  function onCompleted() { console.log('Completed'); }
);
```

The first thing to notice is that we're not explicitly creating an Observer like we did in the code. Most of the time we'll use this shorter version, in which we call the `subscribe` operator in the

Observable with the three functions for the Observer cases: `onNext`, `onCompleted`, and `onError`.

`subscribe` then sets everything in motion. Before the subscription, we had merely declared how the Observable and Observer duo will interact. It is only when we call `subscribe` that the gears start turning.

## There Is (Almost) Always an Operator

In RxJS, methods that transform or query sequences are called *operators*. Operators are found in the static `Rx.Observable` object and in Observable instances. In our example, `create` is one such operator.

`create` is a good choice when we have to create a very specific Observable, but RxJS provides plenty of other operators that make it easy to create Observables for common sources.

Let's look again at our previous example. For such a common operation as an Ajax request there is often an operator ready for us to use. In this case, the RxJS DOM library provides several ways to create Observables from DOM-related sources.[11] Since we're doing a GET request, we can use `Rx.DOM.get`, and our code then becomes this:

```
Rx.DOM.get('/api/contents.json').subscribe(
  function onNext(data) {
console.log(data.response); },
  function onError(err) { console.error(err); }
);
```

This bit of code does exactly the same as our previous one, but we don't have to create a wrapper around `XMLHttpRequest`; it's already there. Notice also that this time we omitted the `onCompleted` callback, because we don't plan to react when the Observable is done. We know that it will yield only one result, and we are already using it in the `onNext` callback.

We'll use plenty of convenient operators like this throughout this book. RxJS comes with "batteries included." In fact, that is one of its main strengths.

**One Data Type to Rule Them All**

In an RxJS program, we should strive to have all data in Observables, not just data that comes from asynchronous sources. Doing that makes it easy to combine data from different origins, like an existing array with the result of a callback, or the result of an XMLHttpRequest with some event triggered by the user.

For example, if we have an array whose items need to be used in combination with data from somewhere else, it's better to make this array into an Observable. (Obviously, if the array is just an intermediate variable that doesn't need to be combined, there is no need to do that.) Throughout the book, you'll learn in which situations it's worth transforming data types into Observables.

---

RxJS provides operators to create Observables from most JavaScript data types. Let's go over the most common ones, which you'll be using all the time: arrays, events, and callbacks.

## Creating Observables from Arrays

We can make any array-like or iterable object into an Observable by using the versatile `from` operator. `from` takes an array as a parameter and returns an Observable that emits each of its elements.

```
Rx.Observable
  .from(['Adrià', 'Jen', 'Sergi'])
  .subscribe(
    function(x) { console.log('Next: ' + x); },
    function(err) { console.log('Error:', err); },
    function() { console.log('Completed'); }
  );
```

`from` is, along with `fromEvent`, one of the most convenient and frequently used operators in RxJS code.

## Creating Observables from JavaScript Events

When we transform an event into an Observable, it becomes a first-class value that can be combined and passed around. For example, here's an Observable that emits the coordinates of the mouse pointer whenever it moves:

```
var allMoves = Rx.Observable.fromEvent(document,
'mousemove')
allMoves.subscribe(function(e) {
  console.log(e.clientX, e.clientY);
});
```

Transforming an event into an Observable unleashes the event from its natural constraints. More importantly, we can create new Observables based on the original Observables. These new ones are independent and can be used for different tasks:

```
var movesOnTheRight = allMoves.filter(function(e)
{
  return e.clientX > window.innerWidth / 2;
});

var movesOnTheLeft = allMoves.filter(function(e) {
  return e.clientX < window.innerWidth / 2;
```

```
});

movesOnTheRight.subscribe(function(e) {
  console.log('Mouse is on the right:',
e.clientX);
});

movesOnTheLeft.subscribe(function(e) {
  console.log('Mouse is on the left:', e.clientX);
});
```

In the preceding code, we create two Observables from the original `allMoves` one. These specialized Observables contain only filtered items from the original one: `movesOnTheRight` contains mouse events that happen on the right side of the screen, and `movesOnTheLeft` contains mouse events that happen on the left side. Neither of them modify the original Observable: `allMoves` will keep emitting all mouse moves. Observables are immutable, and every operator applied to them creates a new Observable.

## Creating Observables from Callback Functions

Chances are you will have to interact with callback-based code if you use third-party JavaScript libraries. We can transform our callbacks into Observables using two functions, `fromCallback` and `fromNodeCallback`. Node.js follows the convention of always invoking the callback function with an error argument first to signal to the callback function that there was a problem. We then use `fromNodeCallback` to create Observables specifically from Node.js-style callbacks:

```
var Rx = require('rx'); // Load RxJS
var fs = require('fs'); // Load Node.js Filesystem
module

// Create an Observable from the readdir method
var readdir =
Rx.Observable.fromNodeCallback(fs.readdir);

// Send a delayed message
var source = readdir('/Users/sergi');

var subscription = source.subscribe(
  function(res) { console.log('List of
directories: ' + res); },
  function(err) { console.log('Error: ' + err); },
  function() { console.log('Done!'); });
```

In the preceding code, we make an Observable `readdir` out of Node.js's `fs.readdir` method. `fs.readdir` accepts a directory path and a callback function `delayedMsg`, which calls once the directory contents are retrieved.

We use `readdir` with the same arguments we'd pass to the original `fs.readdir`, minus the callback function. This returns an Observable that will properly use `onNext`, `onError`, and `onCompleted` when we subscribe an Observer to it.

## Wrapping Up

In this chapter we explored the reactive approach to programming and saw how RxJS can solve the problems of other methods, such as callbacks or promises, through Observables. Now you understand why Observables are powerful, and you know how to create them. Armed with this foundation, we can now go on to create more interesting reactive programs. The next chapter shows you how to create and compose sequence-based programs that provide a more "Observable" approach to some common scenarios in web development.

---

FOOTNOTES

[9] http://queue.acm.org/detail.cfm?id=2169076

[10] https://rx.codeplex.com/

[11] https://github.com/Reactive-Extensions/RxJS-DOM

Chapter 2

# Deep in the Sequence

I have childhood memories of playing a puzzle video game in which you had to guide a falling stream of water across the screen using all kinds of tricks. You could split the stream, merge them back later, or use a tilted plank of wood to change their direction. You had to be creative to make the water reach its final goal.

I find a lot of similarities between that game and working with Observable sequences. Observables are just streams of events that we can transform, combine, and query. It doesn't matter whether we're dealing with simple Ajax callbacks or processing gigabytes of data in Node.js. The way we declare our flows is the same. Once we think in streams, the complexity of our programs goes down.

In this chapter we focus on how to effectively use sequences in our programs. So far we've covered how to create Observables and do simple operations with them. To unleash their power, we have to know to translate our program inputs and outputs into sequences that carry our program flow.

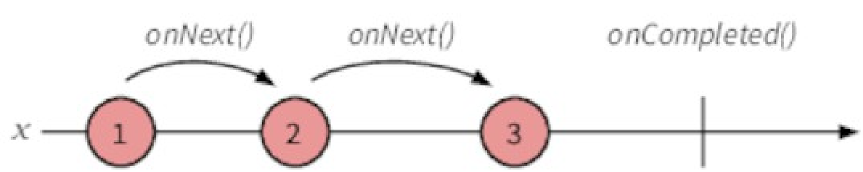
Before we get our hands dirty, we’ll meet some of the basic operators that will help us start to manipulate sequences. Next we’ll implement a real application that shows earthquakes happening in (almost) real time. Let’s get to it!

## Visualizing Observables

You're about to learn some of the operators that we'll use most frequently in our RxJS programs. Talking about what operators do to a sequence can feel abstract. To help developers understand operators in an easy way, we'll use a standard visual representation for sequences, called *marble diagrams*. They visually represent asynchronous data streams, and you will find them in every resource for RxJS.

Let's take the `range` operator, which returns an Observable that emits integers within a specified range: `Rx.Observable.range(1, 3);`

The marble diagram for it looks like this:




The long arrow represents the Observable, and the x-axis represents time. Each circle represents a value the Observable emits by internally calling `onNext()`. After generating the third value, `range` calls `onCompleted`, represented in the diagram by a vertical line.

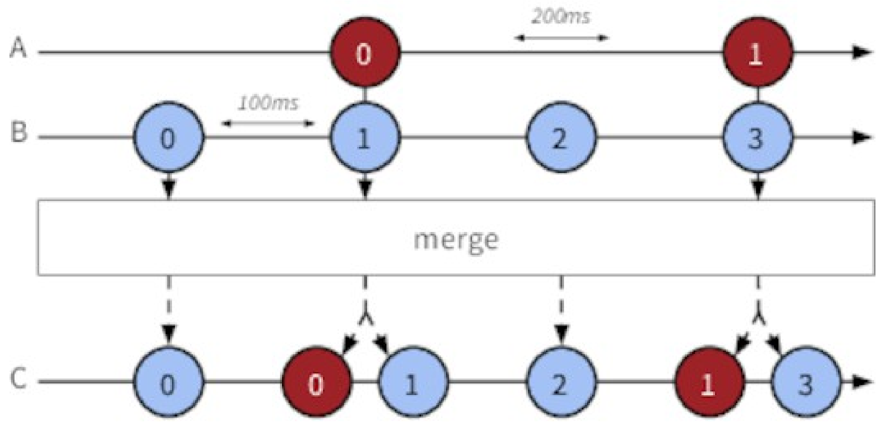
Let's look at an example that involves several Observables. The `merge` operator takes two different Observables and returns a new one with the merged values. The `interval` operator returns an Observable that yields incremental numbers at a given interval of time, expressed in milliseconds.

In the following code we'll merge two different Observables that use `interval` to produce values at different intervals:

```
var a = Rx.Observable.interval(200).map(function
(i) {
  return 'A' + i;
});
var b = Rx.Observable.interval(100).map(function
(i) {
  return 'B' + i;
});

Rx.Observable.merge(a, b).subscribe(function(x) {
  console.log(x);
});
```

```
<= B0, A0, B1, B2, A1, B3, B4...
```

The marble diagram for the merge operator looks like this:




Here, the dotted arrows along the y-axis point to the final result of the transformation applied to each element in sequences A and B. The resulting Observable is represented by C, which contains the merged elements of A and B. If elements of different Observables are emitted at the same time, the order of these elements in the merged sequence is random.

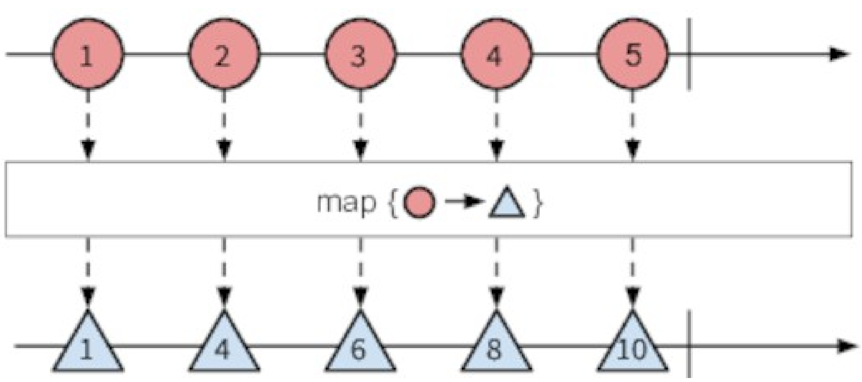
# Basic Sequence Operators

Among the dozens of operators that transform Observables in RxJS, the most used are those that any language with decent collection-processing abilities also have: `map`, `filter`, and `reduce`. In JavaScript, you can find these operators in Array instances.

RxJS follows JavaScript conventions, so you'll find that the syntax for the following operators is almost the same as for array operators. In fact, we'll show the implementation using both arrays and Observables to show how similar the two APIs are.

## Map

`map` is the sequence transformation operator most used. It takes an Observable and a function and applies that function to each of the values in the source Observable. It returns a new Observable with the transformed values.



**JS Arrays**
**JS Arrays**

```js
var src = [1, 2, 3, 4,
5];
var upper = src.map(
function(name) {
  return name * 2;
});

upper.forEach(logValue);
```

**Observables**
**Observables**

```js
var src =
Rx.Observable.range(1
var upper = src.map(
function(name) {
  return name * 2;
});

upper.subscribe(logVa
```

In both cases, `src` doesn't mutate.

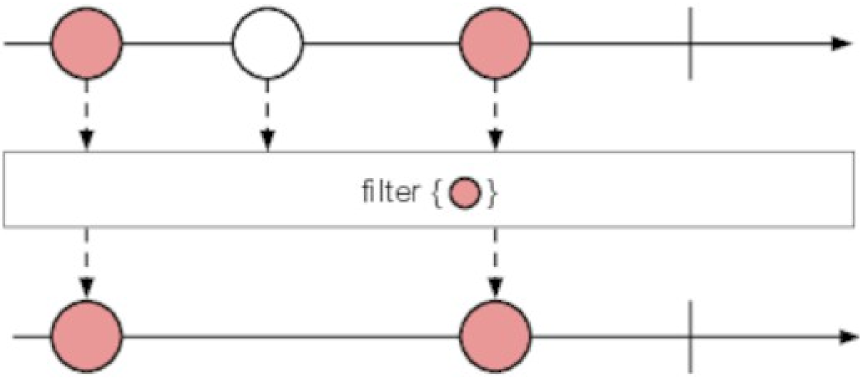
This code, and code that follows, uses this definition of `logValue`:

```js
var logValue = function(val) { console.log(val) };
```

It could be that the function we pass to `map` does some asynchronous computation to transform the value. In that case, `map` would not work as expected. For these cases, it would be better to use *flatMap*.

## Filter

`filter` takes an Observable and a function and tests each element in the Observable using that function. It returns an Observable sequence of all the elements for which the function returned `true`.




| JS Arrays | Observables |
|---|---|

```
var isEven = (function(val) { return val % 2 ===
});
```

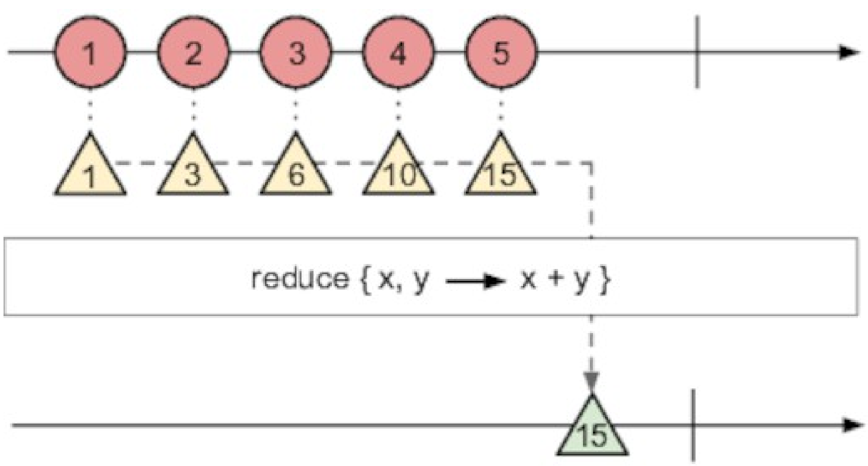
```
var src = [1, 2, 3, 4,
5];
var even =
src.filter(isEven);
```

```
var src =
Rx.Observable.range(1,
5);
var even =
```

| JS Arrays | Observables |
| --- | --- |
| `even.forEach(logValue);` | `src.filter(isEven);` `even.subscribe(logValu` |

## Reduce

`reduce` (also known as *fold*) takes an Observable and returns a new one that always contains a single item, which is the result of applying a function over each element. That function receives the current element and the result of the function's previous invocation.




| JS Arrays | Observables |
| --- | --- |

| JS Arrays | Observables |
|---|---|
| `var src = [1, 2, 3, 4, 5];` | `var src = Rx.Observable.range(1, 5);` |
| `var sum = src.reduce(function (a, b) {` | `var sum = src.reduce( function(acc, x) {` |
| `    return a + b;` | `  return acc + x;` |
| `});` | `});` |
| | |
| `console.log(sum);` | `sum.subscribe(logValue);` |

**reduce** is a powerful operator to manipulate a sequence. It is, in fact, the base implementation for a whole subset of methods called *aggregate operators*.

### Aggregate Operators

Aggregate operators process a sequence and return a single value. For example, **Rx.Observable.first** takes an Observable and an optional predicate function and returns the first element that satisfies the condition in the predicate.

Calculating the average value of a sequence is an aggregate operation as well. RxJS provides the instance operator **average**, but for the sake of this section, we want to see how to implement it using **reduce**. Every aggregate operator can be implemented by using only **reduce**:

sequences/marble.js

```
var avg = Rx.Observable.range(0, 5)
  .reduce(function(prev, cur) {
    return {
      sum: prev.sum + cur,
      count: prev.count + 1
    };
  }, { sum: 0, count: 0 })
  .map(function(o) {
    return o.sum / o.count;
  });

var subscription = avg.subscribe(function(x) {
  console.log('Average is: ', x);
});
```

```
<= Average is: 2
```

In this code we use `reduce` to add each new value to the previous one. Because reduce doesn't provide us with the total number of elements in the sequence, we need to keep count of them. We call `reduce` with an initial value consisting of an object with two fields, `sum` and `count`, where we'll store the sum and total count of elements so far. Every new element will return the same object with updated values.

When the sequence ends, `reduce` will call `onNext` with the object containing the final sum and the final count. At that point we use `map` to return the result of dividing the sum by the count.

**Joe asks:**

### Can We Aggregate Infinite Observables?

Imagine we're writing a program that gives users their average speed while they walk. Even if the user hasn't finished walking, we need to be able to make a calculation using the speed values we know so far. We want to log the average of an infinite sequence in real time. The problem is that if the sequence never ends, an aggregate operator like `reduce` will never call its Observers' `onNext` operator.

Luckily for us, the RxJS team has thought of this kind of scenario and provided us with the `scan` operator, which acts like `reduce` but emits each intermediate result:

```
var avg = Rx.Observable.interval(1000)
  .scan(function (prev, cur) {
    return {
      sum: prev.sum + cur,
      count: prev.count + 1
    };
```

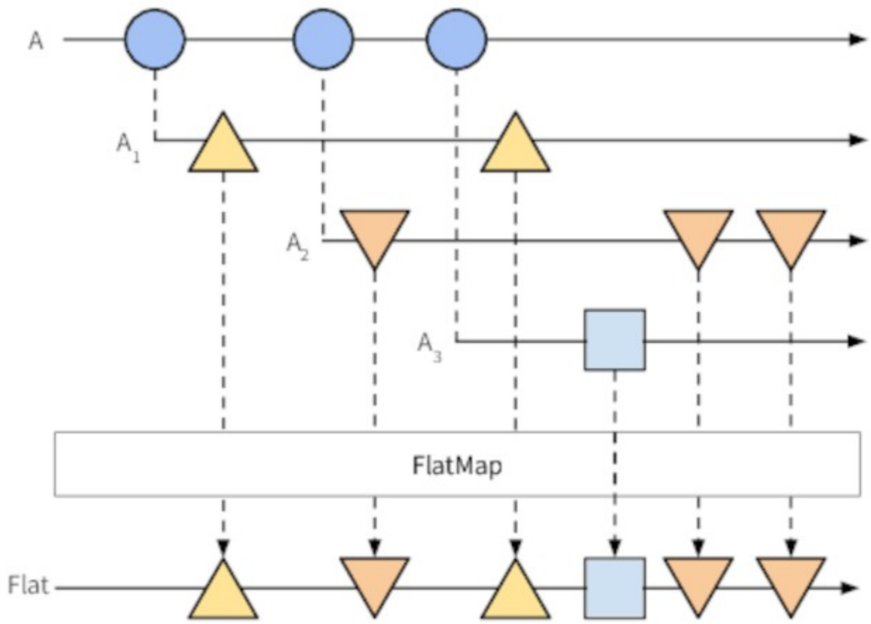
```
  }, { sum: 0, count: 0 })
  .map(function(o) {
    return o.sum / o.count;
  });

var subscription = avg.subscribe( function (x) {
  console.log(x);
});
```

This way, we can aggregate sequences that take a long time to complete or that are infinite. In the preceding example, we generated an incremental integer every second and substituted the previous **reduce** call for **scan**. We now get the average of the values generated so far, every second.

## flatMap

What can you do if you have an Observable whose results are more Observables? Most of the time you'd want to unify items in those nested Observables in a single sequence. That's exactly what **flatMap** does.

The **flatMap** operator takes an Observable A whose elements are also Observables, and returns an Observable with the flattened values of A's child Observables. Let's visualize it with a graph:




We can see that each of the elements in A ($A_1$, $A_2$, $A_3$) are also Observable sequences. Once we apply `flatMap` to A with a transformation function, we get an Observable with all the elements in the different children of A.

`flatMap` is a powerful operator, but it can be harder to understand than the operators we've seen so far. Think of it as a `concatAll()` for Observables.

`concatAll` is a function that takes an array of arrays and returns a "flattened" single array containing the values of all the sub-arrays, instead of the sub-arrays themselves. We can use `reduce` to make such a function:

```
function concatAll(source) {
  return source.reduce(function(a, b) {
```

```
    return a.concat(b);
  });
}
```

We would use it like this:

```
concatAll([[0, 1, 2], [3, 4, 5], [6, 7, 8]]);
// [0, 1, 2, 3, 4, 5, 6, 7, 8]
```

`flatMap` does the same thing, but it flattens Observables instead of arrays. It takes a source Observable and a function that returns a new Observable and applies that function to each element in the source Observable, like `map` does. If the process stopped here, we would end up getting an Observable that emits Observables. But `flatMap` emits to the main sequence the values emitted by each new Observable, "flattening" all Observables into one, the main sequence. In the end, we obtain a single Observable.

# Canceling Sequences

In RxJS we can cancel a running Observable. This is an advantage over other asynchronous forms of communication, such as callbacks and promises, which can't be directly canceled once they're called (some promise implementations support cancellation, though).

There are two main ways we can cancel an Observable: *implicitly* and *explicitly*.

## Explicit Cancellation: The Disposable

Observables themselves don't have a method to get canceled. Instead, whenever we subscribe to an Observable we get a `Disposable` object that represents that particular subscription. We can then call the method `dispose` in that object, and that subscription will stop receiving notifications from the Observable.

In the following example, we subscribe two Observers to the `counter` Observable, which emits an increasing integer every second. After two seconds, we cancel the second subscription and we can see that its output stops but the first subscriber's output keeps going:

sequences/disposable.js

```
var counter = Rx.Observable.interval(1000);

var subscription1 = counter.subscribe(function(i)
{
  console.log('Subscription 1:', i);
});

var subscription2 = counter.subscribe(function(i)
{
  console.log('Subscription 2:', i);
});

setTimeout(function() {
  console.log('Canceling subscription2!');
  subscription2.dispose();
}, 2000);
```

```
<= Subscription 1: 0
   Subscription 2: 0
   Subscription 1: 1
   Subscription 2: 1
   Canceling subscription2!
   Subscription 1: 2
   Subscription 1: 3
```

```
Subscription 1: 4
...
```

## Implicit Cancellation: By Operator

Most of the time, operators will automatically cancel subscriptions for you. Operators such as `range` or `take` will cancel the subscription when the sequence finishes or when the operator conditions are met. More advanced operators such as `withLatestFrom` or `flatMapLatest` will internally create and destroy subscriptions as needed, since they handle several Observables in motion. In short, you should not worry about canceling most subscriptions yourself.

## Observables That Wrap External APIs

When you're using Observables that wrap external APIs that don't provide cancellation, the Observable will still stop emitting notifications when canceled, but the underlying API will not necessarily be canceled. For example, if you're using an Observable that wraps a promise, the Observable will stop emitting when canceled, but the underlying promise will not be canceled.

In the following code, we attempt to cancel a subscription to an Observable that wraps a promise `p`, and at the same time we set an action in the traditional way for when the promise is resolved. The promise should resolve in five seconds, but we cancel the subscription immediately after creating it:

```
var p = new Promise(function(resolve, reject) {
  window.setTimeout(resolve, 5000);
});

p.then(function() {
  console.log('Potential side effect!');
});

var subscription =
Rx.Observable.fromPromise(p).subscribe(function
(msg) {
  console.log('Observable resolved!');
});
subscription.dispose();
```

After 5 seconds, we see:

```
<= Potential side effect!
```

If we cancel the subscription to the Observable it effectively stops it from receiving the notification. But the promise's `then` method still runs, showing that canceling the Observable doesn't cancel the underlying promise.

It's important to know the details of external APIs that we use in Observables. You might think you've canceled a sequence, but the underlying API keeps running and causes some side effects in your program. These errors can be really hard to catch.

# Handling Errors

We can't use the conventional try/catch mechanism in callbacks because it is synchronous. It would run before any asynchronous code, and wouldn't be able to catch any errors.

With callbacks, this was solved by passing the error (if any) as a parameter to the callback function. That works, but it makes the code pretty fragile.

Let's see how to catch errors inside Observables.

## The `onError` Handler

Remember when we talked about the three methods we can call on an Observer, in *First Contact with Observers*? We're familiar with `onNext` and `onCompleted`, but we haven't yet used `onError`; it is the key to effectively handling errors in Observable sequences.

To see how it works, we'll write a simple function to take an array of JSON strings and return an Observable that emits the objects parsed from those strings, using `JSON.parse`:

```
function getJSON(arr) {
  return Rx.Observable.from(arr).map(function(str)
{
```

```
    var parsedJSON = JSON.parse(str);
    return parsedJSON;
  });
}
```

We'll pass an array with three JSON strings to `getJSON`, in which the second string in the array contains a syntax error, so `JSON.parse` won't be able to parse it. Then we'll subscribe to the result, providing handlers for `onNext` and `onError`:

```
getJSON([
  '{"1": 1, "2": 2}',
  '{"success: true}', // Invalid JSON string
  '{"enabled": true}'
]).subscribe(
  function(json) {
    console.log('Parsed JSON: ', json);
  },
  function(err) {
    console.log(err.message);
  }
);
```

```
<= Parsed JSON:  { 1: 1, 2: 2 }
   JSON.parse: unterminated string at line 1 column
```

```
  8 of the JSON data
```

The Observable emits the parsed JSON for the first result but throws an exception when trying to parse the second. The `onError` handler catches this and prints it out. The default behavior is that whenever an error happens, the Observable stops emitting items, and `onCompleted` is not called.

## Catching Errors

So far we've seen how to detect that an error has happened and do something with that information, but we haven't been able to react to it and continue with whatever we were doing. Observable instances have the `catch` operator, which allows us to react to an error in the Observable and continue with another Observable.

`catch` takes either an Observable or a function that receives the error as a parameter and returns another Observable. In our scenario, we want the Observable to emit a JSON object containing an error property if there were errors in the original Observable:

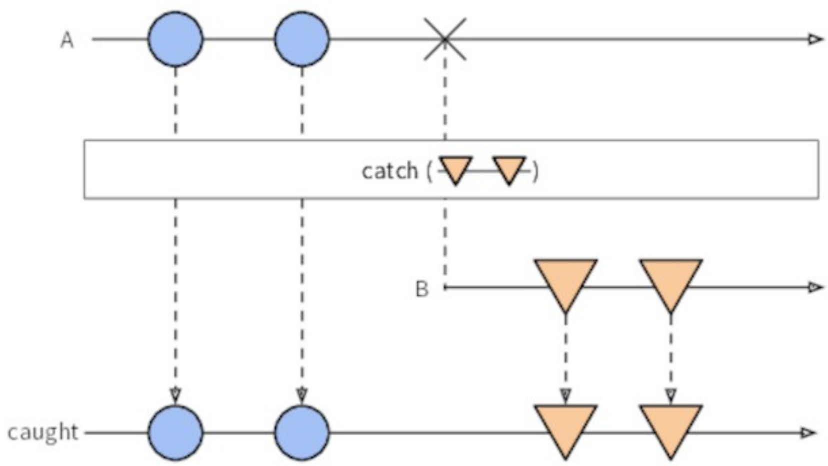
```
function getJSON(arr) {
  return Rx.Observable.from(arr).map(function(str)
{
```

```
    var parsedJSON = JSON.parse(str);
    return parsedJSON;
  });
}

var caught = getJSON(['{"1": 1, "2": 2}', '{"1:
1}']).catch(
  Rx.Observable.return({
    error: 'There was an error parsing JSON'
  })
);

caught.subscribe(
  function(json) {
    console.log('Parsed JSON: ', json);
  },
  // Because we catch errors now, `onError` will
not be executed
  function(e) {
    console.log('ERROR', e.message);
  }
);
```

In the preceding code, we create a new Observable, `caught`, that uses the `catch` operator to catch errors in the original Observable. If there's an error it will continue the sequence with an Observable that emits only one item, with an `error` property describing the error. This is the output:

```
<= Parsed JSON: Object { 1: 1, 2: 2 }
   Parsed JSON: Object { error: "There was an error
   parsing JSON" }
```

And here's the marble diagram for the `catch` operator:




Notice the *X* to indicate that the sequence experienced an error. The different shape of the Observable values—triangles in this case—means that they are values coming from another Observable. Here, that's the Observable we return in case of an error.

`catch` is useful for reacting to errors in a sequence, and it behaves much like the traditional `try/catch` block. In some cases, though, it would be very convenient to ignore an error that happens with an item in the Observable and let the sequence continue. In those cases, we can use the `retry` operator.

## Retrying Sequences

Sometimes errors just happen and there's not much we can do about it. For example, there could be a timeout requesting remote data because the user has a spotty Internet connection, or a remote server we're querying could crash. In these cases it would be great if we could keep requesting the data we need until we succeed. The `retry` operator does exactly that:

sequences/error_handling.js

```
// This will try to retrieve the remote URL up to
5 times.
Rx.DOM.get('/products').retry(5)
  .subscribe(
    function(xhr) { console.log(xhr); },
    function(err) { console.error('ERROR: ', err);
}
  );
```

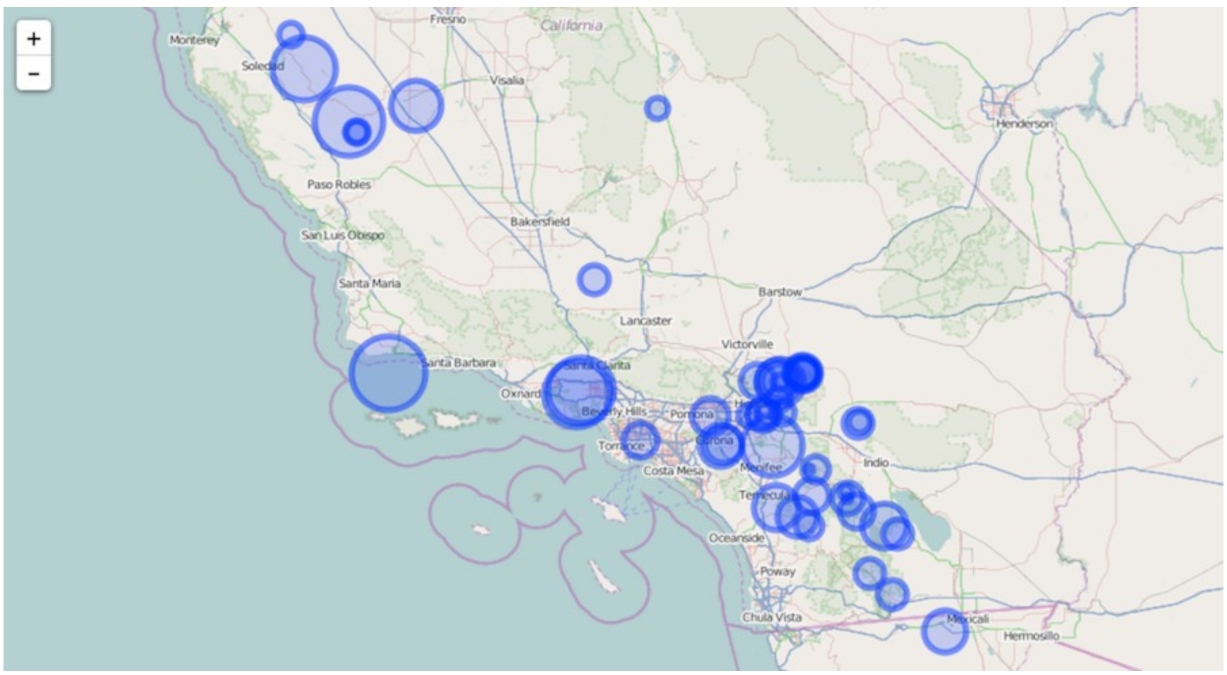
In the preceding code, we create a function that returns an Observable that retrieves contents from a URL using `XMLHttpRequest`. Because our connection might be a bit spotty, we add `retry(5)` before subscribing to it, ensuring that in case of an error, it will try up to five times before giving up and showing an error.

There are two important things to know when using `retry`. First, if we don't pass any parameters, it will retry indefinitely until the sequence is finished with no errors. This is dangerous for performance if the Observable keeps producing errors. If we're using synchronous Observables, it would have the same effect as an infinite loop.

Second, `retry` will always retry the whole Observable sequence again, even if some of the items didn't error. This is important in case you're causing any side effects when processing items, since they will be reapplied with every retry.

## Making a Real-Time Earthquake Visualizer

Using the concepts that we've covered so far in this chapter, we'll build a web application that uses RxJS to show us where earthquakes are happening in real time. We'll start by building a functional but naive reactive implementation, and we'll improve it as we go. The final result will look like this:




### Preparing Our Environment

We'll use the USGS (U.S. Geological Survey) earthquake database,[12] which offers a real-time earthquake dataset in several formats. We will get our data from the weekly dataset in JSONP format.

We’ll also use Leaflet, a JavaScript library, to render interactive maps.[13] Let’s see how our `index.html` looks, and go over the important points:

examples_earthquake/index.html

```
<!DOCTYPE html>
<html lang="en-us">
  <head>
    <meta charset="utf-8">

    <link rel="stylesheet"
    href="http://cdn.leafletjs.com/leaflet-
0.7.3/leaflet.css" />
    <script src="http://cdn.leafletjs.com/leaflet-
0.7.3/leaflet.js"></script>
    <script src="../rx.all-4.0.0.js"></script>
    <script src="../rx.dom-7.0.3.js"></script>

    <title>Earthquake map</title>
    <style type="text/css">

      html, body {
        margin: 0;
        padding: 0;
        height: 100%;
      }
```

```
      ,

      #map { height: 100%; }
    </style>
  </head>

  <body>
①   <div id="map"></div>     <!---->
    <script>
      var QUAKE_URL =
'http://earthquake.usgs.gov/earthquakes/feed/v1.0/
        'summary/all_day.geojsonp';

②     function loadJSONP(url) {
        var script = document.createElement('scri
);
        script.src = url;

        var head = document.getElementsByTagName(
'head')[0];

        head.appendChild(script);
      }

③     var map = L.map('map').setView([33.858631,
-118.279602], 7);
```

```
118.279602], 7);
④       L.tileLayer(
'http://{s}.tile.osm.org/{z}/{x}/{y}.png'
).addTo(map);

     </script>
⑤    <script src="code.js"></script> <!-- -->
   </body>
</html>
```

① This is the placeholder `div` element that Leaflet will use to render our map.

② That's a helper function we use to load JSONP content.

③ We initialize the Leaflet map by setting the coordinates to the center of Los Angeles (plenty of earthquakes there!) with a reasonable zoom level.

④ We tell Leaflet to set the default tile set for our map. The tile set is just a "theme" for our map.

⑤ Finally, we load our code after the DOM and the map have been initialized.

## Retrieving Earthquake Locations

Now that our HTML is ready, we can write the logic for our application. First we need to know what kind of data we get and what data we need to represent earthquakes on a map.

The JSONP data the USGS site gives us back looks like this:

examples_earthquake/jsonp_example.txt

```
eqfeed_callback({
  "type": "FeatureCollection",
  "metadata": {
    "generated": 1408030886000,
    "url":
"http://earthquake.usgs.gov/earthquakes/...",
    "title": "USGS All Earthquakes, Past Day",
    "status": 200, "api": "1.0.13", "count": 134
  },
  "features": [
    {
      "type": "Feature",
      "properties": {
        "mag": 0.82,
        "title": "M 0.8 - 3km WSW of Idyllwild-
Pine Cove, California",
        "place": "3km WSW of Idyllwild-Pine Cove,
California",
        "time": 1408030368460,
        ...
      },
      "geometry": {
        "type": "Point",
```

```
        "coordinates": [ -116.7636667, 33.7303333,
17.33 ]
      },
      "id": "ci15538377"
    },
    ...
  ]
})
```

The `features` array contains an object with the data for every earthquake that happened today. That's a truckload of data! It's amazing (and terrifying) how many earthquakes happen in a single day. For our program we'll need only the coordinates, title, and magnitude for each earthquake.

Joe asks:

### What Is JSONP?

JSONP—or *JSON with padding*—is a sneaky technique that web developers came up with to work around the browser restrictions when requesting data from third-party domains.[14]

It bypasses these restrictions by loading external content using `script` tags instead of the usual `XMLHttpRequest`. Adding a `script` tag to the DOM loads and executes its content directly, and the security restrictions are not applied.

The remote request's content is then normal JSON wrapped in a function call (the *P* in JSONP). It looks like this:

```
callbackFn({ a: 1, b: 2, c: 3})
```

JSONP URLs usually accept a query string parameter so that the caller can specify the name of the callback. The developer then has to define a function in her code that has the same name as the callback in the server response, and when the **script** tag is added to the document, that function will be called with the JSON data as the first parameter.

Libraries like jQuery automate this process by internally creating the global function to handle the JSONP call, and tidying up afterward to avoid polluting the global namespace.

We first want to create an Observable that retrieves the dataset and emits single earthquakes. Here's a first version:

examples_earthquake/code.js

```
var quakes = Rx.Observable.create(function
(observer) {
  window.eqfeed_callback = function(response) {
    var quakes = response.features;
    quakes.forEach(function(quake) {
      observer.onNext(quake);
    });
  };

  loadJSONP(QUAKE_URL);
});
```

```
quakes.subscribe(function(quake) {
  var coords = quake.geometry.coordinates;
  var size = quake.properties.mag * 10000;

  L.circle([coords[1], coords[0]],
size).addTo(map);
});
```

Wait, what is that blatant global function `window.eqfeed_callback` doing in our code? Well, it turns out that JSONP URLs often provide a way—by adding a querystring in the URL—to specify the function name to handle the response, but the USGS site doesn't allow that, so we need to create a global function with the name they decided we must use, which is `eqfeed_callback`.

Our Observable emits all earthquakes in order. We have an earthquake generator now! We don't have to care about asynchronous flows or about having to put all of our logic in the same function. As long as we subscribe to the Observable, earthquakes will just come to us.

By having the earthquake retrieval "blackboxed" in the `quakes` Observable, we can now subscribe to it and process each earthquake. Then we'll draw a circle for each earthquake with a size proportional to its magnitude.

## Going Deeper

Can we do better? You bet! In the preceding code, we're still managing flow by traversing the array and calling `onNext` to yield each earthquake, even if we isolated it inside the Observable. So much for reactiveness!

This is a perfect situation for `flatMap`. We'll retrieve the data and make an Observable out of the `features` array using `Rx.Observable.from`. Then we'll merge that Observable back in the main Observable:

examples_earthquake/code1_1.js

```
var quakes = Rx.Observable.create(function
(observer) {
  window.eqfeed_callback = function(response) {
①    observer.onNext(response);
②    observer.onCompleted();
  };

  loadJSONP(QUAKE_URL);
③}).flatMap(function transform(dataset) {
④  return Rx.Observable.from(dataset.features);
});
```

```
⑤quakes.subscribe(function(quake) {
  var coords = quake.geometry.coordinates;
  var size = quake.properties.mag * 10000;
  L.circle([coords[1], coords[0]],
size).addTo(map);
});
```

We're not manually managing the flow anymore. There are no loops or conditionals to extract the individual earthquake objects and pass them around. Here's what's happening:

① `onNext` only happens once this time, and it yields the whole JSON response.

② Since we'll yield only one time, we signal completion after `onNext`.

③ We're chaining the `flatMap` call to the result of `create`, so `flatMap` will take each result from the Observable (in this case only one), use it as a parameter for the `transform` function, and merge the Observable resulting from that function into the source Observable.

④ Here we take the `features` array containing all the earthquakes and create an Observable from it. Because of `flatMap`, this will become the actual Observable that the `quakes` variable will contain.

⑤ Subscribe doesn't change at all; it keeps dealing with a stream of earthquakes just like before.

## There Is Always a Method

So far we've used RxJS operators included in **rx.all.js**, but it's usually worth checking out operators that come with other RxJS-based libraries. In our case, we'll look at RxJS-DOM.[15] RxJS-DOM is an external library that, among others, contains an operator to handle JSONP requests: **jsonpRequest**. That saves us some code and keeps us from using nasty global functions:

examples_earthquake/code1_2.js

```
var quakes = Rx.DOM.jsonpRequest({
    url: QUAKE_URL,
    jsonpCallback: 'eqfeed_callback'
  })
  .flatMap(function(result) {
    return
Rx.Observable.from(result.response.features);
  })
  .map(function(quake) {
    return {
      lat: quake.geometry.coordinates[1],
      lng: quake.geometry.coordinates[0],
      size: quake.properties.mag * 10000
    };
  });
```

```
quakes.subscribe(function(quake) {
  L.circle([quake.lat, quake.lng],
quake.size).addTo(map);
});
```

Keep in mind that for this code to run, you need to include the file **rx.dom.js** from RxJS-DOM in the HTML. Notice how we've added a **map** operator that transforms the earthquake objects into simple objects containing only the information we need for our visualization: latitude, longitude, and magnitude of the earthquake. The less functionality we put in the **subscribe** operator, the better.

## Making It Real Time

Our reactive version of the earthquake application doesn't update the map of earthquakes in real time. To implement that, we'll use the **interval** operator—which we saw earlier in this chapter—and the über-useful **distinct** operator. Let me show you the code and then we'll go through the changes:

examples_earthquake/code1_3.js

```
var quakes = Rx.Observable
  .interval(5000)
  .flatMap(function() {
    return Rx.DOM.jsonpRequest({
```

```
      url: QUAKE_URL,
      jsonpCallback: 'eqfeed_callback'
    }).retry(3);
  })
  .flatMap(function(result) {
    return
Rx.Observable.from(result.response.features);
  })
  .distinct(function(quake) { return
quake.properties.code; });

quakes.subscribe(function(quake) {
  var coords = quake.geometry.coordinates;
  var size = quake.properties.mag * 10000;

  L.circle([coords[1], coords[0]],
size).addTo(map);
});
```

In the preceding code, we abuse `interval` to make new requests and process them at regular intervals of five seconds. `interval` creates an Observable that emits an incrementing number every five seconds. We don't do anything with those numbers; instead, we use `flatMap` to retrieve the data of the `jsonpRequest`.

Notice also how we use `retry` to try again in case there are problems retrieving the list at first.

The last operator we apply is `distinct`, which emits only elements that haven't been emitted before. It takes a function that returns the property to check for equality. This way we never redraw earthquakes that are already drawn.

In fewer than 20 lines, we've written an application that regularly polls an external JSONP URL, extracts concrete data from its contents, and then filters out earthquakes that have already been imported. After that, we represent the earthquakes on a map, with a size proportional to their magnitude—all written in a self-contained, clear, and concise way, without relying on external state. Not bad at all! That shows how expressive Observables can be.

## Ideas for Improvements

Here are a couple of ideas to put your newly acquired RxJS skills to use and make this little application a bit more interesting:

- When the user hovers the mouse over an earthquake, offer a pop-up that shows more information about that particular earthquake. One way to do that would be to create a new Observable from the `quakes` one with just the properties you want to show, and dynamically filter it upon hovering.
- Implement a counter at the top of the page that shows the number of earthquakes so far today and resets every day.

## Operator Rundown

This chapter presented you with a few new operators, so here's a recap of them, along with some scenarios for ways we can use them in our applications. Remember, you can always find the complete API documentation for operators on the RxJS GitHub site.[16]

- `Rx.Observable.from`

  Default behavior: *Synchronous*

  Since many of the data sources you use in your applications will come from arrays or iterables, it makes sense to have an operator that creates Observables out of them. `from` is one of the operators you'll use the most.

  With `from` we can create Observables from arrays, array-like objects (for instance, the `arguments` object or DOM `NodeLists`), and even types that implement the iterable protocol, such as `String`, `Map`, and `Set`.[17]

- `Rx.Observable.range`

  Default behavior: *Synchronous*

  The `range` operator generates finite Observables that emit integers in a particular range. It is extremely versatile and can be used in many scenarios. For example, you could use `range` to generate the initial squares on the board of a game like Minesweeper.

- `Rx.Observable.interval`

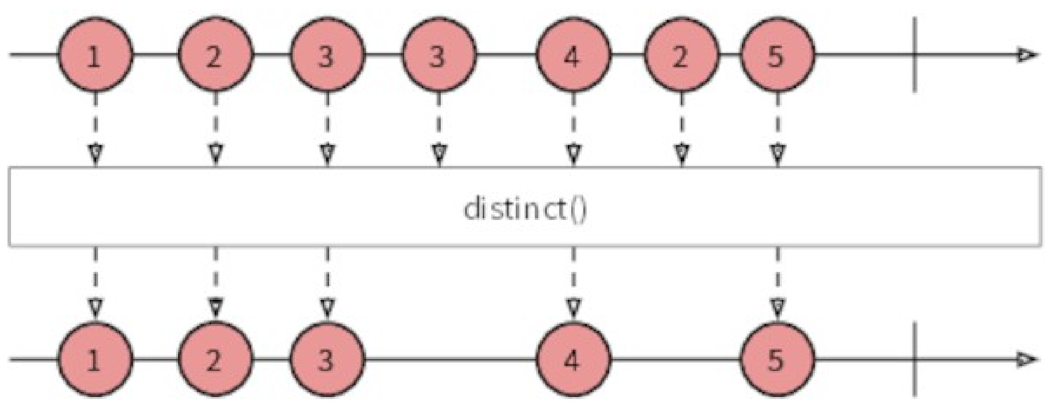
  Default behavior: *Asynchronous*

  Each time you need to generate values spaced in time, you'll probably start with an `interval` operator as the generator. Since `interval` emits sequential integers every `x` milliseconds (where *x* is a parameter we pass), we just need to transform the values to whatever we want. Our game in Chapter 3, *Building Concurrent Programs*, is heavily based on that technique.

- `Rx.Observable.distinct`

  Default behavior: *Same as the Observable it filters*

  `distinct` is one of these extremely simple operators that saves a ton of development work. It filters out of the sequence any value that has already been emitted. That keeps us from writing time and again that error-prone boilerplate code that uses a dictionary somewhere with the emitted results, against which we compare incoming results. You know what kind of code I'm talking about. Yuck. That's gone with `distinct`.



`distinct` lets us use a function that specifies the comparison method. Additionally, we can pass no arguments and it will use strict comparison to compare primitives such as numbers or strings, and run deep comparisons in case of more complex objects.

## Wrapping Up

In this chapter we covered how to visually represent and understand Observable flows using marble diagrams. We've covered the most common operators to transform Observables, and, more importantly, we've built a real-world application using only Observable sequences, avoiding setting any external state, loops, or conditional branches. We expressed our whole program in a declarative way, without having to encode every step to accomplish the task at hand.

In the next chapter we'll continue to explore Observable sequences, this time taking a look at more advanced operators that allow you to control and bend flows and data in your program like you've never imagined possible with procedural code!

---

FOOTNOTES

[12] http://earthquake.usgs.gov/earthquakes/feed/v1.0/

[13] http://leafletjs.com

[14] http://en.wikipedia.org/wiki/Same-origin_policy

[15] https://github.com/Reactive-Extensions/RxJS-DOM

[16] https://github.com/Reactive-Extensions/RxJS/blob/master/doc/api/core/observable.md

[17] https://developer.mozilla.org/ca/docs/Web/JavaScript/Reference/Iteration_protocols

## Chapter 3

# Building Concurrent Programs

Concurrency is the art of doing several things at the same time, correctly and efficiently. To accomplish this, we structure our programs to take advantage of time so that tasks run together in the most efficient way. Examples of everyday concurrency in applications include keeping the user interface responsive while other activities are happening, and processing hundreds of customers’ orders efficiently.

In this chapter we’ll explore concurrency and pure functions in RxJS by making a shoot-’em-up spaceship game for the browser. We’ll first introduce the Observable pipeline, a technique to chain Observable operators and pass state between them. Then I’ll show you how to use the pipeline to build programs without relying on external state or side effects, by encapsulating all your logic and state inside the Observables themselves.

Video games are computer programs that need to keep a lot of state, but we'll write our game with no external state whatsoever, using the power of the Observable pipeline and some great RxJS operators.

## Purity and the Observable Pipeline

An Observable pipeline is a group of operators chained together, where each one takes an Observable as input and returns an Observable as output. We've been using pipelines in this book; they are ubiquitous when programming with RxJS. Here's a simple one:

spaceship_reactive/pipeline.js

```
Rx.Observable
  .from([1, 2, 3, 4, 5, 6, 7, 8])
  .filter(function(val) { return val % 2;  })
  .map(function(val) { return val * 10; });
```

Pipelines are self-contained. All state flows from one operator to the next, without the need for any external variables. But as we build our reactive programs, we may be tempted to store state outside the Observable pipeline (we talked about external state in *Side Effects and External State*). This forces us to keep track of the variables we set outside the pipeline, and all that bean-counting can easily lead to bugs. To avoid this, the operators in a pipeline should always use pure functions.

Pure functions always return the same output given the same input. It's easier to design programs with high concurrency when we can guarantee that a function in the program can't modify state other functions rely on. And that's what pure functions give us.

### Avoiding External State

In the following example we count the even numbers that `interval` has yielded so far. We do that by creating an Observable from `interval` ticks and increasing `evenTicks` when the tick we receive is an even number:

spaceship_reactive/state.js

```
var evenTicks = 0;

function updateDistance(i) {
  if (i % 2 === 0) {
    evenTicks += 1;
  }
  return evenTicks;
}

var ticksObservable = Rx.Observable
  .interval(1000)
  .map(updateDistance)
```

```
ticksObservable.subscribe(function() {
  console.log('Subscriber 1 - evenTicks: ' +
evenTicks + ' so far');
});
```

This is the output we get after the program has been running for four seconds:

```
<= Subscriber 1 - evenTicks: 1 so far
   Subscriber 1 - evenTicks: 1 so far
   Subscriber 1 - evenTicks: 2 so far
   Subscriber 1 - evenTicks: 2 so far
```

Now, just for kicks, let's add another subscriber to `ticksObservable`:

spaceship_reactive/state.js

```
var evenTicks = 0;

function updateDistance(i) {
  if (i % 2 === 0) {
    evenTicks += 1;
  }
  return evenTicks;
}
```

```
var ticksObservable = Rx.Observable
  .interval(1000)
  .map(updateDistance)

ticksObservable.subscribe(function() {
  console.log('Subscriber 1 - evenTicks: ' +
evenTicks + ' so far');
});

ticksObservable.subscribe(function() {
  console.log('Subscriber 2 - evenTicks: ' +
evenTicks + ' so far');
});
```

The output is now the following:

```
<= Subscriber 1 - evenTicks: 1 so far
   Subscriber 2 - evenTicks: 2 so far
   Subscriber 1 - evenTicks: 2 so far
   Subscriber 2 - evenTicks: 2 so far
   Subscriber 1 - evenTicks: 3 so far
   Subscriber 2 - evenTicks: 4 so far
   Subscriber 1 - evenTicks: 4 so far
   Subscriber 2 - evenTicks: 4 so far
```

Hold on a second—the even ticks count on Subscriber 2 is completely off! It should always contain the same `evenTicks` count as Subscriber 1. The reason, as you might have guessed, is that the Observable pipeline will run once for each subscriber, increasing `evenTicks` twice.

Problems caused by sharing external state are often more subtle than this example. In complex applications, opening the door to changing state outside of the pipeline leads to code becoming complicated, and bugs soon start to show up. The solution is to encapsulate as much information as we can inside the pipeline. Here's a way we could refactor the preceding code to avoid external state:

spaceship_reactive/state.js

```
function updateDistance(acc, i) {
  if (i % 2 === 0) {
    acc += 1;
  }
  return acc;
}

var ticksObservable = Rx.Observable
  .interval(1000)
  .scan(updateDistance, 0);
```

```
tickObservable.subscribe(function(evenTicks) {
  console.log('Subscriber 1 - evenTicks: ' +
evenTicks + ' so far');
});

ticksObservable.subscribe(function(evenTicks) {
  console.log('Subscriber 2 - evenTicks: ' +
evenTicks + ' so far');
});
```

And the expected output:

```
<= Subscriber 1 - evenTicks: 1 so far
   Subscriber 2 - evenTicks: 1 so far
   Subscriber 1 - evenTicks: 1 so far
   Subscriber 2 - evenTicks: 1 so far
   Subscriber 1 - evenTicks: 2 so far
   Subscriber 2 - evenTicks: 2 so far
   Subscriber 1 - evenTicks: 2 so far
   Subscriber 2 - evenTicks: 2 so far
```

Using `scan`, we avoid external state altogether. We pass the accumulated count of even ticks to `updateDistance` instead of relying on an external variable to keep the accumulated value.

Most of the time we can avoid relying on external state. Common scenarios for using it are caching values or keeping track of changing values in the program. But, as you'll see in *Spaceship Reactive!*, these scenarios can be handled in several other ways. For example, when we need to cache values, *RxJS's Subject Class*, can help a lot, and when we need to keep track of previous states of the game, we can use methods like `Rx.Observable.scan`.

## Pipelines Are Efficient

The first time I chained a bunch of operators into a pipeline to transform a sequence, my gut feeling was that it couldn't possibly be efficient. I knew transforming arrays in JavaScript by chaining operators is expensive. Yet in this book I'm telling you to design your program by transforming sequences into new ones. Isn't that terribly inefficient?

Chaining looks similar in Observables and in arrays; there are even methods like `filter` and `map` that are present in both types. But there's a crucial difference: array methods create a new array as a result of each operation, which is traversed entirely by the next operation. Observable pipelines, on the other hand, don't create intermediate Observables and apply all operations to each element in one go. The Observable is thus traversed only once, which makes chaining Observables efficient. Check out the following example:

spaceship_reactive/array_chain.js

```
stringArray // represents an array of 1,000
strings
  .map(function(str) {
①   return str.toUpperCase();
  })
② .filter(function(str) {
    return /^[A-Z]+$/.test(str);
  })
③ .forEach(function(str) {
    console.log(str);
  });
```

Let’s suppose `stringArray` is an array with 1,000 strings that we want to convert to uppercase and then filter out the ones that contain anything other than alphabet characters (or no letters at all). Then we want to print each string of the resulting array to the console.

This is what happens behind the scenes:

① Iterate through the array and create a new array with all items uppercase.

② Iterate through the uppercase array, creating another array with 1,000 elements.

③ Iterate through the filtered array and log each result to the console.

In the process of transforming the array, we've iterated arrays three times and created two completely new big arrays. This is far from efficient! You shouldn't program this way if you're concerned about performance or you're dealing with big sequences of items.

This is what the same operation would look like using Observables:

spaceship_reactive/array_chain.js

```
stringObservable  // represents an observable emitting 1,000 strings
  .map(function(str) {
①   return str.toUpperCase();
  })
② .filter(function(str) {
    return /^[A-Z]+$/.test(str);
  })
③ .subscribe(function(str) {
    console.log(str);
  });
```

Observable pipelines look extremely similar to array chains, but their similarities end here. In an Observable, nothing ever happens until we subscribe to it, no matter how many queries and transformations we apply to it. When we chain a transformation like `map`, we're composing a single function that will operate on every item of the array once. So, in the preceding code, this is what will happen:

① Create an uppercase function that will be applied to each item of the Observable and return an Observable that will emit these new items, whenever an Observer subscribes to it.

② Compose a filter function with the previous uppercase function, and return an Observable that will emit the new items, uppercased and filtered, but only when an Observable is subscribed to it.

③ Trigger the Observable to emit items, going through all of them only once and applying the transformations we defined once per item.

With Observables, we'll go through our list only once, and we'll apply the transformations only if absolutely required. For example, let's say we added a `take` operator to our previous example:

spaceship_reactive/array_chain.js

```
stringObservable
  .map(function(str) {
```

```
    return str.toUpperCase();
  })
  .filter(function(str) {
    return /^[A-Z]+$/.test(str);
  })
  .take(5)
  .subscribe(function(str) {
    console.log(str);
  });
```

`take` makes the Observable emit only the first `n` items we specify. In our case, `n` is five, so out of the thousand strings, we'll receive only the first five. The cool part is that our code will never traverse all the items; it will apply our transformations to only the first five.

This makes the developer's life much easier. You can rest assured that when manipulating sequences, RxJS will do only as much work as necessary. This way of operating is called *lazy evaluation*, and it is very common in functional languages such as Haskell and Miranda.

## RxJS's Subject Class

A Subject is a type that implements both Observer and Observable types. As an Observer, it can subscribe to Observables, and as an Observable it can produce values and have Observers subscribe to it.

In some scenarios a single Subject can do the work of a combination of Observers and Observables. For example, for making a proxy object between a data source and the Subject's listeners, we could use this:

spaceship_reactive/subjects.js

```
var subject = new Rx.Subject();
var source = Rx.Observable.interval(300)
  .map(function(v) { return 'Interval message #' +
v; })
  .take(5);

source.subscribe(subject);

var subscription = subject.subscribe(
  function onNext(x) { console.log('onNext: ' +
x); },
  function onError(e) { console.log('onError: ' +
```

```
e.message); },
  function onCompleted() { console.log(
'onCompleted'); }
);

subject.onNext('Our message #1');
subject.onNext('Our message #2');

setTimeout(function() {
  subject.onCompleted();
}, 1000);
```

Output:

```
<= onNext: Our message #1
   onNext: Our message #2
   onNext: Interval message #0
   onNext: Interval message #1
   onNext: Interval message #2
   onCompleted
```

In the preceding example we create a new Subject and a source Observable that emits an integer every 300 milliseconds. Then we subscribe the Subject to the Observable. After that, we subscribe an Observer to the Subject itself. The Subject now behaves as an Observable.

Next we make the Subject emit values of its own (`message1` and `message2`). In the final result, we get the Subject's own messages and then the proxied values from the source Observable. The values from the Observable come later because they are asynchronous, whereas we made the Subject's own values immediate. Notice that even if we tell the `source` Observable to take the first five values, the output shows only the first three. That's because after one second we call `onCompleted` on the Subject. This finishes the notifications to all subscriptions and overrides the `take` operator in this case.

The `Subject` class provides the base for creating more specialized Subjects. In fact, RxJS comes with some interesting ones: `AsyncSubject`, `ReplaySubject`, and `BehaviorSubject`.

## AsyncSubject

`AsyncSubject` emits the last value of a sequence only if the sequence completes. This value is then cached forever, and any Observer that subscribes after the value has been emitted will receive it right away. `AsyncSubject` is convenient for asynchronous operations that return a single value, such as Ajax requests.

Let's see a simple example of an AsyncSubject subscribing to a range:

spaceship_reactive/subjects.js

```
var delayedRange = Rx.Observable.range(0,
5).delay(1000);
var subject = new Rx.AsyncSubject();

delayedRange.subscribe(subject);

subject.subscribe(
  function onNext(item) { console.log('Value:',
item); },
  function onError(err) { console.log('Error:',
err); },
  function onCompleted() { console.log(
'Completed.'); }
);
```

In that example, delayedRange emits the values 0 to 4 after a delay of a second. Then we create a new AsyncSubject subject and subscribe it to delayedRange. The output is the following:

```
<= Value: 4
   Completed.
```

As expected, we get only the last value that the Observer emits. Let’s now use `AsyncSubject` for a more realistic scenario. We’ll retrieve some remote content:

spaceship_reactive/subjects.js

```
function getProducts(url) {
  var subject;

① return Rx.Observable.create(function(observer)
{
    if (!subject) {
      subject = new Rx.AsyncSubject();
②     Rx.DOM.get(url).subscribe(subject);
    }
③   return subject.subscribe(observer);
  });
}

④var products = getProducts('/products');
// Will trigger request and receive the response
when read
⑤products.subscribe(
  function onNext(result) { console.log('Result
1:', result.response); },
  function onError(error) { console.log('ERROR',
```

```
error); }
);

// Will receive the result immediately because
it's cached
⑥setTimeout(function() {
  products.subscribe(
    function onNext(result) { console.log('Result
2:', result.response); },
    function onError(error) { console.log('ERROR'
, error); }
  );
}, 5000);
```

In this code, when **getProducts** is called with a URL, it returns an Observer that emits the result of the HTTP GET request. Here's how it breaks down:

① **getProducts** returns an Observable sequence. We create it here.
If we haven't created an **AsyncSubject** yet, we create it and
② subscribe it to the Observable that **Rx.DOM.Request.get(url)** returns.
We subscribe the Observer to the **AsyncSubject**. Every time an
③ Observer subscribes to the Observable, it will actually be subscribed to the **AsyncSubject**, which is acting as a proxy

between the Observable retrieving the URL and the Observers.

④ We create the Observable that retrieves the URL "products" and store it in the `products` variable.

⑤ This is the first subscription and will kick off the URL retrieval and log the results when the URL is retrieved.

⑥ This is the second subscription, which runs five seconds after the first one. Since at that time the URL has already been retrieved, there's no need for another network request. It will receive the result of the request immediately because it is already stored in the `AsyncSubject subject`.

The interesting bit is that we're using an `AsyncSubject` that subscribes to the `Rx.DOM.Request.get` Observable. Because `AsyncSubject` caches the last result, any subsequent subscription to `products` will receive the result right away, without causing another network request. We can use `AsyncSubject` whenever we expect a single result and want to hold onto it.

Joe asks:

### Does That Mean AsyncSubject Acts Like a Promise?

Indeed.

`AsyncSubject` represents the result of an asynchronous action, and you can use it as a substitute for a promise. The difference internally is that a promise will only ever process a single value, whereas `AsyncSubject` processes all values in a sequence, only ever emitting (and caching) the last one.

Being able to so easily simulate promises shows the flexibility of the RxJS model. (Even without **AsyncSubject**, it would be pretty easy to simulate a promise using Observables.)

## BehaviorSubject

When an Observer subscribes to a **BehaviorSubject**, it receives the last emitted value and then all the subsequent values. **BehaviorSubject** requires that we provide a starting value, so that all Observers will always receive a value when they subscribe to a **BehaviorSubject**.

Imagine we want to retrieve a remote file and print its contents on an HTML page, but we want placeholder text while we wait for the contents. We can use a **BehaviorSubject** for this:

spaceship_reactive/behavior_subject.js

```
var subject = new Rx.BehaviorSubject('Waiting for
content');

subject.subscribe(
  function(result) {
    document.body.textContent = result.response ||
result;
  },
  function(err) {
```

```
    document.body.textContent = 'There was an
error retrieving content';
  }
);

Rx.DOM.get('/remote/content').subscribe(subject);
```

In the code, we initialize a new `BehaviorSubject` with our placeholder content. Then we subscribe to it and change the HTML body content in both `onNext` and `onError`, depending on the result.

Now the HTML body contains our placeholder text, and it will stay that way until the Subject emits a new value. Finally, we request the resource we want and we subscribe our Subject to the resulting Observer.

`BehaviorSubject` guarantees that there will always be at least one value emitted, because we provide a default value in its constructor. Once the `BehaviorSubject` completes it won't emit any more values, freeing the memory used by the cached value.

## ReplaySubject

A `ReplaySubject` caches its values and re-emits them to any Observer that subscribes late to it. Unlike with `AsyncSubject`, the sequence doesn’t need to be completed for this to happen.

| **Subject** | **ReplaySubject** |
|---|---|
| `var subject = new Rx.Subject();` | `var subject = new Rx.ReplaySubject();` |
| | |
| `subject.onNext(1);` | `subject.onNext(1);` |
| | |
| `subject.subscribe(function (n) {` | `subject.subscribe(f (n) {` |
| `  console.log('Received value:', n);` | `  console.log('Rece value:', n);` |
| `});` | `});` |
| | |
| `subject.onNext(2);` | `subject.onNext(2);` |
| `subject.onNext(3);` | `subject.onNext(3);` |

**Subject**

<= Received value: 2

Received value: 3

**ReplaySubject**

<= Received value: 1

Received value: 2

Received value: 3

`ReplaySubject` is useful to make sure that Observers get all the values emitted by an Observable from the start. It spares us from writing messy code that caches previous values, saving us from nasty concurrency-related bugs.

Of course, to accomplish that behavior `ReplaySubject` caches all values in memory. To prevent it from using too much memory, we can limit the amount of data it stores by buffer size or window of time, or by passing particular parameters to the constructor.

The first parameter to the constructor of `ReplaySubject` takes a number that represents how many values we want to buffer:

```
var subject = new Rx.ReplaySubject(2); // Buffer size of 2

subject.onNext(1);
subject.onNext(2);
```

```
subject.onNext(3);

subject.subscribe(function(n) {
  console.log('Received value:', n);
});
```

```
<= Received value: 2
   Received value: 3
```

The second parameter takes a number that represents the time in milliseconds during which we want to buffer values:

```
var subject = new Rx.ReplaySubject(null, 200); // Buffer size of 200ms

setTimeout(function() { subject.onNext(1); }, 100);
setTimeout(function() { subject.onNext(2); }, 200);
setTimeout(function() { subject.onNext(3); }, 300);
setTimeout(function() {
  subject.subscribe(function(n) {
    console.log('Received value:', n);
  });
```

```
  subject.onNext(4);
}, 350);
```

In this example we set a buffer based on time, instead of the number of values. Our **ReplaySubject** will cache values that were emitted up to 200 milliseconds ago. We emit three values, each separated by 100 milliseconds, and after 350 milliseconds we subscribe an Observer and we emit yet another value. At the moment of the subscription the items cached are *2* and *3*, because *1* happened too long ago (around 250 milliseconds ago), so it is no longer cached.

Subjects are a powerful tool that can save you a lot of time. They provide great solutions to common scenarios like caching and repeating. And since at their core they are just Observables and Observers, you don't need to learn anything new.

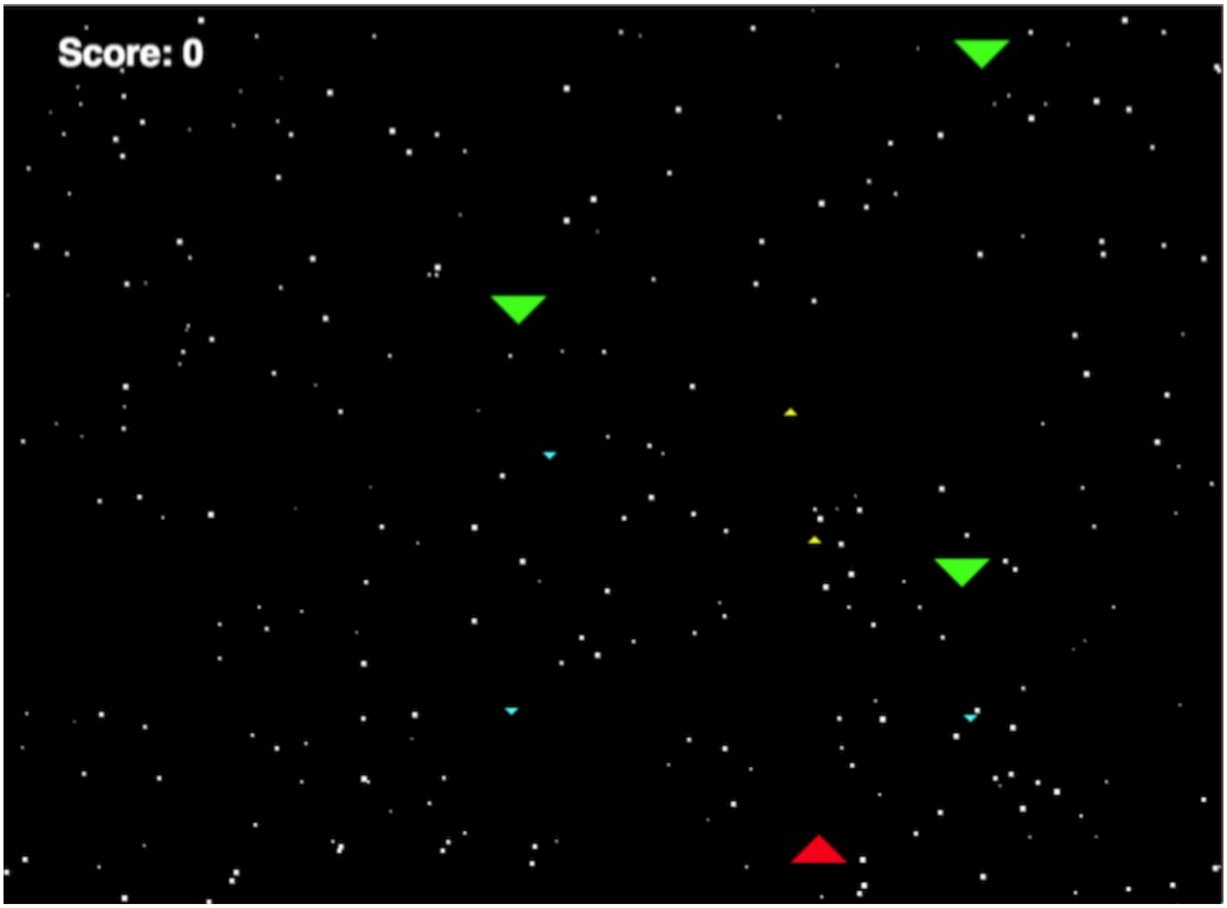
## Spaceship Reactive!

To show how we can keep an application pure, we'll build a video game in which our hero fights endless hordes of enemy spaceships. We'll make heavy use of Observable pipelines, and I'll point out along the way when it might be tempting to store state outside the pipeline and how to avoid it.

Video games notoriously keep a lot of external state—scores, screen coordinates for the characters, timers, and so on. Our plan is to build the whole game without relying on a single external variable that keeps state.

In our game, the player will move the spaceship horizontally using the mouse, and will shoot by clicking the mouse or tapping the spacebar. Our game will have four main actors: the moving star field in the background, the player's spaceship, the enemies, and the shots from both the player and the enemies.

It will look like this:




In the screenshot, the red triangle is our spaceship and the green ones are the enemies. The tinier triangles are the fired shots.

Let’s start by setting the stage; this will be our HTML file:

spaceship_reactive/spaceship.html

```
<!DOCTYPE html>
<html>
  <head>
    <meta charset="utf-8">
    <title>Spaceship Reactive!</title>
```

```
    <script src="../rx.all-4.0.0.js"></script>
    <style>
      html, body {
        margin: 0;
        padding: 0;
      }
    </style>
  </head>
  <body>
    <script src="spaceship.js"></script>
  </body>
</html>
```

It’s just a simple HTML file that loads the JavaScript file we’ll be working with for the rest of the chapter. In that JavaScript file, we start by setting up a `canvas` element where we’ll render our game:

spaceship_reactive/starfield_1.js

```
var canvas = document.createElement('canvas');
var ctx = canvas.getContext("2d");
document.body.appendChild(canvas);
canvas.width = window.innerWidth;
canvas.height = window.innerHeight;
```

With this in place we can start describing our game's components. First let's draw our starry background.

## Creating the Star Field

The first things we need for a game set in space are stars. We'll create a star field that scrolls down to give the feeling of traveling through space. For this, we'll first generate the stars using the `range` operator:

spaceship_reactive/starfield_1.js

```
var SPEED = 40;
var STAR_NUMBER = 250;
var StarStream = Rx.Observable.range(1,
STAR_NUMBER)
  .map(function() {
    return {
      x: parseInt(Math.random() * canvas.width),
      y: parseInt(Math.random() * canvas.height),
      size: Math.random() * 3 + 1
    };
  })
```

Each star will be represented by an object that contains random coordinates and a size between 1 and 4. This code will give us a stream that generates 250 of these "stars."

We want these stars to keep moving. A way to do that is to increase the y-coordinate every few milliseconds for all stars. We'll transform the **StarStream** Observable into an array using **toArray**, which will then emit a single array containing all the objects generated by **range**. Then we can pick up that array with a **flatMap** operator that will transform the Observable into one that yields a value every few milliseconds. Using **map** we can increase the y-coordinate in each item of the original array. We can even get a nice parallax effect for free by moving each star a distance the same as its size:

spaceship_reactive/starfield_1.js

```
var SPEED = 40;
var STAR_NUMBER = 250;
var StarStream = Rx.Observable.range(1,
STAR_NUMBER)
  .map(function() {
    return {
      x: parseInt(Math.random() * canvas.width),
      y: parseInt(Math.random() * canvas.height),
      size: Math.random() * 3 + 1
    };
  })
  .toArray()
  .flatMap(function(starArray) {
```

```
    return Rx.Observable.interval(SPEED).map(
function() {
      starArray.forEach(function(star) {
        if (star.y >= canvas.height) {
          star.y = 0; // Reset star to top of the
screen
        }
        star.y += star.size; // Move star
      });
      return starArray;
    });
  })
```

Inside `map` we check if the star y-coordinate is already outside the screen, and in this case we reset it to 0. By changing the coordinates in every star object we can keep using the same array of stars all the time.

Now we need a small helper function that "paints" an array of stars on our canvas:

spaceship_reactive/starfield_1.js

```
function paintStars(stars) {
  ctx.fillStyle = '#000000';
  ctx.fillRect(0, 0, canvas.width, canvas.height);

```

```
  ctx.fillStyle = '#ffffff';
  stars.forEach(function(star) {
    ctx.fillRect(star.x, star.y, star.size,
star.size);
  });
}
```

**paintStars** paints a black background and draws the stars on the canvas. The only thing left to achieve a moving star field is to subscribe to the **Observable** and call **paintStars** with the resulting array. Here's the final code:

spaceship_reactive/starfield_1.js

```
function paintStars(stars) {
  ctx.fillStyle = '#000000';
  ctx.fillRect(0, 0, canvas.width, canvas.height);
  ctx.fillStyle = '#ffffff';
  stars.forEach(function(star) {
    ctx.fillRect(star.x, star.y, star.size,
star.size);
  });
}

var SPEED = 40;
var STAR_NUMBER = 250;
```

```
var StarStream = Rx.Observable.range(1,
STAR_NUMBER)
  .map(function() {
    return {
      x: parseInt(Math.random() * canvas.width),
      y: parseInt(Math.random() * canvas.height),
      size: Math.random() * 3 + 1
    };
  })
  .toArray()
  .flatMap(function(starArray) {
    return Rx.Observable.interval(SPEED).map(
function() {
      starArray.forEach(function(star) {
        if (star.y >= canvas.height) {
          star.y = 0; // Reset star to top of the
screen
        }
        star.y += star.size; // Move star
      });
      return starArray;
    });
  })
  .subscribe(function(starArray) {
```

```
    paintStars(starArray);
  });
```

Now that we've set the stage, it's time for our hero to make an appearance.

## Adding the Player's Spaceship

Now that we have our beautiful starry background, we're ready to program the hero's spaceship. Even though it's the most important object in the game, our spaceship is deceptively simple. It's an Observer of mouse moves that emits the current mouse x-coordinate and a constant y- coordinate (the player only moves horizontally, so we never change the y-coordinate):

spaceship_reactive/hero_1.js

```
var HERO_Y = canvas.height - 30;
var mouseMove = Rx.Observable.fromEvent(canvas,
'mousemove');
var SpaceShip = mouseMove
  .map(function(event) {
    return {
      x: event.clientX,
      y: HERO_Y
    };
  })
```

```
  .startWith({
    x: canvas.width / 2,
    y: HERO_Y
  });
```

Notice that I used `startWith()`. This sets the first value in the Observable, and I set it to a position in the middle of the screen. Without `startWith` our Observable would start emitting only when the player moves the mouse.

Let's render our hero on the screen. In this game all the characters are triangles (my graphic-design skills are not very impressive), so we'll define a helper function to render triangles on the canvas, given the coordinates, size, and color, and the direction they're facing:

spaceship_reactive/hero_1.js

```
function drawTriangle(x, y, width, color,
direction) {
  ctx.fillStyle = color;
  ctx.beginPath();
  ctx.moveTo(x - width, y);
  ctx.lineTo(x, direction === 'up' ? y - width : y
+ width);
  ctx.lineTo(x + width, y);
```

```
  ctx.lineTo(x - width,y);
  ctx.fill();
}
```

We'll also define paintSpaceShip, which uses the helper function:

spaceship_reactive/hero_1.js

```
function paintSpaceShip(x, y) {
  drawTriangle(x, y, 20, '#ff0000', 'up');
}
```

But we're facing a problem now. If we subscribe to the SpaceShip Observable and call drawTriangle in the subscription, our spaceship would be visible only when we move the mouse, and for just an instant. This is because starStream is updating the canvas many times per second, erasing our spaceship if we don't move the mouse. And because the starStream doesn't have direct access to the spaceship, we can't render the spaceship in the starStream subscription. We could save the latest spaceship coordinates to a variable that the starStream can access, but then we would be breaking our rule of not modifying external state. What to do?

As is usually the case, RxJS has a very convenient operator we can use to solve our problem.

`Rx.Observable.combineLatest` is a handy operator. It takes two or more Observables and emits the last result of each Observable whenever any of them emits a new value. Knowing that `starStream` emits a new item (the array of stars) so frequently, we can remove the `starStream` subscription and use `combineLatest` to combine both the `starStream` and `SpaceShip` Observables and update them as soon as any of them emits a new item:

spaceship_reactive/hero_1.js

```
function renderScene(actors) {
  paintStars(actors.stars);
  paintSpaceShip(actors.spaceship.x,
actors.spaceship.y);
}

var Game = Rx.Observable
  .combineLatest(
    StarStream, SpaceShip,
    function(stars, spaceship) {
      return { stars: stars, spaceship: spaceship
};
    });

Game.subscribe(renderScene);
```

We're now using a function `renderScene` to paint everything on the screen, so you can remove the following subscription code for `StarStream`:

```
.subscribe(function(starArray) {
    paintStars(starArray);
});
```

With this, we'll paint the starry background *and* the spaceship every time any Observable emits a new item. We now have a spaceship flying through space, and we can move it at will using our mouse. Not bad for so little code! But our hero's spaceship is too lonely in the vastness of space. What about giving it some company?

## Generating Enemies

This would be a very boring game if we didn't have any enemies to take care of. So let's create an infinite stream of them! We want to create a new enemy every second and a half to not overwhelm our hero. Let's look at the code for the `Enemies` Observable and then go through it:

spaceship_reactive/enemy_1.js

```
var ENEMY_FREQ = 1500;
var Enemies = Rx.Observable.interval(ENEMY_FREQ)
```

```
  .scan(function(enemyArray) {
    var enemy = {
      x: parseInt(Math.random() * canvas.width),
      y: -30,
    };

    enemyArray.push(enemy);
    return enemyArray;
  }, []);

var Game = Rx.Observable
  .combineLatest(
    StarStream, SpaceShip, Enemies,
    function(stars, spaceship, enemies) {
      return {
        stars: stars,
        spaceship: spaceship,
        enemies: enemies
      };
    });

Game.subscribe(renderScene);
```

To create enemies, we use an `interval` operator to run every 1,500 milliseconds, and then we use the `scan` operator to create an array of enemies.

We briefly saw the `scan` operator in *Can We Aggregate Infinite Observables?*. `scan` aggregates results each time an Observable emits a value, and emits each intermediate result. In the `Enemies` Observable we start with an empty array as `scan`'s first parameter and we push a new object to it in every iteration. The object contains a random x-coordinate, and a fixed y-coordinate outside the visible screen. With this, `Enemies` will emit an array with all the current enemies every 1,500 milliseconds.

The only thing left to render enemies is a helper function to paint each of them on the canvas. This function will also be the one updating the coordinates of each item in the `enemies` array:

spaceship_reactive/enemy_1.js

```
// Helper function to get a random integer
function getRandomInt(min, max) {
  return Math.floor(Math.random() * (max - min +
1)) + min;
}
```

```
function paintEnemies(enemies) {
  enemies.forEach(function(enemy) {
    enemy.y += 5;
    enemy.x += getRandomInt(-15, 15);

    drawTriangle(enemy.x, enemy.y, 20, '#00ff00',
'down');
  });
}
```

You can see in `paintEnemies` that we are also changing the x-coordinate randomly so that enemies move a bit unpredictably to the sides. Now we need to update the function `renderScene` to include a call to `paintEnemies`.

You might have noticed a strange effect while playing the game we have so far: if you move the mouse, the enemies go faster toward you! That *could* be a nice feature in the game, but we definitely didn’t intend to do that. Can you guess what causes this bug?

If you guessed that it was related to the `paintEnemies` function, you’re right on the money. `combineLatest` renders our scene whenever any of the Observables yields a value. If we don’t move the mouse, the fastest emitter will always be `starStream` because it has an interval of 40 milliseconds (the `Enemies` Observable emits only every 1,500 milliseconds). When we move the mouse, though, `SpaceShip` will emit faster than `starStream` (your mouse emits coordinates *many* times per second), and `paintEnemies` will then execute that many times, increasing the enemies' coordinates much faster.

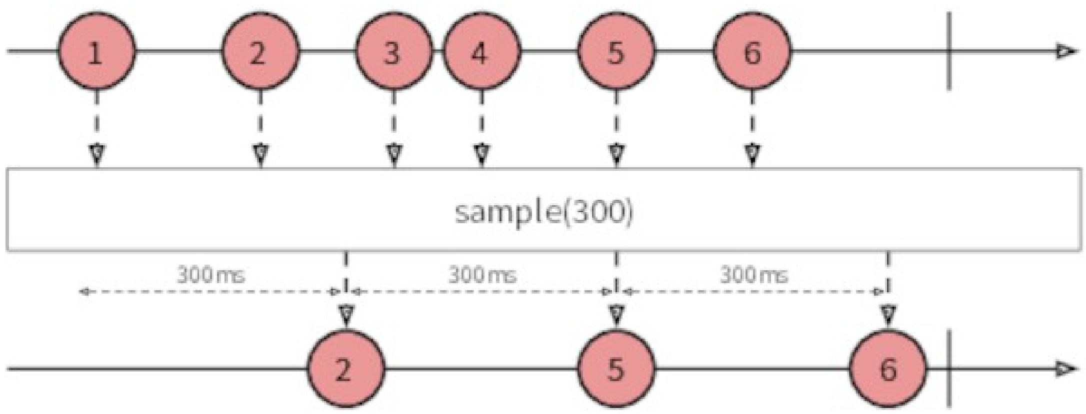
To avoid this scenario and similar problems in the future, we need to normalize the game's speed so that no Observable can emit values faster than our chosen speed for the game.

And yes, as you may have guessed, RxJS has an operator for that.

### Avoid Drinking from the Firehose

There is such a thing as receiving data too fast. Most of the time we want all the speed we can get, but depending on the frequency at which the Observable streams values, we might want to drop some of the values we receive. We're now in one of these scenarios. The speed at which we render things onscreen is proportional to the speed of the fastest Observable we have. It turns out that our fastest Observable is too fast for us, and we need to establish a constant update speed in the game.

`sample` is a method in Observable instances that, given a `time` parameter in milliseconds, returns an Observable that emits the last value emitted by the parent Observable in each `time` interval.




Notice how `sample` drops any values before the last value at the moment of the interval. It's important to consider whether you want this behavior. In our case, we don't care about dropping values because we just want to render the current state of each element every 40 milliseconds. If all the values are important to you, you might want to consider the `buffer` operator:

spaceship_reactive/enemy_2.js

```
Rx.Observable.combineLatest(
```

```
  StarStream, SpaceShip, Enemies,
  function(stars, spaceship, enemies) {
    return {
      stars: stars,
      spaceship: spaceship,
      enemies: enemies
    };
  })
» .sample(SPEED)
  .subscribe(renderScene);
```

By calling **sample** after **combineLatest** we make sure that **combineLatest** will never yield any value faster than 40 milliseconds after the previous one (our constant **SPEED** is set to 40).

## Shooting

It's a bit scary seeing the hordes of enemies coming at us; all we can do about it is move out of the way and hope they don't see us. How about we give our hero the ability to shoot at the evil alien spaceships?

We want our spaceship to shoot whenever we click the mouse or press the spacebar, so we'll create an Observable for each event and merge them into a single Observable called **playerShots**.

Notice that we filter the *keydown* Observable by the key code of the spacebar, 32:

spaceship_reactive/hero_shots.js

```
var playerFiring = Rx.Observable
  .merge(
    Rx.Observable.fromEvent(canvas, 'click'),
    Rx.Observable.fromEvent(document, 'keydown')
      .filter(function(evt) { return evt.keycode
=== 32; })
  )
```

Now that we know about `sample`, we can use it to spice up the game and limit the shooting frequency of our spaceship. Otherwise, the player could shoot at high speed and destroy all enemies too easily. We'll make it so that the player can shoot only every 200 milliseconds at most:

spaceship_reactive/hero_shots.js

```
var playerFiring = Rx.Observable
  .merge(
    Rx.Observable.fromEvent(canvas, 'click'),
    Rx.Observable.fromEvent(document, 'keydown')
      .filter(function(evt) { return evt.keycode
=== 32; })
```

```
  )
  .startWith({})
  .sample(200)
  .timestamp();
```

We've also added a `timestamp` operator, which sets a property *timestamp* in every value our Observable emits, with the exact time it is emitted. We'll use it later. Also, we use `startWith` to start with an initial shot so that we have an initial shot value for when we combine shots with the spaceship's position below.

Finally, to fire shots from our spaceship we need to know the x-coordinate of the spaceship at the firing moment. This is so we can render the shot at the correct x-coordinate. It may be tempting to set an external variable from the `SpaceShip` Observable that always contains the last x-coordinate emitted, but that would be breaking our unwritten agreement to never mutate external state!

Instead we'll accomplish this by using our good friend `combineLatest` again:

spaceship_reactive/hero_shots.js

```
var HeroShots = Rx.Observable
  .combineLatest(
    playerFiring,
```

```
    SpaceShip,
    function(shotEvents, spaceShip) {
      return { x: spaceShip.x };
    })
  .scan(function(shotArray, shot) {
    shotArray.push({x: shot.x, y: HERO_Y});
    return shotArray;
  }, []);
```

We now get the updated values from `SpaceShip` and `playerFiring`, so we can get the x-coordinate we want. We use `scan` in the same way we used it for our `Enemy` Observable, creating an array of current coordinates for each of our shots. With that we should be ready to draw our shots on the screen. We use a helper function to draw every shot in the array of shots:

spaceship_reactive/hero_shots.js

```
var SHOOTING_SPEED = 15;
function paintHeroShots(heroShots) {
  heroShots.forEach(function(shot) {
    shot.y -= SHOOTING_SPEED;
    drawTriangle(shot.x, shot.y, 5, '#ffff00',
'up');
  });
}
```

Then we call `paintHeroShots` from our main `combineLatest` operation:

```
Rx.Observable.combineLatest(
    StarStream, SpaceShip, Enemies, HeroShots,
    function(stars, spaceship, enemies,
heroShots) {
      return {
        stars: stars,
        spaceship: spaceship,
        enemies: enemies,
»       heroShots: heroShots
      };
    })
  .sample(SPEED)
  .subscribe(renderScene);
```

And we add a call to `paintHeroShots` inside `renderScene`:

```
function renderScene(actors) {
  paintStars(actors.stars);
  paintSpaceShip(actors.spaceship.x,
actors.spaceship.y);
  paintEnemies(actors.enemies);
» paintHeroShots(actors.heroShots);
}
```

Now when you run the game you'll notice that *every* time you move the mouse, our spaceship fires an insane number of shots. Not bad for an effect, but that's not what we wanted! Let's look at the `HeroShots` Observable again. In it, we're using `combineLatest` so that we have values from `playerFiring` and `SpaceShip`. This looks similar to the problem we had before. `combineLatest` in `HeroShots` is emitting values every time the mouse moves, and this translates into shots being fired. Throttling won't help in this case, because we want the user to shoot whenever she wants, and throttling would limit the number of shots and drop many of them.

`combineLatest` emits the last value that each Observable emitted, whenever an Observable emits a new value. We can use this to our advantage. Whenever the mouse moves, `combineLatest` emits the new `SpaceShip` position and the last emitted value of `playerFiring`, which will be unchanged unless we fire a new shot. We can then emit a value *only* when the emitted shot is different from the previous one. The `distinctUntilChanged` operator does the dirty work for us.

The operators `distinct` and `distinctUntilChanged` allow us to filter out results that an Observable has already emitted. `distinct` filters out any result previously emitted and `distinctUntilChanged` filters out identical results unless a different one is emitted in between.

We only need to make sure that the new shot is different from the previous one, so `distinctUntilChanged` is enough for us. (It also saves us from the higher memory usage of `distinct`; `distinct` needs to keep all the previous results in memory.)

We modify `heroShots` so it only emits new shots, based on their `timestamp`:

spaceship_reactive/hero_shots2.js

```
var HeroShots = Rx.Observable
  .combineLatest(
    playerFiring,
    SpaceShip,
    function(shotEvents, spaceShip) {
      return {
        timestamp: shotEvents.timestamp,
        x: spaceShip.x
      };
    })
  .distinctUntilChanged(function(shot) { return
shot.timestamp; })
  .scan(function(shotArray, shot) {
    shotArray.push({ x:shot.x, y: HERO_Y });
    return shotArray;
  }, []);
```

If everything went well, we're now able to shoot at enemies from our spaceship!

## Enemy Shots

We should allow enemies to shoot as well; otherwise it's a pretty unfair universe. And a boring one! For enemy shots, we'll do the following:

- Each enemy will keep an updated array of its own shots.
- Each enemy will shoot at a given frequency.

For this, we'll use an `interval` operator to store new shots in the enemy value. We'll also introduce a new helper function, `isVisible`, that helps filter out elements whose coordinates are outside the visible screen. This is how the `Enemy` Observable looks now:

spaceship_reactive/enemy_shots.js

```
function isVisible(obj) {
  return obj.x > -40 && obj.x < canvas.width + 40
    obj.y > -40 && obj.y < canvas.height + 40;
}

var ENEMY_FREQ = 1500;
var ENEMY_SHOOTING_FREQ = 750;
var Enemies = Rx.Observable.interval(ENEMY_FREQ)
```

```
var Enemies = Rx.Observable.interval(ENEMY_FREQ)
  .scan(function(enemyArray) {
    var enemy = {
      x: parseInt(Math.random() * canvas.width),
      y: -30,
      shots: []
    };


    Rx.Observable.interval(ENEMY_SHOOTING_FREQ).sul
function() {
      enemy.shots.push({ x: enemy.x, y: enemy.y })
      enemy.shots = enemy.shots.filter(isVisible);
    });

    enemyArray.push(enemy);
    return enemyArray.filter(isVisible);
  }, []);
```

In that code we create an interval every time we create a new enemy. This interval will keep adding shots to the enemy array of shots, and then it will filter out the ones outside the screen. We can use `isVisible` to filter out enemies that are outside the screen, too, as we do in the `return` statement.

We need to update **paintEnemies** so that it renders enemy shots and updates their y-coordinates. Then we use our handy **drawTriangle** function to draw the shots:

spaceship_reactive/enemy_shots.js

```
function paintEnemies(enemies) {
  enemies.forEach(function(enemy) {
    enemy.y += 5;
    enemy.x += getRandomInt(-15, 15);

    drawTriangle(enemy.x, enemy.y, 20, '#00ff00',
'down');

»   enemy.shots.forEach(function(shot) {
»     shot.y += SHOOTING_SPEED;
»     drawTriangle(shot.x, shot.y, 5, '#00ffff',
'down');
»   });
  });
}
```

With this in place everybody is now shooting everybody else, but nobody is being destroyed! They simply glide past the enemies and our spaceship because we haven’t defined what happens when shots collide with spaceships.

## Managing Collisions

When a shot hits an enemy, we want both the shot and the enemy to disappear. Let's define a helper function to detect whether two targets have collided:

spaceship_reactive/enemy_shots2.js

```
function collision(target1, target2) {
  return (target1.x > target2.x - 20 && target1.x
< target2.x + 20) &&
         (target1.y > target2.y - 20 && target1.y
< target2.y + 20);
}
```

Now let's modify the helper function `paintHeroShots` to check whether each shot hits an enemy. For cases where a hit occurs, we'll set a property `isDead` to `true` on the enemy that has been hit, and we'll set the coordinates of the shot to outside the screen. The shot will eventually be filtered out because it's outside the screen.

spaceship_reactive/enemy_shots2.js

```
function paintEnemies(enemies) {
  enemies.forEach(function(enemy) {
    enemy.y += 5;
    enemy.x += getRandomInt(-15, 15);
```

```
    if (!enemy.isDead) {
      drawTriangle(enemy.x, enemy.y, 20, '#00ff00', 'down');
    }

    enemy.shots.forEach(function(shot) {
      shot.y += SHOOTING_SPEED;
      drawTriangle(shot.x, shot.y, 5, '#00ffff', 'down');
    });
  });
}

var SHOOTING_SPEED = 15;
function paintHeroShots(heroShots, enemies) {
  heroShots.forEach(function(shot, i) {
    for (var l=0; l<enemies.length; l++) {
      var enemy = enemies[l];
      if (!enemy.isDead && collision(shot, enemy)) {
        enemy.isDead = true;
        shot.x = shot.y = -100;
        break;
```

```
      }
    }

    shot.y -= SHOOTING_SPEED;
    drawTriangle(shot.x, shot.y, 5, '#ffff00',
'up');
  });
}
```

Next let’s get rid of any enemies that have the property **isDead** set to **true**. The only caveat is that we need to wait for all the shots from that particular enemy to disappear; otherwise, when we hit an enemy all its shots disappear along with it, which would be weird. So we check for the length of its **shots** and filter out the enemy object only when it has no shots left:

spaceship_reactive/enemy_shots2.js

```
var Enemies = Rx.Observable.interval(ENEMY_FREQ)
  .scan(function(enemyArray) {
    var enemy = {
      x: parseInt(Math.random() * canvas.width),
      y: -30,
      shots: []
    };

    Rx.Observable.interval(ENEMY_SHOOTING_FREQ)
```

```
    Rx.Observable.interval(ENEMY_SHOOTING_FREQ).su
function() {
»       if (!enemy.isDead) {
»         enemy.shots.push({ x: enemy.x, y: enemy.y
»       }
        enemy.shots = enemy.shots.filter(isVisible);
      });


    enemyArray.push(enemy);
    return enemyArray
      .filter(isVisible)
»     .filter(function(enemy) {
»       return !(enemy.isDead && enemy.shots.lengt
»     });
  }, []);
```

To check if the player's ship has been hit, we create a function **gameOver**:

spaceship_reactive/enemy_shots2.js

```
function gameOver(ship, enemies) {
  return enemies.some(function(enemy) {
    if (collision(ship, enemy)) {
      return true;
```

```
    }

    return enemy.shots.some(function(shot) {
      return collision(ship, shot);
    });
  });
}
```

This function returns `true` if an enemy or a shot from an enemy hits the player's spaceship.

Before moving on, let's get to know a useful operator: `takeWhile`. When we call `takeWhile` on an existing Observable, that Observable will keep emitting values until the function passed as a parameter to `takeWhile` returns `false`.

We can use `takeWhile` to tell our main `combineLatest` Observable to keep taking values until `gameOver` returns `true`:

spaceship_reactive/enemy_shots2.js

```
Rx.Observable.combineLatest(
    StarStream, SpaceShip, Enemies, HeroShots,
    function(stars, spaceship, enemies,
heroShots) {
      return {
        stars: stars,
```

```
        spaceship: spaceship,
        enemies: enemies,
        heroShots: heroShots
      };
    })
  .sample(SPEED)
»  .takeWhile(function(actors) {
»    return gameOver(actors.spaceship,
actors.enemies) === false;
»  })
  .subscribe(renderScene);
```

When `gameOver` returns `true`, `combineLatest` will stop emitting values, effectively stopping the game.

## One Last Thing: Keeping Score

What kind of game would it be if we couldn't brag about our results to our friends? We obviously need a way to keep track of how well we did. We need a score.

Let's make a simple helper function to draw the score to the upper left of the screen:

spaceship_reactive/score.js

```
function paintScore(score) {
```

```
  ctx.fillStyle = '#ffffff';
  ctx.font = 'bold 26px sans-serif';
  ctx.fillText('Score: ' + score, 40, 43);
}
```

To keep score we'll use a `BehaviorSubject` with a starting value of `0`. We can easily use it in our `combineLatest`-based main game loop as if it were just another Observable, and we can push values to it whenever we want.

spaceship_reactive/score.js

```
var ScoreSubject = new Rx.BehaviorSubject(0);
var score = ScoreSubject.scan(function (prev, cur)
{
  return prev + cur;
}, 0);
```

In that code we use our friend the `scan` operator to sum each new value to the total aggregate result.

Now we just have to push score to our Subject whenever we hit an enemy; that happens in `paintHeroShots`:

spaceship_reactive/score.js

```
var SCORE_INCREASE = 10;
function paintHeroShots(heroShots, enemies) {
```

```
  heroShots.forEach(function(shot, i) {
    for (var l=0; l<enemies.length; l++) {
      var enemy = enemies[l];
      if (!enemy.isDead && collision(shot,
enemy)) {
»         ScoreSubject.onNext(SCORE_INCREASE);
          enemy.isDead = true;
          shot.x = shot.y = -100;
          break;
      }
    }

    shot.y -= SHOOTING_SPEED;
    drawTriangle(shot.x, shot.y, 5, '#ffff00',
'up');
  });
}
```

And of course, we add **paintScore** to **renderScene** so the score appears onscreen:

spaceship_reactive/score.js

```
function renderScene(actors) {
  paintStars(actors.stars);
  paintSpaceShip(actors.spaceship.x,
```

```
actors.spaceship.y);
  paintEnemies(actors.enemies);
  paintHeroShots(actors.heroShots,
actors.enemies);
» paintScore(actors.score);
}
```

That completes our Spaceship Reactive game. With about 200 lines we've managed to code an entire game in the browser, avoiding changing any external state through the power of Observable pipelines.

## Ideas for Improvements

I'm sure you already have some ideas for making the game even more exciting, but let me propose some improvements that will make the game better and sharpen your RxJS skills at the same time:

- Add a second (or third!) star field that moves at a different speed to create a parallax effect. This could be done in several different ways. Try to reuse existing code and to do it as declaratively as you can.
- Make more unpredictable enemies by making them fire at random intervals instead of the fixed one specified in `ENEMY_SHOOTING_FREQ`. Extra points if you can make them fire more quickly as the player's score gets higher!
- Allow the player to get more points by hitting several enemies in a short amount of time.

## Wrapping Up

We've built an entire game for the browser using only Observables, and along the way we've seen several extremely convenient methods to handle concurrency and to compose and transform Observables. This is one of the strengths of RxJS: there is always a method to help with the problem you're trying to tackle. Feel free to explore them in the RxJS documentation. [18]

Reactive programming makes it easy to write concurrent programs. The Observable abstraction and the powerful RxJS methods make it natural for different parts of a program to interact efficiently. Programming without relying on external state might take some getting used to, but it has enormous benefits. We can encapsulate entire behaviors in a single Observable pipeline, making our program more solid and reliable.

In the next chapter we'll pick up our earthquake visualizer application where we left it and add a Node.js server part that shows tweets related to the earthquakes. We'll also improve its user interface to make it look like a real earthquake dashboard.

FOOTNOTES

[18] https://github.com/Reactive-Extensions/RxJS/blob/master/doc/api/core/observable.md

# Chapter 4

# Building a Complete Web Application

In this chapter we'll build a typical web application, using RxJS in the front end and back end. We'll transform the Document Object Model (DOM) and do client-server communication using WebSockets in a Node.js server.

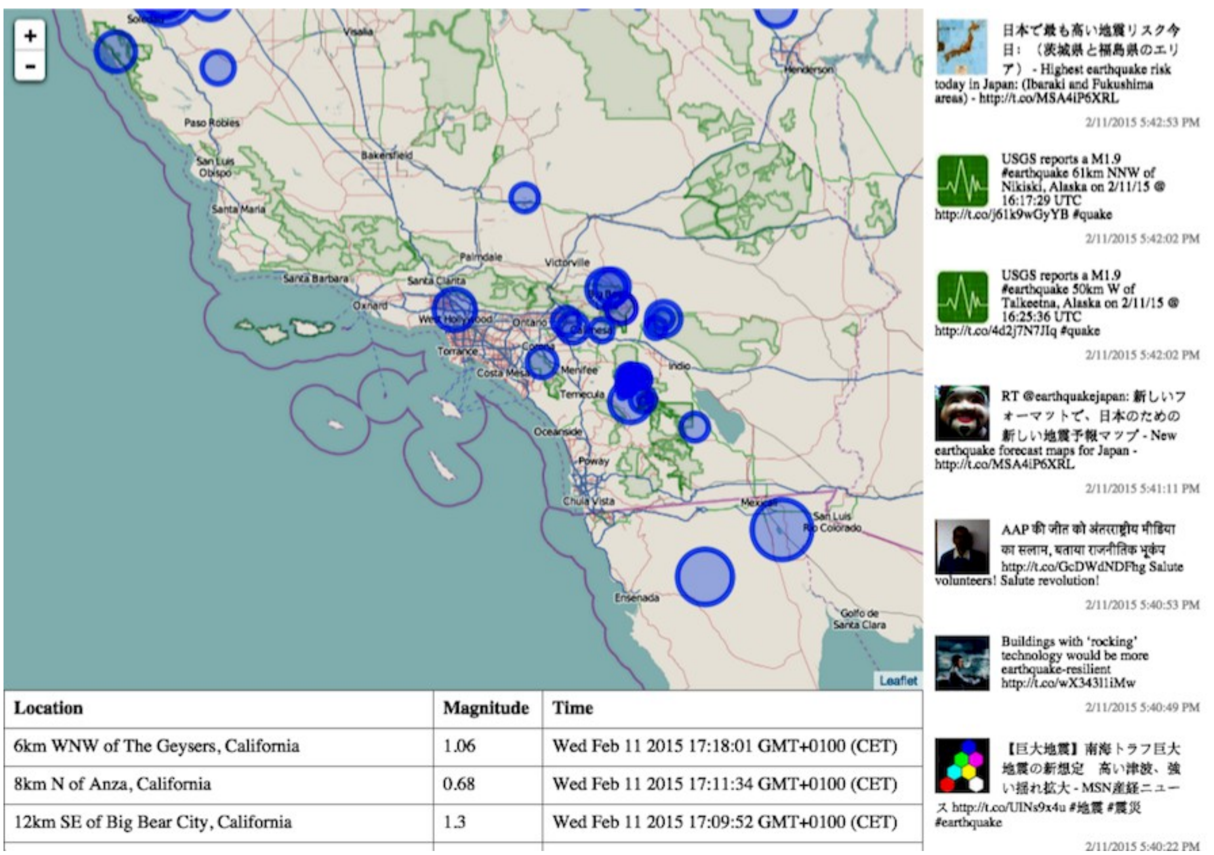
For the user-interface bits, we'll use the RxJS-DOM library, a library by the same team that made RxJS, which provides convenient operators to deal with DOM and browser-related stuff that will make our lives easier. For the server part, we'll use two well-established node libraries and wrap some of their APIs with Observables to use them in our application.

After this chapter, you'll be able to use RxJS to build user interfaces in a declarative way, using the techniques we've seen so far and applying them to the DOM. You'll also be ready to use RxJS in any Node.js project and able to use reactive programming and RxJS in any project.

# Building a Real-Time Earthquake Dashboard

We'll be building both server and client parts for an earthquake dashboard application, picking up where we left the application we started in *Making a Real-Time Earthquake Visualizer*. We'll build the server in Node.js, and improve our application to make it more interactive and informative.

The screenshot shows how the dashboard will look when we're finished:



Our starting point will be the code from *Making a Real-Time Earthquake Visualizer*, which we left like this:

examples_earthquake/code1_3.js

```
var quakes = Rx.Observable
  .interval(5000)
  .flatMap(function() {
    return Rx.DOM.jsonpRequest({
      url: QUAKE_URL,
      jsonpCallback: 'eqfeed_callback'
    }).retry(3);
  })
  .flatMap(function(result) {
    return
Rx.Observable.from(result.response.features);
  })
  .distinct(function(quake) { return
quake.properties.code; });

quakes.subscribe(function(quake) {
  var coords = quake.geometry.coordinates;
  var size = quake.properties.mag * 10000;

  L.circle([coords[1], coords[0]],
size).addTo(map);
```

```
});
```

This code already has one potential bug: it could be executed before the DOM is ready, throwing errors whenever we try to use DOM elements in our code. What we want is to load our code after the `DOMContentLoaded` event is fired, which signals the moment the browser is aware of all the elements on the page.

RxJS-DOM provides the `Rx.DOM.ready()` Observable, which emits once, when `DOMContentLoaded` is fired. So let's wrap our code in an `initialize` function and execute it when we subscribe to `Rx.DOM.ready()`:

examples_earthquake_ui/code1.js

```
function initialize() {
  var quakes = Rx.Observable
    .interval(5000)
    .flatMap(function() {
      return Rx.DOM.jsonpRequest({
        url: QUAKE_URL,
        jsonpCallback: 'eqfeed_callback'
      });
    })
    .flatMap(function(result) {
      return
```

```
Rx.Observable.from(result.response.features);
    })
    .distinct(function(quake) { return
quake.properties.code; });

  quakes.subscribe(function(quake) {
    var coords = quake.geometry.coordinates;
    var size = quake.properties.mag * 10000;

    L.circle([coords[1], coords[0]],
size).addTo(map);
  });
}

Rx.DOM.ready().subscribe(initialize);
```

Next, we'll add an empty table to our HTML, which is where we'll populate earthquake data in the next section:

```
<table>
  <thead>
    <tr>
      <th>Location</th>
      <th>Magnitude</th>
      <th>Time</th>
```

```
    </tr>
  </thead>
  <tbody id="quakes_info">
  </tbody>
</table>
```

With this, we're ready to start writing the new code for our dashboard.

## Adding a List of Earthquakes

The first feature in the new dashboard is to display a real-time list of earthquakes, including information about their locations, magnitudes, and dates. The data for this list is the same as for the map, which comes from the USGS website. We'll first create a function that returns a `row` element given a `props` object parameter:

examples_earthquake_ui/code2.js

```
function makeRow(props) {
  var row = document.createElement('tr');
  row.id = props.net + props.code;

  var date = new Date(props.time);
  var time = date.toString();
  [props.place, props.mag, time].forEach(function
(text) {
    var cell = document.createElement('td');
    cell.textContent = text;
    row.appendChild(cell);
  });

  return row;
}
```

The `props` parameter is the same as the `properties` property in the JSON that we retrieve from the USGS site.

To generate the rows, we'll make another subscription to the `quakes` Observable. This subscription creates a row in the table for each new earthquake received. We add the code at the end of the `initialize` function:

examples_earthquake_ui/code2.js

```
var table = document.getElementById('quakes_info'
);
quakes
  .pluck('properties')
  .map(makeRow)
  .subscribe(function(row) {
table.appendChild(row); });
```

The `pluck` operator extracts the value of `properties` from each earthquake object, because it contains all the info we need for `makeRow`. Then we `map` each earthquake object to `makeRow` to transform it into a populated HTML `tr` element. Finally, in the subscription we append every emitted row to our table.

This should give us a nicely populated table whenever we receive the earthquake data.

Looks good, and it was easy enough! Still, we can make some improvements. First, though, we need to explore an important concept in RxJS: hot and cold Observables.

## Hot and Cold Observables

"Hot" Observables emit values regardless of Observers being subscribed to them. On the other hand, "cold" Observables emit the entire sequence of values from the start to every Observer.

### Hot Observables

An Observer subscribed to a hot Observable will receive values emitted from the exact moment it subscribes to it. Every other Observer subscribed at that moment will receive the exact same values. This is similar to how JavaScript events work.

Mouse events and a stock-exchange ticker are examples of hot Observables. In both cases the Observable emits values regardless of whether it has subscribers, and could already be producing values before any subscriber is listening. Here's an example:

hot_cold.js

```
var onMove = Rx.Observable.fromEvent(document,
'mousemove');
```

```
var subscriber1 = onMove.subscribe(function(e) {
  console.log('Subscriber1:', e.clientX,
e.clientY);
});
var subscriber2 = onMove.subscribe(function(e) {
  console.log('Subscriber2:', e.clientX,
e.clientY);
});

// Result:
// Subscriber1: 23 24
// Subscriber2: 23 24
// Subscriber1: 34 37
// Subscriber2: 34 37
// Subscriber1: 46 49
// Subscriber2: 46 49
// ...
```

In the example, both subscribers receive the same values from the Observable as they are emitted. To JavaScript programmers, that behavior feels natural because it resembles how JavaScript events work.

Now let’s see how cold Observables work.

### Cold Observables

A cold Observable emits values only when Observers subscribe to it.

For example, `Rx.Observable.range` returns a cold Observable. Every new Observer that subscribes to it will receive the whole range:

hot_cold.js

```
function printValue(value) {
  console.log(value);
}

var rangeToFive = Rx.Observable.range(1, 5);
var obs1 = rangeToFive.subscribe(printValue); //
1, 2, 3, 4, 5
var obs2 = Rx.Observable
  .just() // Creates an empty Observable
  .delay(2000)
  .flatMap(function() {
    return rangeToFive.subscribe(printValue); //
1, 2, 3, 4, 5
  });
```

Understanding when we're dealing with hot or cold Observables is essential to avoid subtle and sneaky bugs. For example, **Rx.Observable.interval** returns an Observable that produces an increasing integer value at regular intervals of time. Imagine we want to use it to push the same values to several Observers. We could implement it like this:

hot_cold.js

```
var source = Rx.Observable.interval(2000);
var observer1 = source.subscribe(function (x) {
  console.log('Observer 1, next value: ' + x);
});

var observer2 = source.subscribe(function (x) {
  console.log('Observer 2: next value: ' + x);
});
```

Output:

```
<= Observer 1, next value: 0
   Observer 2: next value: 0
   Observer 1, next value: 1
   Observer 2: next value: 1
   ...
```

That seems to work. But now imagine that we need the second subscriber to join three seconds after the first one:

hot_cold.js

```
var source = Rx.Observable.interval(1000);
var observer1 = source.subscribe(function (x) {
  console.log('Observer 1: ' + x);
});

setTimeout(function() {
  var observer2 = source.subscribe(function (x) {
    console.log('Observer 2: ' + x);
  });
}, 3000);
```

Output:

```
<= Observer 1: 0
   Observer 1: 1
   Observer 1: 2
   Observer 1: 3
   Observer 2: 0
   Observer 1: 4
   Observer 2: 1
   ...
```

Now we see that something is really off. When subscribing three seconds later, `observer2` receives all the values that the source already pushed, instead of starting with the current value and continuing from there, because `Rx.Observable.interval` is a *cold* Observable. If the difference between hot and cold Observables is not clear, scenarios like this can be surprising.

If we have several Observers listening to a cold Observable, they will receive copies of the same sequence of values. So strictly speaking, although the Observers are sharing the same Observable, they are not sharing the same exact sequence of values. If we want the Observers to share the same sequence, we need a hot Observable.

### From Cold to Hot Using publish

We can turn a cold Observable into a hot one using `publish`. Calling `publish` creates a new Observable that acts as a proxy to the original one. It does that by subscribing itself to the original and pushing the values it receives to its subscribers.

A *published* Observable is actually a `ConnectableObservable`, which has an extra method called `connect` that we call to start receiving values. This allows us to subscribe to it before it starts running:

hot_cold.js

```
// Create an Observable that yields a value every
second
```

```
var source = Rx.Observable.interval(1000);
var publisher = source.publish();

// Even if we are subscribing, no values are
pushed yet.
var observer1 = publisher.subscribe(function (x) {
  console.log('Observer 1: ' + x);
});

// publisher connects and starts publishing values
publisher.connect();

setTimeout(function() {
  // 5 seconds later, observer2 subscribes to it
and starts receiving
  // current values, not the whole sequence.
  var observer2 = publisher.subscribe(function (x)
{
    console.log('Observer 2: ' + x);
  });
}, 5000);
```

## Sharing a Cold Observable

Let’s get back to our earthquake example. The code we have so far looks reasonable; we have an Observable `quakes` with two subscriptions: one that paints earthquakes on the map, and one that lists them in the table.

But we can make our code much more efficient. By having two subscribers to `quakes` we’re, in fact, requesting the data twice. You can check that by putting a `console.log` inside the `flatMap` operator in `quakes`.

This happens because `quakes` is a cold Observable, and it will re-emit all its values to each new subscriber, so a new subscription means a new JSONP request. This impacts our application performance by requesting the same resources twice over the network.

For the next example we’ll use the `share` operator, which automatically creates a subscription to the Observable when the number of Observers goes from zero to one. This spares us from calling `connect`:

examples_earthquake_ui/code2.js

```
var quakes = Rx.Observable
  .interval(5000)
  .flatMap(function() {
    return Rx.DOM.jsonpRequest({
```

```
      url: QUAKE_URL,
      jsonpCallback: 'eqfeed_callback'
    });
  })
  .flatMap(function(result) {
    return
Rx.Observable.from(result.response.features);
  })
  .distinct(function(quake) { return
quake.properties.code; })
»  .share()
```

Now `quakes` behaves like a hot Observable, and we don’t have to worry about how many Observers we connect to it, since they will all receive the exact same data.

## Buffering Values

Our preceding code works well, but notice that we insert a `tr` node every time we receive information about an earthquake. That’s inefficient, because with each insertion we’re modifying the DOM and causing a repaint of the page, making the browser do unnecessary work to calculate the new layout. This can cause noticeable performance drop.

Ideally, we would batch several incoming earthquake objects and insert each batch every few seconds. That would be tricky to implement by hand because we'd have to keep counters and element buffers, and we would have to remember to reset them with every batch. But with RxJS we can just use one of the buffer-based RxJS operators, like **bufferWithTime**.

With **bufferWithTime** we can buffer incoming values and release them as an array every *x* period of time:

examples_earthquake_ui/code3.bufferWithTime.js

```
var table = document.getElementById('quakes_info');
quakes
  .pluck('properties')
  .map(makeRow)
① .bufferWithTime(500)
② .filter(function(rows) { return rows.length > 0; }) // )
  .map(function(rows) {
    var fragment = document.createDocumentFragment();
    rows.forEach(function(row) {
③     fragment.appendChild(row);
    });
```

```
    return fragment;
  })
  .subscribe(function(fragment) {
    table.appendChild(fragment);
  });
```

This is what's going on in the new code:

① Buffer every incoming value and release the batch of values every 500 milliseconds.

② `bufferWithTime` executes every 500ms no matter what, and if there have been no incoming values, it will yield an empty array. We'll filter those.

③ We insert every row into a *document fragment*, which is a document without a parent. This means it's not in the DOM, and modifying its contents is very fast and efficient.

④ Finally, we append the fragment to the DOM. An advantage of appending a fragment is that it counts as a single operation, causing just one redraw. It also appends the fragment's children to the same element to which we're appending the fragment itself.

Using buffers and fragments, we manage to keep row insertion performant while keeping the real-time nature of our application (with a maximum delay of half a second). Now we're ready to add the next feature to our dashboard: interactivity!

## Adding Interaction

We now have earthquakes on the map and in a list, but no interaction between both representations yet. It would be nice, for example, to center an earthquake on the map whenever we click it on the list, and to highlight an earthquake with a circle on the map when we move the mouse over its row. Let's get to it.

In Leaflet, you can draw on a map and put drawings in their own layers so you can manipulate them individually. Let's create a group of layers called `quakeLayer` where we'll store all the earthquake circles. Each circle will be a layer inside the group. We'll also create an object `codeLayers` where we'll store the correlation between an earthquake code and the internal layer ID, so that we can refer to circles by the earthquake ID:

examples_earthquake_ui/code3.js

```
var codeLayers = {};
var quakeLayer = L.layerGroup([]).addTo(map);
```

And now in the subscription for the `quakes` Observable inside `initialize`, we'll add each circle to the layer group and store its ID in `codeLayers`. If this seems a bit intricate, it's because that's the only way Leaflet allows us to refer to drawings in a map.

examples_earthquake_ui/code3.js

```
quakes.subscribe(function(quake) {
  var coords = quake.geometry.coordinates;
  var size = quake.properties.mag * 10000;

  var circle = L.circle([coords[1], coords[0]],
size).addTo(map);
»  quakeLayer.addLayer(circle);
»  codeLayers[quake.id] =
quakeLayer.getLayerId(circle);
});
```

Let's now create the hovering effect. We'll write a new function, `isHovering`, which returns an Observable that emits a Boolean value for whether the mouse is over a particular earthquake circle at any given moment:

examples_earthquake_ui/code3.js

```
①var identity = Rx.helpers.identity;

 function isHovering(element) {
②  var over =
 Rx.DOM.mouseover(element).map(identity(true));
③  var out =
 Rx.DOM.mouseout(element).map(identity(false));
```

```
④  return over.merge(out);

 }
```

① `Rx.helpers.identity` is the identity function. Given a parameter *x*, it returns *x*. This way we don't have to write functions that return the value they receive.

② `over` is an Observable that emits `true` when the user hovers the mouse over the element.

③ `out` is an Observable that emits `false` when the user moves the mouse outside of the element.

④ `isHovering` merges both `over` and `out`, returning an Observable that emits `true` when the mouse is over an element, and `false` when it leaves it.

With `isHovering` in place we can modify the subscription that creates the rows, so that we subscribe to events in each row as it is created:

examples_earthquake_ui/code3.js

```
var table = document.getElementById('quakes_info'
);
quakes
  .pluck('properties')
  .map(makeRow)
  .bufferWithTime(500)
```

```
  .filter(function(rows) { return rows.length > 0; })
  .map(function(rows) {
    var fragment = document.createDocumentFragment();
    rows.forEach(function(row) {
①      var circle = quakeLayer.getLayer(codeLayers[row.id]);

②      isHovering(row).subscribe(function(hovering) {
        circle.setStyle({ color: hovering ? '#ff0000' : '#0000ff' });
      });

③      Rx.DOM.click(row).subscribe(function() {
        map.panTo(circle.getLatLng());
      });

      fragment.appendChild(row);
    });
    return fragment;
  })
  .subscribe(function(fragment) {
```

```
    table.appendChild(fragment);
  });
```

① We get the circle element for the earthquake on the map using the ID we get from the row element. With that, `codeLayers` gives us the corresponding internal ID, which gets us the circle element using `quakeLayer.getLayer`.

② We call `isHovering` with the current row and we subscribe to the resulting Observable. If the `hovering` argument is `true`, we'll paint the circle red; otherwise, it will be blue.

③ We subscribe to the Observable created from the `click` event in the current row. When the row in the list is clicked, the map will be centered on the corresponding circle in the map.

## Making It Efficient

Experienced front-end developers know that creating many events on a page is a recipe for bad performance. In our previous example, we created three events for each row. If we get 100 earthquakes on the list, we would have 300 events floating around the page just to do some light highlighting work! That is terrible for performance, and we can do better.

Because events in DOM always bubble up (from children to parent elements), a well-known technique among front-end developers to avoid attaching mouse events to many elements individually is to attach them instead to their parent element.

Once the event is fired on the parent, we can use the event's `target` property to find the child element that was the event's target.

Because we'll need similar functionality for the events `click` and `mouseover`, we'll create a function `getRowFromEvent`:

examples_earthquake_ui/code3.pairwise.js

```
function getRowFromEvent(event) {
  return Rx.Observable
    .fromEvent(table, event)
①    .filter(function(event) {
      var el = event.target;
      return el.tagName === 'TD' &&
el.parentNode.id.length;
    })
②    .pluck('target', 'parentNode')
③    .distinctUntilChanged();
}
```

`getRowFromEvent` gives us the table row in which the event has happened. Here are the details:

① We make sure that we get events happening in a table cell, and we check that the parent of that cell is a row with an ID attribute. These rows are the ones we tagged with the earthquake ID.

② The `pluck` operator extracts the nested property `parentNode` inside the element's `target` property.

③ This prevents getting the same element more than once. That would happen a lot with the `mouseover` event, for example.

In the previous section we attached the events `mouseover` and `mouseout` on each row to change the earthquake circle color each time the mouse entered or exited the row. Now, we'll use only the `mouseover` event on the table, combined with the convenient `pairwise` operator:

examples_earthquake_ui/code3.pairwise.js

```
getRowFromEvent('mouseover')
  .pairwise()
  .subscribe(function(rows) {
     var prevCircle =
quakeLayer.getLayer(codeLayers[rows[0].id]);
     var currCircle =
quakeLayer.getLayer(codeLayers[rows[1].id]);

     prevCircle.setStyle({ color: '#0000ff' });
     currCircle.setStyle({ color: '#ff0000' });
    });
```

`pairwise` groups each emitted value with the previously emitted value in an array. Because we're always getting distinct rows, `pairwise` will always yield the row that the mouse just left and the row where the mouse is hovering now. With this information, it is easy to color each earthquake circle accordingly.

Handling the `click` event is even simpler:

examples_earthquake_ui/code3.pairwise.js

```
getRowFromEvent('click')
  .subscribe(function(row) {
     var circle =
quakeLayer.getLayer(codeLayers[row.id]);
     map.panTo(circle.getLatLng());
    });
```

And we can go back to just subscribing to `quakes` to generate the rows:

examples_earthquake_ui/code3.pairwise.js

```
quakes
  .pluck('properties')
  .map(makeRow)
  .subscribe(function(row) {
table.appendChild(row); });
```

Our code is now much more clean and idiomatic, and it doesn't depend on the rows being there. If there are no rows, `getRowFromEvent` won’t try to yield any.

What’s more important, our code now is very efficient. Regardless of the amount of earthquake information we retrieve, we’ll always have just a single `mouseover` event and a single `click` event, instead of hundreds of events.

## Getting Real-Time Updates from Twitter

The second part of our plan to make a real-time dashboard for earthquakes is to add reports and information from Twitter related to the different earthquakes happening on the planet. For this, we'll create a small Node.js program that will fetch the stream of tweets related to the earthquakes.

### Setting Up Our Node.js Environment

Let's configure our Node.js application. Besides RxJS, we will be using two venerable third-party modules to make our life easier: `ws` and `twit`.[19] Any similar modules should work with minimal changes to the code.

First, let's create a folder for our application and install the modules that we'll use. (Note that the output of the `npm` command may vary depending on the current versions of the packages.)

```
~$ mkdir tweet_stream
~$ cd tweet_stream
~/tweet_stream$ npm install ws twit rx
rx@3.1.2 node_modules/rx


twit@1.1.19 node_modules/twit
```

```
└── oauth@0.9.9

ws@0.8.0 node_modules/ws
├── options@0.0.6
├── ultron@1.0.2
├── utf-8-validate@1.2.1 (bindings@1.2.1,
nan@2.0.9)
└── bufferutil@1.2.1 (bindings@1.2.1, nan@2.0.9)
```

## Client–Server Communication

Now we're ready to start building our application. Let's create a new file called `index.js` inside the `tweet_stream` folder to load the modules we'll use:

examples_earthquake_ui/tweet_stream/index.js

```javascript
var WebSocketServer = require('ws').Server;
var Twit = require('twit');
var Rx = require('rx');
```

To use the Twitter API, you need to request a consumer key and an access token in the Twitter website. Once you have that, create a new `Twit` object with a configuration object, like this:

examples_earthquake_ui/tweet_stream/index.js

```javascript
var T = new Twit({
```

```
  consumer_key: 'rFhfB5hFlth0BHC71qQkEtTyw',

  consumer_secret:
'zcrXEM1jiOdKyiFFlGYFAOo43Hsz383i0cdHYYWqBXTBoVAr1
',
  access_token: '14343133-
nlxZbtLuTEwgAlaLsmfrr3D4QAoiV2fa6xXUVEwW9',
  access_token_secret:
'57Dr99wECljyyQ9tViJWz0H3obNG3V4cr5Lix9sQBXju1'
});
```

Now we can create a function, `onConnect`, that will do all the work of searching tweets and communicating with the client in the future, and we can initiate a WebSocket server that will call `onConnect` once the WebSocket is connected and ready:

examples_earthquake_ui/tweet_stream/index.js

```
function onConnect(ws) {
  console.log('Client connected on localhost:8080'
);
}

var Server = new WebSocketServer({ port: 8080 });
Rx.Observable.fromEvent(Server, 'connection'
).subscribe(onConnect);
```

We can now launch our application, and it should start a WebSocket connection on port 8080:

```
~/tweet_stream$ node index.js
```

The message about a client connection is not printed yet because we haven't connected any browser to this server. Let's now switch to the code for our dashboard and do that. We'll use the `fromWebSocket` operator in RxJS-DOM:

examples_earthquake_ui/code4.js

```
function initialize() {
  var socket = Rx.DOM.fromWebSocket(
'ws://127.0.0.1:8080');
  ...
```

In the preceding code, `fromWebSocket` creates a Subject that serves as the sender and receiver of messages to the WebSocket server. By calling `socket.onNext` we'll be able to send messages to the server, and by subscribing to `socket` we'll receive any messages the server sends us.

We can now send the server messages with the earthquake data we receive:

examples_earthquake_ui/code4.js

```
quakes.bufferWithCount(100)
  .subscribe(function(quakes) {
    console.log(quakes);
    var quakesData = quakes.map(function(quake) {
      return {
        id: quake.properties.net +
quake.properties.code,
        lat: quake.geometry.coordinates[1],
        lng: quake.geometry.coordinates[0],
        mag: quake.properties.mag
      };
    });
»     socket.onNext(JSON.stringify({quakes:
quakesData }));
  });
```

And we can set up a subscriber for messages coming from the server:

examples_earthquake_ui/code4.js

```
socket.subscribe(function(message) {
  console.log(JSON.parse(message.data));
});
```

Now when we reload the browser, the client message should appear in the terminal:

```
~/tweet_stream$ node index.js
Client connected on localhost:8080
```

Fantastic! The browser should be sending commands to the server as soon as it starts receiving earthquakes from the remote JSONP resource. For now, the server completely ignores those messages, though. Time to go back to our tweet stream code and do something with them.

First we'll connect to the `message` events that arrive to the server from the browser client. Whenever the client sends a message, the WebSocket server emits a `message` event with the contents of the message. In our case, the contents are a `stringified` object.

We can write the following code in our `onConnect` function:

examples_earthquake_ui/tweet_stream/index.js

```
var onMessage = Rx.Observable.fromEvent(ws,
'message')
  .subscribe(function(quake) {
    quake = JSON.parse(quake);
    console.log(quake);
  });
```

If we restart the server (`Ctrl`-`C` in the terminal) and reload the browser, we should see the earthquake details being printed in the terminal as they come in. That's perfect. Now we're ready to start looking for tweets related to our earthquakes.

## Retrieving and Sending Tweets

We're using the streaming Twitter client for Node.js `twit` to connect to Twitter and search tweets. All the code in the server from now on will happen inside the `onConnect` function because it assumes that a connection to a WebSocket is already established. Let's initialize the stream of tweets:

examples_earthquake_ui/tweet_stream/index.js

```
var stream = T.stream('statuses/filter', {
  track: 'earthquake',
  locations: []
});
```

This tells our `Twit` instance `T` to start streaming Twitter statuses, filtered by the keyword `earthquake`. This is, of course, very generic and not that directly related to the earthquakes happening right now. But notice the empty `locations` array. This is an array of latitude and longitude boundaries that we can use to filter tweets by their geographic location, along with the word *earthquake*. That's much more specific! Alright, let's subscribe to this stream and start sending tweets to the browser:

examples_earthquake_ui/tweet_stream/index.js

```
Rx.Observable.fromEvent(stream, 'tweet'
).subscribe(function(tweetObject) {
  ws.send(JSON.stringify(tweetObject), function
(err) {
    if (err) {
      console.log('There was an error sending the
message');
    }
  });
});
```

If we restart the server and reload the browser, we should receive tweets in the browser, and the console in the development panel should be printing the tweets.

These tweets are not filtered by earthquake location yet. To do that, we need to do the following things with each piece of earthquake information we receive:

- Take the longitude and latitude pair of epicenter coordinates of each earthquake and create a bounding box that delimits the geographical area of the tweets that we consider related to the earthquake.

- Accumulate all the boundary coordinates so that tweets sent to the client keep being relevant to the earthquakes on the map.
- Update the `twit` stream with the new coordinates every time we receive the message for a new earthquake.

Here’s a way to do it:

examples_earthquake_ui/tweet_stream/index.js

```
Rx.Observable
  .fromEvent(ws, 'message')
  .flatMap(function(quakesObj){
    quakesObj = JSON.parse(quakesObj);
    return Rx.Observable.from(quakesObj.quakes);
  })
① .scan([], function(boundsArray, quake) {
②   var bounds = [
      quake.lng - 0.3, quake.lat - 0.15,
      quake.lng + 0.3, quake.lat + 0.15
    ].map(function(coordinate) {
      coordinate = coordinate.toString();
      return coordinate.match(/\-?\d+(\.\-?
\d{2})?/)[0];
```

```
    });

    boundsArray = boundsArray.concat(bounds);
③    return
boundsArray.slice(Math.max(boundsArray.length -
50, 0));
  })
④  .subscribe(function(boundsArray) {
    stream.stop();
    stream.params.locations =
boundsArray.toString();
    stream.start();
  });
```

And here is the step-by-step of what is happening in the preceding code:

① We meet our old friend **scan** again. Any time we need to accumulate results and yield each intermediate result, **scan** is our friend. In this case, we'll keep accumulating earthquake coordinates in the **boundsArray** array.

From the single latitude/longitude pair of coordinates of the ② epicenter of the earthquake, we create an array that contains an area determined by a north-west coordinate and a south-east one. The numbers used to approximate the bounds create a rectangle the size of a large city.

After that, we use a regular expression to limit the decimal precision of each coordinate to two decimals, to comply with the Twitter API requirements.

We concatenate the generated boundaries to `boundsArray`, ③ which contains every previous earthquake's boundaries. Then we take the last 25 pairs of boundaries (50 items in the array), since that is the limit of the Twitter API.

Finally, we subscribe to the Observable, and in the `onNext` ④ function we restart the current `twit` stream to reload the updated locations to filter by with our new accumulated array of locations, converted to a string.

After restarting the server and reloading the browser, we should be receiving relevant tweets in our browser application. For now, we can only see the raw objects displayed in the developer console, though. In the next section we generate the HTML to display the tweets in our dashboard.

## Showing Tweets on the Dashboard

Now that we're receiving tweets from the server, the only thing left to do is show them nicely on the screen. For this, we'll create a new HTML element where we append incoming tweets:

examples_earthquake_ui/index_final.html

```
<div id="tweet_container"></div>
```

We'll also update our socket Observable subscription to process the incoming tweet objects and append them to the tweet_container element we just created:

examples_earthquake_ui/code5.js

```
socket
  .map(function(message) { return
JSON.parse(message.data); })
  .subscribe(function(data) {
    var container = document.getElementById(
'tweet_container');
    container.insertBefore(makeTweetElement(data),
container.firstChild);
  });
```

Any new tweets will appear at the top of the list, and they will be created by makeTweetElement, a simple function that creates a tweet element and populates it with the data we pass as a parameter:

examples_earthquake_ui/code5.js

```
function makeTweetElement(tweetObj) {
  var tweetEl = document.createElement('div');
  tweetEl.className = 'tweet';
```

```
  var content = '<img src="$tweetImg"
class="avatar" />' +
    '<div class="content">$text</div>' +
    '<div class="time">$time</div>';

  var time = new Date(tweetObj.created_at);
  var timeText = time.toLocaleDateString() + ' ' +
time.toLocaleTimeString();

  content = content.replace('$tweetImg',
tweetObj.user.profile_image_url);
  content = content.replace('$text',
tweetObj.text);
  content = content.replace('$time', timeText);

  tweetEl.innerHTML = content;

  return tweetEl;
}
```

And with this we finally have a sidebar with relevant, geolocated tweets that can give us more insight about the areas affected by the earthquakes.

## Ideas for Improvements

This dashboard is already functional, but there are many improvements that could be done. Some ideas to make it better:

- Add more earthquake databases. USGS is a fantastic resource, but it mainly provides earthquakes happening in the United States. It would be interesting to merge in earthquake reports from around the world, not just the United States, and present them all together in the map. To do this, you could use the help of `merge` and `mergeAll`, and use `distinct` with a selector function to avoid duplicates.
- Whenever the user clicks on a tweet, center the map on the related earthquake. This would involve grouping the tweets by earthquake on the server, and you'd probably want to use the `groupBy` operator to group tweets to a particular geographical area.

## Wrapping Up

In this chapter we've used RxJS to create a reactive user interface that allows us to see different kinds of data about earthquakes happening on the planet in real time. We've used RxJS both in the browser client and in the Node.js server, showing how easy it is to use Observables to manage different areas of an application.

More importantly, we've seen that we can use RxJS in the same way on the client and on the server, bringing the Observable sequence abstraction everywhere in our application. And not only that. We could actually use RxJS concepts and operators across other programming languages, since RxJS is supported in many of them.

Next we'll look at *Schedulers*, a more advanced object type in RxJS that allows us to control time and concurrency with more precision, and provides a great help with testing our code.

---

**FOOTNOTES**

[19] https://github.com/websockets/ws and https://github.com/ttezel/twit

Chapter 5

# Bending Time with Schedulers

As soon as I discovered RxJS, I started using it in my projects. For a while I thought I knew how to use it effectively, but there was a nagging question: how do I know whether the operator I'm using is synchronous or asynchronous? In other words, when exactly do operators emit notifications? This seemed a crucial part of using RxJS correctly, but it felt a bit blurry to me.

The `interval` operator, I thought, is clearly asynchronous, so it must use something like `setTimeout` internally to emit items. But what if I'm using `range`? Does it emit asynchronously as well? Does it block the event loop? What about `from`? I was using these operators everywhere, but I didn't know much about their internal concurrency model.

Then I learned about Schedulers.

Schedulers are a powerful mechanism to precisely manage concurrency in your applications. They give you fine-grained control over how an Observable emits notifications by allowing you to change their concurrency model as you go. In this chapter you'll learn how to use Schedulers and apply them in common scenarios. We'll focus on testing, where Schedulers are especially useful, and you'll learn how to make your own Schedulers.

## Using Schedulers

A Scheduler is a mechanism to "schedule" an action to happen in the future. Each operator in RxJS uses one Scheduler internally, selected to provide the best performance in the most likely scenario.

Let's see how we can change the Scheduler in operators and the consequences of doing so. First let's create an array with 1,000 integers in it:

```
var arr = [];
for (var i=0; i<1000; i++) {
  arr.push(i);
}
```

Then, we create an Observable from `arr` and force it to emit all the notifications by subscribing to it. In the code we also measure the amount of time it takes to emit all the notifications:

```
var timeStart = Date.now();
Rx.Observable.from(arr).subscribe(
  function onNext() {},
  function onError() {},
  function onCompleted() {
    console.log('Total time: ' + (Date.now() -
```

```
timeStart) + 'ms');
  });
```

```
<= "Total time: 6ms"
```

Six milliseconds—not bad! `from` uses `Rx.Scheduler.currentThread` internally, which schedules work to run after any current work is finished. Once it starts, it processes all the notifications synchronously.

Now let's change the Scheduler to `Rx.Scheduler.default`.

```
var timeStart = Date.now();
Rx.Observable.from(arr, null, null, Rx.Scheduler.
default).subscribe(
  function onNext() {},
  function onError() {},
  function onCompleted() {
    console.log('Total time: ' + (Date.now() -
timeStart) + 'ms');
  });
```

```
<= "Total time: 5337ms"
```

Wow, our code runs almost a thousand times slower than with the `currentThread` Scheduler. That's because the `default` Scheduler runs each notification asynchronously. We can verify this by adding a simple log statement after the subscription.

Using the `currentThread` Scheduler:

```
Rx.Observable.from(arr).subscribe( ... );
console.log('Hi there!');
```

```
<= "Total time: 8ms"
   "Hi there!"
```

Using the `default` Scheduler:

```
Rx.Observable.from(arr, null, null,
Rx.Scheduler.timeout).subscribe( ... );
console.log('Hi there!');
```

```
<= "Hi there!"
   "Total time: 5423ms"
```

Because the Observer using the `default` Scheduler emits its items asynchronously, our `console.log` statement (which is synchronous) is executed before the Observable even starts emitting any notification. Using the `currentThread` Scheduler, all notifications happen synchronously, so the `console.log` statement gets executed only when the Observable has emitted all its notifications.

So, Schedulers really can change how our Observables work. In our case here, performance really suffered from asynchronously processing a big, already-available array. But we can actually use Schedulers to improve performance. For example, we can switch the Scheduler on the fly before doing expensive operations on an Observable:

```
arr
  .groupBy(function(value) {
    return value % 2 === 0;
  })
  .map(function(value) {
»   return value.observeOn(Rx.Scheduler.default);
  })
  .map(function(groupedObservable) {
    return expensiveOperation(groupedObservable);
  });
```

In the preceding code we group all the values in the array into two groups: even and uneven values. `groupBy` returns an Observable that emits an Observable for each group created. And here's the cool part: just before running an expensive operation on the items in each grouped Observable, we use `observeOn` to switch the Scheduler to the `default` one, so that the expensive operation will be executed asynchronously, not blocking the event loop.

### observeOn and subscribeOn

In the previous section, we used the `observeOn` operator to change the Scheduler in some Observables. `observeOn` and `subscribeOn` are instance operators that return a copy of the Observable instance, but that use the Scheduler we pass as a parameter.

`observeOn` takes a Scheduler and returns a new Observable that uses that Scheduler. It will make every `onNext` call run in the new Scheduler.

`subscribeOn` forces the subscription and un-subscription work (not the notifications) of an Observable to run on a particular Scheduler. Like `observeOn`, it accepts a Scheduler as a parameter. `subscribeOn` is useful when, for example, we're running in the browser and doing significant work in the subscribe call but we don't want to block the UI thread with it.

### Basic Rx Schedulers

Let's look a bit more in depth at the Schedulers we just used. The ones RxJS's operators use most are `immediate`, `default`, and `currentThread`.

### Immediate Scheduler

The immediate Scheduler emits notifications from the Observable synchronously, so whenever an action is scheduled on the immediate Scheduler, it will be executed right away, blocking the thread. **Rx.Observable.range** is one of the operators that uses the immediate Scheduler internally:

```
console.log('Before subscription');

Rx.Observable.range(1, 5)
  .do(function(a) {
    console.log('Processing value', a);
  })
  .map(function(value) { return value * value; })
  .subscribe(function(value) { console.log(
'Emitted', value); });

console.log('After subscription');
```

```
<= Before subscription
   Processing value 1
   Emitted 1
   Processing value 2
   Emitted 4
```

```
Processing value 3
Emitted 9
Processing value 4
Emitted 16
Processing value 5
Emitted 25
After subscription
```

The program output happens in the order we expect. Each `console.log` statement runs before the notification of the current item.

### When to Use It

The `immediate` Scheduler is very well suited for Observables that execute predictable and not-very-expensive operations in each notification. Also, the Observable has to eventually call `onCompleted`.

## Default Scheduler

The default Scheduler runs actions asynchronously. You can think of it as a rough equivalent of `setTimeout` with zero milliseconds delay that keeps the order in the sequence. It uses the most efficient asynchronous implementation available on the platform it runs (for example, `process.nextTick` in Node.js or `setTimeout` in the browser).

Let's take the previous example with `range` and make it run on the `default` Scheduler. For this, we'll use the `observeOn` operator:

```
console.log('Before subscription');
Rx.Observable.range(1, 5)
  .do(function(value) {
    console.log('Processing value', value);
  })
  .observeOn(Rx.Scheduler.default)
  .map(function(value) { return value * value; })
  .subscribe(function(value) { console.log(
'Emitted', value); });
console.log('After subscription');
```

```
<= Before subscription
  Processing value 1
  Processing value 2
  Processing value 3
  Processing value 4
  Processing value 5
  After subscription
  Emitted 1
```

```
Emitted 4
Emitted 9
Emitted 16
Emitted 25
```

There are significant differences in this output. Our synchronous `console.log` statement runs immediately for every value, but we make the Observable run on the `default` Scheduler, which yields each value asynchronously. That means our log statements in the `do` operator are processed before the squared values.

#### When to Use It

The `default` Scheduler never blocks the event loop, so it's ideal for operations that involve time, like asynchronous requests. It can also be used in Observables that never complete, because it doesn't block the program while waiting for new notifications (which may never happen).

### Current Thread Scheduler

The `currentThread` Scheduler is synchronous like the immediate Scheduler, but in case we use recursive operators, it enqueues the actions to execute instead of executing them right away. A recursive operator is an operator that itself schedules another operator. A good example is `repeat`. The `repeat` operator—if given no parameters—keeps repeating the previous Observable sequence in the chain indefinitely.

You'll get in trouble if you call `repeat` on an operator that uses the `immediate` Scheduler (such as `return`). Let's try this by repeating the value `10` and then use `take` to take only the first value of the repetition. Ideally, the code would print `10` once and then exit:

```
// Be careful: the code below will freeze your
environment!
Rx.Observable.return(10).repeat().take(1)
  .subscribe(function(value) {
    console.log(value);
  });
```

```
<= Error: Too much recursion
```

This code causes an infinite loop. Upon subscription, `return` calls `onNext(10)` and then `onCompleted`, which makes `repeat` subscribe again to `return`. Since `return` is running on the immediate Scheduler, this process repeats itself, causing an infinite loop and never getting to `take`.

But if instead we schedule `return` on the `currentThread` Scheduler by passing it as the second parameter, we get this:

```
var scheduler = Rx.Scheduler.currentThread;
Rx.Observable.return(10,
scheduler).repeat().take(1)
  .subscribe(function(value) {
    console.log(value);
  });
```

```
<= 10
```

Now, when `repeat` resubscribes to `return`, the new `onNext` call will be queued because the previous `onCompleted` is still happening. `repeat` then returns a disposable object to `take`, which calls `onCompleted` and cancels the repetition by disposing `repeat`, and ultimately the call from `subscribe` returns.

As a rule of thumb, `currentThread` should be used to iterate on large sequences and when using recursive operators such as `repeat`.

### When to Use It

The `currentThread` Scheduler is useful for operations that involve recursive operators like `repeat`, and in general for iterations that contain nested operators.

## Scheduling for Animations

For fast visual updates such as canvas or DOM animations, we can either use the `interval` operator with a very low millisecond value or we can make a Scheduler that uses a function like `setTimeout` internally to schedule notifications.

But neither approach is ideal. In both of them we're throwing all these updates at the browser, which may not be able to process them quickly enough. That happens because the browser is trying to render a frame and then it receives instructions to render the next one, so it drops the current frame to keep up the speed. The results are choppy animations. And we have enough of those on the web.

Browsers have a native way to handle animations, and they provide an API to use it called `requestAnimationFrame`. `requestAnimationFrame` allows the browser to optimize performance by lining up animations at the most appropriate time and helping us achieve smoother animations.

### There's a Scheduler for That

The RxDOM library comes with some extra Schedulers, one of which is the `requestAnimationFrame` Scheduler.

Yes, you guessed it. We can use this Scheduler to improve our spaceship video game. In it, we established a refresh speed of 40ms—roughly 25 frames per second—by creating an interval Observable at that speed and then using `combineLatest` to update the whole game scene at the speed set by `interval` (because it is the fastest-updating Observable) ... but who knows how many frames the browser is dropping by using this technique! We would get much better performance by using `requestAnimationFrame`.

Let's create an Observable that uses `Rx.Scheduler.requestAnimationFrame` as its Scheduler. Notice that it works similarly to how the `interval` operator works:

ch_schedulers/starfield_raf.js

```
function animationLoop() {
  return Rx.Observable.generate(
      0,
      function() { return true; }, // Keep generating forever
      function(x) { return x + 1; }, // Increment internal value
      function(x) { return x; }, // Value to return on each notification
      Rx.Scheduler.requestAnimationFrame); //
```

```
Schedule to requestAnimationFrame
}
```

Remember to include the RxDOM library in your HTML so that **Rx.Scheduler.requestAnimationFrame** is available.

Now, wherever we were using **interval** to animate graphics at 25 FPS, we can just use our **animationLoop** function. So our Observable to paint stars, which looked like this before:

spaceship_reactive/spaceship.js

```
var StarStream = Rx.Observable.range(1, 250)
  .map(function() {
    return {
      x: parseInt(Math.random() * canvas.width),
      y: parseInt(Math.random() * canvas.height),
      size: Math.random() * 3 + 1
    };
  })
  .toArray()
  .flatMap(function(arr) {
    return Rx.Observable.interval(SPEED).map(
function() {
      return arr.map(function(star) {
        if (star.y >= canvas.height) {
```

```
          star.y = 0;
        }
        star.y += star.size;
        return star;
      });
    });
  });
```

Becomes this:

ch_schedulers/starfield_raf.js

```
var StarStream = Rx.Observable.range(1, 250)
  .map(function() {
    return {
      x: parseInt(Math.random() * canvas.width),
      y: parseInt(Math.random() * canvas.height),
      size: Math.random() * 3 + 1
    };
  })
  .toArray()
  .flatMap(function(arr) {
»   return animationLoop().map(function() {
      return arr.map(function(star) {
        if (star.y >= canvas.height) {
          star.y = 0;
```

```
        }
        star.y += 3;
        return star;
      });
    });
  });
```

Which gives us a much smoother animation. As a bonus, the code is also cleaner!

## Testing with Schedulers

Testing is perhaps one of the most compelling scenarios where we can use Schedulers. So far in this book we've been coding our hearts out without thinking much about the consequences. But in a real-world software project, we would be writing tests to make sure our code works as we intend.

Testing asynchronous code is hard. We usually run into one of these problems:

- Simulating asynchronous events is complicated and error prone. The whole point of having tests is to avoid bugs and errors, but if your tests themselves have errors, they're not helping.
- If we want to accurately test time-based functionality, automated testing becomes really slow. For example, if we need to accurately test that an error is called after four seconds of trying to retrieve a remote file, each test will take at least that much time to run. If we run our test suite continuously, that impacts our development time.

### The TestScheduler

RxJS gives us the `TestScheduler`, a Scheduler designed to help with testing. `TestScheduler` allows us to emulate time at our convenience and create deterministic tests, where they are guaranteed to be 100% repeatable. Besides that, it allows us to execute operations that would take a considerable amount of time and compress them into an instant, while maintaining the test's accuracy.

A `TestScheduler` is a specialization of a `VirtualTimeScheduler`. `VirtualTimeScheduler`s execute actions in "virtual" time instead of in real time. Scheduled actions go in a queue and are assigned a moment in virtual time. The Scheduler then runs the actions in order when its clock advances. Because it is virtual time, everything runs immediately, without having to wait for the time specified. Let's see an example:

```
var onNext = Rx.ReactiveTest.onNext;
QUnit.test("Test value order", function(assert) {
  var scheduler = new Rx.TestScheduler();
  var subject = scheduler.createColdObservable(
    onNext(100, 'first'),
    onNext(200, 'second'),
    onNext(300, 'third')
  );

  var result = '';
  subject.subscribe(function(value) { result =
```

```
value });

  scheduler.advanceBy(100);
  assert.equal(result, 'first');

  scheduler.advanceBy(100);
  assert.equal(result, 'second');

  scheduler.advanceBy(100);
  assert.equal(result, 'third');
});
```

In the preceding code we test that some values from a cold Observable arrive in the correct order. For this, we use the helper method `createColdObservable` in `TestScheduler` to create an Observable that plays back the `onNext` notifications we pass as parameters. In each notification we specify the time at which the value of the notification should be emitted. After this, we subscribe to this Observable, advance the virtual time in the Scheduler manually, and check that it indeed emitted the expected value. If the example ran in normal time, it would take 300 milliseconds, but because we're using a `TestScheduler` to run the Observable, it will run immediately, but respecting the order.

### Writing a Real-World Test

There's no better way to understand how to bend time using virtual time than to write a test for a time-sensitive task in the real world. Let's recover an Observable from the earthquake viewer we made in *Buffering Values*:

```
quakes
  .pluck('properties')
  .map(makeRow)
  .bufferWithTime(500)
  .filter(function(rows) { return rows.length > 0;
})
  .map(function(rows) {
    var fragment =
document.createDocumentFragment();
    rows.forEach(function(row) {
      fragment.appendChild(row);
    });
    return fragment;
  })
  .subscribe(function(fragment) {
    table.appendChild(fragment);
  });
```

To make the code more testable, let's encapsulate the Observable in a function that takes a Scheduler we use in the `bufferWithTime` operator. It's always a good idea to parameterize Schedulers in Observables that will be tested.

ch_schedulers/testscheduler.js

```
function quakeBatches(scheduler) {
  return quakes.pluck('properties')
    .bufferWithTime(500, null, scheduler || null)
    .filter(function(rows) {
      return rows.length > 0;
    });
}
```

Let's also simplify the code by taking some steps out but keeping the essence. This code takes an Observable of JSON objects that contain a `properties` property, buffers them into batches released every 500 milliseconds, and filters the batches that come empty.

We want to verify that this code works, but we definitely don't want to wait several seconds every time we run tests to make sure that our buffering works as expected. This is where virtual time and the `TestScheduler` will help us:

ch_schedulers/testscheduler.js

```
①var onNext = Rx.ReactiveTest.onNext;
 var onCompleted = Rx.ReactiveTest.onCompleted;
 var subscribe = Rx.ReactiveTest.subscribe;

②var scheduler = new Rx.TestScheduler();

③var quakes = scheduler.createHotObservable(
   onNext(100, { properties: 1 }),
   onNext(300, { properties: 2 }),
   onNext(550, { properties: 3 }),
   onNext(750, { properties: 4 }),
   onNext(1000, { properties: 5 }),
   onCompleted(1100)
 );

④QUnit.test("Test quake buffering", function
 (assert) {
⑤  var results = scheduler.startScheduler(function
 () {
     return quakeBatches(scheduler)
   }, {
     created: 0,
     subscribed: 0,
     disposed: 1200
```

```
  });

⑥  var messages = results.messages;
   console.log(results.scheduler === scheduler);

⑦  assert.equal(
     messages[0].toString(),
     onNext(501, [1, 2]).toString()
   );

   assert.equal(
     messages[1].toString(),
     onNext(1001, [3, 4, 5]).toString()
   );

   assert.equal(
     messages[2].toString(),
     onCompleted(1100).toString()
   );
 });
```

Let's go step by step through the code:

① We start by loading some helper functions from **ReactiveTest**. These register **onNext**, **onCompleted**, and **subscribe** events in virtual time.

② We create a new `TestScheduler` that will drive the whole test.

③ We use the method `createHotObservable` from the `TestScheduler` to create a fake hot Observable that will simulate notifications at particular points in virtual time. In particular, it emits five notifications in the first second, and completes at 1100 milliseconds. Every time it emits an object with a particular `properties` property.

④ We can use any test framework to run the tests. For our examples, I've chosen QUnit.

⑤ We use the `startScheduler` method to create an Observable that uses a test Scheduler. The first parameter is a function that creates the Observable to run with our Scheduler. In our case, we simply return our `quakeBatches` function, to which we pass the `TestScheduler`. The second parameter is an object containing the different virtual times at which we want to create the Observable, subscribe to it, and dispose of it. For our example, we start and subscribe at virtual time 0 and we dispose of the Observable at 1200 (virtual) milliseconds.

⑥ The `startScheduler method` returns an object with a `scheduler` and a `messages` property. In `messages` we can find all the notifications emitted by the Observable in virtual time.

⑦ Our first assertion tests that after 501 milliseconds (just after the first buffer time limit) our Observable yields the values `1` and `2`.

Our second assertion tests that after 1001 milliseconds our Observable yields the remaining values `3`, `4`, and `5`. And finally, our third assertion checks that the sequence is completed exactly at 1100 milliseconds, as we specified in our hot Observable `quakes`.

That code effectively tests our highly asynchronous Observables in a very reliable way, and without having to jump through hoops to simulate asynchronous conditions. We simply specify the times at which we want our code to react in virtual time, and we use a test Scheduler to run the whole operation.

## Wrapping Up

Schedulers are an essential part of RxJS. Even if you can go a long way without explicitly using them, they are the advanced concept that will give you the edge to fine-tune concurrency in your programs. The concept of virtual time is unique to RxJS and is incredibly useful for tasks such as testing asynchronous code.

In the next chapter we'll use Cycle.js, a reactive way to create amazing web apps, based on a concept called *unidirectional dataflow*. With it, we'll create a fast web application using modern techniques that improve dramatically on the traditional way of making web apps.

Chapter 6

# Reactive Web Applications with Cycle.js

With the advent of single-page apps, websites are suddenly expected to do much more, even compete against (gasp!) “native” apps. While trying to make web applications faster, developers realized that particular areas were bottlenecks keeping web applications from being as fast and robust as their native counterparts.

Spearheaded by Facebook React,[20] several web frameworks are coming up with new techniques to make faster web applications while keeping the code simple and declarative.

In this chapter we’ll cover some new techniques to develop web applications that are here to stay, like the Virtual DOM. We’ll be using Cycle.js, a modern, simple, and beautiful framework that uses RxJS internally and applies reactive programming concepts to front-end programming.

## Cycle.js

Cycle.js is a small framework on top of RxJS for creating responsive user interfaces. It offers the features present in modern frameworks like React, such as virtual DOM and unidirectional dataflow.

**Joe asks:**

### What's the Virtual DOM?

The Document Object Model (DOM) defines the tree structure of elements in an HTML document. Every HTML element is a node in the DOM, and each node can be manipulated using methods on the node.

The DOM was originally created to represent static documents, not the super-dynamic websites that we have today. As a consequence, it was not designed to have good performance when the elements in a DOM tree were updated frequently. That's why when we make changes to the DOM there's a performance hit.

The *virtual DOM* is a representation of the DOM made in JavaScript. Every time we change state in a component, we recompute a new virtual DOM tree for the component and compare it with the previous tree. If there are differences, we render only those differences. This approach is extremely fast, because comparing JavaScript objects is fast and we make only the absolutely necessary changes to the "real" DOM.

That approach means we can write code as if we generated the whole app UI for every change. We don't have to keep track of state in the DOM. Behind the scenes, Cycle.js will check if there is anything different for every update and take care of rendering our app efficiently.

Cycle.js is designed in a reactive way, and all the building blocks in Cycle.js are Observables, which gives us enormous advantages. It is also simpler to grasp than other frameworks because there are far fewer concepts to understand and memorize. For example, all operations related to state are out of the way, encapsulated in functions called *drivers*, and we rarely need to create new ones.

# Installing Cycle.js

We could use Cycle.js by including it in an HTML page using `<script><script>` tags, but that would not be the best way to use it because Cycle.js is designed in an extremely modular way. Every module tries to be as self-sufficient as possible, and including several modules as scripts could easily load tons of duplicated code, causing unnecessary downloads and longer start-up times for our applications.

Instead, we'll use the Node Package Manager, `npm`, and *Browserify* to generate the code for our final scripts. First we'll create a new folder where the project will live, and install our project dependencies:

```
<= mkdir wikipedia-search && cd wikipedia-search
   npm install browserify
   npm install @cycle/core
   npm install @cycle/dom
```

The first `npm` command installs Browserify, which allows us to write code for the browser as if it were a Node.js application.[21] With Browserify, we can use Node.js's module loader, and it will be smart about what dependencies to include, making the code to download as small as possible. Next, we install *cycle-core* and *cycle-dom*, which are the two base modules of Cycle.js.

With this in place, we can create a file called **index.js** where we'll edit our application, and we'll compile it into a file called **bundle.js** using the local Browserify binary:

```
<= touch index.js
   `npm bin`/browserify index.js --outfile
   bundle.js
```

The preceding command will go through our dependency tree and create a **bundle.js** file that contains everything necessary to run our application, including any dependency we require in our code. We can directly include **bundle.js** in our **index.html**:

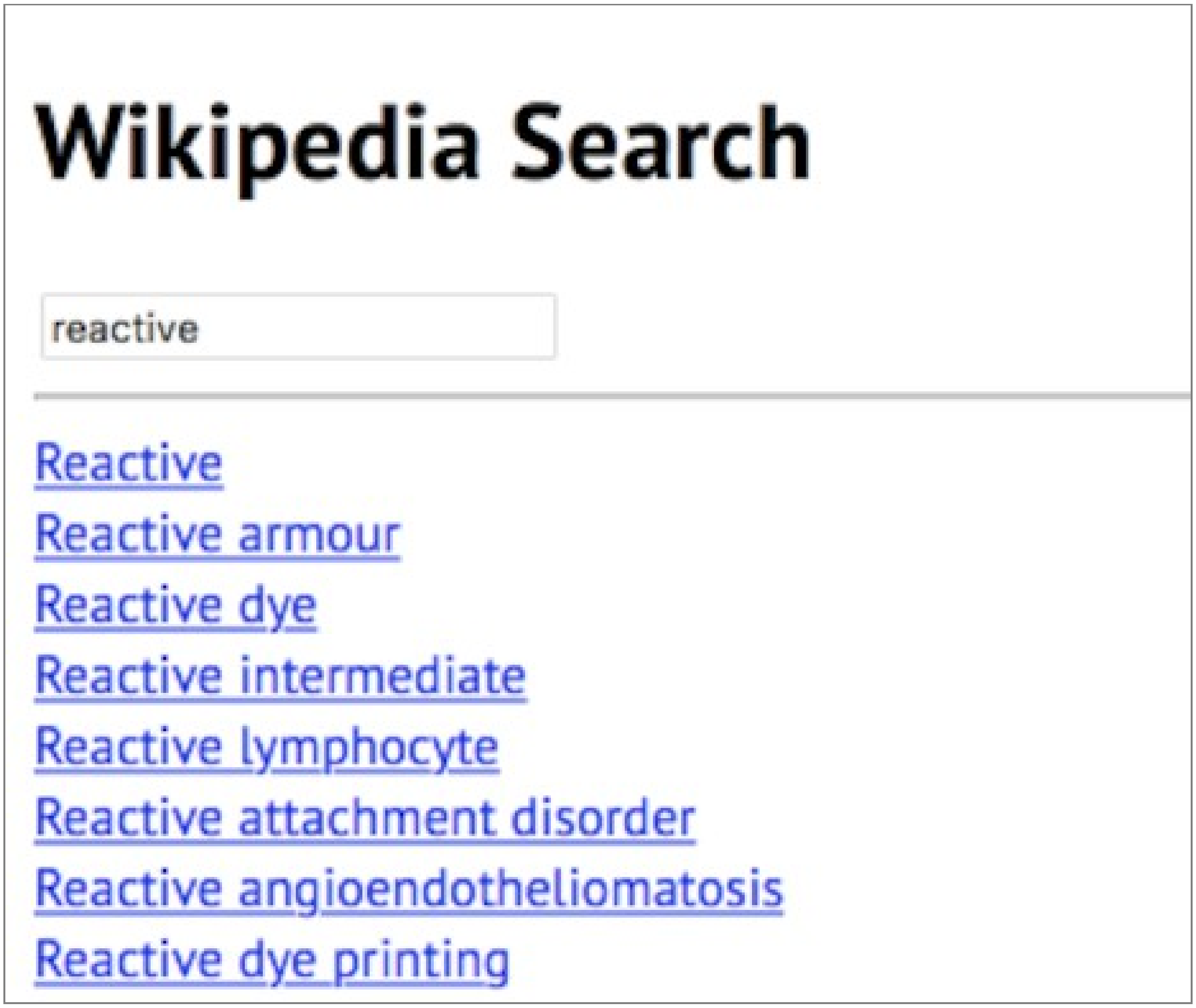
cycle/index.html

```
<!DOCTYPE html>
<html>
  <head>
    <meta charset="utf-8">
    <title>Wikipedia search</title>
  </head>
  <body>
    <div id="container"></div>
    <script src="bundle.js"></script>
```

```
  </body>
</html>
```

## Our Project: Wikipedia Search

In this section we'll build an application that searches Wikipedia as the user types.




RxJS already makes retrieving and processing the remote data easy, but, as you saw in Chapter 4, *Building a Complete Web Application*, we still need to jump through some hoops to make our DOM operations efficient.

One of the objectives of Cycle.js is to completely eliminate DOM manipulation from our code. Let's start with some basic scaffolding:

cycle/step1.js

```
var Cycle = require('@cycle/core');
①var CycleDOM = require('@cycle/dom')
var Rx = Cycle.Rx;

②function main(responses) {
   return {
     DOM: Rx.Observable.just(CycleDOM.h('span',
 'Hi there!'))
   };
 }

var drivers = {
③  DOM: CycleDOM.makeDOMDriver('#container')
 };

④Cycle.run(main, drivers);
```

This code shows the text *Hi there!* onscreen, but there's already quite a lot going on. The important parts are the `main` function and the `drivers` object. Let's go through the steps:

① We require Cycle Core and the Cycle DOM driver. I'll explain what a Cycle.js driver is in the next section.

② The `main` function is always the entry point for our application. It returns a collection of Observables, one for each driver in the application. So far we're only using one driver: the *DOM* driver.

The Observable for the DOM driver emits a virtual tree, which we create using the `h` method in the Cycle DOM library. In this case, we create only a single *span* element with the text `'Hi there!'`. The DOM driver consumes that virtual tree and renders the actual DOM on the page for it.

③ We create a DOM driver that will build the DOM tree from the items emitted by the `main` function. The DOM tree will be built in the element or selector that we pass as a parameter. In this case, `#container`.

④ The `Cycle.run` connects the `main` function with the `drivers` object, creating a circular flow between the two.

## Cycle.js Drivers

Cycle.js drivers are functions we use to cause side effects. Nowhere else in our programs should we be modifying state in any way. Drivers take an Observable that emits data from our application, and they return another Observable that causes the side effects.

We won't be creating drivers very often—only when we need side effects like modifying the DOM, reading and writing from other interfaces (for example, Local Storage), or making requests. In most applications we'll need only the DOM driver (which renders web pages) and the HTTP driver (which we can use to make HTTP requests). In this example, we'll use yet another one, the JSONP driver.

## The User Interface

We need actual content for our page, not just a *span*. Let's make a function that creates the virtual tree that represents our page:

cycle/index.js

```
function vtreeElements(results) {
  var h = CycleDOM.h;
  return h('div', [
    h('h1', 'Wikipedia Search '),
    h('input', {className: 'search-field',
attributes: {type: 'text'}}),
    h('hr'),
    h('div', results.map(function(result) {
      return h('div', [
        h('a', { href: WIKI_URL + result.title },
result.title)
```

```
        ]);
      }))
    ]);
}
```

This function might look a bit strange, but don't panic. It is using *Virtual Hyperscript*, a domain-specific language for creating virtual DOM trees. Virtual Hyperscript contains a single method, called `h`. `h` declares nodes in a way similar to how HTML does, but using JavaScript. We can add attributes to elements or append children to them by passing extra objects or arrays as parameters to `h`. The resulting virtual tree will eventually be rendered into real browser DOM.

`vtreeElements` takes an array of objects, `results`, and returns a virtual tree that represents the simple UI for our app. It renders an input field and a listing of links made from the objects in `results`, which eventually will contain Wikipedia's search results. We'll use `vtreeElements` to render our application.

### Using JSX

Instead of using the `h` function, we could write our UI using JSX, an XML-like syntax extension invented by Facebook that makes writing virtual DOM structures easier and more readable. Our `vtreeElements` function would look like this:

cycle/index.js

```
function vtreeElementsJSX(results) {
  results = results.map(function(result) {
    var link = WIKI_URL + result.title;
    return <div><a href={link}>{result.title}</a>
</div>
  });

  return <div>
    <h1>Wikipedia Search</h1>
    <input className="search-field" type="text" />
    <hr/>
    <div>{results}</div>
  </div>;
}
```

Doesn’t it look nicer? JSX looks more familiar to developers because it resembles HTML, but we can write it alongside JavaScript code, with the added advantage that we can treat it as a JavaScript type. For example, notice how we iterate the `results` array and we return a `<div>` element directly, using the value of `link` and `result.title` in the element itself. (JavaScript values can be inlined by putting them inside curly brackets.)

Since JSX is a syntax extension, we need a compiler that transforms it into the final JavaScript code (which looks very much like our `h`-based code from the previous section). We'll use *Babel* for that. Babel is a compiler that transforms modern JavaScript into JavaScript that runs everywhere.[22] It also transforms some JavaScript extensions, such as JSX, which is our particular use case.

If you want to use JSX, you need to install Babel and use it when compiling the project. Fortunately, Babel has an adapter for Browserify called *Babelify*:

```
<= npm install babelify
```

In every file that uses JSX, we need to add the following lines at the top of the file:

```
/** @jsx hJSX */
var hJSX = CycleDOM.hJSX;
```

This tells Babel to use Cycle.js's `hJSX` adapter to process JSX, instead of using the default React one.

Now when we want to compile our project, we can use the following command:

```
<= browserify index.js -t babelify --outfile
  bundle.js
```

### Getting the Search Term from the User

We need a function that returns an Observable of URLs that query Wikipedia's API using search terms entered by the user:

cycle/index.js

```
var MAIN_URL = 'https://en.wikipedia.org';
var WIKI_URL = MAIN_URL + '/wiki/';
var API_URL = MAIN_URL + '/w/api.php?' +

 'action=query&list=search&format=json&srsearch=';

function searchRequest(responses) {
  return responses.DOM.select('.search-field'
).events('input')
①    .debounce(300)
②    .map(function(e) { return e.target.value })
③    .filter(function(value) { return value.length
> 2 })
④    .map(function(search) { return API_URL +
search });
}
```

First we declare some URLs our application will use to query Wikipedia. In the function `searchRequest` we take a responses object that contains all the drivers in our application, and we use the `get` method in the DOM driver. `select(element).event(type)` behaves similarly to `fromEvent`: it takes a selector for a DOM element and the type of event to listen to and returns an Observable that emits events.

From that moment on, the rest of the code should look pretty familiar to you, since it consists of transforming an Observable's values through our usual operators:

① Throttle results to receive one every 300 milliseconds at most.
② Extract the value of the input box.
③ Take only text longer than two characters.
④ Append the final value to Wikipedia's API URL.

Great! So far we have the function to generate our UI and the function to retrieve user input from that UI. We now need to add the functionality that will get the information from Wikipedia.

## Revising Our main Function

You may have noticed in the code that the `main` function takes a parameter, `responses`, that we're not using. These are the responses that come from drivers in the `run` function. The drivers and the `main` function form a cycle (hence the name of the framework): the output of `main` is the input of the drivers, and the output of the drivers is the input for `main`. And remember, input and outputs are always Observables.

We use JSONP to query Wikipedia, as we did in Chapter 2. We using JSONP instead of HTTP to make it easier to run this example on our local computers, since retrieving data from a different domain using HTTP causes some browsers to block those requests for security reasons. In almost any other situation, especially in production code, use HTTP to retrieve remote data.

In any case, using JSONP doesn't affect the point of this chapter. Cycle has an experimental module for JSONP, and we can install it using `npm`:

```
<= npm install @cycle/jsonp
```

Then we use it in our application like this:

cycle/step2.js

```
var Cycle = require('@cycle/core');
var CycleDOM = require('@cycle/dom');
»var CycleJSONP = require('@cycle/jsonp');
var Rx = Cycle.Rx;
```

```
var h = CycleDOM.h;

function searchRequest(responses) {
  return responses.DOM.select('.search-field'
).events('input')
    .debounce(300)
    .map(function(e) { return e.target.value })
    .filter(function(value) { return value.length
> 2 })
    .map(function(search) { return API_URL +
search });
}

function vtreeElements(results) {
  return h('div', [
    h('h1', 'Wikipedia Search '),
    h('input', {className: 'search-field',
attributes: {type: 'text'}}),
    h('hr'),
    h('div', results.map(function(result) {
      return h('div', [
        h('a', { href: WIKI_URL + result.title },
result.title)
      ]);
```

```
    }))
  ]);
}

function main(responses) {
  return {
    DOM: Rx.Observable.just(CycleDOM.h('span',
'Hey there!')),
»    JSONP: searchRequest(responses)
  };
}

var drivers = {
  DOM: CycleDOM.makeDOMDriver('#container'),
»  JSONP: CycleJSONP.makeJSONPDriver()
};

Cycle.run(main, drivers);
```

We want to plug the result of `searchRequest` into the JSONP driver, so that as soon as the user types a search term, we query Wikipedia with the term.

To do that, we create a new JSONP driver using `CycleJSONP.makeJSONPDriver`, which will receive whatever we put in the property `JSONP` in the return object from `main`. After doing that, we should already be querying Wikipedia when we introduce a search term in the input box, but since we're not connecting the JSONP output to anything, we don't see any changes on the page. Let's change that:

cycle/step3.js

```
function main(responses) {
  var vtree$ = responses.JSONP
    .filter(function(res$) {
①      return res$.request.indexOf(API_URL) === 0;
    })
②    .mergeAll()
③    .pluck('query', 'search')
④    .startWith([])
⑤    .map(vtreeElements);

  return {
    DOM: vtree$,
    JSONP: searchRequest(responses)
  };
}
```

`main` receives the output of all drivers through its `responses` parameter. We can get the result of the JSON calls in `responses.JSONP`, an Observable of all the JSONP responses in our application. Once we have that, we can transform the Observable to get the search results in the form we want:

① `responses.JSONP` emits all JSONP responses in the application. We start by filtering by the ones that contain the API URL of Wikipedia in its request, to make sure that we're processing the relevant responses.

`responses.JSONP` is an Observable of Observables. For each ② response there is an Observable. In this line we flatten them all out, so we deal with the responses themselves from now on, instead of their Observables.

The responses are JSON objects, and the information we're interested in is in the `query.search` property. We use the `pluck` operator to extract it.

We don't know if we'll have any results, so at the very least ③ we ensure we'll have an empty array.

Finally, we apply our `vtreeElements` function to every result ④ from Wikipedia. This will update our UI.

Notice the *$* sign at the end of the variable's name. In this ⑤ chapter I'm adopting a naming convention used in Cycle.js code that adds *$* to the name of a variable to mean that it is an Observable. I found that it makes it much easier to understand Observable-based code!

The most important takeaway from the preceding code is that in the last step we seem to be repainting the whole UI for every single result that we receive. But here's where the virtual DOM shines. No matter how many times we re-render the page, the virtual DOM will always ensure that only the differences are rendered, making it very efficient. If there are no changes to the virtual DOM, no changes will be rendered in the page.

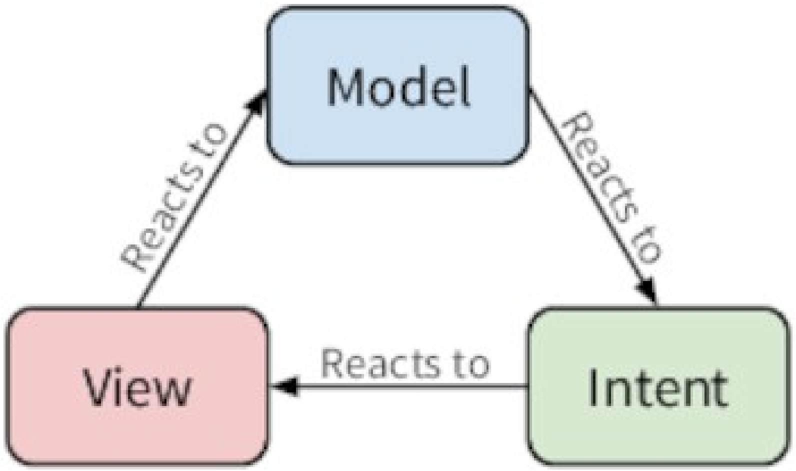
This way we don't have to worry about adding or removing elements. We just render the whole application every time, and we let the Virtual DOM figure out what to actually update under the hood.

## Model-View-Intent

The architectural approach we used to build the Wikipedia real-time search is not just another framework's random approach to programming UI. There's a design pattern behind structuring code like we did: *Model-View-Intent* (MVI).

*Model-View-Intent* is a term coined by the creator of Cycle.js, André Staltz, for an architecture inspired by the Model-View-Controller (MVC) architecture.[23] In MVC we separate the functionality of an application into three components: the model, the view, and the controller. In MVI, the three components are the model, the view, and the intent. MVI is designed to fit the Reactive model of programming like a glove.

MVI being reactive means that each component observes its dependencies and reacts to the dependencies' changes. This is different from MVC, in which a component knows its dependents and modifies them directly. A component (C) *declares* which other components influence it, instead of other components updating (C) explicitly.




The three components in MVI are represented by Observables, the output of each being the input of another component.

The *model* represents the current application state. It takes processed user input from the *intent* and it outputs events about data changes that are consumed by the *view*.

The view is a visual representation of our model. It takes an Observable with the model state, and it outputs all the potential DOM events and the virtual tree of the page.

The intent is the new component in MVI. An intent takes input from the user and translates it to actions in our model.

We can make the three kinds of components more clear in our application if we reshuffle and rename our code a bit:

cycle/index-mvi.js

```
function intent(JSONP) {
```

```
  return JSONP.filter(function(res$) {
      return res$.request.indexOf(API_URL) === 0;
    })
    .concatAll()
    .pluck('query', 'search');
}

function model(actions) {
  return actions.startWith([]);
}

function view(state) {
  return state.map(function(linkArray) {
    return h('div', [
      h('h1', 'Wikipedia Search '),
      h('input', {className: 'search-field',
attributes: {type: 'text'}}),
      h('hr'),
      h('div', linkArray.map(function(link) {
        return h('div', [
          h('a', { href: WIKI_URL + link.title },
link.title)
        ]);
      }))
```

```
    ]);
  });
}

function userIntent(DOM) {
  return DOM.select('.search-field').events('input')
    .debounce(300)
    .map(function(e) { return e.target.value })
    .filter(function(value) { return value.length > 2 })
    .map(function(search) { return API_URL + search });
}

function main(responses) {
  return {
    DOM: view(model(intent(responses.JSONP))),
    JSONP: userIntent(responses.DOM)
  };
}

Cycle.run(main, {
  DOM: CycleDOM.makeDOMDriver('#container'),
```

```
  JSONP: CycleJSONP.makeJSONPDriver()
});
```

By splitting the model, view, and intent into separate functions, we make the code much clearer. (The other intent, `userIntent`, is the input for the JSONP driver.) Most of theappplication logic is expressed as a composition of these three functions in the property we pass to the DOM driver in the `main` function:

```
function main(responses) {
  return {
    DOM: view(model(intent(responses.JSONP))),
    JSONP: userIntent(responses.DOM)
  };
}
```

It doesn't get much more functional than that!

## Creating Reusable Widgets

As we make more complex applications, we'll want to reuse some of their UI components. Our Wikipedia Search application is tiny for the sake of example, but it already has a couple of components that could be reused in other applications. Take the search input box, for example. We can definitely make this into its own widget.

The objective is to encapsulate our widget in its own component so that we use it as any other DOM element. We should also be able to parameterize the component with any properties we want. Then we'll use it in our applications like this:

```
var wpSearchBox = searchBox({
  props$: Rx.Observable.just({
    apiUrl: API_URL
  })
});
```

We'll build our widget using a concept also introduced by Cycle.js, called *nested dialogues*. A nested dialogue, or *dialogue*, is a function (like everything in Cycle.js) that takes an

Observable of events as input, and outputs an Observable—with the result of applying these inputs to its internal logic.

Let's start building the search-box component. We first create a function that takes a **responses** parameter where we'll pass it any properties we want from the main application:

cycle/searchbox.js

```
var Cycle = require('@cycle/core');
var CycleDOM = require('@cycle/dom');
var Rx = Cycle.Rx;
var h = CycleDOM.h;
var a;

function searchBox(responses) {
  var props$ = responses.props$;
  var apiUrl$ = props$.map(function (props) {
    return props['apiUrl'];
  }).first();
```

Every parameter **searchBox** receives is an Observable. In this case **props$** is an Observable that emits a single JavaScript object containing the configuration parameters for our Wikipedia search box.

After retrieving the properties, we define the virtual tree for our widget. In our case, it is a very simple one that contains just an input field:

cycle/searchbox.js

```
var vtree$ = Rx.Observable.just(
  h('div', { className: 'search-field' }, [
    h('input', { type: 'text' })
  ]));
```

We want everything to be an Observable, so we wrapped the virtual tree in a **just** Observable, which *just* returns an Observable that emits the value we pass it.

Now we need the search box to query the Wikipedia API whenever the user types a search term in the input field. We reuse the code in the function **userIntent** from our previous section:

cycle/searchbox.js

```
var searchQuery$ = apiUrl$.flatMap(function
(apiUrl) {
  return responses.DOM.select('.search-field'
).events('input')
    .debounce(300)
    .map(function (e) { return e.target.value; })
```

```
    .filter(function (value) { return value.length > 3; })
    .map(function (searchTerm) { return apiUrl + searchTerm; });
});
```

We still need to connect the output of `searchQuery` to the input of the JSON driver. We do that just like we do it in the normal Cycle application:

cycle/searchbox.js

```
return {
  DOMTree: vtree$,
  JSONPQuery: searchQuery$
};
```

And finally, we shouldn't forget to export the `searchBox` widget:

cycle/searchbox.js

```
module.exports = searchBox; // Export it as a module
```

Now we're ready to use the `searchBox` widget in our application. The `main` method will now look like this:

cycle/index-mvi2.js

```
var h = CycleDOM.h;
①var SearchBox = require('./searchbox');

function main(responses) {
②  var wpSearchBox = SearchBox({
    DOM: responses.DOM,
    props$: Rx.Observable.just({
      apiUrl: API_URL
    })
  });

③  var searchDOM$ = wpSearchBox.DOMTree;
  var searchResults$ = responses.JSONP
    .filter(function(res$) {
      return res$.request.indexOf(API_URL) === 0;
    })
    .concatAll()
    .pluck('query', 'search')
    .startWith([]);

  return {
④    JSONP: wpSearchBox.JSONPQuery,
⑤    DOM: Rx.Observable.combineLatest(
      searchDOM$, searchResults$, function(tree,
```

```
links) {
        return h('div', [
          h('h1', 'Wikipedia Search '),
          tree,
          h('hr'),
          h('div', links.map(function(link) {
            return h('div', [
              h('a', { href: WIKI_URL +
link.title }, link.title)
            ]);
          }))
        ]);
      })
  };
}

Cycle.run(main, {
  DOM: CycleDOM.makeDOMDriver('#container'),
  JSONP: CycleJSONP.makeJSONPDriver()
});
```

Now we delegate the responsibility of handling user input and rendering the search box to the `wpSearchBox` widget, which we could easily reuse in another application that requires a search box that queries URL APIs. These are the main changes:

① Import the `searchBox` widget we just created.

② Create an instance of `SearchBox`, passing the `DOM` driver and the properties we want for our search widget.

③ Our `wpSearchBox` will eventually emit items from its `DOMTree` Observable. We assign it here to use them later when we render the actual DOM.

④ We send the Wikipedia query URLs to the JSONP driver so that it retrieves its results. When those are available, it will emit them in `response.JSONP`, which we refine in `searchResults`.

⑤ To render the final DOM tree, we use `combineLatest` with `searchDOM` and `searchResults`. Each of them causes the layout to change, so we'll re-render the DOM tree whenever one of these two Observables emits an item.

With the final code in hand, we can see the greatest point of Cycle.js. There are no different classes, special types, or "magic" happening in the framework. It's all side effect--free functions that accept Observables and output more Observables. With only that, we have a concise web application framework that is clear, reactive, and fun to use. And it avoids side effects at all costs, making our web applications more robust.

## Ideas for Improvements

Besides being in urgent need of a better graphical design, our application could use some features to be more than a quick redirect to Wikipedia results:

- Let the user bookmark particular results. You could add a little star next to every result in the list so that when the user clicks, it saves that result as a favorite. You could make the star into its own widget. Extra points if you use some persistent API (reactively!), such as Local Storage or IndexedDB.
- Show a “preview” of a result on the right side of the screen if the user clicks the link, with a synopsis and some meta information about it. If the user wants to go to the actual Wikipedia result, you can have a *Read More* link in it. Implement it as a widget.

## Wrapping Up

Now you know how to develop web applications that use modern techniques without abandoning the reactive philosophy. This chapter provided an idea of how to use Observables and RxJS as the internal engine of other frameworks or applications. By standing on the shoulders of Observables and the reactive way of life, we can enormously simplify web applications and reduce state to its minimum expression, making our web applications less fragile and more maintainable.

Thank you for reading this book. I hope it helped you rethink the way you develop JavaScript applications, and challenged some of your existing concepts about programming. Here's to fast, robust, and reactive software!

---

FOOTNOTES

[20] https://facebook.github.io/react/

[21] http://browserify.org/

[22] https://babeljs.io

[23] https://en.wikipedia.org/wiki/Model–view–controller

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