FROM SCRATCH

BUILD A

Frontend Web Framework

Angel Sola Orbaiceta

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welcome

Thank you for purchasing the MEAP for *Build a Frontend Web Framework (From Scratch)*. I hope you enjoy reading this book as much as I've enjoyed writing it. I'm looking forward to you getting the same feeling of accomplishment as I did when you see your own frontend framework—written from the ground up—power web applications. There's something magical about building your own tools and seeing them working.

Throughout the book, you'll learn the most important concepts behind what makes frontend frameworks such useful tools, but not through lots of theory, but by writing all the code yourself. To make the most out of this book, I'll assume that you've got a decent understanding of JavaScript, Node JS and the Document API in the browser.

You'll start by writing an application using just JavaScript, without a framework. From that exercise, you'll identify what are the pain points of writing applications without the help of a framework. It's crucial that you understand the need for them in the first place; after all, we take them for granted these days. You'll then create your own simple framework to address what you'll discover is the main problem with vanilla JavaScript applications: the mix of DOM manipulation and business logic code.

After just two chapters (chapters three and four) you'll have a working framework, a very simple one, but a framework that you can use in small applications nevertheless. From there onwards, you'll keep adding improvements to it, such as a Single Page Application (SPA) router that changes the page without reloading it, or a Webpack loader to transform HTML templates into render functions.

By the end of the book, you'll have written a pretty decent framework of your own. Not only can you use this framework for your own projects (something that's extraordinarily satisfactory), but you'll share it with the rest of the world via NPM. You heard me well! You will be publishing it the same way the big frameworks get released. Sure, the framework won't be even close to competing with the big frameworks out there, but you'll have a good understanding of how they work that you can use to keep improving yours. But more important than creating a framework that can compete is the amount of fun, gratification and learning that you'll get from working on this project.

There's one last thing I want to mention. I'm writing this book for you, so it doesn't matter how much effort I put into it if my explanations aren't clear enough for you to follow. If you get lost, it's definitely not because you don't know enough, it's because I'm not expressing my thoughts as clearly as I could. So, if you do get lost or think I could be explaining things in more detail, I'd love to hear from you. Conversely, if you think I spend too much time explaining things you already know, also let me know. You, as a MEAP reader, have a very important role in making this book useful for the readers that'll come after you. Oh! and if you're enjoying the book as is, please do tell me as well. Your feedback is essential in developing the best book possible, so please visit the liveBook's Discussion Forum and leave your comments.

—Angel Sola Orbaiceta

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APPENDIX

Setting up the project

1 Are frontend frameworks magic to you?

This chapter covers

- Why you should build your own frontend framework
- The features of the framework we'll build together
- The big picture of how frontend frameworks work

How you ever wondered how the frontend frameworks you use work internally? Are you curious about how they decide when to re-render a component, and how they do to only update the parts of the DOM that change? Isn't it interesting how a single HTML page can change its content without reloading? That the URL in the browser's address bar changes without requesting the new page to a server? The inner workings of frontend frameworks are fascinating, and there is no better way to learn about them than by building one yourself, from scratch. But why would you want to learn how frontend frameworks work? Is't it enough to just know how to use them?--you might ask.

Good cooks know their tools; they can use knives skillfully. Great chefs go beyond that: they know the different types of knives, when to use each one, and how to keep their blade sharp. Carpenters know how to use a saw to cut wood, but great carpenters also understand how the saw works and can fix it in case it breaks. Electrical engineers not only understand that electricity is the flow of electrons through a conductor, but also have a deep understanding of the instruments they use to measure and manipulate it; for example, they could build a multimeter themselves. If their multimeter breaks, they can disassemble it, figure out what's wrong, and repair it.

As a developer, you have a frontend framework in your toolbox, but do you know how it works? Or, is it magic to you? If it broke—if you found a bug in it—would you be able to find its source and fix it? When a single-page application changes the route in the browser's URL bar and renders a new page without requesting it from the server, do you understand how that happens?

1.1 Why build your own frontend framework?

The use of frontend frameworks is on the rise; it's uncommon to write pure-vanilla JavaScript applications nowadays, and rightly so. Modern frontend frameworks boost productivity and make building complex interactive applications a breeze. Frontend frameworks have become so popular that there are jokes about the unwieldy amount of them at our disposal. (In the time it took you to read this paragraph so far, a new frontend framework was created.) Some of the most popular frontend frameworks even have their own fan groups, with people arguing about why theirs is the best. Let's not forget that frontend frameworks are tools, a means to an end, and that the end is to build applications that solve real problems.

SIDEBAR **Framework vs. library**

Frameworks and libraries are different. When you use a library, you import its code and call its functions. When you use a framework, you write code that the framework executes. The framework is in charge of running the application, and it executes your code when appropriate trigger happens. Conversely, you call the library's functions when you need them. Angular is an example of a frontend framework, whereas React claims to be a library that you can use to build UIs.

For convenience, I'll refer to both frameworks and libraries as frameworks in this book.

All of the most popular frameworks at the time of this writing are exceptionally good: Vue, Svelte, Angular, React… you name it. Which brings us to the main question you might be asking yourself: **If there are so many great frontend frameworks, why build your own?** That's a great question because if there is something the JavaScript community doesn't need, it's another frontend framework. First, building your own framework is rewarding and so much fun: building a complex piece of software yourself, from scratch, is a great feeling. It sparks joy. But apart from the undeniable joy of it, there are some more pragmatic reasons why you'd want to build a frontend framework yourself. Let me tell you a little story about a personal experience to illustrate this.

1.1.1 "Do you understand how that works?"

When I was a little kid I went to one of my cousins' house to hang out. He was a few years older than me and a handyman. His cabinets were full of cables, screwdrivers, and other tools, and I'd spend hours just observing how he fixed all kinds of appliances. I remember once bringing a remote control car with me so we could play with it. He stared at it for some time, then asked me a question that got me by surprise: "Do you understand how this thing works?" I didn't; I was just a kid with zero electronics knowledge. He then said, "I like to know how the stuff I use works, so what do you say we take it apart and see what's inside?" I sometimes still think about that.

So now, let me ask you a question similar to that my cousin asked me: You use frontend frameworks every day, but do you really understand how they work? You write the code for your components, then hand it over to the framework for it to do its magic. When you load the application into the browser, it just works. It renders the views and handles user interactions, always keeping the page updated (in sync with the application's state). For most frontend developers—and this includes me from years ago—how this happens is a mystery. Is the frontend framework you use a mystery to you?

Sure, most of us have heard about that thing called the "virtual DOM," and that there needs to be a "reconciliation algorithm" that decides what is the smallest set of changes required to update the browser's DOM. We also know that single-page applications (SPAs for short) modify the URL in the browser's address bar without reloading the page, and if you're the curious kind of developer, you might have read about how the browser's history API is used to achieve this. But do you really understand how all of this works together? Have you disassembled and debugged the code of the framework you use? Don't feel bad if you have not; most developers haven't, including some very experienced ones. This reverse-engineering process isn't easy; it requires lots of effort (and motivation).

In this book, you and I—together as a team—will build a frontend framework from scratch. It'll be a simple one, but it'll be complete enough to understand how frontend frameworks work. From then on, what the framework does will no longer be a mystery to you. Oh! And it'll be lots of fun as well.

1.2 The framework we'll build

I like to set expectations early on, so here it goes: We won't build the next Vue or React as part of the book. You might be able to do that yourself after reading this book by filling in the missing details and optimizing a couple things here and there. The framework we'll build together can't compete with the mainstream frameworks—that's not its objective anyway. The objective of this book is to teach you how these frameworks work in general, so what they do isn't magic to you anymore. We don't need to build the most advanced framework in the world to achieve this, one that accounts for all possible edge cases. In fact, that'd require a book four times as thick as this one, and the process of writing it wouldn't be as fun. (Did I mention that writing your own framework is fun? Because it is.)

The framework we'll build borrows ideas from a few existing frameworks, most notably Vue, Mithril, Svelte, React, Preact, Angular and Hyperapp. Our goal is to build a framework that's simple enough to understand, but that at the same time includes the typical features you'd expect from a frontend framework. I also wanted it to be representative of some of the most relevant concepts that are behind the source code of the most popular frameworks.

For example, not all frameworks use the virtual DOM abstraction (Svelte in particular considers it to be "pure overhead", and the reasons are simply brilliant—I recommend you read their blog post), but a big portion of them do. I chose our framework to implement a virtual DOM so that's representative of the framework you're likely using today. In essence, I chose the approach that I thought would result in the most learning for you, the reader. I'll be covering the virtual DOM in detail in chapter 3, but in a nutshell, it's a lightweight representation of the DOM that's used to calculate the smallest set of changes required to update the browser's DOM. For example, the following HTML markup:

```
<div class="name">
  <label for="name-input">Name</label>
  <input type="text" id="name-input" />
  <button>Save</button>
</div>
```

would have a virtual DOM representation like that in figure 1.1. I'll be using these diagrams a lot throughout the book to illustrate how the virtual DOM and the *reconciliation algorithm* works. The reconciliation algorithm is the process that decides what changes need to be made to the browser's DOM to reflect the changes in the virtual DOM, which is the topic of chapter 5.

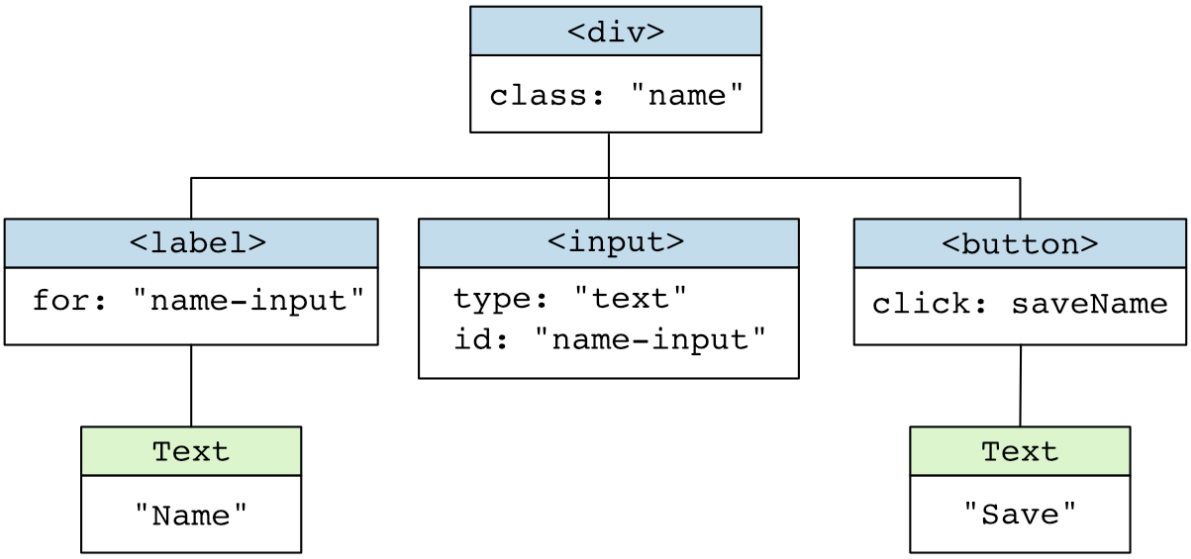


Figure 1.1 A virtual DOM representation of some HTML markup

The framework we'll build will have some shortcomings that make it not an ideal choice for complex production applications, but definitely fit for your latest side project. For example, it'll only support the standard HTML namespace, which means that, neither SVG nor MathML tags will be supported. As you can imagine, most of the popular frameworks support these namespaces, but we'll leave them out for simplicity. There are other features that—for the sake of keeping the book to a reasonable size and the project fun to build—we'll leave out as well. For example, we'll leave out component-scoped CSS support, which is a feature that's present in most of the popular frameworks, one way or another. The bright side is that I'm pretty sure that, after reading this book, you'll be able to implement these features yourself.

1.2.1 Features

The framework we'll build will have the following features, which we'll build one by one, from scratch:

- A virtual DOM abstraction.
- A reconciliation algorithm that updates the browser's DOM.
- A component-based architecture where each component does the following:
  - holds its own state,
  - manages its own lifecycle,
  - re-renders itself and its children when it states changes.
- An SPA router that updates the URL in the browser's address bar without reloading the page.
- Slots to render content inside a component.
- HTML templates that are compiled into JavaScript render functions.
- Server-side rendering.

As you can see, it's a pretty complete framework. It's not a full-blown framework like Vue or

React, but it's enough to understand how they work. And the neat thing is that we'll build it line by line, so you'll understand how it all fits together. I'll use lots of diagrams and illustrations to help you understand the concepts that might be harder to grasp. I recommend you to write the source code yourself as you read the book. Try to understand it line by line, take your time, debug it, and make sure you understand the decisions and trade-offs we make along the way.

Figure 1.2 shows the architecture of the framework we'll build. It includes all the parts of the framework you'll implement, and how they interact with each other.

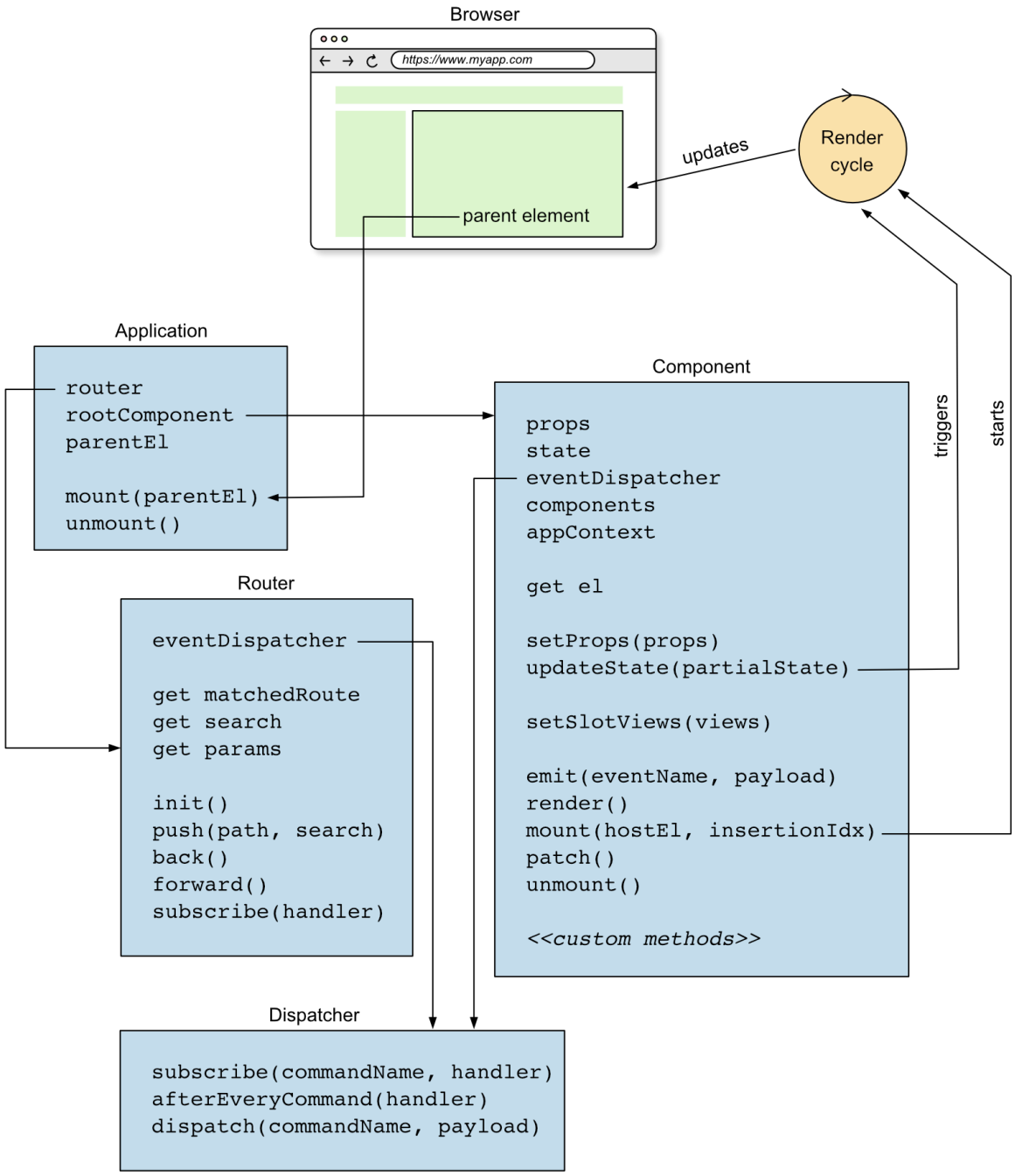


Figure 1.2 Architecture of the framework we'll build

I will revisit this figure, making sure to highlight each part of the framework as we build it. You don't need to understand all the details of the architecture right now, but it's good to have a high-level understanding of it. At the end of the book, this figure will make a lot of sense to you: you'll recognize each and every part, as you'll have built them yourself.

1.2.2 Implementation plan

As you can imagine, we can't build all of this in a single chapter. We want to break it down into smaller pieces so that we can focus on one thing at a time. Figure 1.3 shows the implementation plan for the framework you'll build, chapter by chapter. It resembles a kanban board, where each post-it represents a chapter. You'll pick up a post-it in each chapter.

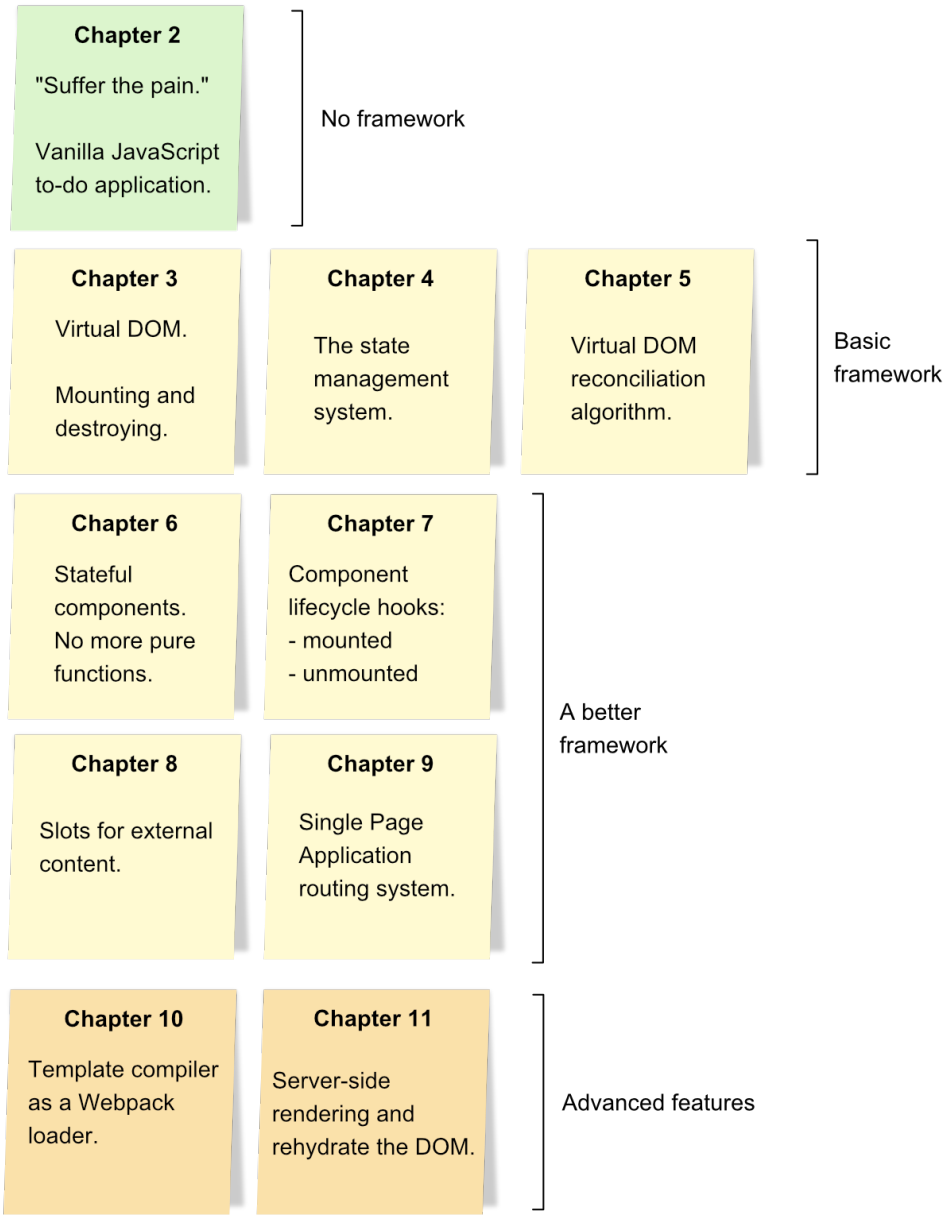


Figure 1.3 Implementation plan for the framework we'll build

The first thing we'll do is implement an example application without frameworks, just vanilla JavaScript. This is something we rarely—if ever—do as frontend developers, but it's a good exercise to understand what kinds of things a framework can help us with. (Once you've suffered the "pain", you'll be in a better position to appreciate the benefits of a framework.)

Implementing it will help us see how the DOM manipulation operations, which result in very imperative code, can be abstracted away by a framework, and allow us to write applications in a much more declarative—and hence clear—way.

STATELESS COMPONENTS AND GLOBAL APPLICATION STATE

We'll start simple by extracting parts of the application's view to stateless components modeled by pure functions that return the virtual DOM representation of their view. We'll have an application object that holds the entire state of the application and the top-level component representing the view. These simple state-less components allow us to focus on the DOM reconciliation algorithm, which is quite likely the most complex part of the framework.

STATEFUL COMPONENTS

Once we have the reconciliation algorithm working, we'll allow components to have their own state. The state of the application will be split among components instead of being centralized in a single object at the application level, which makes state management much simpler to tackle by a developer using the framework.

Pure functions will turn into classes that implement a `render` method; a big change in how components work. A nice feature we'll include at this stage is that only the component whose state changes will be passed to the reconciliation algorithm, not the entire application's view like we did before. Every component will be its own little application with its own lifecycle.

LIFECYCLE HOOKS

Our next step will be to add lifecycle *hooks* to the components. These hooks allow us to "hook into" the application's lifecycle and execute code at certain moments in time, like when the component is mounted into the DOM. By lifecycle, I mean the sequence of events that happen to a component while it's being used by the application and have a special relevance, like when the component is mounted into the DOM or when it's removed from it. An example of using a lifecycle hook is to fetch data from a remote server when the component is mounted into the DOM.

SLOTS TO INSERT CONTENT INSIDE A COMPONENT

Then, we'll add support for *slots*, which allow us to render content inside a component. This is a killer feature, because it allows the creation of reusable components that can be customized by the developer that uses them. The way slots work is going to be very interesting to learn; you'll see it's a trick implemented on top of the virtual DOM abstraction.

SPA ROUTER

We'll then implement a router. Routers are central to the SPA's architecture, and writing one yourself is a worthwhile exercise. The router allows the application to navigate between different pages without reloading the page. Most frameworks don't come with a router bundled; it's typically a plugin or a separate library that you have to install in your project. For the sake of learning, we'll include our router in the framework itself.

HTML TEMPLATES

When you reach this point, you'll have a pretty good understanding of how frontend frameworks work. The features that we'll implement in the rest of the chapters are just icing on the cake: advanced features you can live without, but that'll make our framework more complete and easier to use. We'll implement a Webpack loader module that reads HTML templates and compiles them into JavaScript render functions. Thanks to it, we'll be able to write our components' view in HTML, which is a lot more convenient than using JavaScript functions. So, instead of writing this:

```
function render() {
  return h('div', { class: 'container' }, [
    h('h1', {}, [hString('Look, Ma!')]),
    h('p', {}, [hString("I'm building a framework!")])
  ])
}
```

We'll be able to write this:

```
<div class="container">
  <h1>Look, Ma!</h1>
  <p>I'm building a framework!</p>
</div>
```

Isn't that much nicer? Don't worry if you don't understand what those `h()` and `hString()` calls are; we'll devote the whole chapter 3 to explaining them. In a nutshell, they're functions that create virtual DOM nodes, `h()` for elements and `hString()` for text nodes.

SERVER-SIDE RENDERING & REHYDRATION

Finally, we'll implement server-side rendering and the DOM *rehydration* algorithm (also known as simply *hydration*).

Server-side rendering (SSR) is a technique where the view is rendered on the server (as opposed

to being programmatically created in the browser) that's typically used to improve the time it takes for the page to be fully displayed to the user. This is good for Search Engine Optimization (SEO)--among other things—of the application, because search engines can index the page's content without having to wait for the JavaScript to be executed and programmatically generate the view.

The hydration is the process by which the framework compares the existing HTML markup with the component's virtual DOM, matching each HTML element with its corresponding virtual DOM node. The component's virtual DOM includes event handlers, which have to be attached to the HTML elements to make them respond to user events. This step is necessary to make the HTML markup interactive in the browser.

All good things come with a price, and SSR is no different. To use SSR you need to have a server running to render the application. Serving static HTML, CSS, and JavaScript files is, in general, cheaper than having a Node JS server running, a server that renders pages as the users request them. Once the page is served to the user, the rehydration algorithm binds the browser's HTML to each component's virtual DOM, so when the user interacts with the page, the DOM can be dynamically updated in the browser.

Now that we know about what we'll build together and the plan we'll follow, let's take a quick look at how frontend frameworks work in general terms.

1.3 Overview of how a frontend framework works

Let's quickly review how a frontend framework works when observed from the outside. (We'll learn about the internals in the next chapters.) Let's start from the side of the developer—someone using the framework to build an application. We'll then learn about the browser's perspective.

1.3.1 The developer's side

A developer starts by creating a new project with the framework's CLI (Command Line Interface) tool or by manually installing the dependencies and configuring the project. Reading the framework's documentation is important, as every framework works a little bit differently.

SIDEBAR **A note on using Node JS**

A frontend project is usually a regular Node JS project with its package.json file and its node_modules directory with the dependencies, including the framework used to build the app. Using Node JS is just for convenience; it helps by providing an infrastructure to run scripts, compile, and bundle our code, as well as managing dependencies, but we could very well go without Node JS, download the framework's JavaScript files from a CDN and include them in our HTML file. We'd be responsible to manually upgrade the dependencies when a new version is available and create a script that bundles our JavaScript code, but it's definitely doable—just not convenient.

Another benefit of using Node JS is that all Node JS projects follow the same structure and conventions, something that helps other developers to understand how to work with our codebase.

Inside the application's project, the developer writes the code for the components that define a portion of the application's view and their interactions with the user. These components are usually defined in separate files and very often mix HTML, CSS and JavaScript. With the notable exception of Angular, most frameworks use *single file components* (SFCs), which are files that contain the component's HTML, CSS, and JavaScript in a single file. Angular typically uses three files: one for the template (the HTML), another one for the TypeScript code and one more for the CSS. This allows the developer to have the three different languages—typescript, HTML, and CSS—in separate files, which might help in keeping them small and get better syntax support from the IDE. On the other hand, it makes you jump between files to see the whole component, which can be a bit annoying. We will be using Angular's approach in this book, and use three files for each component. This simplifies the framework's implementation, as you'll see towards the end of the book.

In the case of React or Preact, JSX—an extension of JavaScript—is used instead of writing HTML directly. In other frameworks, such as Vue, Svelte, or Angular, the view is written using HTML templates. Their templating languages include *directives* that allow the developer to add or modify specified behavior of existing DOM elements, such as iterate and display an array of items or conditionally show certain elements. For example, the following is how you'd conditionally show a paragraph in Vue:

```
<p v-if="hasDiscount">
  You get a discount!
</p>
```

The `v-if` directive is a custom directive that Vue provides to conditionally show an element. Other frameworks use slightly different syntaxes, but all of them provide the developer with a way to show or hide elements based on the application's state. Just for the sake of comparison, here's how you'd do the same in Svelte:

```
{#if hasDiscount}
<p>
  You get a discount!
</p>
{/if}
```

And this would be how you'd write it in the case of React:

```
{hasDiscount && <p>You get a discount!</p>}
```

Once the developer is satisfied with the application, when the functionality is implemented and ready to be shipped to the users, the code needs to be bundled into fewer files than were originally written, so the browser can load the application using fewer requests to the server. The files can also be *minified*, that is, made smaller by removing whitespace and comments, and renaming variables to shorter names. This process of turning the application's source source code into the files that are shipped to the users is called *building*.

BUILDING THE APPLICATION

To deploy a frontend application to production, we first need to build it. Most of the work of building an application using a specific framework is done by the framework itself. The framework—typically—provides a CLI tool that we can use to build the application by running a simple NPM script such as `npm run build`.

> **NOTE** **There are many different ways an application can be built, resulting in a wide variety of bundle formats. Here, I'll explain a build process that encapsulates some of the most common practices.**

Building the application includes a few steps:

1. The template for each component is transformed into JavaScript code that, executed in the browser, creates the component's view.
2. The components' code—split in multiple files—is bundled into a single JavaScript file, *app.bundle.js*. (For larger applications it's common to have more than one bundle and *lazy-load* them; that is, load them only when they'll become visible to the user.)
3. The third-party code used by the application is bundled into a single JavaScript file, *vendors.bundle.js*. This file includes the code for the framework itself, along with other third-party libraries.
4. The CSS code in the components is extracted and bundled into a single CSS file: *bundle.css*. (Same as before, larger applications may have more than one CSS bundle.)
5. The HTML file that will be served to the user (*index.html*) is generated or copied from the static assets directory.
6. The static assets (such as images, fonts or audio clips) are copied to the output directory. They can optionally be preprocessed, for example, to optimize images or convert audio files to a different format.

So, a typical build process results in four (or more, in the case of larger apps) files:

- *app.bundle.js* with the application's code,
- *vendors.bundle.js* with the third-party code,
- *bundle.css* with the application's CSS, and
- *index.html*, the HTML file that will be served to the user.

These files are uploaded to a server, and the application is ready to be served to the user. When a user requests the website, the HTML, JS, and CSS files are statically served.

> **NOTE** **When we say a file is statically served, we mean that the server doesn't need to do anything to the file before sending it to the user: it just reads the file from disk and sends it. On the other hand, when the application is rendered on the server, the HTML file is generated by the server before getting sent to the user's browser.**

Figure 1.4 shows a diagram of the build process I just described. Note that, a typical build process is more complex than the one shown in the figure, but this is enough to understand the concepts. I've included a step that transforms the JavaScript code. This is a generic step that refers to any transformation that needs to be done to the code before it's bundled, like for example transpiling it using Babel or TypeScript.

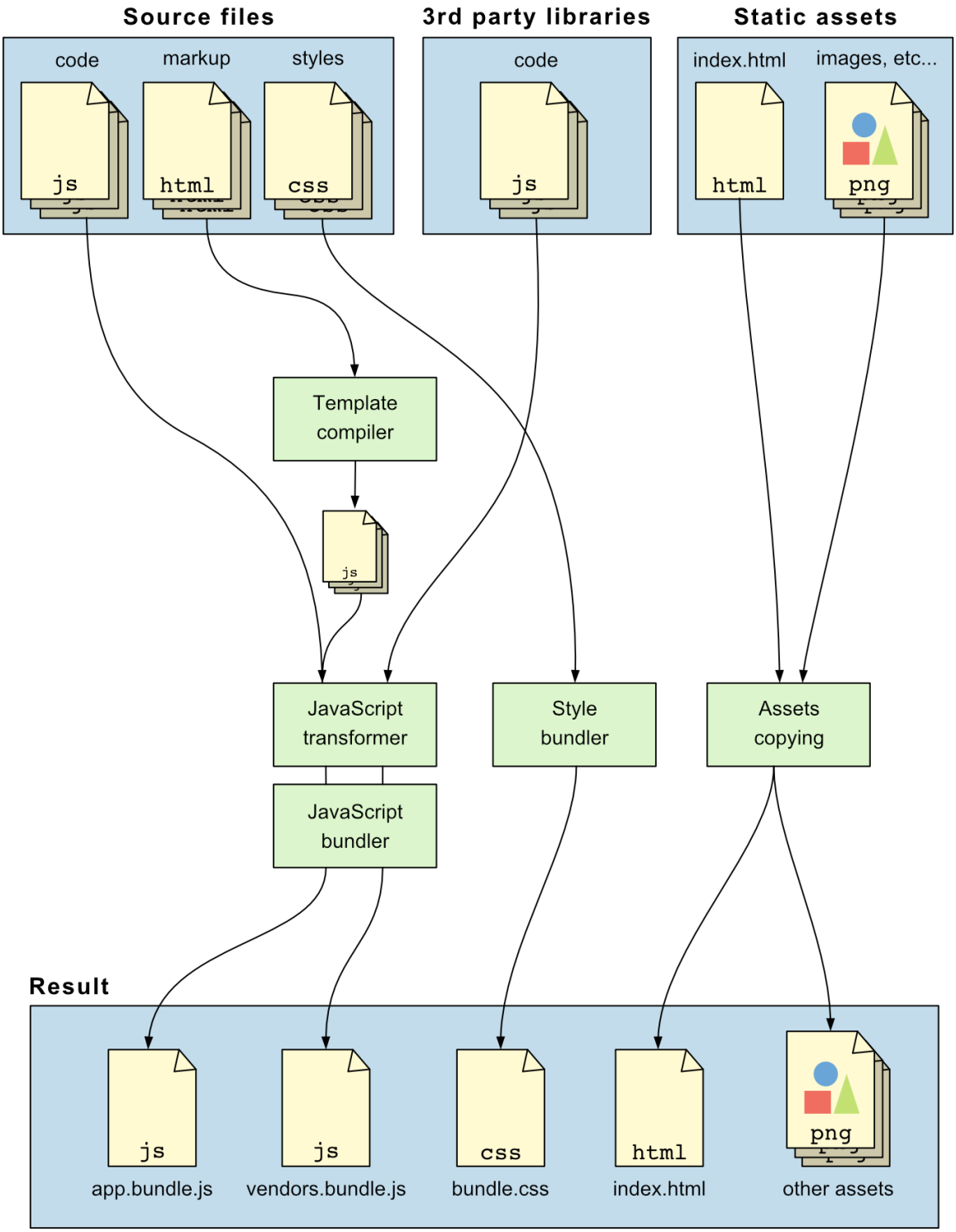


Figure 1.4 A simplified diagram of a frontend application's build process

Let's see what happens in the browser once these files are loaded. The flow is slightly different, depending on whether the application is rendered on the server or statically served.

1.3.2 The browser side of an SPA

When the user loads the application in the browser by writing its URL (1), the browser requests the page's HTML file, which is returned by the server (2). The browser loads the HTML file and parses it. This HTML is mostly empty and is used to load the JavaScript and CSS resources declared in the `<script>` and `<link>` tags (3). These JavaScript files are the application and vendor bundles we talked about in the previous section.

The framework JavaScript code then creates the application's view—defined as a hierarchy of components—using the Document API (4 and 5).

Figure 1.5 depicts the first steps behind how a single-page application works in the browser. Specifically, it shows how the browser loads the application's HTML, JavaScript, and CSS files and how the framework creates the application's initial view.

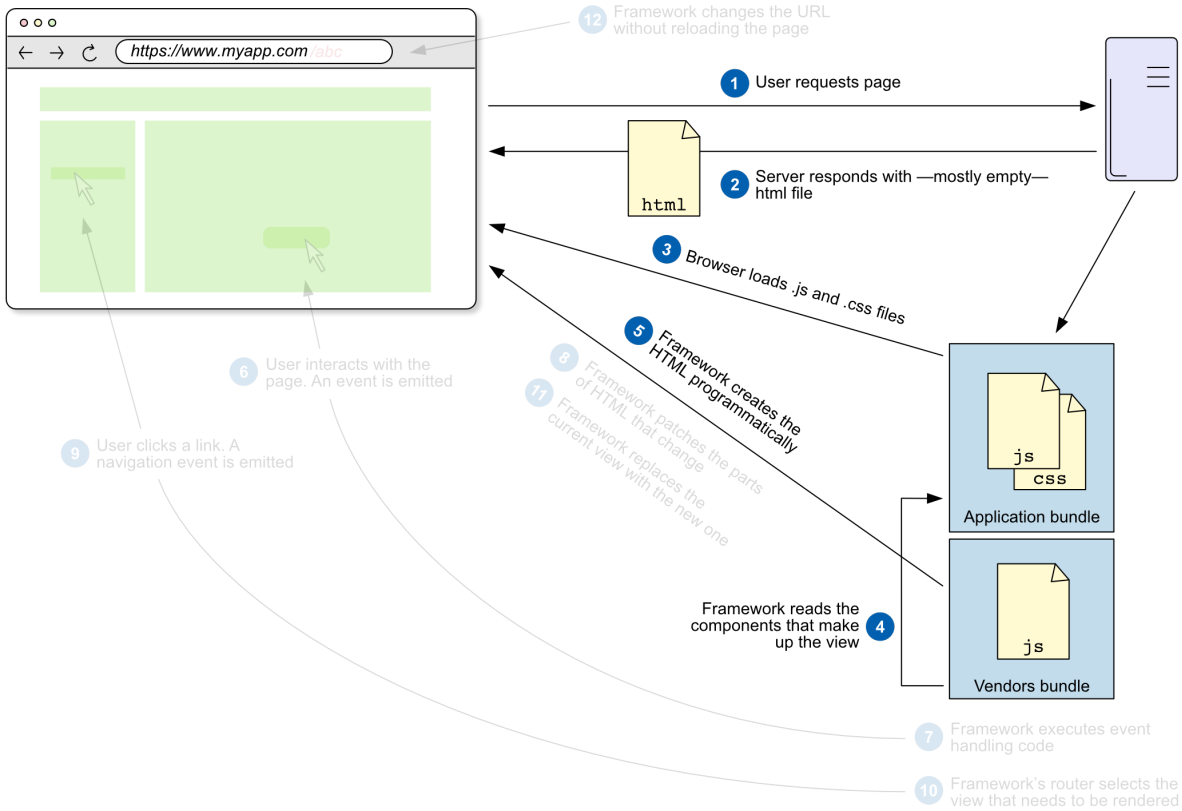


Figure 1.5 Single-page application first render in the browser

The Document API allows the creation of HTML elements programmatically, using JavaScript.

For example, given an empty HTML `<body>` element like the following:

```
<body></body>
```

A paragraph can be programmatically created and appended to the document like so:

```
const paragraph = document.createElement('p')
paragraph.textContent = 'Hello, World!'
document.append(paragraph)
```

This would result in the following HTML:

```
<body>
  <p>Hello, World!</p>
</body>
```

This is how a frontend framework creates the HTML in the browser. The framework is also responsible for handling the events that are raised when the user interacts with the application (6). After the event handling code is executed (7), the framework updates the view to reflect the changes in the application's state, if any (8).

Figure 1.6 depicts how single-page applications respond to user interactions.

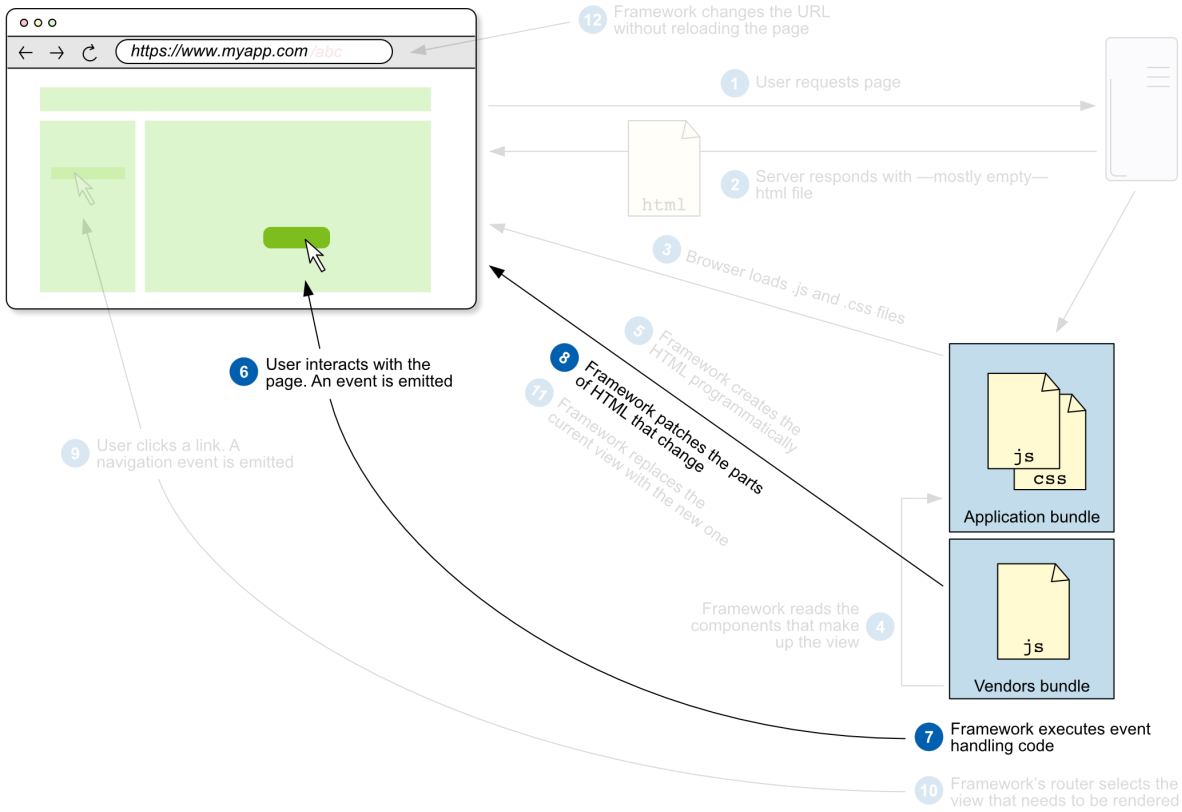


Figure 1.6 Single-page application responding to events

Making changes to the document is expensive, so a well-implemented framework minimizes the number of changes to the document for it to reflect the required updates. By expensive, I mean that the browser needs to repaint and reflow the document to reflect the changes, and that consumes resources.

SIDEBAR To better understand why the changes to the DOM are expensive in terms of computation, I recommend you read web.dev/critical-rendering-path-render-tree-construction. This article explains how the browser renders the document, and gives you an overview of everything that happens under the hood.

IMPORTANT Patching the DOM

A single change made to the DOM by the framework is called a patch. The process of updating the view to reflect the changes in the application's state is called patching the DOM.

How this is achieved varies heavily across frameworks. Some frameworks use a virtual DOM—so will you, in the following chapters—to compare the current state of the document with the desired state and apply only the necessary changes. Other frameworks use a different approach, but the goal is always the same: minimize the number of changes to the document.

SIDEBAR **How some frameworks update the view**

Svelte understands the ways the view can be updated at compilation time, and produces JavaScript code to update the exact parts of the view that need to be patched for each possible state change. Svelte is remarkably performant because it does only the least amount of work in the browser to update the view.

Angular runs a change detection routine—comparing the last state it used to render the view with the current state—every time it detects the state might have changed. Changes to the state of a component typically happen when an event listener runs, when data is requested to a server via an HTTP request, or when MacroTasks (such as `setTimeout()`) or MicroTasks (such as `Promise.then()`) are executed. Angular makes this possible thanks to `zone.js`, an execution context that's aware of the asynchronous tasks running at any given time. Thanks to `zone.js`, Angular can detect when a MacroTask or MicroTask is executed and run the change detection routine. (javascript.info/event-loop is a wonderful resource to learn more about the JavaScript event loop and the difference between the micro- and macro-task queues.)

Most other widely used frameworks—including Vue, React, Preact or Inferno—use a virtual DOM representation of the view. So by comparing the last known virtual DOM with the virtual DOM after the state has changed, they compute the minimum changes required to update the HTML. React does this virtual DOM comparison every time the state is changed by the component, using either `setState()` or the `useState()` hook's mechanism. Vue uses a remarkably smart approach and includes a reactivity layer the developer can use to define the application's state. These reactivity primitives wrap regular JavaScript objects (this includes arrays or sets) and primitives (such as strings, numbers or booleans) and automatically detect when values change and notify the components that use them they need to re-render.

When the user clicks a link (9), the framework's router—working in SPA mode—prevents the default behavior of reloading the page and instead renders the component that's configured for the new route (10 and 11). The router is also in charge of changing the URL (12). A SPA works with a single HTML file were the HTML markup code is programmatically updated by the framework, so new HTML pages aren't requested to the server when the user navigates to a different route.

Figure 1.7 shows the flow of a single-page application when the user navigates to a different route.

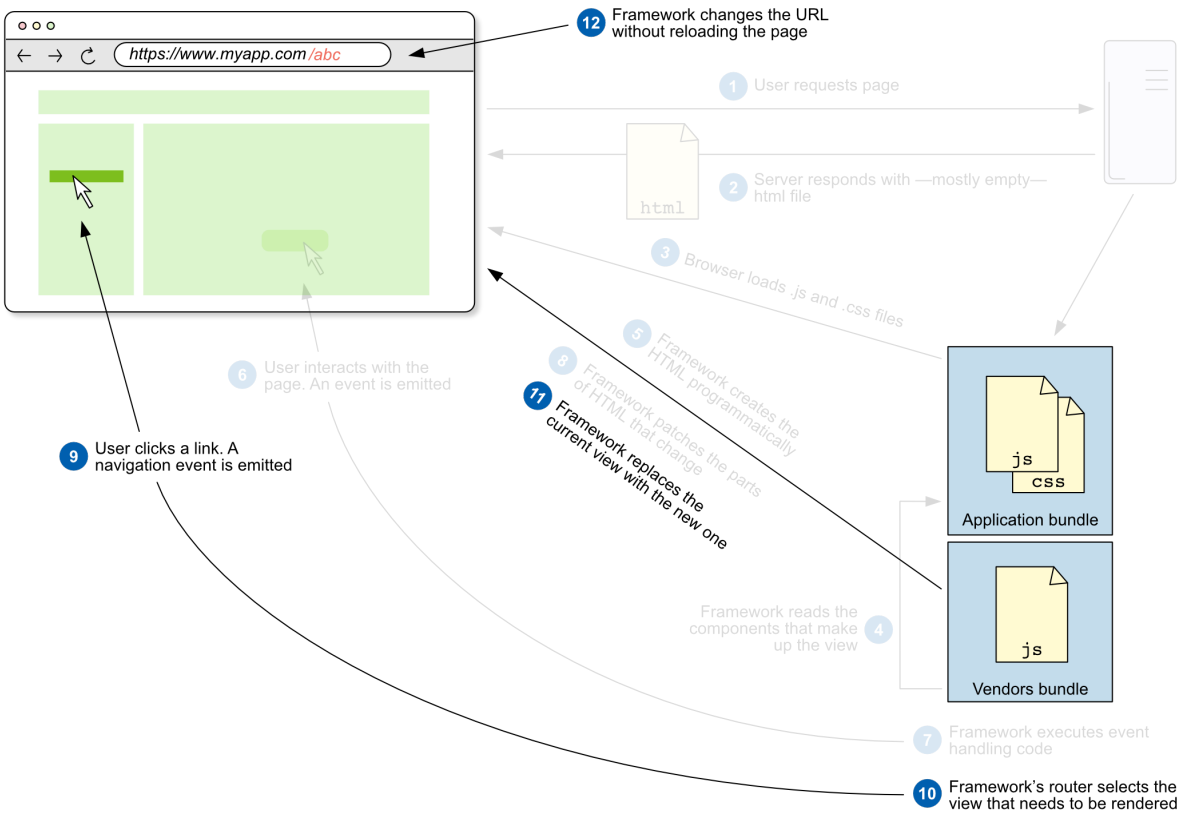


Figure 1.7 Single-page application navigation

Figure 1.8 shows the complete flow of a single-page application, including all the steps described earlier.

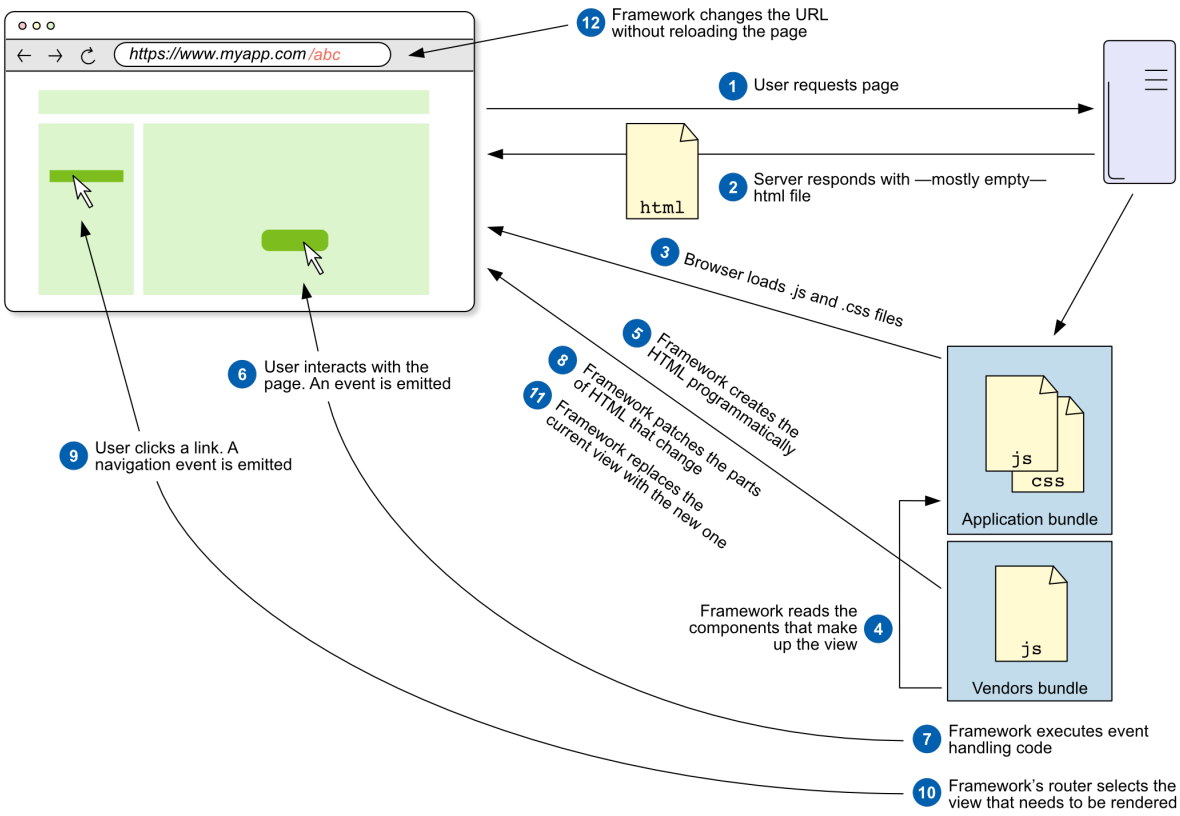


Figure 1.8 The complete flow of a single-page application rendered in the browser

Now that you know how single-page applications work, let's compare them with an application that's server-side rendered.

1.3.3 The browser and server side of a SSR application

When the user loads the application in the browser by writing its URL (1), the browser requests the page's HTML file, which is returned by the server. This time though, the server doesn't just return a static and mostly empty HTML file, but renders a complete page "on the fly" for each request it gets. First of all, the application's router is used to determine which set of components should be rendered for the requested route (2). Each component is instantiated and, before being rendered, it executes its mounting code, which might include loading data from a different server or a database (3). The components are then rendered into a string of HTML and served to the user (4). From the user's perspective, it seems like the HTML page already existed as a static file in the server, but in reality, the server generated it just for them.

The HTML file served to the user displays already rendered HTML markup, so the framework doesn't need to use the Document API to programmatically generate it. This HTML document instructs the browser to load the application JavaScript files and CSS style sheets (5).

Once the JavaScript code is parsed, the framework code needs to connect the existing HTML—produced in the server—to the component's state (6 and 7), the hydration process.

Figure 1.9 shows the main steps behind how a server-side rendered application works in the browser.

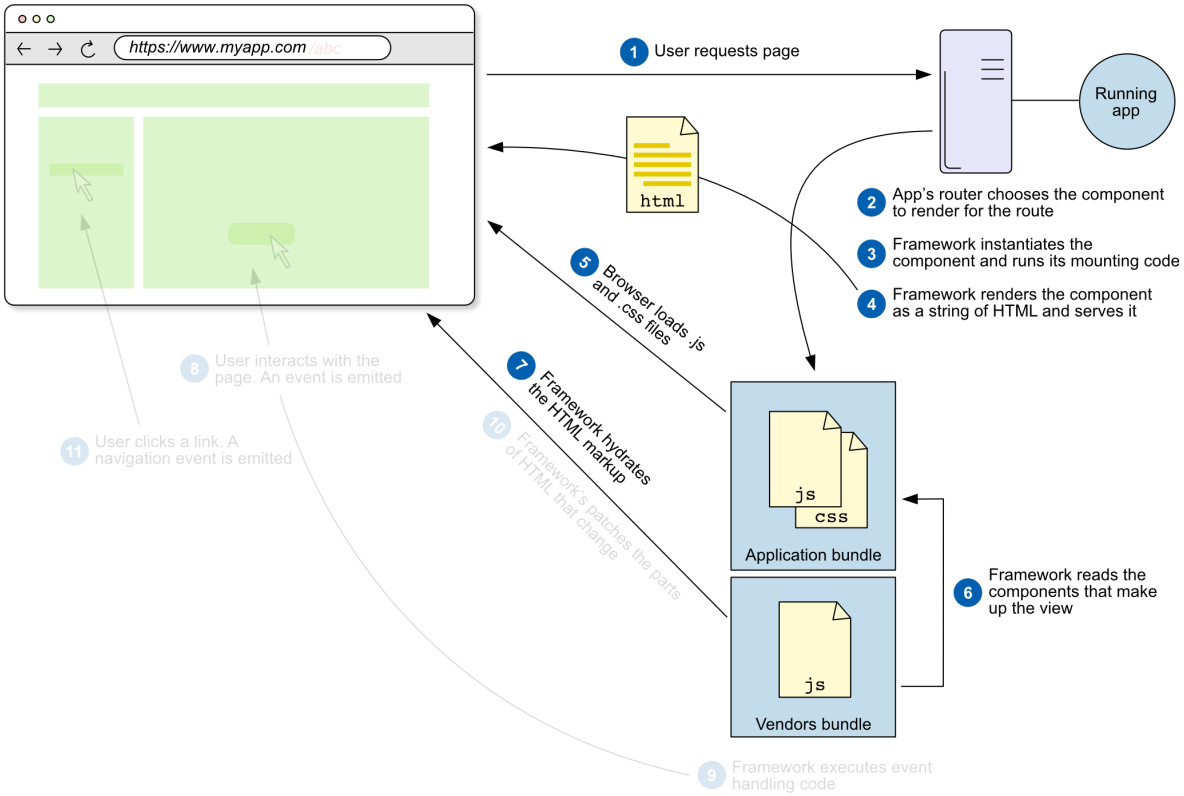


Figure 1.9 Server-side application first render in the browser

The "dry" HTML markup coming from the server doesn't define the event listeners in the component that produced it, so the framework needs to hydrate the DOM to add the interactivity to the page. By *dry* we mean unresponsive; the HTML markup doesn't have any event listeners attached to it.

After the hydration of the DOM, the page becomes interactive, and any events generated by the user interacting with the page work the same way as the previous case of an SPA (8 to 10).

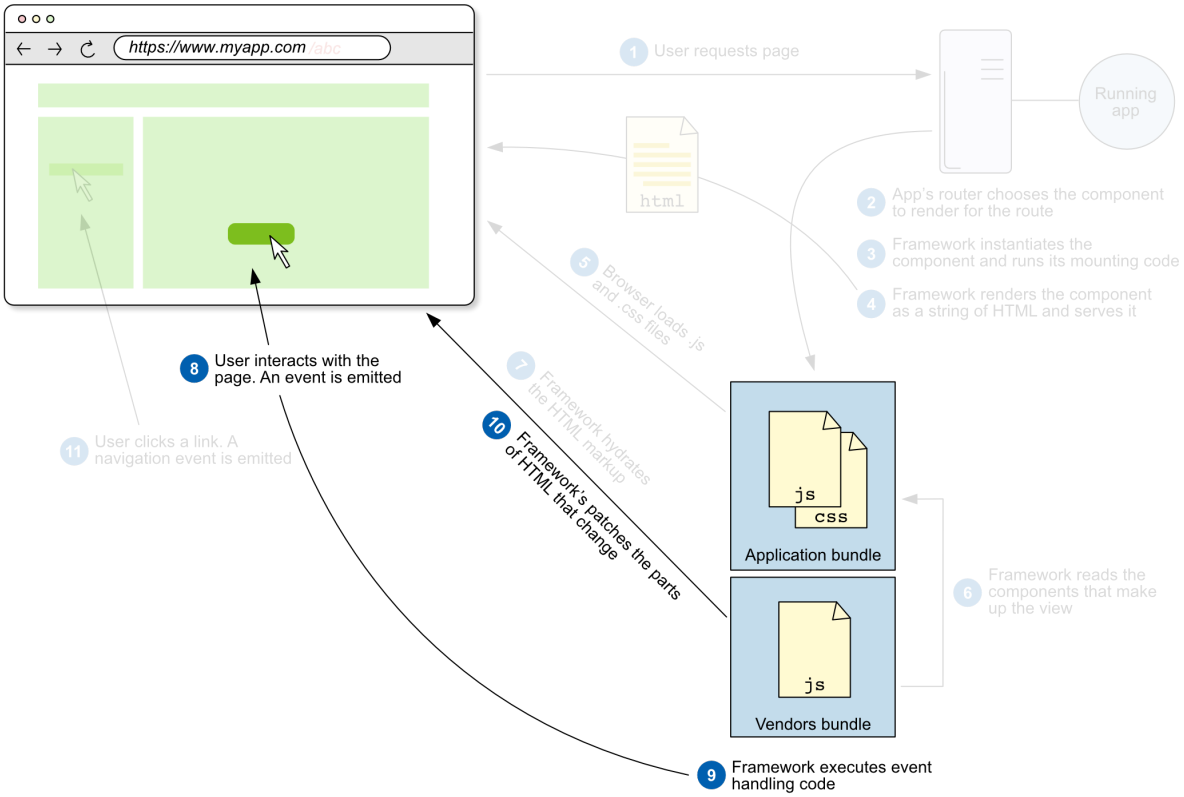


Figure 1.10 Server-side application responding to events

When the user clicks a link (11), the URL is changed by the browser (the framework doesn't do anything in the browser side this time), and the page is reloaded. A new HTML page is requested from the server, and the process starts again from step 2, where the application's router determines which component should be rendered for the new route.

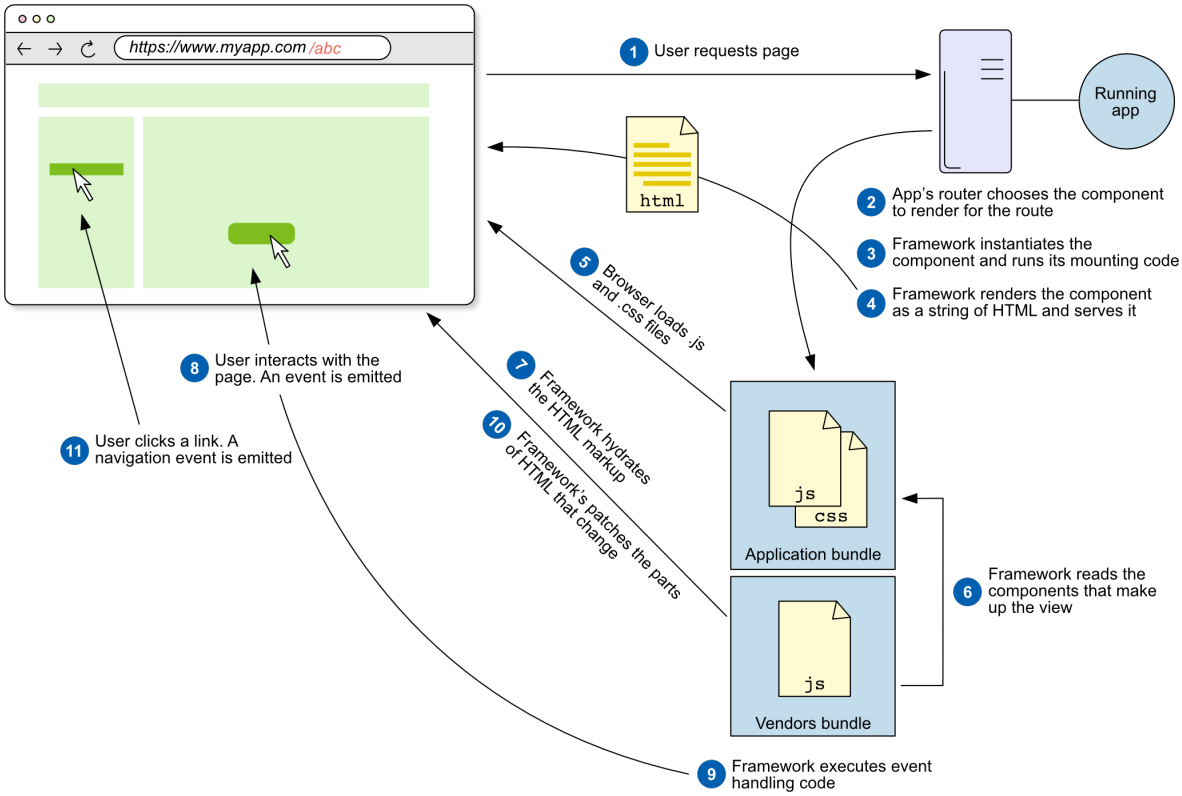


Figure 1.11 The complete flow of a server-side application rendered in the server and hydrated in the browser

And this is how both single-page applications and server-side rendered applications work. What about building a simple application yourself, without using a framework?

1.4 Summary

- Building a frontend framework from scratch is a great way to learn how they work.
- Frontend frameworks bundle the application's code into a single JavaScript file, the third party dependencies into another file, and the CSS styles into yet another file. If the application is large, the framework might split the application's code into multiple bundles that are loaded "lazily," that is, just as they're needed.
- The Document API allows the creation of HTML elements programmatically, using JavaScript. The Document API is used by frontend frameworks to create the application's view.
- Single-page applications consist on a single HTML file that's loaded by the browser and updated by the framework to reflect the application's state. When the route changes, it's the framework changing the view. The browser doesn't reload the page.
- The hydration process is the process of connecting the existing HTML markup, rendered in the server, to the component's state and event listeners.

2 Vanilla JavaScript—like in the old days

This chapter covers

- Building an application using vanilla JavaScript and HTML
- Programmatically creating DOM elements
- Using the Document API to manipulate the DOM

To understand the benefits of using a frontend framework, you first need to understand the problems that it solves, and there is no better way to do this than to write an application without a framework—do the framework's job yourself. The objective of this chapter is making you "suffer the pain" of writing applications without a framework, so that you can build some appreciation for the job that frameworks do for you.

In the old days (I'm not that old, it's just that technology evolves fast), we'd write applications using only vanilla JavaScript and HTML. JQuery was the best we had: it provided a nice API to interact with the DOM, hiding away the browser differences. But we'd still have to write code down to the level of working with the DOM, and to be fair, it wasn't that bad. That is, until we used our first modern frontend framework (it was Angular, in my case). Now there's no going back; we've been there; we know how much simpler it's become to write JavaScript applications.

You're probably accustomed to writing applications leveraging the power of a framework—something you should keep on doing if you get paid to ship applications quickly—so it might be hard for you to realize the problems the framework solves. Or maybe you've been, like me, in the pre-framework era but haven't written an application without a framework in a long time, in which case this chapter will be good for refreshing your memory. If your case is the former, I'm positive that by taking away the framework from you, you'll quickly realize why you were using it in the first place. It's like when you always find your working

space clean and tidy, but you rarely appreciate it because you're used to seeing it that way. That is until the cleaning personnel get sick and you have to clean things up yourself. You suddenly realize that vacuuming every corner of the office is arduous, removing the dust from the shelves and behind your computer is a pain, let alone cleaning the bathroom. Only then you realize how much you value working when things are clean and tidy around you, and start to really appreciate the cleaning personnel's job.

In this chapter, you'll do the cleaning yourself; that is, you'll build a simple application from scratch using only vanilla JavaScript and HTML. The cleaning personnel—the existing frontend frameworks—will be on strike. As you'll see, it'll be surprisingly easy to implement, but that's because the app we'll build is very simple. Despite that simplicity, we'll be able to see how the code we write operates at a very low abstraction level—directly manipulating the DOM—and is very imperative in nature: every change in the application state requires you to explicitly write the code to update the HTML in the document. It'll be plain to see that when the complexity and size of an application grows, not using a framework will become challenging. But the point of this chapter is for you to come to that realization yourself, after seeing with your own eyes what happens when you write an application without the help of a framework.

Before you go any further, go to appendix A and follow the instructions to set up the project where you'll be writing the code. When you finish and without further ado, let's begin the application you'll be building in this chapter.

2.1 The assignment: a TODOs app

So you're a developer in a consulting company, and your manager has just assigned you a new project. There is this new client with an innovative idea for a new application, and they want you to build it. They say it has the potential to disrupt the market, so it might be interesting. Your manager sets up a meeting with the client to discuss the project. In the meeting you make sure you understand the requirements, and you write them down in your notes, which you summarize as the following:

- Main idea: keep a list of the things you need to do (to-dos) in a day.
- A to-do can be marked as done, so it's removed from the list.
- A to-do can be modified, for the cases where the user makes a typo or wants to change the description.

The idea is so simple that you're a bit wary of it being "super-mega revolutionary" (you noted that down; that's what the client said), but your job is to build it, not to question its disruptiveness.

SIDEBAR **TODOs applications and frontend frameworks**

The TODOs application is a classic in the frontend framework world. Framework authors like to use it as an example when they're working on their framework, both to test it and to show other developers how it's used. We don't want to break the tradition, so we'll be using it as well.

Vue.js implemented one, which can be found from the earliest versions, inside the examples directory of the framework's old repository: github.com/vuejs/vue/tree/v0.7.0/examples/todomvc. React did as well, as early as in its initial public release, v0.3.0, which can be found inside the examples directory: github.com/facebook/react/tree/v0.3.0/examples/todomvc. And one more example is Mithril's, which can be found in the examples directory of the framework's repository as well: github.com/MithrilJS/mithril.js/tree/v1.0.0/examples/todomvc.

What you do next is talk with the design team to get the mockups for the application. They love the idea—although they swear they've seen something similar before—and they come up with a quick wireframe design that looks like figure 2.1.

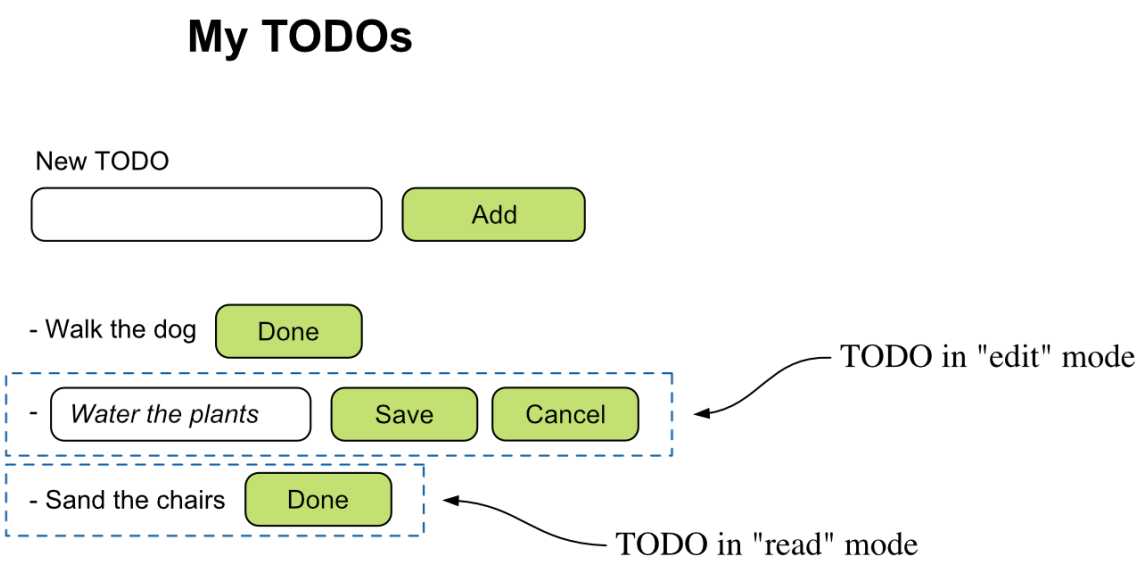


Figure 2.1 Wireframe design for the TODOs app

You show it to the client, and they love it. Time to get down to business.

2.2 Writing the application

Now that you have the requirements and the design for the TODOs app, it's time to start writing the code. Before you start, you decide to take some time to plan ahead how you're going to tackle the task—as every good developer does. You realize the application is a simple one: it doesn't have fancy features or complex requirements. So, the first decision you make is to use plain JavaScript and HTML, without any framework. You might use one later, if the application grows in complexity; but for now you want to keep things simple.

The first thing that you figure out is that part of the HTML markup is static—it won't change as the user interacts with the application—and part of needs to be dynamically generated, because it depends on the application's current state. For example, the list of to-dos will be programmatically generated from JavaScript because we can't know in advance what TODOs the user will write. In contrast, the title "My TODOs," the input box where the user writes a new to-do, its label, and the Add button will always be the same. Figure 2.2 shows the static and dynamic parts of the application.

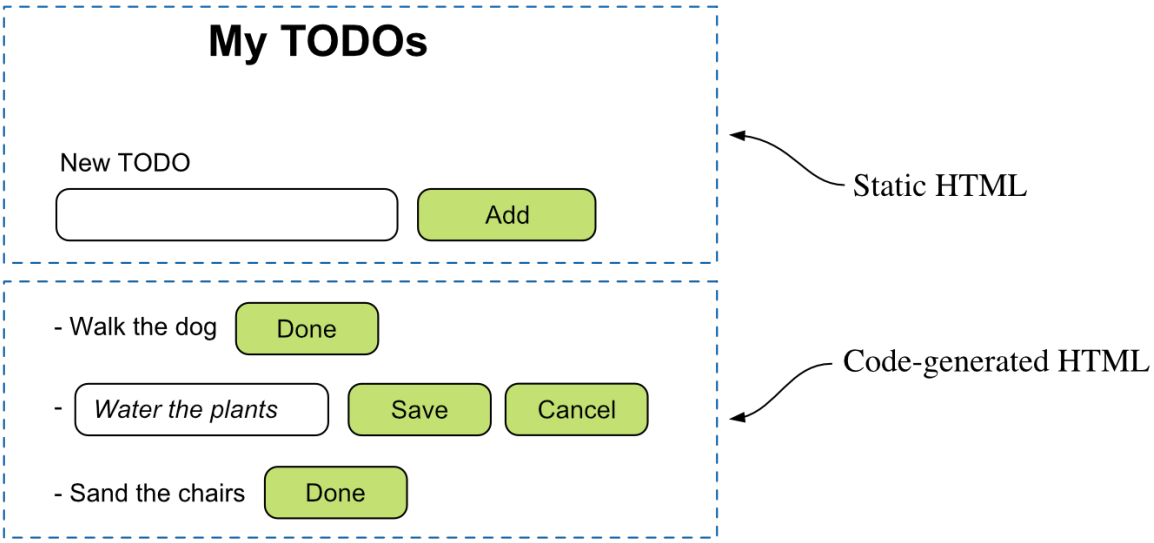


Figure 2.2 Static and dynamic HTML of the TODOs app

Then, you think about what makes up the application's *state*. The state is the information that the application keeps track of that makes it look and behave the way it does at a particular moment in time. The application will look different when there are no to-dos than when there are some, for example. This means that the list of to-dos is part of the application's state, so you'll need an array of strings to keep track of the existing to-dos. The strings represent the to-dos descriptions.

Last, before you start coding, you think about the application's behavior. Based on the requirements, the design, and a short conversation you had with the user-experience specialist, you decide that the application will behave as follows:

- When the user writes a new to-do and clicks Add, the to-do is added to the list of to-dos.
- If the user presses the Enter key while the input field is focused, the to-do is appended to the list of to-dos as well.
- Don't allow the user to add to-dos that are shorter than three characters.
- To edit a to-do, the user has to double-click on it.
- If the user discards the changes by clicking the Cancel button, the to-do is restored to its previous state; the changes are lost.
- When a to-do is marked as done, it's removed from the list of to-dos.

With this in mind, it's time to start writing the code. Let's start by writing the static part of the HTML markup.

2.2.1 The HTML markup

The static part of the HTML markup is pretty simple: it consists of a title (`<h1>`), an input field (`<input>`) with its label (`<label>`), and a button (`<button>`). There should also be a list—empty to start with—where the to-dos will be rendered programmatically (`<ul>`). And, very importantly, the HTML document should load the JavaScript file that will contain the application's code: *todos.js*.

The first thing you need to do is load the *todos.js* file as an ES module inside the `<head>` of the document. This is done by adding the `type="module"` attribute to the `<script>` element. ES modules are supported by all modern browsers, and a neat feature of them is that they are deferred by default, which means that it won't start executing the JavaScript code until the HTML document has been parsed. That's why we can load the JavaScript file at the top of the document, the `<head>`, and still be sure the HTML markup is already available when the JavaScript code starts executing.

> **TIP** **Read more about how ES modules are different from classic scripts in the browser in V8's blog at v8.dev/features/module s. It's a good read that clarifies a lot of concepts around ES modules and their behavior in the browser, written by the people who work on V8 itself.**

Then, you'll add the input field, its label, and the Add button inside a `<div>` element. Note that we need to add `id` attributes to the input field and the button so we can reference them from the JavaScript code. The same goes for the `<ul>` element that will contain the to-dos, which is below the `<div>` element and is empty to start with. The to-dos will be rendered programmatically by the JavaScript code, as `<li>` elements inside the `<ul>` element.

Open the *todos.html* file and add the markup in the following listing to the file.

Listing 2.1 The static HTML markup for the TODOs app (todos.html)

```
<!DOCTYPE html>
<html lang="en">
  <head>
    <meta charset="UTF-8" />
    <title>My TODOs</title>

    <script type="module" src="todos.js"></script>  ❶
  </head>

  <body>
    <h1>My TODOs</h1>

    <div>  ❷
      <label for="todo-input">New TODO</label>
      <input type="text" id="todo-input" />
      <button id="add-todo-btn" disabled>Add</button>
    </div>

    <ul id="todos-list"></ul>  ❸
  </body>
</html>
```

❶ The *todos.js* file loaded as an ES module.

❷ The input field, its label and the Add button.

❸ List where the to-dos will be rendered.

If you now refresh the browser window, you should see something like Figure 2.3.

Figure 2.3 The HTML markup for the TODOs app

The remaining part of the HTML markup will be dynamically generated by the JavaScript code. Here's where the fun begins.

2.2.2 The JavaScript code

You will write the JavaScript code in the *todos.js* file, so make sure you have it open in your editor.

First of all, you want to define the application's state, which is a list of to-dos—an array of strings. You'll add some to-dos already populated in the array, so that when you open the page in the browser, you can see some to-dos already rendered. Then you want to grab references to the DOM elements that you need to interact with, using the `document.getElementById()` function from the Document API.

Open the *todos.js* file and write the following code:

Listing 2.2 The state and HTML element references (todos.js)

```
// State of the app
const todos = ['Walk the dog', 'Water the plants', 'Sand the chairs']

// HTML element references
const addTodoInput = document.getElementById('todo-input')
const addTodoButton = document.getElementById('add-todo-btn')
const todosList = document.getElementById('todos-list')
```

So far, our application doesn't do anything when you type a new to-do description in the input field and click the Add button. The to-do items in the state aren't rendered either. This is because we haven't added event listeners to the HTML elements yet, and we haven't written the code that renders the to-dos. Let's fix that.

INITIALIZING THE VIEW

Now, you want to initialize the view of the application—that is, dynamically generate the HTML markup that depends on the application's state—and attach event listeners to the DOM elements that need them. To initialize the view, you iterate over the to-dos in the application's state and *render* each one using the `renderTodoInReadMode()` function and append it to the `<ul>` element using the `append()` function from the `todosList` element.

> **IMPORTANT** **To render means to transform some data into a visual representation; something we can see. In this context, when we render a to-do, what we're doing is creating the HTML elements that represent the to-do in our application.**

Rendering a to-do—a JavaScript string—into an HTML representation will by done by a function that you'll call `renderTodoInReadMode()`. The naming is important here: we're saying that the to-do is rendered in read mode. If you remember from your discussion with the client,

the to-do can be edited, so we need to render it in "edit mode" as well. In short: a to-do can be rendered in two different ways (it has two different visual representations). You'll also write a `renderTodoInEditMode()` function later on.

After rendering the to-dos—in read mode—you need to add a few event listeners to the DOM elements. First, you'll add a listener on the `<input>` field's `input` event—fired every time the user types something in the input field. This listener function should check if the input field has less than three characters, in which case the button is kept disabled to prevent the user from adding empty (or very short) to-do items. The button is enabled—by removing the `disabled` attribute—when the to-do has at least three characters. If you remember from the HTML markup (see listing 2.1), the Add `<button>` element is disabled by default.

Then, you'll add a listener on the `<input>` field's `keydown` event, which fires every time the user presses a key—any key. But we're not interested in responding to every key the user presses, only the "Enter" key is relevant to us. For this, you want to check if the key pressed is "Enter", and if so, call a function you'll name `addTodo()`, which you'll implement in a minute an will be used to add a new to-do to the application's state, and render it in the HTML.

Finally, you need a listener on the Add `<button>` element's `click` event. The event handler is the same as the one for the `keydown` event: it calls the `addTodo()` function, clears the input field and disables the Add button

NOTE **Event listener vs event handler**

The terms event listener and event handler are sometimes used interchangeably. In this book, I'll use the term event listener to refer to the registration of a function that is called when a specific event—referenced by its name—is fired on an `EventTarget` object (typically a DOM element). And event handler to refer to the function that is called when an event is fired.

Open the *todos.js* file and write the following code below the code you just wrote:

Listing 2.3 The initialization of the application (todos.js)

```
// Initialize the view
for (const todo of todos) {   ❶
  todosList.append(renderTodoInReadMode(todo))
}

addTodoInput.addEventListener('input', () => {   ❷
  addTodoButton.disabled = addTodoInput.value.length < 3
})

addTodoInput.addEventListener('keydown', ({ key }) => {   ❸
  if (key === 'Enter' && addTodoInput.value.length >= 3) {
    addTodo()
  }
})

addTodoButton.addEventListener('click', () => {   ❹
  addTodo()
})

// Functions
function renderTodoInReadMode(todo) {
  // TODO: implement me!
}

function addTodo() {
  // TODO: implement me!
}
```

❶ To-dos rendered as `<li>` items inside `<ul>`.

❷ `<button>` disabled until `<input>` has at least three characters.

❸ Pressing "Enter" adds the to-do written in the `<input>`.

❹ When `<button>` is clicked, the to-do in the `<input>` is added.

Figure 2.4 shows a visual representation of the events you've added to the static part of the HTML markup.

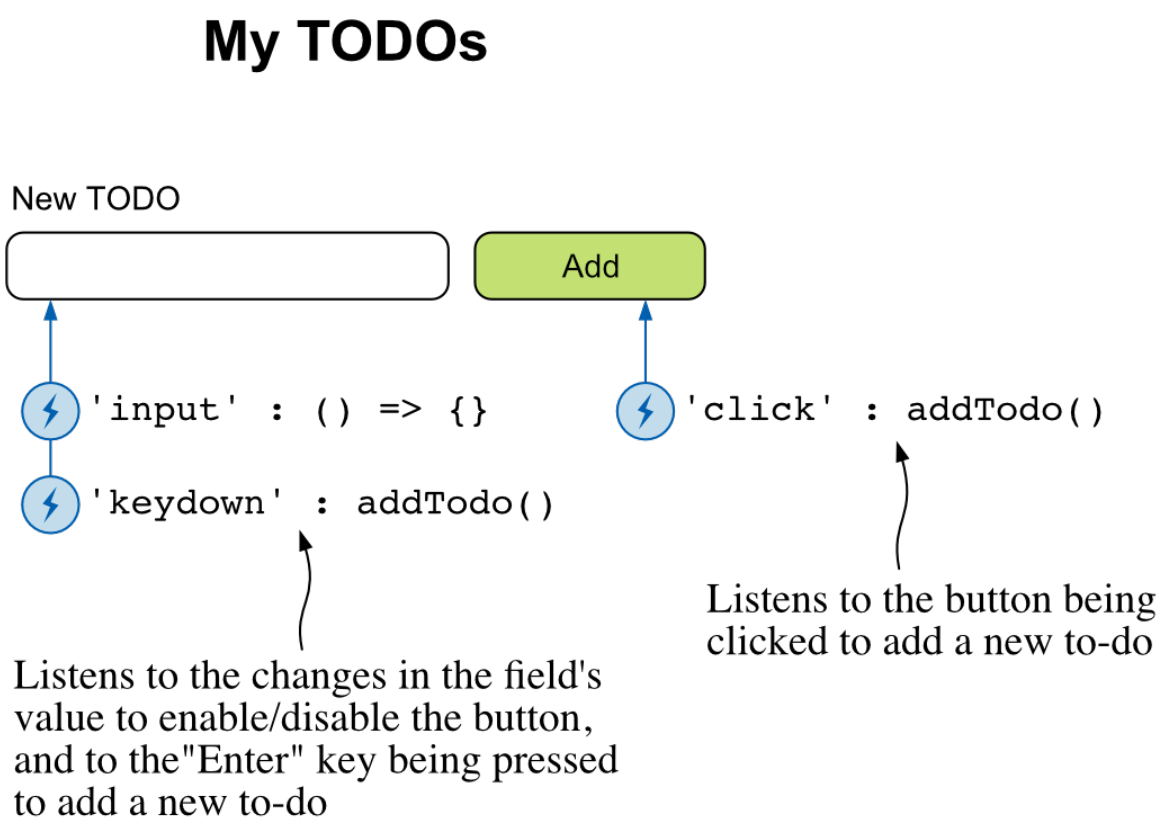


Figure 2.4 The event listeners added to the HTML elements

Now we're getting to the meat of the application: rendering to-dos! This is the part that a framework would do for you, but you're going to do it yourself in this chapter.

RENDERING TO-DOS IN "READ MODE"

To render a to-do in read mode, you need to use the `document.createElement()` method of the Document API to create some HTML elements:

- The to-do items are inside an unordered list element (`<ul>`), so each to-do should go inside a list item element (`<li>`).
- The to-do itself is a simple text that you can render inside a `<span>` element.
- Then, the user should be able to mark a to-do as done, so you need a button to do that.

Figure 2.5 depicts the HTML markup for a to-do in read mode.

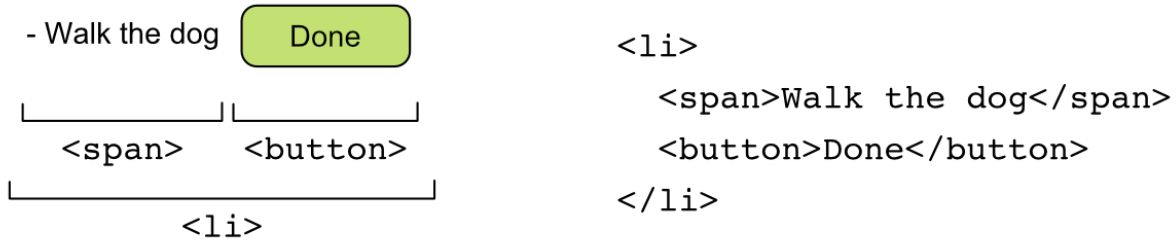


Figure 2.5 A TODO in "read mode" is rendered as a `<li>` element containing a `<span>` element with the to-do text and a button to mark it as done

The to-do description can be added as the `textContent` property of the `<span>` element. We could have created a text node and appended it to the `<span>` element (for example doing: `span.append(todo)`), but setting the `textContent` is a bit more concise.

The `<span>` element needs to have a listener attached to its `dblclick` event that's going to replace the to-do in read mode with the "edit mode" version. To accomplish this, you'll call the `replaceChild()` method on the `<li>` DOM node. This method removes the entire `<li>` element and its children from the list of to-dos and renders the "edit mode" version of the to-do in its place. The rendering is done by calling the `renderTodoInEditMode()` function, which you'll implement in the next section.

Lastly, you want to attach an event listener to the `<button>` element's `click` event that's going to remove the to-do from the list of to-dos. For that, you'll write a `removeTodo()` function that you'll also need to fill in later on.

Now that you know what the plan is, fill in the `renderTodoInReadMode()` function as follows:

Listing 2.4 Rendering the to-dos in "read mode" (todos.js)

```
function renderTodoInReadMode(todo) {
  const li = document.createElement('li')   ❶

  const span = document.createElement('span')   ❷
  span.textContent = todo
  span.addEventListener('dblclick', () => {   ❸
    const idx = todos.indexOf(todo)

    todosList.replaceChild(   ❹
      renderTodoInEditMode(todo),
      todosList.childNodes[idx]
    )
  })
  li.append(span)

  const button = document.createElement('button')   ❺
  button.textContent = 'Done'
  button.addEventListener('click', () => {   ❻
    const idx = todos.indexOf(todo)
    removeTodo(idx)
  })
  li.append(button)

  return li
}

function removeTodo(index) {
  // TODO: implement me!
}
```

❶ A `<li>` element.

❷ A `<span>` with the to-do description.

❸ A `dblclick` event toggles the to-do to edit mode.

❹ Replace the to-do with its edit mode version.

❺ A `<button>` to mark the to-do as done.

❻ Remove the to-do from the list.

Figure 2.6 shows a visual representation of the events you've added to the to-dos in read mode.

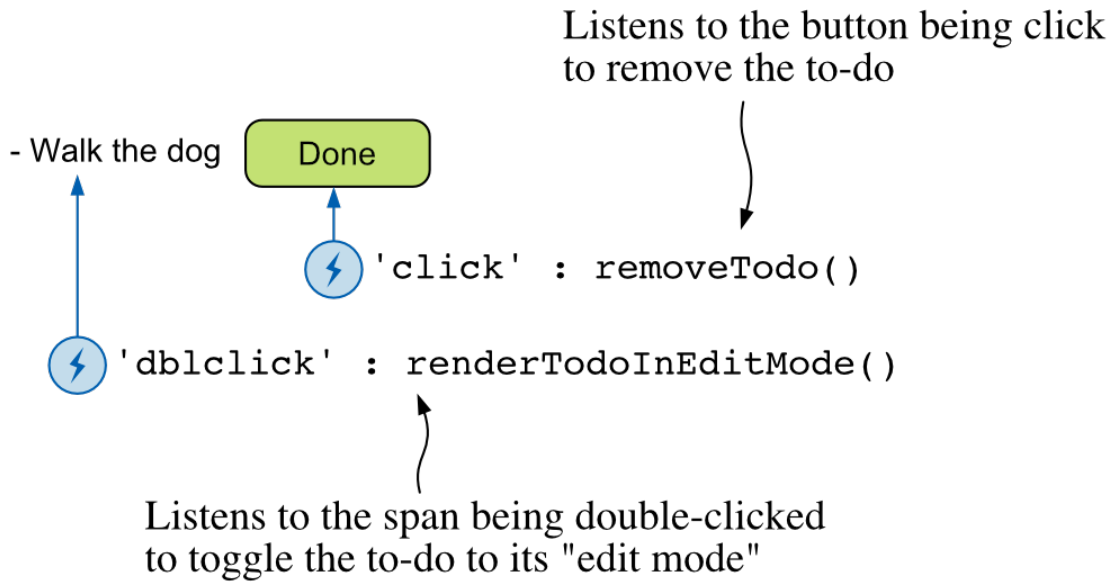
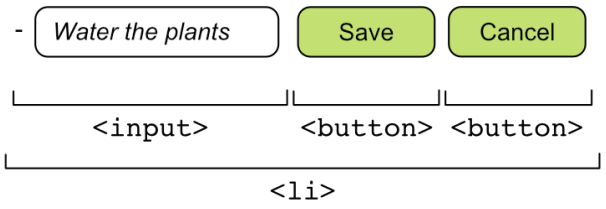


Figure 2.6 The event listeners added to the to-dos in "read mode"

Let's now implement the `renderInEditMode()` function.

RENDERING TO-DOS IN "EDIT MODE"

The to-do in edit mode is also part of the unordered list of to-dos, thus it should also appear inside a `<li>` element. But this time, the `<li>` element should contain an `<input>` element instead of a `<span>` element, so that the user can modify the to-do description. And instead of having one button, we need two: one to save the changes and another to cancel them. Figure 2.7 shows the HTML markup for a to-do in "edit mode".




```
<li>
  <input type="text" />
  <button>Save</button>
  <button>Cancel</button>
</li>
```

Figure 2.7 A TODO in "edit mode" is rendered as a `<li>` element containing an `<input>` element with the to-do text and two buttons to save or cancel the changes

When the user clicks on the save button, a function that you'll write later named `updateTodo()` will modify the to-do description in the state, and replace the to-do in edit mode with the read mode version (once the user is done editing the to-do, we want them to see the updated version back in read mode). When the user clicks on the Cancel button instead, you just need to call the `renderTodoInReadMode()` function.

Write the code for the `renderTodoInEditMode()` function as follows:

Listing 2.5 Rendering the to-dos in "edit mode" (todos.js)

```
function renderTodoInEditMode(todo) {
  const li = document.createElement('li')   ❶

  const input = document.createElement('input')   ❷
  input.type = 'text'
  input.value = todo
  li.append(input)

  const saveBtn = document.createElement('button')   ❸
  saveBtn.textContent = 'Save'
  saveBtn.addEventListener('click', () => {   ❹
    const idx = todos.indexOf(todo)
    updateTodo(idx, input.value)
  })
  li.append(saveBtn)

  const cancelBtn = document.createElement('button')   ❺
  cancelBtn.textContent = 'Cancel'
  cancelBtn.addEventListener('click', () => {   ❻
    const idx = todos.indexOf(todo)
    todosList.replaceChild(   ❼
      renderTodoInReadMode(todo),
      todosList.childNodes[idx]
    )
  })
  li.append(cancelBtn)

  return li
}

function updateTodo(index, description) {
  // TODO: implement me!
}
```

❶ A `<li>` element.

❷ An `<input>` with the editable to-do description.

❸ A `<button>` to save the changes.

❹ Update the to-do description.

❺ A `<button>` to cancel the changes.

❻ A `click` event cancels the changes.

❼ Replace the to-do with its read mode version.

The code is very similar to the one for the read mode version of the to-do. Figure 2.8 shows the events you've added to the to-dos in "edit mode".

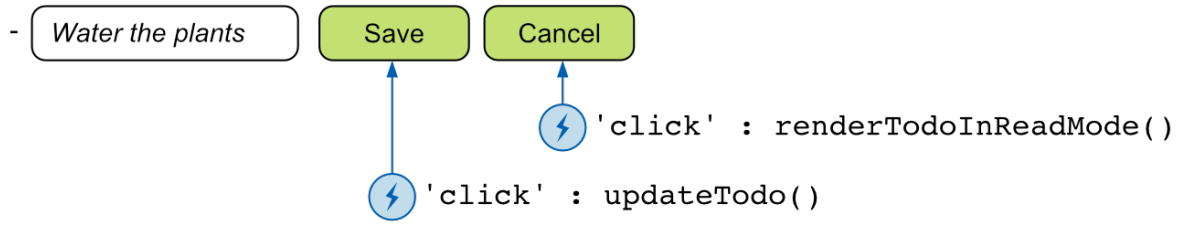


Figure 2.8 The events added to the to-dos in "edit mode"

So, all that's missing to implement are the `addTodo()`, `removeTodo()`, `updateTodo()` functions. Let's do that now.

ADDING, REMOVING AND UPDATING TO-DOS

The functions to add, remove and update to-dos are defined in our `todos.js` file, but they're not implemented yet. We left "TODO" comments (oh, the irony!) in the code to remind us of that. The implementation of these functions is straightforward, so let's see what each of them does.

The `addTodo()` function reads the description for the new to-do from the `<input>` element's `value` property, and pushes it into the array of to-dos. Then it calls the `renderTodoInReadMode()` function to render the HTML for the new to-do and appends it to the `todosList` element. Lastly, it clears the `<input>` element's `value` property so that the user can enter a new to-do description, and disables the add button.

The `removeTodo()` function removes the to-do from the array of to-dos and the `<li>` element from the document. To remove the `<li>` element from its parent `<ul>`, it calls the `remove()` method on the target node, which you can locate by index inside the `childNodes` array of the `<ul>` element.

The `updateTodo()` function needs two parameters passed to it: the index of the to-do to update, and the new description for the to-do. The passed description overwrites whatever is in the array of to-dos at the given index. Then, using the `renderTodoInReadMode()` function, you can render the HTML for the updated to-do, and finally replace the to-do at the given index inside the `todosList` element's `childNodes` array with the new HTML.

Listing 2.6 shows the code for the `addTodo()`, `removeTodo()` and `updateTodo()` functions.

Listing 2.6 Functions to add, remove and edit to-dos (todos.js)

```
function addTodo() {   ❶
  const description = addTodoInput.value

  todos.push(description)
  const todo = renderTodoInReadMode(description)
  todosList.append(todo)

  addTodoInput.value = ''
  addTodoButton.disabled = true
}

function removeTodo(index) {   ❷
  todos.splice(index, 1)
  todosList.childNodes[index].remove()
}

function updateTodo(index, description) {   ❸
  todos[index] = description
  const todo = renderTodoInReadMode(description)
  todosList.replaceChild(todo, todosList.childNodes[index])
}
```

❶ Adding a new to-do.

❷ Removing a to-do at a given index.

❸ Updating a to-do at a given index.

If you refresh the page now, you should be able to add, remove and update to-dos. Your application should look similar to Figure 2.9. Congratulations! You've written a web application without a framework. It wasn't that painful, was it?

Figure 2.9 The finished TODOs app

Try to add a new to-do by writing something like "Sing a song" in the input field and pressing the Add button. Then, press the "Remove" button to remove the to-do from the list. Give a try clicking one of the to-dos to see how it gets replaced by its "edit mode" version, like in Figure 2.10.

Figure 2.10 The TODOs app in "edit mode"

I hope you feel excited about what you've just built: an interactive web application without a framework! But I also hope that you've realized how inefficient it'd be to write a large application like this; that's why using a framework is a great idea. Operating at such a low-level to programmatically generate the HTML markup for the DOM is tedious and error-prone.

The first thing we want our framework to take care for us is the usage of the Document API to create and manipulate the DOM; that's the part that's the most burdensome to write. If we can abstract away the manipulation of the DOM, we can focus on the application logic, which is what makes our applications useful. Think about it: the time spent working on manipulating the DOM doesn't really add value to the final user. We need to do it for the application to be interactive, but it's not what the user cares about. A good framework should allow us to forget about dealing with the DOM and focus on the application logic. That's exactly what we'll do in the next chapter.

2.3 Summary

- Nothing prevents us from writing complete frontend applications without a framework, but doing so can easily result in code that's a mix of application logic and DOM manipulation, that is, using the Document API to modify the browser's document.
- Using vanilla JavaScript to write a fronted application, every event that changes the state of the application forces us to write the code that updates the DOM to reflect the new state. This code tends to be very imperative, verbose, and error-prone.

2.4 Exercises

1. Add some CSS styles to the application so that it doesn’t look so bland.
2. Purposely introduce a bug in the rendering logic of the application and dust off your debugging skills to "find" it. Use the browser’s developer tools for that.
3. Imagine that the customer tells you that they don’t want "done" to-dos to be removed from the list, but instead crossed out. How’d you go about implementing that?
4. How do you think we could abstract the DOM manipulation away from the application logic?

3 Rendering and the virtual DOM

This chapter covers

- What the virtual DOM is
- What problem the virtual DOM solves
- Implementing functions to create virtual DOM nodes
- Defining the concept of a stateless component

As you've seen in the previous chapter, mixing application and DOM manipulation code gets unwieldy quickly. If for every event resulting from the user interacting with the application, we have to implement not only the business logic—the one that gives value to the application—but also the code to update the DOM, the codebase becomes a hard-to-maintain mess. This is because we mix two different levels of abstraction together: the application logic and the DOM manipulation. What a maintenance nightmare!

Manipulating the DOM results is very *imperative code*, that is, code that describes how to do something, step by step. This is in contrast with *declarative code*, which describes what to do, without specifying how to do it—those details are implemented somewhere else. Also, manipulating the DOM is a very *low level* operation, that is, it requires a lot of knowledge of the Document API, and sits below the application logic. Contrast this with *higher level* application code, which is framed in a language that is close to the business, and anyone working in the project can—should—understand.

We would have a much cleaner codebase if we could describe in a more declarative manner what we want the view of our application to look like and let the framework take care of manipulating the DOM to create the view. What we need is similar to the blueprints of a house: a description of what needs to be built without specifying how to build it. The architect designs the blueprints for the house and lets the construction company take care of building it. Imagine if the architect

had to, not only design the house, but also go to the construction site and build it; or at least tell the construction workers how they need to do their job, step by step, without missing any single detail. That would be a very inefficient way of building.

For the sake of productivity, the architect focuses on the "what" needs to be built, and let the construction company take care of the "how" it's built. Similarly, we want the application developer to focus on the "what" (what the view should look like), and let the framework take care of the "how" (how to assemble the view using the Document API).

3.1 Separating concerns—DOM manipulation vs. application logic

In the previous chapter, you wrote all the code together as part of the application, like you can see in figure 3.1. That code was in charge of initializing the application and its state, programmatically build the view using the Document API, and handling the events that result from the user interacting with the application by modifying the DOM accordingly.

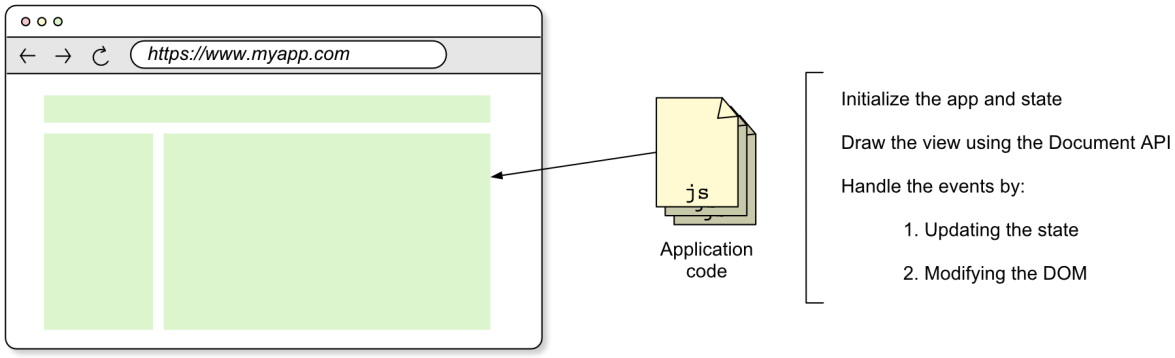


Figure 3.1 So far, all the code is written together as part of the application

What we want to accomplish in this chapter is separating the code that describes the view—the application's code—from the code that uses the Document API to manipulate the DOM and create the view—the framework's code. There's a term widely used in the software industry: *separation of concerns*. It means splitting the code so that the parts of it that carry out different responsibilities can be found separated from each other, which helps the developer understand the code and maintain it. Figure 3.2 shows the separation of concerns we want to achieve: splitting the application code from the framework code that deals with the DOM manipulation and keeps track of the state. We will be focusing on rendering the view in this and the next chapter, and leave the state management for the next one.

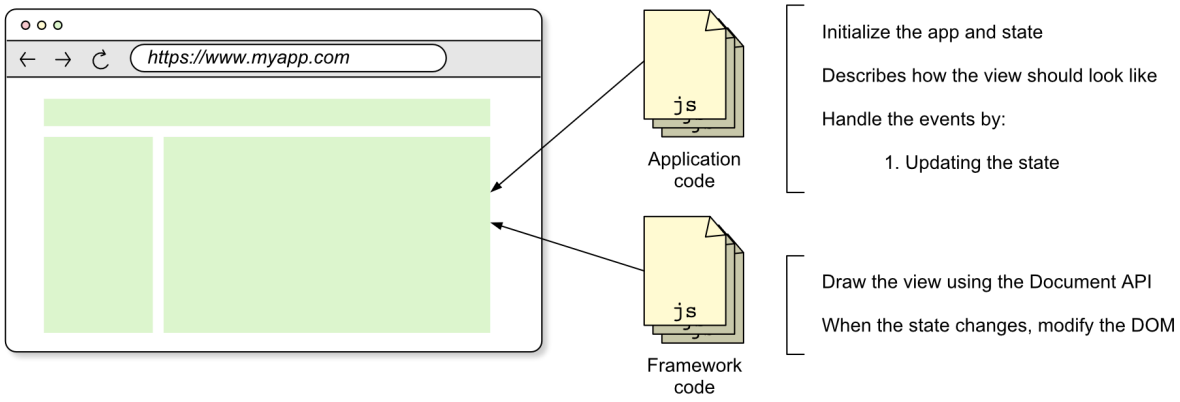


Figure 3.2 By the end of next chapter, you'll have separated the code that describes the view from the code that manipulates the DOM

The main objective of this separation of concerns is to simplify the application's developer job: they only need to focus on the application logic, and let the framework take care of the DOM manipulation. This results in three clear benefits:

- *Developer productivity*—the application developer doesn't need to write DOM manipulation code, they can instead focus on the application logic. They have to write less code, and that makes them ship value faster.
- *Code maintainability*—the DOM manipulation and application logic aren't mixed together, and that makes the code more succinct and easier to understand.
- *Framework performance*—the framework author, who's likely to understand how to produce efficient DOM manipulation code better than the application developer, can optimize how the DOM is manipulated to make the framework more performant.

Going back to the blueprint analogy: how do you define how the view should look like, the same way the architect does with the blueprints? The answer is the *virtual DOM*, which we'll explain in the next section. In a nutshell, the virtual DOM is a JavaScript tree data structure that describes the HTML markup that needs to be rendered in the browser. You—as the developer—can describe the view of your application using a virtual DOM representation, then let the framework take care of building the real DOM in the browser. You're like the architect designing the blueprint and the framework is the construction company building the house.

3.1.1 Getting ready

Before you start writing the code in this and the next chapters, make sure you've followed the instructions in Appendix A to set up the project. Your project should include a *packages* directory, containing three NPM workspaces: *compiler*, *loader* and *runtime*. These workspaces have a *src/* directory containing a barrel file: *index.js*. Everything that the packages export should appear in this file (it should be currently empty). There should be a script called *build* declared in the *package.json* file that uses Rollup to bundle the runtime project into a file named *<fwk-name>.js*, inside a *dist* directory, where *<fwk-name>* is the name you chose for your framework.

All the code you'll write in this and the following chapters is part of the *runtime* package of the framework. I'll be referring to the *src/* directory of the *runtime* package as simply *src/* from now on. So, if I tell you to create a new file inside *src/*, I'm referring to this directory unless I say otherwise explicitly.

3.2 The virtual DOM

The word "virtual" is used to describe something that isn't real, but mimics something that is. A *virtual machine* is, for example, software written to mimic the behavior of a real machine—hardware. It gives you the impression that you're running a real machine, but it's actually software running on top of your computer's hardware. We often hear *virtual reality* to describe a technology that mimics the real world, and there are plenty more examples of virtual things (can you think of any?).

What is then the virtual DOM? The virtual DOM is a representation of the actual DOM (the Document Object Model in the browser). The DOM is an in-memory tree of nodes representing the HTML in the page, so the virtual DOM has to be a similar data structure that defines the view of our application: a tree; but made of pure JavaScript objects. Each node in this tree is a *virtual node*, and the tree itself is what we call *virtual DOM*.

IMPORTANT **The virtual DOM is a representation of the DOM consisting on a tree of JavaScript objects. The nodes in the actual DOM are heavy objects that have hundreds of properties, whereas the virtual nodes are lightweight objects that only contain the information needed to render the view. Virtual nodes are cheap to create and manipulate.**

Let's imagine that we want to produce the following HTML:

```
<form action="/login" class="login-form">
  <input type="text" name="user" />
  <input type="password" name="pass" />
  <button>Log in</button>
</form>
```

The HTML consists of a form with three child nodes: two inputs and a button. A virtual DOM representation for this HTML needs to contain the same information as the DOM, namely:

- What nodes are in the tree and their attributes.
- The hierarchy of the nodes in the tree.
- The relative position of the nodes in the tree.

For example, it's important that the virtual DOM includes the `<form>` as the root node, and that the two `<input>` and `<button>` are its children. The form has an `action` and a `class` attribute, and the button—although not visible in the HTML—has an `onclick` event handler. The `type` and `name` attributes of the `<input>` elements are also crucial: it's not the same an `<input>` of type `text` and an `<input>` of type `password`. Also, the relative position of the form's children is important: the button should go below the inputs. The framework needs all this information for the view to be rendered correctly.

A possible virtual DOM representation—made of pure JavaScript objects—for this HTML could be the following:

```
{
  type: 'element',
  tag: 'form',
  props: { action: '/login', class: 'login-form' },
  children: [
    {
      type: 'element',
      tag: 'input',
      props: { type: 'text', name: 'user' }
    },
    {
      type: 'element',
      tag: 'input',
      props: { type: 'password', name: 'pass' }
    },
    {
      type: 'element',
      tag: 'button',
      props: { on: { click: () => login() } },
      children: [
        {
          type: 'text',
          value: 'Log in'
        }
      ]
    }
  ]
}
```

Each node in the virtual DOM is an object with a `type` property that identifies what kind of node it is. In this example, there are two types of nodes:

- *element*—represents a regular HTML element, such as `<form>`, `<input>`, or `<button>`.
- *text*—represents a text node, such as the "Log in" text of the `<button>` element in the example above.

We'll see one more type of node later in the chapter, the *fragment* node: a node used to group other nodes together, but has no semantic meaning of its own. Each type of node has its own set of properties that describe it. Text nodes, for example, have one property apart from the `type`:

- `value`: the string of text.

Element virtual nodes have three properties:

- `tag`: the tag name of the HTML element.
- `props`: the attributes of the HTML element, including the event handlers inside an `on` property.
- `children`: the ordered children of the HTML element. If absent, the element is a leaf node.

And as we'll see, fragment nodes have a `children` array of nodes, similar to the `children` array of element nodes.

Using this virtual DOM representation allows the developer to describe how the view of their application—the rendered HTML—should look like. You—the framework author—implement the code that takes that virtual DOM representation and builds the real one in the browser. This way, you effectively separate the code that describes the view from the code that manipulates the DOM.

We can represent the virtual DOM in the previous example graphically as a tree, as shown in figure 3.3. The `<form>` element is the root node of the tree, and the two `<input>` and `<button>` elements are its children. The properties of each node are inside the node's box, such as the `action` and `class` attributes of the `<form>` element. The `<button>` element has a child node, a text node with the text "Login".

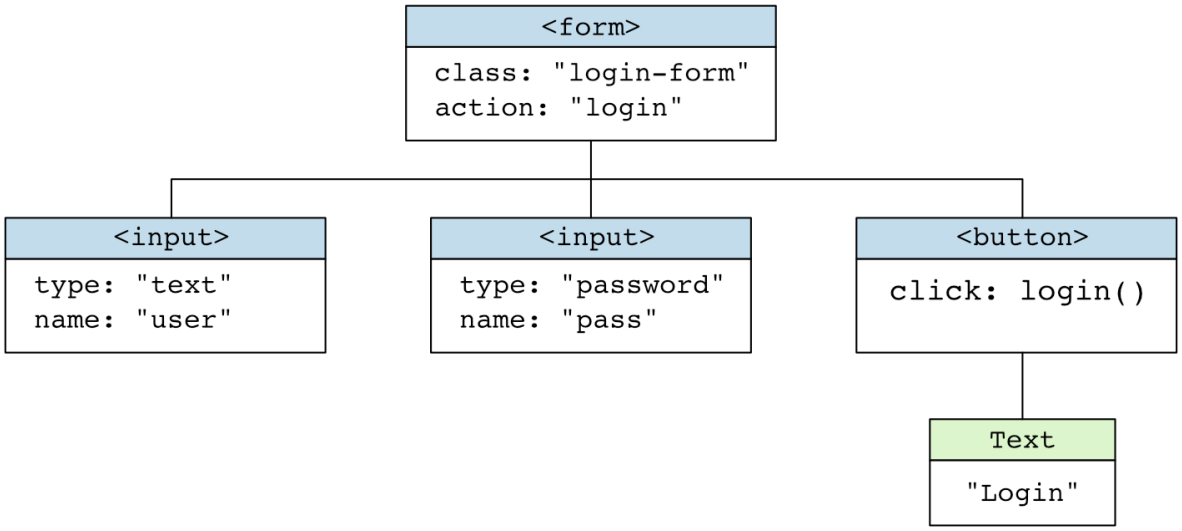


Figure 3.3 The virtual DOM is a representation of the DOM made of JavaScript objects

This representation of an application's view holds all the information that we need to know in order to unequivocally build the DOM. It maintains the hierarchy of the elements, the attributes, event handlers and position of the child elements. If you are given such a virtual DOM, you can derive the corresponding HTML markup without any ambiguity.

IMPORTANT **The virtual DOM is the blueprint of the view of an application. It describes how the final rendered HTML should look like, but it doesn't tell the framework how it should handle the details of building it.**

As you can imagine, creating these virtual trees by hand is a tedious task, and it's easy to make mistakes like misspelling the name of a property. Instead of letting the developer define the virtual nodes by hand, you'll write functions that create each type of virtual node, so that the process of defining the view of their application is less painful. Even with these functions, you'll see that the process of defining a view as a virtual DOM isn't that convenient—you're probably used to writing HTML templates, or JSX—but it's a starting point. You'll implement a template engine towards then end of the book that will make the process of defining views much easier. But let's not get ahead of ourselves; let's start with the virtual DOM creation functions first.

3.3 Element nodes

Element nodes are the most common type of virtual node: they represent the regular HTML elements that you use to define the structure of your web pages. To name a few, you have `<h1>` trough `<h6>` for headings, `<p>` for paragraphs, `<ul>` and `<ol>` for lists, `<a>` for links, and `<div>` for generic containers. These nodes have a tag name (such as `<p>`), attributes (such as a class name or the `type` attribute of an `<input>` element), and children nodes (the nodes that are inside of them, between the opening and closing tags).

You'll now implement a function `h()` that takes in the element's tag name, an object with its attributes (that we'll call *props*, for properties), and an array of its children nodes, and creates an element node. The name `h()` is short for *hyperscript*, or a script that creates hypertext. (Recall that HTML is acronym for *HyperText Markup Language*.) The name `h()` for the function is a common one used in some frontend frameworks, probably because it's short and easy to type, which is important because you'll be using it a lot.

SIDEBAR **`h()`, `hyperscript()`, or `createElement()`**

React uses the `React.createElement()` function to create virtual nodes. It's a long name, but you typically never call that function directly, as you use JSX instead. Each HTML element you write in JSX is transpiled to a `React.createElement()` call.

Other frameworks, such as Vue, do name the virtual node producing function `h()`. Mithril, for example, gives the user a function called `m()` to create the virtual DOM, but it's the same idea. Internally, Mithril implements the virtual node creating function named as `hyperscript()`. The user facing function has a nice and short name (`m()`), but the internal function has this more descriptive name.

Before you implement the `h()` function, remember that as far as we've seen, you can have three different types of DOM nodes that need to be represented as virtual nodes:

- *Text nodes*—They represent text content.
- *Element nodes*—The most common type of node; they represent HTML elements that have a tag name, such as a `'div'` or a `'p'`.
- *Fragment nodes*—They represent a collection of nodes that don't have a parent node until they are attached to the DOM. (We haven't covered them yet, but we will shortly.)

Since they have different properties, each type of node will be created using a different function: `hString()`, `h()` and `hFragment()`, respectively. These functions return an object—the virtual node—with the `type` property set to the corresponding type string, so we know what type of node we're dealing with. In the case of a text node, the `type` will be `'text'`; for an element node, `'element'`; and for a fragment node, it'll be `'fragment'`.

Later on, you'll have to write code that operates on the virtual nodes and do something different depending on the type of node. It's therefore a good idea to define a constant for each of these types, so you avoid typos.

Create a new file called *h.js* under *src/*. Inside, write the following code:

```
export const DOM_TYPES = {
  TEXT: 'text',
  ELEMENT: 'element',
  FRAGMENT: 'fragment',
}
```

You have defined three constants, one for each type of node:

- `DOM_TYPES.TEXT`: the type for a text node, which is `'text'`.
- `DOM_TYPES.ELEMENT`: the type for an element node, which is `'element'`.
- `DOM_TYPES.FRAGMENT`: the type for a fragment node, which is `'fragment'`.

Let's now implement the `h()` function that creates element virtual nodes. In the *h.js* file, write the code in bold:

```
import { withoutNulls } from './utils/arrays'

export const DOM_TYPES = {
  TEXT: 'text',
  ELEMENT: 'element',
  FRAGMENT: 'fragment',
}

export function h(tag, props = {}, children = []) {
  return {
    tag,
    props,
    children: mapTextNodes(withoutNulls(children)),
    type: DOM_TYPES.ELEMENT,
  }
}
```

You've first imported the `withoutNulls()` function from the *utils/arrays.js* module, but you haven't implemented it yet; you will in a minute. Then you've defined the `h()` function below the `DOM_TYPES` object, which takes three arguments: `tag`, `props`, and `children`. The last two arguments have default values, so that you can call the function with only the tag name, as in `h('div')`. The object returned by the function—the virtual node—has the `type` property set to `DOM_TYPES.ELEMENT`, and the `tag` and `props` properties set to their corresponding arguments.

With the children, you've done a bit more: you've passed them to the `withoutNulls()` function, which returns a new array with all the `null` values removed, then you've passed the result to the `mapTextNodes()` function, which transforms any string in the array into a text virtual node. Let's implement these two functions now.

3.3.1 Conditional rendering—removing *`null`* values

When using *conditional rendering*, that is, rendering nodes only when a condition is met, some children might be `null` in the array, and this means that they shouldn't be rendered at all. We want these `null` values to be removed from the array of children.

Let's use our TODO app as an example. Recall that the add new to-do button is disabled when there's no text in the input, or the text is too short. If instead of disabling the button you decided to remove it from the page, you'd have a conditional like the following:

```
{
  tag: 'div',
  children: [
    { tag: 'input', props: { type: 'text' } },
    addTodoInput.value.length > 2
      ? { tag: 'button', children: ['Add'] }
      : null
  ]
}
```

When the condition `addTodoInput.value.length > 2` is `false`, a `null` node is added to the `div` node's children array:

```
{
  tag: 'div',
  children: [
    { tag: 'input', props: { type: 'text' } },
    null
  ]
}
```

This `null` value means that the button shouldn't be added to the DOM. The simplest way to make this work is to filter out `null` values from the children array when a new virtual node is created, so that a `null` node isn't passed around the framework:

```
{
  tag: 'div',
  children: [
    { tag: 'input', props: { type: 'text' } }
  ]
}
```

Create a new directory under *src/* called *utils/*, and inside add a new file: *arrays.js*. Inside it, write a function called `withoutNulls()` that takes an array and returns a new array with all the `null` values removed.

```
export function withoutNulls(arr) {
  return arr.filter((item) => item != null)
}
```

Note the usage of the `!=` operator, as opposed to using `!==`: this is so you remove both `null` and `undefined` values. You aren't expecting `undefined` values, but this way you'll remove them if they appeared—just in case. (Your linter might complain about this if you have the eqeqeq rule enabled, but you can disable it for this line; tell the linter you know what you're doing.)

3.3.2 Mapping strings to text nodes

After filtering out the `null` values from the children array, you pass the result to a the `mapTextNodes()` function. We said that this function transforms strings into text virtual nodes. Why do we want to do this? Well, just as a convenience for creating text nodes, so instead of doing:

```
h('div', {}, [hString('Hello '), hString('world!')])
```

we can do:

```
h('div', {}, ['Hello ', 'world!'])
```

As you can anticipate, you'll use text children a lot, so this will make your life easier—if only a little bit. Let's now write that missing `mapTextNodes()` function. In the *h.js* file, below the `h()`

function, write the code for the function as follows:

```
function mapTextNodes(children) {
  return children.map((child) =>
    typeof child === 'string' ? hString(child) : child
  )
}
```

You've used the `hString()` function to create text virtual nodes out of strings, but that function doesn't exist yet. That's the next thing you'll do: implement the function that creates text virtual nodes.

3.4 Text nodes

Text nodes are the nodes in the DOM that contain text. They have no tag name, no attributes, and no children; just text.

Creating text nodes is the simplest of the three types of virtual nodes. A text virtual node is simply an object with the `type` property set to `DOM_TYPES.TEXT`, and the `value` property set to the text content. In the *h.js* file, write the `hString()` function like so:

```
export function hString(str) {
  return { type: DOM_TYPES.TEXT, value: str }
}
```

That was easy! You're just missing the `hFragment()` function to create fragment virtual nodes.

3.5 Fragment nodes

A fragment is a type of node used to group multiple nodes that need to be attached to the DOM together. Once attached to the DOM, the children are removed from the fragment, leaving an empty fragment behind. Fragments are a temporal construct used to build subtrees of the DOM: once attached, their mission is over. They are useful when you want to attach multiple child nodes to the DOM at once, without having to create a parent node for them.

Since you might have never used fragments before, let's see how they work.

3.5.1 How fragments work

A fragment can be created using the Document API's `createDocumentFragment()` method:

```
const fragment = document.createDocumentFragment()
```

You can append elements to it using its `append()` method. Let's add two paragraphs to the fragment:

```
const hi = document.createElement('p')
hi.textContent = 'Oh, hi!'

const bye = document.createElement('p')
bye.textContent = 'Bye!'

fragment.append(hi, bye)
```

You now have a fragment with two paragraphs, but it isn't attached to the DOM yet. You can inspect the fragment's children using the `children` property and be sure that they are there:

```
fragment.children // HTMLCollection(2) [p, p]
```

If you attach the fragment to the document's `<body>` like so:

```
document.body.append(fragment)
```

The resulting HTML is:

```
<body>
  <p>Oh, hi!</p>
  <p>Bye!</p>
</body>
```

As you see, there's no trace of the fragment in the DOM: nothing like a `<fragment>` element; but its children are there. In fact, the children of the fragment were attached to the DOM, but also removed from the fragment. If you check the fragment's `children` property again:

```
fragment.children // HTMLCollection []
```

They are gone! Fragments are a great way to build subtrees that don't have a parent node when their virtual DOM is defined, but get one when they are attached to the DOM. This allows us to not add artificial nodes to the DOM and keep the number of nodes low. (We'll see examples of this later on.)

3.5.2 Implementing fragment nodes

Fragments are just an array of child nodes, so it's implementation is very simple. In the *h.js* file, write the `hFragment()` function as follows:

```
export function hFragment(vNodes) {
  return {
    type: DOM_TYPES.FRAGMENT,
    children: mapTextNodes(withoutNulls(vNodes)),
  }
}
```

Same as before, you've filtered out the `null` values from the array of children, and then you've mapped the strings in the `children` array to text virtual nodes. That's all there is to it!

3.5.3 Testing the virtual DOM functions

You can now use the `h()`, `hString()`, and `hFragment()` functions to create virtual DOM representations of the view of your application. What we'll implement next is the code that takes in a virtual DOM and creates the real DOM for it, but first, let's put the virtual DOM functions to the test. Let's use the `h()` function to define the view of a login form:

```
h('form', { class: 'login-form', action: 'login' }, [
  h('input', { type: 'text', name: 'user' }),
  h('input', { type: 'password', name: 'pass' }),
  h('button', { on: { click: login } }, ['Login'])
])
```

This will create a virtual DOM depicted in figure 3.4. Arguably, using the `h()` functions is more concise than defining the virtual DOM manually, as a tree of JavaScript objects.

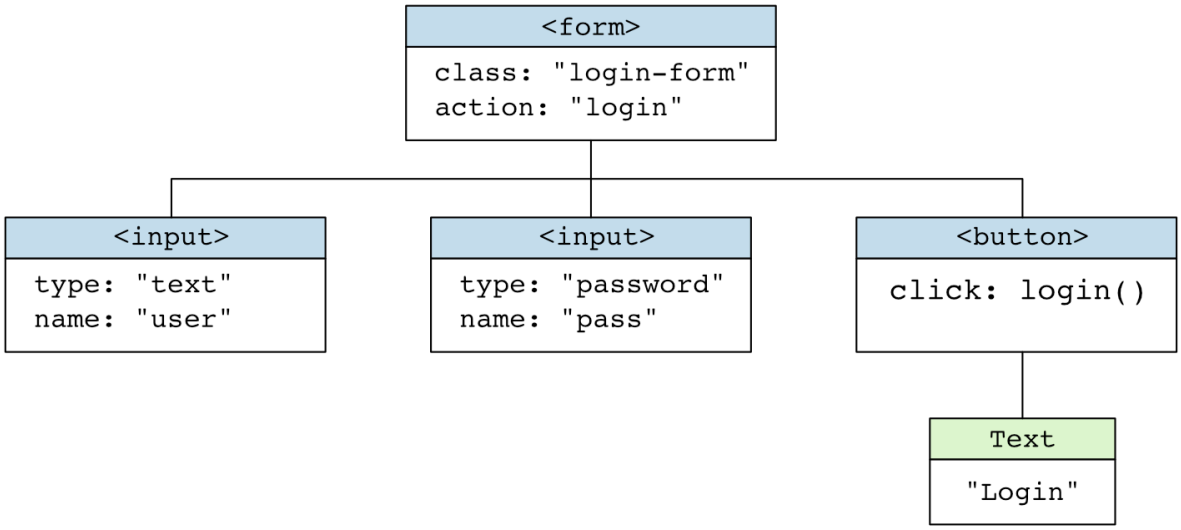


Figure 3.4 Example of creating a virtual DOM tree

This virtual DOM, passed to the framework, will be used to create the real DOM, the HTML code that will be rendered in the browser. In this case, the HTML markup would be:

```
<form class="login-form" action="login">
  <input type="text" name="user">
  <input type="password" name="pass">
  <button>Login</button>
</form>
```

NOTE **The `<button>` element doesn't have a `click` event handler rendered in the HTML markup. This is because the framework will add the event handler to the button programmatically, when it is attached to the DOM. The event handlers added from JavaScript aren't shown in the HTML.**

As you can imagine, you typically don't define the virtual DOM for your entire application in

one place; that can get unwieldy as the application grows in size. What you do instead is split the view into subparts, each of which we call a *component*. Components are the cornerstone of frontend frameworks: they allow us to break down a large application into smaller, more manageable pieces, each of which in charge of a specific part of the view.

Let's see what makes a component in your early version of the framework.

3.6 Components—the cornerstone of frontend frameworks

The component has emerged as the revolutionary concept that has made frontend frameworks so popular. The ability to break down a large application into smaller parts, each of which defines a specific part of the view, and manages its interaction with the user, has been a game changer (well, arguably; because a good use of the MVC or MVVM patterns could already get us as far). Every frontend framework uses the concept of components, and yours will be no different.

Let's take a small detour from the implementation of the virtual DOM to understand how you'll decompose the view of your application into components using your first version of the framework.

3.6.1 What is a component?

A component in your framework will be a mini-application of its own: it'll have its own internal state and lifecycle, and it'll be in charge of rendering a part of the view. It'll communicate with the rest of the application emitting events, and receive *props* (data passed to the component from the outside), re-rendering its view when a new set of props is passed to it. But it'll take us a few chapters to get there. Your first version of a component will be much simpler: a pure function that takes in the state of the whole application and returns the virtual DOM representing the view of the component. In a later chapter, you'll make components have their own internal state and lifecycle, but for now, let's start by breaking down the view of the application into pure functions that, given the state, return the virtual DOM representing a part of it.

3.6.2 The virtual DOM as a function of the state

The view of an application depends on the state of the application, thus we can say that the virtual DOM is a function of the state. Each time the state changes, the virtual DOM should be re-evaluated, and the framework needs to update the real DOM accordingly. This dependency between the state and the view is depicted in figure 3.5. In the left column, the state consists in a list of to-dos with just one to-do, "Walk the dog". In the right column, the state changes to also include a second to-do, "Water the plants". Notice how the virtual DOM changes accordingly, and how the HTML markup changes as well.

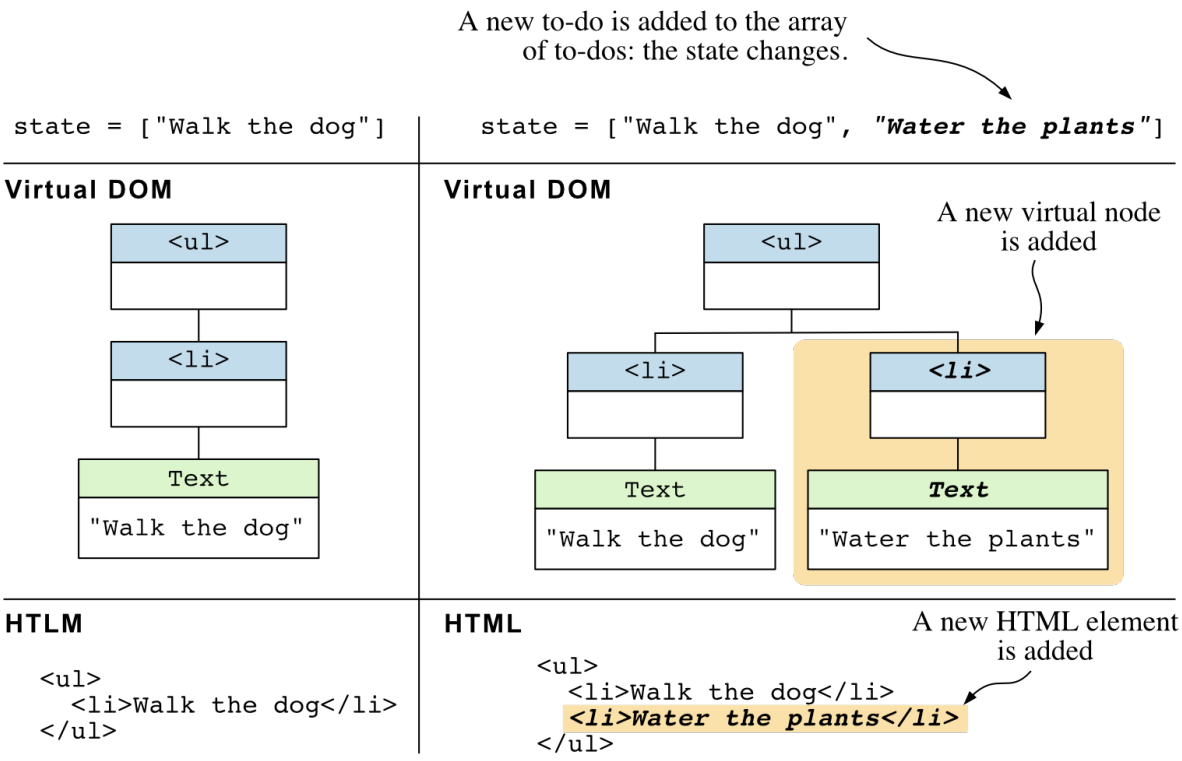


Figure 3.5 The view of an application is a function of the state. When a new to-do is added to the state, the virtual DOM is re-evaluated and the DOM is updated with the new to-do

This means that, to produce the virtual DOM representing the view, the current state of the application must be taken into account, and that, when the state changes, the virtual DOM must be re-evaluated. If we generate the virtual DOM that represents the view of the application by calling a function that receives the state as parameter, we can easily re-evaluate it when the state changes. For example, in the case of our TODOs application, the virtual DOM for the list of to-dos (consisting of only the to-do description, for the sake of simplicity) could be generated by a function like this:

```
function TodosList(todos) {
  return h('ul', {}, todos.map((todo) => h('li', {}, [todo])))
}
```

If we call the `TodosList()` function with the following list of to-dos as argument:

```
TodosList(['Walk the dog', 'Water the plants'])
```

the function would return the following virtual DOM (the empty `props` objects have been omitted for brevity):

```
{
  tag: 'ul',
  type: 'element',
  children: [
    { tag: 'li', children: [{ type: 'text', value: 'Walk the dog' }] },
    { tag: 'li', children: [{ type: 'text', value: 'Water the plants' }] }
  ]
}
```

This virtual DOM representing the list of to-dos would be rendered by the framework into the following HTML:

```
<ul>
  <li>Walk the dog</li>
  <li>Water the plants</li>
</ul>
```

You can see this process summarized in figure 3.6: the application code—written by the developer—generates the virtual DOM describing the view, then the framework—written by yourself—creates the real DOM from the virtual DOM and inserts it into the browser's document.

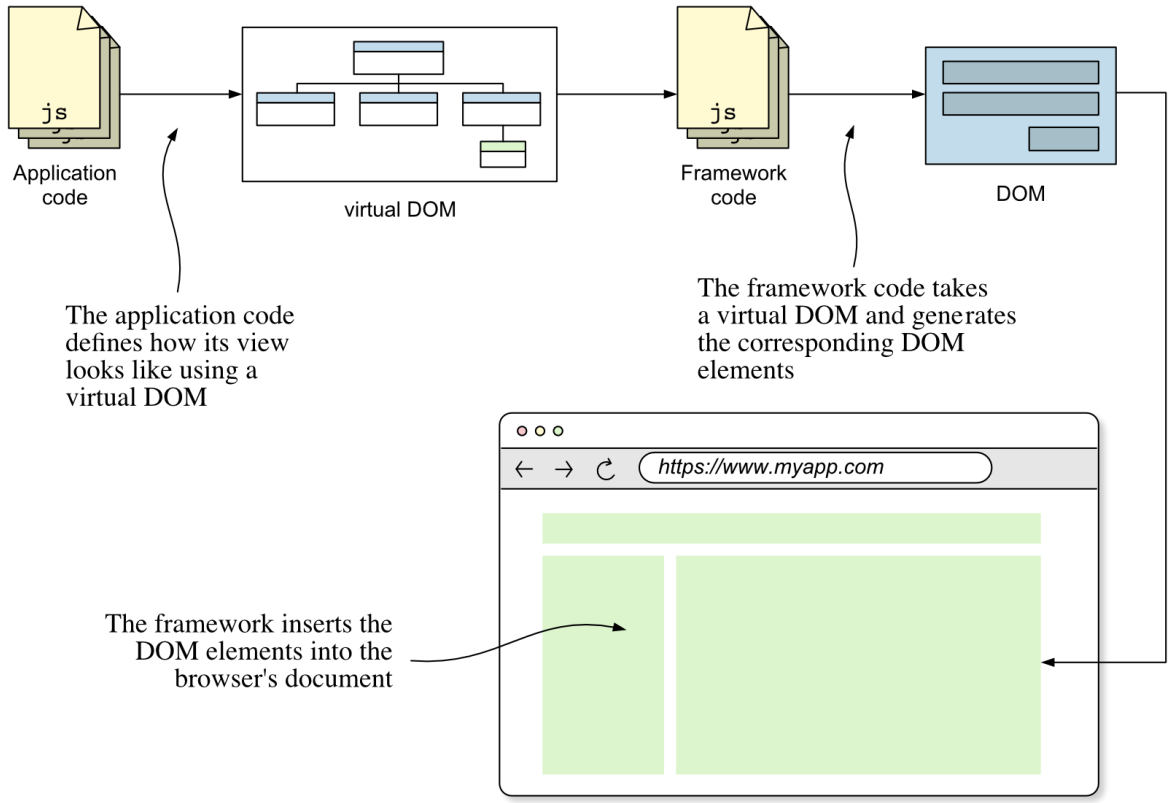


Figure 3.6 The application creates the virtual DOM that the framework renders into the DOM

One nice property of using functions to produce the virtual DOM, receiving the application's state as argument, is that we can break the view into smaller parts. Pure functions—functions which don't produce any side effects and always return the same result for the same input

arguments—can be easily composed to build more complex views.

3.6.3 Composing views—components as children

Pure functions have the nice property that they can be composed nicely to build more complex functions. If we generate the virtual DOM to represent the view of the application by composing smaller functions, we can easily break the view into smaller parts. These sub-functions represent a part of the view, a fraction of the application's UI, the *components*. The arguments passed to a component are known as *props*, as we've already mentioned.

> **IMPORTANT** **Components are functions that generate the virtual DOM for a part of the application's view. They take the state of the application, or part of it, as their argument. The arguments passed to a component, the data coming from outside the component, are known as props.**
>
> **This definition of a component will change later in the book, as components will be more than pure functions and will handle their own state and lifecycle.**

Let's work an example with the TODOs application view. If we don't break the view into smaller parts, we'll have a single function that generates the virtual DOM for the entire application. Such a function would be long and hard to understand by other developers—and probably by ourselves as well. But we can clearly distinguish two parts in the view: the form to add a new to-do and the list of to-dos (see figure 3.7); those can be generated by two different functions. That is, we can break the view into two sub-components.

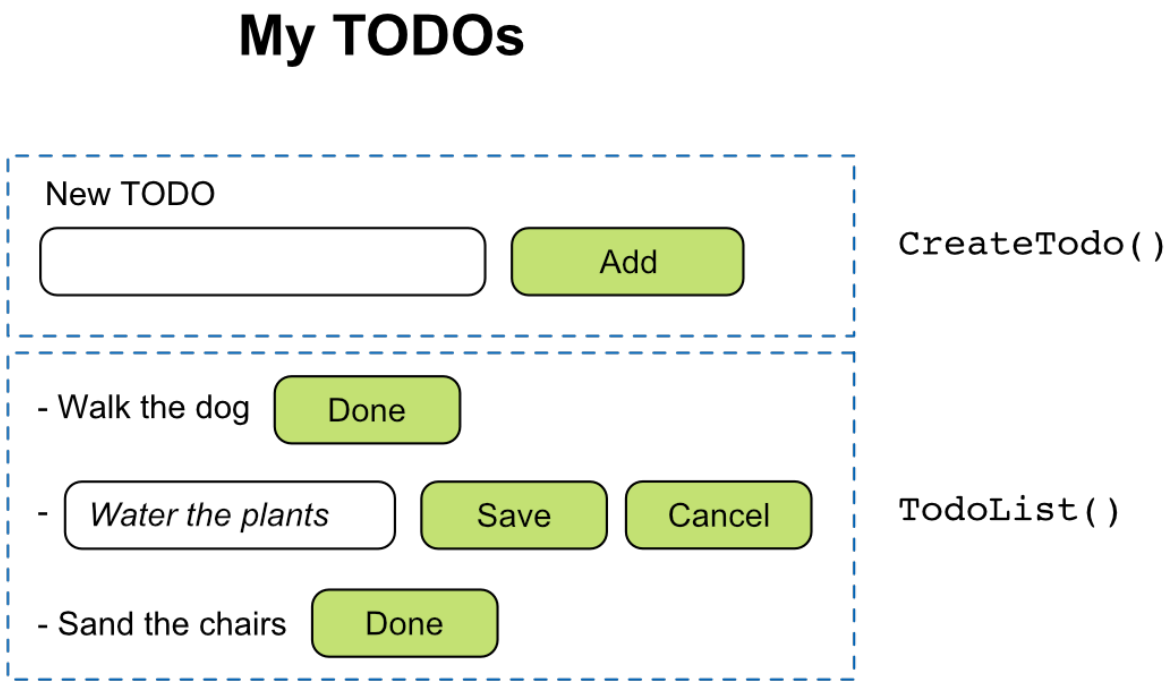


Figure 3.7 The TODOs application can be broken into two sub-components: `CreateTodo()` and `TodoList()`

So the virtual DOM for the whole application could be created by a component like the following:

```
function App(state) {
  return hFragment([
    h('h1', {}, ['My TODOs']),
    CreateTodo(state),
    TodoList(state)
  ])
}
```

Note that in this case, there isn't a parent node in the virtual DOM that contains the header of the application and the two sub-components: we use a fragment to group the elements together. Also note the naming convention: the functions that generate the virtual DOM are written in *PascalCase*. This is to signal that they are components that create a virtual DOM tree, and not regular functions.

Similarly, the `TodoList()` component—as you've probably guessed—can be further broken down into another sub-component, the `TodoItem()`. You can see this illustrated in figure 3.8.

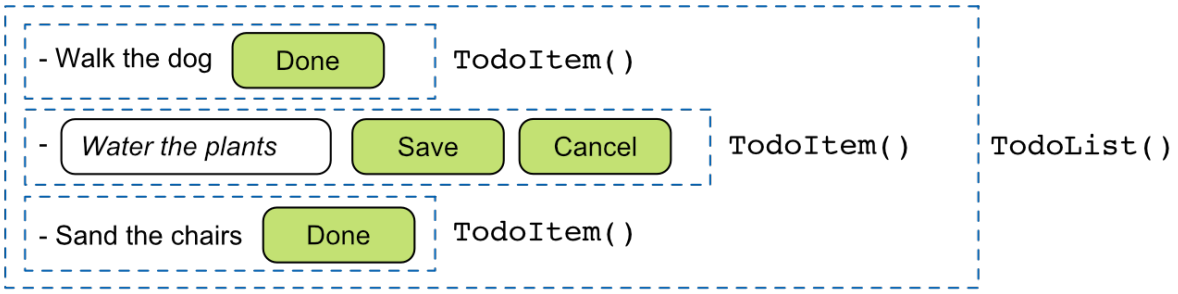


Figure 3.8 The `TodoList()` component can be broken down into a `TodoItem()` sub-component

and thus, the `TodoList()` component would look similar to the following:

```
function TodoList(state) {
  return h('ul', {},
    children: state.todos.map(
      (todo, i) => TodoItem(todo, i, state.editingIdxs)
    )
  )
}
```

The `TodoItem()` component would render a different thing depending on whether the to-do is in "read" or "edit" mode. Those could be further decomposed into two different sub-components: `TodoInReadMode()` and `TodoInEditMode()`. It'd be something like the following:

```
// idxInList is the index of this todo item in the list of todos.
// editingIdxs is a Set of indexes of todos that are being edited.
function TodoItem(todo, idxInList, editingIdxs) {
  const isEditing = editingIdxs.has(idxInList)

  return h('li', {}, [
      isEditing
        ? TodoInEditMode(todo, idxInList)
        : TodoInReadMode(todo, idxInList)
    ]
  )
}
```

Defining the views of our application using pure functions—the components—allows you to easily compose them to build more complex views. This is probably not new to you; you've been decomposing your applications into a hierarchy of components when using frontend frameworks like React, Vue, Svelte or Angular.

We can visualize the hierarchy of components for the example above in a tree, as shown in figure 3.9.

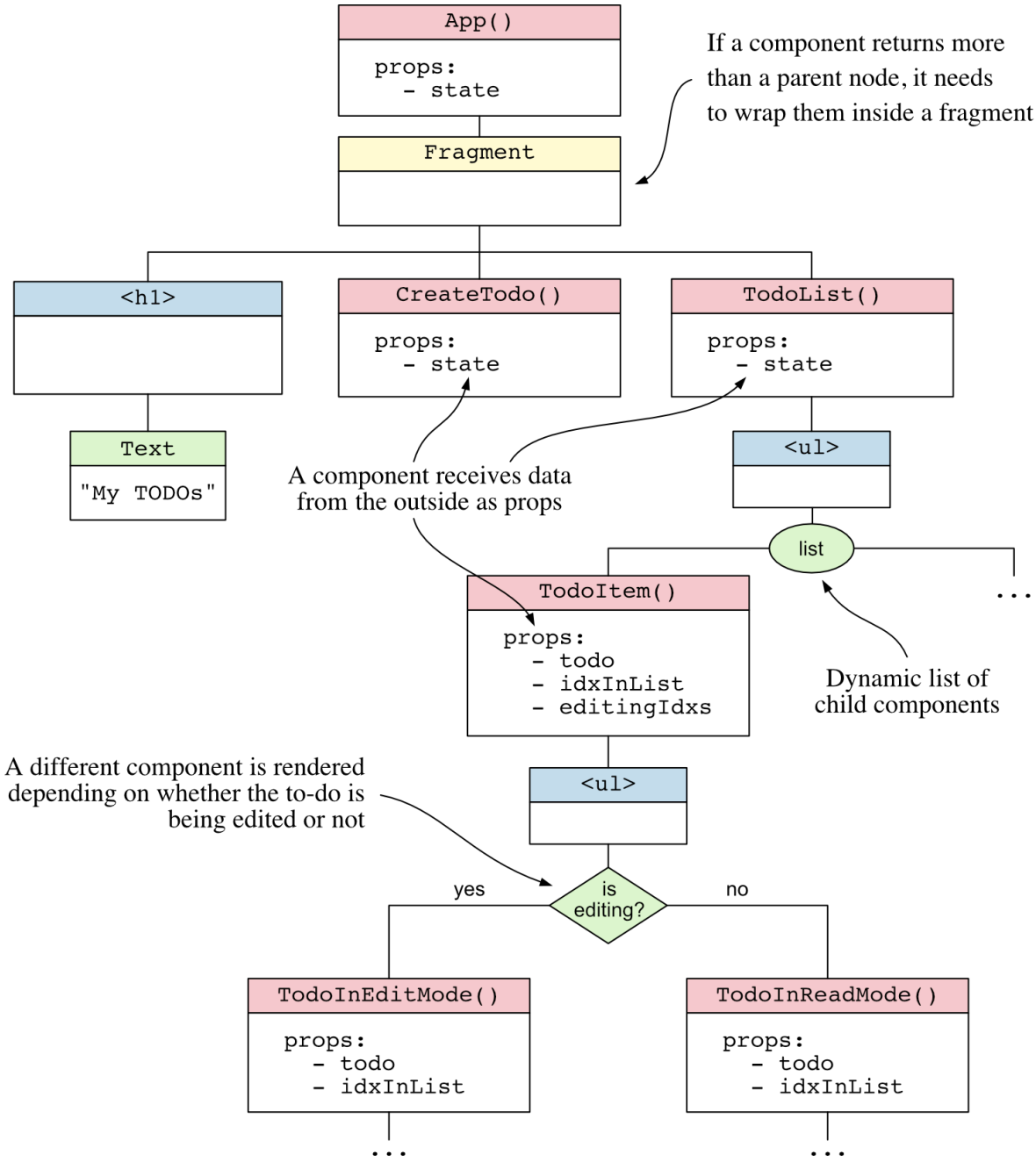


Figure 3.9 The hierarchy of components of the TODOs application, where each component has below the virtual DOM nodes it generates

In this diagram we see the view of the application as a tree of components with the virtual DOM nodes they generate below them. The `App()` component is the root of the tree, and it has three children: an `<h1>` element, and the `CreateTodo()` and `TodoList()` components. A component can only return a single virtual DOM node as its root, so the three children of `App()` are grouped together in a fragment.

Then, following the hierarchy down, we see the `TodoList()` component has a single child, the `<ul>` element, which in turn has a list of `TodoItem()` components. The ellipsis in the tree

indicates that the `<ul>` element might have more children than the ones shown in the diagram, a number that depends on how many to-dos are in the list. Finally, the `TodoItem()` component has two children: the `TodoInEditMode()` and `TodoInReadMode()` components. These components would render more virtual DOM nodes, but we don't show them in the diagram for simplicity.

> **NOTE** **As you can see in the diagram, the nodes of the tree all have a title indicating their type. The components are written in PascalCase and include the parenthesis to indicate they are functions. The HTML elements are written in all lowercase letters and between angle brackets. Text nodes are inside a box whose title is simply "Text", and fragments are titled "Fragment".**

Now that you understand how to break down the view of your application into components—pure functions that generate the virtual DOM given the state of the application—you're ready to implement the code in the framework which is in charge of mounting the virtual DOM returned by the `h()` functions to the browser's DOM. You'll do exactly that in the next chapter.

3.7 Summary

- The virtual DOM is the blueprint for the view of the application: it allows the developer describe how the view should look like in a declarative way (similar to what an architect does with the blueprints of a house) and moves the responsibility of manipulating the DOM to the framework.
- Thanks to using a virtual DOM to declare how the view should look like, the application developer is freed from having to know how to manipulate the DOM using the Document API, and they don't need to mix business logic with DOM manipulation code.
- A component is a pure function—a function with no side effects—that takes the state of the application as input and returns a virtual DOM tree representing a chunk of the view of the application. In later chapters, the definition of a component will be extended to include the ability to have internal state and a lifecycle that's independent from that of the application.
- There are three types of virtual nodes: text nodes, element nodes, and fragment nodes. The most interesting one is the element node, as it represents the regular HTML elements that can have attributes, children, and event listeners.
- The `hString()`, `h()`, and `hFragment()` functions are used to create text, element, and fragment virtual nodes, respectively. The virtual DOM can be directly declared as a tree of JavaScript objects, but calling these functions makes the process simpler.
- Fragments allow creating a subpart of the DOM tree by appending child nodes to it. Once the fragment is appended to the DOM, it moves its children to the element where the fragment is appended, but the fragment doesn't get attached to the DOM.
- Fragments are useful when a component would return a list of virtual nodes without a parent node. The DOM—and by extension the virtual DOM—is a tree data structure, every level in the tree (except the root) must have a parent node, so a fragment can be used to create a temporary parent node for the list of virtual nodes.

3.8 Exercises

1. At the beginning of the chapter, when I explained what the virtual DOM is, I defined the term *virtual* and gave several examples of virtual things (virtual machine, for example). Can you think of more examples of virtual things? Why do we call them virtual?
2. Using the Document API in the browser's console, create a fragment node, append two paragraphs to it, and then append the fragment to the `<body>` element. Explore the content of the fragment (the paragraphs should be gone).
3. Given the HTML markup below, can you draw the corresponding virtual DOM tree diagram (similar to figure 3.3)?

```
<div id="app">
  <h1>TODOs</h1>
  <input type="text" placeholder="What needs to be done?">

  <ul>
    <li>
      <input type="checkbox">
      <label>Buy milk</label>
      <button>Remove</button>
    </li>
    <li>
      <input type="checkbox">
      <label>Buy eggs</label>
      <button>Remove</button>
    </li>
  </ul>
</div>
```

4 Mounting and destroying the virtual DOM

This chapter covers

- Creating HTML nodes from virtual DOM nodes
- Inserting the HTML nodes into the browser's document
- Removing HTML nodes from the browser's document

In the previous chapter, you learnt what the virtual DOM is and how to create it. You implemented the `h()`, `hString()`, and `hFragment()` functions to create virtual nodes of type `element`, `text`, and `fragment`, respectively. Now it's time to learn how to create the real DOM nodes from the virtual DOM nodes, and insert them into the browser's document. This is achieved using the Document API, as you'll see in this chapter.

When the view of your application is no longer needed, you want to remove the HTML nodes from the browser's document. You'll learn how to do this in this chapter as well.

4.1 Mounting the virtual DOM

Given a virtual DOM tree, you want your framework to create the real DOM tree out of it and attach it to the browser's document. We call this process *mounting* the virtual DOM. You implement this code in the framework, so that the developers using it don't need to use the Document API themselves. You'll implement this process in the `mountDOM()` function.

Figure 4.1 is a visual representation of how the `mountDOM()` function works. You can see the first argument is a virtual DOM—represented in the style of our diagrams—and the second argument is the parent element where we want the view inserted, in this case the document's `<body>` element. The result is a DOM tree attached to the parent element—the `<body>` of the document.

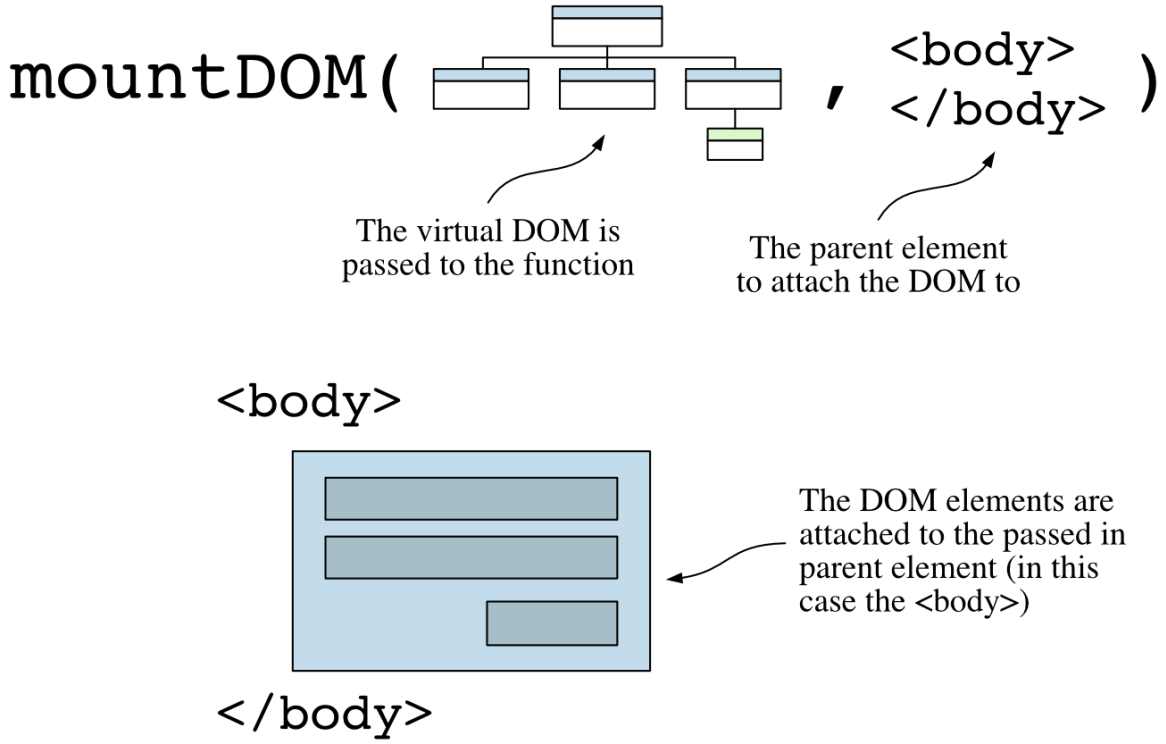


Figure 4.1 Mounting a virtual DOM to the browser's document `<body>` element

When the `mountDOM()` function creates each of the DOM nodes for the virtual DOM, it needs to save a reference to the real DOM node in the virtual node, under the `el` property (`el` for *element*). You can see this in figure 4.2. This reference is used by the reconciliation algorithm you'll write in chapters 7 and 8, to know what DOM nodes to update.

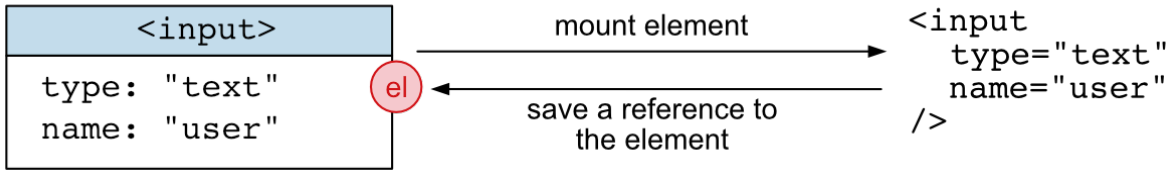


Figure 4.2 The virtual node's `el` property keeps a reference to the real DOM node

Similarly, if the node included event listeners, the `mountDOM()` function saves a reference to the event listener in the virtual node, under the `listeners` property.

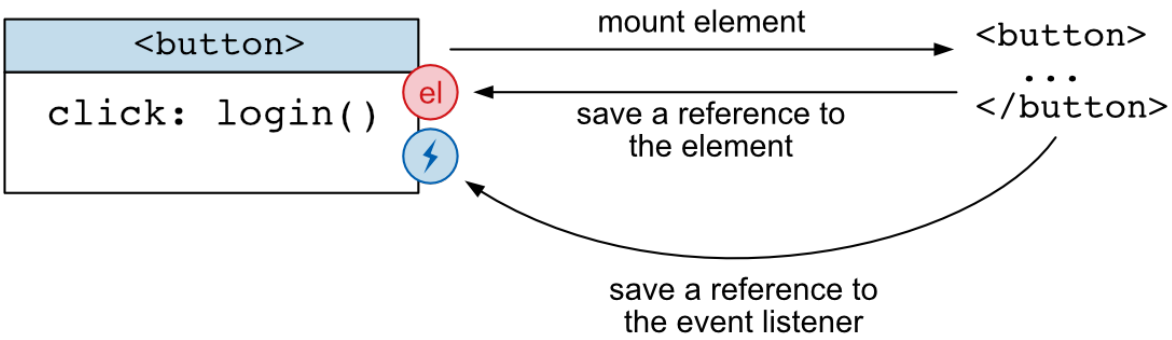


Figure 4.3 The virtual node's `listeners` property keeps a reference to the event listener

Saving these references has a double purpose. First, it allows the framework to remove the event listeners and detach the element from the DOM when the virtual node is unmounted. Second, it's required by the reconciliation algorithm to know what element in the DOM needs to be updated. This will become clear when you implement the reconciliation algorithm; for now, bear with me.

Using the example from earlier, the virtual DOM we defined as:

```
const vdom = h('form', { class: 'login-form', action: 'login' }, [
  h('input', { type: 'text', name: 'user' }),
  h('input', { type: 'password', name: 'pass' }),
  h('button', { on: { click: login } }, ['Login'])
])
```

Passed to the `mountDOM()` function as follows:

```
mountDOM(vdom, document.body)
```

would result in the virtual DOM tree depicted in figure 4.4, where you can see the `el` and `listeners` references in the virtual nodes.

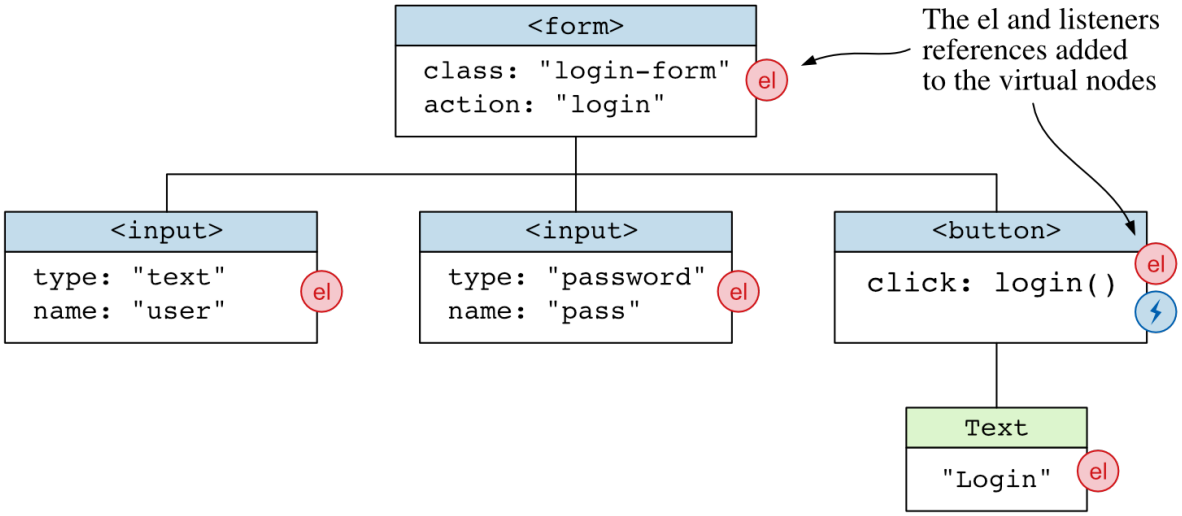


Figure 4.4 The login form virtual DOM example mounted to the browser's document `<body>` element. The virtual nodes keep a reference to the real DOM nodes in the `el` property, and to the event listeners in the `listeners` property (shown as a lightning icon).

This HTML tree would be attached to the `<body>` element, and the resulting HTML markup would be:

```
<body>
  <form class="login-form" action="login">
    <input type="text" name="user">
    <input type="password" name="pass">
    <button>Login</button>
  </form>
</body>
```

Different types of virtual nodes require different DOM nodes to be created, namely:

- A virtual node of type `text` requires a `Text` node to be created (via the `document.createTextNode()` method).
- A virtual node of type `element` requires an `Element` node to be created (via the `document.createElement()` method).
- A virtual node of type `fragment` requires a `DocumentFragment` node to be created (via the `document.createDocumentFragment()` method).

The `mountDOM()` function needs to differentiate between the different values of the `type` property of the virtual node, and create the appropriate DOM node.

With this in mind, let's implement the `mountDOM()` function.

4.1.1 Mounting virtual nodes into the DOM

Create a new file called *mount-dom.js* in the *src/* directory. Then, write the `mountDOM()` function as is in listing 4.1. The listing also includes some *TODO* comments towards the end of the file. You don't need to write those comments in your code; there are there as placeholders to show you were you will be implementing the missing functions later.

Listing 4.1 The `mountDOM()` function used to mount the virtual DOM to the browser's document (mount-dom.js)

```
import { DOM_TYPES } from './h'

export function mountDOM(vdom, parentEl) {
  switch (vdom.type) {
    case DOM_TYPES.TEXT: {
      createTextNode(vdom, parentEl)   ❶
      break
    }

    case DOM_TYPES.ELEMENT: {
      createElementNode(vdom, parentEl)   ❷
      break
    }

    case DOM_TYPES.FRAGMENT: {
      createFragmentNode(vdom, parentEl)   ❸
      break
    }

    default: {
      throw new Error(Can't mount DOM of type: ${vdom.type})
    }
  }
}

// TODO: implement createTextNode()

// TODO: implement createElementNode()

// TODO: implement createFragmentNode()
```

❶ Mount a text virtual node

❷ Mount a fragment virtual node

❸ Mount an element virtual node

The function uses a `switch` statement that checks the type of the virtual node. Depending on the node's type, the appropriate function to create the real DOM node gets called. If the node type isn't one of the three supported types, the function throws an error. (If you made a mistake, like misspelling the type of a virtual node, this error will help you find it.)

4.1.2 Mounting text nodes

Text nodes are the simplest type of node to create because they don't have any attributes or event listeners. To create a text node, the Document API provides you with the `createTextNode()` method. It expects a string as an argument, which is the text that the text node will contain.

If you recall, the virtual nodes created by the `hString()` function you implemented earlier have the following structure:

```
{
  type: DOM_TYPES.TEXT,
  value: 'I need more coffee'
}
```

These virtual nodes have a `type` property, identifying them as a text node, and a `value` property, which is set to the string that the `hString()` function received as an argument. This is the text that you need to pass to the `createTextNode()` method. After creating the text DOM node, you need to do two things:

1. Save a reference to the real DOM node in the virtual node, under the `el` property.
2. Attach the text node to the parent element.

Inside the *mount-dom.js* file, write the `createTextNode()` function as follows:

```
function createTextNode(vdom, parentEl) {
  const { value } = vdom

  const textNode = document.createTextNode(value)   ❶
  vdom.el = textNode   ❷

  parentEl.append(textNode)   ❸
}
```

❶ Create a text node

❷ Save a reference of the node

❸ Append to the parent element

Let's now implement the `createFragmentNode()` function.

4.1.3 Mounting fragment nodes

Fragments are a bit more nuanced than text nodes (but definitely simpler than element nodes). What's important to remember about fragments is that they aren't attached to the DOM themselves. When you append a fragment to an element in the DOM, the fragment moves its children inside that element, after which it becomes empty.

You shouldn't save a reference to the fragment node in the virtual node's `el` property, because it won't reference anything in the DOM. In fact, as we explained earlier, fragments don't have a

representation in the DOM; they're just temporal constructs used to create a subpart of the DOM tree. What you want to do instead is save a reference to the parent element passed into the `createFragmentNode()` function; this is the actual DOM node where the fragment's children will be attached to, as represented in figure 4.5.

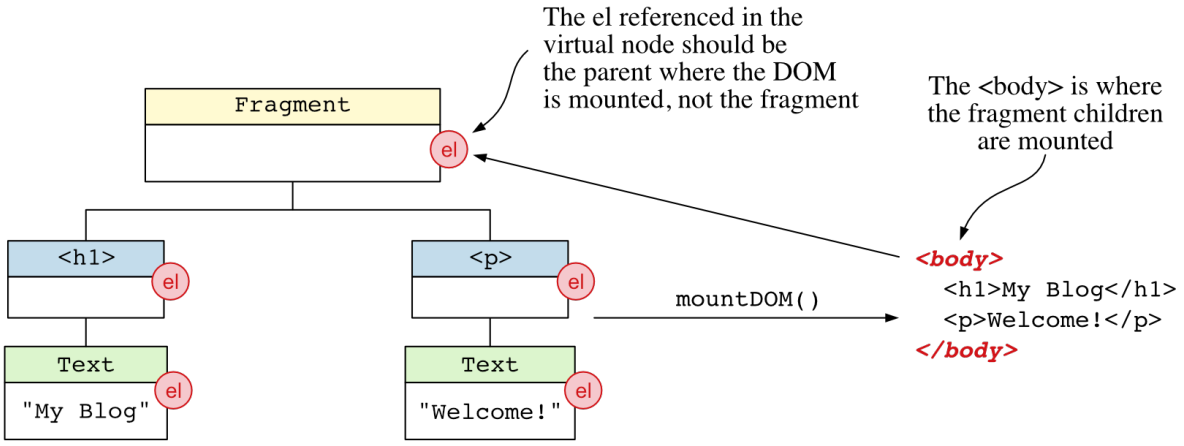


Figure 4.5 Fragment's `el` shouldn't reference the fragment, but rather the parent element where its children are attached to

To create a fragment node, you use the `createDocumentFragment()` method from the Document API. You then pass each child node to the `mountDOM()` function, with the fragment node as the parent element. This creates the corresponding DOM node for each child and attaches it to the fragment node. Last, you attach the fragment node to the parent element.

It's important to note that, if you have a hierarchy of virtual nodes where the parent at several consecutive levels is a fragment node, all those fragments will be appended to the same parent element. This means that all the `el` references of those fragments would point to the same parent element, as you can see depicted in figure 4.6.

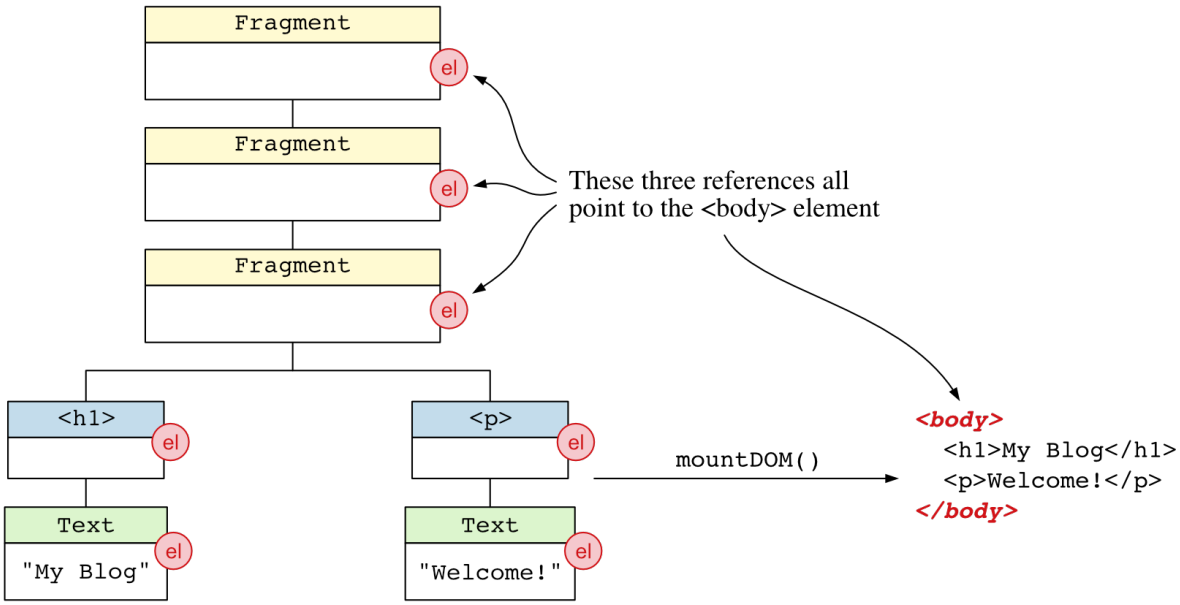


Figure 4.6 Nested fragments will all point to the same parent element

Now that you have a good understanding of how fragments work, it's time to write some code. Write the `createFragmentNode()` function inside the *mount-dom.js* file as follows:

```
function createFragmentNode(vdom, parentEl) {
  const { children } = vdom

  const fragment = document.createDocumentFragment()   ❶
  vdom.el = parentEl   ❷

  children.forEach((child) => mountDOM(child, fragment))   ❸
  parentEl.append(fragment)   ❹
}
```

❶ Create a fragment node

❷ Save a reference of the parent element

❸ Mount the children into the fragment

❹ Append to the parent element

It's important that you realize that, when you do:

```
children.forEach((child) => mountDOM(child, fragment))
```

you're filling in the fragment with the children; but nothing is appended to the real DOM yet. (The `mountDOM()` function creates the DOM nodes for each of the child virtual nodes and attach them to the fragment.) At this point, the fragment will have these nodes inside it, as its children. But then, in the next line, when you do:

```
parentEl.append(fragment)
```

that's when the fragment's children are moved to the parent element, and hence the fragment becomes empty. It's at this point that the fragment has done its job and can be discarded. This is why you don't save a reference to the fragment node inside the virtual node, but instead reference the parent element passed into the function.

Great—Now you're ready to implement the `createElementNode()` function. It's the most important one, because it's the one that creates the element nodes; the visual bits of the DOM tree.

4.1.4 Mounting element nodes

To create element nodes (those regular HTML elements with tags like `<div>` and `<span>`), you use the `createElement()` method from the Document API. You have to pass the tag name to the `createElement()` function, and the Document API will return an element node that matches that tag, or `HTMLUnknownElement` if the tag is unrecognized.

You can try this yourself in the browser console:

```
document.createElement('foobar').__proto__ // HTMLUnknownElement
```

An obviously inexistent tag like `foobar` will return an `HTMLUnknownElement` node. So, if a virtual node has a tag that isn't recognized by the Document API, the `document.createElement()` function returns an `HTMLUnknownElement` node. We're not going to worry about this case: if an `HTMLUnknownElement` results from the `createElement()` function: we'll assume it's an error on the developer's part.

If you recall, calling the `h()` function to create element virtual nodes returns an object with the `type` property set to `DOM_TYPES.ELEMENT`, a `tag` property with the tag name, and a `props` property with the attributes and event listeners. If the virtual node has children, they appear inside the `children` property.

For example, a `<button>` virtual node with a class of `btn` and an `onclick` event listener would look like this:

```
{
  type: DOM_TYPES.ELEMENT,
  tag: 'button',
  props: {
    class: 'btn',
    on: { click: () => console.log('yay!') }
  },
  children: [
    {
      type: DOM_TYPES.TEXT,
      value: 'Click me!'
    }
  ]
}
```

To create the corresponding DOM element from the virtual node, you need to:

1. Create the element node using the `document.createElement()` function.
2. Add the attributes and event listeners to the element node, saving the added event listeners in a new property of the virtual node, called `listeners`.
3. Save a reference to the element node in the virtual node, under the `el` property.
4. Mount the children, recursively, into the element node.
5. Attach the element node to the parent element.

As you can see, the `props` property of the virtual node is the one that contains the attributes and event listeners, both together. But attributes and event listeners are handled differently, so you'll need to separate them.

Then, from the attributes, there are two special cases that need special handling as well, and are those related to styling: `style` and `class`. You'll extract those from the `props` object as well, and handle them separately.

Go ahead and write the `createElementNode()` function inside the *mount-dom.js* file:

Listing 4.2 Mounting an element node into a parent element (mount-dom.js)

```
import { setAttributes } from './attributes'
import { addEventListeners } from './events'

// --snip-- //

function createElementNode(vdom, parentEl) {
  const { tag, props, children } = vdom

  const element = document.createElement(tag)   ❶
  addProps(element, props, vdom)   ❷
  vdom.el = element

  children.forEach((child) => mountDOM(child, element))
  parentEl.append(element)
}

function addProps(el, props, vdom) {
  const { on: events, ...attrs } = props   ❸

  vdom.listeners = addEventListeners(events, el)   ❹
  setAttributes(el, attrs)   ❺
}
```

❶ Create an element node

❷ Add the attributes and event listeners

❸ Split listeners from attributes

❹ Add event listeners

❺ Set attributes

Note that you're using two functions you haven't implemented yet: `setAttributes()` and

`addEventListeners()`, imported from the *attributes.js* and *events.js* files, respectively. You will write them in a minute.

Setting the attributes and adding event listeners is the part where the code differs from the previous two types of nodes: neither of them had attributes nor event listeners. The case of the fragment is clear because it doesn't get attached to the DOM, and hence, it doesn't make sense for it to have attributes or event listeners attached. In the case of the text node, you want to attach event listeners and set attributes to it's parent element node, not to the text node itself.

> **NOTE** **Both the `Text` and `DocumentFragment` types defined in the Document API inherit from the `EventTarget` interface, which declares the `addEventListener()` method. So, in principle, you can add event listeners to a text node or a fragment node. But if you go ahead and try to do that in the browser, you'll see that the event listeners are never called. In the case of the fragment, because it never gets attached to the DOM (so you can't really click it), and in the case of the text node, it just doesn't work.**

Let's now implement the `addEventListeners()` function, in charge of adding event listeners to an element node. After it, we shall look at the `setAttributes()` function, and we'll be done with creating element nodes.

4.1.5 Adding event listeners

To add an event listener to an element node, you call its `addEventListener()` method. This method is available because an element node is an instance of the `EventTarget` interface. This interface—which declares the `addEventListener()` method—is implemented by all the DOM nodes that can receive events. All instances returned by calling `document.createElement()` implement the `EventTarget` interface, so you can safely call the `addEventListener()` method on them.

Our implementation of the `addEventListener()` function in this chapter of the book is going to be very simple: it'll just call the `addEventListener()` method on the element and return the event handler function it registered. You want to return the function registered as event handler, because later on, when you implement the `destroyDOM()` method—which as you can figure out it does the opposite of `mountDOM()`--you'll need to remove the event listeners to avoid memory leaks. You need the handler function that was registered in the event listener to be able to remove it, by passing it as an argument to the `removeEventListener()` method.

Later, in chapter 9, when you make the components of your framework stateful (recall that they'll be pure functions with no state for the moment), you'll also have references to the event listeners added to the components, which will behave in a different way than the event handlers of the DOM nodes. At this point in the book, you'll need to come back and modify the

implementation of the `addEventListener()` function to account for this new case. So if you wonder why we're implementing a function that does so little of its own, this is the reason; it's just a placeholder for the more complex implementation that you'll write later.

Create a new file under the *src/* directory called *events.js* and add the following code:

```
export function addEventListener(eventName, handler, el) {
  el.addEventListener(eventName, handler)
  return handler
}
```

As promised, the `addEventListener()` function is very simple. But, if you recall, the event listeners defined in a virtual node come packed in an object, where the keys are the event names and the values are the event handler functions, like so:

```
{
  type: DOM_TYPES.ELEMENT,
  tag: 'button',
  props: {
    on: {
      mouseover: () => console.log('almost yay!'),
      click: () => console.log('yay!') ,
      dblclick: () => console.log('double yay!'),
    }
  }
}
```

So it makes sense to have another function—if only for convenience—that allows you to add multiple event listeners in the form of an object to an element node. So, inside the *events.js* file, add another function called `addEventListeners()` (in plural):

```
export function addEventListeners(listeners = {}, el) {
  const addedListeners = {}

  Object.entries(listeners).forEach(([eventName, handler]) => {
    const listener = addEventListener(eventName, handler, el)
    addedListeners[eventName] = listener
  })

  return addedListeners
}
```

You might feel tempted to simplify that function by removing the `addedListeners` variable, and simply return the same `listeners` object the function got as input:

```
export function addEventListeners(listeners = {}, el) {
  Object.entries(listeners).forEach( ... )

  return listeners
}
```

After all, the same event handler functions that we got as input we're returning as output, so the refactor seems legit. But, that is now; it won't be the case later when you make the components have their own state. You won't be adding the same functions as event handlers, but new

functions that will be created by the framework with some extra logic around them. This might sound confusing now, but stick with me, and you'll see how this makes sense later.

Now that you've implemented the event listeners, let's move on and implement the `setAttributes()` function. We're getting closer to having a working `mountDOM()` function.

4.1.6 Setting the attributes

To set an attribute in an `HTMLElement` instance in code, you set the value in the corresponding property of the element. Setting the property of the element will reflect the value in the corresponding attribute of the rendered HTML. It's important to understand that, when you're manipulating the DOM through code, you're working with DOM nodes, instances of the `HTMLElement` class. These instances have properties that you can set in code, as any other JavaScript object do. When these properties are set, the corresponding attribute is automatically reflected in the rendered HTML.

For instance, if you have a paragraph in HTML, such as the following:

```
<p id="foo">Hello, world!</p>
```

Assuming you have a reference to the `<p>` element in a variable called `p`, you can set the `id` property of the `p` element to a different value, like so:

```
p.id = 'bar'
```

And the rendered HTML reflects the change:

```
<p id="bar">Hello, world!</p>
```

In a nutshell: `HTMLElement` instances (such the `<p>` element, which is an instance of the `HTMLParagraphElement` class) have properties that correspond to the attributes that are rendered in the HTML markup. When you set the value of these properties, the corresponding attributes in the rendered HTML are automatically updated. Even though things are a bit more nuanced than that, this is the gist of it.

CAUTION **There are some attributes that work a bit differently. For instance, the `value` attribute of an `<input>` element is not reflected in the rendered HTML. If you you have the following HTML:**

```
<input type="text" />
```

And you programmatically set its value like so:

```
input.value = 'yolo'
```

You'll see the string "yolo" in the input, but the rendered HTML will still be the same; no `value` attribute will be rendered. But even more interesting is the fact that, you can add the attribute in the HTML markup:

```
<input type="text" value="yolo" />
```

And the "yolo" string will appear in the input when it first renders, but if you type in something different, the same value for the `value` attribute will remain in the rendered HTML. But you can read whatever was typed in the input by reading the `value` property of the input element.

Read more about this behavior in the HTML specification at http://mng.bz/yQ17.

There are, nevertheless, two special attributes that we'll handle differently: the `style` attribute and the `class` attribute. You'll see why in a moment.

Let's start by writing the `setAttributes()` function: the one you used in listing 4.2 to set the attributes on the element node. The role of this function is to extract the attributes that require special handling (the `style` and `class` attributes) from the rest of the attributes, and then call the `setStyle()` and `setClass()` functions to set those attributes. The rest of the attributes are passed to the `setAttribute()` function. You'll write these `setStyle()`, `setClass()`, and `setAttribute()` functions later.

Start by creating the *attributes.js* file under the *src/* directory and write the code in listing 4.3.

Listing 4.3 Setting the attributes of an element node (attributes.js)

```
export function setAttributes(el, attrs) {
  const { class: className, style, ...otherAttrs } = attrs  ❶

  if (className) {
    setClass(el, className)  ❷
  }

  if (style) {
    Object.entries(style).forEach(([prop, value]) => {
      setStyle(el, prop, value)  ❸
    })
  }

  for (const [name, value] of Object.entries(otherAttrs)) {
    setAttribute(el, name, value)  ❹
  }
}

// TODO: implement setClass

// TODO: implement setStyle

// TODO: implement setAttribute
```

❶ Split the attributes.

❷ Set the `class` attribute.

❸ Set the `style` attribute.

❹ Set the rest of the attributes.

Now that you have the function that splits the attributes into the ones that require special handling and the rest, and calls the appropriate functions to set them, let's go ahead and look at each of those in turn. In order of appearance, the first one is the `setClass()` function, which is in charge of setting the `class` attribute. Note that you've destructured the `attrs` property and aliased the `class` attribute to the `className` variable, as `class` is a reserved word in JavaScript.

SETTING THE "CLASS" ATTRIBUTE

When you write HTML, you set the `class` attribute of an element node like this:

```
<div class="foo bar baz"></div>
```

In this case, the `<div>` element has three classes: `foo`, `bar`, and `baz`. Easy! But now comes the tricky part: a DOM element (an instance of the `Element` class) doesn't have a `class` property, but instead has two properties, namely `className` and `classList`, that are related to the `class` attribute. Let's look at the `classList` first.

The `classList` property returns an object, a `DOMTokenList` to be more specific, that comes in pretty handy when you want to add, remove, or toggle classes on an element. A `DOMTokenList` object has an `add()` method, which takes multiple class names, and adds them to the element.

For example, if you had a `<div>` element like the following:

```
<div></div>
```

and wanted to add the `foo`, `bar`, and `baz` classes to it, you could do it like this:

```
div.classList.add('foo', 'bar', 'baz')
```

This would result in the following HTML:

```
<div class="foo bar baz"></div>
```

Then is the `className` property, which is a `string` that contains the value of the `class` attribute. Following the example above, if you wanted to add the same three classes to the `<div>` element, you could do it like this:

```
div.className = 'foo bar baz'
```

And this would yield the same HTML as the previous example.

You actually want to use both ways of setting the `class` attribute, depending on the situation. We should allow the developers using your framework to set the `class` attribute in two ways: either as a `string` or as an `array` of `string` items. So, to add multiple classes to an element, the developer could define the following virtual node:

```
{
  type: DOM_TYPES.ELEMENT,
  tag: 'div',
  props: {
    class: ['foo', 'bar', 'baz']
  }
}
```

Or, alternatively, they can use a single `string` like this:

```
{
  type: DOM_TYPES.ELEMENT,
  tag: 'div',
  props: {
    class: 'foo bar baz'
  }
}
```

Both of these options should work. Thus, the `setClass()` function needs to distinguish between the two cases and handle them accordingly. With this in mind, write the following code in the *attributes.js* file:

```
function setClass(el, className) {
  el.className = ''   ❶

  if (typeof className === 'string') {
    el.className = className   ❷
  }

  if (Array.isArray(className)) {
    el.classList.add(...className)   ❸
  }
}
```

❶ Clear the class attribute

❷ Class attribute as a string

❸ Class attribute as an array

With the `setClass()` function out of the way, let's move on to the `setStyle()` function, which is in charge of setting the `style` attribute of an element.

SETTING THE "STYLE" ATTRIBUTE

The `style` property of an `HTMLElement` instance is a `CSSStyleDeclaration` object. What you need to know about this object is that you can set the value of a CSS property using conventional object notation, like this:

```
element.style.color = 'red'
element.style.fontFamily = 'Georgia'
```

Changing the `style` property key-value pairs of an `HTMLElement` instance is reflected in the value of the `style` attribute of the element. If the `element` in the previous snippet was a paragraph (<p>), the resulting HTML would be:

```
<p style="color: red; font-family: Georgia;"></p>
```

The `CSSStyleDeclaration` is converted into a `string` with the set of semi-colon-separated key-value pairs. You can inspect this string representation of the `style` attribute by using the `cssText` property in code:

```
element.style.cssText // 'color: red; font-family: Georgia;'
```

For example, using the `element` from the previous snippet, you could remove the `color` style by doing this:

```
element.style.color = null
element.style.cssText // 'font-family: Georgia;'
```

Now that you know how to work with the `style` property of an `HTMLElement` instance, go ahead and write the `setStyle()` and `removeStyle()` functions. The first function takes an

`HTMLElement` instance, the name of the style to set, and the value of the style, and sets that style on the element. The second function takes an `HTMLElement` instance and the name of the style to remove, and removes that style from the element.

Inside the *attributes.js* file, write the following code:

```
export function setStyle(el, name, value) {
  el.style[name] = value
}

export function removeStyle(el, name) {
  el.style[name] = null
}
```

Note that you haven't used the `removeStyle()` function yet. The code you wrote before only used the `setStyle()` function, but as you'll need to remove styles later on, this was a good time to write it.

You're almost done; you're only missing the `setAttributes()` function, which is in charge of setting the rest of the attributes other than the `class` and `style`.

SETTING THE REST OF THE ATTRIBUTES

The `setAttribute()` function takes three arguments: an `HTMLElement` instance, the name of the attribute to set, and the value of the attribute. If the value of the attribute is `null`, the attribute is removed from the element. (By convention, setting a DOM element's property to `null` is the same as removing the attribute.) If the attribute is of the form `data-*`, the attribute is set using the `setAttribute()` function. Otherwise, the attribute is set to the given value using object notation (`object.key = value`). (Or we shall say the property of the DOM element is set to the given value, and the attribute in the HTML will reflect that value.) To remove an attribute, you want to both set it to `null` and remove it from the `attributes` object, using the `removeAttribute()` method.

Inside the *attributes.js* file, write the following code:

```
export function setAttribute(el, name, value) {
  if (value == null) {
    removeAttribute(el, name)
  } else if (name.startsWith('data-')) {
    el.setAttribute(name, value)
  } else {
    el[name] = value
  }
}

export function removeAttribute(el, name) {
  el[name] = null
  el.removeAttribute(name)
}
```

And with this last function, you're done implementing the `mountDOM()` function, that takes a

virtual DOM and mounts it to the real DOM inside the passed in parent element. Congratulations!

4.1.7 A *mountDOM()* example

Thanks to this function, you can now define a view using the virtual DOM representation of it, and mount it to the real DOM. For example, you can create a view like this:

```
const vdom = h('section', {} [
  h('h1', {}, ['My Blog']),
  h('p', {}, ['Welcome to my blog!'])
])

mountDOM(vdom, document.body)
```

And the resulting HTML would be:

```
<body>
  <section>
    <h1>My Blog</h1>
    <p>Welcome to my blog!</p>
  </section>
</body>
```

You now want to have a function that, given a mounted virtual DOM, destroys it and removes it from the document: `destroyDOM()`. With this function you'll be able to clear the document's body from the previous example, like so:

```
destroyDOM(vdom, document.body)
```

The work done by `mountDOM()` is undone by `destroyDOM()`. This would result in the document's body being empty again:

```
<body></body>
```

In the next chapter you'll create a state management system that, when a change is made to the state of the application, it'll call the `destroyDOM()` function to completely get rid of the old HTML and then call the `mountDOM()` function to mount the new HTML view. That'll be your first version of a working framework—exciting! It'll be a very inefficient one—it recreates the entire view ever time the state changes--, but a complete framework nonetheless. That inefficiency won't last long; in chapters 7 and 8 you'll write a function called `patchDOM()` that'll be in charge of updating the DOM in place, instead of destroying and remounting the whole DOM: the reconciliation algorithm. At that point, your framework will already be quite decent, and you'll be able to start using it to build real applications.

Now that you see the plan ahead of us, let's close this chapter implementing the `destroyDOM()` function.

4.2 Destroying the DOM

Destroying the DOM is simpler than mounting it. Well, destroying anything is always simpler than creating it in the first place. Destroying the DOM is the process by which the HTML elements that were created by the `mountDOM()` function are removed from the document. This process is depicted in 4.7.

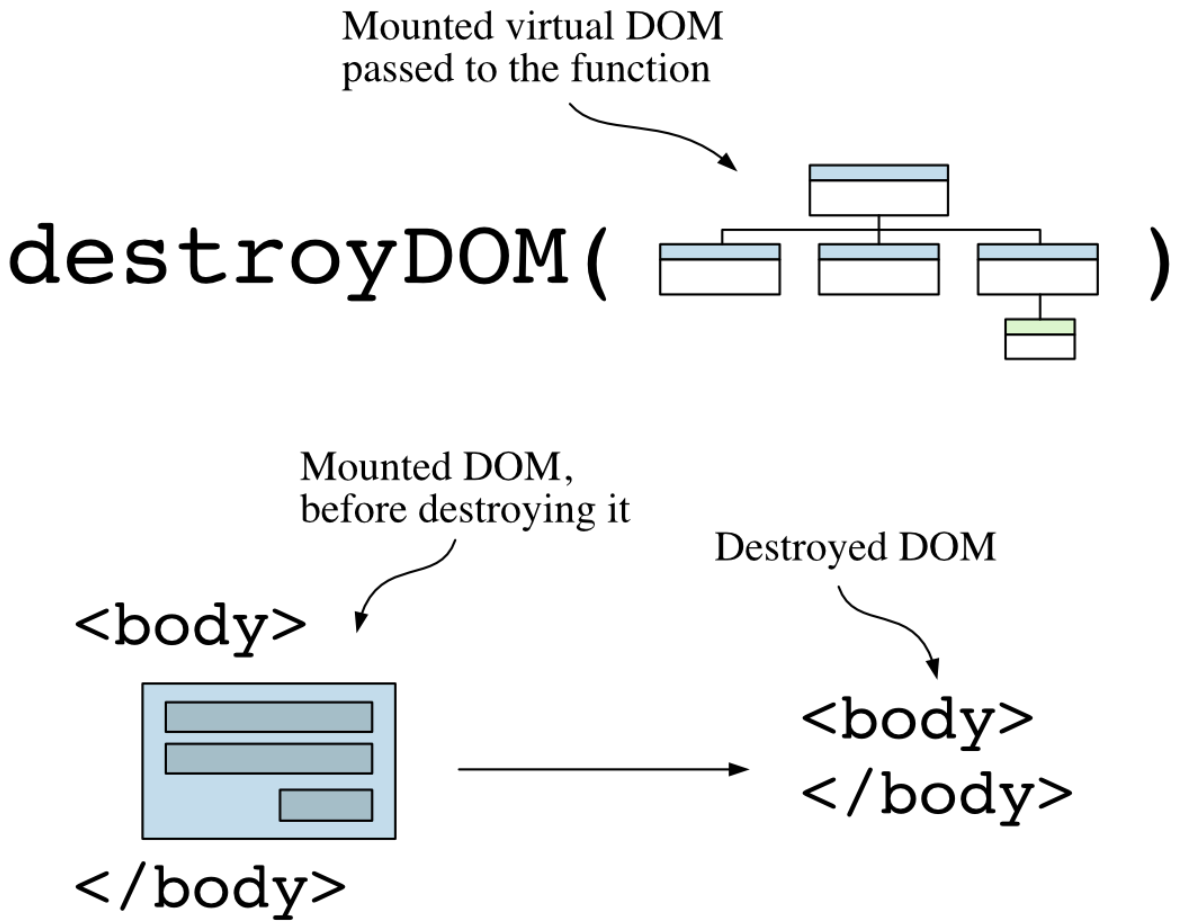


Figure 4.7 Destroying the DOM

To destroy the DOM associated to a virtual node, you have to take into account what type of node it is:

- *text node*—remove the text node from its parent element using the `remove()` method.
- *fragment node*—remove each of its children from the parent element, which if you recall, is referenced in the `el` property of the fragment virtual node.
- *element node*—do the two previous things, plus remove the event listeners from the element.

In all of the cases, you want to remove the `el` property from the virtual node, and in the case of an element node, also remove the `listeners` property. This is so that you can tell that the virtual node has been destroyed and allow the garbage collector to free the memory of the HTML

element. When a virtual node doesn't have an `el` property, you can safely assume that it's not mounted to the real DOM.

To handle these three cases, you need a `switch` statement that, depending on the `type` property of the virtual node calls a different function.

You are ready to implement the `destroyDOM()` function. Create a new file inside the *src* folder called *destroy-dom.js* and write the code in Listing 4.4.

Listing 4.4 Destroying the virtual DOM (destroy-dom.js)

```
import { removeEventListeners } from './events'
import { DOM_TYPES } from './h'

export function destroyDOM(vdom) {
  const { type } = vdom

  switch (type) {
    case DOM_TYPES.TEXT: {
      removeTextNode(vdom)
      break
    }

    case DOM_TYPES.ELEMENT: {
      removeElementNode(vdom)
      break
    }

    case DOM_TYPES.FRAGMENT: {
      removeFragmentNode(vdom)
      break
    }

    default: {
      throw new Error(Can't destroy DOM of type: ${type})
    }
  }

  delete vdom.el
}

// TODO: implement removeTextNode()

// TODO: implement removeElementNode()

// TODO: implement removeFragmentNode()
```

You've written the algorithm for destroying the DOM associated with a passed in virtual node: `vdom`. You've handled each type of virtual node separately—you'll need to write the missing functions in a minute—and you've lastly deleted the `el` property from the virtual node. This process is depicted in 4.8.

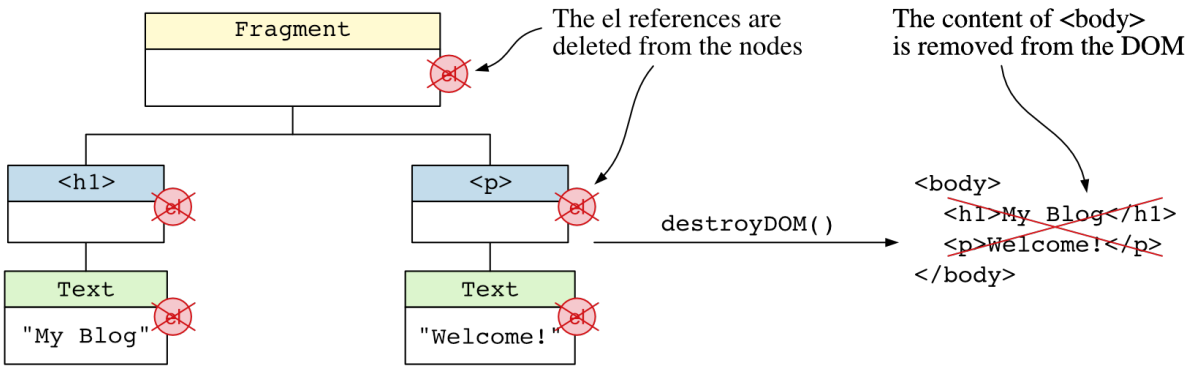


Figure 4.8 Removing the `el` references from the virtual nodes

Note that you've imported the `removeEventListeners()` function from the *events.js* file, but you haven't implemented that one yet. You will in a minute.

Let's start with the code for destroying a text node.

4.2.1 Destroying a text node

Destroying a text node is the simplest case:

```
function removeTextNode(vdom) {
  const { el } = vdom
  el.remove()
}
```

Let's move on to the code for destroying an element, which is a bit more interesting.

4.2.2 Destroying an element

To destroy an element you start by removing it from the DOM, in a similar fashion to how you just did with a text node. Then, you want to recursively destroy the children of the element, by calling the `destroyDOM()` function for each of them. Finally, you want to remove the event listeners from the element and delete the `listeners` property from the virtual node.

Go ahead and implement the `destroyElement()` function in the *destroy-dom.js* file:

```
function removeElementNode(vdom) {
  const { el, children, listeners } = vdom

  el.remove()
  children.forEach(destroyDOM)

  if (listeners) {
    removeEventListeners(listeners, el)
    delete vdom.listeners
  }
}
```

Here's where you've used the missing `removeEventListeners()` function to remove the event listeners from the element. Then, you've also deleted the `listeners` property from the virtual

node.

Let's write the `removeEventListeners()` function now. It's a function that given an object of event names and event handlers, it removes the event listeners from the element. Recall that the `listeners` property of the virtual node is an object that maps event names to event handlers. the following could be an example of the `listeners` object for a virtual node representing a button:

```
{
  mouseover: () => { ... },
  click: () => { ... },
  dblclick: () => { ... }
}
```

There would be three event handlers to remove in the case above. So, for each of them, you want to call the `Element` object's `removeEventListener()` method (that it inherits from the `EventTarget` interface):

```
el.removeEventListener('mouseover', listeners['mouseover'])
el.removeEventListener('click', listeners['click'])
el.removeEventListener('dblclick', listeners['dblclick'])
```

Open the *events.js* file and fill in the missing code:

```
export function removeEventListeners(listeners = {}, el) {
  Object.entries(listeners).forEach(([eventName, handler]) => {
    el.removeEventListener(eventName, handler)
  })
}
```

Great! You're only missing the code for destroying a fragment.

4.2.3 Destroying a fragment

Destroying a fragment is simple: you simply need to call the `destroyDOM()` function for each of its children. But you have to be careful not to remove the `el` referenced in the fragment's virtual node, because that references the element where the fragment is mounted, not the fragment itself. If the fragment was mounted inside the `<body>`, and you called the `remove()` method on the element, you would remove the whole document from the DOM. That's not what you want. Figure 4.9 shows the problem in a more graphical way.

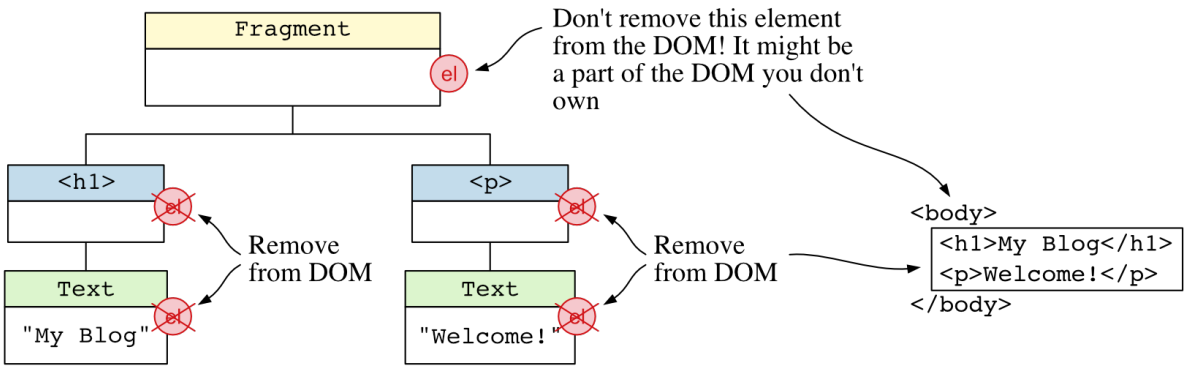


Figure 4.9 When destroying a fragment, don't remove it's referenced element from the DOM; it might be the <body> or some other element that you didn't create, and therefore don't own

The implementation of the `destroyFragment()` is therefore very simple:

```
function removeFragmentNode(vdom) {
  const { children } = vdom
  children.forEach(destroyDOM)
}
```

That's it! You've implemented the `mountDOM()` and `destroyDOM()` functions. These functions, together with the state management system that you'll implement in the next chapter, will be the core of the first version of your framework. You will use the framework to refactor the TODOs application.

The first version won't be very sophisticated—it'll destroy the entire DOM and mount it from scratch for every change in the state—but it will be enough to get you started. After finishing the next chapter you'll have a working framework, so I hope you're excited about it!

See you in the next chapter!

4.3 Summary

- Mounting a virtual DOM means to create the DOM nodes that represent each virtual node in the tree, and to insert them into the DOM, inside a parent element.
- Destroying a virtual DOM means to remove the DOM nodes created out of it, also making sure to remove the event listeners from the DOM nodes.

4.4 Exercises

- Use the `h()` function to create a virtual node representing a `<div>` element with a `<p>` element inside it, with the text "Hello world!".
- Use the `mountDOM()` function to mount the virtual node you created in the previous exercise in the DOM, inside the `<body>` element.
- Use the `destroyDOM()` function to destroy the view you created in the previous exercise.
- Use the `hFragment()` function to create a virtual node with three `<p>` children, each with a different text. Then, use the `mountDOM()` function to mount the virtual node in the DOM, inside the `<body>` element.
    - Inspect the `<body>` element in the browser's developer tools and see what got inserted to the DOM.
    - Check the `el` property of the fragment's virtual node and see what it references.
    - Check the `el` property of the virtual nodes of the children of the fragment and see what they reference.

5 State management and the application's lifecycle

This chapter covers

- What state management is
- Implementing a state management solution
- Mapping JavaScript events to commands that change the state
- Updating the state using reducer functions
- Re-rendering the view when the state changes

I remember some time ago I went to the coast in the south of Spain, to a small village in Cadiz. There was this restaurant, so popular that they'd run out of food quickly; they had a limited number of each of the dishes they served, and they would update a chalkboard with the number of servings they had left. When there was no more of a particular dish, they'd cross it out. The waiter took orders from the customers and updated the chalkboard to reflect the new state of the restaurant: having one less of that dish. Us, the customers, could easily know what we could order by looking at the chalkboard. But from time to time, and due to the work load, the waiter forgot to update the chalkboard, and customers would find out the dish they've been waiting so long in line to order was sold out. You can picture the drama. It's clearly important for the restaurant to have an updated chalkboard that matched the remaining servings of each dish.

To have a working framework, you're missing a key piece that does a similar job as to the waiter in the restaurant, a *state manager*. In the restaurant anecdote, the waiter is in charge of keeping the chalkboard in sync with the state of the restaurant: the number of servings of each dish they had left. In a frontend application, the state changes as the user interacts with it, and the view needs to be updated to reflect that changes. The state manager keeps the application's state in

sync with the view, responding to user input by modifying the state accordingly, and notifying the *renderer* when the state has changed. The renderer is the entity in your framework that takes the virtual DOM and mounts it into the DOM.

In this chapter, you'll implement both the renderer (using the `mountDOM()` and `destroyDOM()` functions from the previous chapter) and the state manager entities, and you'll learn how they communicate. By the end of the chapter, you'll have your first version of the framework, whose architecture (shown in figure 5.1) is basically the state manager and renderer glued together. (The state manager is displayed with a question mark because we'll discover how it works in this chapter.)

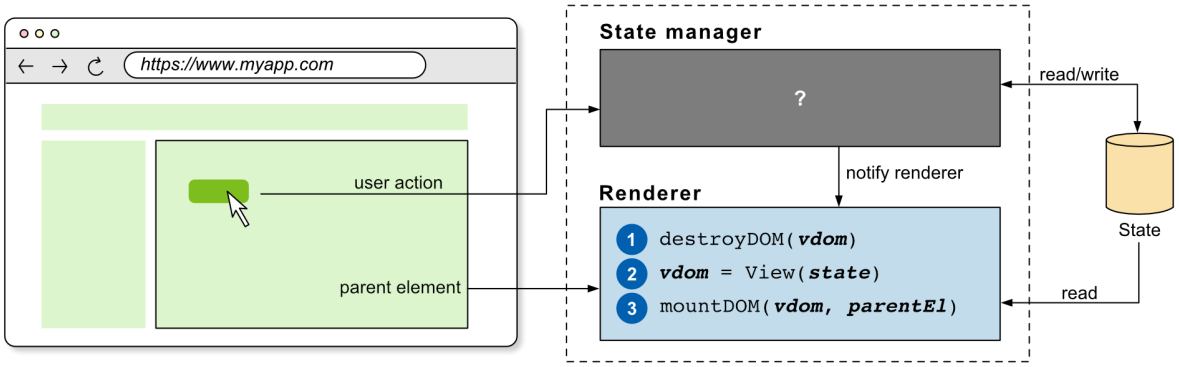


Figure 5.1 Your first framework is just a state manager and a renderer glued together.

The framework you'll have at the end of the chapter is very rudimentary: to ensure the view reflects the current state, its renderer completely destroys and mounts the DOM every time the state changes. As you can see in the diagram in figure 5.1, the renderer draws the view as a three-step process:

1. Completely destroy the current DOM (calling `destroyDOM()`).
2. Produce the virtual DOM representing the view given the current state (calling the `View()` function, the top level component).
3. Mount the virtual DOM into the real DOM (calling `mountDOM()`).

Destroying and mounting the DOM from scratch is far from ideal, and we'll discuss why later on. In any case, it's a good starting point, and you'll improve the rendering mechanism in chapters 7 and 8, where thanks to the reconciliation algorithm, your framework can update the DOM in a more efficient way. You have to walk before you can run, they say.

How does what you'll do in this chapter—implementing a renderer and state manager—fit into the bigger picture of your framework? Let's briefly take a step back. If you recall from our discussion in chapter 1, when the browser loads an application, the framework code renders the application's view (step 5 in figure 5.2, reproduced from figure 1.5 for convenience). This can be done by the renderer alone—the state manager doesn't intervene here. (Well—it might. But let's leave that case for now.)

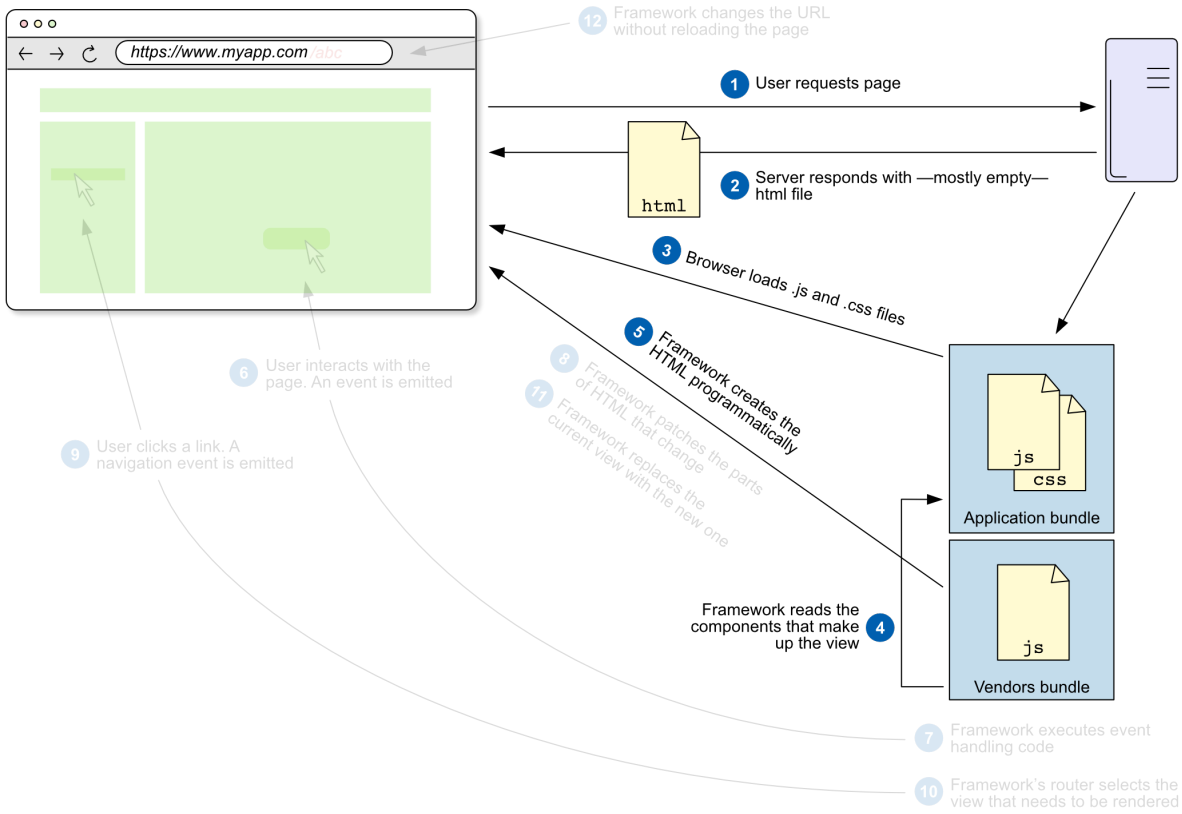


Figure 5.2 Single-page application first render in the browser

Then, when the user interacts with the application (step 6 in figure 5.3, reproduced from figure 1.6), the state manager updates the state (step 7) and notifies the renderer to re-render the view (step 8). This dynamic is a bit more complex and requires the state manager and renderer to work together.

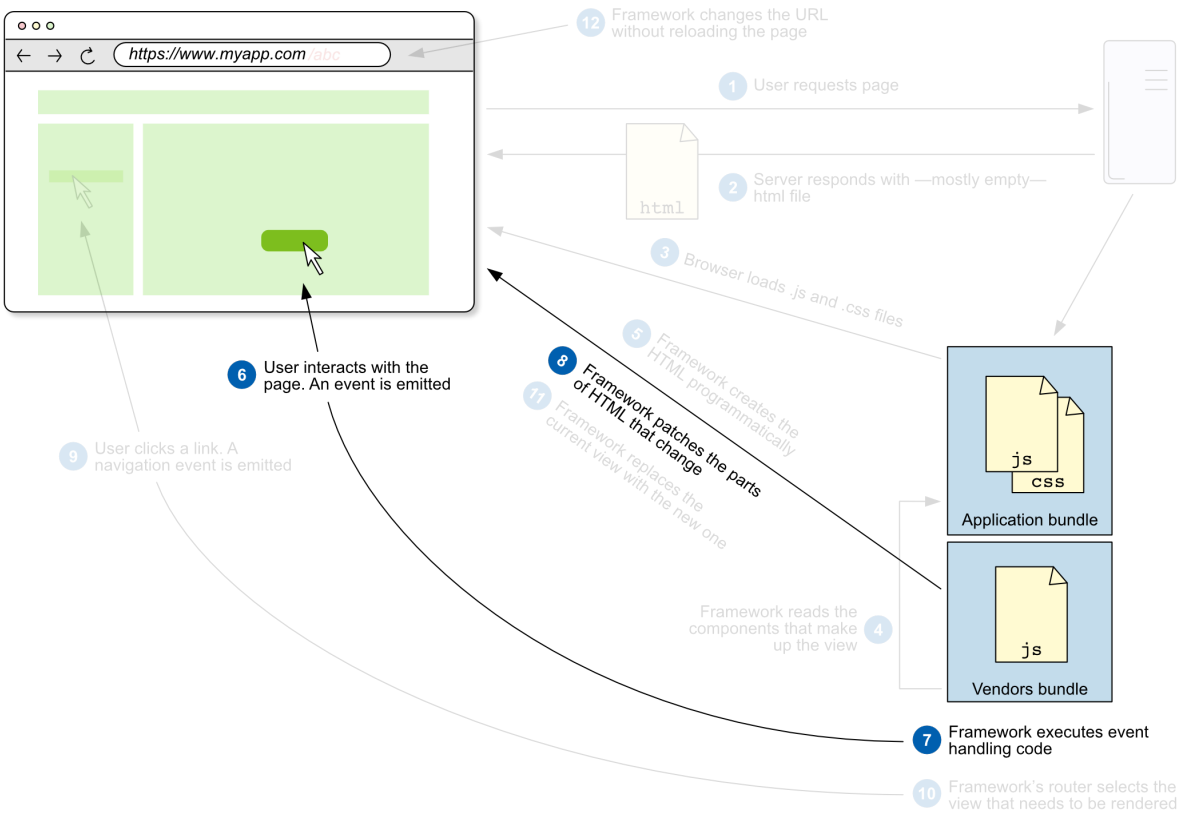


Figure 5.3 Single-page application responding to events

The state manager somehow needs to be aware of the events that the user interactions can trigger, such as clicking a button or typing in an input field, and know what to do with the state when those events take place. In a way, it needs to know beforehand everything the user might do with the application, and how that affects the state.

In this chapter, you'll learn exactly how to do that. So, with the big picture in mind, let's start working on the state manager.

5.1 The state manager

Let's study the chronology of everything that happens between the user interacting with the application and the view being updated. In the list that follows, the actor goes first, then the action it performs.

1. *The user*—interacts with the application's view (for example, clicks a button).
2. *The browser*—dispatches a native JavaScript `event` (for example, `MouseEvent`, `KeyboardEvent`).
3. *The application developer*—tells the framework how to update the state for that particular event.
4. *The framework's state manager*—updates the state according to the instructions given by the application developer.
5. *The framework's renderer*—re-renders the view with the new state.

Well, this isn't exactly a chronology, because the application developer doesn't intervene between the user interacting with the application and the state manager updating the state, but rather gives those instructions on how to update the state during the application development (not at runtime). But still, it's a good way to understand the flow of events. Figure 5.4 illustrates this pseudo-chronology in the architectural diagram of the framework I presented in figure 5.1.

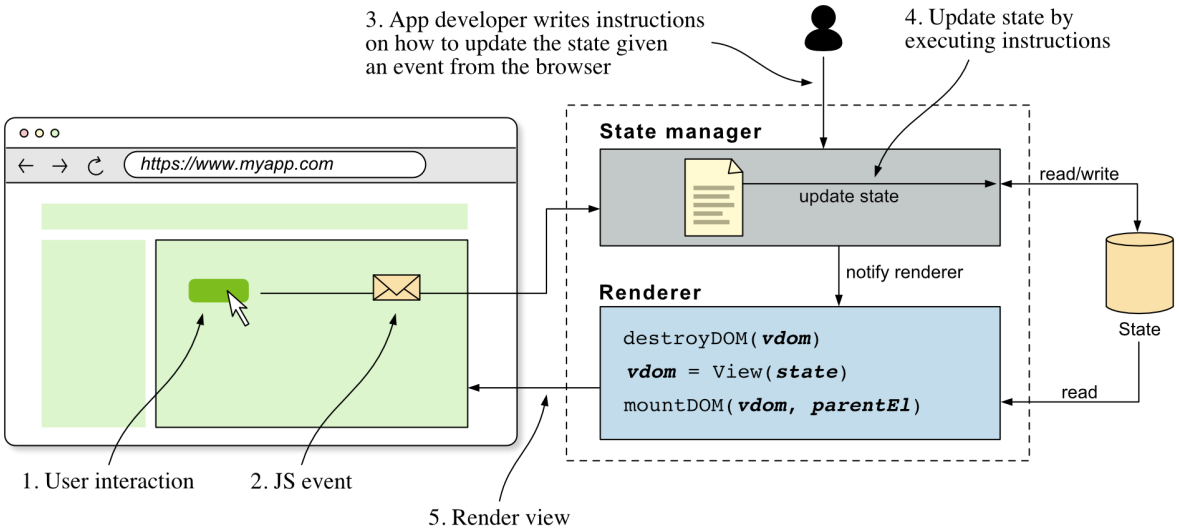


Figure 5.4 The pseudo-chronology of events in a frontend application

From this pseudo-chronology, there're two key questions that we should ask ourselves: *how does the application developer instruct the framework how to update the state when a particular event is dispatched?* And, *how does the state manager execute those instructions?* In the answer to these questions lays the key to understanding the state manager.

5.1.1 From JavaScript events to application domain commands

The first thing that you need to notice is that the JavaScript events dispatched by the browser don't have a concrete meaning in the application domain on their own. The user clicked this button, so what? It's the application developer who translates user actions into something meaningful for the application. Think about the TODOs application:

- When the user clicked the *Add* button or pressed the *Enter* key, that meant they wanted to add a new TODO item to the list.
- "*Adding a to-do*" is framed in the language of the application, whereas "*clicking a button* " is a very generic thing to do. (You click buttons in all sorts of applications, but that only translates to "*adding a to-do*" in the TODOs application.)

If the application developer wants to update the state when a particular event is dispatched, they first need to determine what that event means in terms of the application domain. They then map that event to a *command* that the framework can understand. A command is a request to do something, as opposed to an event, which is a notification about something that has happened.

These commands are a request to the framework to update the state, and are expressed using the domain language of the application.

SIDEBAR **Events vs. commands**

An event is a notification about something that has happened. "A button was clicked," "a key was pressed," "a network request was completed" are all examples of events. Events aren't requesting the framework or application to do anything, they're just notifications. Event names are usually framed in the past tense, because they're communications about something that has already happened: `'button-clicked'`, `'key-pressed'`, `'network-request-completed'`, and so on.

A command is a request to do something. "Add todo," "edit todo," "remove todo" are three examples of commands. Commands are written in imperative tense, because they're requests to do something: `'add-todo'`, `'edit-todo'`, `'remove-todo'`, and more.

Following with the TODOs application example, here's a table of a few events that the user can trigger and the commands that the application developer would dispatch to the framework in response to those events.

Table 5.1 Mapping between browser events and application commands in the TODOs application

Browser Event	Command	Explanation
Click the Add button	`add-todo`	Clicking the Add button adds a new to-do item to the list.
Press the Enter key (while the input field is focused)	`add-todo`	Pressing the Enter key adds a new to-do item to the list.
Click the Done button	`remove-todo`	Clicking the Done button marks the to-do item as done, removing it from the list.
Double-click a to-do item	`start-editing-todo`	Double-clicking a on a to-do item sets the to-do item in edit mode.

And in figure 5.5 you can see the same mapping in the form of a diagram. In it, you can appreciate the mapping between the browser events and the application commands, which are dispatched by the application developer to the framework, using the `dispatch()` function. You'll learn more about this function in a minute.

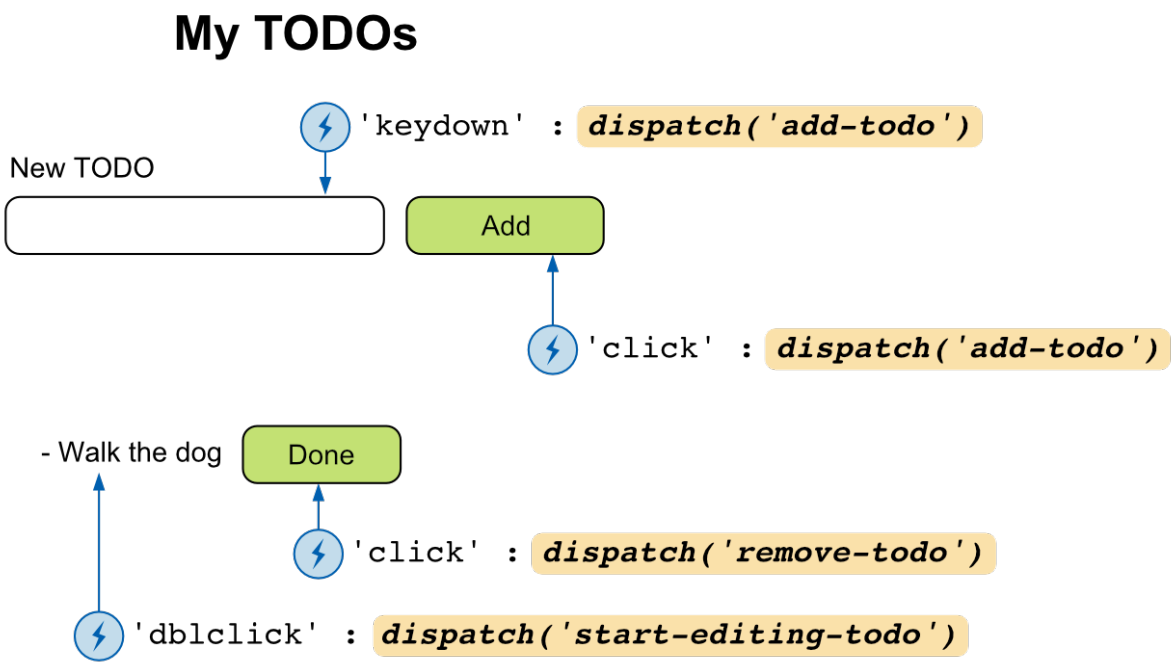


Figure 5.5 The mapping between browser events and application commands

Why is this relevant to answer the previous questions? you might be asking. Because once the application domain commands are identified, the application developer can supply functions that update the state as a response to those commands. The state manager executes those functions to update the state. Let's look into what these functions are and how they're executed.

5.1.2 The reducer functions

Reducer functions can be implemented in a few different ways, but if we decide to stick to the functional programming principles of using *pure functions* and making data *immutable*, instead of updating the state by mutating it, these functions should create a new one. This is illustrated in figure 5.6.

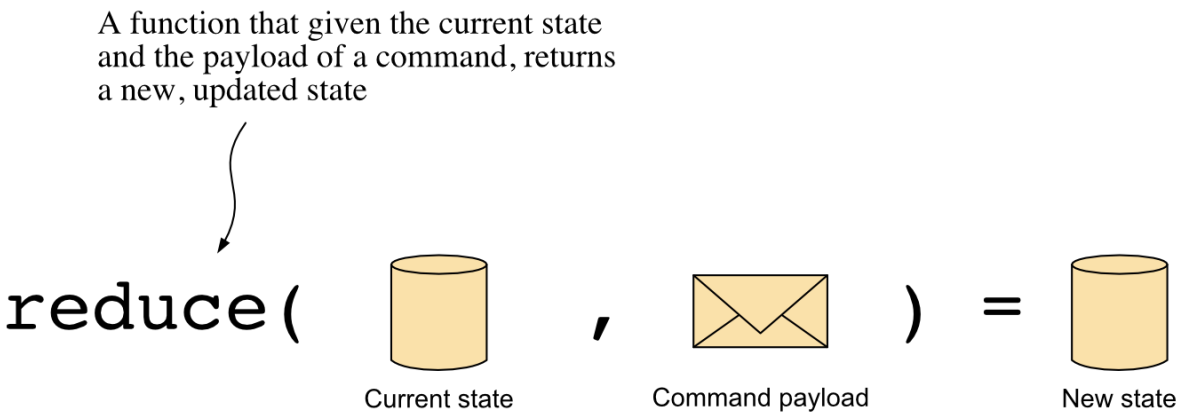


Figure 5.6 A reducer function takes the current state and a payload and returns a new state

> **NOTE** This might sound familiar to you if you've used Redux before: these functions are the reducers. (The term reducer comes from the reduce function in functional programming.) A reducer, in our context, is a function that takes the current state and a payload (the command's data) and returns a new updated state. These functions never mutate the state that's passed to them (that'd be considered a side effect, and therefore the function wouldn't be pure), but instead create a new state.

Let's see an example with the TODOs application. To create a new version of the state when the user removes a to-do item from the list (recall that the state was just the list of to-dos), the reducer function associated to this `'remove-todo'` command would look like this:

```
function removeTodo(state, todoIndex) {
  return state.filter((todo, index) => index !== todoIndex)
}
```

If we had the following state:

```
let todos = ['Walk the dog', 'Water the plants', 'Sand the chairs']
```

And we wanted to remove the to-do item at index 1, the new state would be computed using the `removeTodo()` reducer, as follows:

```
todos = removeTodo(todos, 1)
// todos = ['Walk the dog', 'Sand the chairs']
```

In this case, the payload associated with the `'remove-todo'` command is the index of the to-do item to remove. Note how the original array is not mutated, but a new one is created instead (the `filter()` method of an array returns a new array).

Let's do a quick recap of what we've seen so far. We've seen that the application developer translates user actions into application domain commands, and that the state manager executes the reducer functions associated to those commands to update the state. But, how does the state manager know which reducer function to execute when a command is dispatched? There needs to be something that maps the commands to the reducer functions. We'll call this mechanism a *dispatcher*, and it's the state manager's central piece.

5.1.3 The dispatcher

The association between commands and reducer functions is done by an entity we'll call the *dispatcher*. The name *dispatcher* reflects the fact that this entity is responsible for dispatching the commands to the functions that handle the command, that is, for executing the corresponding handler functions in response to commands. To do this, it needs to be told—by the application developer—which handler function (or functions, as there might be more than one) to execute in response to each command.

These command handler functions are *consumers*. Consumer is the technical term to refer to a function that accepts a single parameter—the command's payload in our case—and returns no value, as figure 5.7 shows.

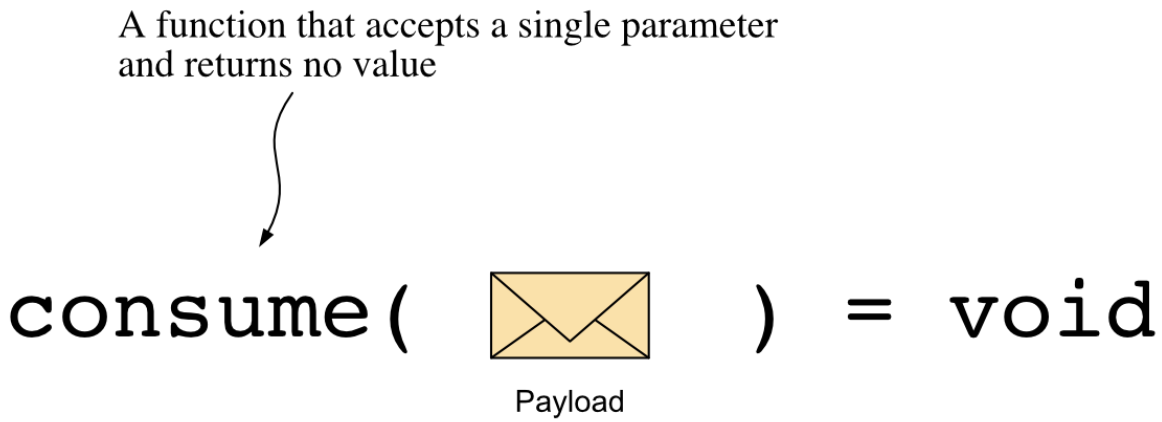


Figure 5.7 A consumer function takes a single parameter and returns no value

A consumer that handles a command can easily wrap a reducer function, as the following example shows:

```
function removeTodoHandler(todoIndex) {
  // Calls the removeTodo() reducer function to update the state.
  state = removeTodo(state, todoIndex)
}
```

As you can see, the command handler function that removes a to-do from the list receives the to-do index as its single parameter, and then calls the `removeTodo()` reducer function to update the state. The handler simply wraps the reducer function, and it's the dispatcher's responsibility to execute the handler function in response to the `'remove-todo'` command.

But how do you tell the dispatcher which handler function to execute in response to a command?

ASSIGNING HANDLERS TO COMMANDS

Your dispatcher needs to have a `subscribe()` method that registers a handler to respond to commands with a given name. And the same way you can register a handler for a command, you should be able to un-register it when it doesn't need to be executed anymore (because the relevant view has been removed from the DOM, for example). To accomplish this, the `subscribe()` method should return a function that can be called to un-register the handler.

From what you've seen so far, you might already start to discern how the command dispatcher works. You can see a diagram of the dispatcher in figure 5.8. The dispatcher is a registry of command handlers by command name, added using the `subscribe()` method. When a command is dispatched—using the `dispatch()` method—the dispatcher looks up the command name in the registry and executes the handler functions associated to that command.

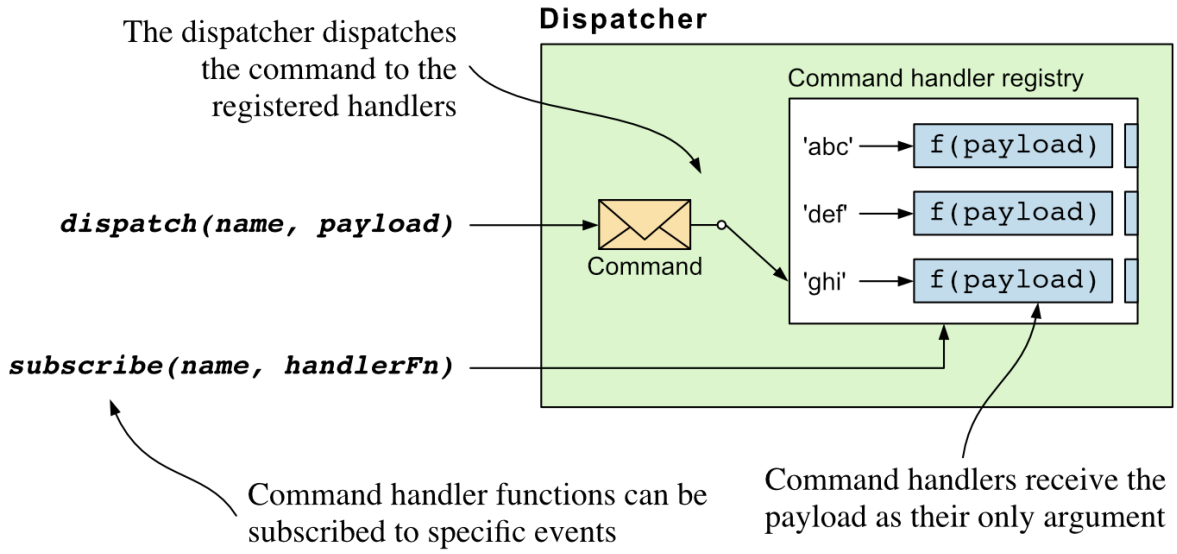


Figure 5.8 The dispatcher's `subscribe()` method registers handlers to respond to commands with a given name

It's time to implement the dispatcher. Create a new file called *dispatcher.js* in the *src/* directory, and write the following code:

Listing 5.1 Registering handlers to respond to commands (dispatcher.js)

```
export class Dispatcher {
  #subs = new Map()

  subscribe(commandName, handler) {
    if (!this.#subs.has(commandName)) {   ❶
      this.#subs.set(commandName, [])
    }

    const handlers = this.#subs.get(commandName)
    if (handlers.includes(handler)) {   ❷
      return () => {}
    }

    handlers.push(handler)   ❸

    return () => {   ❹
      const idx = handlers.indexOf(handler)
      handlers.splice(idx, 1)
    }
  }
}
```

❶ Create the array of subscriptions if it doesn't exist yet

❷ Check if the handler is already registered

❸ Register the handler

❹ Return a function to un-register the handler

The `Dispatcher` is a class with a private variable called `subs` (short for *subscriptions*): a JavaScript map to store the registered handlers by event name. Note how more than one handler can be registered for the same command name.

NOTE **The hash `#` in front of the variable name is the ES2020 way to make the variable private. Inside a class, starting from ES2020, any variable or method that starts with a hash is private and can only be accessed from within the class.**

The `subscribe()` method takes a command name and a handler function as parameters, checks if there's an entry in `subs` for that command name, and creates one with an empty array if there isn't. Then appends the handler to the array in case it wasn't already registered. If the handler was already registered, you simply return a function that does nothing, because there's nothing to unregister.

If the handler function was registered, the `subscribe()` method returns a function that removes the handler from the corresponding array of handlers, so it's never notified again. To do this, you first look for the index of the handler in the array, and then call its `splice()` method to remove the element at that index. Note that the index lookup only happens when the returned function—the un-registering function—is called. This is a very important detail, because if you

did the lookup outside that function—inside the `subscribe()` method body—the index that you'd get might not be valid by the time you want to unregister the handler, because the array might have changed in the meantime.

> **WARNING** **In the case where the handler is already registered, instead of returning an empty function, you might be tempted to return a function that un-registers the existing handler. But returning an empty function is a better idea, because it avoids the side effects of a developer inadvertently calling the returned function twice (one for each time they called `subscribe()` using the same handler). In this case, when the same handler is unregistered for the second time, `indexOf()` returns `-1`, because the handler isn't in the array anymore. It'd then call `splice()` with an index of `-1`, which would remove the last handler in the array, and this is not what you want.**
>
> **This silent failure—something going wrong without throwing an exception—is something we want to avoid at all costs, as debugging these kinds of issues can be a nightmare.**

Now that you've implemented the dispatcher first method, `subscribe()`, there's something we haven't addressed yet: how does the dispatcher tell the renderer about state changes? Let's try to figure this out next.

NOTIFYING THE RENDERER ABOUT STATE CHANGES

In the beginning of this chapter we said that the state manager is in charge of keeping the state in sync with the views. It does so by notifying the renderer about state changes, so that the renderer can update the views accordingly. The question is then: how does the dispatcher notify the renderer?

You know that the state can change only in response to commands. A command triggers the execution of one or more handler functions, which execute reducers, which in turn update the state. Therefore, the best moment to notify the renderer about state changes is after the handlers for a given command have been executed. You should allow the dispatcher to register special handler functions, which we'll call *after-command handlers*, and are executed after the reducer functions for a given command have been executed. The framework uses these handlers to notify the renderer about potential state changes, so it can update the view.

The diagram in figure 5.9 shows how the `afterEveryCommand()` as part of the dispatcher's architecture. The functions registered with this method are called after every command is handled, which you can use to notify the renderer about state changes.

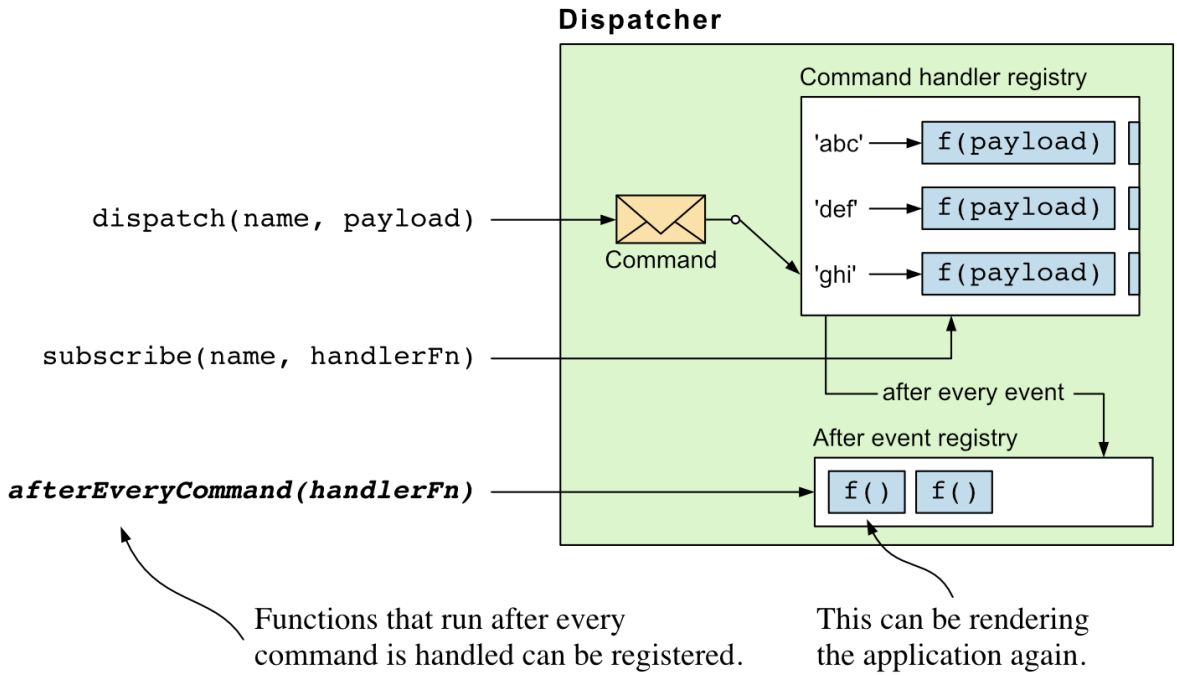


Figure 5.9 The dispatcher's `afterEveryCommand()` method registers handlers to run after every command is handled

Write the code in bold font that's shown inside the `Dispatcher` class, to add the `afterEveryCommand()` method:

Listing 5.2 Registering functions to run after commands (dispatcher.js)

```
export class Dispatcher {
  #subs = new Map()
  #afterHandlers = []

  // --snip-- //

  afterEveryCommand(handler) {
    this.#afterHandlers.push(handler)  ❶

    return () => {  ❷
      const idx = this.#afterHandlers.indexOf(handler)
      this.#afterHandlers.splice(idx, 1)
    }
  }
}
```

❶ Register the handler

❷ Return a function to un-register the handler

This method is very similar to the `subscribe()` method, except that it doesn't take a command name as a parameter: these handlers are called for all dispatched commands. This time we're not checking for duplicates; we're allowing for the same handler to be registered multiple times. After-command handlers don't modify the state, they are a notification mechanism, and so notifying about the same event multiple times might be a valid use-case.

The last part that's missing is the `dispatch()` method, to dispatch a command and call all the registered handlers.

DISPATCHING COMMANDS

A dispatcher wouldn't be much of a dispatcher if it didn't have a `dispatch()` method, would it? This method takes two parameters: the name of the command to dispatch and its payload. It looks up the handlers registered for the given command name, and calls them one by one, in order, passing them the command's payload as parameter. Last, it runs the after-command handlers.

Listing 5.3 Dispatching a command given its name and payload (dispatcher.js)

```
export class Dispatcher {
  // --snip-- //

  dispatch(commandName, payload) {
    if (this.#subs.has(commandName)) {   ❶
      this.#subs.get(commandName).forEach((handler) => handler(payload))
    } else {
      console.warn(`No handlers for command: ${commandName}`)
    }

    this.#afterHandlers.forEach((handler) => handler())   ❷
  }
}
```

❶ Check if there are handlers registered and call them

❷ Run the after-command handlers

Note that, if a command with no handlers associated is dispatched, we warn the developer about it in the console. This will be handy later on when we write our example applications, because it's easy to misspell a command name and not notice it, but then bang your head against the wall because you don't understand why your code isn't working.

That's it! Figure 5.10 shows the framework's first version architecture. You've implemented the dispatcher—the state manager—and now it's time to integrate it with the renderer to form a working framework.

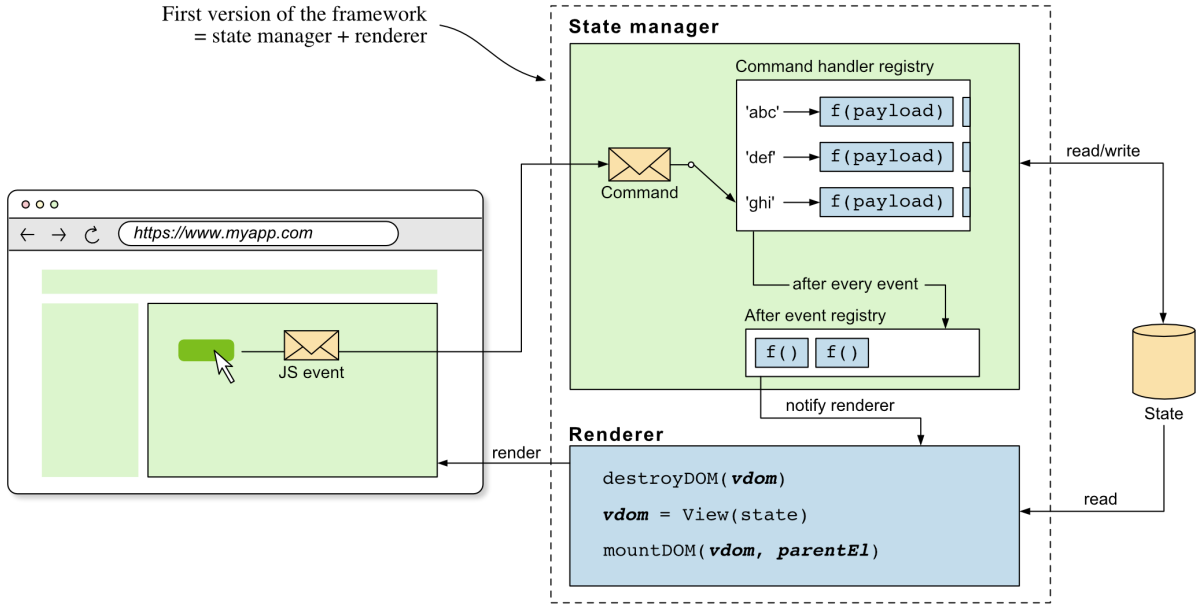


Figure 5.10 The framework's first version architecture

Before integrating the dispatcher with the rendering system, make sure the code you wrote matches the one in listing 5.4 in the next section. If you need to copy and paste to compare, you can find the complete listing at the book's GitHub repository (see appendix A for more information).

RESULT

Just for your reference, here's the complete `Dispatcher` class implementation:

Listing 5.4 Complete `Dispatcher` implementation (dispatcher.js)

```
export class Dispatcher {
  #subs = new Map()
  #afterHandlers = []

  subscribe(commandName, handler) {
    if (!this.#subs.has(commandName)) {
      this.#subs.set(commandName, [])
    }

    const handlers = this.#subs.get(commandName)
    if (handlers.includes(handler)) {
      return () => {}
    }

    handlers.push(handler)

    return () => {
      const idx = handlers.indexOf(handler)
      handlers.splice(idx, 1)
    }
  }

  afterEveryCommand(handler) {
    this.#afterHandlers.push(handler)

    return () => {
      const idx = this.#afterHandlers.indexOf(handler)
      this.#afterHandlers.splice(idx, 1)
    }
  }

  dispatch(commandName, payload) {
    if (this.#subs.has(commandName)) {
      this.#subs.get(commandName).forEach((handler) => handler(payload))
    } else {
      console.warn(`No handlers for command: ${commandName}`)
    }

    this.#afterHandlers.forEach((handler) => handler())
  }
}
```

Make sure you wrote the code correctly and your implementation matches the one in listing 5.4. If so, let's move on to the next section.

5.2 Assembling the state manager into the framework

Assemble is defined by Merriam-Webster as *to bring together (as in a particular place or for a particular purpose)*. To assemble the state manager and renderer, you need a "particular place" where to bring them together. This would be an object that contains and connects them so they can communicate. If you think about it, this object represents the running application that uses your framework, so we can refer to it as the *application instance*. Let's think about how you want developers to create an application instance in your framework.

5.2.1 The application instance

The application instance is the object that manages the lifecycle of the application: it manages the state, renders the views, and updates the state in response to user input. There are three things that developers need to pass to the application instance:

- The initial state of the application.
- The reducers that update the state in response to commands.
- The top-level component of the application.

Your framework can take care of the rest: instantiating a renderer and a state manager, and wiring them together. (Remember, your initial version of the framework won't be much more than these two things glued together.) The application instance can expose a `mount()` method that takes a DOM element as parameter, mounts the application in it, and kicks off the application's lifecycle. From this point on, the application instance is in charge of keeping the state in sync with the views, like the waiter in the restaurant from the beginning of the chapter.

This might sound a bit abstract a the moment, but it'll become clear later on when you rewrite the TODO application using your framework. For now, bear with me and let's move on to implementing the application instance. Let's start with the renderer.

5.2.2 The application instance's renderer

To start, you implement a function called `createApp()` that returns an object with a single method, `mount()`, which takes a DOM element as parameter and mounts the application in it. This object is the application instance inside which you implement the renderer and the state manager.

The `createApp()` function takes an object with two properties: `state` and `view`. The `state` property is the initial state of the application, and the `view` property is the top-level component of the application. You'll add the reducers later.

You need two variables in the closure of the `createApp()` function: `parentEl` and `vdom`. They keep track of the DOM element where the application is mounted and the virtual DOM tree of the previous view, respectively. They should both be initialized to `null` because the application hasn't been mounted yet.

Then goes the renderer, which is implemented as a function: `renderApp()`. This function, as previously discussed, renders the view by first destroying the current DOM tree—if there is one—and mounting the new one. At this point, this function is called only once: when the application is mounted by the `mount()` method, the only method exposed to the developer. It takes a DOM element as parameter and mounts the application in it. Note how you save the DOM element in the `parentEl` variable so that you can use it later to unmount the application.

Create a new file called *app.js* and write the code in listing 5.5.

Listing 5.5 The application instance with its renderer (app.js)

```
import { destroyDOM } from './destroy-dom'
import { mountDOM } from './mount-dom'

export function createApp({ state, view }) {   ❶
  let parentEl = null
  let vdom = null

  function renderApp() {
    if (vdom) {
      destroyDOM(vdom)   ❷
    }

    vdom = view(state)
    mountDOM(vdom, parentEl)   ❸
  }

  return {
    mount(_parentEl) {   ❹
      parentEl = _parentEl
      renderApp()
    },
  }
}
```

❶ The function that creates the application object

❷ If there was a previous view, unmount it

❸ Mount the new view

❹ Method to mount the application in the DOM

Okay, you've got the renderer, you could already render an application in the browser, but it wouldn't respond to user input. For that, you need the state manager, that tells the renderer to re-render the application when the state changes. Let's move on to that.

5.2.3 The application instance's state manager

The state manager is a bit more complex that just a function, like the renderer was. The `Dispatcher` class you implemented in the previous section is the central piece of the state manager, but you have to hook some things up. Most notably, you need to wrap the state reducers—given by the developer—in a consumer function that will be called by the dispatcher every time a command is dispatched. Let's see how this is done.

Write the code in bold in listing 5.6. Note that part of the code you wrote earlier is elided for clarity.

Listing 5.6 Adding the state manager to the application instance (app.js)

```
import { destroyDOM } from './destroy-dom'
import { Dispatcher } from './dispatcher'
import { mountDOM } from './mount-dom'

export function createApp({ state, view, reducers = {} }) {
  let parentEl = null
  let vdom = null

  const dispatcher = new Dispatcher()
  const subscriptions = [dispatcher.afterEveryCommand(renderApp)]   ❶

  for (const actionName in reducers) {
    const reducer = reducers[actionName]

    const subs = dispatcher.subscribe(actionName, (payload) => {
      state = reducer(state, payload)   ❷
    })
    subscriptions.push(subs)   ❸
  }

  // --snip-- //
}
```

❶ Re-render the application after every command

❷ Update the state calling the reducer function

❸ Add each command subscription to the subscriptions array

Let's unpack what you've done here. First, you've added a `reducers` property into the `createApp()` function parameter. This property is an object that maps command names to reducer functions, functions that take the current state and the command's payload and return a new state.

Next, you've created an instance of the `Dispatcher` class and saved it in the `dispatcher` variable. The line below that is crucial: you've subscribed the `renderApp()` function to be an after-command handler, so that the application is re-rendered after every command is handled. Not every command necessarily changes the state, but you don't know that in advance, so you have to re-render the application after every command.

> **NOTE** To avoid re-rendering the application when the state didn't change, you could compare the state before and after the command was handled. This comparison can nevertheless become expensive if the state is a heavy and deeply nested object and the commands are frequent. In chapters 7 and 8 you'll improve the performance of the renderer, by only patching the DOM where it's necessary, so re-rendering the application will be a reasonably fast operation. Not checking if the state changed is a trade-off we're making to keep the code simple.

Can you see why the concept of after-command handlers were a good idea now? Note that, the

`afterEveryCommand()` function returns a function that unsubscribes the handler, so you've saved it in the `subscriptions` array, an array that you've initialized to have this function as its first element.

You then iterate the `reducers` object, wrap each of the reducers inside a handler function that calls the reducer and updates the state, and subscribe that handler to the dispatcher. You've been careful to save the subscription functions in the `subscriptions` array, so that you can unsubscribe them later when the application is unmounted.

Great—you've got the state manager hooked up to the renderer. But there's something we haven't talked about yet: how do the components dispatch commands? Let's look at that next.

5.2.4 Components dispatching commands

If you recall, you virtual DOM implementation allows to attach event listeners to DOM elements:

```
h(
  'button',
  { on: { click: () => { ... } } },
  ['Click me']
)
```

If you want to be able to dispatch commands from within those event listeners, you need to pass the dispatcher to the components. In a way, you can imagine the dispatcher as a remote control, where each button dispatches a command whose handler function can modify the state of the application (see figure 5.11). By passing the dispatcher to the components, you give them the ability to dispatch commands in response to user input.

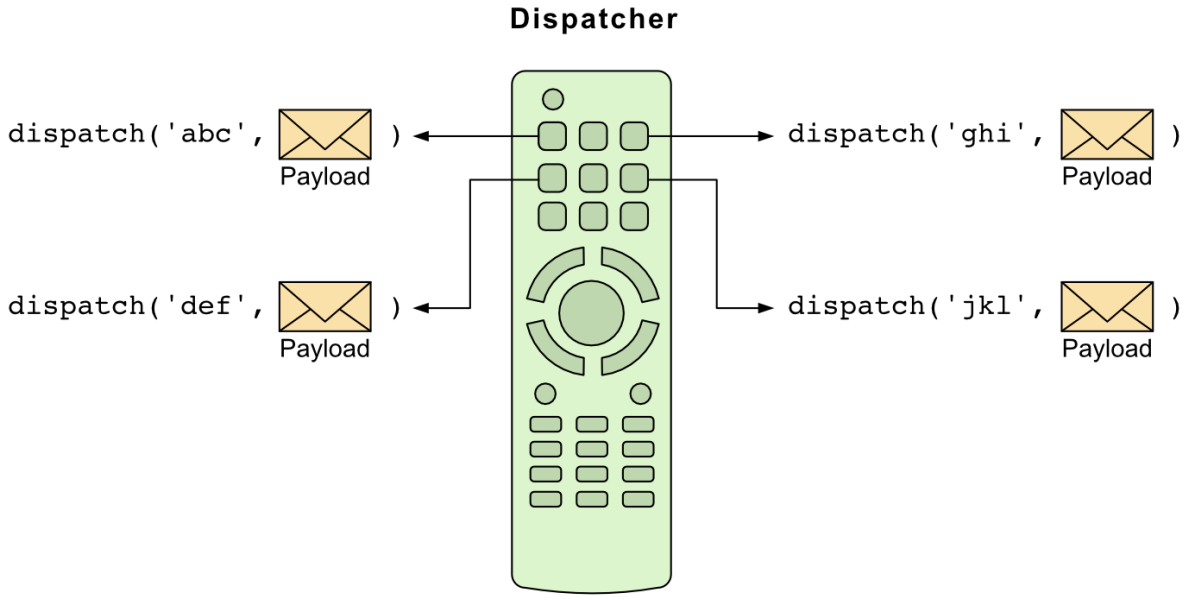


Figure 5.11 The dispatcher can be thought of as a remote control, where each button dispatches a command whose handler function can modify the state of the application

The dispatcher in the application instance has the command handlers that the developer has provided. The component can dispatch those commands using the `dispatch()` method of the dispatcher. For example, to remove a to-do item from the list, the component can dispatch a `remove-todo` command like this:

```
h(
  'button',
  {
    on: {
      click: () => dispatcher.dispatch('remove-todo', todoIdx)
    }
  },
  ['Done']
)
```

To allow the components to dispatch commands, change your code in *app.js*, adding the code in bold in listing 5.7.

Listing 5.7 Allowing components to dispatch commands (app.js)

```
export function createApp({ state, view, reducers = {} }) {
  let parentEl = null
  let vdom = null

  const dispatcher = new Dispatcher()
  const subscriptions = [dispatcher.afterEveryCommand(renderApp)]

  function emit(eventName, payload) {
    dispatcher.dispatch(eventName, payload)
  }

  // --snip-- //

  function renderApp() {
    if (vdom) {
      destroyDOM(vdom)
    }

    vdom = view(state, emit)
    mountDOM(vdom, parentEl)
  }

  // --snip-- //
}
```

To allow components to dispatch commands in a more convenient way, you've implemented an `emit()` function. So instead of writing `dispatcher.dispatch()`, you can write `emit()` inside the components, which is a bit more concise. Then, you've passed the `emit()` function to the components as a second argument.

Bear in mind that, from now onward, components will receive two arguments: the state and the `emit()` function. If a component doesn't need to dispatch commands, it can ignore the second argument.

You're almost done! There's only one thing missing: unmounting the application.

5.2.5 Unmounting the application

When an application instance is created, the state reducers are subscribed to the dispatcher, and the `renderApp()` function is subscribed to the dispatcher as an after-command handler. When the application is unmounted, apart from destroying the view, you need to unsubscribe the reducers and the `renderApp()` function from the dispatcher.

To clean up the subscriptions and destroy the view, you need to add an `unmount()` method to the application instance, as shown in bold in listing 5.8.

Listing 5.8 Unmounting the application (app.js)

```
export function createApp({ state, view, reducers = {} }) {
  let parentEl = null
  let vdom = null

  // --snip-- //

  return {
    mount(_parentEl) {
      parentEl = _parentEl
      renderApp()
    },

    unmount() {
      destroyDOM(vdom)
      vdom = null
      subscriptions.forEach((unsubscribe) => unsubscribe())
    },
  }
}
```

The `unmount()` method uses the `destroyDOM()` from last chapter to destroy the view, sets the `vdom` property to `null`, and unsubscribes the reducers and the `renderApp()` function from the dispatcher.

That's it! It's a good time to review the code you wrote in *app.js* to make sure you got it right.

5.2.6 Result

Your *app.js* should look like the code in listing 5.9.

Listing 5.9 The application instance (app.js)

```
import { destroyDOM } from './destroy-dom'
import { Dispatcher } from './dispatcher'
import { mountDOM } from './mount-dom'

export function createApp({ state, view, reducers = {} }) {
  let parentEl = null
  let vdom = null

  const dispatcher = new Dispatcher()
  const subscriptions = [dispatcher.afterEveryCommand(renderApp)]

  function emit(eventName, payload) {
    dispatcher.dispatch(eventName, payload)
  }

  for (const actionName in reducers) {
    const reducer = reducers[actionName]

    const subs = dispatcher.subscribe(actionName, (payload) => {
      state = reducer(state, payload)
    })
    subscriptions.push(subs)
  }

  function renderApp() {
    if (vdom) {
      destroyDOM(vdom)
    }

    vdom = view(state, emit)
    mountDOM(vdom, parentEl)
  }

  return {
    mount(_parentEl) {
      parentEl = _parentEl
      renderApp()
    },

    unmount() {
      destroyDOM(vdom)
      vdom = null
      subscriptions.forEach((unsubscribe) => unsubscribe())
    },
  }
}
```

That's the first version of your framework! Put together in less than 50 lines of code, it's a pretty simple framework, but it's enough to build simple applications.

In the next chapter, you build and publish your framework to NPM and refactor the TODOs application to use it.

5.3 Summary

- Your framework's first version is made of a renderer and a state manager wired together.
- The renderer first destroys the DOM (if it exists) and then creates it from scratch. This isn't very efficient and creates problems with the focus of input fields, among other things.
- The state manager is in charge of keeping the state and view of the application in sync.
- The developer of an application maps the user interactions to commands, framed in the business language, that are dispatched to the state manager.
- The commands are processed by the state manager, updating the state and notifying the renderer that the DOM needs to be updated.
- The state manager uses a reducer function to derive the new state from the old state and the command's payload.

A Setting up the project

Before you write any code, you need to have an NPM project set up. In this appendix, I'll help you create and configure a project to write the code for your framework.

I understand you might not typically configure an NPM project from scratch with a bundler, a linter, and a test library yourself, as most frameworks come with a CLI tool (like, for example *create-react-app* or *angular-cli*) which does the scaffolding and generating the boilerplate code structure for you. So I'll give you two options to create your project:

1. Use the CLI tool I created for this book. With a single command, you can create a project where you can start writing your code right away.
2. Configure the project yourself, from scratch. It's more laborious, but you get to learn how to configure the project.

If you want to get started quickly with the book and can't wait to write your awesome frontend framework, I recommend you use the CLI tool. In this case, you need to read section A.6. But if you are the kind of developer who enjoys configuring everything from scratch, you can follow the steps to configure the project yourself in section A.7.

Before you start configuring your project, let's first cover some basics about where you can find the code for the book and the technologies you'll use.

A.1 Where to find the source code

The source code for the book is publicly available at:

https://github.com/angelsolaorbaiceta/fe-fwk-book

I recommend you to clone the repository or download the ZIP archive of the repository, to follow along with the book. It contains all the listings that appear the book (in the *listings* folder), sorted by chapter. I'm assuming you're familiar with git and know how to clone a repository and checkout tags or branches. If previous sentence sounded like nonsense to you, don't worry, you

can still follow along with the book. Download the project as a ZIP archive by clicking the <> *Code* button in the repository and then clicking on the *Download ZIP* button.

A.1.1 Checking out the code for each chapter

I tagged the source code with the number of each chapter where a new version of the framework is available. The tag name follows the pattern *chX*, where *X* is the number of the chapter. For example, the first working version of the framework appears in chapter 6, so the corresponding code can be checked out with the following git command:

```
$ git checkout ch6
```

Then, in chapters 7 and 8, you implement the reconciliation algorithm, resulting in a new, more performant version of the framework. The corresponding code can be checked out as follows:

```
$ git checkout ch8
```

By checking out the code for each chapter, you can see how the framework evolves as we add new features. You can also compare your code by the end of each chapter with the code in the repository. Note that not all chapters have a tag in the repository, only those that have a working version of the framework, which are every chapter starting at chapter 4. I also wrote unit tests for the framework that I won't cover in the book, but you can look at them to find ideas on how to test your code.

> **NOTE** **If you're not familiar with the concept of git tags, you can learn about them in https://git-scm.com/book/en/v2/Git-Basics-Tagging. Basic git knowledge is assumed for this book.**

I recommend you to avoid copy/pasting the code from the book and instead type it yourself. If you get stuck because your code doesn't seem to work, look at the code in the repository, try to figure out the differences, and then fix it yourself. If you write a unit test to reproduce the problem, much better. I know this is more cumbersome, but it's the best way to learn, and it's actually how you'd probably want to tackle a real-world bug in your code.

You can find instructions on how to run and work with the code in the README file of the repository. This file contains up-to-date documentation on everything you need to know about the code. Make sure to quickly read it before you start working with the code. (When you get started with the code of an open-source repository, reading the README file is the first thing you should do.)

A.1.2 A note on the code

The emphasis of the code I wrote wasn't to be the most performant and safest code possible. There are a lot of places in the code that could use better error handling, or where I could have done things in a more performant way by applying some optimizations. But I didn't, because I put the emphasis on writing code that's easy to understand, that's clean and concise. Code that you read and immediately understand what it does.

I pruned the code of all the unnecessary details that would've made it harder to understand, and left just the essence of the concept which I want to teach. I've gone to great lengths to simplify the code as much as I could, and I hope you'll find it easy to follow and make sense of.

So, just bear in mind that the code you'll find in the repository and the book has the purpose of teaching efficiently, not being production-ready.

A.1.3 Reporting issues in the code

As many tests as I wrote and as many times as I reviewed the code, I'm sure there are still bugs in it. Frontend frameworks are complex beasts, and it's hard to get everything right. If you find a bug in the code, please report it in the repository by opening a new issue.

To open a new issue, go to the issues tab of the repository:

https://github.com/angelsolaorbaiceta/fe-fwk-book/issues

Then, click on the *New issue* button. In the row that reads *Bug report*, click on the *Get started* button. Fill in the form with the details of the bug you found, and click on the *Submit new issue* button. You'll need to give enough information for me to easily reproduce and fix the bug. These are the sections you need to fill in:

- *Describe the bug*—describe the bug you found in a short and concise way, such that I can quickly understand what the problem is.
- *To reproduce*—describe the steps you took to reproduce the bug.
- *Expected behavior*—describe what you expected to happen when you followed the steps to reproduce the bug.
- *Screenshots*—if you can, and in the cases when it makes sense, add screenshots of the bug.
- *Context*—fill in the details of your operating system, the chapter of the book where the bug was found, and if the bug was reproduced in a browser, the browser name and version; if it was reproduced in Node JS, which version you used.
- *Additional context*—add any other information that you think might be relevant to the bug.

I know it takes time to file a bug report with these many details, but it's considered good etiquette in the open source community. It shows respect from your side towards the maintainers

of a project, who use their free time to create and maintain it for everyone to use free of charge. It's good that we get used to being respectful citizens of the open source community.

A.1.4 Fixing a bug yourself

If you find a bug in the code, and you know how to fix it, you can open a pull request with the fix. Even better than opening an issue is to offer a solution to it yourself—that's how open source projects work. You might also want to take a look at bugs that other people reported and try to fix them yourself. This is a great exercise to learn how to contribute to open source projects, and I'll be forever grateful if you do so.

If you don't know what GitHub pull requests are, I recommend you to read about them at https://docs.github.com/en/pull-requests. Pull requests are the way to contribute to open source projects on GitHub (and also how many software companies add changes to their codebase), so it's good to know how they work.

Moving on. Before you create your project, let's take a look at the technologies you'll use and how the project will be structured.

A.2 Note on the technologies used

There are heated discussions in the frontend ecosystem about what are the best tools. You'll hear things like "you should use Bun, because it's much faster than Node JS," or "Webpack is old now, you should start using Vite for all your projects." Some people argue over which bundler is the best, or which linter and transpiler you should be using. Something that I find especially harmful are the "top 10 reasons why you should stop using X"-kind of blog posts. Apart from being obvious clickbait, they don't usually help the frontend community, let alone junior developers that have a hard time understanding what set of tools they "should be using."

I once worked for a start-up that grew quickly but wasn't doing great. We had very few customers using our app—if any at all—and every time we added something in the code, we'd introduce new bugs. (Code quality wasn't a priority; speed was, and automated testing was nowhere to be found.) Surprisingly, we blamed it on the tools we were using. We were convinced that, when we migrated the code to the newest version of the framework we were using, we would get more customers and things would work great from then onwards. Yes, I know how ridiculous this sounds now. But we made it to "modernize" the tooling, and guess what? the code was still the same: a hard-to-maintain mess that would break if you stared at it for too long. Turns out that using more modern tools doesn't make your code better if the code is poorly written in the first place.

What do I want to say with this? That I believe your time is better used writing quality code than arguing about what tools will make your application successful. Well architected and modularized code with a great suite of automated tests that, apart from making sure the code

works and can be refactored safely, also serves as documentation, beats any tooling. That is not to say the tools don't matter, because they obviously do. Ask a carpenter if they can be productive using a rusty hammer or a blunt saw.

For this book, I've tried to choose tools that are mature and that most frontend developers might be familiar with. Choosing the newest, shiniest or trendiest tool wasn't my goal.

I want to teach you how frontend frameworks work, and the truth is, that most tools work perfectly fine for this purpose. The knowledge that I'll teach you in this book transcends the tools we choose to use. So, having said this, if you have a preference for a tool and some experience with it, feel free to use it instead of the ones I'll recommend here.

A.2.1 Package manager—npm

We'll use the *npm* package manager to create the project and run the scripts. If you're more comfortable with *yarn* or *pnpm*, you can use them instead. They work very similarly, so you shouldn't have any problems using your preferred one.

We'll use npm *workspaces*, which were introduced in version 7, so you want to make sure you have at least version 7 installed:

```
$ npm --version
8.19.2
```

Both yarn and pnpm also support workspaces, so you can use them as well. (In fact, they introduced workspaces before npm did.)

A.2.2 Bundler—Rollup and Webpack

To bundle the JavaScript code together into a single file, we'll use *Rollup*. Rollup is very popular among JavaScript libraries, and it's very simple to use. If you prefer Webpack, Parcel or Vite, you can use them instead. You'll have to make sure you configure them to output a single ESM file (as we'll see later).

Towards the end of the book, when you use your framework to build applications, you'll also use Webpack. In fact, you'll write a Webpack loader that'll transform the templates for your components into render functions.

In summary: you'll use Rollup to bundle your framework, and Webpack to bundle the applications you'll build with your framework.

A.2.3 Linter—ESLint

To lint the code, we'll use *ESLint*. It's a very popular linter, and it's very easy to configure. I'm a firm believer that static analysis tools are a must for any serious project where the quality of the code is important (as it always is the case).

ESLint will prevent us from having unused variables declared, imports that are not used, and many other things that can go wrong in our code. ESLint is super configurable, but most developers are happy with the default configuration: it's a good starting point. We'll use the default configuration for this book as well, but you can always change it to your liking. If there's a linting rule you deem important, you can add it to your configuration.

A.2.4 (Optional) Testing—Vitest

I won't be showing unit tests for the code which you'll write in this book to keep its size reasonable, but if you check the source code of the framework I wrote for the book, you'll see lots of them. (In fact, you can use them to better understand how the framework works. Tests are—when well written—a great source of documentation.) You might want to write tests yourself as well, to make sure the framework works as expected and you don't break it when you make new changes. Every serious project should have tests accompanying it and serving as a safety net as well as documentation.

I've worked a lot with *Jest*; it's been my go-to testing framework for a long time, but I recently started using *Vitest* and decided to stick with it as it's orders of magnitude faster. The API is very similar to Jest, so you won't have any problems if you do decide to use it as well. If you want to use Jest, that'll do just fine.

A.2.5 The language—JavaScript

Saying we'll use JavaScript might seem obvious, but if I was writing the framework for myself, I'd use TypeScript without any hesitation. TypeScript is fantastic for large projects: types tell you a lot about the code, and the compiler will help you catch bugs before you even run the code (how many times have you accessed a property that didn't exist in an object using JavaScript? Does `TypeError` sends shivers down your spine?). Non-typed languages are great for scripting, but for large projects, I'd recommend having a compiler as your companion.

So why am I using JavaScript for this book? Because the code tends to be shorter without types, and what I want to do here is teach you the principles of how frontend frameworks work, principles that apply equally well to both JavaScript and TypeScript. I prefer to use JavaScript because the code listings will be shorter and I can get to the point faster, and thus teach you more efficiently.

As with the previous tools, if you feel strongly about using TypeScript, you can use it instead of

JavaScript. You'll need to figure out the types yourself, but that's part of the fun, right? Also, don't forget to setup the compilation step in your build process.

A.3 Read the docs

Explaining how to configure the tools you'll use in detail, and how they work, is out of the scope of this book. I want to encourage you to go to their websites or repository pages and read the documentation. One great thing about frontend tools is that they tend to be extremely well documented. In fact, I'm convinced that they compete against each other to see which one has the best documentation.

If you're not familiar with any of the tools you'll be using, take some time to read the documentation. That'll save you a lot of time in the long run. I'm a firm believer that developers should strive to understand the tools they use, and not just use them blindly (that's what got me into understanding how frontend frameworks work in the first place—which explains why I'm writing this book).

One of the most important lessons I've learned over the years is that taking the time to read the documentation is a great investment of your time. Reading the docs before you start using a new tool or library saves you the time you'd spend trying to figure out how to do something that, somewhere in the documentation, someone has taken the time and care to explain in detail. The time that you end up spending trying to figure things out on your own, and searching StackOverflow for answers, is—in my personal experience—usually greater than the time you'd have spent should you read the documentation upfront.

Be a good developer—read the docs.

A.4 Structure of the project

Let's briefly go over the structure of the project where you'll write the code for your framework. Your framework will consist of three packages (NPM workspaces):

- *runtime*—the framework's runtime, the code that's executed in the browser and is in charge of rendering the views and handling the events. Basically, the framework itself.
- *compiler*—the compiler that transforms HTML templates into render functions.
- *loader*—the Webpack loader that uses the compiler to transform templates at build time.

The main package, and where you'll spend most of the time, is the *runtime* package. This package is the framework itself. The other two, *compiler* and *loader*, are tooling—dev dependencies in NPM parlance—that developers need at build time if they want to write templates instead of render functions. (This might sound confusing at the moment, but it'll eventually make sense.)

The folder structure of the project will be as follows:

```
- examples/
- packages/
  - compiler/
  - loader/
  - runtime/
```

Each package has its own *package.json* file, with its dependencies, and it's bundled separately. It's effectively three separate projects, but they are all part of the same repository. This project structure is very common these days, and it's called a *monorepo*.

The three packages will define the same scripts:

- *build*—builds the package, bundling all the JavaScript files into a single file, which is published to NPM.
- *test*—runs the automated tests in watch mode.
- *test:run*—runs the automated tests once.
- *lint*—runs the linter to detect issues in your code.
- *lint:fix*—runs the linter and automatically fixes the issues it can.
- *prepack*—a special life cycle script that runs before the package is published to NPM. It's used to make sure the package is built before being published.

A.5 Finding a name for your framework

Before you create the project or write any code, you need a name for your framework. Be creative! It needs to be a name that no one else is using in NPM (you will be publishing your framework to NPM), so you need to be original. If you're not sure what to call it, you can simply call it *<your name>-fe-fwk* (your name followed by *-fe-fwk*). You want to make sure the name is unique, so check if it's available on npmjs.com, by adding it to the URL:

www.npmjs.com/package/<your framework name>

If the URL displays the *404—not found* page, that means nobody is using that name for a Node JS package yet, so you're good to go; you can use that name.

I will use the *<fwk-name>* placeholder to refer to the name of your framework in the sections that follow. Whenever you see *<fwk-name>* in a command, you should replace it with the name you chose for your framework.

Let's now create the project. Remember that you have two options. If you want to configure things yourself, you want to skip the next section and jump to section A.7. If you want to use the CLI tool to get started quickly, read the next section.

A.6 Option A—Using the CLI tool

Using the CLI tool I created for the book is the fastest way to get started. It'll save you the time it takes to create and configure the project from scratch, so you can start writing code right away. You just need to open your terminal, move to the directory where you want the project to be created, and run the following command:

```
$ npx fe-fwk-cli init <fwk-name>
```

With *npx* you don't even need to install the CLI tool locally, it will be downloaded and executed automatically.

When the command finishes executing, it'll instruct you to `cd` in to the project directory and run `npm install` to install the dependencies:

```
$ cd <fwk-name>
$ npm install
```

That's it! You can now jump to the A.8 section to learn how to publish your framework to NPM.

A.7 Option B—Configuring the project from scratch

To create the project yourself, you first want to create a directory for it. Using the command line, you can do that by running the following command:

```
$ mkdir <fwk-name>
```

Then, you want to initialize an npm project in that directory:

```
$ cd <fwk-name>
$ npm init -y
```

This command will create a *package.json* file in the directory. There are a few edits you need to make to the file. You want to edit the `description` field to something like:

```
"description": "A project to learn how to write a frontend framework"
```

Then, you want to make this package private, so you don't accidentally publish it to NPM (it's the workspace packages you'll create in a minute that you'll publish to NPM, not the parent project itself):

```
"private": true
```

Finally, you want to add a `workspaces` field to the file, with an array of the directories where you'll be creating the three packages your project will consist of:

```
"workspaces": [
  "packages/runtime",
  "packages/compiler",
  "packages/loader"
]
```

Your *package.json* file should look similar to this:

```
{
  "name": "<fwk-name>",
  "version": "1.0.0",
  "description": "A project to learn how to write a frontend framework",
  "private": true,
  "workspaces": [
    "packages/runtime",
    "packages/compiler",
    "packages/loader"
  ]
}
```

You might have other fields, such as `author`, `license`, etc., but the ones in the previous snippet are the ones you need to make sure are there. Let's now create a directory in your project where you can add example applications to test your framework.

A.7.1 The examples folder

Throughout the book, you'll be improving your framework and adding new features to it. Each time you add a new feature, you'll want to test it by using it in example applications. Here, you'll configure a directory where you can add these applications, and a script to serve them locally.

Create an *examples* directory at the root of your project:

```
$ mkdir examples
```

While the examples folder remains empty, that is, before you write any example application, you might want to add a *.gitkeep* file to it, so that git picks up the directory and includes it in the repository. (Git doesn't track empty directories.) As soon as you put a file in the directory, you can remove the *.gitkeep* file, but keeping it doesn't hurt anyway.

To keep the *examples* directory tidy, you want to create a subdirectory for each chapter: *examples/ch02*, *examples/ch03*, etc. Each subdirectory will contain the example applications using the framework resulting from the chapter, which allows you to see the progress in how the framework becomes more and more powerful, and easier to use. You don't need to create the subdirectories now, you'll create them as you need them in the book.

Now you need a script to serve the example applications. Your applications will consist of an entry HTML file, which loads other files, such as JavaScript files, CSS files, and images. For the

browser to be able to load these files, you need to serve them from a web server. The `http-server` package is a very simple web server that you can use to serve the example applications. In the *package.json* file, add the following script:

```
"scripts": {
  "serve:examples": "npx http-server . -o ./examples/"
}
```

The project doesn't require the `http-server` package installed, as you're using `npx` to run it. The `-o` flag tells the server to open the browser and navigate to the specified directory, in the case of the previous command, the *examples* directory.

Great—Let's now create the three packages that will make up your framework code.

A.7.2 Creating the packages

As we've already discussed, your framework will consist of three packages: *runtime*, *compiler*, and *loader*. They all have the same dependencies and scripts, so, once you've created the first of them, you can copy and paste it, making sure to change the name of the folder and the name of the package in the *package.json* file.

Before you create the packages, you need to create a directory where you'll put them, the *packages* directory you specified in the `workspaces` field of the *package.json* file. Inside your project directory, create a *packages* directory:

```
$ mkdir packages
```

Let's start with the *runtime* package.

THE RUNTIME PACKAGE

First, make sure you `cd` into the *packages* folder:

```
$ cd packages
```

Then create the folder for the *runtime* package and `cd` into it:

```
$ mkdir runtime
$ cd runtime
```

Next, initialize an NPM project in the *runtime* folder:

```
$ npm init -y
```

Open the *package.json* file that was created for you and make sure the following fields have the right values (you can leave the other fields as they are):

```
{
  "name": "<fwk-name>",
  "version": "1.0.0",
  "main": "dist/<fwk-name>.js",
  "files": [
    "dist/<fwk-name>.js"
  ]
}
```

Remember to replace *<fwk-name>* with the name of your framework. The `main` field specifies the entry point of the package, which is the file that will be loaded when you `import` the package. This means that, when you import code from this package like so:

```
import { something } from '<fwk-name>'
```

JavaScript resolves the path to the file specified in the `main` field. You've told NPM that the file is the *dist/<fwk-name>.js* file, which is the bundled file containing all the code for the *runtime* package. This file will be generated by Rollup, by running the `build` script you'll add to the *package.json* file in the next section.

The `files` field specifies the files that will be included in the package when you publish it to the NPM repository. The only file that you want to include is the bundled file, so you've specified that in the `files` field. Files like the README, the LICENSE, and the *package.json* file are automatically included in the package, so you don't need to include them here.

Let's now add Rollup to bundle the framework code.

INSTALLING AND CONFIGURING ROLLUP

Rollup is the bundler that you'll use to bundle your framework code. It's very simple to configure and use.

First, install the `rollup` package:

```
$ npm install --save-dev rollup
```

You also want to install two plugins for Rollup:

- `rollup-plugin-cleanup`: to remove comments from the generated bundle.
- `rollup-plugin-filesize`: to display the size of the generated bundle.

Install them with the following command:

```
$ npm install --save-dev rollup-plugin-cleanup rollup-plugin-filesize
```

Now, you need to configure Rollup. Create a *rollup.config.mjs* file (note the `.mjs` extension, to tell Node JS this file should be treated as an ES module and thus can use the `import` syntax) in the *runtime* folder and add the following code:

```
import cleanup from 'rollup-plugin-cleanup'
import filesize from 'rollup-plugin-filesize'

export default {
  input: 'src/index.js',   ❶
  plugins: [cleanup()],   ❷
  output: [
    {
      file: 'dist/<fwk-name>.js',   ❸
      format: 'esm',   ❹
      plugins: [filesize()],   ❺
    },
  ],
}
```

❶ The entry point of the framework code.

❷ Remove comments from the generated bundle.

❸ The name of the generated bundle.

❹ Format the bundle as an ES module.

❺ Display the size of the generated bundle.

The configuration, explained in plain english, means the following:

- The entry point of the framework code is the *src/index.js* file: starting from this file, Rollup will bundle all the code that is imported from it.
- The comments in the source code should be removed from the generated bundle (they occupy space and are not needed for the code to execute). This is what the `plugin-rollup-cleanup` plugin does.
- The generated bundle should be an ES module (using `import/export` syntax, supported by all major browsers) that is saved in the *dist* folder, as *<fwk-name>*.js.
- We want the size of the generated bundle to be displayed in the terminal to keep an eye on it and make sure it doesn't grow too much. This is what the `plugin-rollup-filesize` plugin does.

Now add a script to the *package.json* file to run Rollup and bundle all the code, and another one to run it automatically before publishing the package:

```
"scripts": {
  "prepack": "npm run build",
  "build": "rollup -c"
}
```

The `prepack` script is a special script that is run automatically by NPM before publishing the package, which you do by running the `npm publish` command (more on this later). This makes sure that, whenever you publish a new version of the package, the bundle is generated. The `prepack` script simply runs the `build` script, which in turn runs Rollup.

To run Rollup, you simply call the `rollup` command and pass the `-c` flag to tell it to use the *rollup.config.mjs* file as configuration. (If you don't pass a specific file to the `-c` flag, Rollup will

look for a *rollup.config.js* or *rollup.config.mjs* file.)

Before you test the `build` command, you need to create the *src* folder and the *src/index.js* file. You can do that with the following commands:

```
$ mkdir src
$ touch src/index.js
```

(In windows shell *touch* will not work use *call* > *filename* instead.)

Inside the *src/index.js* file, add the following code:

```
console.log('This will soon be a frontend framework!')
```

You can now run the `build` command to bundle the code:

```
$ npm run build
```

This command processes all the files imported from the *src/index.js* file (none at the moment) and bundles them into the *dist* folder. The output in your terminal should look similar to the following:

```
src/index.js  dist/<fwk-name>.js...


   Destination: dist/<fwk-name>.js
   Bundle Size:  56 B
   Minified Size:  55 B
   Gzipped Size:  73 B


created dist/<fwk-name>.js in 62ms
```

Recall that, instead of *<fwk-name>*, you should use the name of your framework. That rectangle in the middle of the output is the `rollup-plugin-filesize` plugin in action. It's reporting the size of the generated bundle (56 bytes in this case), and also the size it'd have if the file was minified and gzipped. We won't be minifying the code for this book, as the framework is going to be small anyway, but for a production-ready framework, you should definitely do it. A minified JavaScript can be loaded faster by the browser, and thus improve the TTI (Time to Interactive) of the web application using it.

A new file, *dist/<fwk-name>.js*, has been created in the *dist* folder. If you open it, you'll see it just contains the `console.log()` statement you added to the *src/index.js* file.

Great!--Let's now install and configure ESLint.

INSTALLING AND CONFIGURING ESLINT

ESLint is a linter that will help you write better code. It analyzes the code you write and reports any errors or potential problems.

To install it, run the following command:

```
$ npm install --save-dev eslint
```

You'll use the ESLint recommended configuration, which is a set of rules that ESLint will enforce in your code. Create a *.eslintrc.js* file with the following content:

```
module.exports = {
  env: {
    browser: true,
    es2021: true,
  },
  extends: 'eslint:recommended',
  overrides: [],
  parserOptions: {
    ecmaVersion: 'latest',
    sourceType: 'module',
  },
  rules: {},
}
```

And lastly, add the following two scripts to the *package.json* file:

```
"scripts": {
  "prepack": "npm run build",
  "build": "rollup -c",
  "lint": "eslint src",
  "lint:fix": "eslint src --fix"
}
```

You can run the `lint` script to check the code for errors, and the `lint:fix` script to automatically fix some of them, those that ESLint knows the fix for. I won't be showing the output of the `lint` script in the book, but you can run it yourself to see what it reports as you write your code.

Let's now install Vitest to run the automated tests.

INSTALLING VITEST (OPTIONAL)

As I've mentioned, I used a lot of tests while developing the code for this book, but I won't be showing them in the book. You can take a look at them in the source code of the framework and try to write your own as you follow along. Having tests in your code will help you make sure things work as expected as you move forward with the development of your framework.

We'll use Vitest to run the tests. To install Vitest, run the following command:

```
$ npm install --save-dev vitest
```

Tests can run in different environments, such as Node JS, JSDOM, or a real browser. Because we will use the Document API to create DOM elements, we'll use JSDOM as the environment. (If you want to know more about JSDOM, please refer to their repository: https://github.com/jsdom/jsdom.)

To install JSDOM, run the following command:

```
$ npm install --save-dev jsdom
```

With Vitest and JSDOM installed, you can now create the *vitest.config.js* file with the following content:

```
import { defineConfig } from 'vitest/config'

export default defineConfig({
  test: {
    reporters: 'verbose',
    environment: 'jsdom',
  },
})
```

This configuration tells Vitest to use the JSDOM environment and to use the *verbose* reporter, which outputs a very descriptive report of the tests.

You should place your test files inside the *src/__tests__* folder, and name them **.test.js* for Vitest to find them. Go ahead and create the *src/__tests__* folder:

```
$ mkdir src/__tests__
```

Inside, you can create a *sample.test.js* file with the following content:

```
import { expect, test } from 'vitest'

test('sample test', () => {
  expect(1).toBe(1)
})
```

Now, add the following two scripts to the *package.json* file:

```
"scripts": {
  "prepack": "npm run build",
  "build": "rollup -c",
  "lint": "eslint src",
  "lint:fix": "eslint src --fix",
  "test": "vitest",
  "test:run": "vitest run"
}
```

The `test` script runs the tests in watch mode, and the `test:run` script runs the tests once and exits. Tests in watch mode are handy when you're working with TDD (Test Driven Development), as they run again every time you make changes in the test file or the code being tested.

Give a try to the tests by running the following command:

```
$ npm run test:run
```

You should see the following output:

```
 src/__tests__/sample.test.js (1)
   sample test

Test Files  1 passed (1)
     Tests  1 passed (1)
  Start at  15:50:11
  Duration  1.47s (transform 436ms, setup 1ms, collect 20ms, tests 3ms)
```

You can run individual tests passing the name or path of the test file as an argument to the `test:run` and `test` scripts. All the tests matching the name or path will be run. For example, to run the *sample.test.js* test, you can run the following command:

```
$ npm run test:run sample
```

This will run only the *sample.test.js* test and produce the following output:

```
 src/__tests__/sample.test.js (1)
   sample test

Test Files  1 passed (1)
     Tests  1 passed (1)
  Start at  15:55:42
  Duration  1.28s (transform 429ms, setup 0ms, collect 32ms, tests 3ms)
```

Let's now create the *compiler* and *loader* packages.

THE COMPILER PACKAGE

The *compiler* package will use the exact same structure and configuration as the *runtime* package. So, you can copy the *runtime* folder and rename it to *compiler* using the following command (make sure you're in the *packages* folder):

```
$ cp -r runtime compiler
```

This copies everything, including the *node_modules* folder. The only thing that you need to change is the *package.json*'s *name* field, like so:

```
"name": "<fwk-name>-compiler",
```

That is, the name of your framework followed by the *-compiler* suffix. That's it.

THE LOADER PACKAGE

You can also copy the *runtime* folder and rename it to *loader* using the following command:

```
$ cp -r runtime loader
```

And make sure that you change the *package.json*'s *name* field to:

```
"name": "<fwk-name>-loader",
```

One last thing you want to do for the *package.lock* file to be correctly generated, including the dependencies of the *compiler* and *loader* packages, is to `cd` into the root folder of the *runtime* package and run the following command:

```
$ npm install
```

Done! You're all set to start developing your framework.

A.8 Publishing your framework to NPM

As exciting as it is to develop your own framework, it's even more exciting to share it with the world. NPM allows us to ship our package with just one simple command:

```
$ npm publish
```

But before you can do that, you need to create an account on NPM and log in to it from the command line. Let's do that now. If you don't plan to publish your framework, you can skip this section.

A.8.1 Creating an NPM account

To create an NPM account, go to https://www.npmjs.com/signup and fill out the form. It's that simple, and it's free.

A.8.2 Logging in to NPM

To log in to NPM in your terminal, run the following command:

```
$ npm login
```

and follow the prompts. To make sure you're logged in, run the following command:

```
$ npm whoami
```

You should see your username printed in the terminal.

A.8.3 Publishing your framework

To publish your framework, you need to make sure your terminal is in the right directory: inside *packages/runtime*. (Remember that the *runtime* package is the code for the framework.) Then, just run the following command:

```
$ npm publish
```

You might be wondering what gets published to NPM. There are some files in your project that always get published, and these are the *package.json* file, the *README.md* file, and the *LICENSE* file. Apart from these, you can specify which files to publish in the *files* field of the *package.json* file. If you recall from a previous section, the *files* field in the *package.json* file of the *runtime* package looks like this:

```
"files": [
  "dist/<fwk-name>.js"
],
```

So, you're only publishing the *dist/<fwk-name>.js* file, the bundled version of your framework. The source files inside the *src/* folder are not published.

The package is published with the version specified in the *package.json* file's *version* field. Bear in mind that you can't publish a package with the same version twice. Throughout the book, we'll increment the version number every time we publish a new version of the framework.

A.9 Using a CDN to import the framework

Once you've published your framework to NPM, you can create a Node JS project and install it as a dependency:

```
$ npm install <fwk-name>
```

This is great if you plan to set up an NPM project with a bundler (such as Rollup or Webpack) configured to bundle your application and the framework together. This is what you typically do when you're building a production application with a frontend framework. But for small projects or quick experiments that use only a handful of files—as those you'll work on in this book—it's simpler to import the framework directly from the *dist/* directory in your project, or from a *Content Delivery Network* (CDN).

One free CDN that you can use is unpkg.com. Everything that's published to NPM is also available on unpkg.com, so once you've published your framework to NPM, you can import it from there, like so:

```
import { createApp, h } from 'https://unpkg.com/<fwk-name>'
```

In fact, if you browse to https://unpkg.com/fwk-name, you'll see the *dist/<fwk-name>.js* file you published in NPM. This is what the CDN serves to your browser when you import the framework from there. If you don't specify a version, it'll serve the latest version of the package. If you want to use a specific version of your framework, you can specify it in the URL, like so:

```
import { createApp, h } from 'https://unpkg.com/<fwk-name>@1.0.0'
```

I recommend you to use unpkg using the versioned URL, so that you don't have to worry about

breaking changes in the framework that might break your examples as you publish new versions of it. If you import the framework directly from the *dist/* folder in your project, every time you bundle a new version that's not backwards compatible, your example applications will break. You could overcome this by instructing Rollup to include the framework version in the bundled file name, but I'll be using unpkg in this book.

You're all set! Time to start developing your framework.