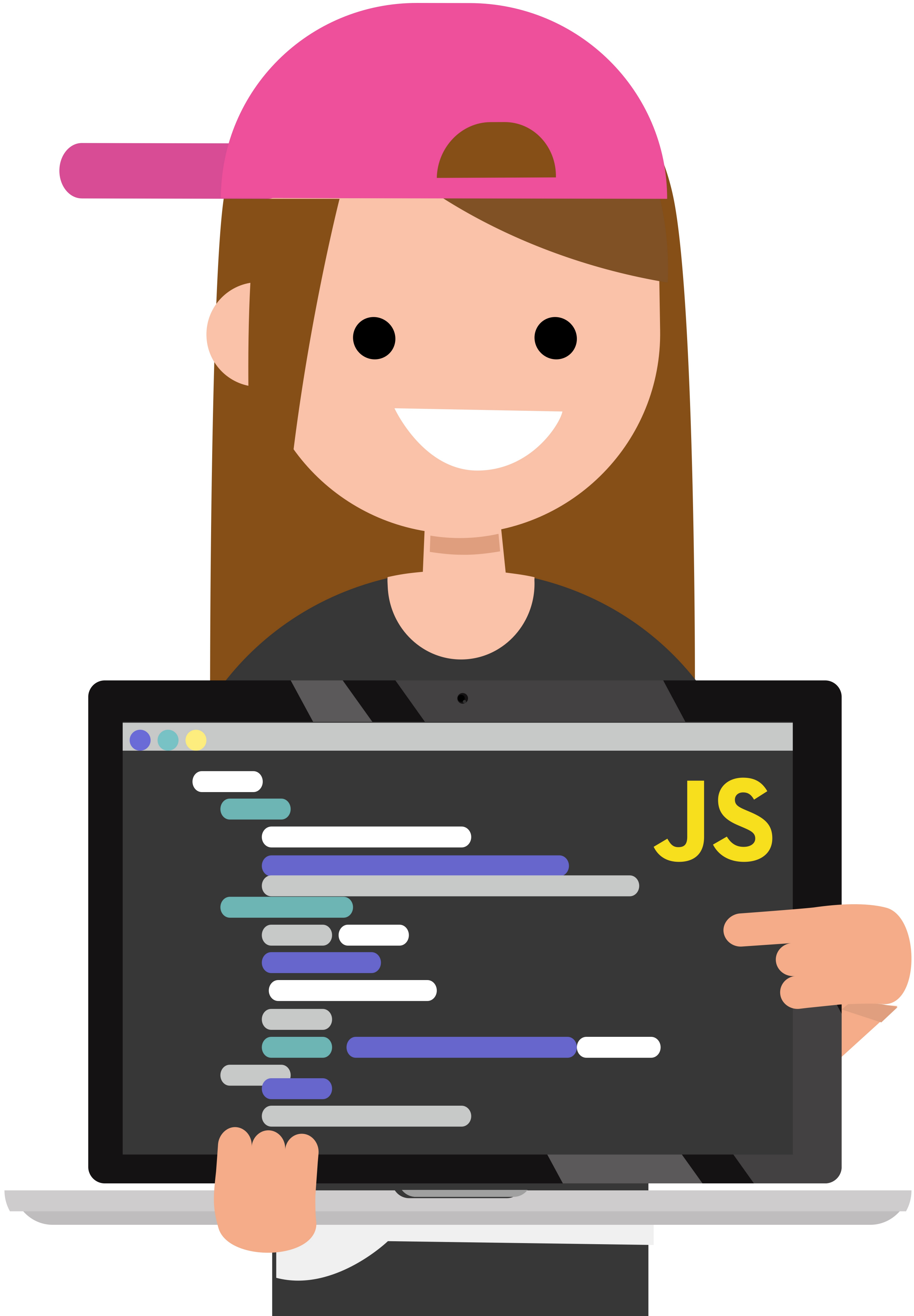
Learning

Patterns

By Lydia Hallie and Addy Osmani

ABOUT



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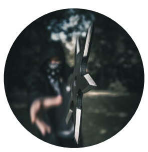

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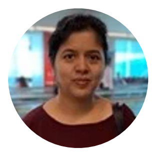

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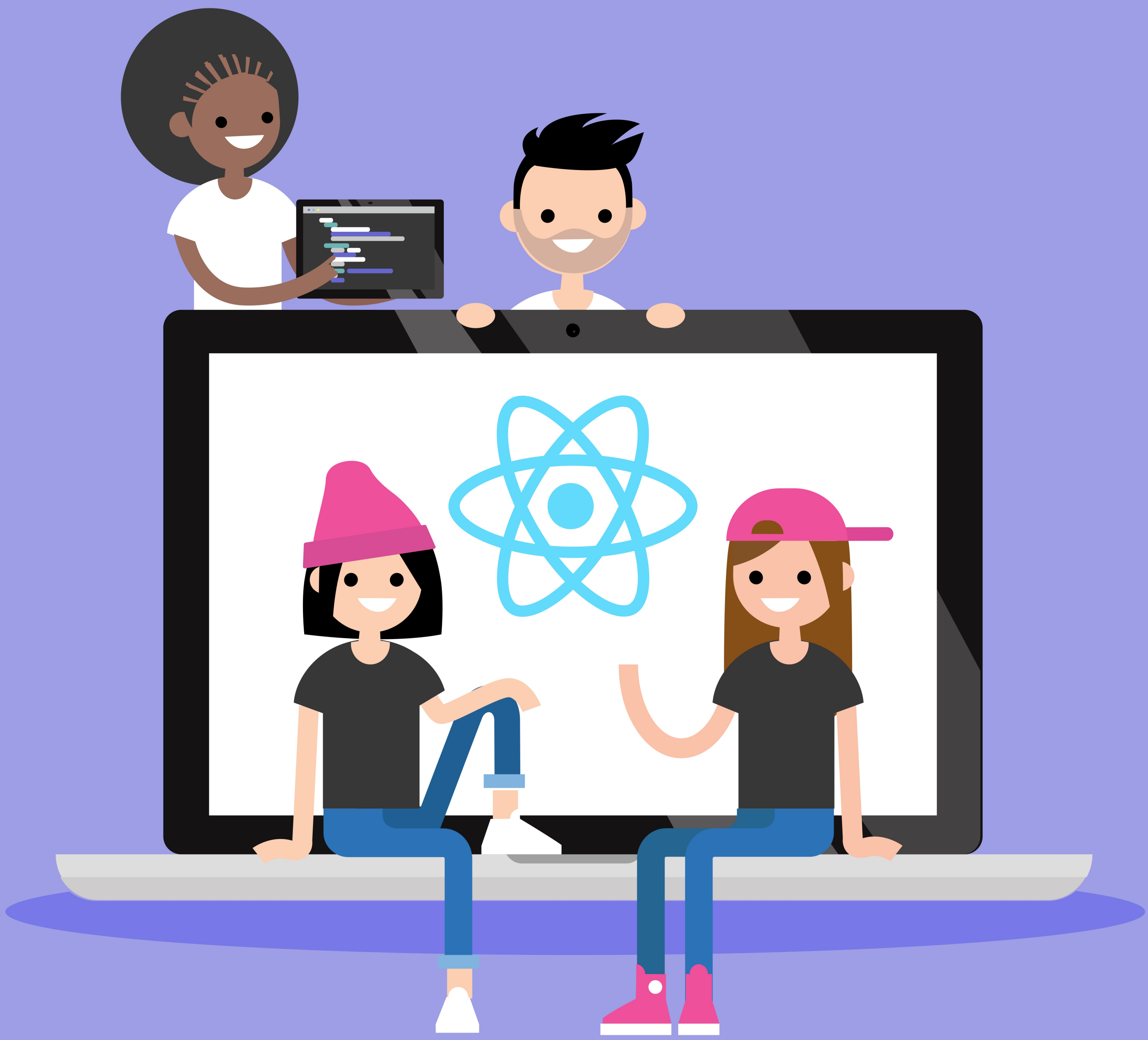
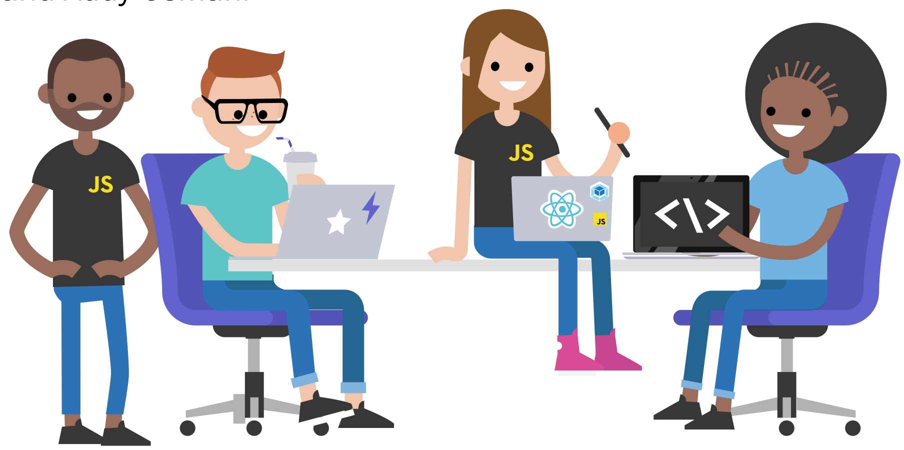


DESIGN PATTERNS

With Lydia Hallie

and Addy Osmani



INTRODUCTION

Design patterns are a fundamental part of software development, as they provide typical solutions to commonly recurring problems in software design. Rather than providing specific pieces of software, design patterns are merely concepts that can be used to handle recurring themes in an optimized way.

Over the past couple of years, the web development ecosystem has changed rapidly. Whereas some well-known design patterns may simply not be as valuable as they used to be, others have evolved to solve modern problems with the latest technologies.

Facebook's JavaScript library React has gained massive traction in the past 5 years, and is currently the most frequently downloaded framework on NPM compared to competing JavaScript libraries such as Angular, Vue, Ember and Svelte. Due to the popularity of React, design patterns have been modified, optimized, and new ones have been created in order to provide value in the current modern web development ecosystem. The latest version of React introduced a new feature called Hooks, which plays a very important role in your application design and can replace many traditional design patterns.

Modern web development involves lots of different kinds of patterns. This project covers the implementation, benefits and pitfalls of common design patterns using ES2015+, React-specific design patterns and their possible modification and implementation using React Hooks, and many more patterns and optimizations that can help improve your modern web app!

Overview of React.js

A UI library for building reusable user interface components

Over the years, there has been an increased demand for straight-forward ways to **compose** user-interfaces using JavaScript. React, also referred to as React.js, is an open-source JavaScript library designed by Facebook, used for building user interfaces or UI components.

React is of course not the only UI library out there. Preact, Vue, Angular, Svelte, Lit and many others are also great for composing interfaces from reusable elements. Given React's popularity, it's worth walking through how it works given we will be using it to walk through some of the design, rendering and performance patterns in this guide.

When front-end developers talk about code, it's most often in the context of designing interfaces for the web. And the way we think of interface composition is in elements, like buttons, lists, navigation, and the likes. React provides an optimized and simplified way of expressing interfaces in these elements. It also helps build complex and tricky interfaces by organizing your interface into three key concepts— *components, props,* and *state.*

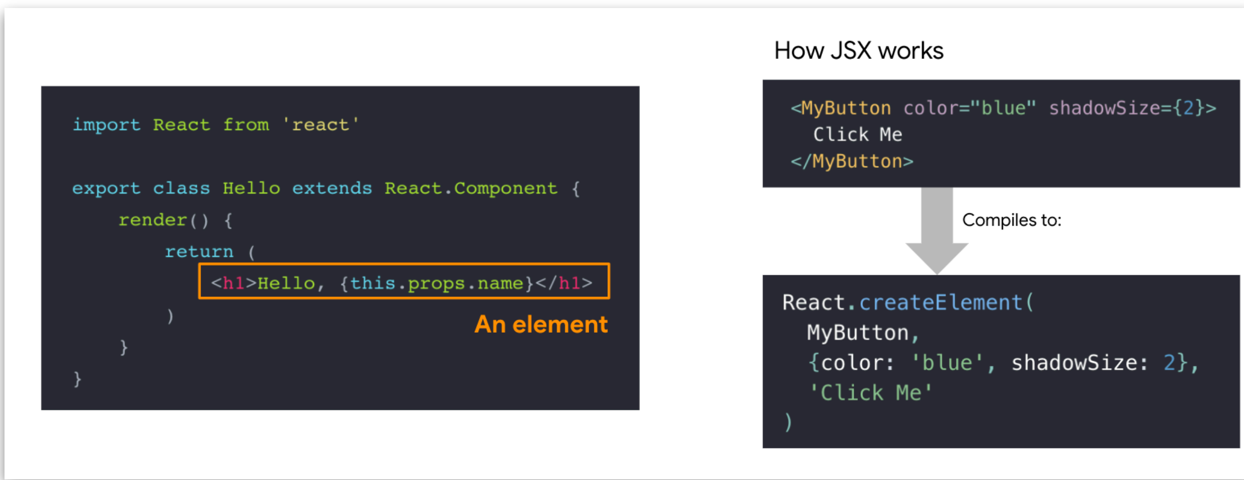
Because React is composition-focused, it can, perfectly map to the elements of your design system. So, in essence, designing for React actually rewards you for thinking in a modular way. It allows you to design individual components before putting together a page or view, so you fully understand each component's scope and purpose—a process referred to as *componentization*.

Terminology we will use:

- **React / React.js / ReactJS** - React library, created by Facebook in 2013
- **ReactDOM** - The package for DOM and server rendering
- **JSX** - Syntax extension to JavaScript
- **Redux** - Centralized state container
- **Hooks** - A new way to use state and other React features without writing a class
- **React Native** - The library to develop cross-platform native apps with Javascript
- **Webpack** - JavaScript module bundler, popular in React community.
- **CRA (Create React App)** - A CLI tool to create a scaffolding React app for bootstrapping a project.
- **Next.js** - A React framework with many best-in-class features including SSR, Code-splitting, optimized for performance, etc.

Rendering with JSX

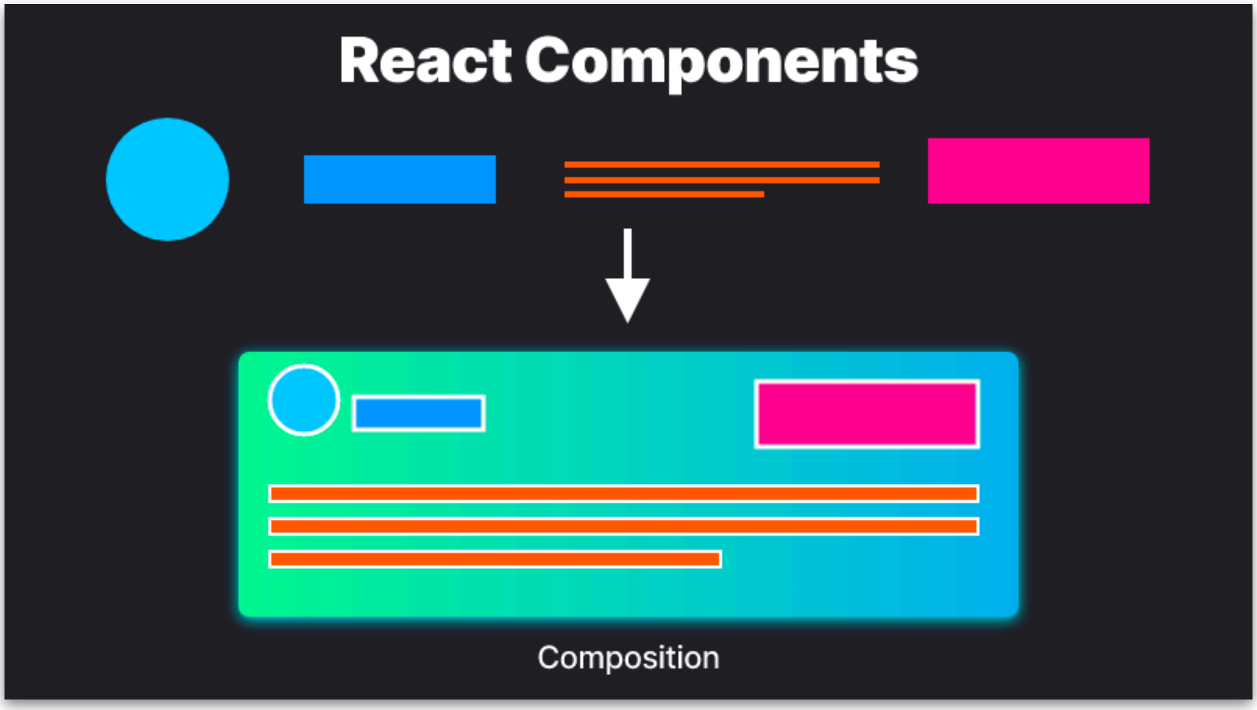
We will be using JSX in a number of our examples. JSX is an extension to JavaScript which embeds template HTML in JS using XML-like syntax. It is meant to be transformed into valid JavaScript, though the semantics of that transformation are implementation-specific. JSX rose to popularity with the React library, but has since seen other implementations as well.



Components, Props, and State

Components, props, and state are the three key concepts in React. Virtually everything you're going to see or do in React can be classified into at least one of these key concepts, and here's a quick look at these key concepts:

Components



Components are the building blocks of any React app. They are like JavaScript functions that accept arbitrary input (*Props*) and return React elements describing what should be displayed on the screen.

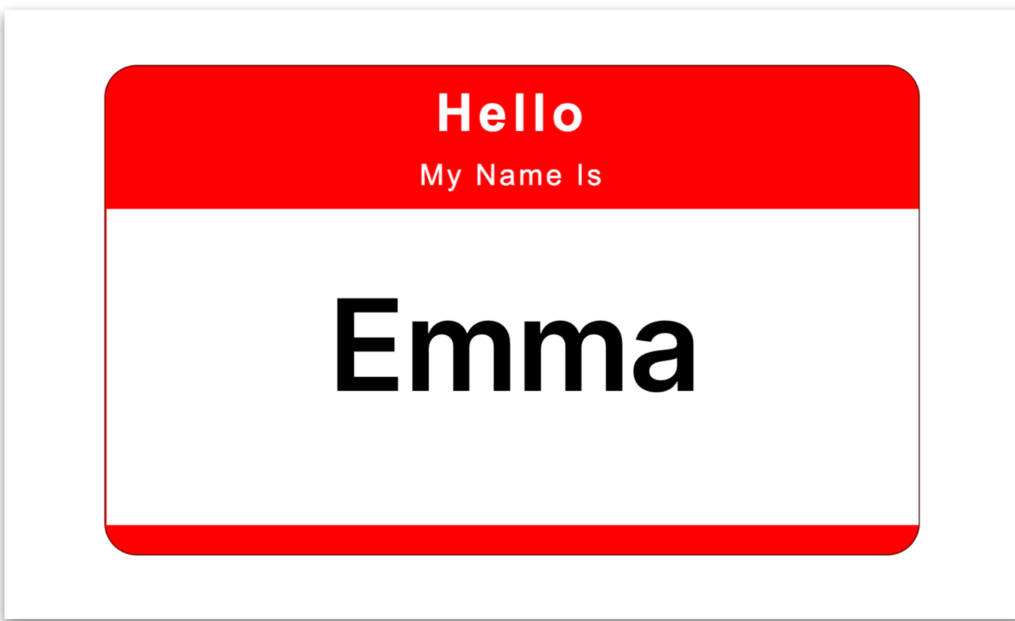
The first thing to understand is that everything on screen in a React app is part of a component. Essentially, a React app is just components within components within components. So developers don't build pages in React; they build components.

Components let you split your UI into independent, reusable pieces. If you're used to designing pages, thinking in this modular way might seem like a big change. But if you use a design system or style guide? Then this might not be as big of a paradigm shift as it seems.

The most direct way to define a component is to write a JavaScript function.

```
function Badge(props) {
  return <h1>Hello, my name is {props.name}</h1>;
}
```

This function is a valid React component because it accepts a single prop (*which stands for properties*) object argument with data and returns a React element. Such components are called "*function components*" because they are literally JavaScript functions.

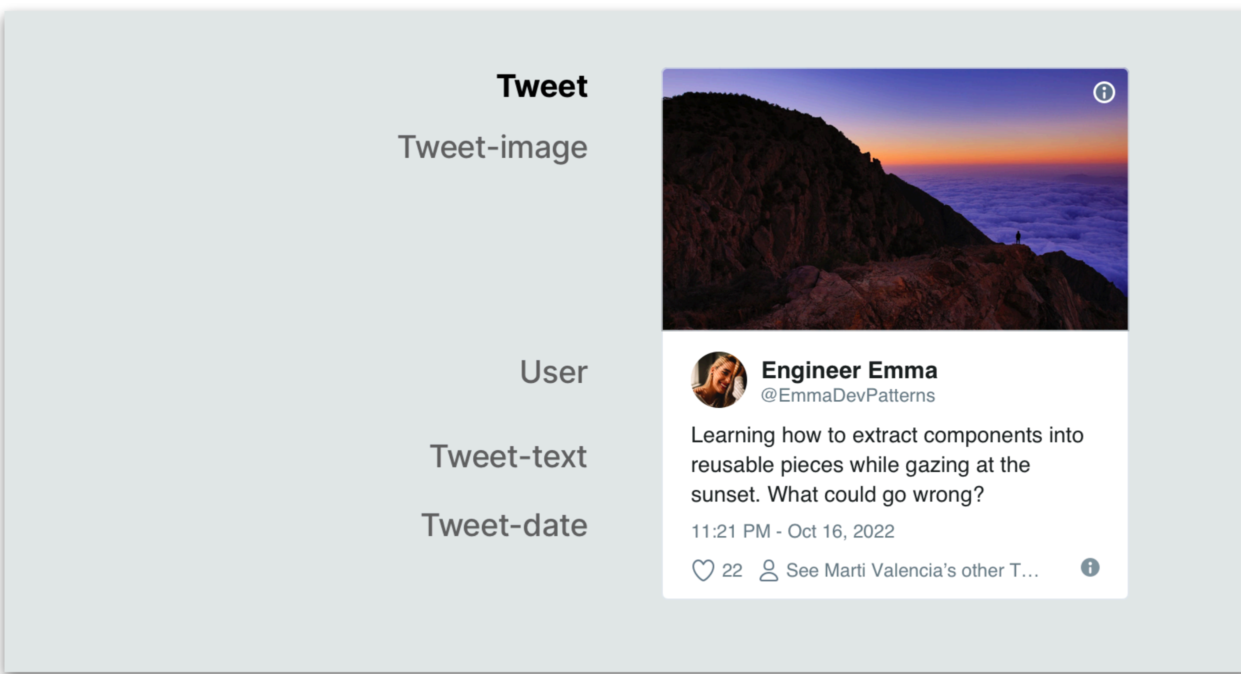


Aside from function components, another type of component are "*class components*." A class component is different from a function component in that it is defined by an ES6 class, as shown below:

```
class Badge extends React.Component {
  render() {
    return <h1>Hello, my name is {this.props.name}</h1>;
  }
}
```

Extracting components

To illustrate the facts that components can be split into smaller components, consider the following `Tweet` component:



Which can be implemented as follows:

```
function Tweet(props) {
  return (
    <div className="Tweet">
      <div className="User">
        <img className="Avatar"
          src={props.author.avatarUrl}
          alt={props.author.name}
        />
        <div className="User-name">
          {props.author.name}
        </div>
      </div>
      <div className="Tweet-text">
        {props.text}
      </div>
      <img className="Tweet-image"
          src={props.image.imageUrl}
          alt={props.image.description}
        />
      <div className="Tweet-date">
        {formatDate(props.date)}
      </div>
    </div>
  );
}
```

This component can be a bit difficult to manipulate because of how clustered it is, and reusing individual parts of it would also prove difficult. But, we can still extract a few components from it.

The first thing we will do is extract *Avatar*:

```
function Avatar(props) {
  return (
    <img className="Avatar"
      src={props.user.avatarUrl}
      alt={props.user.name}
    />
  );
}
```

This component can be a bit difficult to manipulate because of how clustered it is, and reusing individual parts of it would also prove difficult. But, we can still extract a few components from it.

The first thing we will do is extract *Avatar*:

```
function Tweet(props) {
  return (
    <div className="Tweet">
      <div className="User">
        <Avatar user={props.author} />
        <div className="User-name">
          {props.author.name}
        </div>
      </div>
      <div className="Tweet-text">
        {props.text}
      </div>
      <img className="Tweet-image"
          src={props.image.imageUrl}
          alt={props.image.description}
        />
      <div className="Tweet-date">
        {formatDate(props.date)}
      </div>
    </div>
  );
}
```

Avatar doesn't need to know that it is being rendered inside a `Comment`. This is why we have given its prop a more generic name: *user* rather than *author*.

```
function User(props) {
  return (
    <div className="User">
      <Avatar user={props.user} />
      <div className="User-name">
        {props.user.name}
      </div>
    </div>
  );
}
```

Now we will simplify the comment a little:

The next thing we will do is to a `User` component that renders an_ Avatar _next to the user's name:

```
function Tweet(props) {
  return (
    <div className="Tweet">
      <User user={props.author} />
      <div className="Tweet-text">
        {props.text}
      </div>
      <img className="Tweet-image"
          src={props.image.imageUrl}
          alt={props.image.description}
        />
      <div className="Tweet-date">
        {formatDate(props.date)}
      </div>
    </div>
  );
}
```

Extracting components seems like a tedious job, but having reusable components makes things easier when coding for larger apps. A good criterion to consider when simplifying components is this: if a part of your UI is used several times (*Button, Panel, Avatar*), or is complex enough on its own (*App, FeedStory, Comment*), it is a good candidate to be extracted to a separate component.

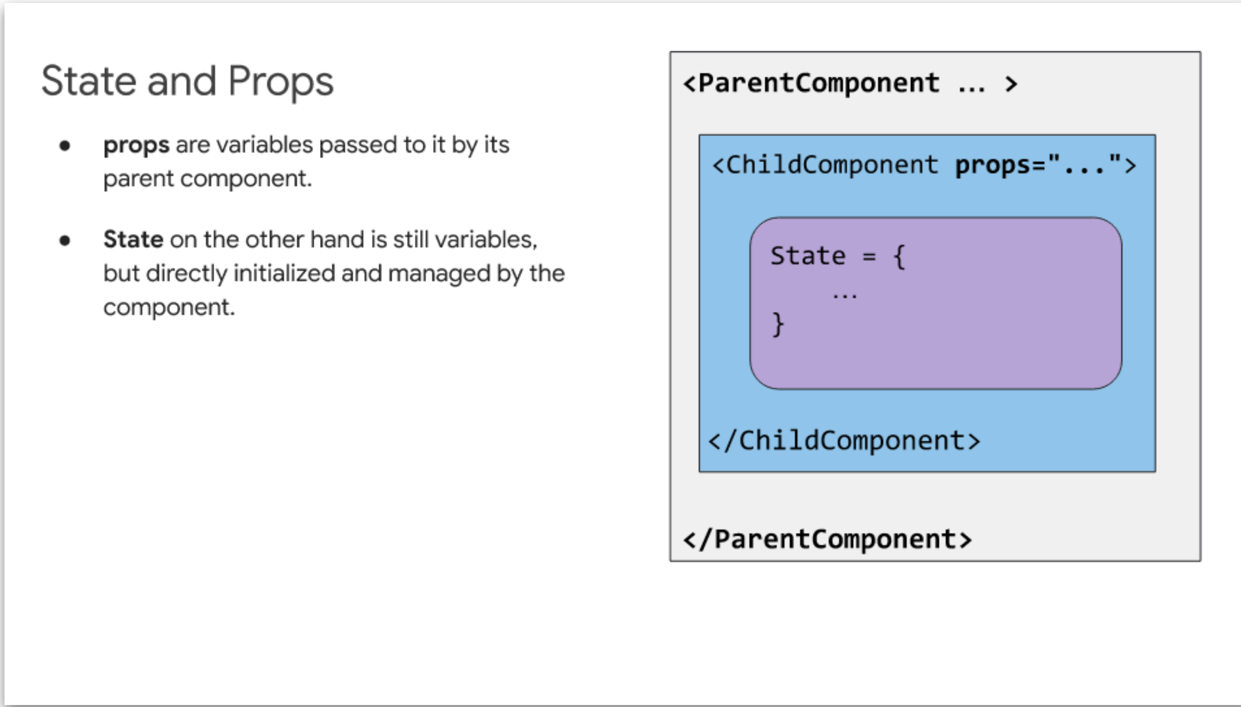
Props

Props are a short form for properties, and they simply refer to the internal data of a component in React. They are written inside component calls and are passed into components. They also use the same syntax as HTML attributes, e.g._ `prop="value"`. Two things that are worth remembering about props; Firstly, we determine the value of a prop and use it as part of the blueprint before the component is built. Secondly, the value of a prop will never change, i.e. props are read-only once they are passed into components.

The way you access a prop is by referencing it via the "this.props" property that every component has access to.

State

State is an object that holds some information that may change over the lifetime of the component. Meaning it is just the current snapshot of data stored in a component's Props. The data can change over time, so techniques to manage the way that data changes become necessary to ensure the component looks the way engineers want it to, at just the right time — this is called *State management.*



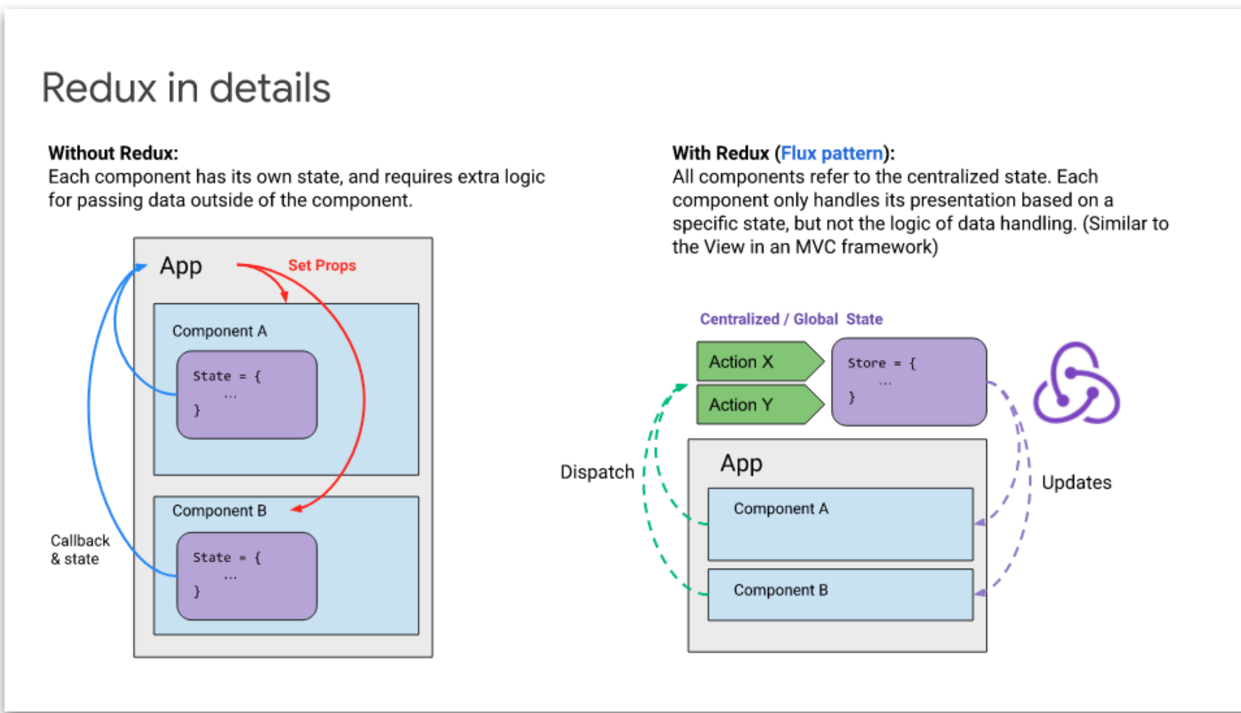
It's almost impossible to read one paragraph about React without coming across the idea of state-management. Developers love expounding upon this topic, but at its core, state management isn't really as complex as it sounds.

In React, state can also be tracked globally, and data can be shared between components as needed. Essentially, this means that in React apps, loading data in new places is not as expensive as it is with other technologies. React apps are smarter about which data they save and load, and when. This opens up opportunities to make interfaces that use data in new ways.

Think of React components like micro-applications with their own data, logic, and presentation. Each component should have a single purpose. As an engineer, you get to decide that purpose and have complete control over how each component behaves and what data is used. You're no longer limited by the data on the rest of the page. In your design, you can take advantage of this in all kinds of ways. There are opportunities to present additional data that can improve the user experience or make areas within the design more contextual.

How to add State in React

When designing, Including state is a task that you should save for last. It is much better to design everything as stateless as possible, using props and events. This makes components easier to maintain, test, and understand. Adding states should be done through either state containers such as Redux and MobX, or a container/wrapper component. Redux is a popular state management system for other reactive frameworks. It implements a centralized state machine driven by actions.



In the example below, the place for the state could be *LoginContainer* itself. Let's use React Hooks (this will be discussed in the next section) for this:

```
const LoginContainer = () => {
  const [username, setUsername] = useState("");
  const [password, setPassword] = useState("");

  const login = async event => {
    event.preventDefault();
    const response = await fetch("/api", {
      method: "POST",
      body: JSON.stringify({
        username,
        password,
      }),
    });
    // Here we could check response.status to login or show error
  };

  return (
    <LoginForm onSubmit={login}>
      <FormInput
        name="username"
        title="Username"
        onChange={event => setUsername(event.currentTarget.value)}
        value={username}
      />
      <FormPasswordInput
        name="password"
        title="Password"
        onChange={event => setPassword(event.currentTarget.value)}
        value={password}
      />
      <SubmitButton>Login</SubmitButton>
    </LoginForm>
  );
};
```

For further examples such as the above, see Thinking in React 2020.

Props vs State

Props and state can sometimes be confused with each other because of how similar they are. Here are some key differences between them:

Props	**State**
The data remains unchanged from component to component.	Data is the current snapshot of data stored in a component's Props. It changes over the lifecycle of the component.
The data is read-only	The data can be asynchronous
The data in props cannot be modified	The data in state can be modified using *this.setState*
Props are what is passed on to the component	State is managed within the component

Other Concepts in React

Components, props, and state are the three key concepts for everything you'll be doing in react. But there are also other concepts to learn about:

Lifecycle

Every react component goes through three stages; mounting, rendering, and dismounting. The series of events that occur during these three stages can be referred to as the component's lifecycle. While these events are partially related to the component's state (its internal data), the lifecycle is a bit different. React has internal code that loads and unloads components as needed, and a component can exist in several stages of use within that internal code.

There are a lot of lifecycle methods, but the most common ones are:

`render()` This method is the only required method within a class component in React and is the most used. As the name suggests, it handles the rendering of your component to the UI, and it happens during the mounting and rendering of your component.

When the component is created or removed:

- `componentDidMount()` runs after the component output has been rendered to the DOM.

- `componentWillUnmount()` is invoked immediately before a component is unmounted and destroyed

When the props or states get updated:

- `shouldComponentUpdate()` is invoked before rendering when new props or state are being received.

- `componentDidUpdate()` is invoked immediately after updating occurs. This method is not called for the initial render.

Higher-order component(HOC)

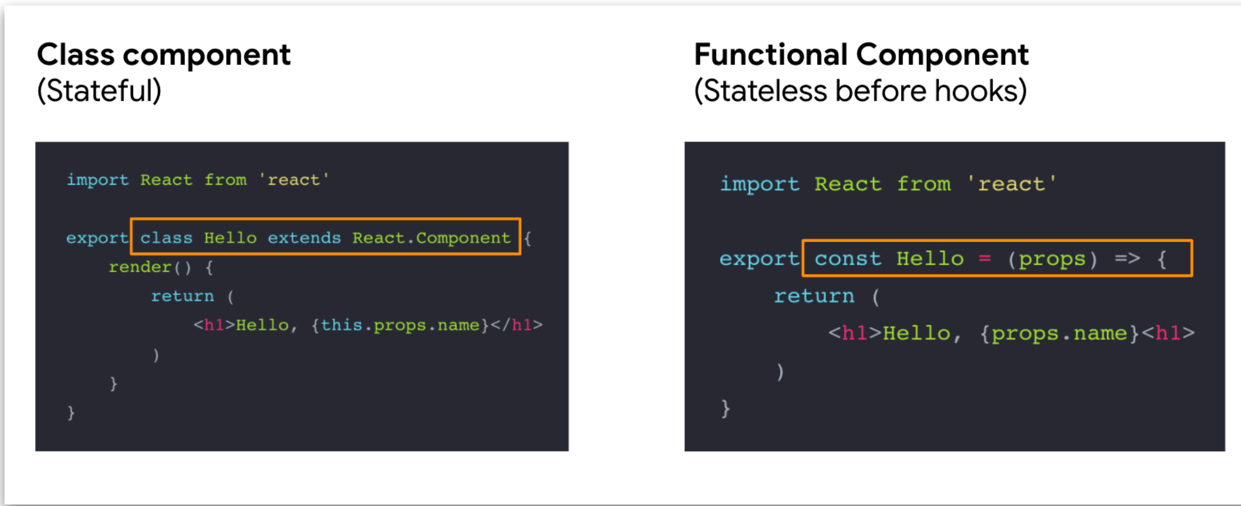
Higher-order components (HOC) are an advanced technique in React for reusing component logic. Meaning a higher-order component is a function that takes a component and returns a new component. They are patterns that emerge from React's compositional nature. While a component transforms props into UI, a higher-order component transforms a component into another component, and they tend to be popular in third-party libraries.

Context

In a typical React app, data is passed down via props, but this can be cumbersome for some types of props that are required by many components within an application. Context provides a way to share these types of data between components without having to explicitly pass a prop through every level of hierarchy. Meaning with context, we can avoid passing props through intermediate elements.

React Hooks

Hooks are functions that let you "hook into" React state and lifecycle features from functional components. They let you use state and other React features without writing a class. You can learn more about Hooks in our Hooks guide.



Thinking in React

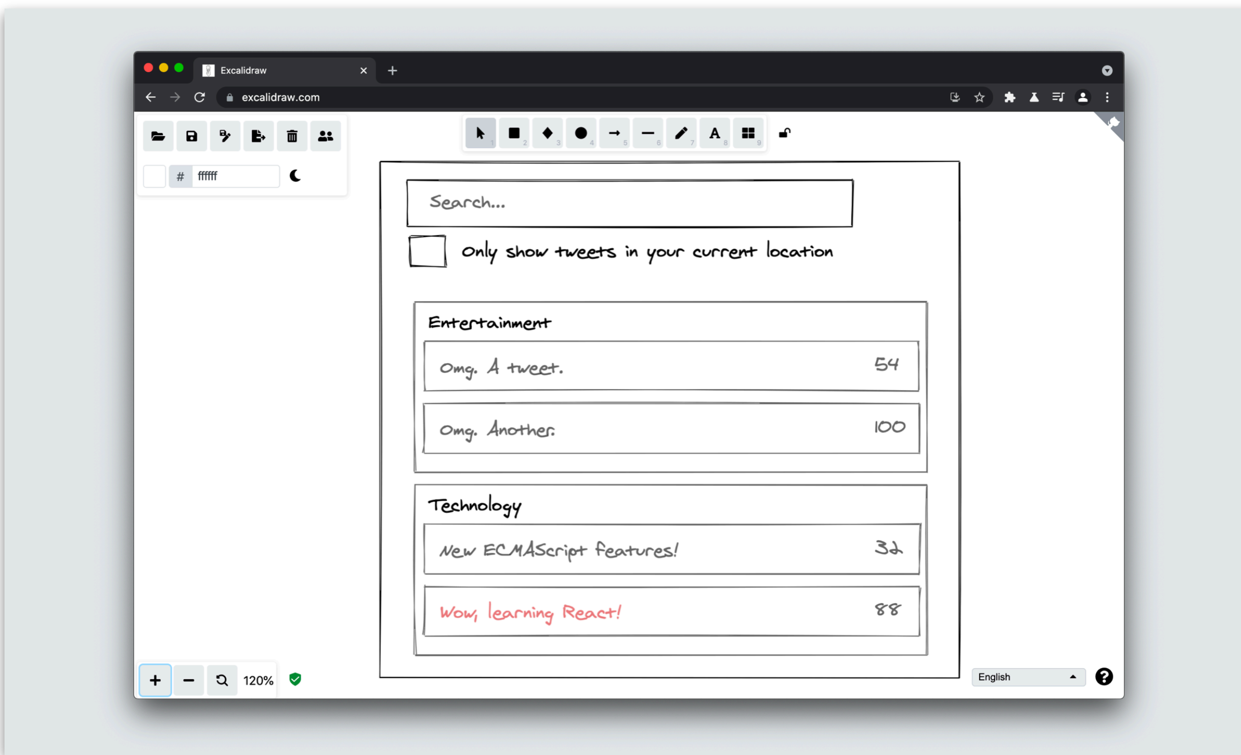
One thing that is really amazing about React is how it makes you think about apps as you build them. In this section, we'll walk you through the thought process of building a *Searchable product data table* using React Hooks.

Step 1: Start with a Mock

Imagine that we already have a JSON API and a mock of our interface:

Our JSON API returns some data that looks like this:

Tip: You may find free tools like [Excalidraw](https://excalidraw.com) useful for drawing out a high-level



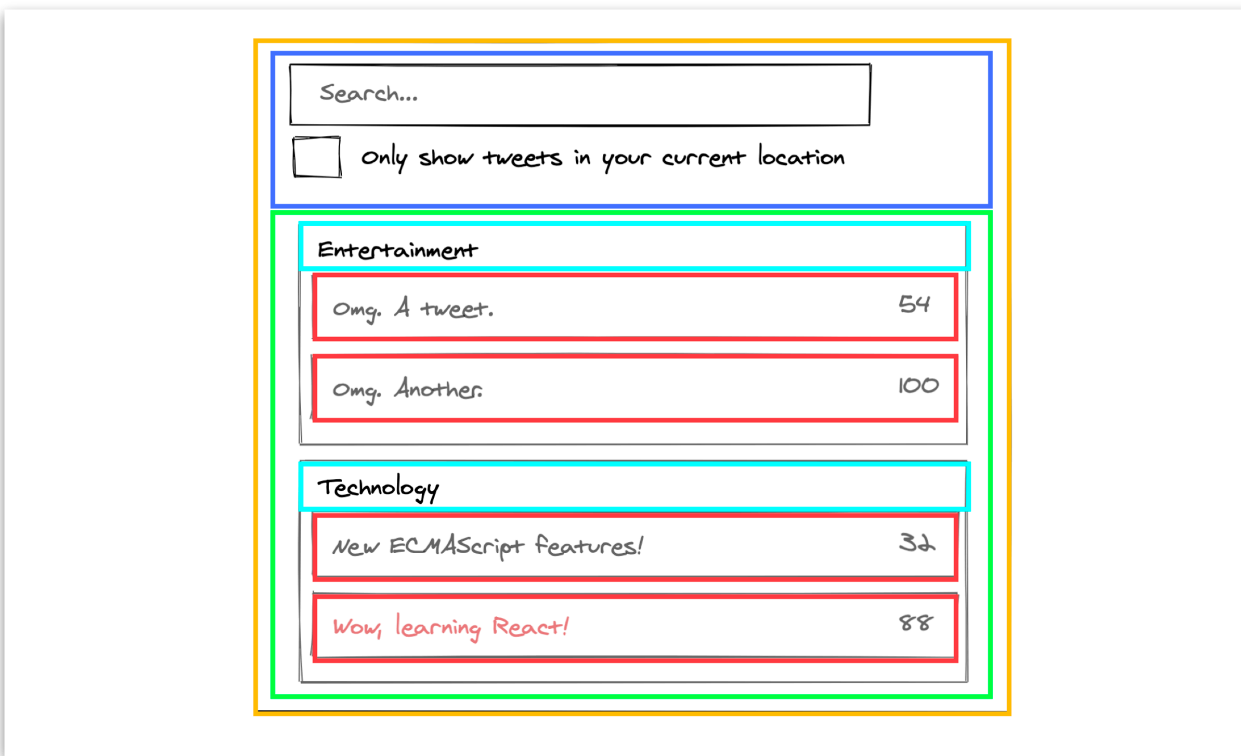
mock of your UI and components.

```
[
  {category: "Entertainment", retweets: "54", isLocal: false, text: "Omg. A tweet."},
  {category: "Entertainment", retweets: "100", isLocal: false, text: "Omg. Another."},
  {category: "Technology", retweets: "32", isLocal: false, text: "New ECMAScript features!"},
  {category: "Technology", retweets: "88", isLocal: true, text: "Wow, learnin React!"}
];
```

Step 2: Break the UI into a Hierarchy Component

When you have your mock, the next thing to do is to draw boxes around every component (and subcomponent) in the mock and name all of them, as shown below.

Use the single responsibility principle: a component should ideally have a single function. If it ends up growing, it should be broken down into smaller subcomponents. Use this same technique for deciding if you should create a new function or object.



You'll see in the image above that we have five components in our app. We've listed the data each component represents.

- **TweetSearchResults (orange):** container for the full component
- **SearchBar (blue):** user input for what to search for
- **TweetList (green):** displays and filters tweets based on user input
- **TweetCategory (turquoise):** displays a heading for each category
- **TweetRow (red):** displays a row for each tweet

Now that the components in the mock have been identified, the next thing to do would be to sort them into a hierarchy. Components that are found within another component in the mock should appear as a child in the hierarchy. Like this:

- TweetSearchResults
    - SearchBar
    - TweetList
        - TweetCategory
        - TweetRow

Step 3: Implement the components in React

The next step after completing the component hierarchy is to implement your app. Before last year, the quickest way was to build a version that takes your data model and renders the UI but has zero interactivity, but since the introduction of React Hooks, an easier way to implement your app is to use the Hooks as seen below:

Filterable list of tweets

```
const TweetSearchResults = ({tweets}) => {
  const [filterText, setFilterText] = useState('');
  const [inThisLocation, setInThisLocation] = useState(false);
  return (
    <div>
      <SearchBar
        filterText={filterText}
        inThisLocation={inThisLocation}
        setFilterText={setFilterText}
        setInThisLocation={setInThisLocation}
      />
      <TweetList
        tweets={tweets}
        filterText={filterText}
        inThisLocation={inThisLocation}
      />
    </div>
  );
}
```

SearchBar

```
const SearchBar = ({
  filterText,
  inThisLocation,
  setFilterText,
  setInThisLocation
}) => (
  <form>
    <input
      type="text"
      placeholder="Search..."
      value={filterText}
      onChange={(e) => setFilterText(e.target.value)}
    />
    <p>
      <label>
        <input
          type="checkbox"
          checked={inThisLocation}
          onChange={(e) => setInThisLocation(e.target.checked)}
        />
        {' '}
        Only show tweets in your current location
      </label>
    </p>
  </form>
);
```

Tweet list (list of tweets)

```
const TweetList = ({tweets, filterText, inThisLocation}) => {
  const rows = [];
  let lastCategory = null;

  tweets.forEach((tweet) => {
    if (tweet.text.toLowerCase().indexOf(filterText.toLowerCase()) === -1) {
      return;
    }
    if (inThisLocation && !tweet.isLocal) {
      return;
    }
    if (tweet.category !== lastCategory) {
      rows.push(
        <TweetCategory
          category={tweet.category}
          key={tweet.category} />
      );
    }
    rows.push(
      <TweetRow
        tweet={tweet}
        key={tweet.text} />
    );
    lastCategory = tweet.category;
  });

  return (
    <table>
      <thead>
        <tr>
          <th>Tweet Text</th>
          <th>Retweets</th>
        </tr>
      </thead>
      <tbody>{rows}</tbody>
    </table>
  );
}
```

Tweet category row

```
const TweetCategory = ({category}) => (
  <tr>
    <th colSpan="2">
      {category}
    </th>
  </tr>
);
```

Tweet Row

```
const TweetRow = ({tweet}) =>  {
  const color = tweet.isLocal ? 'inherit' : 'red';

  return (
    <tr>
      <td><span style="">{tweet.text}</span></td>
      <td>{tweet.retweets}</td>
    </tr>
  );
}
```

The final implementation would be all the code written together in the previously stated hierarchy :

- TweetSearchResults
    - SearchBar
    - TweetList
        - TweetCategory
        - TweetRow

Getting Started

There are various ways to start using React.

Load directly on the web page: This is the simplest way to set up React. Add the React JavaScript to your page, either as an `npm` dependency or via a CDN.

Use create-react-app: create-react-app is a project aimed at getting you to use React as soon as possible, and any React app that needs to outgrow a single page will find that create-react-app meets that need quite easily. More serious production applications should consider using Next.js as it has stronger defaults (like code-splitting) baked in.

Code Sandbox: An easy way to have the create-react-app structure, without installing it, is to go to https://codesandbox.io/s and choose "React."

Codepen: If you are prototyping a React component and enjoy using Codepen, a number of React starting points are also available for use.

Conclusion

The React.js library was designed to make the process of building modular, reusable user interface components simple and intuitive. As you read through some of our other guides, we hope you found this brief introduction a helpful high-level overview.

This guide would not have been possible without the teaching styles shared in the official React components and props, thinking in React, thinking in React Hooks and the scriptverse docs

Singleton Pattern

Share a single global instance throughout our application

Singletons are classes which can be instantiated once, and can be accessed globally. This single instance can be shared throughout our application, which makes Singletons great for managing global state in an application.

First, let's take a look at what a singleton can look like using an ES2015 class. For this example, we're going to build a `Counter` class that has:

```
let counter = 0;

class Counter {
  getInstance() {
    return this;
  }

  getCount() {
    return counter;
  }

  increment() {
    return ++counter;
  }

  decrement() {
    return --counter;
  }
}
```

a `getInstance` method that returns the value of the instance

a `getCount` method that returns the current value of the `counter` variable

an `increment` method that increments the value of `counter` by one

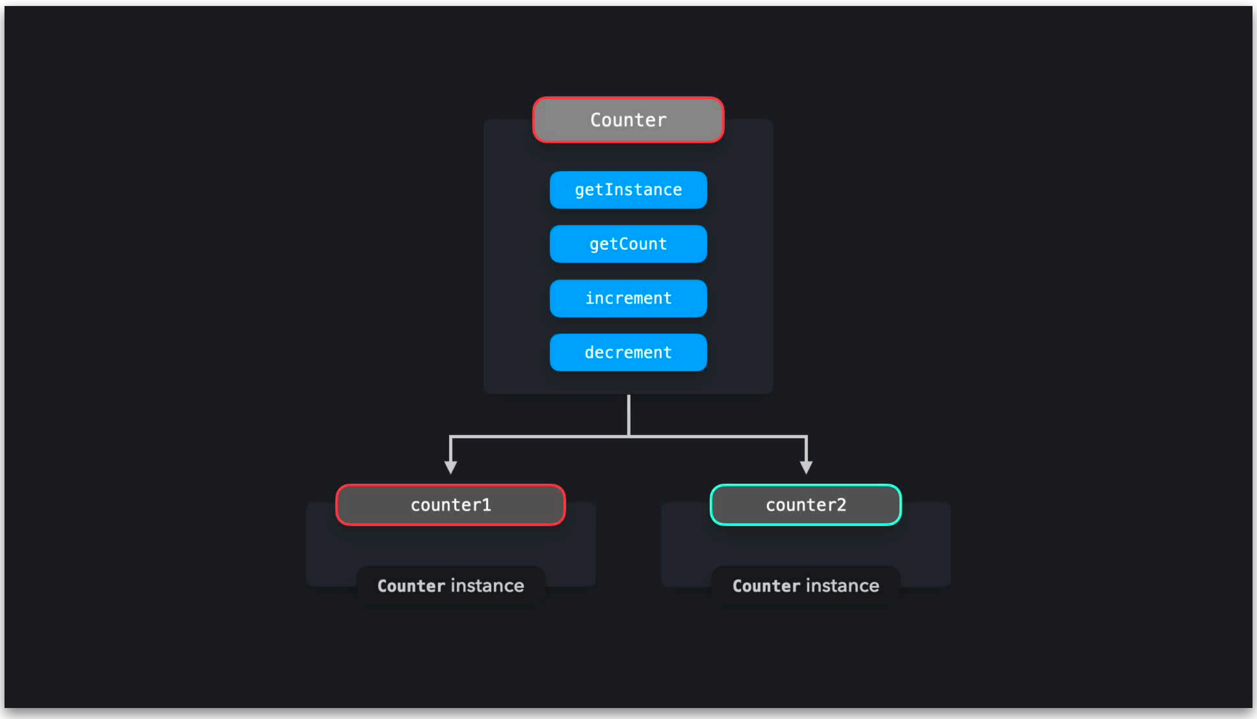
a `decrement` method that decrements the value of `counter` by one

However, this class doesn't meet the criteria for a Singleton! A Singleton should only be able to get instantiated once. Currently, we can create multiple instances of the `Counter` class.

```
let counter = 0;

class Counter {
  getInstance() {
    return this;
  }

  getCount() {
    return counter;
  }

  increment() {
    return ++counter;
  }

  decrement() {
    return --counter;
  }
}

const counter1 = new Counter();
const counter2 = new Counter();

console.log(counter1.getInstance() === counter2.getInstance()); // false
```

By calling the new method twice, we just set `counter1` and `counter2` equal to different instances. The values returned by the getInstance method on `counter1` and `counter2` effectively returned references to different instances: they aren't strictly equal!

Let's make sure that only one instance of the `Counter` class can be created.



One way to make sure that only one instance can be created, is by creating a variable called instance. In the constructor of `Counter`, we can set instance equal to a reference to the instance when a new instance is created. We can prevent new instantiations by checking if the instance variable already had a value. If that's the case, an instance already exists. This shouldn't happen: an error should get thrown.

```javascript
let instance;
let counter = 0;

class Counter {
  constructor() {
    if (instance) {
      throw new Error("You can only create one instance!");
    }
    instance = this;
  }

  getInstance() {
    return this;
  }

  getCount() {
    return counter;
  }

  increment() {
    return ++counter;
  }

  decrement() {
    return --counter;
  }
}

const counter1 = new Counter();
const counter2 = new Counter();
// Error: You can only create one instance!
```

Perfect! We aren't able to create multiple instances anymore.

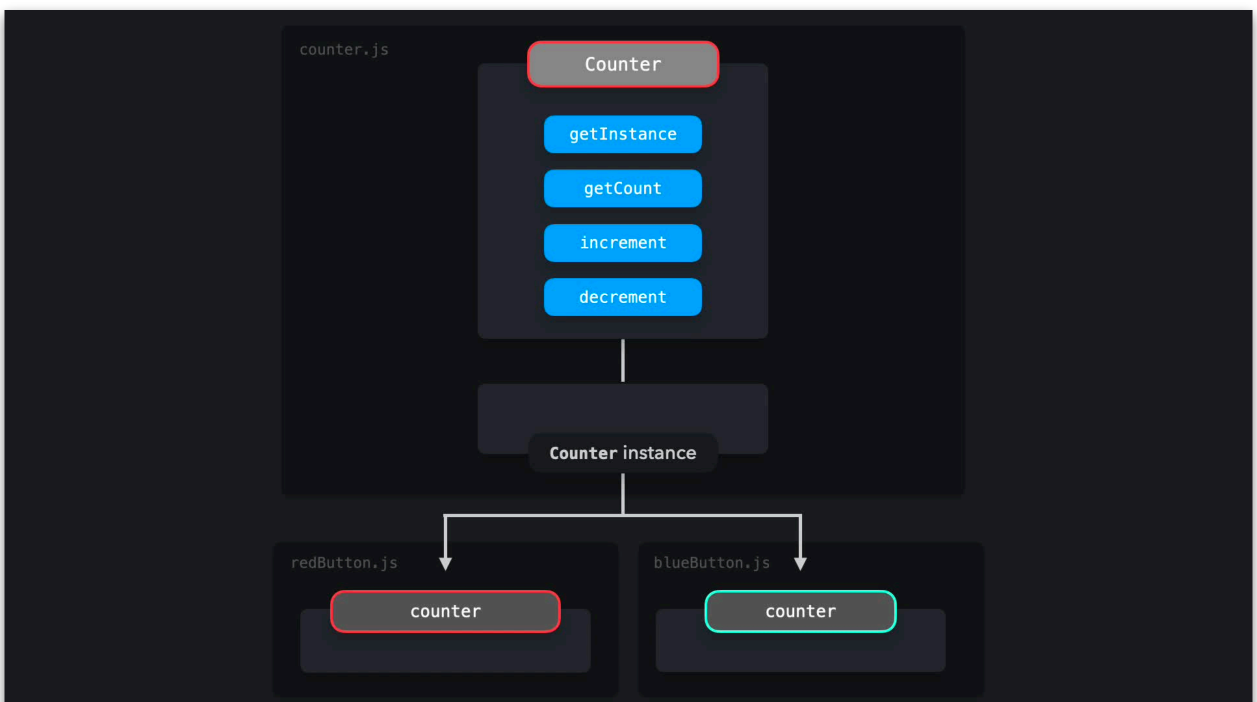
Let's export the `Counter` instance from the `counter.js` file. But before doing so, we should freeze the instance as well.

The `Object.freeze` method makes sure that consuming code cannot modify the Singleton. Properties on the frozen instance cannot be added or modified, which reduces the risk of accidentally overwriting the values on the Singleton.

```
let instance;
let counter = 0;

class Counter {
  constructor() {
    if (instance) {
      throw new Error("You can only create one instance!");
    }
    instance = this;
  }

  getInstance() {
    return this;
  }

  getCount() {
    return counter;
  }

  increment() {
    return ++counter;
  }

  decrement() {
    return --counter;
  }
}

const singletonCounter = Object.freeze(new Counter());
export default singletonCounter;
```

Let's take a look at an application that implements the Counter example. We have the following files:

- `counter.js`: contains the `Counter` class, and exports a `Counter` instance as its default export
- `index.js`: loads the `redButton.js` and `blueButton.js` modules
- `redButton.js`: imports `Counter`, and adds `Counter`'s `increment` method as an event listener to the red button, and logs the current value of counter by invoking the `getCount` method
- `blueButton.js`: imports Counter, and adds Counter's increment method as an event listener to the blue button, and logs the current value of counter by invoking the getCount method



Both `blueButton.js` and `redButton.js` import the same instance from `counter.js`. This instance is imported as `Counter` in both files.

When we invoke the increment method in either `redButton.js` or `blueButton.js`, the value of the counter property on the `Counter` instance updates in both files. It doesn't matter whether we click on the red or blue button: the same value is shared among all instances. This is why the counter keeps incrementing by one, even though we're invoking the method in different files.

(Dis)advantages

Restricting the instantiation to just one instance could potentially save a lot of memory space. Instead of having to set up memory for a new instance each time, we only have to set up memory for that one instance, which is referenced throughout the application. However, Singletons are actually considered an anti-pattern, and can (or.. should) be avoided in JavaScript.

In many programming languages, such as Java or C++, it's not possible to directly create objects the way we can in JavaScript. In those object-oriented programming languages, we need to create a class, which creates an object. That created object has the value of the instance of the class, just like the value of instance in the JavaScript example.

However, the class implementation shown in the examples above is actually overkill. Since we can directly create objects in JavaScript, we can simply use a regular object to achieve the exact same result. Let's cover some of the disadvantages of using Singletons!

Using a regular object

Let's use the same example as we saw previously. However this time, the counter is simply an object containing:

- a `count` property
- an `increment` method that increments the value of `count` by one
- a `decrement` method that decrements the value of `count` by one

```
let count = 0;

const counter = {
  increment() {
    return ++count;
  },
  decrement() {
    return --count;
  }
};

Object.freeze(counter);
export { counter };
```

Since objects are passed by reference, both `redButton.js` and `blueButton.js` are importing a reference to the same singleton `Counter` object. Modifying the value of count in either of these files will modify the value on the singletonCounter, which is visible in both files.

Testing

Testing code that relies on a Singleton can get tricky. Since we can't create new instances each time, all tests rely on the modification to the global instance of the previous test. The order of the tests matter in this case, and one small modification can lead to an entire test suite failing. After testing, we need to reset the entire instance in order to reset the modifications made by the tests.

```js
import Counter from "../src/counterTest";

test("incrementing 1 time should be 1", () => {
  Counter.increment();
  expect(Counter.getCount()).toBe(1);
});

test("incrementing 3 extra times should be 4", () => {
  Counter.increment();
  Counter.increment();
  Counter.increment();
  expect(Counter.getCount()).toBe(4);
});

test("decrementing 1  times should be 3", () => {
  Counter.decrement();
  expect(Counter.getCount()).toBe(3);
});
```

Dependency hiding

When importing another module, superCounter.js in this case, it may not be obvious that that module is importing a Singleton. In other files, such as index.js in this case, we may be importing that module and invoke its methods. This way, we accidentally modify the values in the Singleton. This can lead to unexpected behavior, since multiple instances of the Singleton can be shared throughout the application, which would all get modified as well.

index.js

```
import Counter from "./counter";
import SuperCounter from "./superCounter";
const counter = new SuperCounter();

counter.increment();
counter.increment();
counter.increment();

console.log("Counter in index.js", Counter.getCount())
```

Global behavior

A Singleton instance should be able to get referenced throughout the entire app. Global variables essentially show the same behavior: since global variables are available on the global scope, we can access those variables throughout the application.

Having global variables is generally considered as a bad design decision. Global scope pollution can end up in accidentally overwriting the value of a global variable, which can lead to a lot of unexpected behavior.

In ES2015, creating global variables is fairly uncommon. The new let and const keyword prevent developers from accidentally polluting the global scope, by keeping variables declared with these two keywords block-scoped. The new module system in JavaScript makes creating globally accessible values easier without polluting the global scope, by being able to export values from a module, and import those values in other files.

However, the common usecase for a Singleton is to have some sort of global state throughout your application. Having multiple parts of your codebase rely on the same mutable object can lead to unexpected behavior.

Usually, certain parts of the codebase modify the values within the global state, whereas others consume that data. The order of execution here is important: we don't want to accidentally consume data first, when there is no data to consume (yet)! Understanding the data flow when using a global state can get very tricky as your application grows, and dozens of components rely on each other.

State management in React

In React, we often rely on a global state through state management tools such as Redux or React Context instead of using Singletons. Although their global state behavior might seem similar to that of a Singleton, these tools provide a read-only state rather than the mutable state of the Singleton. When using

Redux, only pure function reducers can update the state, after a component has sent an action through a dispatcher.

Although the downsides to having a global state don't magically disappear by using these tools, we can at least make sure that the global state is mutated the way we intend it, since components cannot update the state directly.

Proxy Pattern

Share a single global instance throughout our application

With a **Proxy** object, we get more control over the interactions with certain objects. A proxy object can determine the behavior whenever we're interacting with the object, for example when we're getting a value, or setting a value.

Generally speaking, a proxy means a stand-in for someone else. Instead of speaking to that person directly, you'll speak to the proxy person who will represent the person you were trying to reach. The same happens in JavaScript: instead of interacting with the target object directly, we'll interact with the `Proxy` object.

Let's create a `person` object, that represents John Doe.

```
const person = {
  name: "John Doe",
  age: 42,
  nationality: "American"
};
```

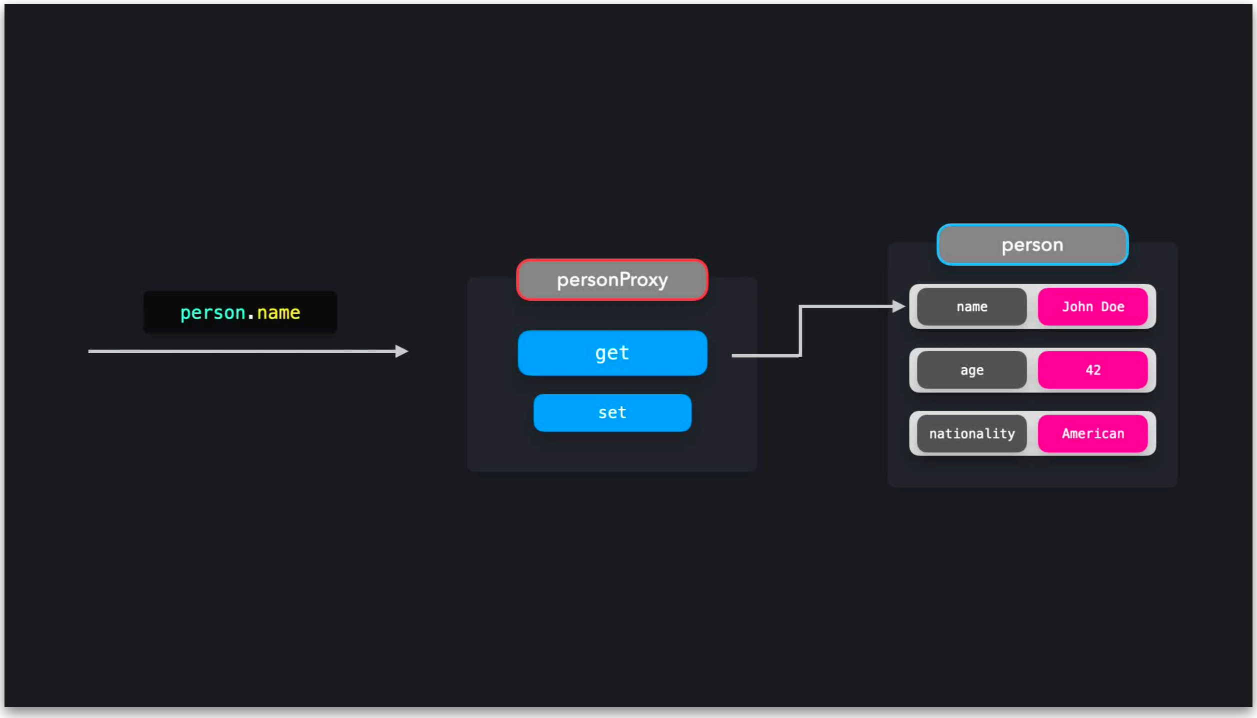
Instead of interacting with this object directly, we want to interact with a proxy object. In JavaScript, we can easily create a new proxy with by creating a new instance of `Proxy`.

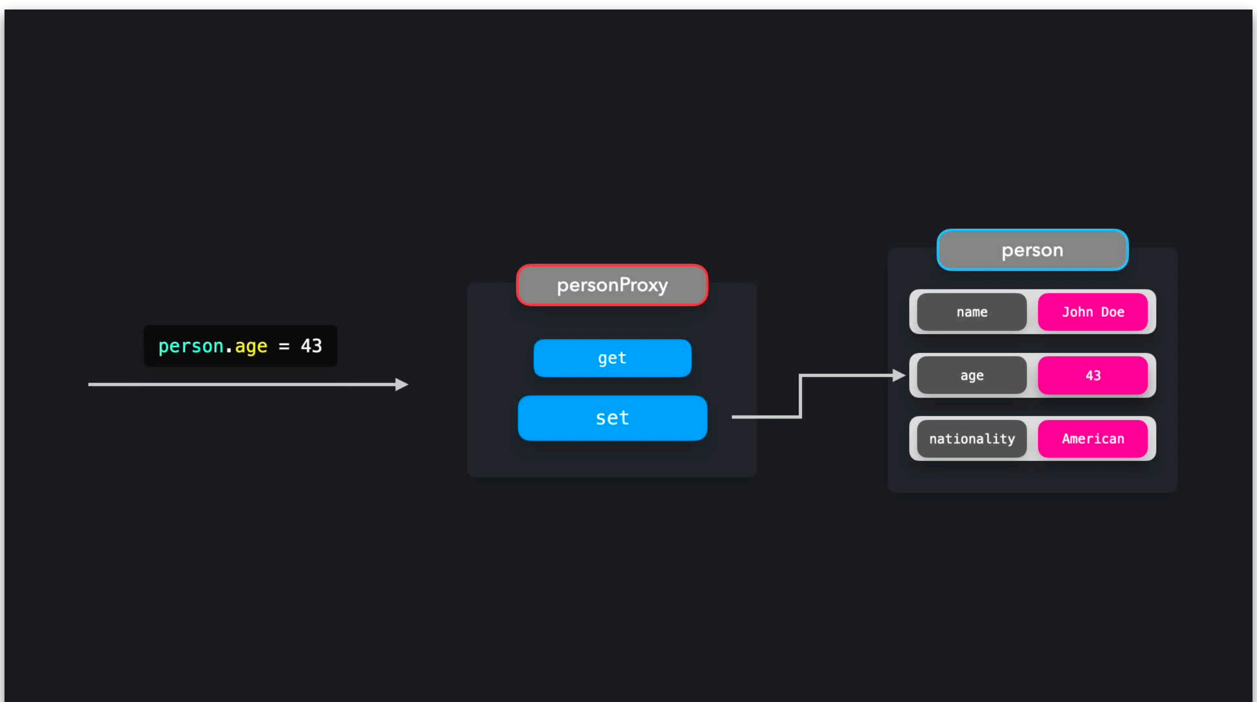
```javascript
const person = {
  name: "John Doe",
  age: 42,
  nationality: "American"
};

const personProxy = new Proxy(person, {});
```

The second argument of `Proxy` is an object that represents the handler. In the handler object, we can define specific behavior based on the type of interaction. Although there are many methods that you can add to the `Proxy` handler, the two most common ones are `get` and `set`:

- `get`: Gets invoked when trying to access a property
- `set`: Gets invoked when trying to modify a property

Effectively, what will end up happening is the following:





Instead of interacting with the person object directly, we'll be interacting with the `personProxy`.

Let's add handlers to the `personProxy`. When trying to modify a property, thus invoking the set method on the proxy, we want it to log the previous value and the new value of the property. When trying to access a property, thus invoking the get a method on the Proxy, we want it to log a more readable sentence that contains the key any value of the property.

```
const personProxy = new Proxy(person, {
  get: (obj, prop) => {
    console.log(`The value of ${prop} is ${obj[prop]}`);
  },
  set: (obj, prop, value) => {
    console.log(`Changed ${prop} from ${obj[prop]} to ${value}`);
    obj[prop] = value;
  }
});
```

Perfect! Let's see what happens when we're trying to modify or retrieve a property.

```
const person = {
  name: "John Doe",
  age: 42,
  nationality: "American"
};

const personProxy = new Proxy(person, {
  get: (obj, prop) => {
    console.log(`The value of ${prop} is ${obj[prop]}`);
  },
  set: (obj, prop, value) => {
    console.log(`Changed ${prop} from ${obj[prop]} to ${value}`);
    obj[prop] = value;
    return true;
  }
});

personProxy.name;
personProxy.age = 43;
```

When accessing the name property, the `personProxy` returned a better sounding sentence: `The value of name is John Doe`. When modifying the age property, the Proxy returned the previous and new value of this property: `Changed age from 42 to 43`.

A proxy can be useful to add **validation**. A user shouldn't be able to change person's age to a string value, or give him an empty name. Or if the user is trying to access a property on the object that doesn't exist, we should let the user know.

```
const personProxy = new Proxy(person, {
  get: (obj, prop) => {
    if (!obj[prop]) {
      console.log(
        `Hmm.. this property doesn't seem to exist on the target object`
      );
    } else {
      console.log(`The value of ${prop} is ${obj[prop]}`);
    }
  },
  set: (obj, prop, value) => {
    if (prop === "age" && typeof value !== "number") {
      console.log(`Sorry, you can only pass numeric values for age.`);
    } else if (prop === "name" && value.length < 2) {
      console.log(`You need to provide a valid name.`);
    } else {
      console.log(`Changed ${prop} from ${obj[prop]} to ${value}.`);
      obj[prop] = value;
    }
  }
});
```

The proxy makes sure that we weren't modifying the person object with faulty values, which helps us keep our data pure!

Reflect

JavaScript provides a built-in object called `Reflect`, which makes it easier for us to manipulate the target object when working with proxies.

Previously, we tried to modify and access properties on the target object within the proxy through directly getting or setting the values with bracket notation. Instead, we can use the `Reflect` object. The methods on the `Reflect` object have the same name as the methods on the handler object.

Instead of accessing properties through `obj[prop]` or setting properties through `obj[prop] = value`, we can access or modify properties on the target object through `Reflect.get()` and `Reflect.set()`. The methods receive the same arguments as the methods on the handler object.

```
const personProxy = new Proxy(person, {
  get: (obj, prop) => {
    console.log(`The value of ${prop} is ${Reflect.get(obj, prop)}`);
  },
  set: (obj, prop, value) => {
    console.log(`Changed ${prop} from ${obj[prop]} to ${value}`);
    Reflect.set(obj, prop, value);
  }
});
```

Perfect! We can access and modify the properties on the target object easily with the `Reflect` object.

```javascript
const person = {
  name: "John Doe",
  age: 42,
  nationality: "American"
};

const personProxy = new Proxy(person, {
  get: (obj, prop) => {
    console.log(`The value of ${prop} is ${Reflect.get(obj, prop)}`);
  },
  set: (obj, prop, value) => {
    console.log(`Changed ${prop} from ${obj[prop]} to ${value}`);
    return Reflect.set(obj, prop, value);
  }
});

personProxy.name;
personProxy.age = 43;
personProxy.name = "Jane Doe";
```

Proxies are a powerful way to add control over the behavior of an object. A proxy can have various use-cases: it can help with validation, formatting, notifications, or debugging.

Overusing the `Proxy` object or performing heavy operations on each handler method invocation can easily affect the performance of your application negatively. It's best to not use proxies for performance-critical code.

Provider Pattern

Make data available to multiple child components

In some cases, we want to make available data to many (if not all) components in an application. Although we can pass data to components using props, this can be difficult to do if almost all components in your application need access to the value of the props.

We often end up with something called prop drilling, which is the case when we pass props far down the component tree. Refactoring the code that relies on the props becomes almost impossible, and knowing where certain data comes from is difficult.

Let's say that we have one App component that contains certain data. Far down the component tree, we have a `ListItem`, `Header` and `Text` component that all need this data. In order to get this data to these components, we'd have to pass it through multiple layers of components.

In our codebase, that would look something like the following:

```
function App() {
  const data = { ... }

  return (
    <div>
      <SideBar data={data} />
      <Content data={data} />
    </div>
  )
}

const SideBar = ({ data }) => <List data={data} />
const List = ({ data }) => <ListItem data={data} />
const ListItem = ({ data }) => <span>{data.listItem}</span>

const Content = ({ data }) => (
  <div>
    <Header data={data} />
    <Block data={data} />
  </div>
)
const Header = ({ data }) => <div>{data.title}</div>
const Block = ({ data }) => <Text data={data} />
const Text = ({ data }) => <h1>{data.text}</h1>
```

Passing props down this way can get quite messy. If we want to rename the data prop in the future, we'd have to rename it in all components. The bigger your application gets, the trickier *prop drilling* can be.

It would be optimal of we could skip all the layers of components that don't need to use this data. We need to have something that gives the components that need access to the value of data direct access to it, without relying on *prop drilling*.

This is where the Provider Pattern can help us out! With the Provider Pattern, we can make data available to multiple components. Rather than passing that data down each layer through props, we can wrap all components in a `Provider`. A `Provider` is a higher order component provided to us by the a `Context` object. We can create a `Context` object, using the `createContext` method that React provides for us.

The `Provider` receives a value prop, which contains the data that we want to pass down. All components that are wrapped within this provider have access to the value of the value prop.

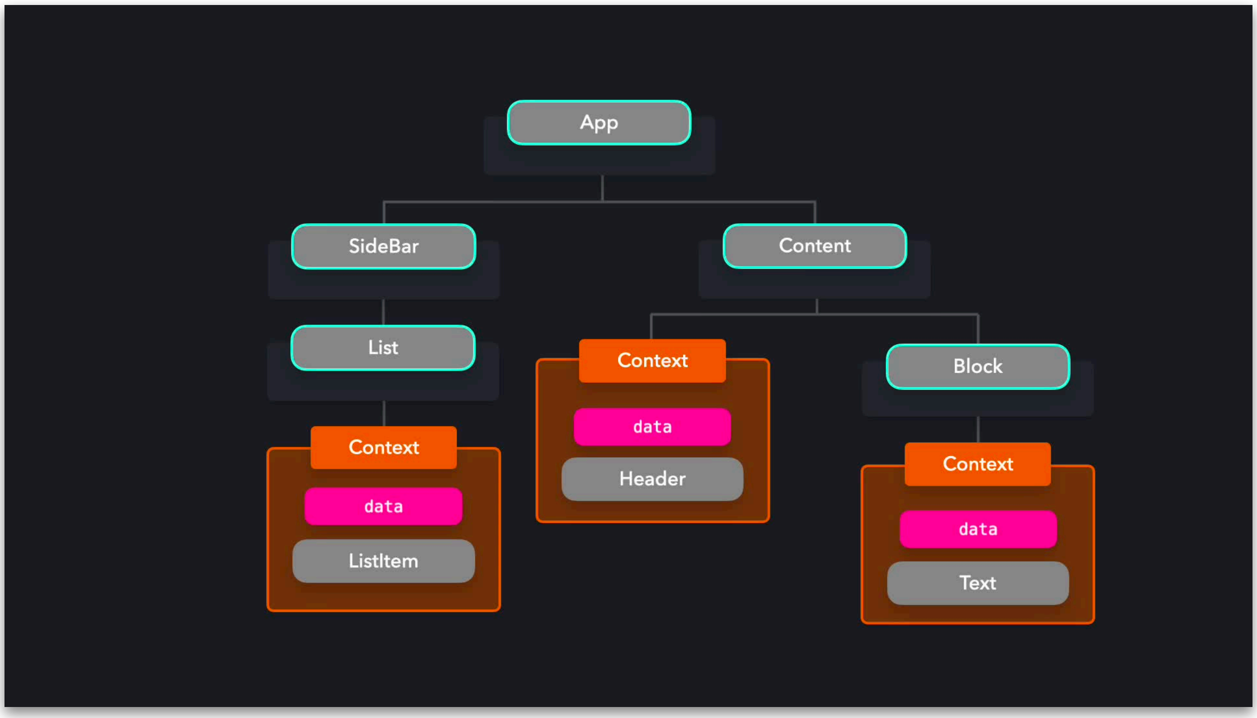
```
const DataContext = React.createContext()

function App() {
  const data = { ... }

  return (
    <div>
      <DataContext.Provider value={data}>
        <SideBar />
        <Content />
      </DataContext.Provider>
    </div>
  )
}
```

We no longer have to manually pass down the data prop to each component!

Each component can get access to the data, by using the `useContext` hook. This hook receives the context that data has a reference with, `DataContext` in this case. The `useContext` hook lets us read and write data to the context object.

```
const DataContext = React.createContext();

function App() {
  const data = { ... }

  return (
    <div>
      <SideBar />
      <Content />
    </div>
  )
}

const SideBar = () => <List />
const Content = () => <div><Header /><Text /></div>

function List() {
  const { data } = React.useContext(DataContext);
  return <ul>{data.list}</ul>;
}

function Text() {
  const { data } = React.useContext(DataContext);
  return <h1>{data.text}</h1>;
}

function Header() {
  const { data } = React.useContext(DataContext);
  return <div>{data.title}</div>;
}
```

The components that aren't using the data value won't have to deal with data at all. We no longer have to worry about passing props down several levels through components that don't need the value of the props, which makes refactoring a lot easier.



The Provider pattern is very useful for sharing global data. A common use case for the provider pattern is sharing a theme UI state with many components.

Say we have a simple app that shows a list.

App.js

```
import React from "react";
import "./styles.css";

import List from "./List";
import Toggle from "./Toggle";

export default function App() {
  return (
    <div className="App">
      <Toggle />
      <List />
    </div>
  );
}
```

List.js

```
import React from "react";
import ListItem from "./ListItem";

export default function Boxes() {
  return (
    <ul className="list">
      {new Array(10).fill(0).map((x, i) => (
        <ListItem key={i} />
      ))}
    </ul>
  );
}
```

We want the user to be able to switch between light mode and dark mode, by toggling the switch. When the user switches from dark- to light mode and vice versa, the background color and text color should change! Instead of passing the current theme value down to each component, we can wrap the components in a `ThemeProvider`, and pass the current theme colors to the provider.

```
export const ThemeContext = React.createContext();

const themes = {
  light: { background: "#fff",  color: "#000" },
  dark: { background: "#171717", color: "#fff" }
};

export default function App() {
  const [theme, setTheme] = useState("dark");

  function toggleTheme() {
    setTheme(theme === "light" ? "dark" : "light");
  }

  const providerValue = { theme: themes[theme], toggleTheme };

  return (
    <div className={`App theme-${theme}`}>
      <ThemeContext.Provider value={providerValue}>
        <Toggle />
        <List />
      </ThemeContext.Provider>
    </div>
  );
}
```

Since the `Toggle` and `List` components are both wrapped within the `ThemeContext` provider, we have access to the values `theme` and `toggleTheme` that are passed as a value to the provider.

Within the `Toggle` component, we can use the `toggleTheme` function to update the theme accordingly.

```
import React, { useContext } from "react";
import { ThemeContext } from "./App";

export default function Toggle() {
  const theme = useContext(ThemeContext);

  return (
    <label className="switch">
      <input type="checkbox" onClick={theme.toggleTheme} />
      <span className="slider round" />
    </label>
  );
}
```

The `List` component itself doesn't care about the current value of the theme. However, the `ListItem` components do! We can use the theme context directly within the `ListItem`.

```
import React, { useContext } from "react";
import { ThemeContext } from "./App";

export default function ListItem() {
  const theme = useContext(ThemeContext);

  return <li style={theme.theme}>...</li>;
}
```

Perfect! We didn't have to pass down any data to components that didn't care about the current value of the theme.

Hooks

We can create a hook to provide context to components. Instead of having to import `useContext` and the `Context` in each component, we can use a hook that returns the context we need.

```
function useThemeContext() {
  const theme = useContext(ThemeContext);
  return theme;
}
```

To make sure that it's a valid theme, let's throw an error if `useContext(ThemeContext)` returns a falsy value.

```
function useThemeContext() {
  const theme = useContext(ThemeContext);
  if (!theme) {
    throw new Error("useThemeContext must be used within ThemeProvider");
  }
  return theme;
}
```

Instead of wrapping the components directly with the `ThemeContext.Provider` component, we can create a HOC that wraps this component to provide its values. This way, we can separate the context logic from the rendering components, which improves the reusability of the provider.

```
function ThemeProvider({children}) {
  const [theme, setTheme] = useState("dark");

  function toggleTheme() {
    setTheme(theme === "light" ? "dark" : "light");
  }

  const providerValue = { theme: themes[theme], toggleTheme };

  return (
    <ThemeContext.Provider value={providerValue}>
      {children}
    </ThemeContext.Provider>
  );
}

export default function App() {
  return (
    <div className={`App theme-${theme}`}>
      <ThemeProvider>
        <Toggle />
        <List />
      </ThemeProvider>
    </div>
  );
}
```

Each component that needs to have access to the ThemeContext, can now simply use the useThemeContext hook.

```
export default function ListItem() {
  const theme = useThemeContext();

  return <li style={theme.theme}>...</li>;
}
```

Prototype Pattern

Share properties among many objects of the same type

The prototype pattern is a useful way to share properties among many objects of the same type. The prototype is an object that's native to JavaScript, and can be accessed by objects through the prototype chain.

In our applications, we often have to create many objects of the same type. A useful way of doing this is by creating multiple instances of an ES6 class.

Let's say we want to create many dogs! In our example, dogs can't do that much: they simply have a name, and they can bark!

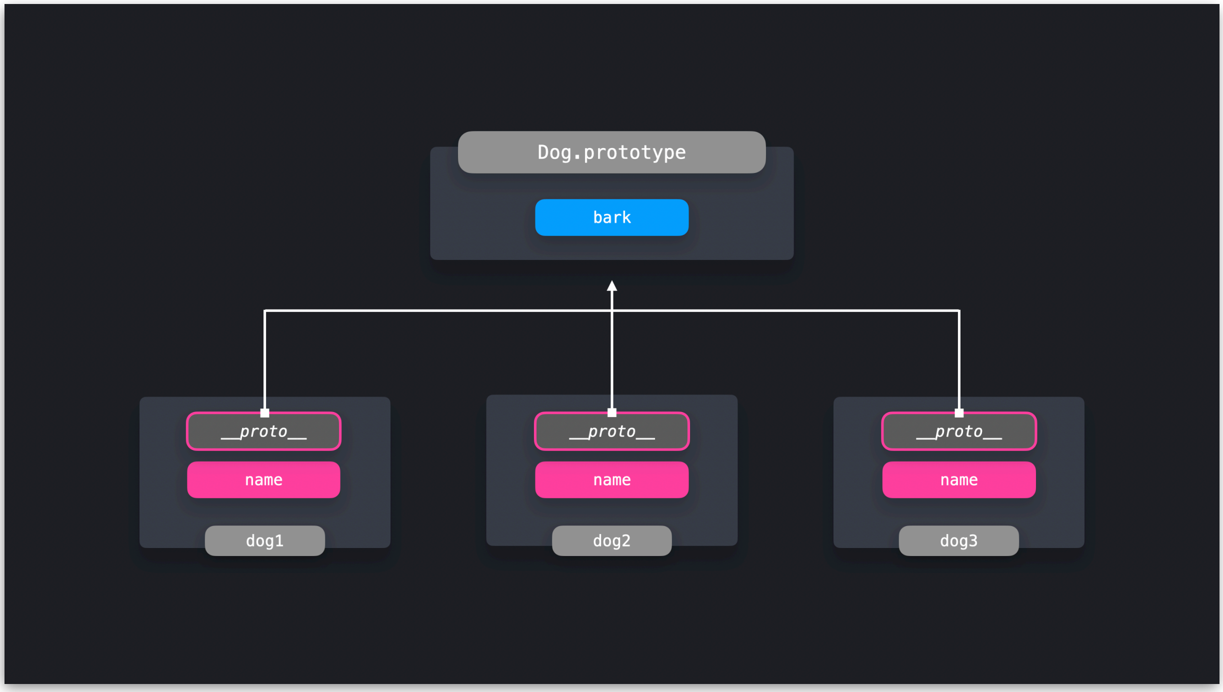
```
class Dog {
  constructor(name) {
    this.name = name;
  }

  bark() {
    return `Woof!`;
  }
}

const dog1 = new Dog("Daisy");
const dog2 = new Dog("Max");
const dog3 = new Dog("Spot");
```

Notice here how the constructor contains a `name` property, and the class itself contains a `bark` property. When using ES6 classes, all properties that are defined on the class itself, `bark` in this case, are automatically added to the prototype.

We can see the prototype directly through accessing the prototype property on a constructor, or through the `__proto__` property on any instance.

```
console.log(Dog.prototype);
// constructor: ƒ Dog(name, breed) bark: ƒ bark()

console.log(dog1.__proto__);
// constructor: ƒ Dog(name, breed) bark: ƒ bark()
```

The value of `__proto__` on any instance of the constructor, is a direct reference to the constructor's prototype! Whenever we try to access a property on an object that doesn't exist on the object directly, JavaScript will go down the prototype chain to see if the property is available within the prototype chain.



The prototype pattern is very powerful when working with objects that should have access to the same properties. Instead of creating a duplicate of the property each time, we can simply add the property to the prototype, since all instances have access to the prototype object.

Since all instances have access to the prototype, it's easy to add properties to the prototype even after creating the instances.

Say that our dogs shouldn't only be able to bark, but they should also be able to play! We can make this possible by adding a play property to the prototype.

```
class Dog {
  constructor(name) {
    this.name = name;
  }

  bark() {
    return `Woof!`;
  }
}

const dog1 = new Dog("Daisy");
const dog2 = new Dog("Max");
const dog3 = new Dog("Spot");

Dog.prototype.play = () => console.log("Playing now!");

dog1.play();
```

The term **prototype chain** indicates that there could be more than one step. Indeed! So far, we've only seen how we can access properties that are directly available on the first object that `__proto__` has a reference to. However, prototypes themselves also have a `__proto__` object!

Let's create another type of dog, a super dog! This dog should inherit everything from a normal `Dog`, but it should also be able to fly. We can create a super dog by extending the `Dog` class and adding a `fly` method.

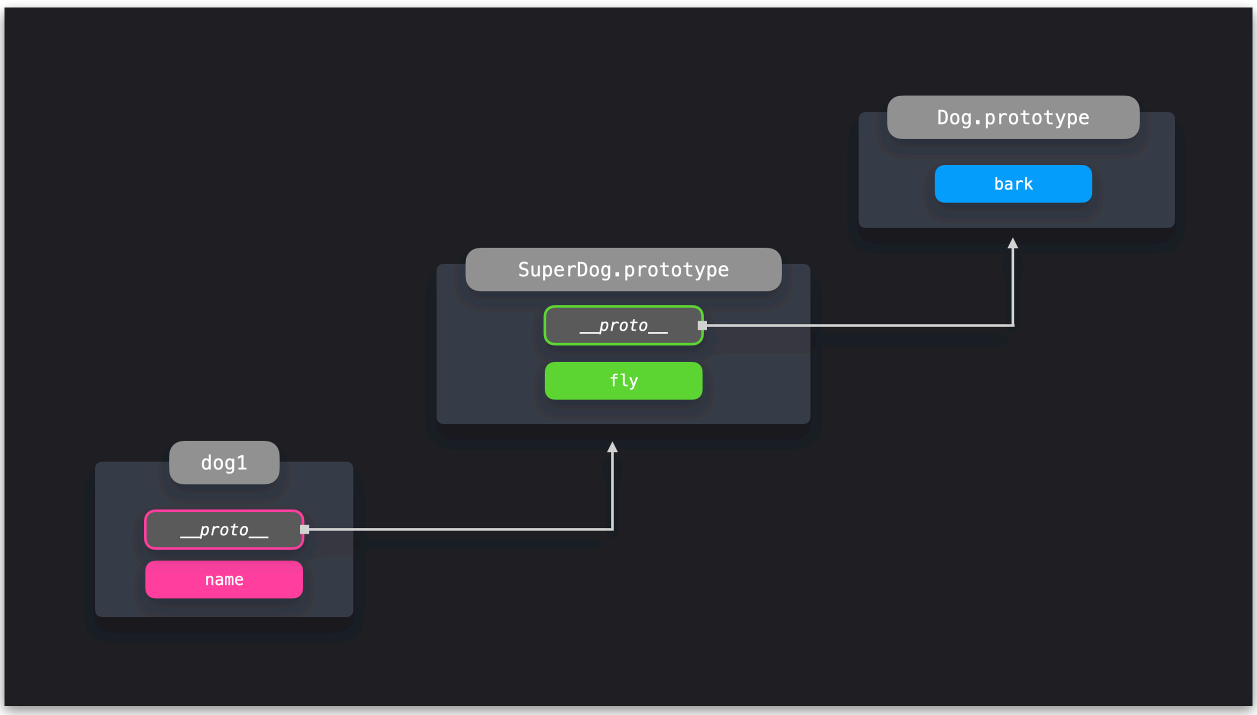
```
class SuperDog extends Dog {
  constructor(name) {
    super(name);
  }

  fly() {
    return "Flying!";
  }
}
```

Let's create a flying dog called Daisy, and let her bark and fly!

```
class Dog {
  constructor(name) {
    this.name = name;
  }

  bark() {
    console.log("Woof!");
  }
}

class SuperDog extends Dog {
  constructor(name) {
    super(name);
  }

  fly() {
    console.log(`Flying!`);
  }
}

const dog1 = new SuperDog("Daisy");
dog1.bark();
dog1.fly();
```

We have access to the `bark` method, as we extended the `Dog` class. The value of `__proto__` on the prototype of `SuperDog` points to the `Dog.prototype` object!

It gets clear why it's called a prototype chain: when we try to access a property that's not directly available on the object, JavaScript recursively walks down all the objects that `__proto__` points to, until it finds the property!



`Object.create`

The `Object.create` method lets us create a new object, to which we can explicitly pass the value of its prototype.

```
const dog = {
  bark() {
    return `Woof!`;
  }
};

const pet1 = Object.create(dog);
```

Although `pet1` itself doesn't have any properties, it does have access to properties on its prototype chain! Since we passed the `dog` object as `pet1`’s prototype, we can access the `bark` property.

```
const dog = {
  bark() {
    console.log(`Woof!`);
  }
};

const pet1 = Object.create(dog);

pet1.bark(); // Woof!
console.log("Direct properties on pet1: ", Object.keys(pet1));
console.log("Properties on pet1's prototype: ",
Object.keys(pet1.__proto__));
```

Perfect! `Object.create` is a simple way to let objects directly inherit properties from other objects, by specifying the newly created object's prototype. The new object can access the new properties by walking down the prototype chain.

The prototype pattern allows us to easily let objects access and inherit properties from other objects. Since the prototype chain allows us to access properties that aren't directly defined on the object itself, we can avoid duplication of methods and properties, thus reducing the amount of memory used.

Container/ Presentational Pattern

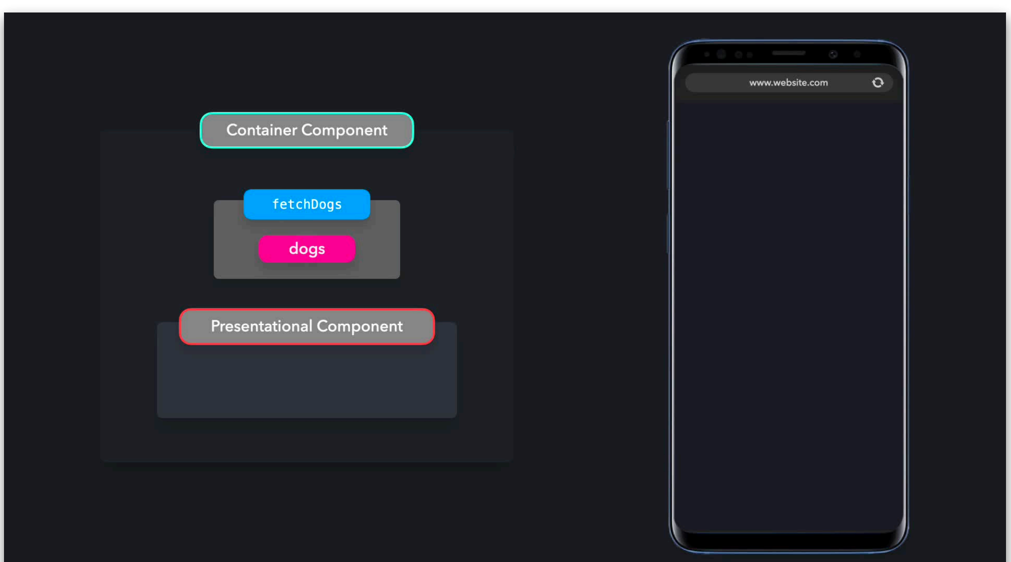
Enforce separation of concerns by separating the view from the application logic

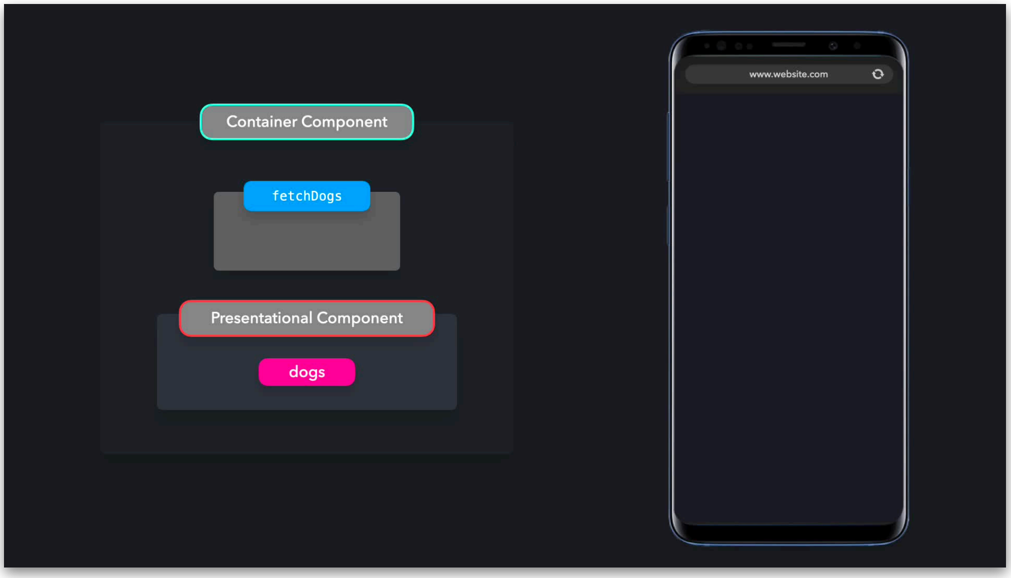
In React, one way to enforce separation of concerns is by using the Container/Presentational pattern. With this pattern, we can separate the view from the application logic.

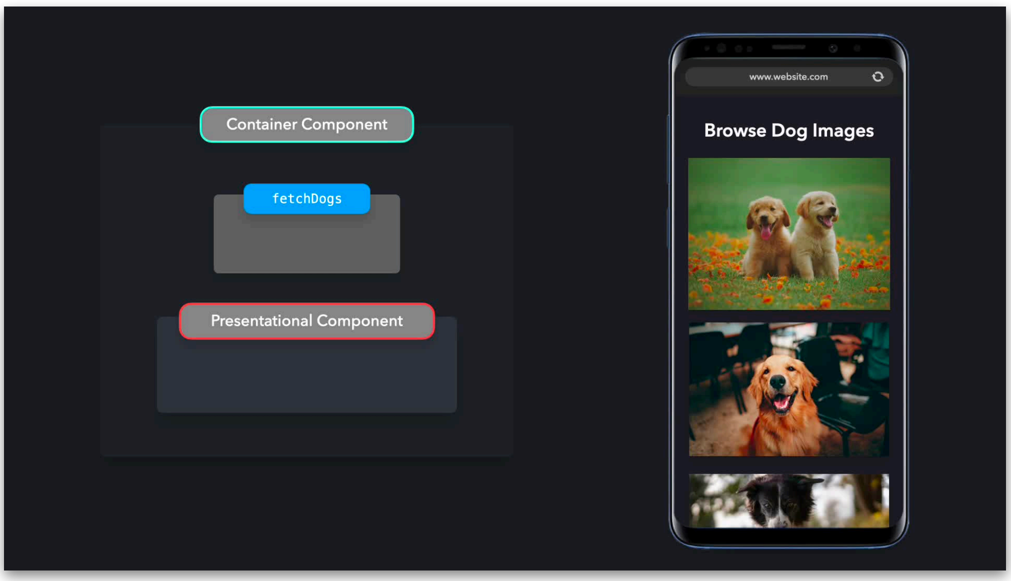
Let's say we want to create an application that fetches 6 dog images, and renders these images on the screen. Ideally, we want to enforce separation of concerns by separating this process into two parts:

1. **Presentational Components**: Components that care about how data is shown to the user. In this example, that's the rendering the list of dog images.

2. **Container Components**: Components that care about what data is shown to the user. In this example, that's fetching the dog images.







Fetching the dog images deals with application logic, whereas displaying the images only deals with the view.

Presentational Component

A presentational component receives its data through props. Its primary function is to simply display the data it receives the way we want them to, including styles, without modifying that data.

Let's take a look at the example that displays the dog images. When rendering the dog images, we simply want to map over each dog image that was fetched from the API, and render those images. In order to do so, we can create a functional component that receives the data through props, and renders the data it received.

DogImages.js

```
import React from "react";

export default function DogImages({ dogs }) {
  return dogs.map((dog, i) => <img src={dog} key={i} alt="Dog" />);
}
```

The `DogsImages` component is a presentational component. Presentational components are usually stateless: they do not contain their own React state, unless they need a state for UI purposes. The data they receive, is not altered by the presentational components themselves.

Presentational components receive their data from container components.

Container Components

The primary function of container components is to pass data to presentational components, which they contain. Container components themselves usually don't render any other components besides the presentational components that care about their data. Since they don't render anything themselves, they usually do not contain any styling either.

In our example, we want to pass dog images to the `DogsImages` presentational component. Before being able to do so, we need to fetch the images from an external API. We need to create a container component that fetches this data, and passes this data to the presentational component `DogsImages` in order to display it on the screen.

DogImagesContainer.js

```
import React from "react";
import DogImages from "./DogImages";

export default class DogImagesContainer extends React.Component {
  constructor() {
    super();
    this.state = {
      dogs: []
    };
  }

  componentDidMount() {
    fetch("https://dog.ceo/api/breed/labrador/images/random/6")
      .then(res => res.json())
      .then(({ message }) => this.setState({ dogs: message }));
  }

  render() {
    return <DogImages dogs={this.state.dogs} />;
  }
}
```

Combining these two components together makes it possible to separate handling application logic with the view.

Hooks

In many cases, the Container/Presentational pattern can be replaced with React Hooks. The introduction of Hooks made it easy for developers to add statefulness without needing a container component to provide that state.

Instead of having the data fetching logic in the `DogsImagesContainer` component, we can create a custom hook that fetches the images, and returns the array of dogs.

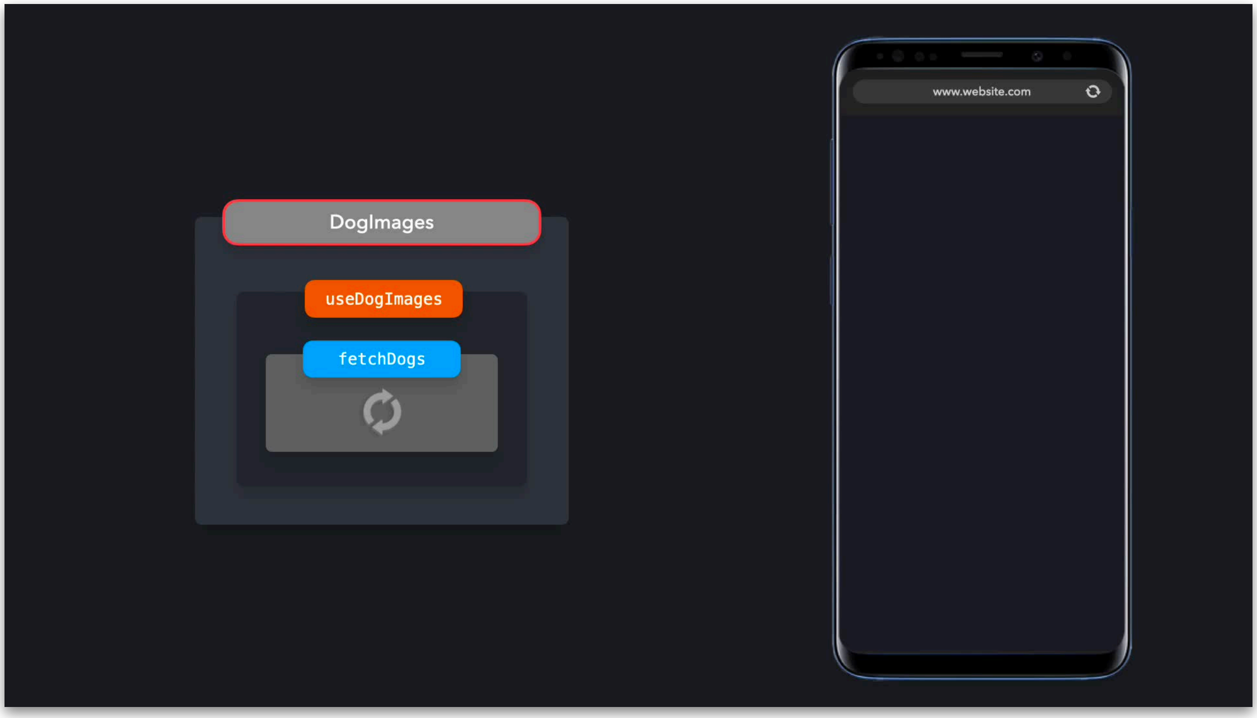
```
export default function useDogImages() {
  const [dogs, setDogs] = useState([]);

  useEffect(() => {
    fetch("https://dog.ceo/api/breed/labrador/images/random/6")
      .then(res => res.json())
      .then(({ message }) => setDogs(message));
  }, []);

  return dogs;
}
```

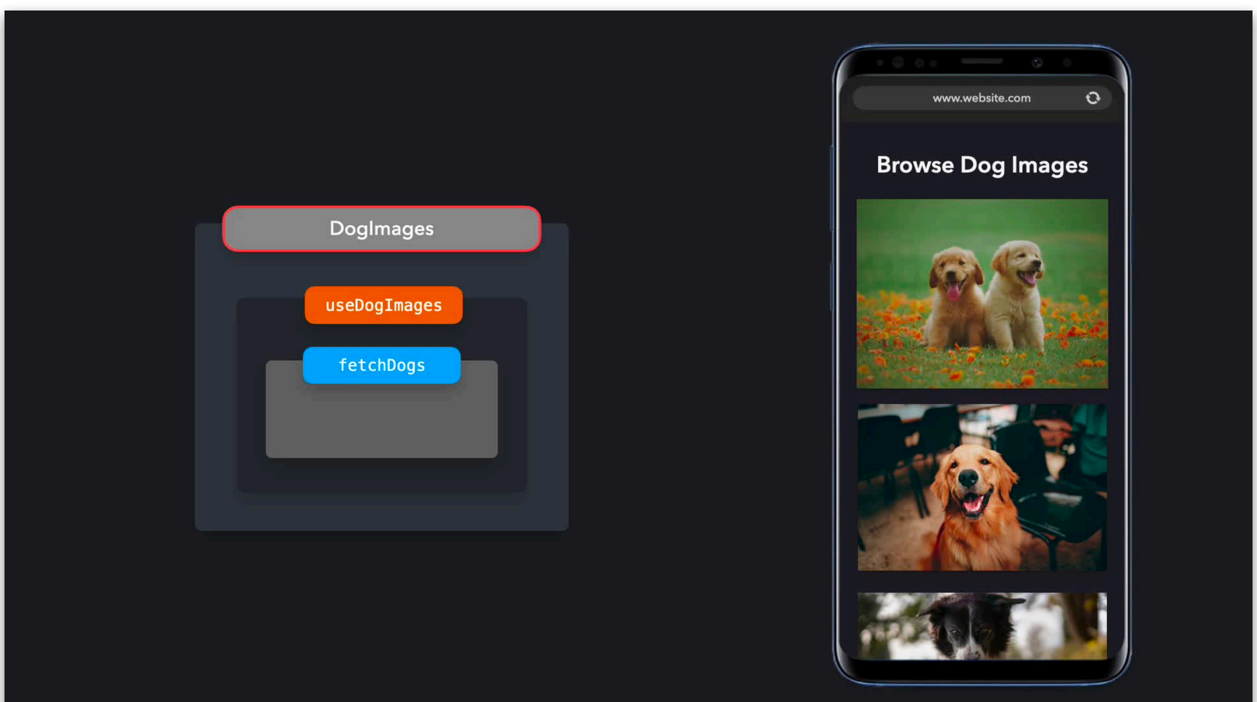
By using this hook, we no longer need the wrapping `DogsImagesContainer` container component to fetch the data, and send this to the presentational `DogsImages` component. Instead, we can use this hook directly in our presentational `DogsImages` component!

```
import React from "react";
import useDogImages from "./useDogImages";

export default function DogImages() {
  const dogs = useDogImages();

  return dogs.map((dog, i) => <img src={dog} key={i} alt="Dog" />);
}
```

```
import { useState, useEffect } from "react";

export default function useDogImages() {
  const [dogs, setDogs] = useState([]);

  useEffect(() => {
    async function fetchDogs() {
      const res = await fetch(
        "https://dog.ceo/api/breed/labrador/images/random/6"
      );
      const { message } = await res.json();
      setDogs(message);
    }

    fetchDogs();
  }, []);

  return dogs;
}
```

By using the `useDogImages` hook, we still separated the application logic from the view. We're simply using the returned data from the `useDogImages` hook, without modifying that data within the `DogImages` component.





Hooks make it easy to separate logic and view in a component, just like the Container/Presentational pattern. It saves us the extra layer that was necessary in order to wrap the presentational component within the container component.

Pros

There are many benefits to using the Container/Presentational pattern.

The Container/Presentational pattern encourages the separation of concerns. Presentational components can be pure functions which are responsible for the UI, whereas container components are responsible for the state and data of the application. This makes it easy to enforce the separation of concerns

Presentational components are easily made reusable, as they simply display data without altering this data. We can reuse the presentational components throughout our application for different purposes.

Since presentational components don't alter the application logic, the appearance of presentational components can easily be altered by someone without knowledge of the codebase, for example a designer. If the presentational component was reused in many parts of the application, the change can be consistent throughout the app.

Testing presentational components is easy, as they are usually pure functions. We know what the components will render based on which data we pass, without having to mock a data store.

Cons

The Container/Presentational pattern makes it easy to separate application logic from rendering logic. However, Hooks make it possible to achieve the same result without having to use the Container/Presentational pattern, and without having to rewrite a stateless functional component into a class component. Note that today, we don't need to create class components to use state anymore.

Although we can still use the Container/Presentational pattern, even with React Hooks, this pattern can easily be an overkill in smaller sized application.

Observer Pattern

Use observables to notify subscribers when an event occurs

With the observer pattern, we can subscribe certain objects, the observers, to another object, called the observable. Whenever an event occurs, the observable notifies all its observers!

An observable object usually contains 3 important parts:

- observers: an array of observers that will get notified whenever a specific event occurs
- `subscribe()`: a method in order to add observers to the observers list
- `unsubscribe()`: a method in order to remove observers from the observers list
- `notify()`: a method to notify all observers whenever a specific event occurs

Perfect, let’s create an observable! An easy way of creating one, is by using an ES6 class.

```
class Observable {
  constructor() {
    this.observers = [];
  }

  subscribe(func) {
    this.observers.push(func);
  }

  unsubscribe(func) {
    this.observers = this.observers.filter(observer => observer !== func);
  }

  notify(data) {
    this.observers.forEach(observer => observer(data));
  }
}
```

Awesome! We can now add observers to the list of observers with the subscribe method, remove the observers with the unsubscribe method, and notify all subscribes with the notify method.

Let’s build something with this observable. We have a very basic app that only consists of two components: a `Button`, and a `Switch`.

```jsx
export default function App() {
  return (
    <div className="App">
      <Button>Click me!</Button>
      <FormControlLabel control={<Switch />} />
    </div>
  );
}
```

We want to keep track of the user interaction with the application. Whenever a user either clicks the button or toggles the switch, we want to log this event with the timestamp. Besides logging it, we also want to create a toast notification that shows up whenever an event occurs!

Whenever the user invokes the `handleClick` or `handleToggle` function, the functions invoke the notify method on the observer. The notify method notifies all subscribers with the data that was passed by the `handleClick` or `handleToggle` function!

First, let's create the `logger` and `tastily` functions. These functions will eventually receive data from the notify method.

```jsx
import { ToastContainer, toast } from "react-toastify";

function logger(data) {
  console.log(`${Date.now()} ${data}`);
}

function toastify(data) {
  toast(data);
}

export default function App() {
  return (
    <div className="App">
      <Button>Click me!</Button>
      <FormControlLabel control={<Switch />} />
      <ToastContainer />
    </div>
  );
}
```

Currently, the `logger` and `toastify` functions are unaware of observable: the observable can't notify them yet! In order to make them observers, we'd have to subscribe them, using the subscribe method on the observable!

```
import { ToastContainer, toast } from "react-toastify";

function logger(data) {
  console.log(`${Date.now()} ${data}`);
}

function toastify(data) {
  toast(data);
}

observable.subscribe(logger);
observable.subscribe(toastify);

export default function App() {
  return (
    <div className="App">
      <Button>Click me!</Button>
      <FormControlLabel control={<Switch />} />
      <ToastContainer />
    </div>
  );
}
```

Whenever an event occurs, the `logger` and `toastify` functions will get notified. Now we just need to implement the functions that actually notify the observable: the `handleClick` and `handleToggle` functions! These functions should invoke the notify method on the observable, and pass the data that the observers should receive.

```jsx
import { ToastContainer, toast } from "react-toastify";

function logger(data) {
  console.log(`${Date.now()} ${data}`);
}

function toastify(data) {
  toast(data);
}

observable.subscribe(logger);
observable.subscribe(toastify);

export default function App() {
  function handleClick() {
    observable.notify("User clicked button!");
  }

  function handleToggle() {
    observable.notify("User toggled switch!");
  }

  return (
    <div className="App">
      <Button>Click me!</Button>
      <FormControlLabel control={<Switch />} />
      <ToastContainer />
    </div>
  );
}
```

Awesome! We just finished the entire flow: `handleClick` and `handleToggle` invoke the notify method on the observer with the data, after which the observer notifies the subscribers: the `logger` and `toastify` functions in this case.

Whenever a user interacts with either of the components, both the logger and the `toastify` functions will get notified with the data that we passed to the notify method!

Observable.js

```
class Observable {
  constructor() {
    this.observers = [];
  }

  subscribe(f) {
    this.observers.push(f);
  }

  unsubscribe(f) {
    this.observers = this.observers.filter(subscriber => subscriber !==
f);
  }

  notify(data) {
    this.observers.forEach(observer => observer(data));
  }
}

export default new Observable();
```

App.js

```
import React from "react";
import { Button, Switch, FormControlLabel } from "@material-ui/core";
import { ToastContainer, toast } from "react-toastify";
import observable from "./Observable";

function handleClick() {
  observable.notify("User clicked button!");
}

function handleToggle() {
  observable.notify("User toggled switch!");
}

function logger(data) {
  console.log(`${Date.now()} ${data}`);
}

function toastify(data) {
  toast(data, {
    position: toast.POSITION.BOTTOM_RIGHT,
    closeButton: false,
    autoClose: 2000
  });
}

observable.subscribe(logger);
observable.subscribe(toastify);

export default function App() {
  return (
    <div className="App">
      <Button variant="contained" onClick={handleClick}>
        Click me!
      </Button>
      <FormControlLabel
        control={<Switch name="" onChange={handleToggle} />}
        label="Toggle me!"
      />
      <ToastContainer />
    </div>
  );
}
```

Although we can use the observer pattern in many ways, it can be very useful when working with asynchronous, event-based data. Maybe you want certain components to get notified whenever certain data has finished downloading, or whenever users sent new messages to a message board and all other members should get notified.

Pros

Using the observer pattern is a great way to enforce separation of concerns and the single-responsiblity principle. The observer objects aren't tightly coupled to the observable object, and can be (de)coupled at any time. The observable object is responsible for monitoring the events, while the observers simply handle the received data.

Cons

If an observer becomes too complex, it may cause performance issues when notifying all subscribers.

Case study

A popular library that uses the observable pattern is RxJS.

ReactiveX combines the Observer pattern with the Iterator pattern and functional programming with collections to fill the need for an ideal way of managing sequences of events. - RxJS

With RxJS, we can create observables and subscribe to certain events! Let's look at an example that's covered in their documentation, which logs whether a user was dragging in the document or not.

```
import React from "react";
import ReactDOM from "react-dom";
import { fromEvent, merge } from "rxjs";
import { sample, mapTo } from "rxjs/operators";

import "./styles.css";

merge(
  fromEvent(document, "mousedown").pipe(mapTo(false)),
  fromEvent(document, "mousemove").pipe(mapTo(true))
)
  .pipe(sample(fromEvent(document, "mouseup")))
  .subscribe(isDragging => {
    console.log("Were you dragging?", isDragging);
  });

ReactDOM.render(
  <div className="App">
    Click or drag anywhere and check the console!
  </div>,
  document.getElementById("root")
);
```

Module Pattern

Split up your code into smaller, reusable pieces

As your application and codebase grow, it becomes increasingly important to keep your code maintainable and separated. The module pattern allows you to split up your code into smaller, reusable pieces.

Besides being able to split your code into smaller reusable pieces, modules allow you to keep certain values within your file private. Declarations within a module are scoped (encapsulated) to that module , by default. If we don't explicitly export a certain value, that value is not available outside that module. This reduces the risk of name collisions for values declared in other parts of your codebase, since the values are not available on the global scope.

ES2015 Modules

ES2015 introduced built-in JavaScript modules. A module is a file containing JavaScript code, with some difference in behavior compared to a normal script.

Let's look at an example of a module called `math.js`, containing mathematical functions.

math.js

```
function add(x, y) {
  return x + y;
}
function multiply(x) {
  return x * 2;
}
function subtract(x, y) {
  return x - y;
}
function square(x) {
  return x * x;
}
```

We have a `math.js` file containing some simple mathematical logic. We have functions that allow users to add, multiply, subtract, and get the square of values that they pass.

However, we don't just want to use these functions in the `math.js` file, we want to be able to reference them in the `index.js` file!

In order to make the functions from `math.js` available to other files, we first have to export them. In order to export code from a module, we can use the `export` keyword.

One way of exporting the functions, is by using named exports: we can simply add the `export` keyword in front of the parts that we want to publicly expose. In this case, we'll want to add the export keyword in front of every function, since `index.js` should have access to all four functions.

math.js

```
export function add(x, y) {
  return x + y;
}

export function multiply(x) {
  return x * 2;
}

export function subtract(x, y) {
  return x - y;
}

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

We just made the `add`, `multiply`, `subtract`, and `square` functions exportable! However, just exporting the values from a module is not enough to make them publicly available to all files. In order to be able to use the exported values from a module, you have to explicitly import them in the file that needs to reference them.

We have to import the values on top of the `index.js` file, by using the import keyword. To let javascript know from which module we want to import these functions, we need to add a from value and the relative path to the module.

index.js

```
import { add, multiply, subtract, square } from "./math.js";
```

We just imported the four functions from the `math.js` module in the `index.js` file! Let's try and see if we can use the functions now!

```
import { add, multiply, subtract, square } from "./math";

console.log(add(2, 3));
console.log(multiply(2));
console.log(subtract(2, 3));
console.log(square(2));
```

The reference error is gone, we can now use the exported values from the module!

A great benefit of having modules, is that we only have access to the values that we explicitly exported using the `export` keyword. Values that we didn't explicitly export using the `export` keyword, are only available within that module.

Let's create a value that should only be referenceable within the `math.js` file, called `privateValue`.

math.js

```
const privateValue = "This is a value private to the module!";

export function add(x, y) {
  return x + y;
}

export function multiply(x) {
  return x * 2;
}

export function subtract(x, y) {
  return x - y;
}

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

Notice how we didn't add the export keyword in front of privateValue. Since we didn't export the privateValue variable, we don't have access to this value outside of the `math.js` module!

By keeping the value private to the module, there is a reduced risk of accidentally polluting the global scope. You don't have to fear that you will accidentally overwrite values created by developers using your module, that may have had the same name as your private value: it prevents naming collisions.

Sometimes, the names of the exports could collide with local values.

```
import { add, multiply, subtract, square } from "./math.js";

function add(...args) {
  return args.reduce((acc, cur) => cur + acc);
} /* Error: add has  already been declared */

function multiply(...args) {
  return args.reduce((acc, cur) => cur * acc);
}
/* Error: multiply has already been declared */
```

In this case, we have functions called add and multiply in `index.js`. If we would import values with the same name, it would end up in a naming collision: `add` and `multiply` have already been declared! Luckily, we can rename the imported values, by using the as keyword.

Let's rename the imported `add` and `multiply` functions to `addValues` and `multiplyValues`.

index.js

```
import {
  add as addValues,
  multiply as multiplyValues,
  subtract,
  square
} from "./math.js";

function add(...args) {
  return args.reduce((acc, cur) => cur + acc);
}

function multiply(...args) {
  return args.reduce((acc, cur) => cur * acc);
}

/* From math.js module */
addValues(7, 8);
multiplyValues(8, 9);
subtract(10, 3);
square(3);

/* From index.js file */
add(8, 9, 2, 10);
multiply(8, 9, 2, 10);
```

Besides named exports, which are exports defined with just the `export` keyword, you can also use a default export. You can only have one default export per module.

Let's make the add function our default export, and keep the other functions as named exports. We can export a default value, by adding `export default` in front of the value.

math.js

```
export default function add(x, y) {
  return x + y;
}

export function multiply(x) {
  return x * 2;
}

export function subtract(x, y) {
  return x - y;
}

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

The difference between named exports and default exports, is the way the value is exported from the module, effectively changing the way we have to import the value.

Previously, we had to use the brackets for our named exports: `import { module } from 'module'`. With a default export, we can import the value without the brackets: import module from 'module'.

index.js

```
import * as math from "./math.js";

math.default(7, 8);
math.multiply(8, 9);
math.subtract(10, 3);
math.square(3);
```

The value that's been imported from a module without the brackets, is always the value of the default export, if there is a default export available.

Since JavaScript knows that this value is always the value that was exported by default, we can give the imported default value another name than the name we exported it with. Instead of importing the add function using the name add, we can call it `addValues`, for example.

index.js

```
import addValues, { multiply, subtract, square } from "./math.js";

addValues(7, 8);
multiply(8, 9);
subtract(10, 3);
square(3);
```

Even though we exported the function called `add`, we can import it calling it anything we like, since JavaScript knows you are importing the default export.

We can also import all exports from a module, meaning all named exports and the default export, by using an asterisk `*` and giving the name we want to import the module as. The value of the import is equal to an object containing all the imported values.

Say that you want to import the entire module as `math`.

index.js

```
import * as math from "./math.js";
```

The imported values are properties on the `math` object.

index.js

```
import * as math from "./math.js";

math.default(7, 8);
math.multiply(8, 9);
math.subtract(10, 3);
math.square(3);
```

In this case, we're importing all exports from a module. Be careful when doing this, since you may end up unnecessarily importing values. Using the * only imports all exported values. Values private to the module are still not available in the file that imports the module, unless you explicitly exported them.

React

When building applications with React, you often have to deal with a large amount of components. Instead of writing all of these components in one file, we can separate the components in their own files, essentially creating a module for each component.

We have a basic todo-list, containing a list, list items, an input field, and a button.

App.js

```
import React from "react";
import { render } from "react-dom";

import { TodoList } from "./components/TodoList";
import "./styles.css";

render(
  <div className="App">
    <TodoList />
  </div>,
  document.getElementById("root")
);
```

Button.js

```
import React from "react";
import Button from "@material-ui/core/Button";

export default function CustomButton(props) {
  return (
    <Button {...props}>
      {props.children}
    </Button>
  );
}
```

Input.js

```
import React from "react";
import Input from "@material-ui/core/Input";

export default function CustomInput(props, { variant = "standard" }) {
  return (
    <Input
      {...props}
      variant={variant}
      placeholder="Type..."
    />
  );
}
```

We just split our components in their separate files:

- `TodoList.js` for the `List` component
- `Button.js` for the customized `Button` component
- `Input.js` for the customized `Input` component.

Throughout the app, we don't want to use the default `Button` and `Input` component, imported from the material-ui library. Instead, we want to use our custom version of the components, by adding custom styles to it defined in the styles object in their files.

Rather than importing the default `Button` and `Input` component each time in our application and adding custom styles to it over and over, we can now simply import the default `Button` and `Input` component once, add styles, and export our custom component.

Dynamic import

When importing all modules on the top of a file, all modules get loaded before the rest of the file. In some cases, we only need to import a module based on a certain condition. With a dynamic import, we can import modules on demand.

```
import("module").then(module => {
  module.default();
  module.namedExport();
});

// Or with async/await
(async () => {
  const module = await import("module");
  module.default();
  module.namedExport();
})();
```

Let's dynamically import the `math.js` example used in the previous paragraphs. The module only gets loaded, if the user clicks on the button.

```javascript
const button = document.getElementById("btn");

button.addEventListener("click", () => {
  import("./math.js").then((module) => {
    console.log("Add: ", module.add(1, 2));
    console.log("Multiply: ", module.multiply(3, 2));

    const button = document.getElementById("btn");
    button.innerHTML = "Check the console";
  });
});
```

By dynamically importing modules, we can reduce the page load time. We only have to load, parse, and compile the code that the user really needs, when the user needs it.

With the module pattern, we can encapsulate parts of our code that should not be publicly exposed. This prevents accidental name collision and global scope pollution, which makes working with multiple dependencies and namespaces less risky. In order to be able to use ES2015 modules in all JavaScript runtimes, a transpiler such as Babel is needed.

Mixin Pattern

Add functionality to objects or classes without inheritance

A mixin is an object that we can use in order to add reusable functionality to another object or class, without using inheritance. We can't use mixins on their own: their sole purpose is to add functionality to objects or classes without inheritance.

Let's say that for our application, we need to create multiple dogs. However, the basic dog that we create doesn't have any properties but a name property.

```
class Dog {
  constructor(name) {
    this.name = name;
  }
}
```

A dog should be able to do more than just have a name. It should be able to bark, wag its tail, and play! Instead of adding this directly to the `Dog`, we can create a mixin that provides the `bark`, `wagTail` and `play` property for us.

```
const dogFunctionality = {
  bark: () => console.log("Woof!"),
  wagTail: () => console.log("Wagging my tail!"),
  play: () => console.log("Playing!")
};
```

We can add the `dogFunctionality` mixin to the `Dog` prototype with the Object.assign method. This method lets us add properties to the target object: `Dog.prototype` in this case. Each new instance of `Dog` will have access to the the properties of `dogFunctionality`, as they're added to the `Dog`'s prototype!

```
class Dog {
  constructor(name) {
    this.name = name;
  }
}

const dogFunctionality = {
  bark: () => console.log("Woof!"),
  wagTail: () => console.log("Wagging my tail!"),
  play: () => console.log("Playing!")
};

Object.assign(Dog.prototype, dogFunctionality);
```

Let's create our first pet, `pet1`, called Daisy. As we just added the `dogFunctionality` mixin to the Dog's prototype, Daisy should be able to walk, wag her tail, and play!

```
const pet1 = new Dog("Daisy");

pet1.name; // Daisy
pet1.bark(); // Woof!
pet1.play(); // Playing!
```

Perfect! Mixins make it easy for us to add custom functionality to classes or objects without using inheritance.

Although we can add functionality with mixins without inheritance, mixins themselves can use inheritance!

Most mammals (besides dolphins.. and maybe some more) can walk and sleep as well. A dog is a mammal, and should be able to walk and sleep! Let's create a `animalFunctionality` mixin that adds the `walk` and `sleep` properties.

```
const animalFunctionality = {
  walk: () => console.log("Walking!"),
  sleep: () => console.log("Sleeping!")
};
```

We can add these properties to the `dogFunctionality` prototype, using `Object.assign`. In this case, the target object is `dogFunctionality`.

```
const animalFunctionality = {
  walk: () => console.log("Walking!"),
  sleep: () => console.log("Sleeping!")
};

const dogFunctionality = {
  bark: () => console.log("Woof!"),
  wagTail: () => console.log("Wagging my tail!"),
  play: () => console.log("Playing!"),
  walk() {
    super.walk();
  },
  sleep() {
    super.sleep();
  }
};

Object.assign(dogFunctionality, animalFunctionality);
Object.assign(Dog.prototype, dogFunctionality);
```

Perfect! Any new instance of Dog can now access the walk and sleep methods as well.

```
class Dog {
  constructor(name) {
    this.name = name;
  }
}

const animalFunctionality = {
  walk: () => console.log("Walking!"),
  sleep: () => console.log("Sleeping!")
};

const dogFunctionality = {
  __proto__: animalFunctionality,
  bark: () => console.log("Woof!"),
  wagTail: () => console.log("Wagging my tail!"),
  play: () => console.log("Playing!"),
  walk() {
    super.walk();
  },
  sleep() {
    super.sleep();
  }
};

Object.assign(Dog.prototype, dogFunctionality);

const pet1 = new Dog("Daisy");

console.log(pet1.name);
pet1.bark();
pet1.play();
pet1.walk();
pet1.sleep();
```

An example of a mixin in the real world is visible on the Window interface in a browser environment. The `Window` object implements many of its properties from the `WindowOrWorkerGlobalScope` and `WindowEventHandlers` mixins, which allow us to have access to properties such as `setTimeout` and `setInterval`, `indexedDB`, and `isSecureContext`.

Since it's a mixin, thus is only used to add functionality to objects, you won't be able to create objects of type `WindowOrWorkerGlobalScope`.

```
window.indexedDB.open("toDoList");

window.addEventListener("beforeunload", event => {
  event.preventDefault();
  event.returnValue = "";
});

window.onbeforeunload = () => console.log("Unloading!");

console.log("From WindowEventHandlers mixin: onbeforeunload",
  window.onbeforeunload
);

console.log("From WindowOrWorkerGlobalScope mixin: isSecureContext",
  window.isSecureContext
);

console.log("WindowEventHandlers itself is undefined",
  window.WindowEventHandlers
);

console.log("WindowOrWorkerGlobalScope itself is undefined",
  window.WindowOrWorkerGlobalScope
);
```

React (pre ES6)

Mixins were often used to add functionality to React components before the introduction of ES6 classes. The React team discourages the use of mixins as it easily adds unnecessary complexity to a component, making it hard to maintain and reuse. The React team encouraged the use of higher order components instead, which can now often be replaced by Hooks.

Mixins allow us to easily add functionality to objects without inheritance by injecting functionality into an object's prototype. Modifying an object's prototype is seen as bad practice, as it can lead to prototype pollution and a level of uncertainty regarding the origin of our functions.

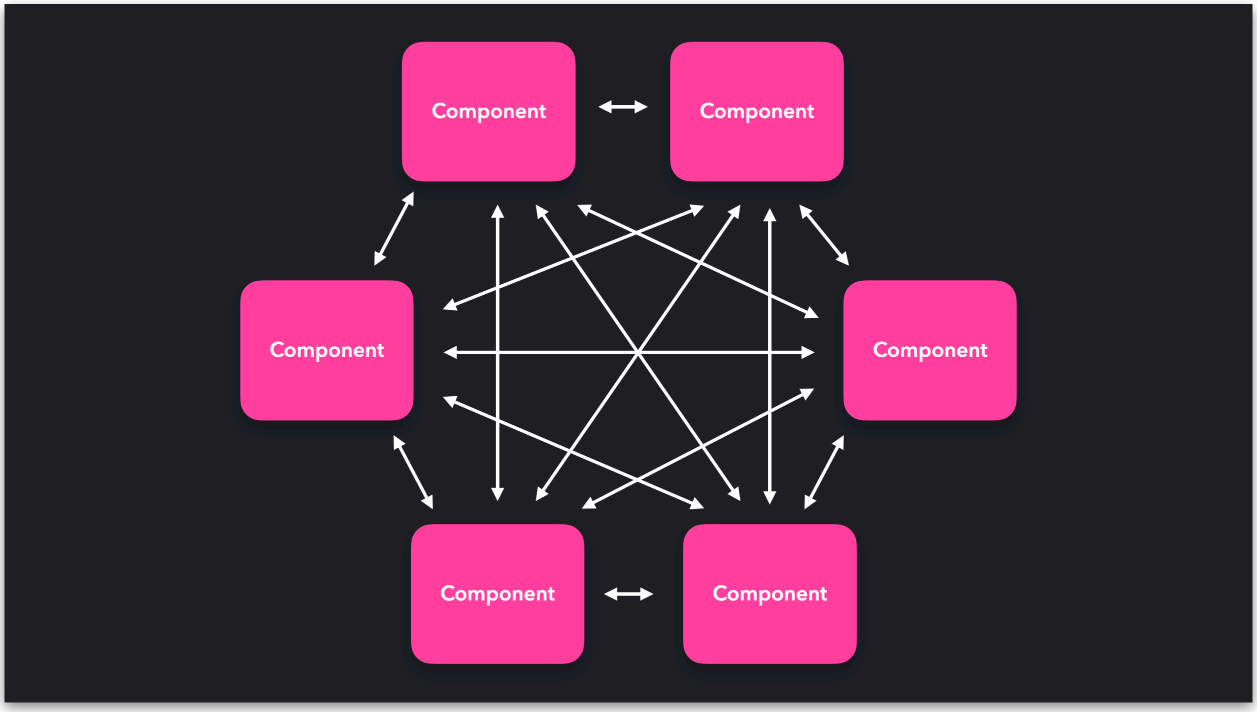
Mediator/ Middleware Pattern

Use a central mediator object to handle communication between components

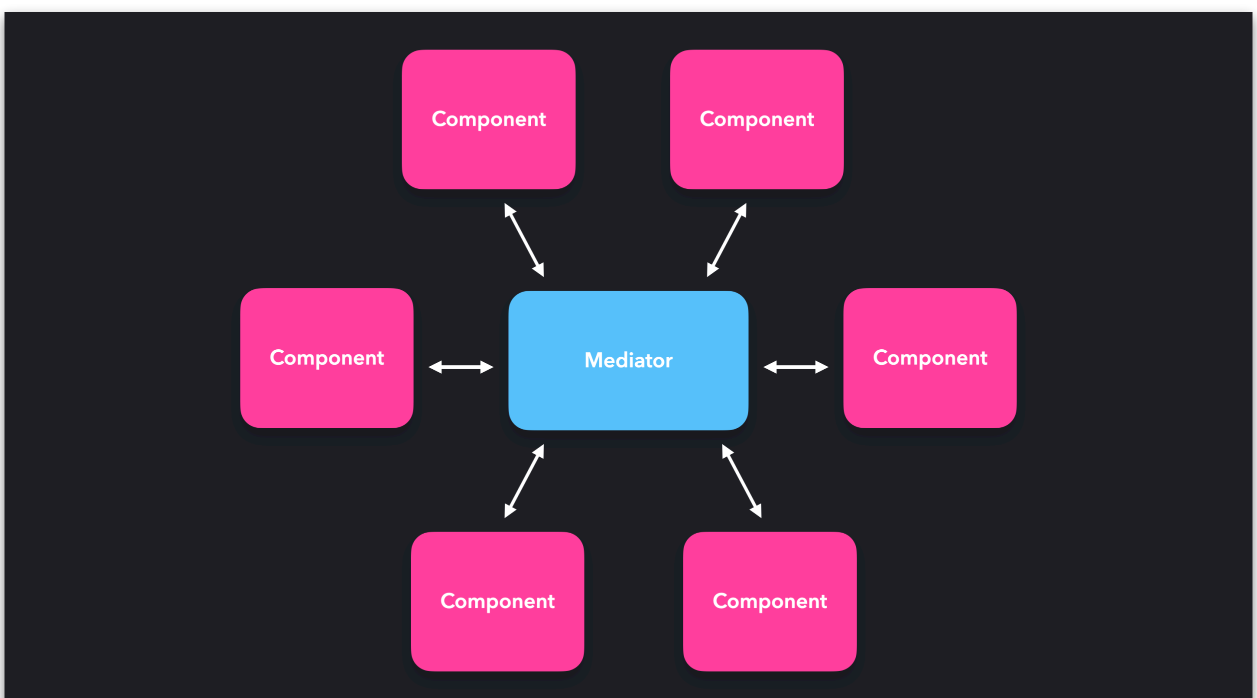
The mediator pattern makes it possible for components to interact with each other through a central point: the mediator. Instead of directly talking to each other, the mediator receives the requests, and sends them forward! In JavaScript, the mediator is often nothing more than an object literal or a function.

You can compare this pattern to the relationship between an air traffic controller and a pilot. Instead of having the pilots talk to each other directly, which would probably end up being quite chaotic, the pilots talk the air traffic controller. The air traffic controller makes sure that all planes receive the information they need in order to fly safely, without hitting the other airplanes.

Although we're hopefully not controlling airplanes in JavaScript, we often have to deal with multidirectional data between objects. The communication between the components can get rather confusing if there is a large number of components.



Instead of letting every objects talk directly to the other objects, resulting in a many-to-many relationship, the object's requests get handled by the mediator. The mediator processes this request, and sends it forward to where it needs to be.



A good use case for the mediator pattern is a chatroom! The users within the chatroom won't talk to each other directly. Instead, the chatroom serves as the mediator between the users.

```
class ChatRoom {
  logMessage(user, message) {
    const time = new Date();
    const sender = user.getName();

    console.log(`${time} [${sender}]: ${message}`);
  }
}

class User {
  constructor(name, chatroom) {
    this.name = name;
    this.chatroom = chatroom;
  }

  getName() {
    return this.name;
  }

  send(message) {
    this.chatroom.logMessage(this, message);
  }
}
```

We can create new users that are connected to the chat room. Each user instance has a send method which we can use in order to send messages.

```
class ChatRoom {
  logMessage(user, message) {
    const sender = user.getName();
    console.log(`${new Date().toLocaleString()} [${sender}]: ${message}`);
  }
}

class User {
  constructor(name, chatroom) {
    this.name = name;
    this.chatroom = chatroom;
  }

  getName() {
    return this.name;
  }

  send(message) {
    this.chatroom.logMessage(this, message);
  }
}

const chatroom = new ChatRoom();

const user1 = new User("John Doe", chatroom);
const user2 = new User("Jane Doe", chatroom);

user1.send("Hi there!");
user2.send("Hey!");
```

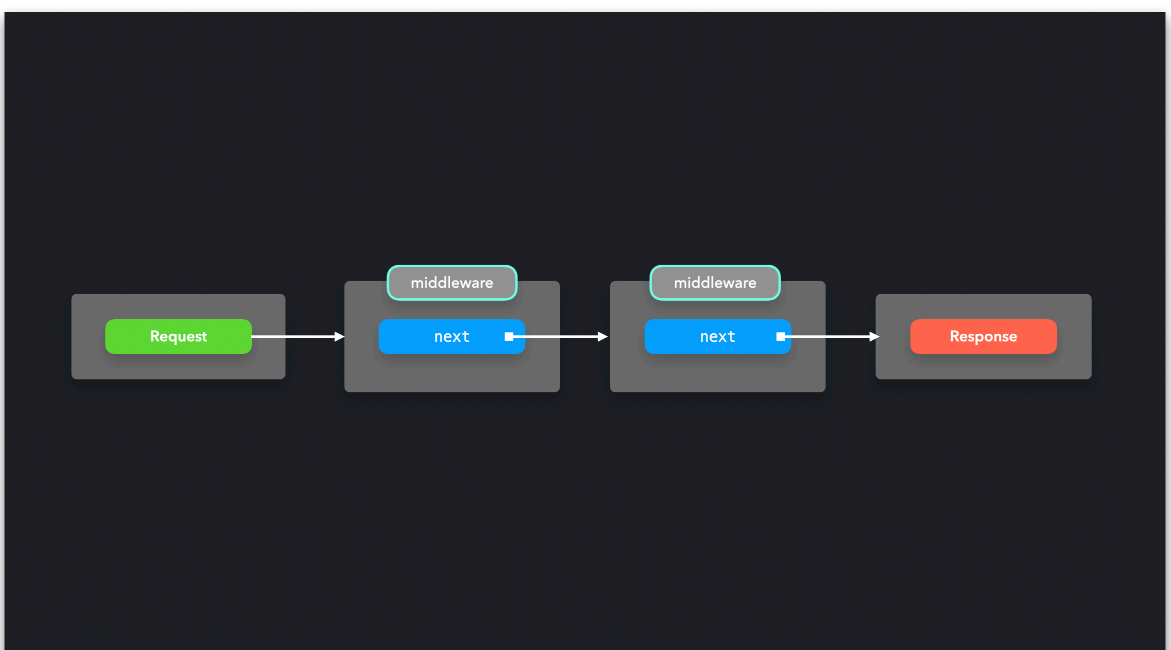
Case Study

Express.js is a popular web application server framework. We can add callbacks to certain routes that the user can access.

Say we want add a header to the request if the user hits the root `/`. We can add this header in a middleware callback.

```
const app = require("express")();

app.use("/", (req, res, next) => {
  req.headers["test-header"] = 1234;
  next();
});
```

The `next` method calls the next callback in the request-response cycle. We'd effectively be creating a chain of middleware functions that sit between the request and the response, or vice versa.



Let's add another middleware function that checks whether the test-header was added correctly. The change added by the previous middleware function will be visible throughout the chain.

```
const app = require("express")();

app.use(
  "/",
  (req, res, next) => {
    req.headers["test-header"] = 1234;
    next();
  },
  (req, res, next) => {
    console.log(`Request has test header: ${!!req.headers["test-header"]}`);
    next();
  }
);
```

Perfect! We can track and modify the request object all the way to the response through one or multiple middleware functions.

```
const app = require("express")();
const html = require("./data");

app.use(
  "/",
  (req, res, next) => {
    req.headers["test-header"] = 1234;
    next();
  },
  (req, res, next) => {
    console.log(`Request has test header: ${!!req.headers["test-header"]}`);
    next();
  }
);

app.get("/", (req, res) => {
  res.set("Content-Type", "text/html");
  res.send(Buffer.from(html));
});

app.listen(8080, function() {
  console.log("Server is running on 8080");
});
```

Every time the user hits a root endpoint '/', the two middleware callbacks will be invoked.

The middleware pattern makes it easy for us to simplify many-to-many relationships between objects, by letting all communication flow through one central point.

Render Props Pattern

Pass JSX elements to components through props

In the section on Higher Order Components, we saw that being able to reuse component logic can be very convenient if multiple components need access to the same data, or contain the same logic.

Another way of making components very reusable, is by using the render prop pattern. A render prop is a prop on a component, which value is a function that returns a JSX element. The component itself does not render anything besides the render prop. Instead, the component simply calls the render prop, instead of implementing its own rendering logic.

Imagine that we have a `Title` component. In this case, the `Title` component shouldn't do anything besides rendering the value that we pass. We can use a render prop for this! Let's pass the value that we want the `Title` component to render to the render prop.

```
<Title render={() => <h1>I am a render prop!</h1>} />
```

Within the `Title` component, we can render this data by returning the invoked render prop!

```
const Title = props => props.render();
```

To the `Title` element, we have to pass a prop called render, which is a function that returns a React element.

```
import "./styles.css";

const Title = (props) => props.render();

render(
  <div className="App">
    <Title
      render={() => (
        <h1>I am a render prop!</h1>
      )}
    />
  </div>,
  document.getElementById("root")
);
```

Perfect, works smoothly! The cool thing about render props, is that the component that receives the prop is very reusable. We can use it multiple times, passing different values to the render prop each time.

```
import React from "react";
import { render } from "react-dom";
import "./styles.css";

const Title = (props) => props.render();

render(
  <div className="App">
    <Title render={() => <h1>✨ First render prop! ✨</h1>} />
    <Title render={() => <h2>🔥 Second render prop! 🔥</h2>} />
    <Title render={() => <h3>🚀 Third render prop! 🚀</h3>} />
  </div>,
  document.getElementById("root")
);
```

Although they're called render props, a render prop doesn't have to be called render. Any prop that renders JSX is considered a render prop! Let's rename the render props that were used in the previous example, and give them specific names instead!

```
import React from "react";
import { render } from "react-dom";
import "./styles.css";

const Title = (props) => (
  <>
    {props.renderFirstComponent()}
    {props.renderSecondComponent()}
    {props.renderThirdComponent()}
  </>
);

render(
  <div className="App">
    <Title
      renderFirstComponent={() => <h1>✨ First render prop! ✨</h1>}
      renderSecondComponent={() => <h2>🔥 Second render prop! 🔥</h2>}
      renderThirdComponent={() => <h3>🚀 Third render prop! 🚀</h3>}
    />
  </div>,
  document.getElementById("root")
);
```

Great! We've just seen that we can use render props in order to make a component reusable, as we can pass different data to the render prop each time. But, why would you want to use this?

A component that takes a render prop usually does a lot more than simply invoking the render prop. Instead, we usually want to pass data from the component that takes the render prop, to the element that we pass as a render prop!

```
function Component(props) {
  const data = { ... }

  return props.render(data)
}
```

The render prop can now receive this value that we passed as its argument.

```
<Component render={data => <ChildComponent data={data} />}
```

Let's look at an example! We have a simple app, where a user can type a temperature in Celsius. The app shows the value of this temperature in Fahrenheit and Kelvin.

```jsx
import React, { useState } from "react";
import "./styles.css";

function Input() {
  const [value, setValue] = useState("");

  return (
    <input
      type="text"
      value={value}
      onChange={e => setValue(e.target.value)}
      placeholder="Temp in °C"
    />
  );
}

export default function App() {
  return (
    <div className="App">
      <h1>☃️ Temperature Converter 🌞</h1>
      <Input />
      <Kelvin />
      <Fahrenheit />
    </div>
  );
}

function Kelvin({ value = 0 }) {
  return <div className="temp">{value + 273.15}K</div>;
}

function Fahrenheit({ value = 0 }) {
  return <div className="temp">{(value * 9) / 5 + 32}°F</div>;
}
```

Hmm.. Currently there's a problem. The stateful Input component contains the value of the user's input, meaning that the Fahrenheit and Kelvin component don't have access to the user's input!

Lifting state

One way to make the users input available to both the `Fahrenheit` and `Kelvin` component in the above example, we'd have to lift the state

In this case, we have a stateful `Input` component. However, the sibling components `Fahrenheit` and `Kelvin` also need access to this data. Instead of having a stateful Input component, we can lift the state up to the first common ancestor component that has a connection to `Input`, `Fahrenheit` and `Kelvin`: the App component in this case!

```
function Input({ value, handleChange }) {
  return <input value={value} onChange={e => handleChange(e.target.value)} />;
}

export default function App() {
  const [value, setValue] = useState("");

  return (
    <div className="App">
      <h1>☃️ Temperature Converter 🌞</h1>
      <Input value={value} handleChange={setValue} />
      <Kelvin value={value} />
      <Fahrenheit value={value} />
    </div>
  );
}
```

Although this is a valid solution, it can be tricky to lift state in larger applications with components that handle many children. Each state change could cause a re-render of all the children, even the ones that don't handle the data, which could negatively affect the performance of your app.

Instead, we can use render props! Let's change the Input component in a way that it can receive render props

```
function Input(props) {
  const [value, setValue] = useState("");

  return (
    <>
      <input
        type="text"
        value={value}
        onChange={e => setValue(e.target.value)}
        placeholder="Temp in °C"
      />
      {props.render(value)}
    </>
  );
}

export default function App() {
  return (
    <div className="App">
      <h1>☃️ Temperature Converter 🌞</h1>
      <Input
        render={value => (
          <>
            <Kelvin value={value} />
            <Fahrenheit value={value} />
          </>
        )}
      />
    </div>
  );
}
```

Perfect, the `Kelvin` and `Fahrenheit` components now have access to the value of the user's input!

Besides regular JSX components, we can pass functions as children to React components. This function is available to us through the children prop, which is technically also a render prop.

Let's change the `Input` component. Instead of explicitly passing the render prop, we'll just pass a function as a child for the `Input` component.

```
export default function App() {
  return (
    <div className="App">
      <h1>☃️ Temperature Converter 🌞</h1>
      <Input>
        {value => (
          <>
            <Kelvin value={value} />
            <Fahrenheit value={value} />
          </>
        )}
      </Input>
    </div>
  );
}
```

.

We have access to this function, through the `props.children` prop that's available on the Input component. Instead of calling `props.render` with the value of the user input, we'll call props.children with the value of the user input.

```
function Input(props) {
  const [value, setValue] = useState("");

  return (
    <>
      <input
        type="text"
        value={value}
        onChange={e => setValue(e.target.value)}
        placeholder="Temp in °C"
      />
      {props.children(value)}
    </>
  );
}
```

Hooks

In some cases, we can replace render props with Hooks. A good example of this is Apollo Client.

One way to use Apollo Client is through the `Mutation` and `Query` components. Let's look at the same Input example that was covered in the Higher Order Components section. Instead of using a the `graphql()` higher order component, we'll now use the `Mutation` component that receives a render prop.

```
import React from "react";
import "./styles.css";

import { Mutation } from "react-apollo";
import { ADD_MESSAGE } from "./resolvers";

export default class Input extends React.Component {
  constructor() {
    super();
    this.state = { message: "" };
  }

  handleChange = (e) => {
    this.setState({ message: e.target.value });
  };

  render() {
    return (
      <Mutation
        mutation={ADD_MESSAGE}
        variables={{ message: this.state.message }}
        onCompleted={() =>
          console.log(`Added with render prop: ${this.state.message} `)
        }
      >
        {(addMessage) => (
          <div className="input-row">
            <input
              onChange={this.handleChange}
              type="text"
              placeholder="Type something..."
            />
            <button onClick={addMessage}>Add</button>
          </div>
        )}
      </Mutation>
    );
  }
}
```

In order to pass data down from the `Mutation` component to the elements that need the data, we pass a function as a child. The function receives the value of the data through its arguments.

```
<Mutation mutation={...} variables={...}>
  {addMessage => <div className="input-row">...</div>}
</Mutation>
```

Although we can still use the render prop pattern and is often preferred compared to the higher order component pattern, it has its downsides.

One of the downsides is deep component nesting. We can nest multiple `Mutation` or `Query` components, if a component needs access to multiple mutations or queries.

```
<Mutation mutation={...} variables={...}>
  {addMessage => <div cl<Mutation mutation={FIRST_MUTATION}>
  {firstMutation => (
    <Mutation mutation={SECOND_MUTATION}>
      {secondMutation => (
        <Mutation mutation={THIRD_MUTATION}>
          {thirdMutation => (
            <Element
              firstMutation={firstMutation}
              secondMutation={secondMutation}
              thirdMutation={thirdMutation}
            />
          )}
        </Mutation>
      )}
    </Mutation>
  )}
</Mutation>assName="input-row">...</div>}
</Mutation>
```

After the release of Hooks, Apollo added Hooks support to the Apollo Client library. Instead of using the `Mutation` and `Query` render props, developers can now directly access the data through the hooks that the library provides.

Let's look at an example that uses the exact same data as we previously saw in the example with the `Query` render prop. This time, we'll provide the data to the component by using the `useQuery` hook that Apollo Client provided for us.

```
import React, { useState } from "react";
import "./styles.css";

import { useMutation } from "@apollo/react-hooks";
import { ADD_MESSAGE } from "./resolvers";

export default function Input() {
  const [message, setMessage] = useState("");
  const [addMessage] = useMutation(ADD_MESSAGE, {
    variables: { message }
  });

  return (
    <div className="input-row">
      <input
        onChange={(e) => setMessage(e.target.value)}
        type="text"
        placeholder="Type something..."
      />
      <button onClick={addMessage}>Add</button>
    </div>
  );
}
```

By using the `useQuery` hook, we reduced the amount of code that was needed in order to provide the data to the component.

Pros

Sharing logic and data among several components is easy with the render props pattern. Components can be made very reusable, by using a render or children prop. Although the Higher Order Component pattern mainly solves the same issues, namely reusability and sharing data, the render props pattern solves some of the issues we could encounter by using the HOC pattern.

The issue of naming collisions that we can run into by using the HOC pattern no longer applies by using the render props pattern, since we don't automatically merge props. We explicitly pass the props down to the child components, with the value provided by the parent component.

Since we explicitly pass props, we solve the HOC's implicit props issue. The props that should get passed down to the element, are all visible in the render prop's arguments list. This way, we know exactly where certain props come from.

We can separate our app's logic from rendering components through render props. The stateful component that receives a render prop can pass the data onto stateless components, which merely render the data.

Cons

The issues that we tried to solve with render props, have largely been replaced by React Hooks. As Hooks changed the way we can add reusability and data sharing to components, they can replace the render props pattern in many cases.

Since we can't add lifecycle methods to a render prop, we can only use it on components that don't need to alter the data they receive.

Hooks Pattern

Use functions to reuse stateful logic among multiple components throughout the app

React 16.8 introduced a new feature called Hooks. Hooks make it possible to use React state and lifecycle methods, without having to use a ES2015 class component.

Although Hooks are not necessarily a design pattern, Hooks play a very important role in your application design. Many traditional design patterns can be replaced by Hooks.

Class components

Before Hooks were introduced in React, we had to use class components in order to add state and lifecycle methods to components. A typical class component in React can look something like:

```
class MyComponent extends React.Component {
  /* Adding state and binding custom methods */
  constructor() {
    super()
    this.state = { ... }

    this.customMethodOne = this.customMethodOne.bind(this)
    this.customMethodTwo = this.customMethodTwo.bind(this)
  }

  /* Lifecycle Methods */
  componentDidMount() { ...}
  componentWillUnmount() { ... }

  /* Custom methods */
  customMethodOne() { ... }
  customMethodTwo() { ... }

  render() { return { ... }}
}
```

A class component can contain a state in its constructor, lifecycle methods such as `componentDidMount` and `componentWillUnmount` to perform side effects based on a component's lifecycle, and custom methods to add extra logic to a class.

Although we can still use class components after the introduction of React Hooks, using class components can have some downsides! Let's look at some of the most common issues when using class components.

Understanding ES2015 classes

Since class components were the only component that could handle state and lifecycle methods before React Hooks, we often ended up having to refactor functional components into a class components, in order to add the extra functionality.

In this example, we have a simple div that functions as a button.

```
function Button() {
  return <div className="btn">disabled</div>;
}
```

Instead of always displaying disabled, we want to change it to enabled when the user clicks on the button, and add some extra CSS styling to the button when that happens.

In order to do that, we need to add state to the component in order to know whether the status is enabled or disabled. This means that we'd have to refactor the functional component entirely, and make it a class component that keeps track of the button's state.

```
export default class Button extends React.Component {
  constructor() {
    super();
    this.state = { enabled: false };
  }

  render() {
    const { enabled } = this.state;
    const btnText = enabled ? "enabled" : "disabled";

    return (
      <div
        className={`btn enabled-${enabled}`}
        onClick={() => this.setState({ enabled: !enabled })}
      >
        {btnText}
      </div>
    );
  }
}
```

Finally, our button works the way we want it to!

```
import React from "react";
import "./styles.css";

export default class Button extends React.Component {
  constructor() {
    super();
    this.state = { enabled: false };
  }

  render() {
    const { enabled } = this.state;
    const btnText = enabled ? "enabled" : "disabled";

    return (
      <div
        className={`btn enabled-${enabled}`}
        onClick={() => this.setState({ enabled: !enabled })}
      >
        {btnText}
      </div>
    );
  }
}
```

In this example, the component is very small and refactoring wasn't a such a great deal. However, your real-life components probably contain of many more lines of code, which makes refactoring the component a lot more difficult.

Besides having to make sure you don't accidentally change any behavior while refactoring the component, you also need to understand how ES2015 classes work. Why do we have to bind the custom methods? What does the constructor do? Where does the this keyword come from? It can be difficult to know how to refactor a component properly without accidentally changing the data flow.

Restructuring

The common way to share code among several components, is by using the Higher Order Component or Render Props pattern. Although both patterns are valid and a good practice, adding those patterns at a later point in time requires you to restructure your application.

Besides having to restructure your app, which is trickier the bigger your components are, having many wrapping components in order to share code among deeper nested components can lead to something that's best referred to as a wrapper hell. It's not uncommon to open your dev tools and seeing a structure similar to:

```
<WrapperOne>
  <WrapperTwo>
    <WrapperThree>
      <WrapperFour>
        <WrapperFive>
          <Component>
            <h1>Finally in the component!</h1>
          </Component>
        </WrapperFive>
      </WrapperFour>
    </WrapperThree>
  </WrapperTwo>
</WrapperOne>
```

The wrapper hell can make it difficult to understand how data is flowing through your application, which can make it harder to figure out why unexpected behavior is happening.

Complexity

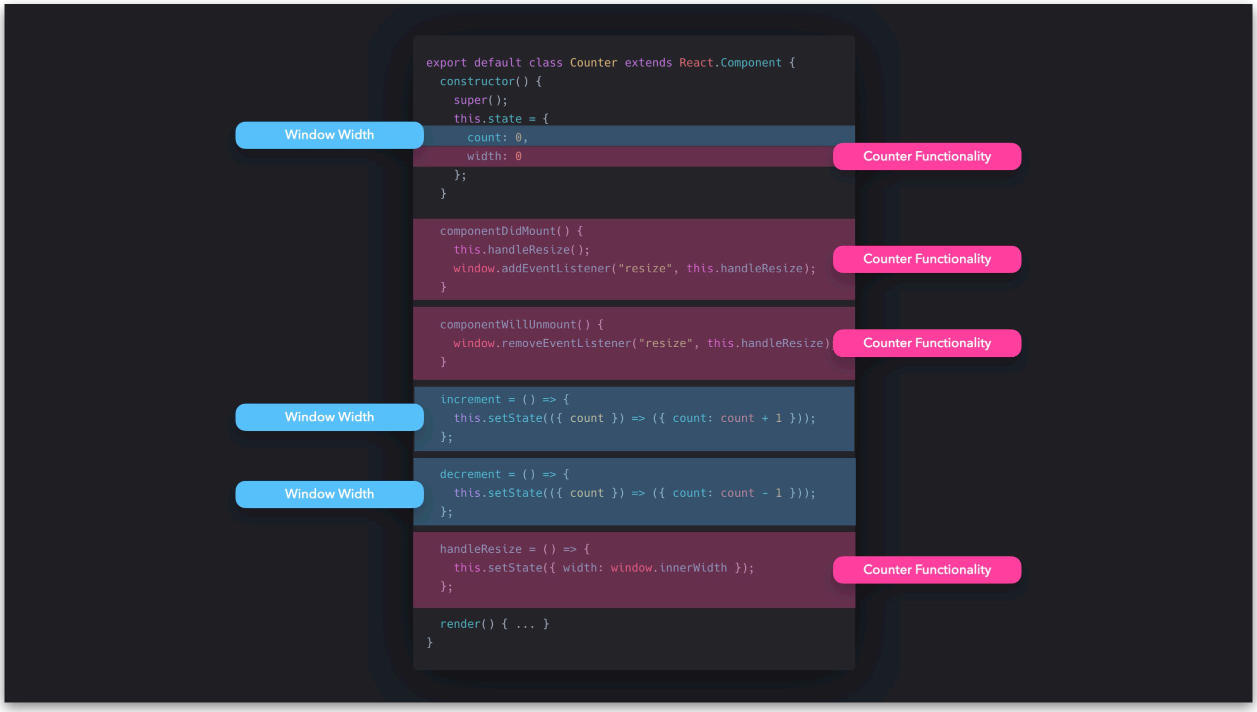
As we add more logic to class components, the size of the component increases fast. Logic within that component can get tangled and unstructured, which can make it difficult for developers to understand where certain logic is used in the class component. This can make debugging and optimizing performance more difficult.

Lifecycle methods also require quite a lot of duplication in the code. Let's take a look at an example, which uses a Counter component and a Width component.

```
import React from "react";
import "./styles.css";

import { Count } from "./Count";
import { Width } from "./Width";

export default class Counter extends React.Component {
  constructor() {
    super();
    this.state = {
      count: 0,
      width: 0
    };
  }
```

```
  componentDidMount() {
    this.handleResize();
    window.addEventListener("resize", this.handleResize);
  }

  componentWillUnmount() {
    window.removeEventListener("resize", this.handleResize);
  }

  increment = () => {
    this.setState(({ count }) => ({ count: count + 1 }));
  };

  decrement = () => {
    this.setState(({ count }) => ({ count: count - 1 }));
  };

  handleResize = () => {
    this.setState({ width: window.innerWidth });
  };

  render() {
    return (
      <div className="App">
        <Count
          count={this.state.count}
          increment={this.increment}
          decrement={this.decrement}
        />
        <div id="divider" />
        <Width width={this.state.width} />
      </div>
    );
  }
}
```

The way the App component is structured can be visualized as the following:



Although this is a small component, the logic within the component is already quite tangled. Whereas certain parts are specific for the counter logic, other parts are specific for the width logic. As your component grows, it can get increasingly difficult to structure logic within your component, find related logic within the component.

Besides tangled logic, we're also duplicating some logic within the lifecycle methods. In both `componentDidMount` and `componentWillUnmount`, we're customizing the behavior of the app based on the window's resize event.

Hooks

It's quite clear that class components aren't always a great feature in React. In order to solve the common issues that React developers can run into when using class components, React introduced React Hooks. React Hooks are functions that you can use to manage a components state and lifecycle methods. React Hooks make it possible to:

- add state to a functional component
- manage a component's lifecycle without having to use lifecycle methods such as `componentDidMount` and `componentWillUnmount`
- reuse the same stateful logic among multiple components throughout the app

First, let's take a look at how we can add state to a functional component, using React Hooks.

State Hook

React provides a hook that manages state within a functional component, called `useState`.

Let's see how a class component can be restructured into a functional component, using the useState hook. We have a class component called Input, which simply renders an input field. The value of input in the state updates, whenever the user types anything in the input field.

```jsx
class Input extends React.Component {
  constructor() {
    super();
    this.state = { input: "" };

    this.handleInput = this.handleInput.bind(this);
  }

  handleInput(e) {
    this.setState({ input: e.target.value });
  }

  render() {
    <input onChange={handleInput} value={this.state.input} />;
  }
}
```

In order to use the `useState` hook, we need to access the `useState` method that React provides for us. The `useState` method expects an argument: this is the initial value of the state, an empty string in this case.

We can destructure two values from the useState method:

1. The current value of the state.

2. The method with which we can update the state.

```js
const [value, setValue] = React.useState(initialValue);
```

The first value can be compared to a class component's `this.state.[value]`. The second value can be compared to a class component's `this.setState` method.

Since we're dealing with the value of an input, let's call the current value of the state input, and the method in order to update the state `setInput`. The initial value should be an empty string.

```
const [input, setInput] = React.useState("");
```

We can now refactor the `Input` class component into a stateful functional component.

```
function Input() {
  const [input, setInput] = React.useState("");

  return <input onChange={(e) => setInput(e.target.value)} value={input} />;
}
```

The value of the input field is equal to the current value of the input state, just like in the class component example. When the user types in the input field, the value of the input state updates accordingly, using the setInput method.

```
import React, { useState } from "react";

export default function Input() {
  const [input, setInput] = useState("");

  return (
    <input
      onChange={e => setInput(e.target.value)}
      value={input}
      placeholder="Type something..."
    />
  );
}
```

Effect Hook

We've seen we can use the `useState` component to handle state within a functional component, but another benefit of class components was the possibility to add lifecycle methods to a component.

With the `useEffect` hook, we can "hook into" a components lifecycle. The `useEffect` hook effectively combines the `componentDidMount`, `componentDidUpdate`, and `componentWillUnmount` lifecycle methods.

Let's use the input example we used in the State Hook section. Whenever the user is typing anything in the input field, we also want to log that value to the console.

```
componentDidMount() { ... }
useEffect(() => { ... }, [])

componentWillUnmount() { ... }
useEffect(() => { return () => { ... } }, [])

componentDidUpdate() { ... }
useEffect(() => { ... })
```

We need to use a `useEffect` hook that "listens" to the input value. We can do so, by adding input to the dependency array of the `useEffect` hook. The dependency array is the second argument that the `useEffect` hook receives.

```
import React, { useState, useEffect } from "react";

export default function Input() {
  const [input, setInput] = useState("");

  useEffect(() => {
    console.log(`The user typed ${input}`);
  }, [input]);

  return (
    <input
      onChange={e => setInput(e.target.value)}
      value={input}
      placeholder="Type something..."
    />
  );
}
```

The value of the input now gets logged to the console whenever the user types a value.

Custom Hooks

Besides the built-in hooks that React provides (`useState`, `useEffect`, `useReducer`, `useRef`, `useContext`, `useMemo`, `useContext`, `useImperativeHandle`, `useLayoutEffect`, `useDebugValue`, `useCallback`), we can easily create our own custom hooks.

You may have noticed that all hooks start with use. It's important to start your hooks with use in order for React to check if it violates the rules of Hooks.

Let's say we want to keep track of certain keys the user may press when writing the input. Our custom hook should be able to receive the key we want to target as its argument.

```
function useKeyPress(targetKey) {}
```

We want to add a keydown and keyup event listener to the key that the user passed as an argument. If the user pressed that key, meaning the keydown event gets triggered, the state within the hook should toggle to true. Else, when the user stops pressing that button, the keyup event gets triggered and the state toggles to false.

```
function useKeyPress(targetKey) {
  const [keyPressed, setKeyPressed] = React.useState(false);

  function handleDown({ key }) {
    if (key === targetKey) {
      setKeyPressed(true);
    }
  }

  function handleUp({ key }) {
    if (key === targetKey) {
      setKeyPressed(false);
    }
  }


  React.useEffect(() => {
    window.addEventListener("keydown", handleDown);
    window.addEventListener("keyup", handleUp);

    return () => {
      window.removeEventListener("keydown", handleDown);
      window.removeEventListener("keyup", handleUp);
    };
  }, []);

  return keyPressed;
}
```

```
import React from "react";
import useKeyPress from "./useKeyPress";

export default function Input() {
  const [input, setInput] = React.useState("");
  const pressQ = useKeyPress("q");
  const pressW = useKeyPress("w");
  const pressL = useKeyPress("l");

  React.useEffect(() => {
    console.log(`The user pressed Q!`);
  }, [pressQ]);

  React.useEffect(() => {
    console.log(`The user pressed W!`);
  }, [pressW]);

  React.useEffect(() => {
    console.log(`The user pressed L!`);
  }, [pressL]);

  return (
    <input
      onChange={e => setInput(e.target.value)}
      value={input}
      placeholder="Type something..."
    />
  );
}
```

Perfect! We can use this custom hook in our input application. Let's log to the console whenever the user presses the q, l or w key.

Instead of keeping the key press logic local to the Input component, we can now reuse the `useKeyPress` hook throughout multiple components, without having to rewrite the same logic over and over.

Another great advantage of Hooks, is that the community can build and share hooks. We just wrote the `useKeyPress` hook ourselves, but that actually wasn't necessary at all! The hook was already built by someone else and ready to use in our application if we just installed it!

Let's rewrite the counter and width example shown in the previous section. Instead of using a class component, we'll rewrite the app using React Hooks.

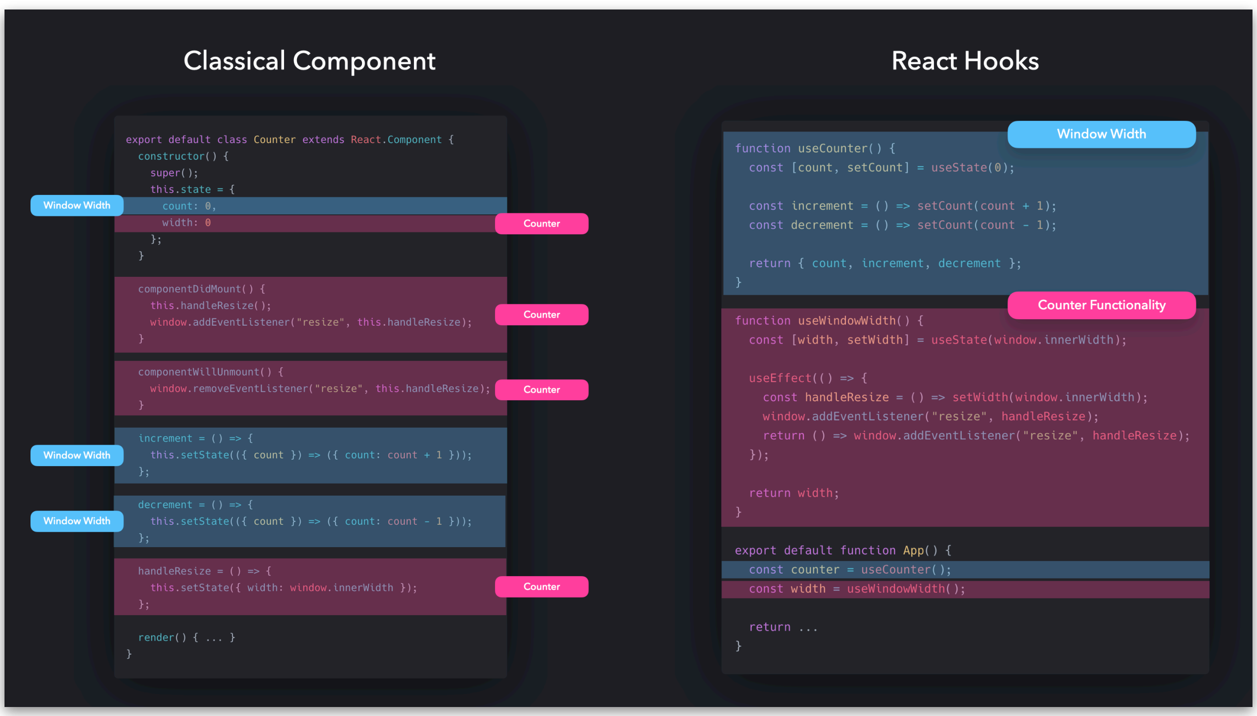
```
import React, { useState, useEffect } from "react";
import "./styles.css";

import { Count } from "./Count";
import { Width } from "./Width";

function useCounter() {
  const [count, setCount] = useState(0);

  const increment = () => setCount(count + 1);
  const decrement = () => setCount(count - 1);

  return { count, increment, decrement };
}

function useWindowWidth() {
  const [width, setWidth] = useState(window.innerWidth);

  useEffect(() => {
    const handleResize = () => setWidth(window.innerWidth);
    window.addEventListener("resize", handleResize);
    return () => window.addEventListener("resize", handleResize);
  });

  return width;
}

export default function App() {
  const counter = useCounter();
  const width = useWindowWidth();

  return (
    <div className="App">
      <Count
        count={counter.count}
        increment={counter.increment}
        decrement={counter.decrement}
      />
      <div id="divider" />
      <Width width={width} />
    </div>
  );
}
```

We broke the logic of the App function into several pieces:

- `useCounter`: A custom hook that returns the current value of count, an increment method, and a decrement method.
- `useWindowWidth`: A custom hook that returns the window's current width.
- App: A functional, stateful component that returns the `Counter` and `Width` component.

By using React Hooks instead of a class component, we were able to break the logic down into smaller, reusable pieces that separated the logic.

Let's visualize the changes we just made, compared to the old App class component.



Using React Hooks just made it much clearer to separate the logic of our component into several smaller pieces. Reusing the same stateful logic just became much easier, and we no longer have to rewrite functional components into class components if we want to make the component stateful. A good knowledge of ES2015 classes is no longer required, and having reusable stateful logic increases the testability, flexibility and readability of components.

Adding Hooks

Like other components, there are special functions that are used when you want to add Hooks to the code you have written. Here's a brief overview of some common Hook functions:

`useState`

The `useState` Hook enables developers to update and manipulate state inside function components without needing to convert it to a class component. One advantage of this Hook is that it is simple and does not require as much complexity as other React Hooks.

`useEffect`

The `useEffect` Hook is used to run code during major lifecycle events in a function component. The main body of a function component does not allow mutations, subscriptions, timers, logging, and other side effects. If they are allowed, it could lead to confusing bugs and inconsistencies within the UI. The useEffect hook prevents all of these "side effects" and allows the UI to run smoothly. It is a combination of `componentDidMount` , `componentDidUpdate` , and `componentWillUnmount`, all in one place.

`useContext`

The `useContext` Hook accepts a context object, which is the value returned from `React.createContext`, and returns the current context value for that context. The useContext Hook also works with the React Context API in order to share data throughout the app without the need to pass your app props down through various levels.

It should be noted that the argument passed to the `useContext` hook must be the context object itself and any component calling the `useContext` always re-render whenever the context value changes.

`useReducer`

The `useReducer` Hook gives an alternative to `useState` and is especially preferable to it when you have complex state logic that involves multiple sub-values or when the next state depends on the previous one. It takes on a reducer function and an initial state input and returns the current state and a dispatch function as output by means of array destructuring. `useReducer` also optimizes the performance of components that trigger deep updates.

Pros and Cons of using Hooks

Here are some benefits of making use of Hooks:

Fewer lines of code Hooks allows you group code by concern and functionality, and not by lifecycle. This makes the code not only cleaner and concise but also shorter. Below is a comparison of a simple stateless component of a searchable product data table using React, and how it looks in Hooks after using the `useState` keyword.

Stateless Component

```
class TweetSearchResults extends React.Component {
  constructor(props) {
    super(props);
    this.state = {
      filterText: '',
      inThisLocation: false
    };

    this.handleFilterTextChange = this.handleFilterTextChange.bind(this);
    this.handleInThisLocationChange = this.handleInThisLocationChange.bind(this);
  }

  handleFilterTextChange(filterText) {
    this.setState({
      filterText: filterText
    });
  }

  handleInThisLocationChange(inThisLocation) {
    this.setState({
      inThisLocation: inThisLocation
    })
  }

  render() {
    return (
      <div>
        <SearchBar
          filterText={this.state.filterText}
          inThisLocation={this.state.inThisLocation}
          onFilterTextChange={this.handleFilterTextChange}
          onInThisLocationChange={this.handleInThisLocationChange}
        />
        <TweetList
          tweets={this.props.tweets}
          filterText={this.state.filterText}
          inThisLocation={this.state.inThisLocation}
        />
      </div>
    );
  }
}
```

Same component with Hooks

```
const TweetSearchResults = ({tweets}) => {
  const [filterText, setFilterText] = useState('');
  const [inThisLocation, setInThisLocation] = useState(false);
  return (
    <div>
      <SearchBar
        filterText={filterText}
        inThisLocation={inThisLocation}
        setFilterText={setFilterText}
        setInThisLocation={setInThisLocation}
      />
      <TweetList
        tweets={tweets}
        filterText={filterText}
        inThisLocation={inThisLocation}
      />
    </div>
  );
}
```

Simplifies complex components

JavaScript classes can be difficult to manage, hard to use with hot reloading and may not minify as well. React Hooks solves these problems and ensures functional programming is made easy. With the implementation of Hooks, We don't need to have class components.

Reusing stateful logic Classes in JavaScript encourage multiple levels of inheritance that quickly increase overall complexity and potential for errors.

However, Hooks allow you to use state, and other React features without writing a class. With React, you can always reuse stateful logic without the need to rewrite the code over and over again. This reduces the chances of errors and allows for composition with plain functions.

Sharing non-visual logic

Until the implementation of Hooks, React had no way of extracting and sharing non-visual logic. This eventually led to more complexities, such as the HOC patterns and Render props, just to solve a common problem. But, the introduction of Hooks has solved this problem because it allows for the extraction of stateful logic to a simple JavaScript function.

There are of course some potential downsides to Hooks worth keeping in mind:

- Have to respect its rules, without a linter plugin, it is difficult to know which rule has been broken.
- Need a considerable time practicing to use properly (Exp: `useEffect`).
- Be aware of the wrong use (Exp: `useCallback`, `useMemo`).

React Hooks vs Classes

When Hooks were introduced to React, it created a new problem: how do we know when to use function components with Hooks and class components? With the help of Hooks, it is possible to get state and partial lifecycle Hooks even in function components. Hooks also allow you to use local state and other React features without writing a class.

Here are some differences between Hooks and Classes to help you decide:

React Hooks	Classes
It helps avoid multiple hierarchies and make code clearer	Generally, when you use HOC or *renderProps,* you have to restructure your App with multiple hierarchies when you try to see it in DevTools
It provides uniformity across React components.	Classes confuse both humans and machines due to the need to understand binding and the context in which functions are called.

HOC Pattern

Pass reusable logic down as props to components throughout your application

Within our application, we often want to use the same logic in multiple components. This logic can include applying a certain styling to components, requiring authorization, or adding a global state.

One way of being able to reuse the same logic in multiple components, is by using the higher order component pattern. This pattern allows us to reuse component logic throughout our application.

A Higher Order Component (HOC) is a component that receives another component. The HOC contains certain logic that we want to apply to the component that we pass as a parameter. After applying that logic, the HOC returns the element with the additional logic.

Say that we always wanted to add a certain styling to multiple components in our application. Instead of creating a style object locally each time, we can simply create a HOC that adds the style objects to the component that we pass to it

```
function withStyles(Component) {
  return props => {
    const style = { padding: '0.2rem', margin: '1rem' }
    return <Component style={style} {...props} />
  }
}

const Button = () = <button>Click me!</button>
const Text = () => <p>Hello World!</p>

const StyledButton = withStyles(Button)
const StyedText = withStyles(Text)
```

We just created a `StyledButton` and `StyledText` component, which are the modified versions of the `Button` and `Text` component. They now both contain the style that got added in the `withStyles` HOC!

Let's take a look at the same `DogImages` example that was previously used in the Container/Presentational pattern! The application does nothing more than rendering a list of dog images, fetched from an API.

Let's improve the user experience a little bit. When we're fetching the data, we want to show a *`Loading...`* screen to the user. Instead of adding data to the `DogImages` component directly, we can use a Higher Order Component that adds this logic for us.

Let's create a HOC called `withLoader`. A HOC should receive an component, and return that component. In this case, the withLoader HOC should receive the element which should display *`Loading...`* until the data is fetched.

Let's create the bare minimum version of the withLoader HOC that we want to use!

```
function withLoader(Element) {
  return props => <Element />;
}
```

However, we don't just want to return the element it received. Instead, we want this element to contain logic that tells us whether the data is still loading or not.

To make the `withLoader` HOC very reusable, we won't hardcode the Dog API url in that component. Instead, we can pass the URL as an argument to the withLoader HOC, so this loader can be used on any component that needs a loading indicator while fetching data from a different API endpoint.

```
function withLoader(Element, url) {
  return props => {};
}
```

A HOC returns an element, a functional component `props => {}` in this case, to which we want to add the logic that allows us to display a text with *`Loading...`* as the data is still being fetched. Once the data has been fetched, the component should pass the fetched data as a prop.

```
import React, { useEffect, useState } from "react";

export default function withLoader(Element, url) {
  return (props) => {
    const [data, setData] = useState(null);

    useEffect(() => {
      async function getData() {
        const res = await fetch(url);
        const data = await res.json();
        setData(data);
      }

      getData();
    }, []);

    if (!data) {
      return <div>Loading...</div>;
    }

    return <Element {...props} data={data} />;
  };
}
```

Perfect! We just created a HOC that can receive any component and url.

In the `useEffect` hook, the `withLoader` HOC fetches the data from the API endpoint that we pass as the value of url. While the data hasn't returned yet, we return the element containing the *`Loading...`* text.

Once the data has been fetched, we set data equal to the data that has been fetched. Since data is no longer null, we can display the element that we passed to the HOC!

So, how can we add this behavior to our application, so it'll actually show the *`Loading`*... indicator on the `DogImages` list?

In `DogImages.js`, we no longer want to just export the plain `DogImages` component. Instead, we want to export the "wrapped" `withLoader` HOC around the `DogImages` component.

```
export default withLoader(DogImages);
```

The `withLoader` HOC also expects the url to know which endpoint to fetch the data from. In this case, we want to add the Dog API endpoint.

```
export default withLoader(
  DogImages,
  "https://dog.ceo/api/breed/labrador/images/random/6"
);
```

Since the `withLoader` HOC returned the element with an extra data prop, `DogImages` in this case, we can access the data prop in the `DogImages` component.

```
import React from "react";
import withLoader from "./withLoader";

function DogImages(props) {
  return props.data.message.map((dog, index) => (
    <img src={dog} alt="Dog" key={index} />
  ));
}

export default withLoader(
  DogImages,
  "https://dog.ceo/api/breed/labrador/images/random/6"
);
```

Perfect! We now see a `Loading`... screen while the data is being fetched.

The Higher Order Component pattern allows us to provide the same logic to multiple components, while keeping all the logic in one single place. The `withLoader` HOC doesn't care about the component or url it receives: as long as it's a valid component and a valid API endpoint, it'll simply pass the data from that API endpoint to the component that we pass.

Composing

We can also compose multiple Higher Order Components. Let's say that we also want to add functionality that shows a Hovering! text box when the user hovers over the `DogImages` list.

We need to create a HOC that provides a hovering prop to the element that we pass. Based on that prop, we can conditionally render the text box based on whether the user is hovering over the DogImages list.

```
import React from "react";
import withLoader from "./withLoader";
import withHover from "./withHover";

function DogImages(props) {
  return (
    <div {...props}>
      {props.hovering && <div id="hover">Hovering!</div>}
      <div id="list">
        {props.data.message.map((dog, index) => (
          <img src={dog} alt="Dog" key={index} />
        ))}
      </div>
    </div>
  );
}

export default withHover(
  withLoader(DogImages, "https://dog.ceo/api/breed/labrador/images/random/6")
);
```

We can now wrap the `withHover` HOC around the `withLoader`

The `DogImages` element now contains all props that we passed fr

both `withHover` and `withLoader`. We can now conditionally render the `Hovering!` text box, based on whether the value of the hovering prop is true or false.

A well-known library used for composing HOCs is recompose. Since HOCs can largely be replaced by React Hooks, the recompose library is no longer maintained, thus won't be covered in this article.

Hooks

In some cases, we can replace the HOC pattern with React Hooks.

Let's replace the `withHover` HOC with a `useHover` hook. Instead of having a higher order component, we export a hook that adds a `mouseOver` and `mouseLeave` event listener to the element. We cannot pass the element anymore like we did with the HOC. Instead, we'll return a ref from the hook for that should get the `mouseOver` and `mouseLeave` events.

```
import { useState, useRef, useEffect } from "react";

export default function useHover() {
  const [hovering, setHover] = useState(false);
  const ref = useRef(null);

  const handleMouseOver = () => setHover(true);
  const handleMouseOut = () => setHover(false);

  useEffect(() => {
    const node = ref.current;
    if (node) {
      node.addEventListener("mouseover", handleMouseOver);
      node.addEventListener("mouseout", handleMouseOut);

      return () => {
        node.removeEventListener("mouseover", handleMouseOver);
        node.removeEventListener("mouseout", handleMouseOut);
      };
    }
  }, [ref.current]);

  return [ref, hovering];
}
```

The `useEffect` hook adds an event listener to the component, and sets the value hovering to true or false, depending on whether the user is currently hovering over the element. Both the `ref` and `hovering` values need to be returned from the hook: `ref` to add a ref to the component that should receive the `mouseOver` and `mouseLeave` events, and hovering in order to be able to conditionally render the Hovering! text box.

Instead of wrapping the DogImages component with the withHover HOC, we can use the useHover hook right inside the DogImages component.

```
import React from "react";
import withLoader from "./withLoader";
import useHover from "./useHover";

function DogImages(props) {
  const [hoverRef, hovering] = useHover();

  return (
    <div ref={hoverRef} {...props}>
      {hovering && <div id="hover">Hovering!</div>}
      <div id="list">
        {props.data.message.map((dog, index) => (
          <img src={dog} alt="Dog" key={index} />
        ))}
      </div>
    </div>
  );
}

export default withLoader(
  DogImages,
  "https://dog.ceo/api/breed/labrador/images/random/6"
);
```

Perfect! Instead of wrapping the DogImages component with the withHover component, we can simply use the useHover hook within the component directly.

Generally speaking, React Hooks don't replace the HOC pattern. As the React docs tell us, using Hooks can reduce the depth of the component tree. Using the HOC pattern, it's easy to end up with a deeply nested component tree.

```
<withAuth>
  <withLayout>
    <withLogging>
      <Component />
    </withLogging>
  </withLayout>
</withAuth>
```

By adding a Hook to the component directly, we no longer have to wrap components.

Using Higher Order Components makes it possible to provide the same logic to many components, while keeping that logic all in one single place. Hooks allow us to add custom behavior from within the component, which could potentially increase the risk of introducing bugs compared to the HOC pattern if multiple components rely on this behavior.

Best use-cases for a HOC:

- The same, uncustomized behavior needs to be used by many components throughout the application.
- The component can work standalone, without the added custom logic.

Best use-cases for Hooks:

- The behavior has to be customized for each component that uses it.
- The behavior is not spread throughout the application, only one or a few components use the behavior.
- The behavior adds many properties to the component

Case Study

Some libraries that relied on the HOC pattern added Hooks support after the release. A good example of this is Apollo Client.

One way to use Apollo Client is through the `graphql()` higher order component.

```
import React from "react";
import "./styles.css";

import { graphql } from "react-apollo";
import { ADD_MESSAGE } from "./resolvers";

class Input extends React.Component {
  constructor() {
    super();
    this.state = { message: "" };
  }

  handleChange = (e) => {
    this.setState({ message: e.target.value });
  };

  handleClick = () => {
    this.props.mutate({ variables: { message: this.state.message } });
  };

  render() {
    return (
      <div className="input-row">
        <input
          onChange={this.handleChange}
          type="text"
          placeholder="Type something..."
        />
        <button onClick={this.handleClick}>Add</button>
      </div>
    );
  }
}

export default graphql(ADD_MESSAGE)(Input);
```

```
import React, { useState } from "react";
import "./styles.css";

import { useMutation } from "@apollo/react-hooks";
import { ADD_MESSAGE } from "./resolvers";

export default function Input() {
  const [message, setMessage] = useState("");
  const [addMessage] = useMutation(ADD_MESSAGE, {
    variables: { message }
  });

  return (
    <div className="input-row">
      <input
        onChange={(e) => setMessage(e.target.value)}
        type="text"
        placeholder="Type something..."
      />
      <button onClick={addMessage}>Add</button>
    </div>
  );
}
```

With the `graphql()` HOC, we can make data from the client available to components that are wrapped by the higher order component! Although we can still use the `graphql()` HOC currently, there are some downsides to using it.

When a component needs access to multiple resolvers, we need to compose multiple `graphql()` higher order components in order to do so. Composing multiple HOCs can make it difficult to understand how the data is passed to your components. The order of the HOCs can matter in some cases, which can easily lead to bugs when refactoring the code.

After the release of Hooks, Apollo added Hooks support to the Apollo Client library. Instead of using the `graphql()` higher order component, developers can now directly access the data through the hooks that the library provides.

Pros

Using the Higher Order Component pattern allows us to keep logic that we want to re-use all in one place. This reduces the risk of accidentally spreading bugs throughout the application by duplicating code over and over, potentially introducing new bugs each time. By keeping the logic all in one place, we can keep our code DRY and easily enforce separation of concerns

Cons

The name of the prop that a HOC can pass to an element, can cause a naming collision.

```
function withStyles(Component) {
  return props => {
    const style = { padding: '0.2rem', margin: '1rem' }
    return <Component style={style} {...props} />
  }
}

const Button = () = <button style={{ color: 'red' }}>Click me!</button>
const StyledButton = withStyles(Button)
```

In this case, the `withStyles` HOC adds a prop called style to the element that we pass to it. However, the `Button` component already had a prop called style, which will be overwritten! Make sure that the HOC can handle accidental name collision, by either renaming the prop or merging the props.

```
function withStyles(Component) {
  return props => {
    const style = {
      padding: '0.2rem',
      margin: '1rem',
      ...props.style
    }

    return <Component style={style} {...props} />
  }
}

const Button = () = <button style={{ color: 'red' }}>Click me!</button>
const StyledButton = withStyles(Button)
```

When using multiple composed HOCs that all pass props to the element that's wrapped within them, it can be difficult to figure out which HOC is responsible for which prop. This can hinder debugging and scaling an application easily.

Flyweight Pattern

Reuse existing instances when working with identical objects

The flyweight pattern is a useful way to conserve memory when we're creating a large number of similar objects.

In our application, we want users to be able to add books. All books have a title, an author, and an isbn number! However, a library usually doesn't have just one copy of a book: it usually has multiple copies of the same book.

It wouldn't be very useful to create a new book instance each time if there are multiple copies of the exact same book. Instead, we want to create multiple instances of the `Book` constructor, that represent a single book.

```
class Book {
  constructor(title, author, isbn) {
    this.title = title;
    this.author = author;
    this.isbn = isbn;
  }
}
```

Let's create the functionality to add new books to the list. If a book has the same ISBN number, thus is the exact same book type, we don't want to create an entirely new `Book` instance. Instead, we should first check whether this book already exists.

```
const books = new Map();

const createBook = (title, author, isbn) => {
  const existingBook = books.has(isbn);

  if (existingBook) {
    return books.get(isbn);
  }
};
```

If it doesn't contain the book's ISBN number yet, we'll create a new book and add its ISBN number to the isbnNumbers set.

```
const createBook = (title, author, isbn) => {
  const existingBook = books.has(isbn);

  if (existingBook) {
    return books.get(isbn);
  }

  const book = new Book(title, author, isbn);
  books.set(isbn, book);

  return book;
};
```

The `createBook` function helps us create new instances of one type of book. However, a library usually contains multiple copies of the same book! Let's create an `addBook` function, which allows us to add multiple copies of the same book. It should invoke the `createBook` function, which returns either a newly created `Book` instance, or returns the already existing instance.

In order to keep track of the total amount of copies, let's create a `bookList` array that contains the total amount of books in the library.

```
const bookList = [];

const addBook = (title, author, isbn, availability, sales) => {
  const book = {
    ...createBook(title, author, isbn),
    sales,
    availibility,
    isbn
  };

  bookList.push(book);
  return book;
};
```

Perfect! Instead of creating a new `Book` instance each time we add a copy, we can effectively use the already existing `Book` instance for that particular copy. Let's create 5 copies of 3 books: Harry Potter, To Kill a Mockingbird, and The Great Gatsby.

```javascript
addBook("Harry Potter", "JK Rowling", "AB123", false, 100);
addBook("Harry Potter", "JK Rowling", "AB123", true, 50);
addBook("To Kill a Mockingbird", "Harper Lee", "CD345", true, 10);
addBook("To Kill a Mockingbird", "Harper Lee", "CD345", false, 20);
addBook("The Great Gatsby", "F. Scott Fitzgerald", "EF567", false, 20);
```

Although there are 5 copies, we only have 3 Book instances!

```javascript
class Book {
  constructor(title, author, isbn) {
    this.title = title;
    this.author = author;
    this.isbn = isbn;
  }
}

const books = new Map();
const bookList = [];

const addBook = (title, author, isbn, availability, sales) => {
  const book = {
    ...createBook(title, author, isbn),
    sales,
    availability,
    isbn
  };

  bookList.push(book);
  return book;
};
```

```
const createBook = (title, author, isbn) => {
  const existingBook = books.has(isbn);

  if (existingBook) {
    return books.get(isbn);
  }

  const book = new Book(title, author, isbn);
  books.set(isbn, book);

  return book;
};

addBook("Harry Potter", "JK Rowling", "AB123", false, 100);
addBook("Harry Potter", "JK Rowling", "AB123", true, 50);
addBook("To Kill a Mockingbird", "Harper Lee", "CD345", true, 10);
addBook("To Kill a Mockingbird", "Harper Lee", "CD345", false, 20);
addBook("The Great Gatsby", "F. Scott Fitzgerald", "EF567", false, 20);

console.log("Total amount of copies: ", bookList.length);
console.log("Total amount of books: ", books.size);
```

The flyweight pattern is useful when you're creating a huge number of objects, which could potentially drain all available RAM. It allows us to minimize the amount of consumed memory.

In JavaScript, we can easily solve this problem through prototypal inheritance. Nowadays, hardware has GBs of RAM, which makes the flyweight pattern less important.

Factory Pattern

Use a factory function in order to create objects

With the factory pattern we can use factory functions in order to create new objects. A function is a factory function when it returns a new object without the use of the new keyword!

Say that we need many users for our application. We can create new users with a `firstName`, `lastName`, and `email` property. The factory function adds a `fullName` property to the newly created object as well, which returns the `firstName` and the `lastName`.

```
const createUser = ({ firstName, lastName, email }) => ({
  firstName,
  lastName,
  email,
  fullName() {
    return `${this.firstName} ${this.lastName}`;
  }
});
```

Perfect! We can now easily create multiple users by invoking the `createUser` function.

```javascript
const createUser = ({ firstName, lastName, email }) => ({
  firstName,
  lastName,
  email,
  fullName() {
    return `${this.firstName} ${this.lastName}`;
  }
});

const user1 = createUser({
  firstName: "John",
  lastName: "Doe",
  email: "john@doe.com"
});

const user2 = createUser({
  firstName: "Jane",
  lastName: "Doe",
  email: "jane@doe.com"
});

console.log(user1);
console.log(user2);
```

The factory pattern can be useful if we're creating relatively complex and configurable objects. It could happen that the values of the keys and values are dependent on a certain environment or configuration. With the factory pattern, we can easily create new objects that contain the custom keys and values!

```javascript
const createObjectFromArray = ([key, value]) => ({
  [key]: value
});

createObjectFromArray(["name", "John"]); // { name: "John" }
```

Pros

The factory pattern is useful when we have to create multiple smaller objects that share the same properties. A factory function can easily return a custom object depending on the current environment, or user-specific configuration.

Cons

In JavaScript, the factory pattern isn't much more than a function that returns an object without using the new keyword. ES6 arrow functions allow us to create small factory functions that implicitly return an object each time.

However, in many cases it may be more memory efficient to create new instances instead of new objects each time.

```
class User {
  constructor(firstName, lastName, email) {
    this.firstName = firstName;
    this.lastName = lastName;
    this.email = email;
  }

  fullName() {
    return `${this.firstName} ${this.lastName}`;
  }
}

const user1 = new User({
  firstName: "John",
  lastName: "Doe",
  email: "john@doe.com"
});

const user2 = new User({
  firstName: "Jane",
  lastName: "Doe",
  email: "jane@doe.com"
});
```

Compound Pattern

Create multiple components that work together to perform a single task

In our application, we often have components that belong to each other. They're dependent on each other through the shared state, and share logic together. You often see this with components like select, dropdown components, or menu items. The compound component pattern allows you to create components that all work together to perform a task.

Context API

Let's look at an example: we have a list of squirrel images! Besides just showing squirrel images, we want to add a button that makes it possible for the user to edit or delete the image. We can implement a `FlyOut` component that shows a list when the user toggles the component.

Within a `FlyOut` component, we essentially have three things:

- The `FlyOut` wrapper, which contains the toggle button and the list
- The `Toggle` button, which toggles the List
- The `List` , which contains the list of menu items

Using the Compound component pattern with React's Context API is perfect for this example!

First, let's create the `FlyOut` component. This component keeps the state, and returns a `FlyOutProvider` with the value of the toggle to all the children it receives.

```
const FlyOutContext = createContext();

function FlyOut(props) {
  const [open, toggle] = useState(false);

  const providerValue = { open, toggle };

  return (
    <FlyOutContext.Provider value={providerValue}>
      {props.children}
    </FlyOutContext.Provider>
  );
}
```

We now have a stateful `FlyOut` component that can pass the value of open and toggle to its children!

Let's create the `Toggle` component. This component simply renders the component on which the user can click in order to toggle the menu.

```
function Toggle() {
  const { open, toggle } = useContext(FlyOutContext);

  return (
    <div onClick={() => toggle(!open)}>
      <Icon />
    </div>
  );
}
```

In order to actually give `Toggle` access to the `FlyOutContext` provider, we need to render it as a child component of `FlyOut`! We could just simply render this as a child component. However, we can also make the `Toggle` component a property of the `FlyOut` component!

```
const FlyOutContext = createContext();

function FlyOut(props) {
  const [open, toggle] = useState(false);

  return (
    <FlyOutContext.Provider value={{ open, toggle }}>
      {props.children}
    </FlyOutContext.Provider>
  );
}

function Toggle() {
  const { open, toggle } = useContext(FlyOutContext);

  return (
    <div onClick={() => toggle(!open)}>
      <Icon />
    </div>
  );
}

FlyOut.Toggle = Toggle;
```

This means that if we ever want to use the `FlyOut` component in any file, we only have to import `FlyOut`!

```
import React from "react";
import { FlyOut } from "./FlyOut";

export default function FlyoutMenu() {
  return (
    <FlyOut>
      <FlyOut.Toggle />
    </FlyOut>
  );
}
```

Just a toggle is not enough. We also need to have a `List` with list items, which open and close based on the value of open.

```
function List({ children }) {
  const { open } = React.useContext(FlyOutContext);
  return open && <ul>{children}</ul>;
}

function Item({ children }) {
  return <li>{children}</li>;
}
```

The `List` component renders its children based on whether the value of open is true or false. Let's make `List` and `Item` a property of the `FlyOut` component, just like we did with the `Toggle` component.

```
const FlyOutContext = createContext();

function FlyOut(props) {
  const [open, toggle] = useState(false);

  return (
    <FlyOutContext.Provider value={{ open, toggle }}>
      {props.children}
    </FlyOutContext.Provider>
  );
}

function Toggle() {
  const { open, toggle } = useContext(FlyOutContext);

  return (
    <div onClick={() => toggle(!open)}>
      <Icon />
    </div>
  );
}

function List({ children }) {
  const { open } = useContext(FlyOutContext);
  return open && <ul>{children}</ul>;
}

function Item({ children }) {
  return <li>{children}</li>;
}

FlyOut.Toggle = Toggle;
FlyOut.List = List;
FlyOut.Item = Item;
```

We can now use them as properties on the `FlyOut` component! In this case, we want to show two options to the user: Edit and Delete. Let's create a `FlyOut.List` that renders two `FlyOut.Item` components, one for the Edit option, and one for the Delete option.

```
import React from "react";
import { FlyOut } from "./FlyOut";

export default function FlyoutMenu() {
  return (
    <FlyOut>
      <FlyOut.Toggle />
      <FlyOut.List>
        <FlyOut.Item>Edit</FlyOut.Item>
        <FlyOut.Item>Delete</FlyOut.Item>
      </FlyOut.List>
    </FlyOut>
  );
}
```

Perfect! We just created an entire `FlyOut` component without adding any state in the `FlyOutMenu` itself!

The compound pattern is great when you're building a component library. You'll often see this pattern when using UI libraries like Semantic UI.

`React.Children.map`

We can also implement the Compound Component pattern by mapping over the children of the component. We can add the open and toggle properties to these elements, by cloning them with the additional props.

```
export function FlyOut(props) {
  const [open, toggle] = React.useState(false);

  return (
    <div>
      {React.Children.map(props.children, child =>
        React.cloneElement(child, { open, toggle })
      )}
    </div>
  );
}
```

All children components are cloned, and passed the value of open and toggle. Instead of having to use the Context API like in the previous example, we now have access to these two values through props.

```jsx
import React from "react";
import Icon from "./Icon";

const FlyOutContext = React.createContext();

export function FlyOut(props) {
  const [open, toggle] = React.useState(false);

  return (
    <div>
      {React.Children.map(props.children, child =>
        React.cloneElement(child, { open, toggle })
      )}
    </div>
  );
}

function Toggle() {
  const { open, toggle } = React.useContext(FlyOutContext);

  return (
    <div className="flyout-btn" onClick={() => toggle(!open)}>
      <Icon />
    </div>
  );
}

function List({ children }) {
  const { open } = React.useContext(FlyOutContext);
  return open && <ul className="flyout-list">{children}</ul>;
}

function Item({ children }) {
  return <li className="flyout-item">{children}</li>;
}

FlyOut.Toggle = Toggle;
FlyOut.List = List;
FlyOut.Item = Item;
```

Pros

Compound components manage their own internal state, which they share among the several child components. When implementing a compound component, we don't have to worry about managing the state ourselves.

When importing a compound component, we don't have to explicitly import the child components that are available on that component.

```
import { FlyOut } from "./FlyOut";

export default function FlyoutMenu() {
  return (
    <FlyOut>
      <FlyOut.Toggle />
      <FlyOut.List>
        <FlyOut.Item>Edit</FlyOut.Item>
        <FlyOut.Item>Delete</FlyOut.Item>
      </FlyOut.List>
    </FlyOut>
  );
}
```

Cons

When using the `React.children.map` to provide the values, the component nesting is limited. Only direct children of the parent component will have access to the open and toggle props, meaning we can't wrap any of these components in another component.

```jsx
export default function FlyoutMenu() {
  return (
    <FlyOut>
      {/* This breaks */}
      <div>
        <FlyOut.Toggle />
        <FlyOut.List>
          <FlyOut.Item>Edit</FlyOut.Item>
          <FlyOut.Item>Delete</FlyOut.Item>
        </FlyOut.List>
      </div>
    </FlyOut>
  );
}
```

Cloning an element with `React.cloneElement` performs a shallow merge. Already existing props will be merged together with the new props that we pass. This could end up in a naming collision, if an already existing prop has the same name as the props we're passing to the `React.cloneElement` method. As the props are shallowly merged, the value of that prop will be overwritten with the latest value that we pass.

Command Pattern

Decouple methods that execute tasks by sending commands to a commander

With the Command Pattern, we can decouple objects that execute a certain task from the object that calls the method.

Let's say we have an online food delivery platform. Users can place, track, and cancel orders.

```
class OrderManager() {
  constructor() {
    this.orders = []
  }

  placeOrder(order, id) {
    this.orders.push(id)
    return `You have successfully ordered ${order} (${id})`;
  }

  trackOrder(id) {
    return `Your order ${id} will arrive in 20 minutes.`
  }

  cancelOrder(id) {
    this.orders = this.orders.filter(order => order.id !== id)
    return `You have canceled your order ${id}`
  }
}
```

On the `OrderManager` class, we have access to the `placeOrder`, `trackOrder` and `cancelOrder` methods. It would be totally valid JavaScript to just use these methods directly!

```
const manager = new OrderManager();

manager.placeOrder("Pad Thai", "1234");
manager.trackOrder("1234");
manager.cancelOrder("1234");
```

However, there are downsides to invoking the methods directly on the manager instance. It could happen that we decide to rename certain methods later on, or the functionality of the methods change.

Say that instead of calling it `placeOrder`, we now rename it to `addOrder`! This would mean that we would have to make sure that we don't call the `placeOrder` method anywhere in our codebase, which could be very tricky in larger applications.

Instead, we want to decouple the methods from the manager object, and create separate command functions for each command!

Let's refactor the `OrderManager` class: instead of having the `placeOrder`, `cancelOrder` and `trackOrder` methods, it will have one single method: `execute`. This method will execute any command it's given.

Each command should have access to the orders of the manager, which we'll pass as its first argument.

```
class OrderManager {
  constructor() {
    this.orders = [];
  }

  execute(command, ...args) {
    return command.execute(this.orders, ...args);
  }
}
```

We need to create three Commands for the order manager:

- `PlaceOrderCommand`
- `CancelOrderCommand`
- `TrackOrderCommand`

```
class Command {
  constructor(execute) {
    this.execute = execute;
  }
}

function PlaceOrderCommand(order, id) {
  return new Command(orders => {
    orders.push(id);
    return `You have successfully ordered ${order} (${id})`;
  });
}

function CancelOrderCommand(id) {
  return new Command(orders => {
    orders = orders.filter(order => order.id !== id);
    return `You have canceled your order ${id}`;
  });
}

function TrackOrderCommand(id) {
  return new Command(() => `Your order ${id} will arrive in 20 minutes.`);
}
```

Perfect! Instead of having the methods directly coupled to the `OrderManager` instance, they're now separate, decoupled functions that we can invoke through the execute method that's available on the `OrderManager`.

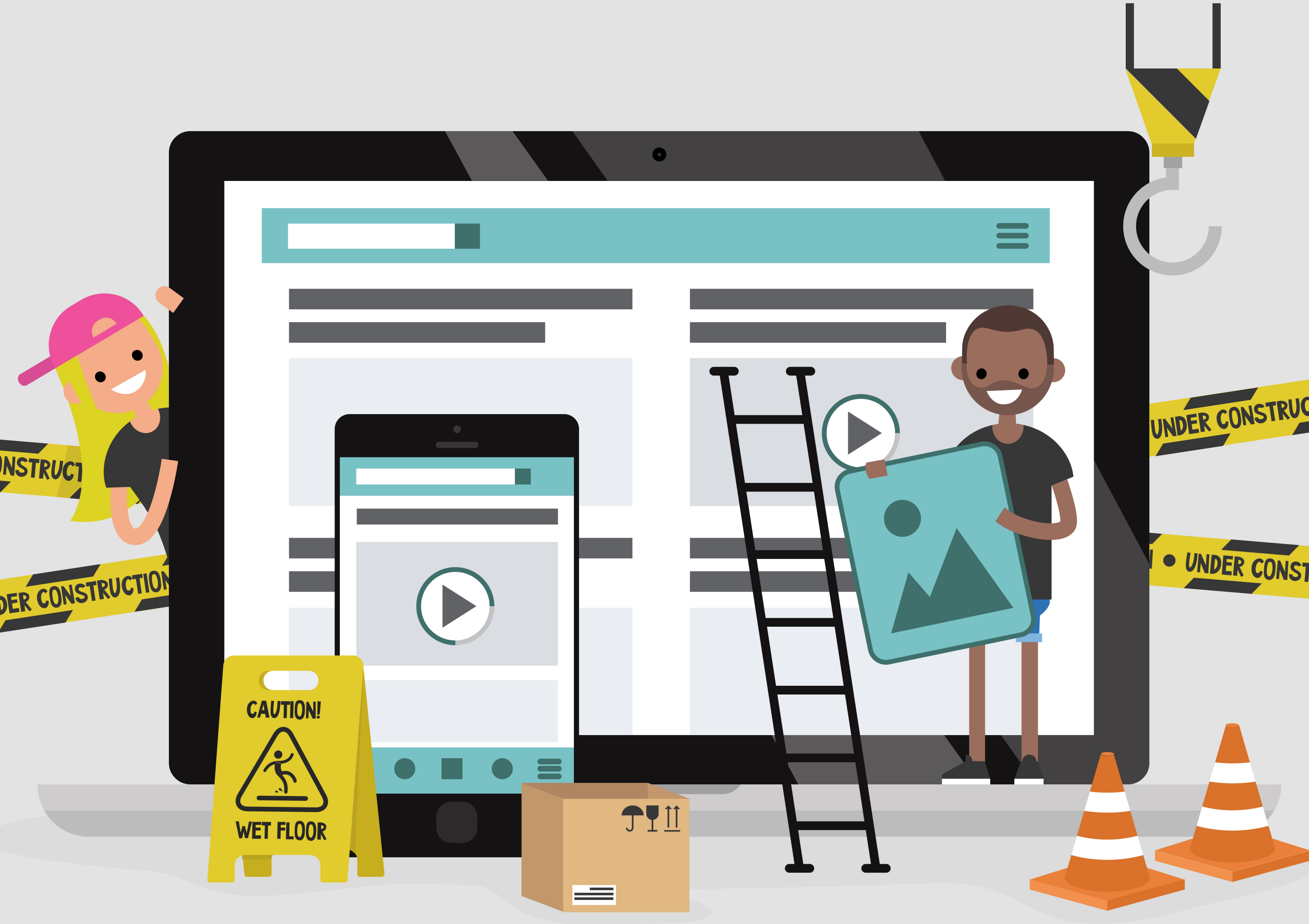
```javascript
class OrderManager {
  constructor() {
    this.orders = [];
  }

  execute(command, ...args) {
    return command.execute(this.orders, ...args);
  }
}

class Command {
  constructor(execute) {
    this.execute = execute;
  }
}

function PlaceOrderCommand(order, id) {
  return new Command(orders => {
    orders.push(id);
    console.log(`You have successfully ordered ${order} (${id})`);
  });
}

function CancelOrderCommand(id) {
  return new Command(orders => {
    orders = orders.filter(order => order.id !== id);
    console.log(`You have canceled your order ${id}`);
  });
}

function TrackOrderCommand(id) {
  return new Command(() =>
    console.log(`Your order ${id} will arrive in 20 minutes.`)
  );
}

const manager = new OrderManager();

manager.execute(new PlaceOrderCommand("Pad Thai", "1234"));
manager.execute(new TrackOrderCommand("1234"));
manager.execute(new CancelOrderCommand("1234"));
```

Pros

The command pattern allows us to decouple methods from the object that executes the operation. It gives you more control if you're dealing with commands that have a certain lifespan, or commands that should be queued and executed at specific times.

Cons

The use cases for the command pattern are quite limited, and often adds unnecessary boilerplate to an application.



RENDERING

Rendering content on the web can be done in many ways today. The decision on how and where to fetch and render content is key to the performance of an application. The available frameworks and libraries can be used to implement different rendering patterns like Client-Side Rendering, Static Rendering, Hydration, Progressive Rendering and Server-Side Rendering. It is important to understand the implications of each of these patterns before we can decide which is best suited for our application.

The Chrome team has encouraged developers to consider static rendering or server-side rendering over a full rehydration approach. Over time, progressive loading and rendering techniques by default may help strike a good balance of performance and feature delivery when using a modern framework

The following sections will provide a guideline on measuring the performance requirements for an application with respect to web rendering and suggest patterns that best satisfy each of these requirements. Subsequently, we will explore each pattern in-depth and learn how it can be implemented. We will also talk a bit about Next.js which can be used to implement these patterns. However, before we go into the available patterns or Next.js, let's take a look at how we got here and what were the drivers that resulted in the creation of the React framework and Next.js.

A brief history of web rendering

Web technologies have been continuously evolving to support changing application requirements. The building blocks for all websites HTML, CSS and

JavaScript have also evolved over time to support changing requirements and utilize browser advancements.

In the early 2000's we had sites where HTML content was rendered completely by the server. Developers relied on server-side scripting languages like PHP and ASP to render HTML. Page reloads were required for all key navigations and JavaScript was used by clients minimally to hide/show or enable/disable HTML elements.

In 2006, Ajax introduced the possibility of Single-Page Applications (SPA), Gmail being the most popular example. Ajax allowed developers to make dynamic requests to the server without loading a new page. Thus, SPAs could be built to resemble desktop applications. Soon developers started using JavaScript to fetch and render data. JavaScript libraries and frameworks were created that could be used to build the view layer functionality in the MVC framework. Client-side frameworks like JQuery, Backbone.js and AngularJS made it easier for developers to build core features using JavaScript.

React was introduced in 2013 as a flexible framework for building user interfaces and UI components and provided a base for developing both single-page web and mobile applications. From 2015 to 2020 the React ecosystem has evolved to include supporting data-flow architecture libraries (Redux), CSS frameworks (React-Bootstrap), routing libraries and mobile application framework (React Native). However, there are some drawbacks of a pure Client-Side rendering framework. As a result, developers have started exploring new ways to get the best of both the Client-side and Server-side rendering worlds.

Rendering - Key Performance Indicators

Before we talk about drawbacks, let us understand how we could measure the performance of a rendering mechanism. A basic understanding of the following terms will help us to compare the different patterns discussed here.

Acronym	Description
TTFB	Time to First Byte - the time between clicking a link and the first bit of content coming in.
FP	First Paint - First time any content becomes visible to the user or the time when the first few pixels are painted on the screen
FCP	First Contentful Paint - Time when all the requested content becomes visible
LCP	Largest Contentful Paint - Time when the main page content becomes visible. This refers to the largest image or text block visible within the viewport.
TTI	Time to Interactive - Time when the page becomes interactive e.g., events are wired up, etc.
TBT	Total Blocking Time - The total amount of time between FCP and TTI.

Some important notes about these performance parameters are as follows.

- A large JavaScript bundle could increase how long a page takes to reach FCP and LCP. The user will be required to wait for some time to go from a mostly blank page to a page with content loaded.
- Larger JavaScript bundles also affect TTI and TBT as the page can only become interactive once the minimal required JavaScript is loaded and events are wired.
- The time required for the first byte of content to reach the browser (TTFB) is dependent on the time taken by the server to process the request.

- Techniques such as preload, prefetch and script attributes can affect the above parameters as different browsers interpret them differently. It is helpful to understand the loading and execution priorities assigned by the browser for such attributes before using them.

We can now use these parameters to understand what exactly each pattern has to offer with respect to rendering requirements.

Patterns - A Quick Look

Client-Side Rendering (CSR) and Server-Side Rendering (SSR) form the two extremes of the spectrum of choices available for rendering. The other patterns listed in the following illustration use different approaches to provide some combination of features borrowed from both CSR and SSR.

	Server			Browser
	Server Rendering	"Static SSR"	SSR with (Re)hydration	CSR with Prerendering	Full CSR
Overview:	An application where input is navigation requests and the output is HTML in response to them.	Built as a Single Page App, but all pages prerendered to static HTML as a build step, and the JS is **removed**.	Built as a Single Page App. The server prerenders pages, but the full app is also booted on the client.	A Single Page App, where the initial shell/skeleton is prerendered to static HTML at build time.	A Single Page App. All logic, rendering and booting is done on the client. HTML is essentially just script & style tags.
Authoring:	Entirely server-side (request-response, HTML)	Built as if client-side (components, DOM*, fetch)	Built as client-side	Client-side	Client-side
Rendering:	Dynamic HTML	Static HTML	Dynamic HTML **and** JS/DOM	Partial static HTML, then JS/DOM	Entirely JS/DOM
Server role:	Controls all aspects. (thin client)	Delivers static HTML	Renders pages (navigation requests)	Delivers static HTML	Delivers static HTML
Pros:	👍 TTI = FCP 👍 Fully streaming	👍 Fast TTFB 👍 TTI = FCP 👍 Fully streaming	👍 Flexible	👍 Flexible 👍 Fast TTFB	👍 Flexible 👍 Fast TTFB
Cons:	👎 Slow TTFB 👎 Inflexible	👎 Inflexible 👎 Leads to hydration	👎 Slow TTFB 👎 TTI >>> FCP 👎 Usually buffered	👎 TTI > FCP 👎 Limited streaming	👎 TTI >>> FCP 👎 No streaming
Scales via:	Infra size / cost	build/deploy size	Infra size & JS size	JS size	JS size
Examples:	Gmail HTML, Hacker News	Docusaurus, Netflix*	Next.js, Razzle, etc	Gatsby, Vuepress, etc	Most apps

We will explore each of these patterns in detail. Before that, however, let us talk about Next.js which is a React-based framework. Next.js is relevant to our discussion because it can be used to implement all of the following patterns.

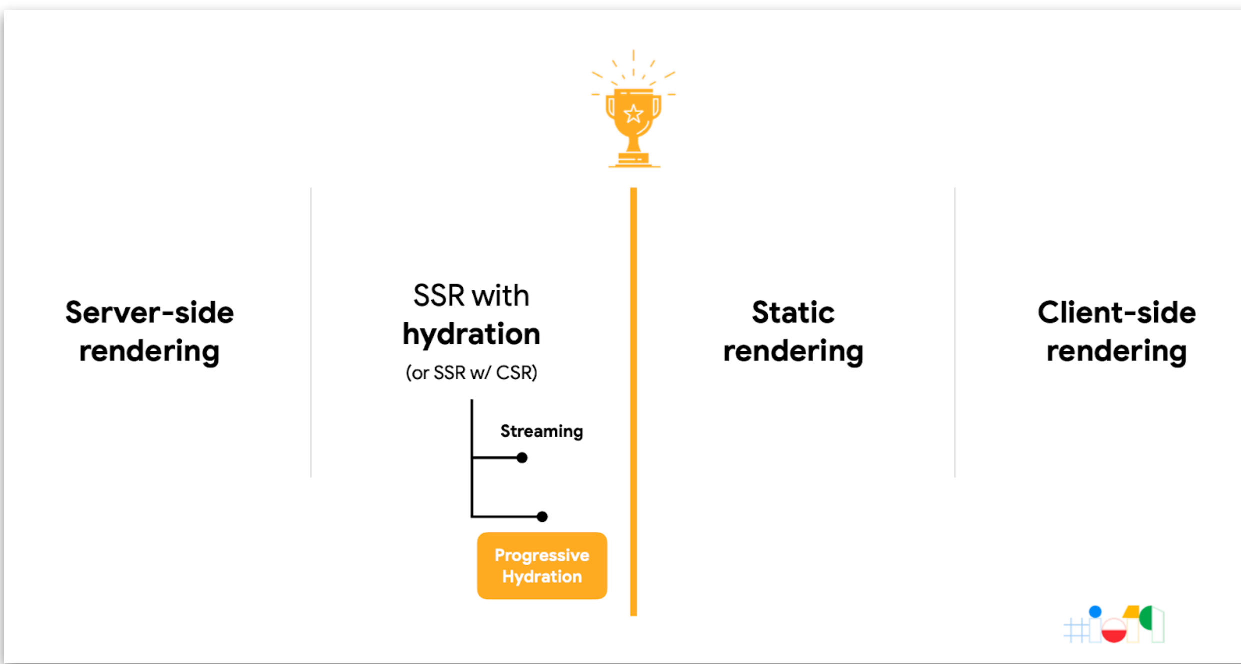
- SSR

- Static SSR (experimental flag)
- SSR with Rehydration
- CSR with Prerendering also known as Automatic Static Optimization
- Full CSR

based framework. Next.js is relevant to our discussion because it can be used to implement all of the following patterns.

Conclusion

We have now covered four patterns that are essentially variations of SSR. These variations use a combination of techniques to lower one or more of the performance parameters like TTFB (Static and Incremental Static Generation), TTI (Progressive Hydration) and FCP/FP (Streaming). The patterns build upon existing client-side frameworks like React and allow for some sort of rehydration to achieve the interactivity levels of CSR. Thus, we have multiple options to achieve the ultimate goal of combining both SSR and CSR benefits.



Summary

Depending on the type of the application or the page type, some of the patterns may be more suitable than the others. The following chart revisits, summarizes and compares the highlights of each pattern that we discussed in the previous sections and provides use cases for each.

	Classic SSR	SSR with Hydration	Streaming	Progressive Hydration	Static Generation	Incremental Static Generation	CSR
HTML generated on	Server	Server	Server	Server	Build Server	Build Server	Client
JavaScript for Hydration	No Hydration	JS for all components to be loaded for hydration	JS is streamed with HTML	JS is loaded progressively	Minimal JS	Minimal JS	No Hydration but JS for all components is required for rendering and interactivity
SPA Behaviour	Not Possible	Limited	Limited	Limited	Not Possible	Not Possible	Extensive
Crawler Readability	Full	Full	Full	Full	Full	Full	Limited
Caching	Minimum	Minimum	Minimum	Minimum	Extensive	Extensive	Minimum
TTFB	High	High	Low and consistent across page sizes	High	Low	Low	Low
TTI : FCP	TTI = FCP	TTI > FCP	TTI > FCP	TTI > FCP	TTI = FCP	TTI = FCP	TTI >> FCP
Implemented Using	Server side scripting languages like PHP	React for Server, Next.js	React for Server (React 16 onwards)	Full fledged React solution under development	Next.js	Next.js	CSR frameworks like React, Angular etc
Suitable For	Static content pages like news or encyclopedia pages	Mostly static pages with few interactive components. E.g., comments section of a blog	Mostly static pages that can be streamed in chunks. E.g., search results listing pages	Interactive pages where activation of some components may be delayed. E.g., Chatbot	Static content that does not change often. About Us or Contact us pages of websites	Huge quantities of static content that may change frequently. Blog listing or Product listing pages.	Highly Interactive apps where user experience is critical. E.g., Social media messaging and commenting

Overview of Next.js

Vercel's framework for hybrid React applications

Next.js, created by Vercel, is a framework for hybrid React applications. It is often difficult to understand all the different ways you might load content. Next.js abstracts this to make it as easy as possible. The framework allows you to build scalable, performant React code and comes with a zero-config approach. This allows developers to focus on building features.

Let us explore the Next.js features that are relevant to our discussion

Basic Features

Pre-rendering

By default, Next.js generates the HTML for each page in advance and not on the client-side. This process is called pre-rendering. Next.js ensures that JavaScript code required to make the page fully interactive gets associated with the generated HTML. This JavaScript code runs once the page loads. At this point, React JS works in a Shadow DOM to ensure that the rendered content matches with what the React application would render without actually manipulating it. This process is called hydration.

Each page is a React component exported from a `.js`, `.jsx`, `.ts`, or `.tsx` file in the pages directory. The route is determined based on the file name. E.g., `pages/about.js` corresponds to the route `/about`. Next.js supports pre-rendering through both Server-Side Rendering (SSR) and Static generation. You can also mix different rendering methods in the same app where some pages are generated using SSR and others using Static generation. Client-side rendering may also be used to render certain sections of these pages.

Data Fetching

Next.js supports data fetching with both SSR and Static generation. Following functions in the Next.js framework make this possible.

- `getStaticProps`
    - Used with Static generation to render data
- `getStaticPaths`
    - Used with Static generation to render dynamic routes
- `getServerSideProps`
    - Applicable to SSR

Static File Serving

Static files like images can be served under a folder called `public` in the root directory. The same image may then be referenced in the `<img>` tag code on different pages using the root URL. E.g., `src=/logo.png`.

Automatic Image Optimization

Next.js implements Automatic Image Optimization which allows for resizing, optimizing, and serving images in modern formats when the browser supports it. Thus, large images are resized for smaller viewports when required. Image optimization is implemented by importing the Next.js Image component which is an extension of the HTML `<img>` element. To use the Image component, it should be imported as follows.

```
import Image from 'next/image'
```

The image component can be served on the page using the following code.

```
<Image src="/logo.png" alt="Logo" width={500} height={500} />
```

Routing

Next.js supports routing through the `pages` directory. Every .js file in this directory or its nested subdirectories becomes a page with the corresponding route. Next.js also supports the creation of dynamic routes using named parameters where the actual document displayed is determined by the value of the parameter.

For example, a page `pages/products/[pid].js`, will get matched to routes like `/post/1` with `pid=1` as one of the query parameters. Linking to these dynamic routes on other pages is also supported in Next.js

Code Splitting

Code splitting ensures that only the required JavaScript is sent to the client which helps to improve performance. Next.js supports two types of code splitting.

- Route-based: This is implemented by default in Next.js. When a user visits a route, Next.js only sends the code needed for the initial route. The other chunks are downloaded as required when the user navigates around the application. This limits the amount of code that needs to be parsed and compiled at once thereby improving the page load times.

- Component-based: This type of code splitting allows splitting large components into separate chunks that can be lazy-loaded when required. Next.js supports component-based code splitting through dynamic import(). This allows you to import JavaScript modules (including React components) dynamically and load each import as a separate chunk.

Client-side Rendering

Render your application's UI on the client

In Client-Side Rendering (CSR) only the barebones HTML container for a page is rendered by the server. The logic, data fetching, templating and routing required to display content on the page is handled by JavaScript code that executes in the browser/client. CSR became popular as a method of building single-page applications. It helped to blur the difference between websites and installed applications.
To better appreciate the benefits provided by other patterns, let us first take a deeper look at Client-Side Rendering (CSR) and find out which are the situations where it works great and what are its drawbacks.

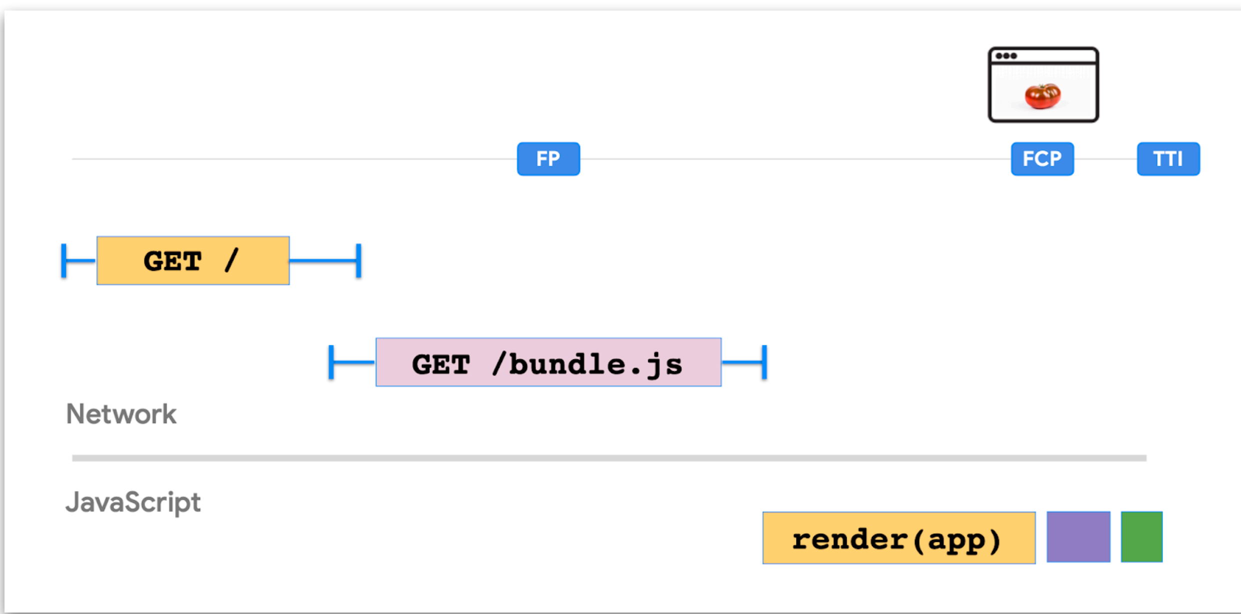
Consider this simple example for showing and updating the current time on a page using React.

```
function tick() {
  const element = (
    <div>
      <h1>Hello, world!</h1>
      <h2>It is {new Date().toLocaleTimeString()}.</h2>
    </div>
  );
 ReactDOM.render(element,document.getElementById('root'));
}
setInterval(tick, 1000);
```

The HTML consists of just a single root div tag. Content display and updates on the other hand are handled completely in JavaScript. There is no round trip to the server and rendered HTML is updated in-place. Here time could be replaced by any other real-time information like exchange rates or stock prices obtained from an API and displayed without refreshing the page or a round trip to the server.

JavaScript bundles and Performance

As the complexity of the page increases to show images, display data from a data store and include event handling, the complexity and size of the JavaScript code required to render the page will also increase. CSR resulted in large JavaScript bundles which increased the FCP and TTI of the page.



As shown in the above illustration, as the size of bundle.js increases, the FCP and TTI are pushed forward. This implies that the user will see a blank screen for the entire duration between FP and FCP.

Client-side React - Pros and Cons

With React most of the application logic is executed on the client and it interacts with the server through API calls to fetch or save data. Almost all of the UI is thus generated on the client. The entire web application is loaded on the first request. As the user navigates by clicking on links, no new request is generated to the server for rendering the pages. The code runs on the client to change the view/data.

CSR allows us to have a Single-Page Application that supports navigation without page refresh and provides a great user experience. As the data processed to change the view is limited, routing between pages is generally faster making the CSR application seem more responsive. CSR also allows developers to achieve a clear separation between client and server code. Despite the great interactive experience that it provides, there are a few pitfalls to this CSR.

1. **SEO considerations**: Most web crawlers can interpret server rendered websites in a straight-forward manner. Things get slightly complicated in the case of client-side rendering as large payloads and a waterfall of network requests (e.g for API responses) may result in meaningful content not being rendered fast enough for a crawler to index it. Crawlers may understand JavaScript but there are limitations. As such, some workarounds are required to make a client-rendered website SEO friendly.

2. **Performance**: With client-side rendering, the response time during interactions is greatly improved as there is no round trip to the server. However, for browsers to render content on client-side the first time, they have to wait for the JavaScript to load first and start processing. Thus users will experience some lag before the initial page loads. This may affect the user experience as the size of JS bundles get bigger and/or the client does not have sufficient processing power.

3. **Code Maintainability**: Some elements of code may get repeated across client and server (APIs) in different languages. In other cases, clean separation of business logic may not be possible. Examples of this could include validations and formatting logic for currency and date fields.

4. **Data Fetching**: With client-side rendering, data fetching is usually event-driven. The page could initially be loaded without any data. Data may be subsequently fetched on the occurrence of events like page-load or button-clicks using API calls. Depending on the size of data this could add to the load/interaction time of the application.

The importance of these considerations may be different across applications. Developers are often interested in finding SEO friendly solutions that can serve pages faster without compromising on the interaction time. Priorities assigned to the different performance criteria may be different based on application requirements. Sometimes it may be enough to use client- side rendering with some tweaks instead of going for a completely different pattern.

Improving CSR performance

Since performance for CSR is inversely proportional to the size of the JavaScript bundle, the best thing we can do is structure our JavaScript code for optimal performance. Following is a list of pointers that could help.

1. **Budgeting JavaScript**: Ensure that you have a reasonably tight JavaScript budget for your initial page loads. An initial bundle of < 100-170KB minified and gzipped is a good starting point. Code can then be loaded on-demand as features are needed

2. **Preloading**: This technique can be used to preload critical resources that would be required by the page, earlier in the page lifecycle. Critical resources may include JavaScript which can be preloaded by including the following directive in the <head> section of the HTML

```
<link rel="preload" as="script" href="critical.js">
```

This informs the browser to start loading the critical.js file before the page rendering mechanism starts. The script will thus be available earlier and will not block the page rendering mechanism thereby improving the performance.

1. **Lazy loading**: With lazy loading, you can identify resources that are non-critical and load these only when needed. Initial page load times can be improved using this approach as the size of resources loaded initially is

reduced. For example., a chat widget component would generally not be needed immediately on page load and can be lazy loaded.

2. **Code Splitting**: To avoid a large bundle of JavaScript code, you could start splitting your bundles. Code-Splitting is supported by bundlers like Webpack where it can be used to create multiple bundles that can be dynamically loaded at runtime. Code splitting also enables you to lazy load JavaScript resources.

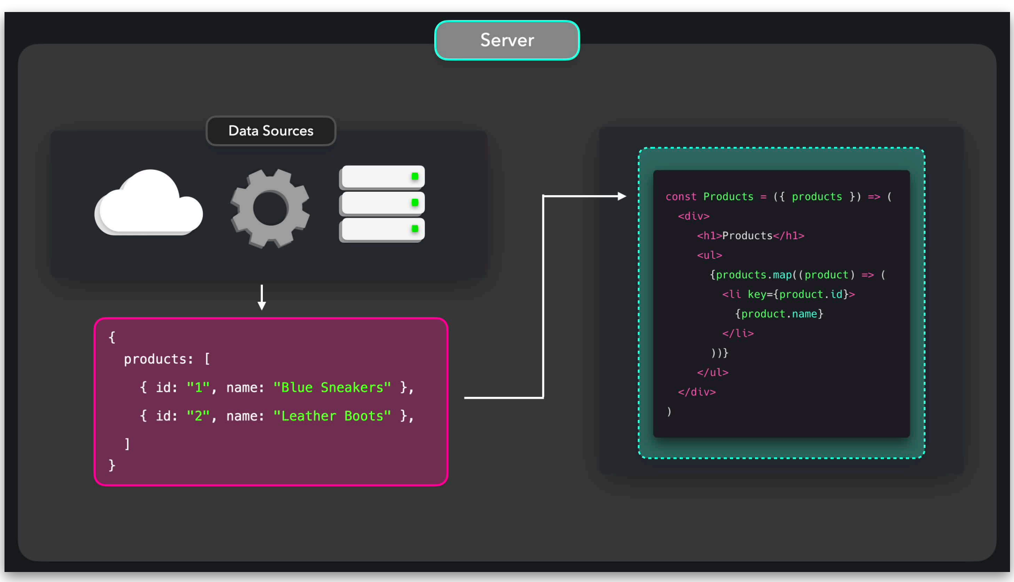
3. **Application shell caching with service workers**: This technique involves caching the application shell which is the minimal HTML, CSS, and JavaScript powering a user interface. Service workers can be used to cache the application shell offline. This can be useful in providing a native single-page app experience where the remaining content is loaded progressively as needed.

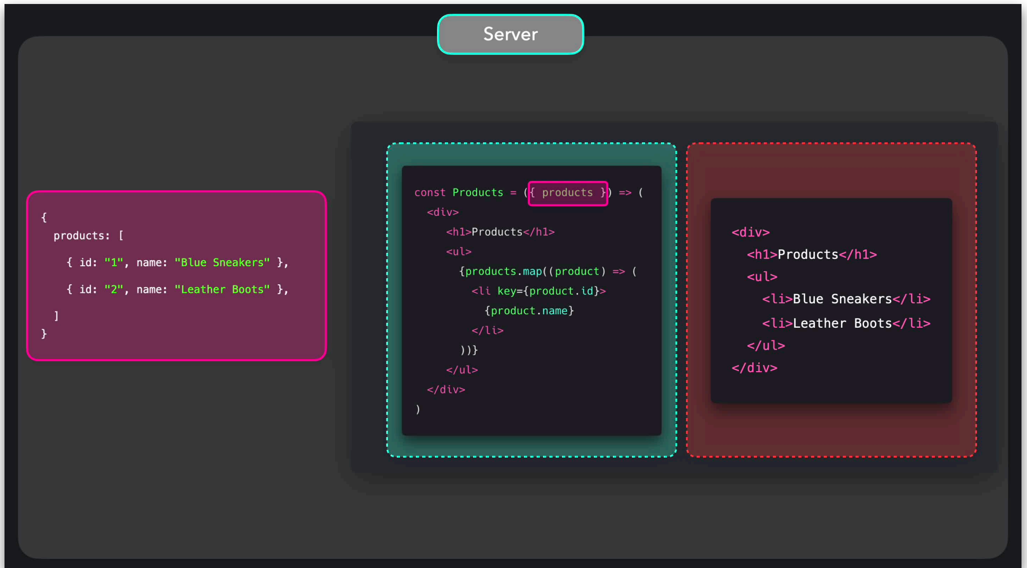
With these techniques, CSR can help to provide a faster Single-Page Application experience with a decent FCP and TTI. Next, we will see what is available at the other end of the spectrum with Server-Side Rendering.

Server-side Rendering

Generate HTML to be rendered on the server in response to a user request

Server-side rendering (SSR) is one of the oldest methods of rendering web content. SSR generates the full HTML for the page content to be rendered in response to a user request. The content may include data from a datastore or external API.




Server
{
products: [
{ id: "1", name: "Blue Sneakers" },
{ id: "2", name: "Leather Boots" },
]
}
const Products = ({ products }) => (
<div>
<h1>Products</h1>

{products.map((product) => (
<li key={product.id}>
{product.name}

))}

</div>
)
<div>
<h1>Products</h1>

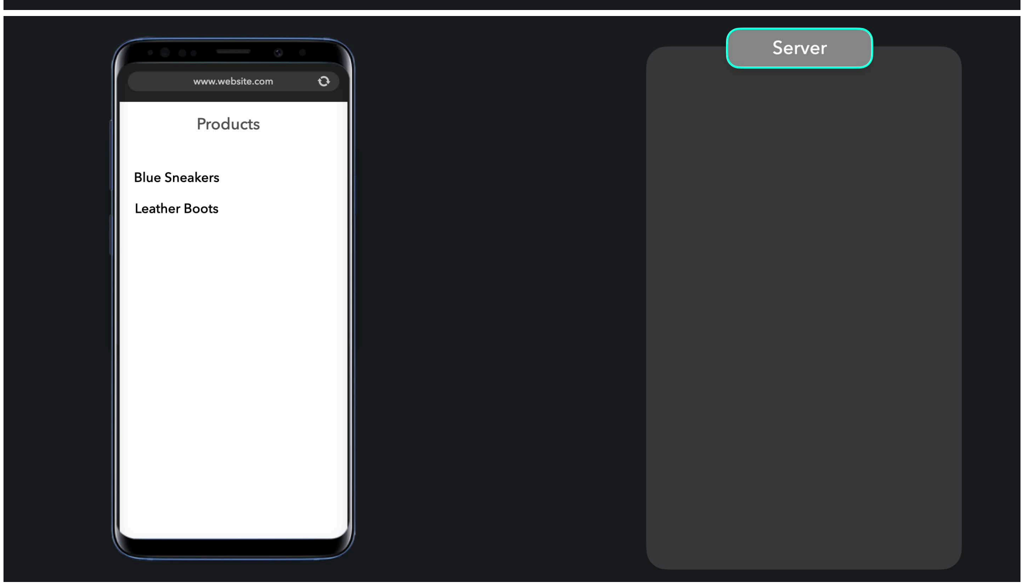
Blue Sneakers
Leather Boots

</div>


www.website.com
GET /
Server
<div>
<h1>Products</h1>

Blue Sneakers
Leather Boots

</div>


www.website.com
Products
Blue Sneakers
Leather Boots
Server

The connect and fetch operations are handled on the server. HTML required to format the content is also generated on the server. Thus, with SSR we can avoid making additional round trips for data fetching and templating. As such, rendering code is not required on the client and the JavaScript corresponding to this need not be sent to the client.

With SSR every request is treated independently and will be processed as a new request by the server. Even if the output of two consecutive requests is not very different, the server will process and generate it from scratch. Since the server is common to multiple users, the processing capability is shared by all active users at a given time.

Classic SSR Implementation

Let us see how you would create a page for displaying the current time using classic SSR and JavaScript.

index.html

```
<!DOCTYPE html>
<html>
   <head>
       <title>Time</title>
   </head>
   <body>
       <div>
       <h1>Hello, world!</h1>
       <b>It is <div id=currentTime></div></b>
       </div>
   </body>
</html>
```

index.js

```
function tick() {
    var d = new Date();
    var n = d.toLocaleTimeString();
    document.getElementById("currentTime").innerHTML = n;
}
setInterval(tick, 1000);
```

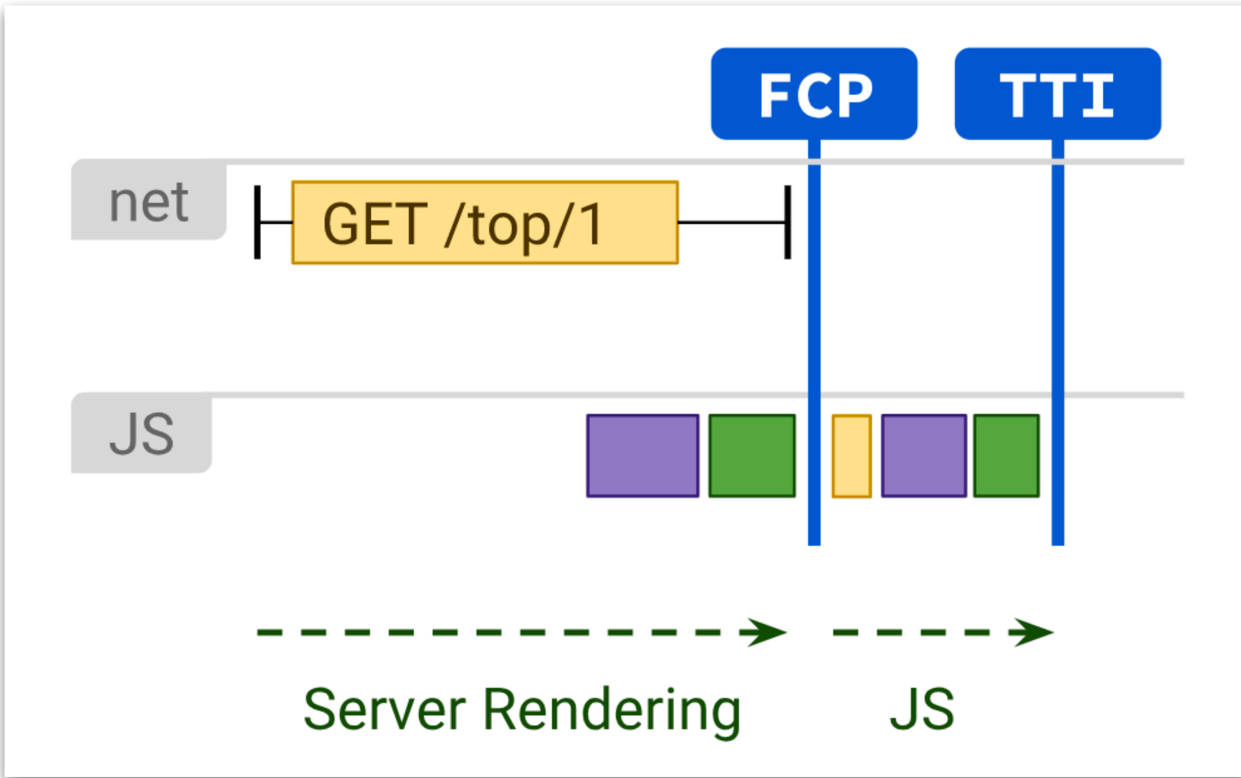
Note how this is different from the CSR code that provides the same output. Also note that, while the HTML is rendered by the server, the time displayed here is the local time on the client as populated by the JavaScript function `tick()`. If you want to display any other data that is server specific, e.g., server time, you will need to embed it in the HTML before it is rendered. This means it will not get refreshed automatically without a round trip to the server.

SSR - Pros and Cons

Executing the rendering code on the server and reducing JavaScript offers the following advantages.

Lesser JavaScript leads to quicker FCP and TTI

In cases where there are multiple UI elements and application logic on the page, SSR has considerably less JavaScript when compared to CSR. The time required to load and process the script is thus lesser. FP, FCP and TTI are shorter and FCP = TTI. With SSR, users will not be left waiting for all the screen elements to appear and for it to become interactive.



Provides additional budget for client-side JavaScript

Development teams are required to work with a JS budget that limits the amount of JS on the page to achieve the desired performance. With SSR, since you are directly eliminating the JS required to render the page, it creates additional space for any third party JS that may be required by the application.

SEO enabled

Search engine crawlers are easily able to crawl the content of an SSR application thus ensuring higher search engine optimization on the page. SSR works great for static content due to the above advantages. However, it does have a few disadvantages because of which it is not perfect for all scenarios.

Slow TTFB

Since all processing takes place on the server, the response from the server may be delayed in case of one or more of the following scenarios

- Multiple simultaneous users causing excess load on the server.
- Slow network
- Server code not optimized.

Full page reloads required for some interactions

Since all code is not available on the client, frequent round trips to the server are required for all key operations causing full page reloads. This could increase the time between interactions as users are required to wait longer between operations. A single-page application is thus not possible with SSR.

To address these drawbacks, modern frameworks and libraries allow rendering on both server and client for the same application. We will go into details of these in the following sections. First, let's look at a simpler form of SSR with Next.js.

SSR with Next.js

The Next.js framework also supports SSR. This pre-renders a page on the server on every request. It can be accomplished by exporting an async function called `getServerSideProps()` from a page as follows.

```
export async function getServerSideProps(context) {
  return {
    props: {}, // will be passed to the page component as props
  }
}
```

The context object contains keys for HTTP request and response objects, routing parameters, querystring, locale, etc.

React for the Server

React can be rendered isomorphically, which means that it can function both on the browser as well as other platforms like the server. Thus, UI elements may be rendered on the server using React.

React can also be used with universal code which will allow the same code to run in multiple environments. This is made possible by using Node.js on the server or what is known as a Node server. Thus, universal JavaScript may be used to fetch data on the server and then render it using isomorphic React.

Let us take a look at the react functions that make this possible.

```
ReactDOMServer.renderToString(element)
```

This function returns an HTML string corresponding to the React element. The HTML can then be rendered to the client for a faster page load.

The `renderToString()` function may be used with `ReactDOM.hydrate()`. This will ensure that the rendered HTML is preserved as-is on the client and only the event handlers attached after load.

To implement this, we use a `.js` file on both client and server corresponding to every page. The `.js` file on the server will render the HTML content, and the `.js` file on the client will hydrate it.

Assume you have a React element called App which contains the HTML to be rendered defined in the universal `app.js` file. Both the server and client-side React can recognize the App element.

The `ipage.js` file on the server can have the code:

```
app.get('/', (req, res) => {
  const app = ReactDOMServer.renderToString(<App />);
})
```

The constant App can now be used to generate the HTML to be rendered. The ipage.js on the client side will have the following to ensure that the element App is hydrated.

```
ReactDOM.hydrate(<App />, document.getElementById('root'));
```

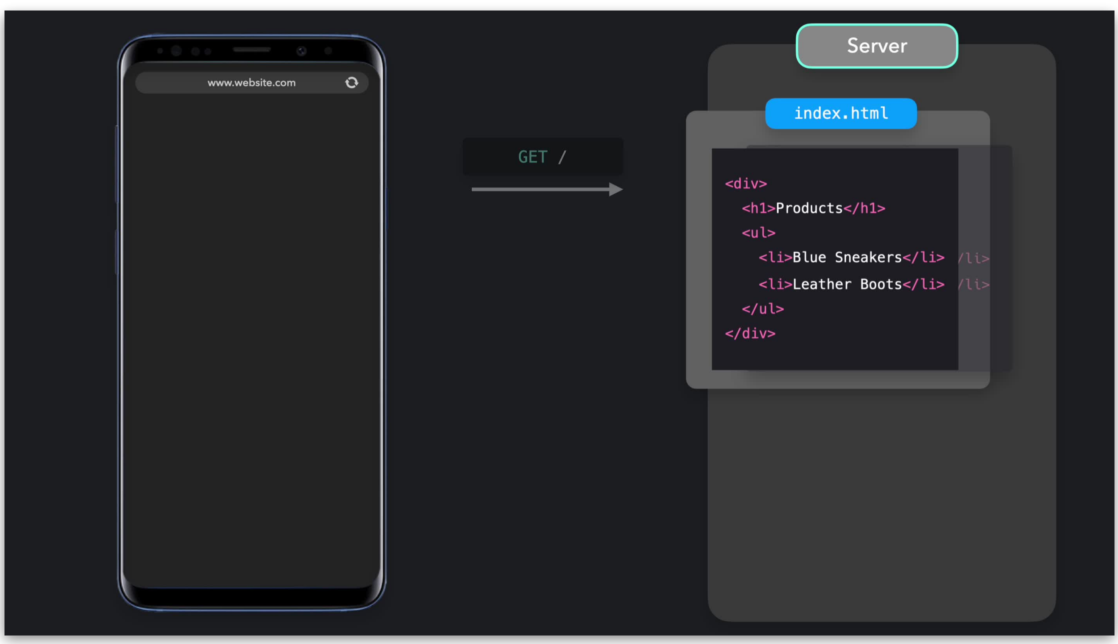
Static Rendering

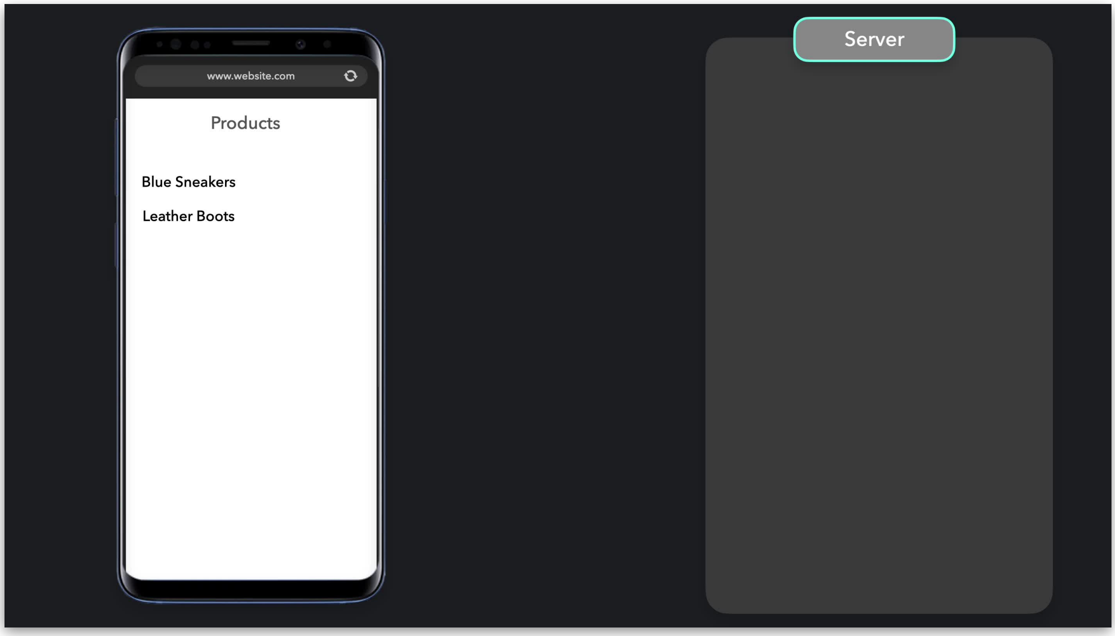
Deliver pre-rendered HTML content that was generated when the site was built

Based on our discussion on SSR, we know that a high request processing time on the server negatively affects the TTFB. Similarly, with CSR, a large JavaScript bundle can be detrimental to the FCP, LCP and TTI of the application due to the time taken to download and process the script.

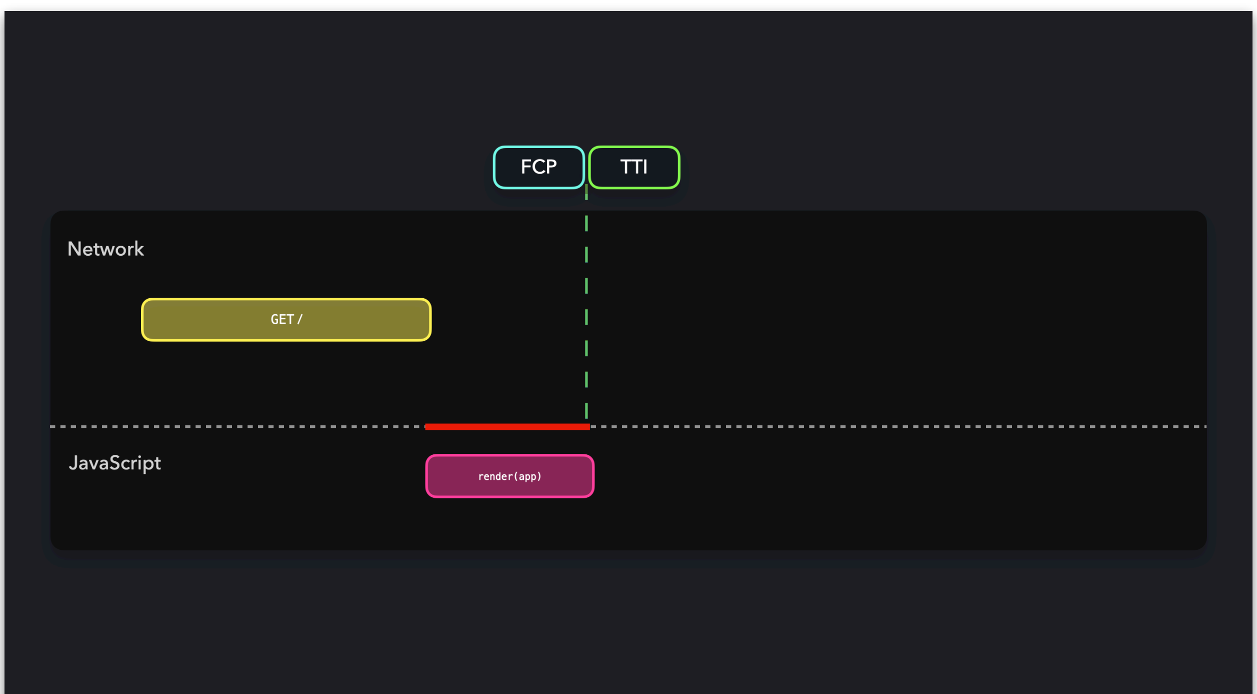
Static rendering or static generation (SSG) attempts to resolve these issues by delivering pre-rendered HTML content to the client that was generated when the site was built.

A static HTML file is generated ahead of time corresponding to each route that the user can access. These static HTML files may be available on a server or a CDN and fetched as and when requested by the client.





Static files may also be cached thereby providing greater resiliency. Since the HTML response is generated in advance, the processing time on the server is negligible thereby resulting in a faster TTFB and better performance. In an ideal scenario, client-side JS should be minimal and static pages should become interactive soon after the response is received by the client. As a result, SSG helps to achieve a faster FCP/TTI



Basic Structure

As the name suggests, static rendering is ideal for static content, where the page need not be customized based on the logged-in user (e.g personalized recommendations). Thus static pages like the ‘About us', ‘Contact us', Blog pages for websites or product pages for e-commerce apps, are ideal candidates for static rendering. Frameworks like Next.js, Gatsby, and VuePress support static generation. Let us start with this simple Next.js example of static content rendering without any data.

pages/about.js

```
export default function About() {
 return <div>
   <h1>About Us</h1>
   {/* ... */}
 </div>
}
```

.

When the site is built, this page will be pre-rendered into an HTML file `about.html` accessible at the route `/about`.

SSG with Data

Static content like that in 'About us' or 'Contact us' pages may be rendered as-is without getting data from a data-store. However, for content like individual blog pages or product pages, the data from a data-store has to be merged with a specific template and then rendered to HTML at build time.

The number of HTML pages generated will depend on the number of blog posts or the number of products respectively. To get to these pages, you may also have listing pages which will be HTML pages that contain a categorized and formatted list of data items. These scenarios can be addressed using Next.js static rendering. We can generate listing pages or individual item pages based on the available items. Let us see how.

Listing Page - All Items

Generation of a listing page is a scenario where the content to be displayed on the page depends on external data. This data will be fetched from the database at build time to construct the page. In Next.js this can be achieved by exporting the function getStaticProps() in the page component. The function is called at build time on the build server to fetch the data. The data can then be passed to the page's props to pre-render the page component.

```
// This function runs at build time on the build server
export async function getStaticProps() {
 return {
   props: {
     products: await getProductsFromDatabase()
   }
 }
}

// The page component receives products prop from getStaticProps at build time
export default function Products({ products }) {
 return (
   <>
     <h1>Products</h1>
     <ul>
       {products.map((product) => (
         <li key={product.id}>{product.name}</li>
       ))}
     </ul>
   </>
 )
}
```

The function will not be included in the client-side JS bundle and hence can even be used to fetch the data directly from a database.

Individual Details Page - Per Item

In the above example, we could have an individual detailed page for each of the products listed on the listing page. These pages could be accessed by clicking on the corresponding items on the listing page or directly through some other route.

Assume we have products with product ids 101,102 103, and so on. We need their information to be available at routes /products/101, /products/102, / products/103 etc. To achieve this at build time in Next.js we can use the function getStaticPaths() in combination with dynamic routes.

We need to create a common page component products/[id].js for this and export the function getStaticPaths() in it. The function will return all possible product ids which can be used to pre-render individual product pages at build time. The following Next.js skeleton available here shows how to structure the code for this.

```
pages/products/[id].js

// In getStaticPaths(), you need to return the list of
// ids of product pages (/products/[id]) that you'd
// like to pre-render at build time. To do so,
// you can fetch all products from a database.
export async function getStaticPaths() {
 const products = await getProductsFromDatabase()

 const paths = products.map((product) => ({
   params: { id: product.id }
 }))

 // fallback: false means pages that don't have the correct id will 404.
 return { paths, fallback: false }
}

// params will contain the id for each generated page.
export async function getStaticProps({ params }) {
 return {
   props: {
     product: await getProductFromDatabase(params.id)
   }
 }
}

export default function Product({ product }) {
 // Render product
}
```

The details on the product page may be populated at build time by using the function getStaticProps for the specific product id. Note the use of the fallback: false indicator here. It means that if a page is not available corresponding to a specific route or product Id, the 404 error page will be shown.

Thus we can use SSG to pre-render many different types of pages.

Key Considerations

As discussed, SSG results in a great performance for websites as it cuts down the processing required both on the client and the server. The sites are also SEO friendly as the content is already there and can be rendered by web-crawlers with no extra effort. While performance and SEO make SSG a great rendering pattern, the following factors need to be considered when assessing the suitability of SSG for specific applications.

1. **A large number of HTML files:** Individual HTML files need to be generated for every possible route that the user may access. For example, when using it for a blog, an HTML file will be generated for every blog post available in the data store. Subsequently, edits to any of the posts will require a rebuild for the update to be reflected in the static HTML files. Maintaining a large number of HTML files can be challenging.

2. **Hosting Dependency**: For an SSG site to be super-fast and respond quickly, the hosting platform used to store and serve the HTML files should also be good. Superlative performance is possible if a well-tuned SSG website is hosted right on multiple CDNs to take advantage of edge-caching.

3. **Dynamic Conten**t: An SSG site needs to be built and re-deployed every time the content changes. The content displayed may be stale if the site has not been built + deployed after any content change. This makes SSG unsuitable for highly dynamic content.

Incremental Static Generation

Update static content after you have built your site

Static Generation (SSG) addresses most of the concerns of SSR and CSR but is suitable for rendering mostly static content. It poses limitations when the content to be rendered is dynamic or changing frequently.

Think of a growing blog with multiple posts. You wouldn't possibly want to rebuild and redeploy the site just because you want to correct a typo in one of the posts. Similarly, one new blog post should also not require a rebuild for all the existing pages. Thus, SSG on its own is not enough for rendering large websites or applications.

The Incremental Static Generation (iSSG) pattern was introduced as an upgrade to SSG, to help solve the dynamic data problem and help static sites scale for large amounts of frequently changing data. iSSG allows you to update existing pages and add new ones by pre-rendering a subset of pages in the background even while fresh requests for pages are coming in.

Sample Code

iSSG works on two fronts to incrementally introduce updates to an existing static site after it has been built.

1. Allows addition of new pages
2. Allows updates to existing pages also known as Incremental Static “Re"generation

Adding New pages

The lazy loading concept is used to include new pages on the website after the build. This means that the new page is generated immediately on the first request. While the generation takes place, a fallback page or a loading indicator can be shown to the user on the front-end. Compare this to the SSG scenario discussed earlier for individual details page per product. The 404 error page was shown here as a fallback for non-existent pages.

Let us now look at the Next.js code required for lazy-loading the non-existent page with iSSG.

pages/products/[id].js

```
// In getStaticPaths(), you need to return the list of
// ids of product pages (/products/[id]) that you'd
// like to pre-render at build time. To do so,
// you can fetch all products from a database.
export async function getStaticPaths() {
  const products = await getProductsFromDatabase();

  const paths = products.map((product) => ({
     params: { id: product.id }
  }));


  // fallback: true means that the missing pages
  // will not 404, and instead can render a fallback.
  return { paths, fallback: true };
}

// params will contain the id for each generated page.
export async function getStaticProps({ params }) {
  return {
    props: {
      product: await getProductFromDatabase(params.id)
    }
  }
}



export default function Product({ product }) {
  const router = useRouter();

  if (router.isFallback) {
    return <div>Loading...</div>;
  }

  // Render product
}
```

Here, we have used `fallback: true`. Now if the page corresponding to a specific product is unavailable, we show a fallback version of the page, eg., a loading indicator as shown in the Product function above. Meanwhile, Next.js will generate the page in the background. Once it is generated, it will be cached and shown instead of the fallback page. The cached version of the page will now be shown to any subsequent visitors immediately upon request. For both new and existing pages, we can set an expiration time for when Next.js should revalidate and update it. This can be achieved by using the revalidate property as shown in the following section.

Update Existing pages

To re-render an existing page, a suitable timeout is defined for the page. This will ensure that the page is revalidated whenever the defined timeout period has elapsed. The timeout could be set to as low as 1 second. The user will continue to see the previous version of the page, till the page has finished revalidation. Thus, iSSG uses the stale-while-revalidate strategy where the user receives the cached or stale version while the revalidation takes place. The revalidation takes place completely in the background without the need for a full rebuild.

Let us go back to the example for generating a static listing page for products based on the data in the database. To make it serve a relatively dynamic list of products, we will include the code to set the timeout for rebuilding the page. This is what the code will look like after including the timeout.

pages/products/[id].js

```
// This function runs at build time on the build server
export async function getStaticProps() {
  return {
    props: {
      products: await getProductsFromDatabase(),
      revalidate: 60, // This will force the page to revalidate after 60 seconds
    }
  }
}

// The page component receives products prop from getStaticProps at build time
export default function Products({ products }) {
  return (
    <>
      <h1>Products</h1>
      <ul>
        {products.map((product) => (
          <li key={product.id}>{product.name}</li>
        ))}
      </ul>
    </>
  )
}
```

The code to revalidate the page after 60 seconds is included in the getStaticProps() function. When a request comes in the available static page is served first. Every one minute the static page gets refreshed in the background with new data. Once generated, the new version of the static file becomes available and will be served for any new requests in the subsequent minute. This feature is available in Next.js 9.5 and above.

iSSG Advantages

iSSG provides all the advantages of SSG and then some more. The following list covers them in detail.

1. **Dynamic data**: The first advantage is obviously why iSSG was envisioned. Its ability to support dynamic data without a need to rebuild the site.

2. **Speed**: iSSG is at least as fast as SSG because data retrieval and rendering still takes place in the background. There is little processing required on the client or the server.

3. **Availability**: A fairly recent version of any page will always be available online for users to access. Even if the regeneration fails in the background, the old version remains unaltered.

4. **Consistent**: As the regeneration takes place on the server one page at a time, the load on the database and the backend is low and performance is consistent. As a result, there are no spikes in latency.

5. **Ease of Distribution**: Just like SSG sites, iSSG sites can also be distributed through a network of CDN's used to serve pre-rendered web pages.

Progressive Hydration

Delay loading JavaScript for less important parts of the page

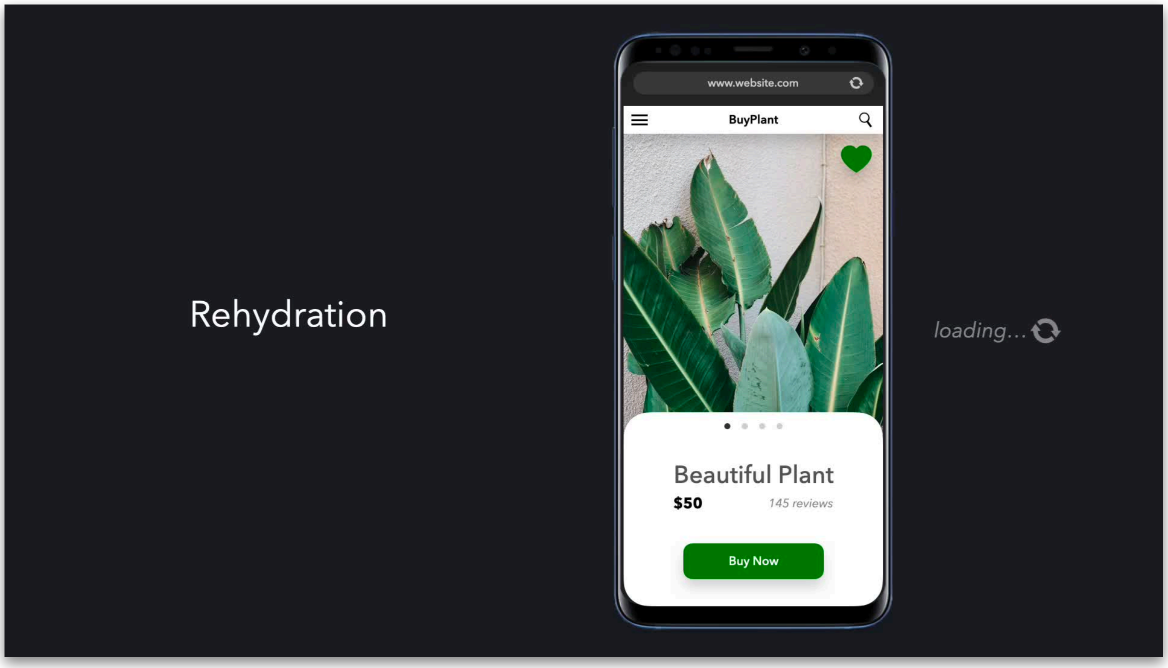
A server rendered application uses the server to generate the HTML for the current navigation. Once the server has completed generating the HTML contents, which also contains the necessary CSS and JSON data to display the static UI correctly, it sends the data down to the client. Since the server generated the markup for us, the client can quickly parse this and display it on the screen, which produces a fast First Contentful Paint!

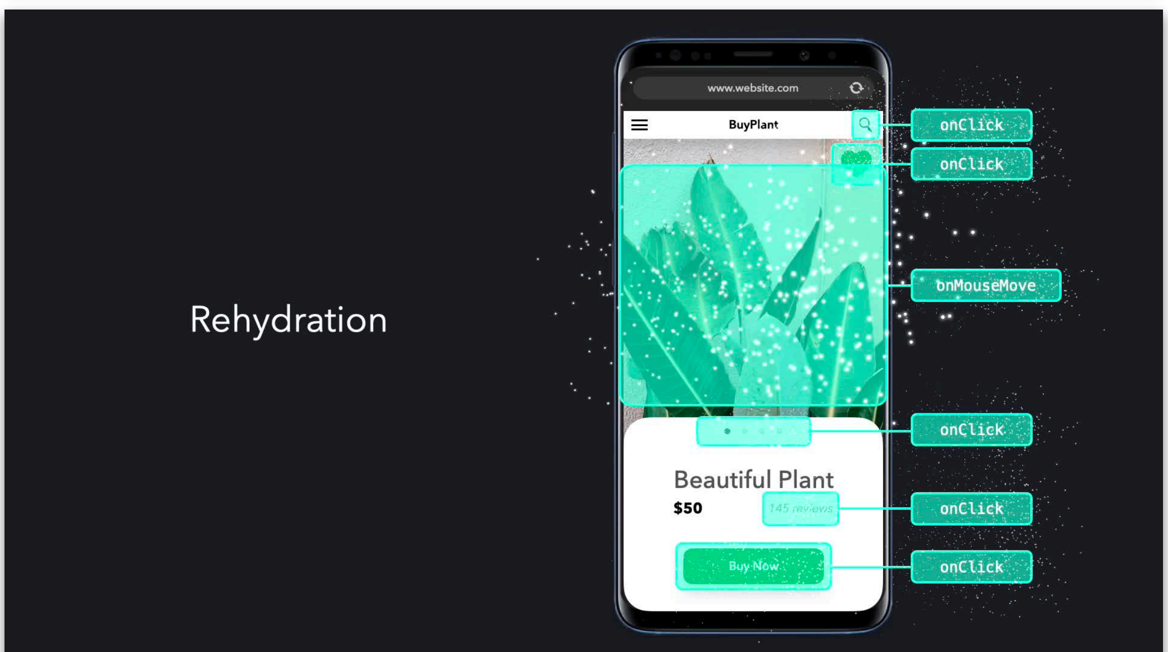
Although server rendering provides a faster First Contentful Paint, it doesn't always provide a faster Time To Interactive. The necessary JavaScript in order to be able to interact with our website hasn't been loaded yet.
Buttons may look interactive, but they aren't interactive (yet). The handlers will only get attached once the JavaScript bundle has
been loaded and processed. This process is called hydration: React checks the current DOM nodes, and hydrates the nodes with the corresponding JavaScript.

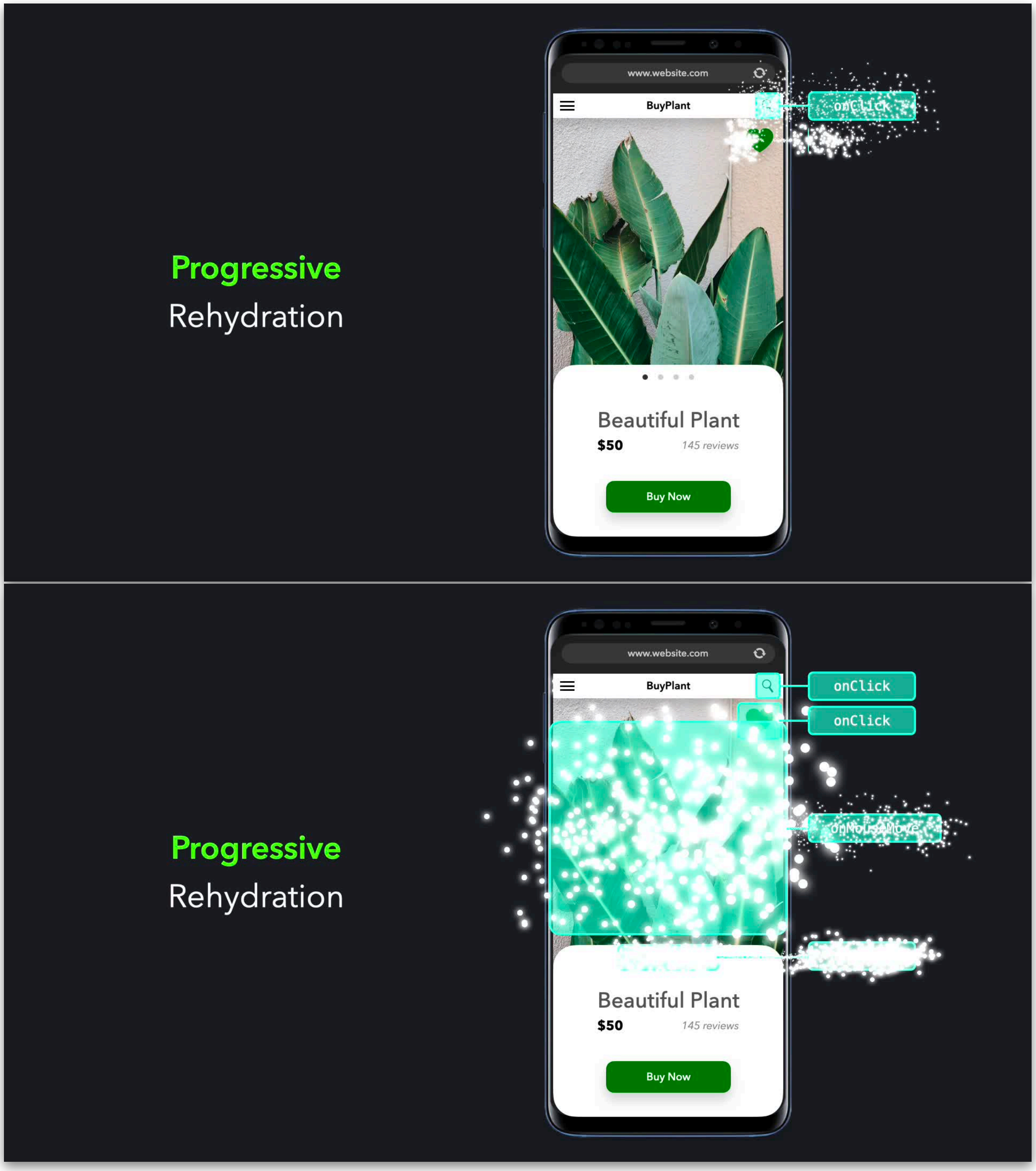
The time that the user sees non-interactive UI on the screen is also refered to as the uncanny valley: although users may think that they can interact with the website, there are no handlers attached to the components yet. This can be a frustrating experience for the user, as the UI may can like it's frozen!

It can take a while before the DOM components that were received from the server are fully hydrated. Before the components can be hydrated, the

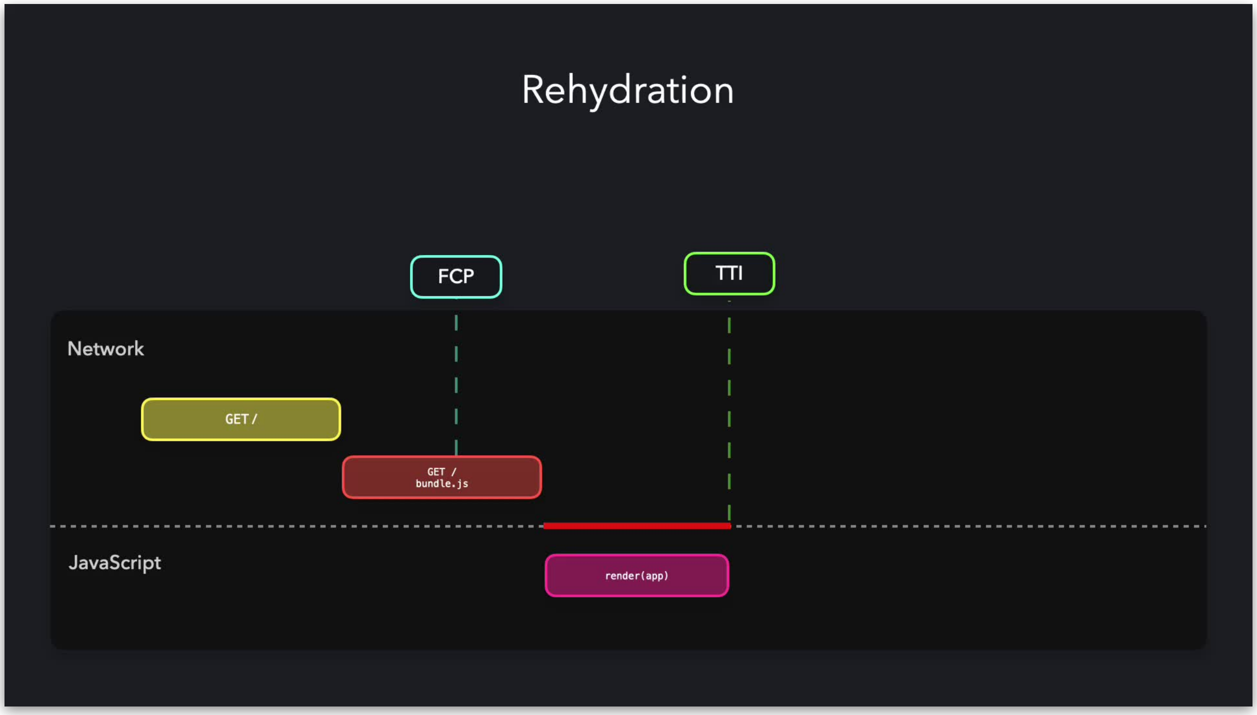
JavaScript file needs to be loaded, processed, and executed. Instead of hydrating the entire application at once, like we did previously, we can also progressively hydrate the DOM nodes. Progressive hydration makes it possible to individually hydrate nodes over time, which makes it possible to only request the minimum necessary JavaScript.

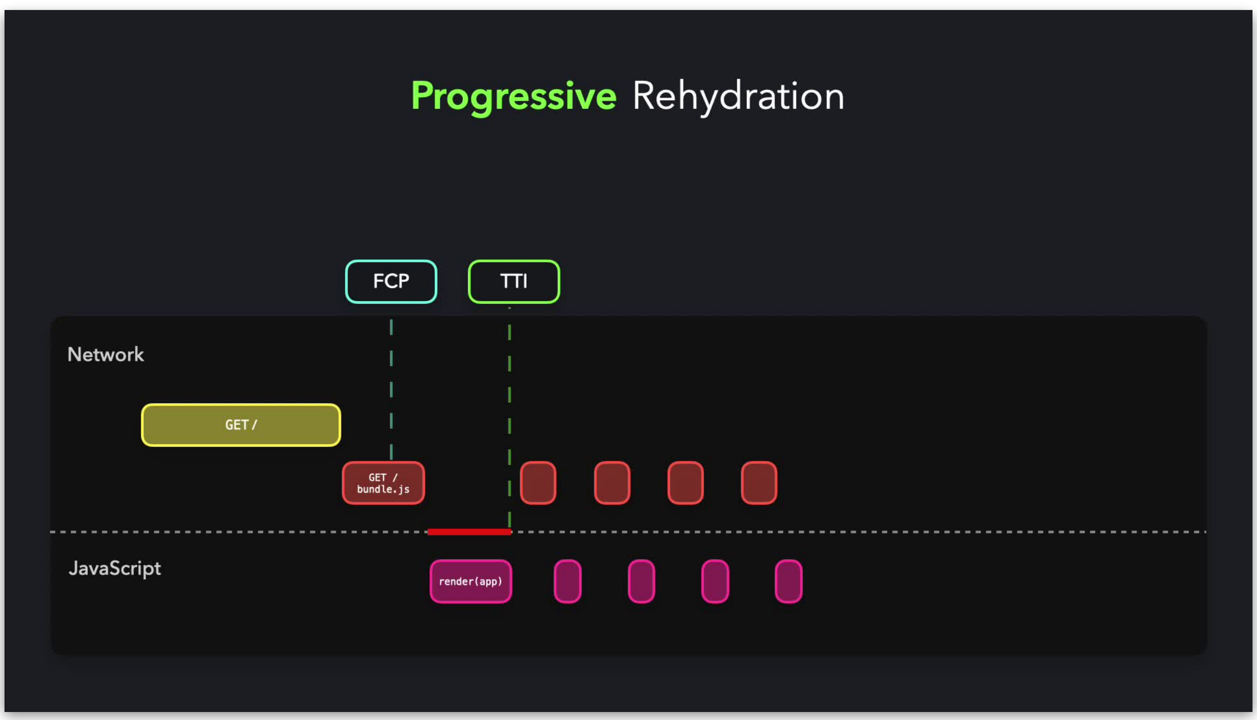






By progressively hydrating the application, we can delay the hydration of less important parts of the page. This way, we can reduce the amount of JavaScript we have to request in order to make the page interactive, and only hydrate the nodes once the user needs it. Progressive hydration also helps avoid the most common SSR Rehydration pitfalls where a server-rendered DOM tree gets destroyed and then immediately rebuilt.





Progressive hydration allows us to only hydrate components based on a certain condition, for example when a component is visible in the viewport.

In the following example, we have a list of users that gets progressively hydrated once the list is in the viewport. The purple flash shows when the component has been hydrated!

client.js

```javascript
import React from "react";
import { hydrate } from "react-dom";
import App from "./components/App";

hydrate(<App />, document.getElementById("root"));
```

server.js

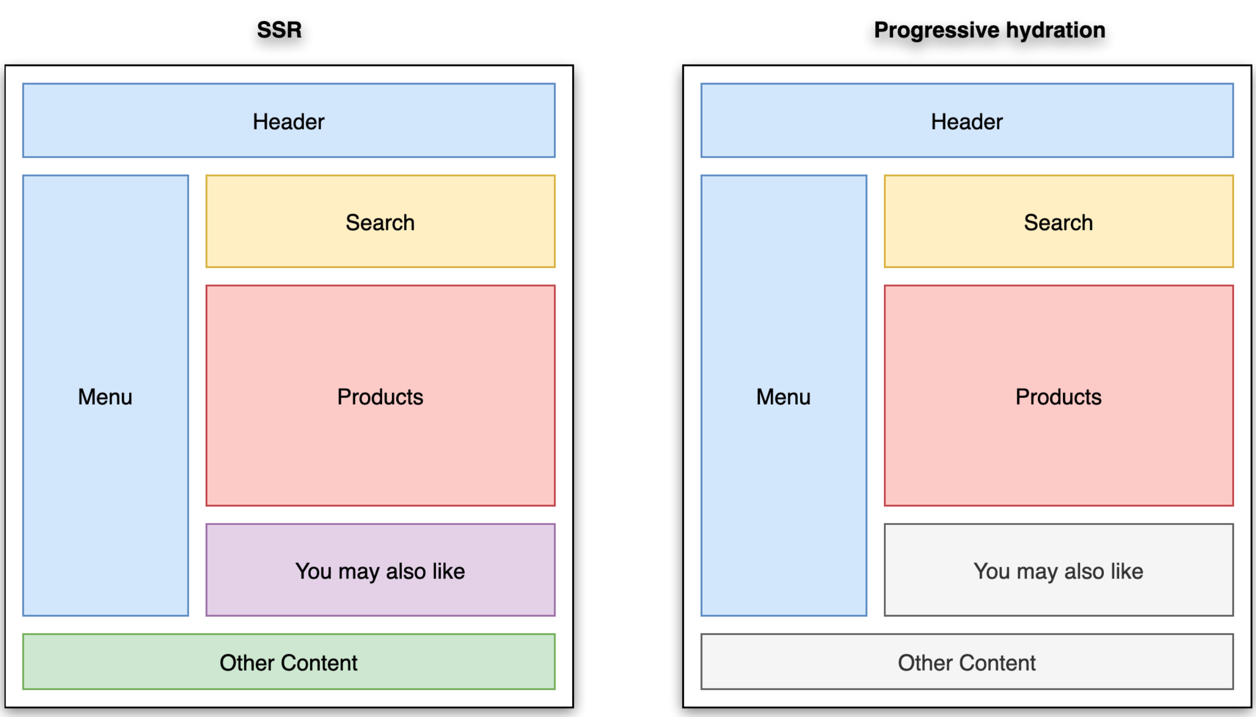
```javascript
import React from "react";
import { renderToNodeStream } from "react-dom/server";
import App from "./components/App";

export default async () => renderToNodeStream(<App />);
```

Progressive Hydration Implementation

In the section on implementing SSR with React, we discussed client-side hydration for an app that is rendered on the server. Hydration allows client-side React to recognize the ReactDOM components that are rendered on the server and attach events to these components. Thus, it introduces continuity and seamlessness for an SSR app to function like a CSR app once it is available on the client.

For all components on the page to become interactive via hydration, the React code for these components should be included in the bundle that gets downloaded to the client. Highly interactive SPAs that are largely controlled by JavaScript would need the entire bundle at once. However, mostly static websites with a few interactive elements on the screen, may not need all components to be active immediately. For such websites sending a huge React bundle for each component on the screen becomes an overhead.

Progressive Hydration solves this problem by allowing us to hydrate only certain parts of the application when the page loads. The other parts are hydrated progressively as required.



With Progressive hydration, the "You may also like" and "Other content" components can be hydrated later.

Instead of initializing the entire application at once, the hydration step begins at the root of the DOM tree, but the individual pieces of the server-rendered application are activated over a period of time. The hydration process may be arrested for various branches and resumed later when they enter the viewport or based on some other trigger. Note that, the loading of resources required to perform each hydration is also deferred using code-splitting techniques, thereby reducing the amount of JavaScript required to make pages interactive.

The idea behind progressive hydration is to provide a great performance by activating your app in chunks. Any progressive hydration solution should also take into account how it will impact the overall user experience. You cannot have chunks of screen popping up one after the other but blocking any activity or user input on the chunks that have already loaded. Thus, the requirements for a holistic progressive hydration implementation are as follows.

- Allows usage of SSR for all components.
- Supports splitting of code into individual components or chunks.
- Supports client side hydration of these chunks in a developer defined sequence.
- Does not block user input on chunks that are already hydrated.\
- Allows usage of some sort of a loading indicator for chunks with deferred hydration.

React concurrent mode will address all these requirements once it is available to all. It allows React to work on different tasks at the same time and switch between them based on the given priority. When switching, a partially rendered tree need not be committed, so that the rendering task can continue once React switches back to the same task.

Concurrent mode can be used to implement progressive hydration. In this case, hydration of each of the chunks on the page, becomes a task for React concurrent mode. If a task of higher priority like user input needs to be performed, React will pause the hydration task and switch to accepting the user input. Features like lazy(), Suspense() allow you to use declarative loading states. These can be used to show the loading indicator while chunks are being lazy loaded. SuspenseList() can be used to define the priority for lazy loading components.This demo shared by Dan Abramov shows concurrent mode in action and implements progressive hydration.

React concurrent mode can also be combined with another React feature **Server Components**. This will allow you to refetch components from the server and render them on the client as they stream in instead of waiting for the whole fetch to finish. Thus, the client's CPU is put to work even as we wait for the network fetch to finish.

While the React concurrent mode based progressive hydration implementation is still getting ready, many other contenders for a partial hydration implementation are available. Progressive hydration was demonstrated at Google I/O '19. The demo for progressive hydration showed the use of a Hydrator component to hydrate selected sections of the page.

Multiple implementations have spawned from this for different client-side frameworks. Implementations are also available for Vue, Angular and Next.js. Let is take a quick look at one such method using Preact and Next.js

This is a POC for partial hydration using

- `pool-attendant-preact`: A library that implements partial hydration with preact x.
- `next-super-performance`: A Next.js plugin that uses this library to improve client-side performance.

The `pool-attendant-preact` library includes an API called withHydration which lets you mark your more interactive components for hydration. These will be hydrated first. You can use this to define your page content as follows.

```
import Teaser from "./teaser";
import { withHydration } from "next-super-performance";

const HydratedTeaser = withHydration(Teaser);

export default function Body() {
 return (
   <main>
     <Teaser column={1} />
     <HydratedTeaser column={2} />
     <HydratedTeaser column={3} />

     <Teaser column={1} />
     <Teaser column={2} />
     <Teaser column={3} />

     <Teaser column={1} />
     <Teaser column={2} />
     <Teaser column={3} />
   </main>
 );
}
```

The component HydratedTeaser in columns 2 and 3 will be hydrated first. You can now hydrate the remaining components on the client using the hydrate() API which is also included in the library.

```
import { hydrate } from "next-super-performance";
import Teaser from "./components/teaser";

hydrate([Teaser]);
```

The component HydrationData is used to write serialized props to the client. It will ensure that the required props are available to the components being hydrated.

```
import Header from "../components/header";
import Main from "../components/main";
import { HydrationData } from "next-super-performance";

export default function Home() {
 return (
   <section>
     <Header />
     <Main />
     <HydrationData />
   </section>
 );
}
```

Pros and Cons

Progressive hydration provides server-side rendering with client-side hydration while also minimizing the cost of hydration. Following are some of the advantages that can be gained from this.

1. **Promotes code-splitting**: Code-splitting is an integral part of progressive hydration because chunks of code need to be created for individual components that are lazy- loaded.

2. **Allows on-demand loading for infrequently used parts of the page**: There may be components of the page that are mostly static, out of the viewport and/or not required very often. Such components are ideal candidates for lazy loading. Hydration code for these components need not be sent when the page loads. Instead, they may be hydrated based on a trigger.

3. **Reduces bundle size**: Code-splitting automatically results in a reduction of bundle size. Less code to execute on load helps reduce the time between FCP and TTI.

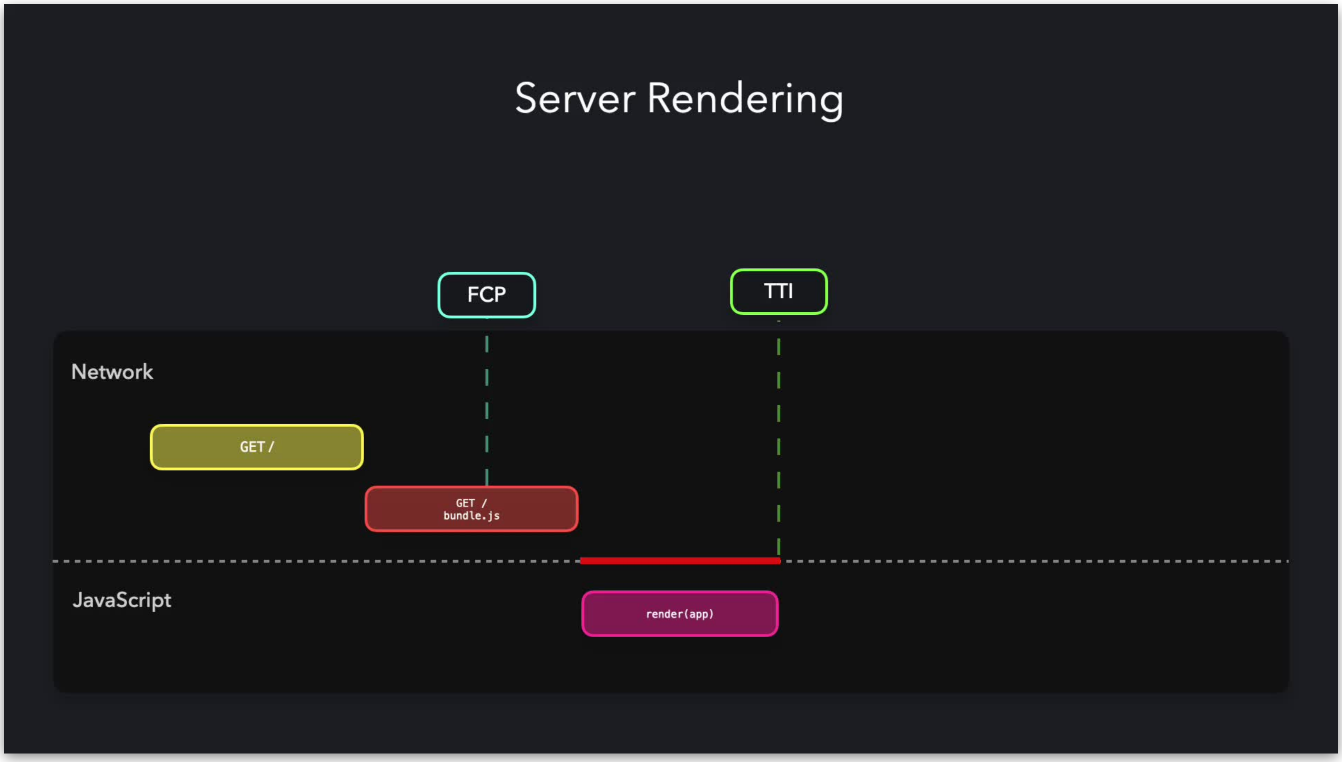
On the downside, progressive hydration may not be suitable for dynamic apps where every element on the screen is available to the user and needs to be made interactive on load. This is because, if developers do not know where the user is likely to click first, they may not be able to identify which components to hydrate first.

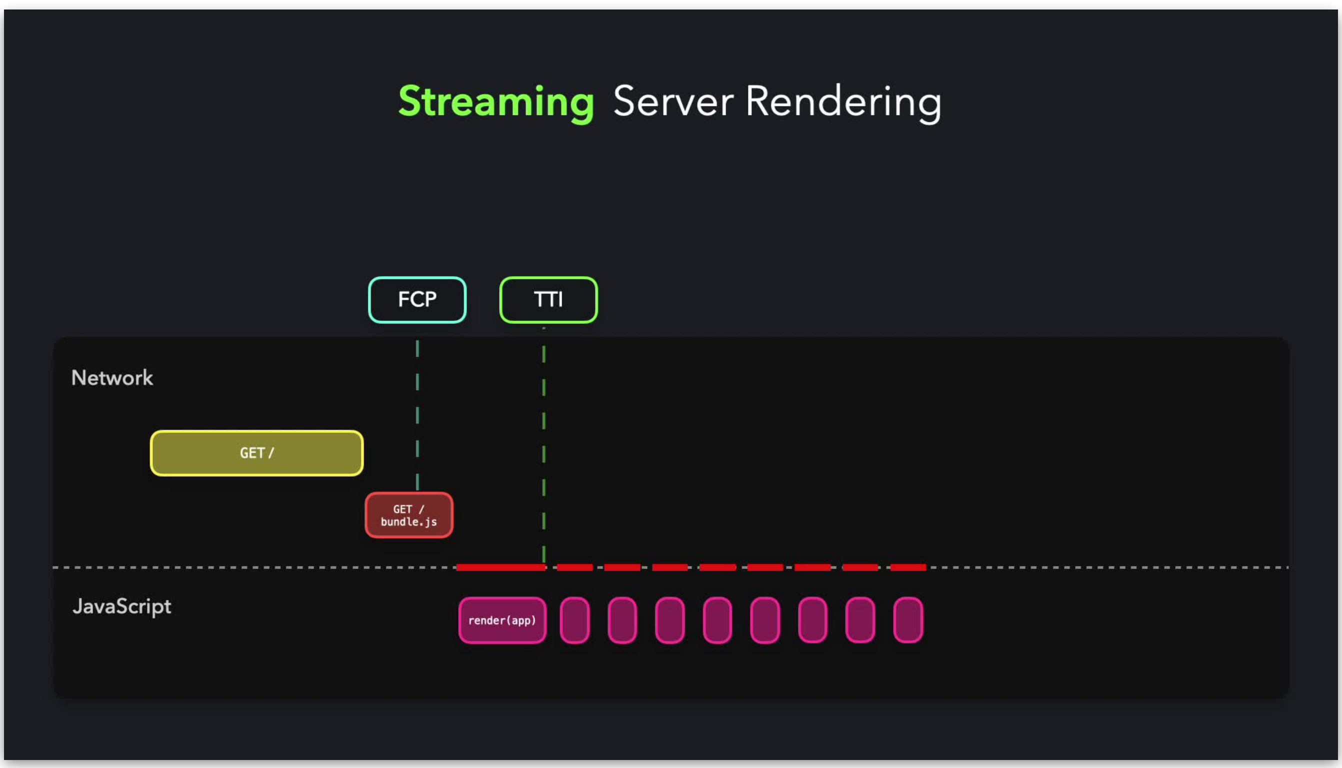
Streaming Server-Side Rendering

Generate HTML to be rendered on the server in response to a user request

We can reduce the TTI while still server rendering our application by streaming server rendering the contents of our application. Instead of generating one large HTML file containing the necessary markup for the current navigation, we can split it up into smaller chunks! Node streams allow us to data into the response object, which means that we can continuously send data down to the client. The moment the client receives the chunks of data, it can start rendering the contents.

React's built-in renderToNodeStream makes it possible for us to send our application in smaller chunks. As the client can start painting the UI when it's still receiving data, we can create a very performant first-load experience. Calling the hydrate method on the received DOM nodes will attach the corresponding event handlers, which makes the UI interactive!


Server Rendering
FCP
TTI
Network
GET /
GET /
bundle.js
JavaScript
render(app)


Streaming Server Rendering
FCP
TTI
Network
GET /
GET /
bundle.js
JavaScript
render(app)

```
import React from "react";
import path from "path";
import express from "express";
import { renderToNodeStream } from "react-dom/server";

import App from "./src/App";

const app = express();

app.get("/favicon.ico", (req, res) => res.end());
app.use("/client.js", (req, res) => res.redirect("/build/client.js"));

const DELAY = 500;
app.use((req, res, next) => {
  setTimeout(() => next(), DELAY);
});

const BEFORE = `
<!DOCTYPE html>
  <html>
    <head>
      <title>Cat Facts</title>
      <link rel="stylesheet" href="/style.css">
      <script type="module" defer src="/build/client.js"></script>
    </head>
    <body>
      <h1>Stream Rendered Cat Facts!</h1>
      <div id="approot">
`.replace(/
s*/g, "");
```

```
app.get("/", async (request, response) => {
  try {
    const stream = renderToNodeStream(<App />);
    const start = Date.now();

    stream.on("data", function handleData() {
      console.log("Render Start: ", Date.now() - start);
      stream.off("data", handleData);
      response.useChunkedEncodingByDefault = true;
      response.writeHead(200, {
        "content-type": "text/html",
        "content-transfer-encoding": "chunked",
        "x-content-type-options": "nosniff"
      });
      response.write(BEFORE);
      response.flushHeaders();
    });
    await new Promise((resolve, reject) => {
      stream.on("error", err => {
        stream.unpipe(response);
        reject(err);
      });
      stream.on("end", () => {
        console.log("Render End: ", Date.now() - start);
        response.write("</div></body></html>");
        response.end();
        resolve();
      });
      stream.pipe(response, { end: false });
    });
  } catch (err) {
    response.writeHead(500, { "content-type": "text/plain" });
    response.end(String((err && err.stack) || err));
    return;
  }
});

app.use(express.static(path.resolve(__dirname, "src")));
app.use("/build", express.static(path.resolve(__dirname, "build")));
```

Let's say we have an app that shows the user thousands of cat facts in the App component!

```
<!DOCTYPE html>
<html>
  <head>
    <title>Cat Facts</title>
    <link rel="stylesheet" href="/style.css" />
    <script type="module" defer src="/build/client.js"></script>
  </head>
  <body>
    <h1>Stream Rendered Cat Facts!</h1>
    <div id="approot"></div>
  </body>
</html>
```

The App component gets stream rendered using the built-in renderToNodeStream method. The initial HTML gets sent to the response object alongside the chunks of data from the App component,

This data contains useful information that our app has to use in order to render the contents correctly, such as the title of the document and a stylesheet. If we were to server render the App component using the renderToString method, we would have had to wait until the application has received all data before it can start loading and processing this metadata. To speed this up, renderToNodeStream makes it possible for the app to start loading and processing this information as it's still receiving the chunks of data from the App component!

Concepts

Like progressive hydration, streaming is another rendering mechanism that can be used to improve SSR performance. As the name suggests, streaming implies chunks of HTML are streamed from the node server to the client as they are generated. As the client starts receiving "bytes" of HTML earlier even for large pages, the TTFB is reduced and relatively constant. All major browsers start parsing and rendering streamed content or the partial response earlier. As the rendering is progressive, it results in a fast FP and FCP. Streaming responds well to network backpressure. If the network is clogged and not able to transfer any more bytes, the renderer gets a signal and stops streaming till the network is cleared up. Thus, the server uses less memory and is more responsive to I/O conditions. This enables your Node.js server to render multiple requests at the same time and prevents heavier requests from blocking lighter requests for a long time. As a result, the site stays responsive even in challenging conditions.

React for streaming

React introduced support for streaming in React 16 released in 2016. The following API's were included in the `ReactDOMServer` to support streaming.

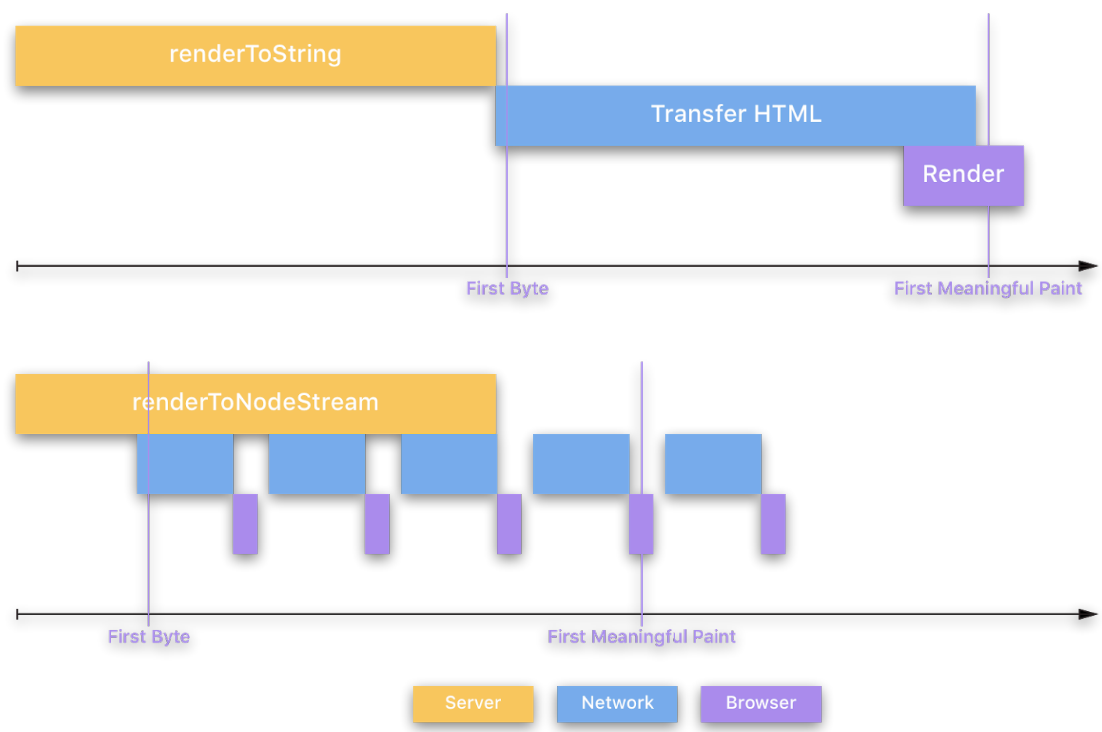
- `ReactDOMServer.renderToNodeStream(element)`: The output HTML from this function is the same as `ReactDOMServer.renderToNodeStream(element)` but is in a Node.js readablestream format instead of a string. The function will only work on the server to render HTML as a stream. The client receiving this stream can subsequently call `ReactDOM.hydrate()` to hydrate the page and make it interactive.

- `ReactDOMServer.renderToStaticNodeStream(element)`: This corresponds to `ReactDOMServer.renderToStaticNodeStream(element)`. The HTML output is the same but in a stream format. It can be used for rendering static, non-interactive pages on the server and then streaming them to the client.

```
import { renderToNodeStream } from 'react-dom/server';
import Frontend from '../client';

app.use('*', (request, response) => {
  // Send the start of your HTML to the browser
  response.write('<html><head><title>Page</title></head><body><div id="root">');

  // Render your frontend to a stream and pipe it to the response
  const stream = renderToNodeStream(<Frontend />);
  stream.pipe(response, { end: 'false' });
  // Tell the stream not to automatically end the response when the renderer
finishes.

  // When React finishes rendering send the rest of your HTML to the browser
  stream.on('end', () => {
    response.end('</div></body></html>');
  });
});
```

The readable stream output by both functions can emit bytes once you start reading from it. This can be achieved by piping the readable stream to a writable stream such as the response object. The response object progressively sends chunks of data to the client while waiting for new chunks to be rendered.

A comparison between TTFB and First Meaningful Paint for normal SSR Vs Streaming is available in the following image.



Pros and cons

Streaming aims to improve the speed of SSR with React and provides the following benefits

1. **Performance Improvement**: As the first byte reaches the client soon after rendering starts on the server, the TTFB is better than that for SSR. it is also more consistent irrespective of the page size. Since the client can start parsing HTML as soon as it receives it, the FP and FCP are also lower.

2. **Handling of Backpressure**: Streaming responds well to network backpressure or congestion and can result in responsive websites even under challenging conditions.

3. **Supports SEO**: The streamed response can be read by search engine crawlers, thus allowing for SEO on the website.

It is important to note that streaming implementation is not a simple find-replace from `renderToString` to `renderToNodeStream`(). There are cases where the code that works with SSR may not work as-is with streaming. Following are some examples where migration may not be easy.

1. Frameworks that use the server-render-pass to generate markup that needs to be added to the document before the SSR-ed chunk. Examples are frameworks that dynamically determine which CSS to add to the page in a preceding `<style>` tag, or frameworks that add elements to the document <`head`> while rendering. A workaround for this has been discussed here.

2. Code, where `renderToStaticMarkup` is used to generate the page template and `renderToString` calls are embedded to generate dynamic content. Since the string corresponding to the component is expected in these cases, it cannot be replaced by a stream. An example of such code provided here is as follows.

Both Streaming and Progressive Hydration can help to bridge the gap between a pure SSR and a CSR experience. Let us now compare all the patterns that we have explored and try to understand their suitability for different situations.

React Server Components

Server Components compliment SSR, rendering to an intermediate abstraction without needing to add to the JavaScript bundle

The React team are working on zero-bundle-size React Server Components, which aim to enable modern UX with a server-driven mental model. This is quite different to Server-side Rendering (SSR) of components and could result in significantly smaller client-side JavaScript bundles.

The direction of this work is exciting, and while it isn't yet production ready, is worth keeping on your radar. The RFC is worth reading as is Dan and Lauren's talk worth watching for more detail.

Server-side rendering limitations

Today's Server-side rendering of client-side JavaScript can be suboptimal. JavaScript for your components is rendered on the server into an HTML string. This HTML is delivered to the browser, which can appear to result in a fast First Contentful Paint or Largest Contentful Paint.

However, JavaScript still needs to be fetched for interactivity which is often achieved via a hydration step. Server-side rendering is generally used for the initial page load, so post-hydration you're unlikely to see it used again.

Note: While it's true that one could build a server-only React app leveraging SSR and avoiding hydrating on the client at all, heavy interactivity in the model often involves stepping outside of React. The hybrid model that Server Components enable will allow deciding this on a per-component basis.
With React Server Components, our components can be refetched regularly. An application with components which rerender when there is new data can be run on the server, limiting how much code needs to be sent to the client.

```
// *Before* Server Components
import marked from "marked"; // 35.9K (11.2K gzipped)
import sanitizeHtml from "sanitize-html"; // 206K (63.3K gzipped)

function NoteWithMarkdown({text}) {
  const html = sanitizeHtml(marked(text));
  return (/* render */);
}
```

Server Components

React's new Server Components compliment Server-side rendering, enabling rendering into an intermediate abstraction format without needing to add to the JavaScript bundle. This both allows merging the server-tree with the client-side tree without a loss of state and enables scaling up to more components.

Server Components are not a replacement for SSR. When paired together, they support quickly rendering in an intermediate format, then having Server-side rendering infrastructure rendering this into HTML enabling early paints to still be fast. We SSR the Client components which the Server components emit, similar to how SSR is used with other data-fetching mechanisms.

This time however, the JavaScript bundle will be significantly smaller. Early explorations have shown that bundle size wins could be significant (-18-29%), but the React team will have a clearer idea of wins in the wild once further infrastructure work is complete.

```
import marked from "marked"; // zero bundle size
import sanitizeHtml from "sanitize-html"; // zero bundle size

function NoteWithMarkdown({text}) {
  // same as before
}
```

Automatic Code-Splitting

It's been considered a best-practice to only serve code users need as they need it by using code-splitting. This allows you to break your app down into smaller bundles requiring less code to be sent to the client. Prior to Server Components, one would manually use React.lazy() to define "split-points" or rely on a heuristic set by a meta-framework, such as routes/pages to create new chunks.

Some of the challenges with code-splitting are:

- Outside of a meta-framework (like Next.js), you often have to tackle this optimization manually, replacing import statements with dynamic imports.
- It might delay when the application begins loading the component impacting the user-experience.

Server Components introduce automatic code-splitting treating all normal imports in Client components as possible code-split points. They also allow developers to select which component to use much earlier (on the server), allowing the client to fetch it earlier in the rendering process.

Will Server Components replace Next.js SSR?

No. They are quite different. Initial adoption of Server Components will actually be experimented with via meta-frameworks such as Next.js as research and experimentation continue.

To summarize a good explanation of the differences between Next.js SSR and Server Components from Dan Abramov:

- **Code for Server Components is never delivered to the client**. In many implementations of SSR using React, component code gets sent to the client via JavaScript bundles anyway. This can delay interactivity.
- **Server components enable access to the back-end from anywhere in the tree**. When using Next.js, you're used to accessing the back-end via `getServerProps()` which has the limitation of only working at the top-level page. Random npm components are unable to do this.

- **Server Components may be refetched while maintaining Client-side state inside of the tree**. This is because the main transport mechanism is much richer than just HTML, allowing the refetching of a server-rendered part (e.g such as a search result list) without blowing away state inside (e.g search input text, focus, text selection)

Some of the early integration work for Server Components will be done via a webpack plugin which:

- Locates all Client components
- Creates a mapping between IDs => chunk URLs
- A Node.js loader replaces imports to Client components with references to this map.
- Some of this work will require deeper integrations (e.g with pieces such as Routing) which is why getting this to work with a framework like Next.js will be valuable.

As Dan notes, one of the goals of this work is to enable meta-frameworks to get much better.

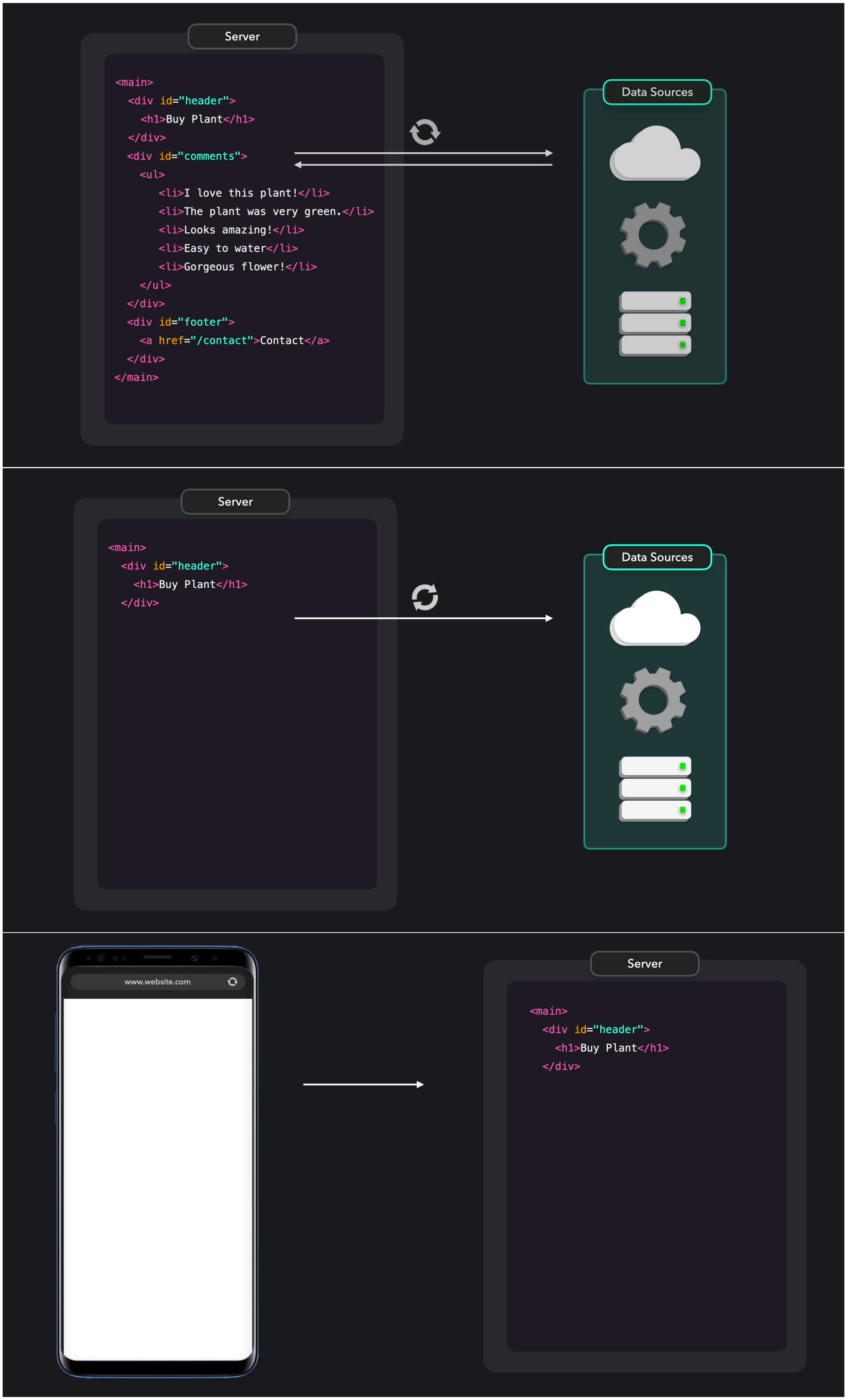
Selective Hydration

How to use combine streaming server-side rendering with a new approach to hydration, selective hydration

In previous articles, we covered how SSR with hydration can improve user experience. React is able to (quickly) generate a tree on the server using the renderToString method that the react-dom/server library provides, which gets sent to the client after the entire tree has been generated. The rendered HTML is non interactive, until the JavaScript bundle has been fetched and loaded, after which React walks down the tree to hydrate and attaches the handlers. However, this approach can lead to some performance issues due to some limitations with the current implementation.

Before the server-rendered HTML tree is able to get sent to the client, all components need to be ready. This means that components that may rely on an external API call or any process that could cause some delays, might end up blocking smaller components from being rendered quickly.

Besides a slower tree generation, another issue is the fact that React only hydrates the tree once. This means that before React is able to hydrate any of the components, it needs to have fetched the JavaScript for all of the components before it's able to hydrate any of them. This means that smaller components (with smaller bundles) have to wait for the larger components's code to be fetched and loaded, until React is able to hydrate anything on your website. During this time, the website remained non-interactive.


Server
<main>
<div id="header">
<h1>Buy Plant</h1>
</div>
<div id="comments">

I love this plant!
The plant was very green.
Looks amazing!
Easy to water
Gorgeous flower!

</div>
<div id="footer">
Contact
</div>
</main>
Data Sources
Server
<main>
<div id="header">
<h1>Buy Plant</h1>
</div>
Data Sources
www.website.com
Server
<main>
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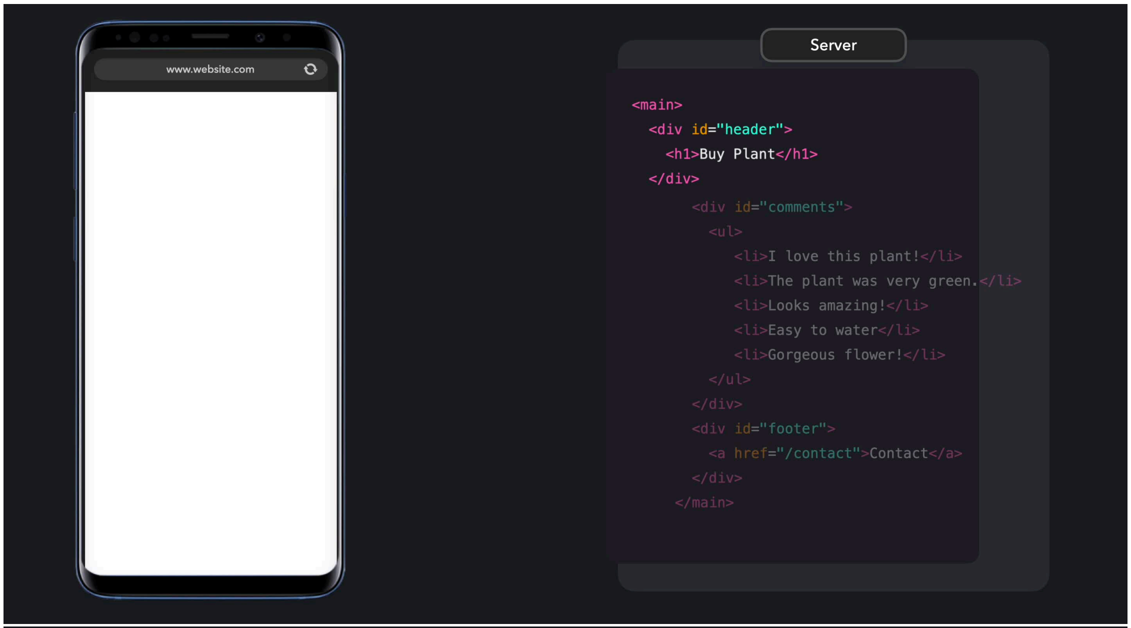
</div>



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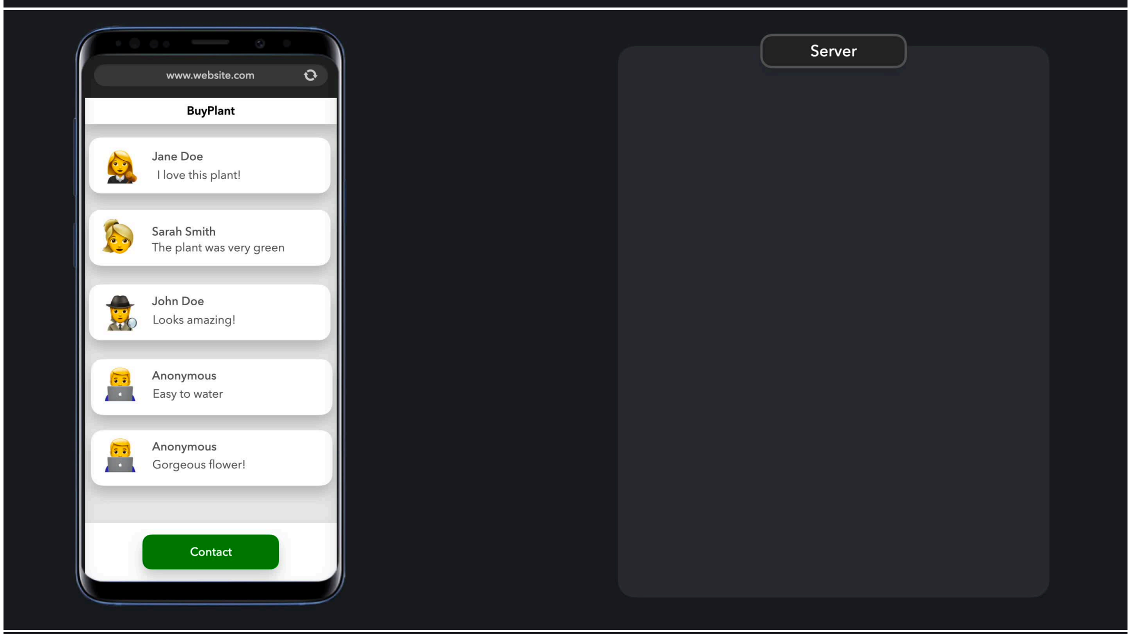

www.website.com
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Sarah Smith
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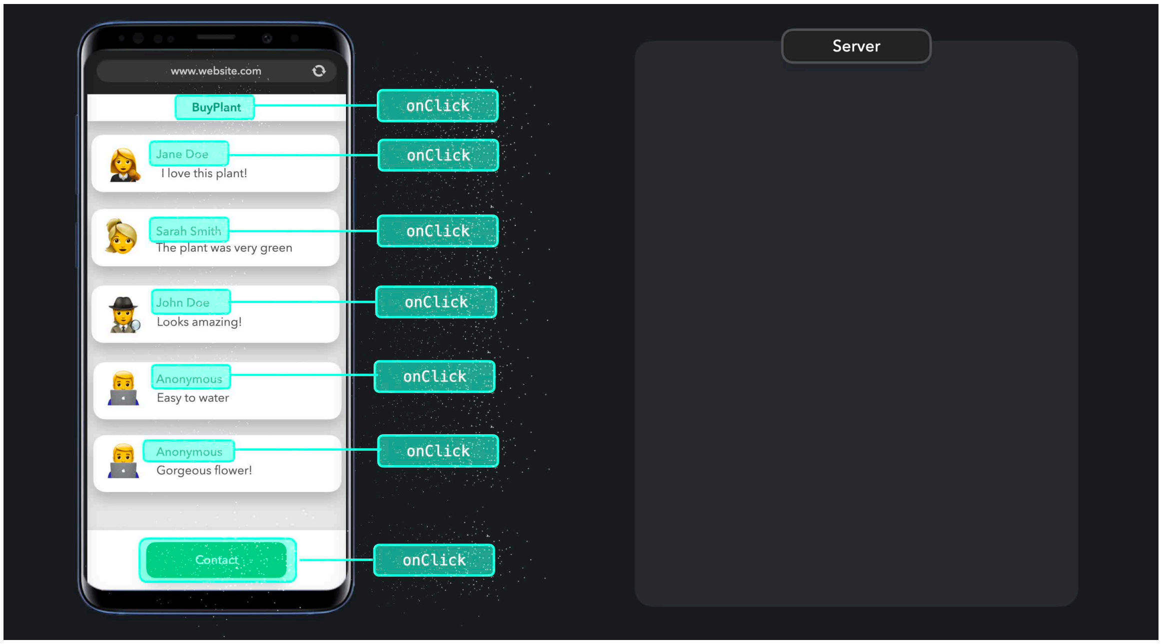
Server
bundle1.js
bundle2.js
bundle3.js



React 18 solves these problems by allowing us to combine streaming server-side rendering with a new approach to hydration: Selective Hydration!

Instead of using the renderToString method that we covered earlier, we can now stream render HTML using the new pipeToNodeStream method on the server.

This method, in combination with the createRoot method and Suspense, makes it possible to start streaming HTML without having to wait for the larger components to be ready. This means that we can lazy-load components when using SSR, which wasn't (really) possible before!

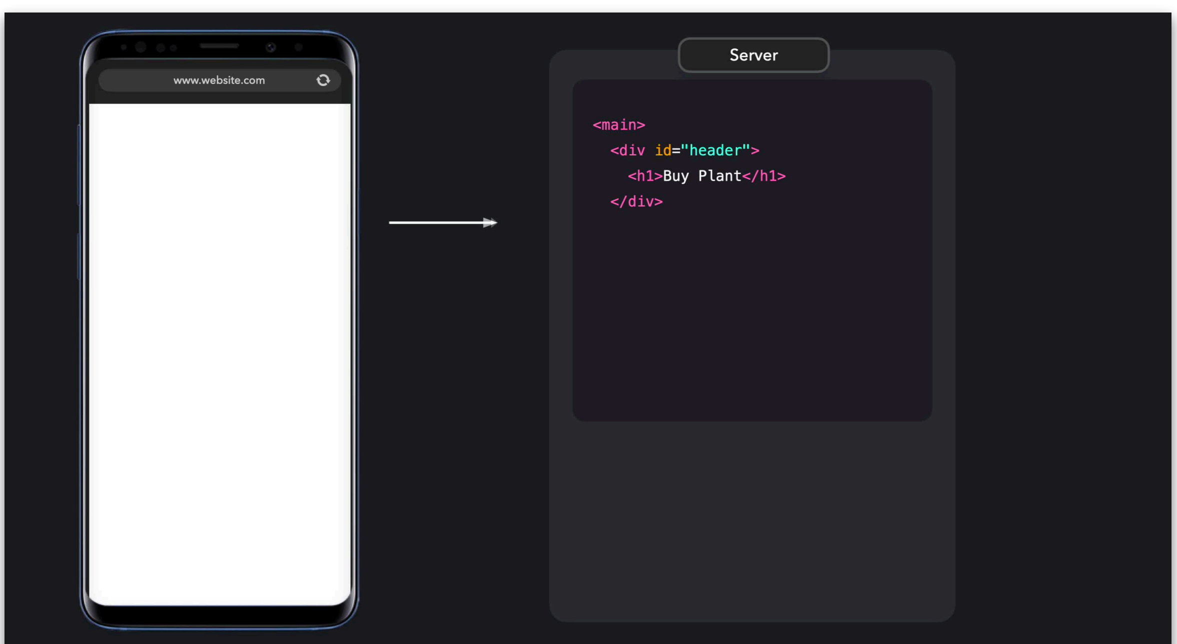
index.js

```
import { hydrateRoot } from "react-dom";
import App from './App';

hydrateRoot(document, <App />);
```

server.js

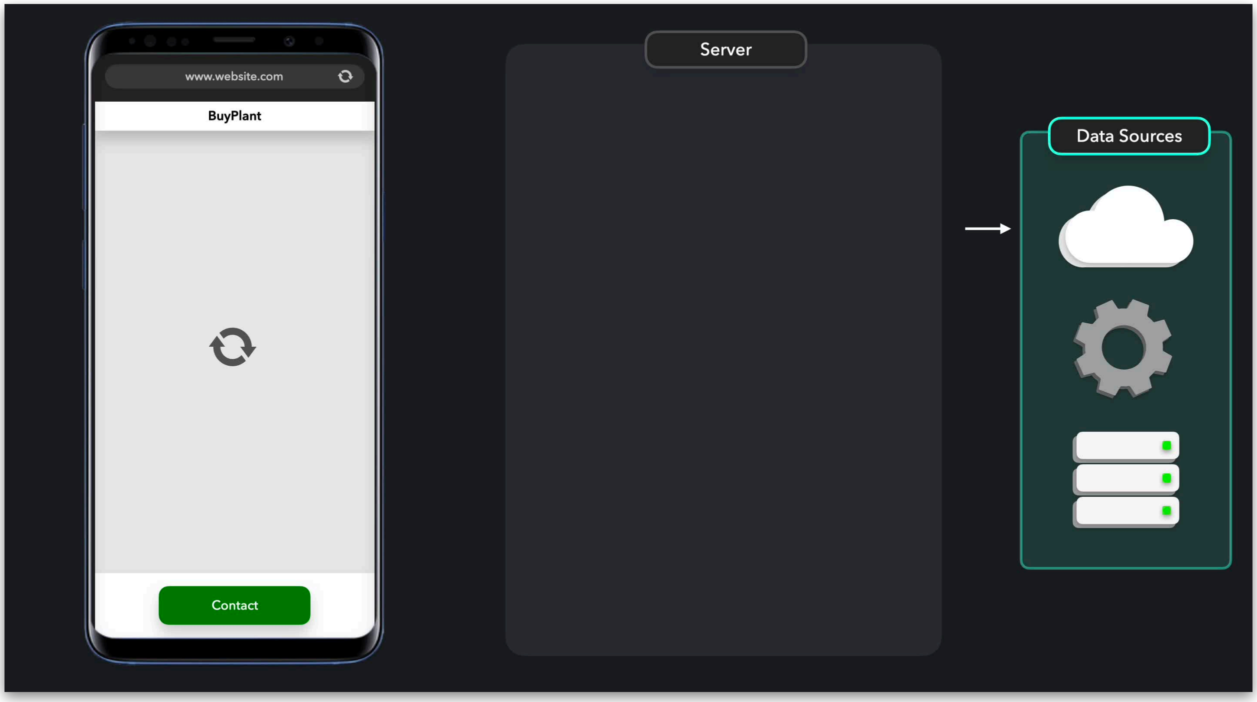
```
import { pipeToNodeStream} from "react-dom/server";

export function render(res) {
  const data = createServerData();
  const { startWriting, abort } = pipeToNodeWritable(
    <DataProvider data={data}>
      <App assets={assets} />
    </DataProvider>,
    res,
    {
      onReadyToStream() {
        res.setHeader('Content-type', 'text/html');
        res.write('<!DOCTYPE html>');
        startWriting();
      }
    }
  );
};
```

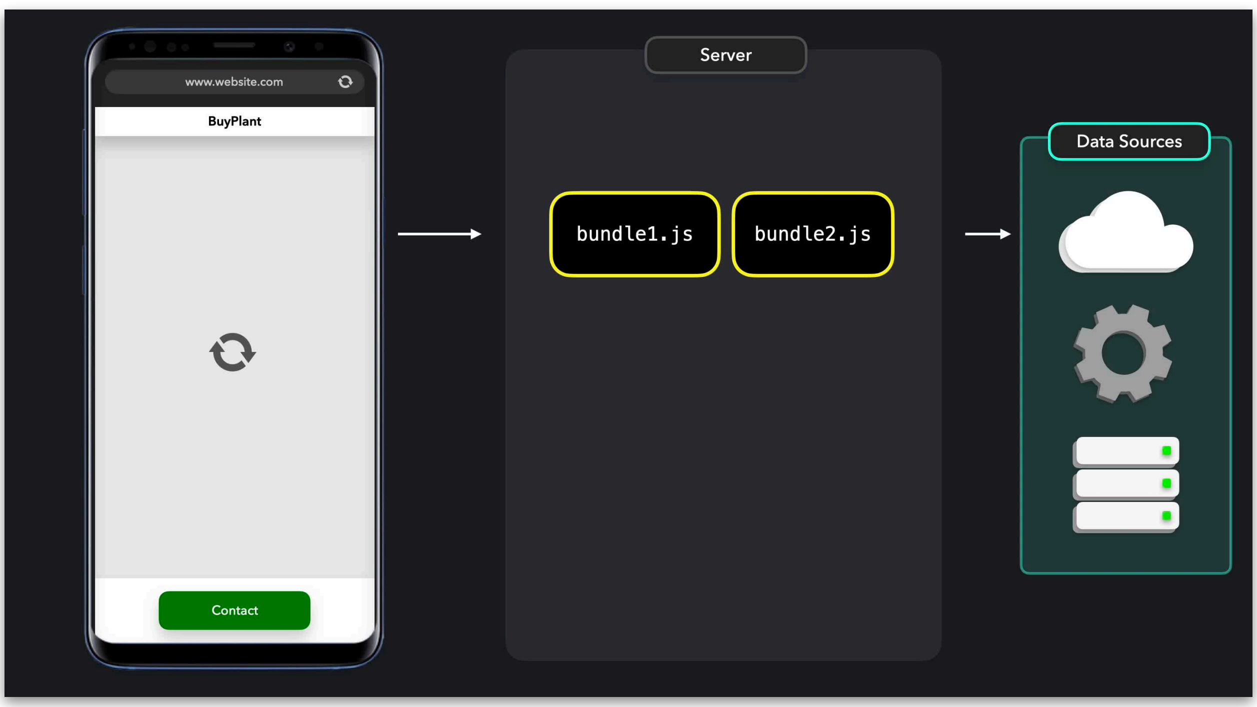
The Comments component, which earlier slowed down the tree generation and TTI, is now wrapped in Suspense. This tells React to not let this component slow down the rest of the tree generation. Instead, React inserts the fallback components as the initially rendered HTML, and continues to generate the rest of the tree before it's sent to the client.

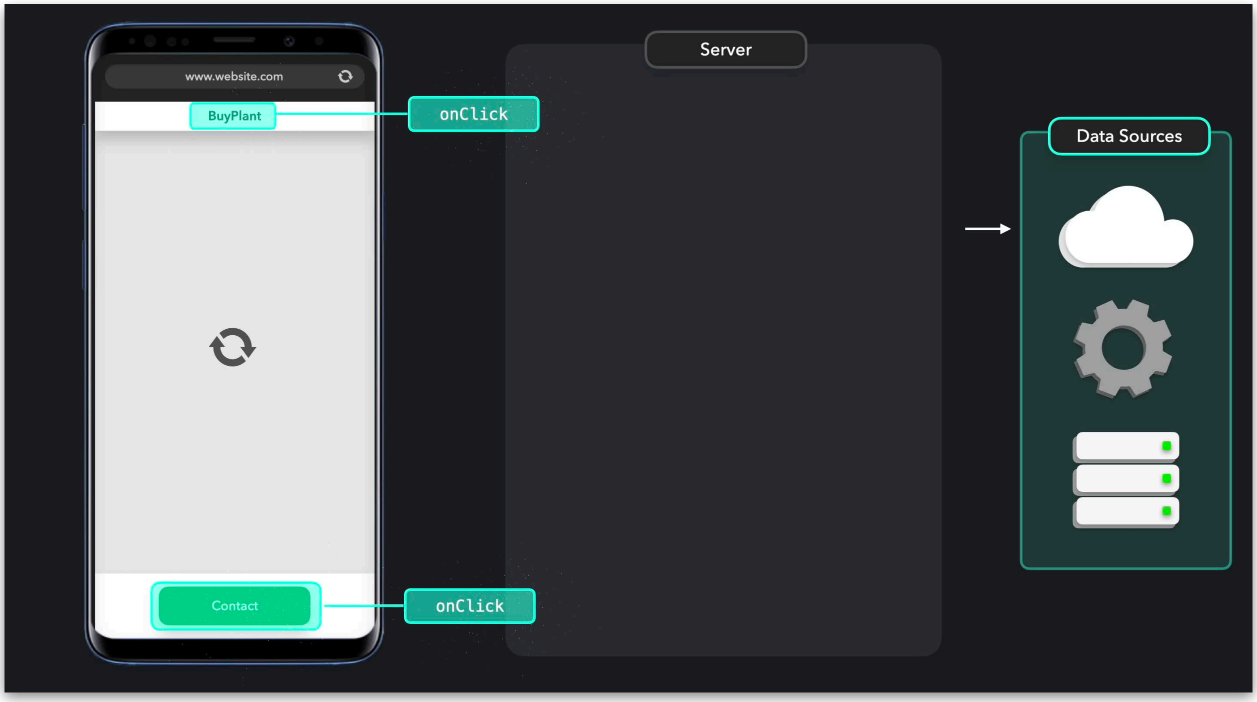


In the meantime, we're still fetching the external data that we need for the Comments component.

Selective hydration makes it possible to already hydrate the components that were sent to the client, even before the Comments component has been sent!

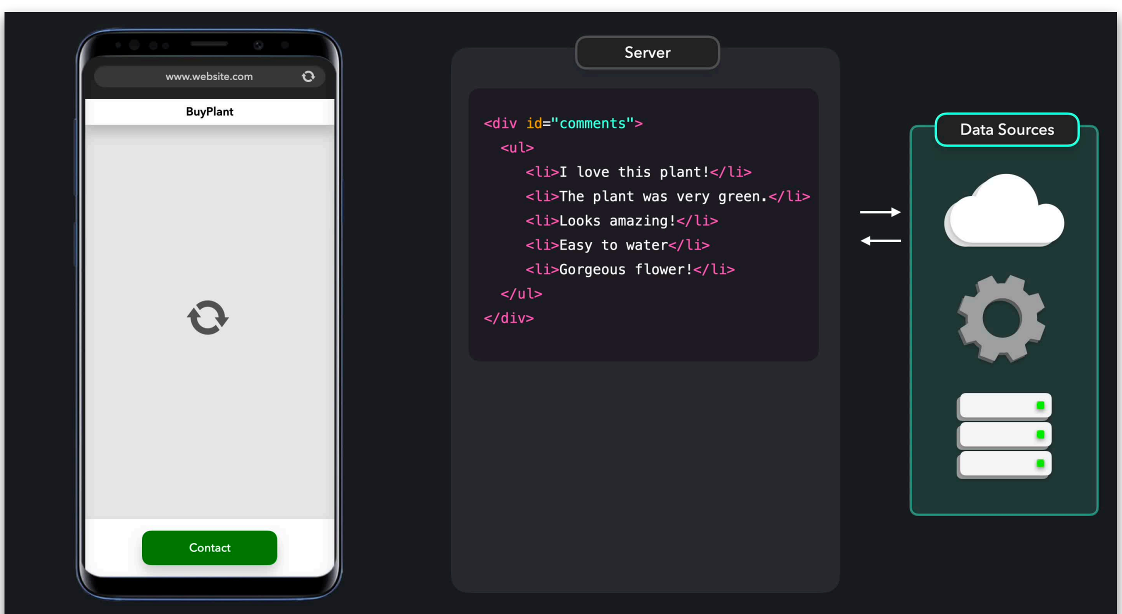


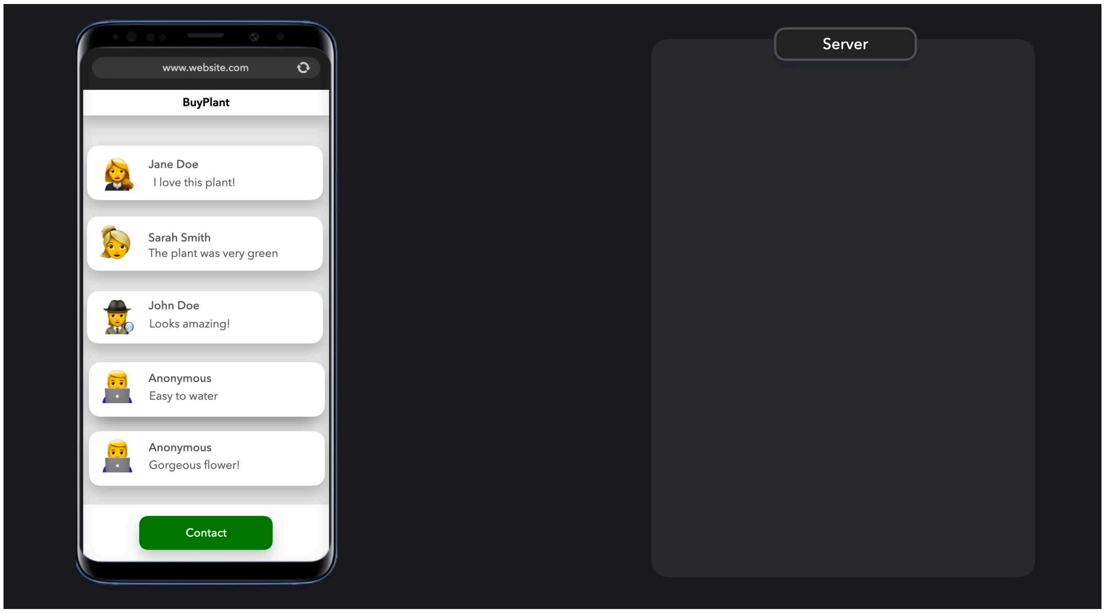




Once the data for the Comments component is ready, React starts streaming the HTML for this component, as well as a small <script> to replace the fallback loader.

React starts the hydration after the new HTML has been injected.

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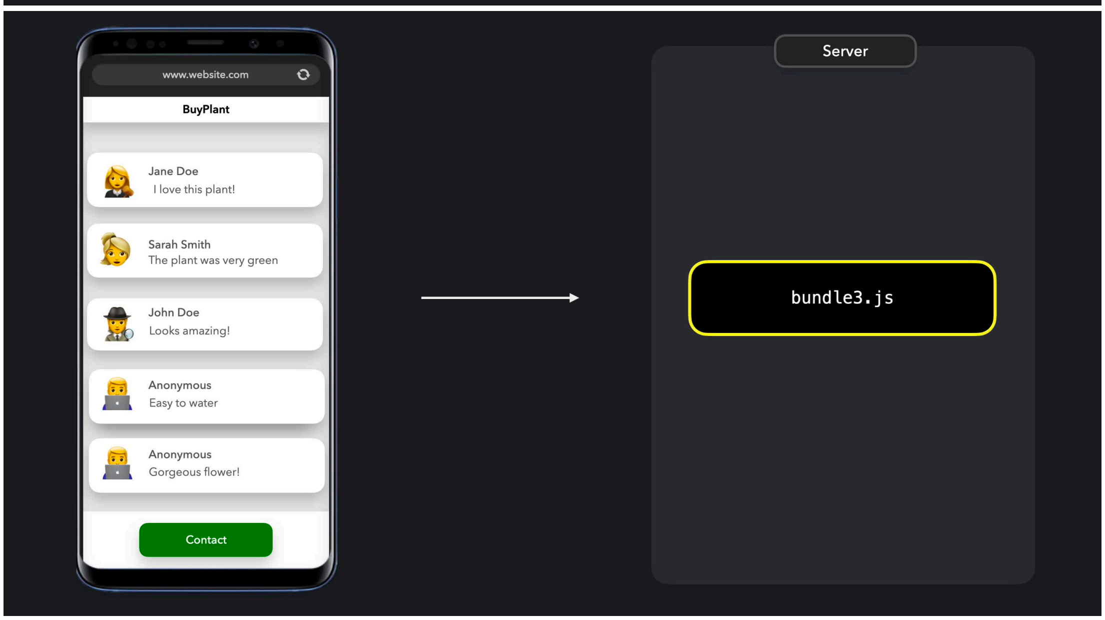
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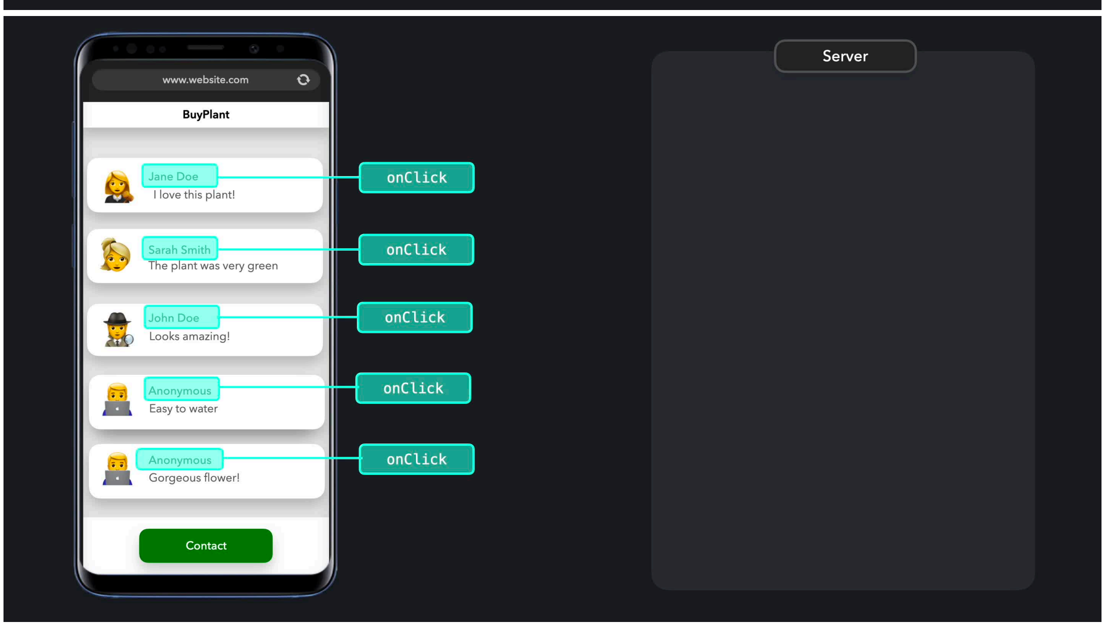
bundle3.js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onClick
Contact
Server

React 18 fixes some issues that people often encountered when using SSR with React.

Streaming rendering allows you to start streaming components as soon as they're ready, without risking a slower FCP and TTI due to components that might take longer to generate on the server.

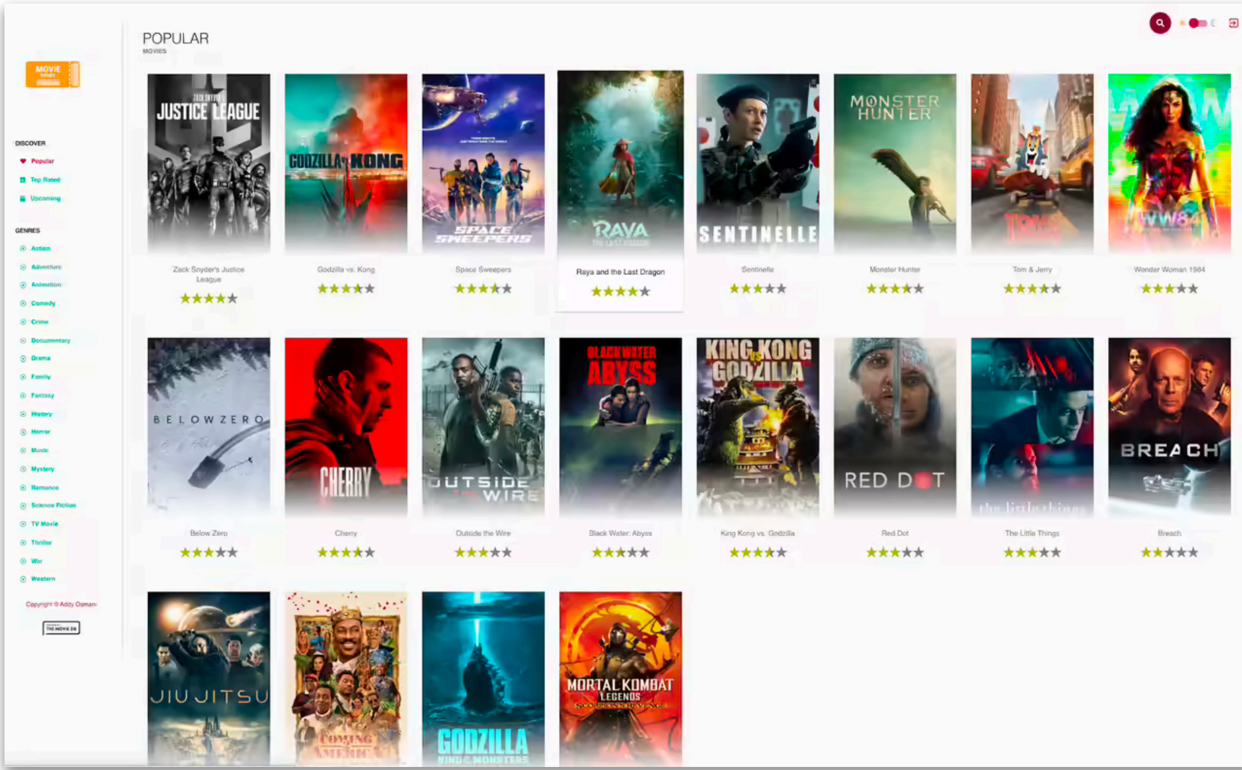
Components can be hydrated as soon as they're streamed to the client, since we no longer have to wait for all JavaScript to load to start hydrating and can start interacting with the app before all components have been hydrated.

Optimizing for the Core Web Vitals on a Next.js app

A case study optimizing a Next.js app for performance

Next.js by Vercel is a React meta-framework that enhances the React development experience. It enables the creation of production-ready apps and supports static site generation and server-side rendering, easy configuration, fast refresh, image optimization, file-system routing, and optimized code-splitting and bundling.

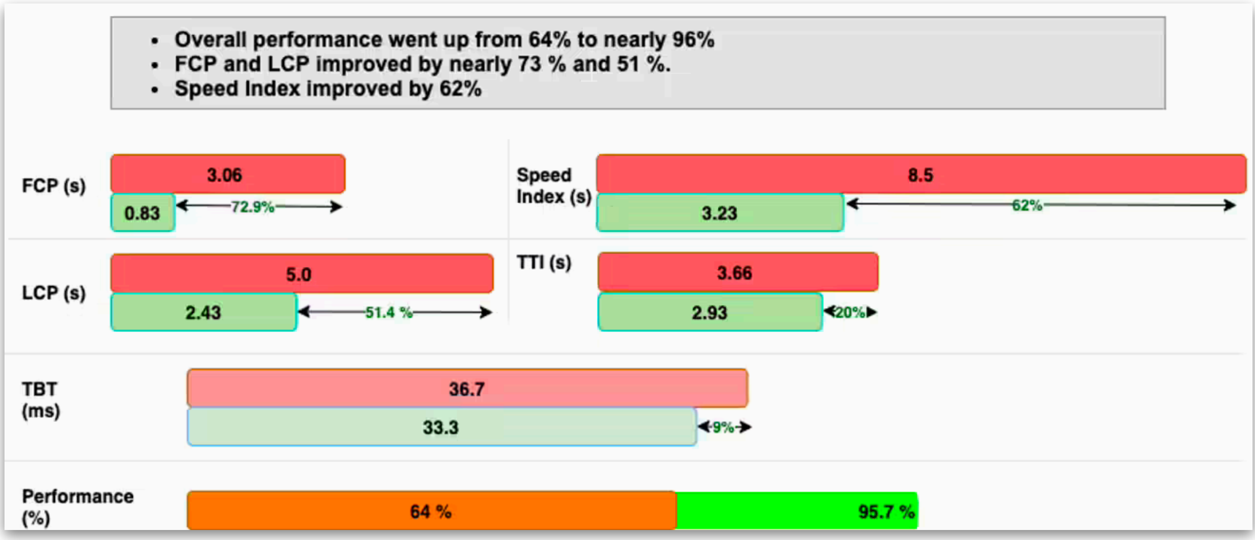
To evaluate how to optimize a React + Next.js application using third-party dependencies, we created the Next.js Movies app. This is a non-trivial movie browsing application and a fully-featured client of TMDB. It incorporates a rich set of features that allow you to search and browse through a comprehensive and categorized movie listing, view details and manage personal favorites through membership and authentication.



Subsequently, the Next.js Movies app was the benchmark that we used to implement a series of performance tweaks and identify the ones that were beneficial from an overall user experience perspective. Today, I want to talk about the performance improvement achieved on the whole and dig into each of the tweaks that we tried with their outcomes.

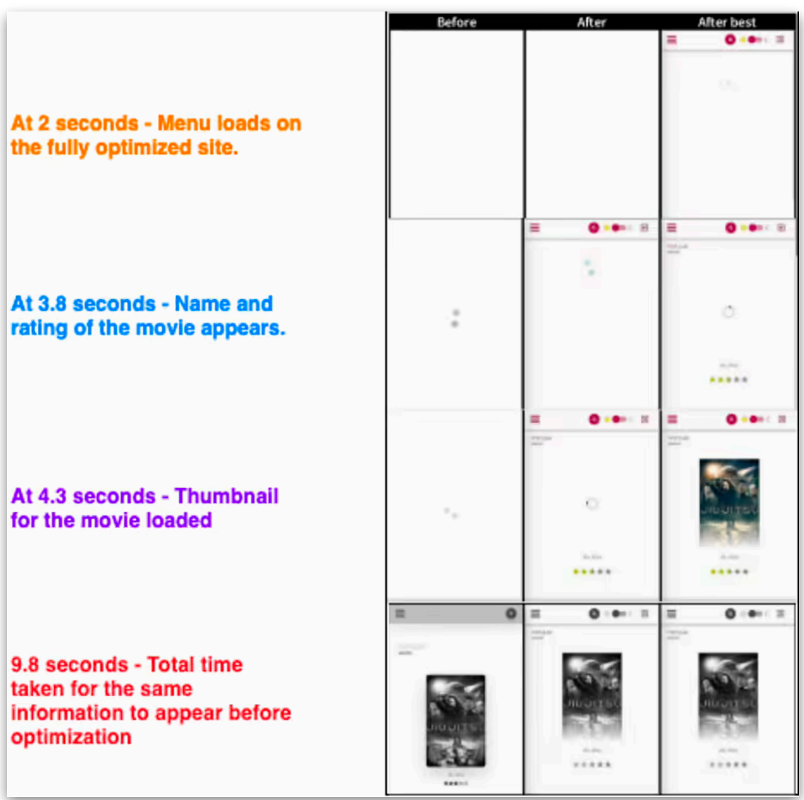
Cumulative Improvements

We were able to achieve a significant aggregate performance improvement with all optimizations in place. This automatically translated to a better user experience. The metrics depicted here were captured before and after the implementation of all the code changes meant to optimize the performance.



To understand what the overall improvement implies from a user experience perspective, take a look at the following comparison for the actual page load experience

- Before optimization
- With a few changes
- With all optimizations in place.



In addition to the overall performance improvement, metrics were captured using Lighthouse and WPT after every code change for relevant pages. The tests were repeated multiple times to eliminate any lags due to sleeping servers or other conditions both before and after the change. The average calculated for each parameter thus gave us a reliable value to use for our analysis.

With that background, let's talk about every change implemented and how it contributed to the overall performance improvement we achieved.

Packages Switched

Initially, a number of third-party React components helped to quickly implement the different features required for the Movies app. We decided to analyze the impact on metrics by trying other available alternatives for individual third-party components especially those that were heavy or blocking the main thread.

Most of these attempts were extremely fruitful in bringing down the values of different metrics

- Using `@svgr/webpack` instead of Font-Awesome for SVG icons helped to boost Speed Index by 34%, LCP by 23%, and TBT by 51%
- Using a custom-built component to replace react-burger-menu and removing the `resize-observer-polyfill` from `react-sicky-box` led to a reduction in bundle size by 34.28 kB (gZipped).

- React Select Search was used instead of React Select which led to a 35% improvement in the LCP with a 100% improvement in CLS and 18% in TBT.
- The use of React Glider instead of React Slick improved TBT by 77%.
- Usage of React Scrolling instead of native smooth scrolling provided cross-browser compatibility for the scrolling feature.
- React Stars component was used instead of React Rating which helped to boost TBT by 33%.

SVG icon library

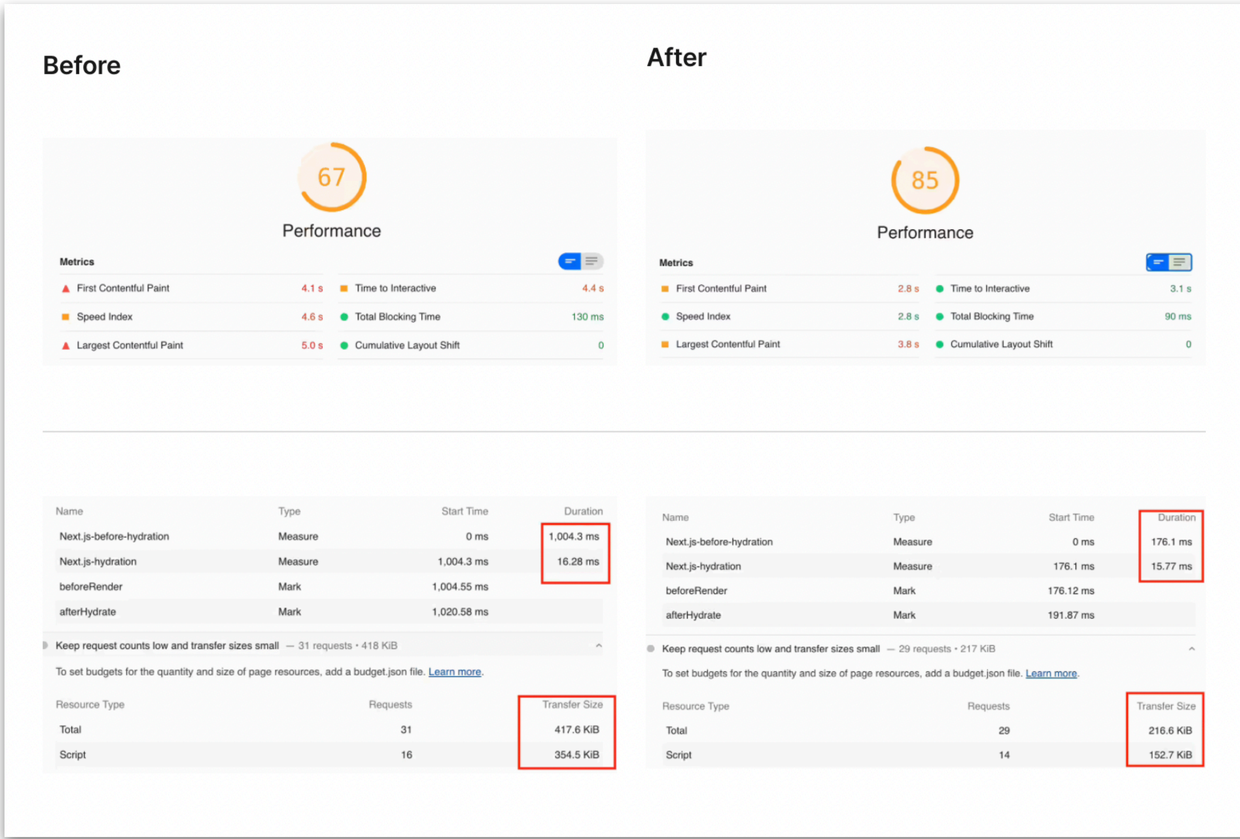
SVG icons were the obvious choice for all our icon needs across the Movies app. We initially chose Font-Awesome due to its popularity and ease of use as a scalable vector icon library with icons that are customizable using CSS. However, there had been concerns that Font-Awesome may be slow to load on web pages due to the large transfer sizes when loading the library. This affects Lighthouse performance score.

We replaced Font-Awesome with `@svgr/webpack` as our SVG icon provider. Another change was to import individual icons on all our pages instead of the library itself even if the page uses multiple icons. For example:

```
import { FontAwesomeIcon } from '@fortawesome/react-fontawesome';

// replaced by
import HeartIcon from 'public/assets/svgs/icons/heart.svg';
import PollIcon from 'public/assets/svgs/icons/poll.svg';
import CalendarIcon from 'public/assets/svgs/icons/calendar.svg';
import DotCircleIcon from 'public/assets/svgs/icons/dot-circle.svg';
```

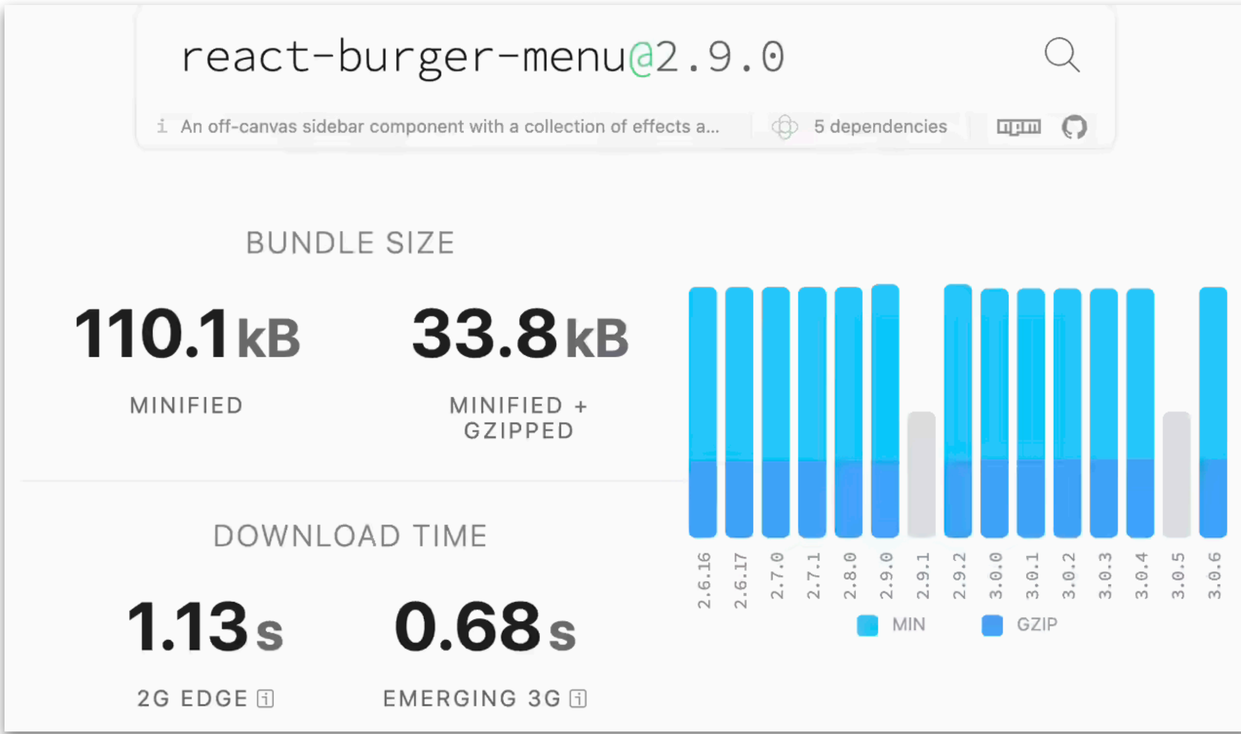
This helped to improve the Lighthouse score across the board. Here is a snapshot of the score before and after the change. Also, note a difference of almost 200 KiB in request transfer size and the change in user timings before and after the change.

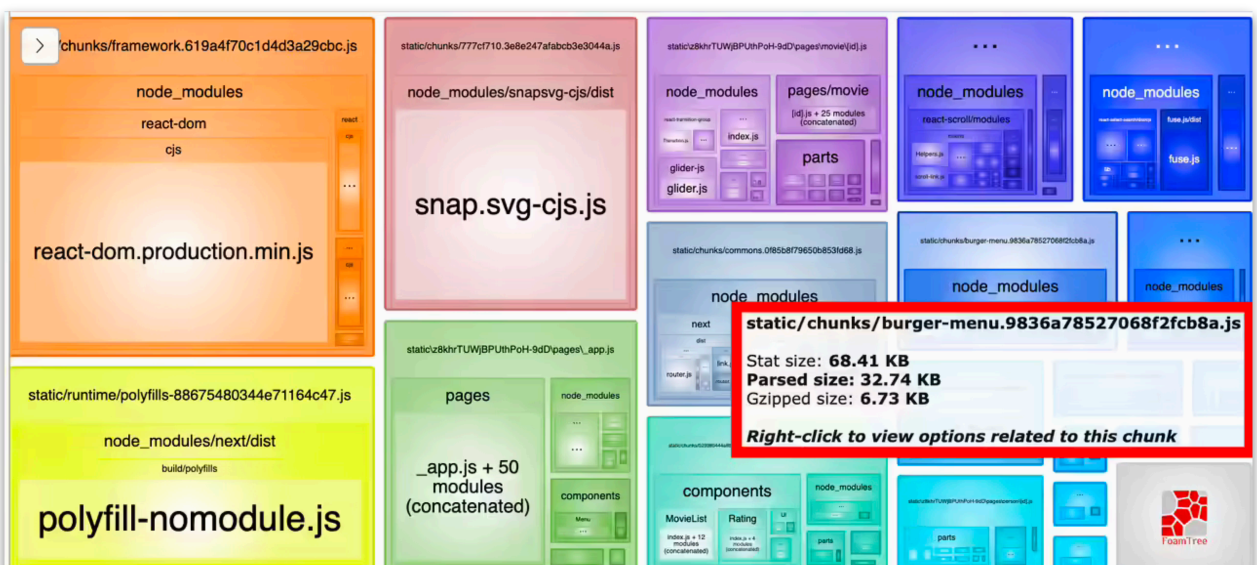


Application Menu

The initial version of the app used `react-burger-menu` as an off-canvas side-bar component to display the application menu by clicking the burger icon. The component comes with a collection of inbuilt CSS styles and animations that provide options to customize the menu.

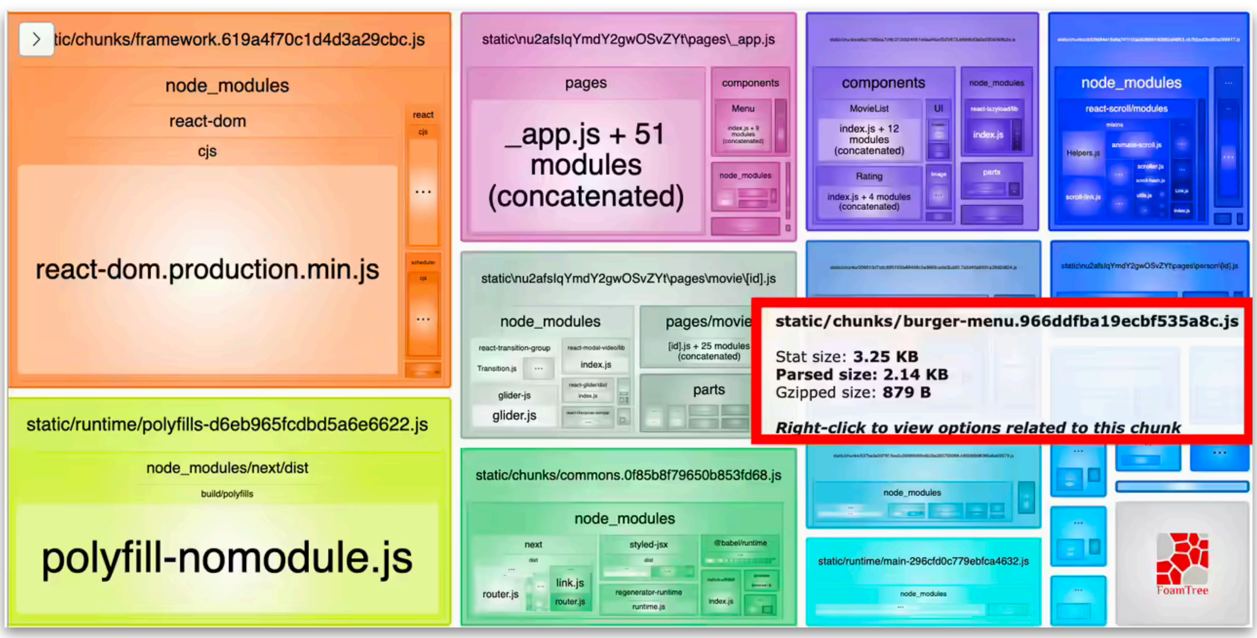
An analysis of bundle sizes for `react-burger-menu` and the app revealed that we could do better.





We did not need all the features included in the react-burger-menu component and thought that a simple custom component would serve our needs just as well.

This helped to reduce the bundle size corresponding to the burger menu component considerably without affecting the required functionality. As seen in the treemap analysis of the chunks before and after the change, the gzipped size of the burger-menu chunk was 6.73 kB earlier but reduced to 879 B after the change. The parsed size also went down from 32.74 kB to 2.14 kB. Thus, the change helped to reduce both the download time as well as the parse time for the chunk



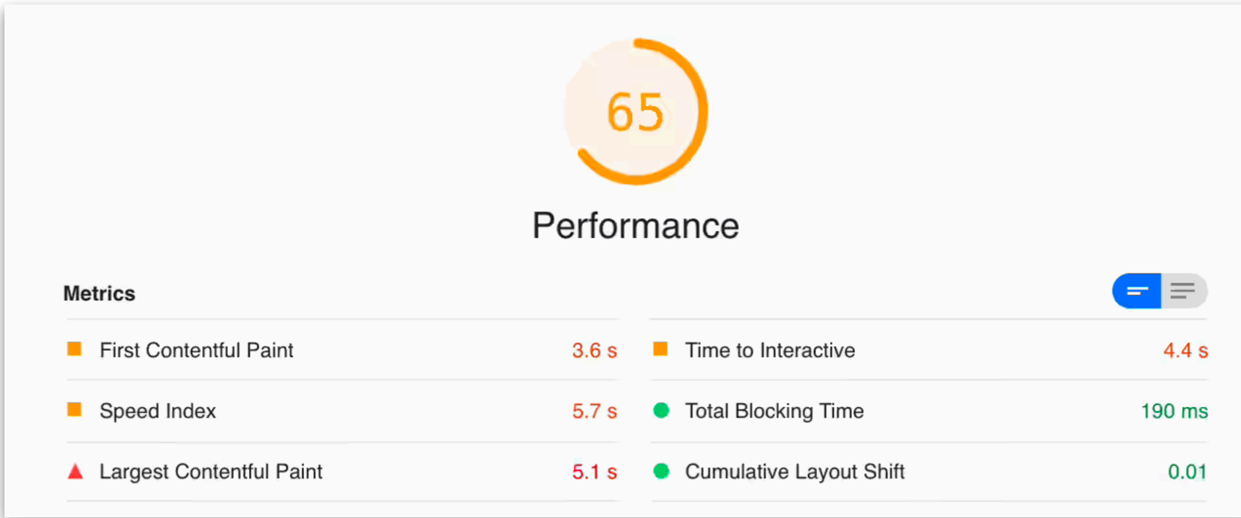
Dropdown for Sort feature

The Movies app allows you to sort movies belonging to a particular genre or starring a selected actor. You can sort by Popularity, Votes, Release Date, or Original Title. To allow users to select a sort option, we had previously used the react-select component. The component allows for multiple-select, search, animation, and access to styling API using emotion. The bundle size for the component is 27.2 kB minified and gzipped with 7 dependencies.

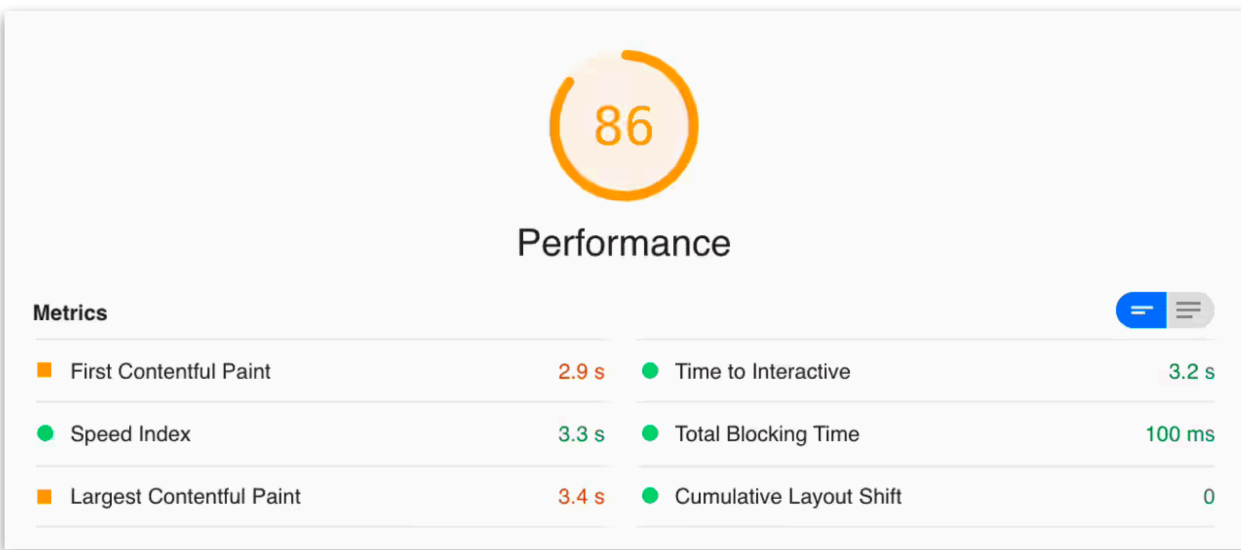
For the sort dropdown, we merely needed a simple single-select component without any styling features. As such, we decided to go with the react-select-search component. It is a lightweight component (3.2 kB minified and gzipped) with zero dependencies. While it supports multi-select and search features, styling features can be included by developers as required.

The following highlights the changes in the UI itself due to the component change and corresponding improvement in Lighthouse performance.

Before

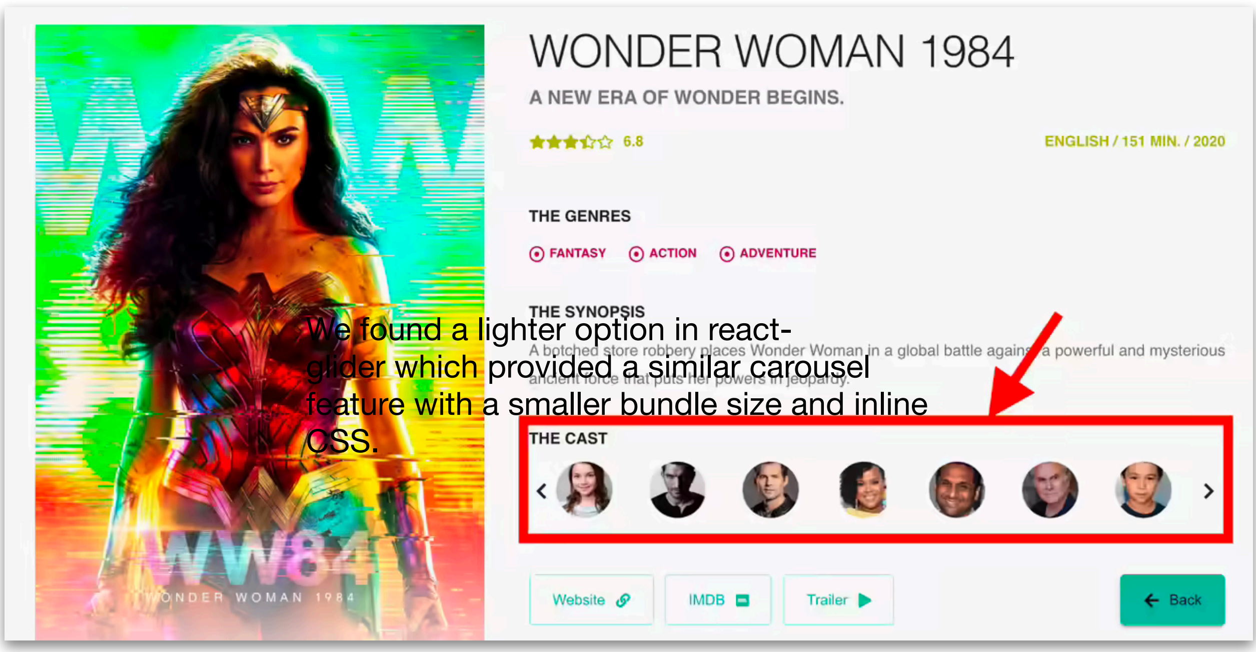


After

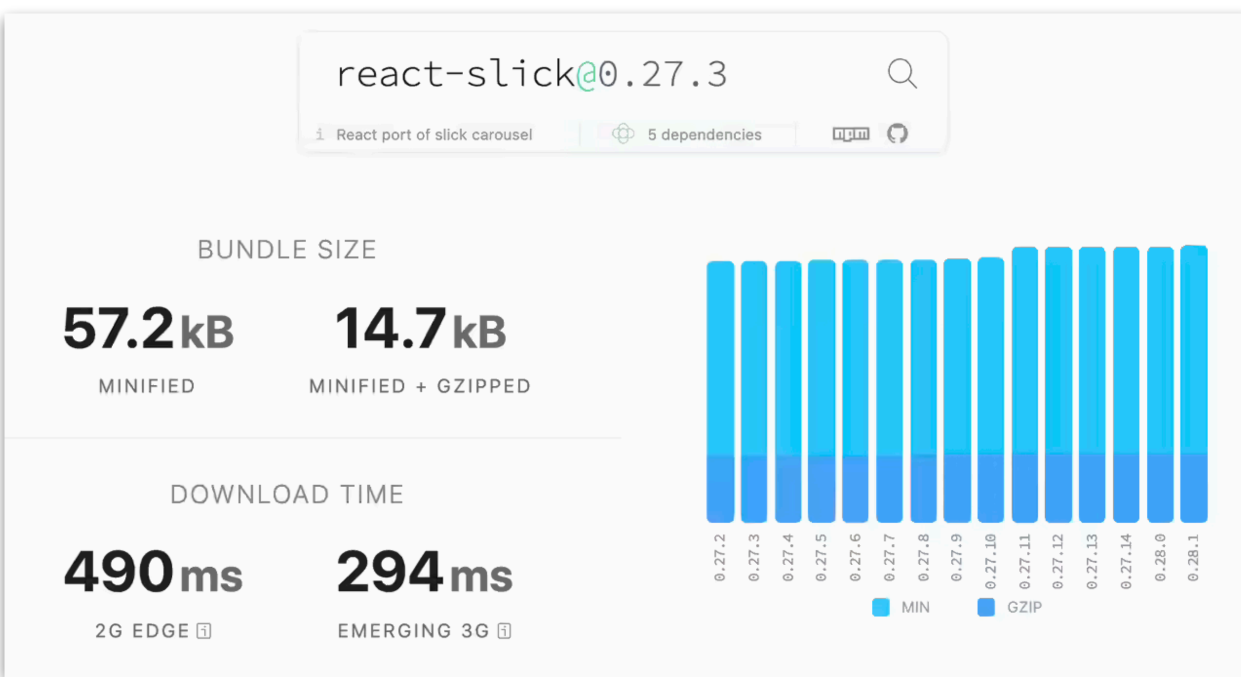


Cart Carousel

We had used the `react-slick` component on our movie pages that allowed users to horizontally "glide" through the movie cast. The react-slick component however is quite heavy when it comes to the bundle size. At 14.7 kB it comes with 5 dependencies.



We found a lighter option in react-glider which provided a similar carousel feature with a smaller bundle size and inline CSS.



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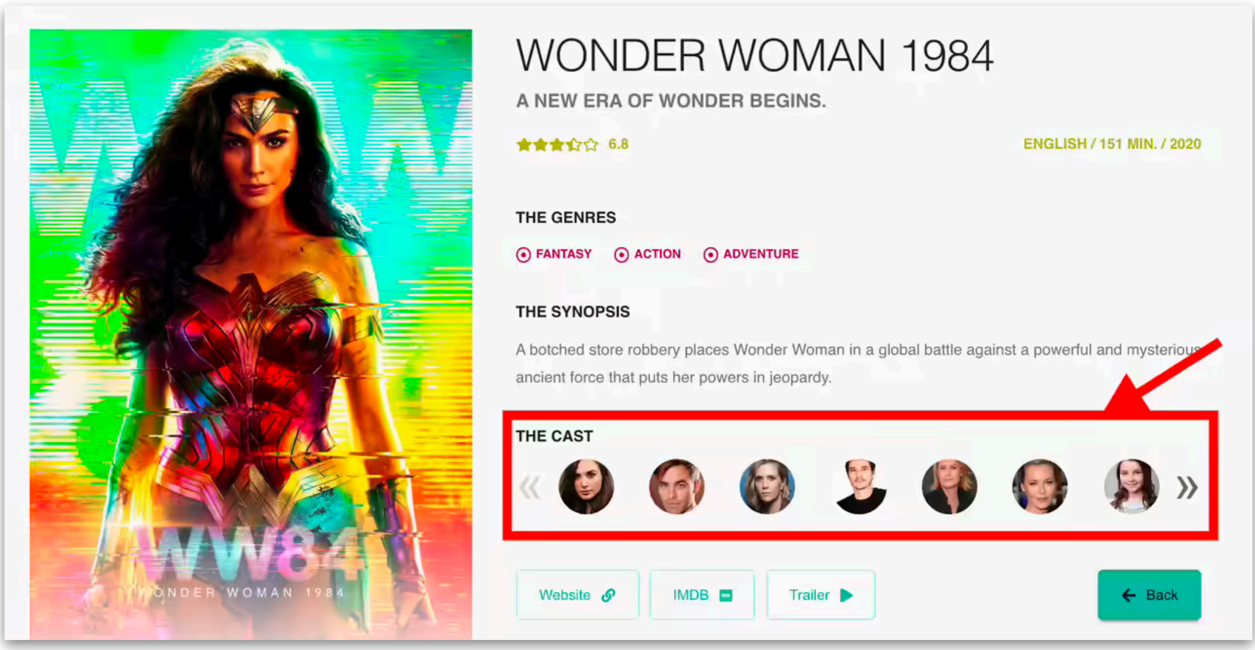
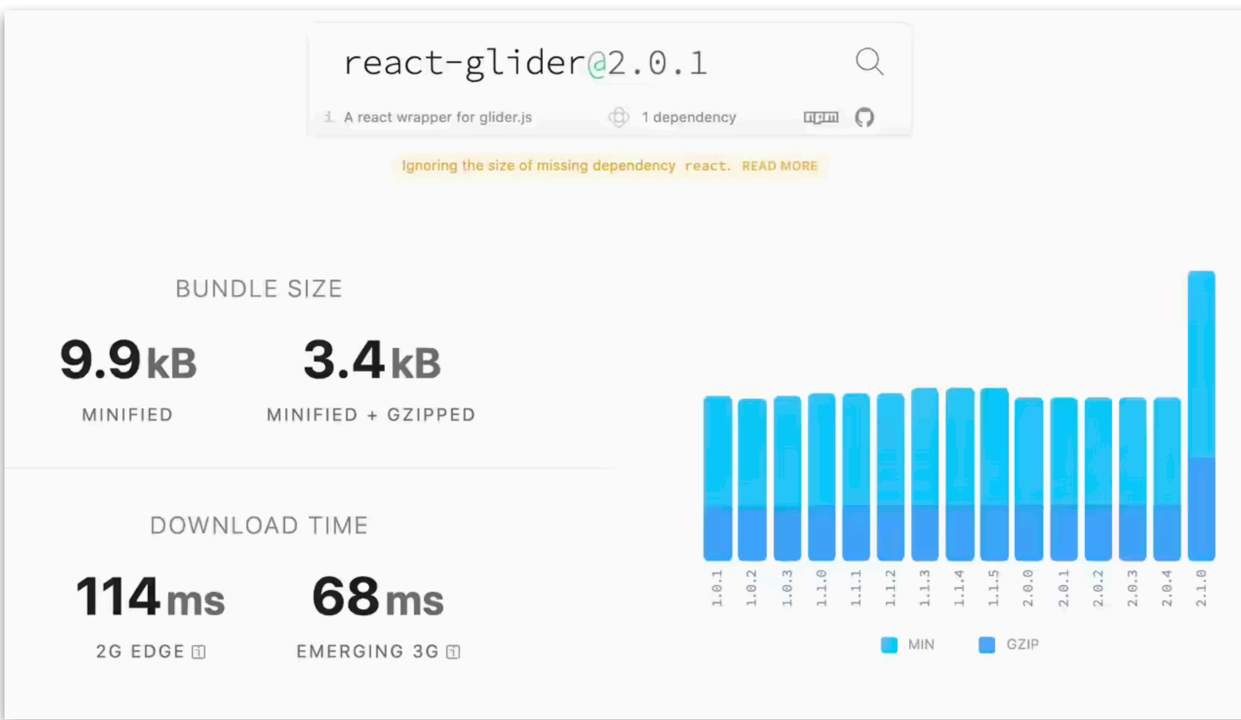




A reduction in bundle size from 14.7 kB to 3.4 kB was quite a jump (78% improvement) with zero impact on functionality. This change was a welcome addition. In the future, we may rewrite this component to use CSS Scroll Snap.

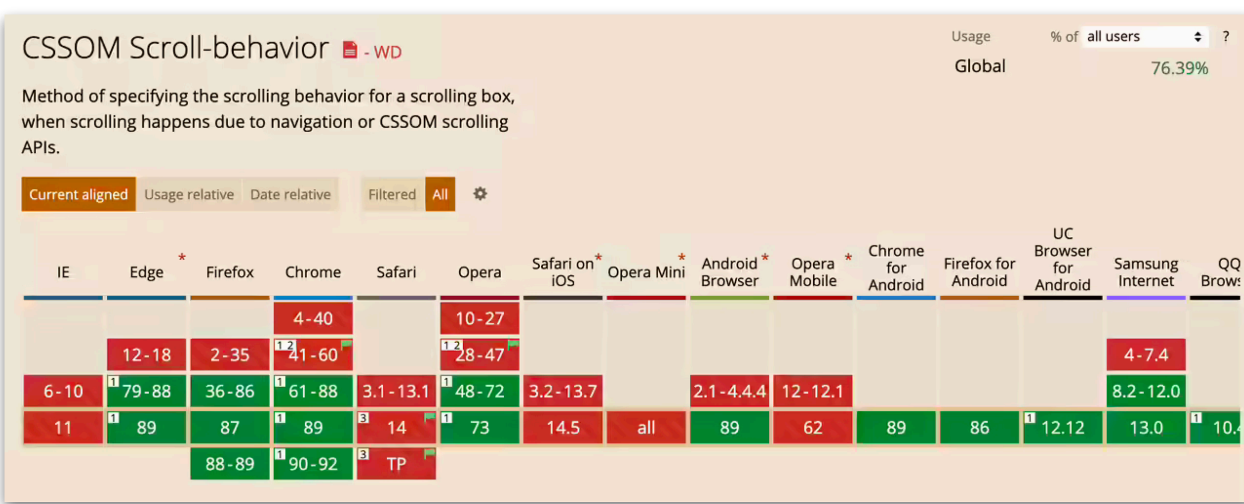
The scrolling component

The Movies App implements pagination on the movie listing pages to switch from one page to the other. Every time the previous or next page button is clicked, the view needs to scroll to the top of the new page. For the transition to be smooth, we had used the native smooth scroll function as follows.

```
window.scroll({
  top: 0,
  left: 0,
  behavior: 'smooth'
});

document.querySelector(`.${SCROLL_TO_ELEMENT}`)
  ?.scrollIntoView({  behavior: 'smooth' });
```

Native smooth scroll functions are however not supported across all browsers.

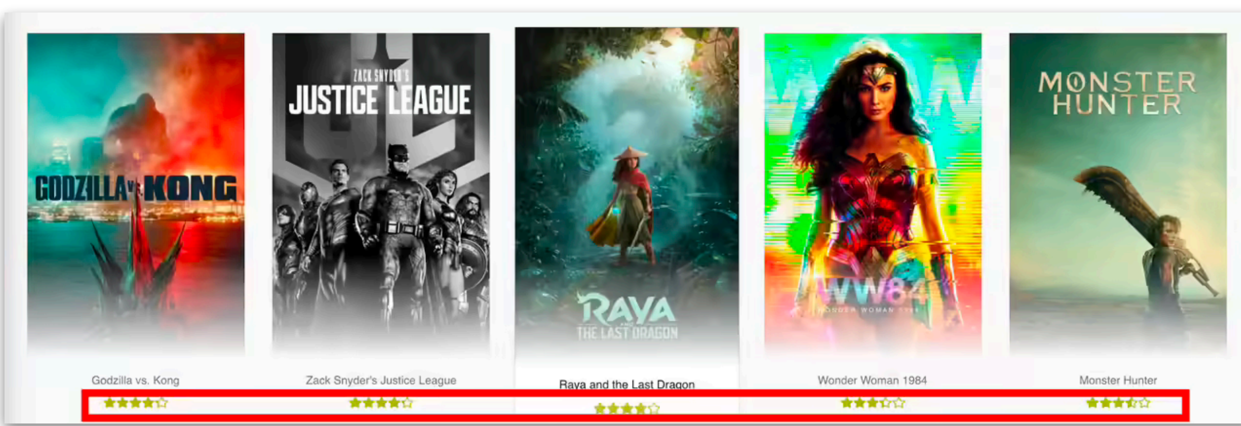


To allow us to animate the vertical scrolling, we decided to use a scrolling library called `react-scroll` (6.8 kB gzipped). This not only helped to recreate the same scroll effect with a small regression in performance as can be seen in the following comparison.

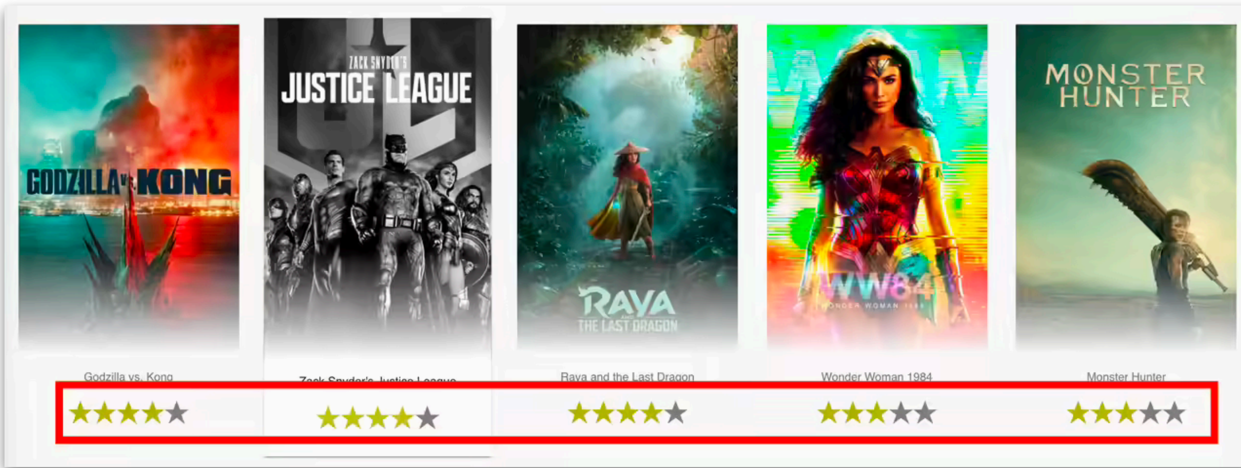
Performance Metric	FCP (s)	Speed Index (s)	LCP (s)	TTI (s)	TBT (ms)	CLS	Performance (%)
Before	0.8	3.93	2.63	1.73	16.66	0	94.33
After	0.92	3.78	2.9	2.26	66	0	92.8
% Change	15	3.81	10.26	39.63	296.15	0	

The rating component

`react-rating`, the rating component that we had originally used, allows you to customize the look by using different symbols for rating; eg., stars, circles, thumbs-up, etc. We had used the star symbol for rating earlier and did not need the other features that were part of the library. The cost of including the bundle for this component was 2.6kB.

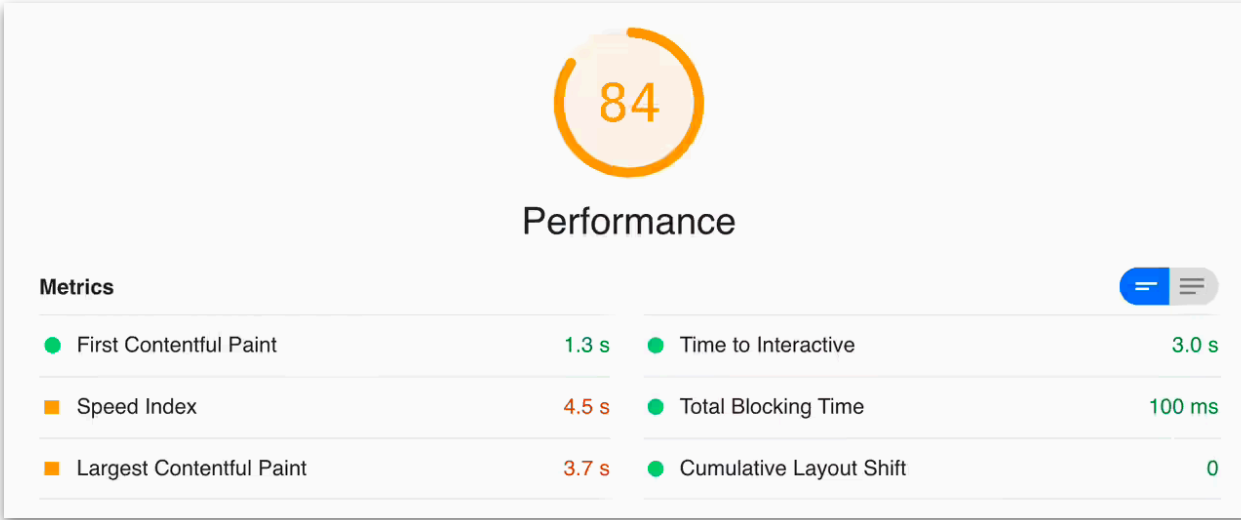


The `react-stars` component served our purpose and we were able to show star ratings for movies on the movie listing screen using this component too. This component was only 2 kB minified and gzipped. We used this component and inlined the source for further optimization.

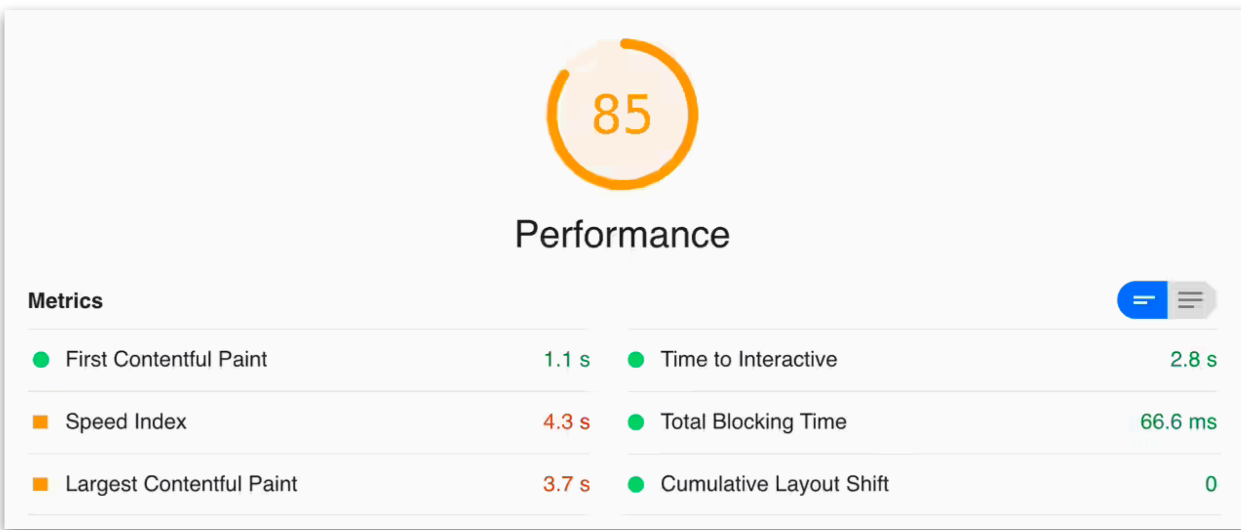


Although, the library sizes do not look very different, the react-rating component uses SVG icons for ratings while the react-stars component uses the symbol "★". As the component gets repeated 20 times on the movie listing page, the size of the icon/image also contributes to the overall savings due to the component change. This is apparent from the Lighthouse scores before and after the change.

Before



After



Although the other parameters are more or less unchanged, we noticed a significant difference in TBT (33%). This was because the chunk that included the rating component (react-rating package) was excluded from the long main-thread tasks.

Other techniques used for Optimization

Experimenting with alternate libraries was one part of the performance analysis and optimization project. We also tried other mechanisms that have been known to enhance performance. Let's talk about what was attempted and what worked or didn't work for us.

Code-Splitting

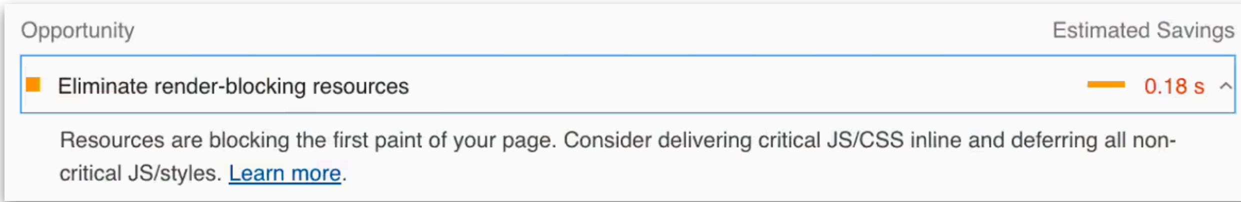
We used code-splitting to lazy-load the Menu component - being collapsed by default on mobile, this was an opportunity to only do work when a user actually needed it. We had initially tried lazy loading with the Burger Menu sidebar component and observed some gain in performance. After we replaced this with a custom component for the sidebar menu, we lazy-loaded the custom component.

We used the `LazyLoadingErrorBoundary` component which acts as a wrapper for react lazy and react suspense. This ensures that the menu component is loaded after page load. While FCP and LCP remained about the same, there was a substantial reduction in TBT by 71% as can be seen in the following comparison.

Performance Metric	FCP (s)	Speed Index (s)	LCP (s)	TTI (s)	TBT (ms)	CLS	Performance (%)
Before	0.86	4.2	3.46	2.53	70	0	87.66
After	0.83	3.63	3.3	1.73	20	0	**90.33**
% Change	**3.48**	**13.57**	**4.62**	**31.62**	**71.42**	0	

Inline the critical, defer the non-critical

Our Lighthouse audits were consistently generating this suggestion that we certainly needed to act upon.



CSS is a render-blocking resource, i.e., it must be loaded and processed before the page is rendered. Some of the CSS may be required to style the content that is visible on the initial page load. This is the critical CSS that needs to be inlined to optimize the page. There may be other CSS that is not required initially and can be deferred.

As part of our optimizations, we in-lined the CSS required for dark/light modes transition which was identified as critical CSS.

As per Next.js documentation, we had initially imported all our node module CSS files in the `/pages/_app.js` file. We are using two components react-glider and `react-modal-video` that require CSS import from node modules. Importing this CSS through `_app.js` would be render-blocking for the app as these components are not required on all the pages.

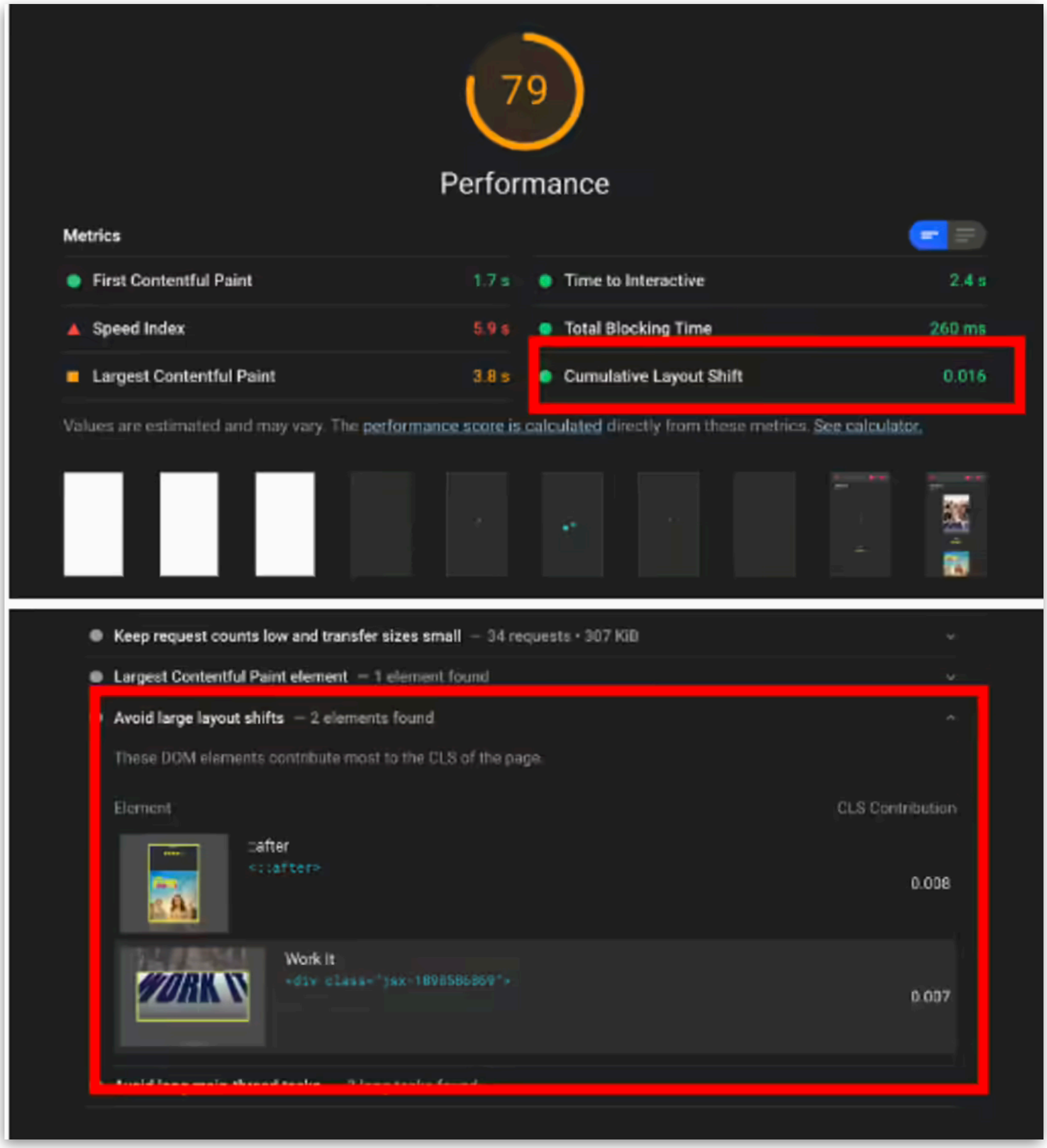
The CSS required by these components was inlined in the files where the component was used. For example, after optimization, the code in our cast component includes the syntax to render the Glider along with the styles that it uses.

```
<div ref={ref} className='cast'>
  <Glider
    hasArrows
    slidesToShow={slidesToShow}
    slidesToScroll={1}
    itemWidth={GLIDER_ITEM_WIDTH}
  >
    {cast.map(person => (
      <PersonLink
        key={person.id}
        person={person}
        baseUrl={baseUrl}
      />
    ))}
  </Glider>
</div>
<style jsx>{`/*CSS Classes required for Glider*/`}</style>
```

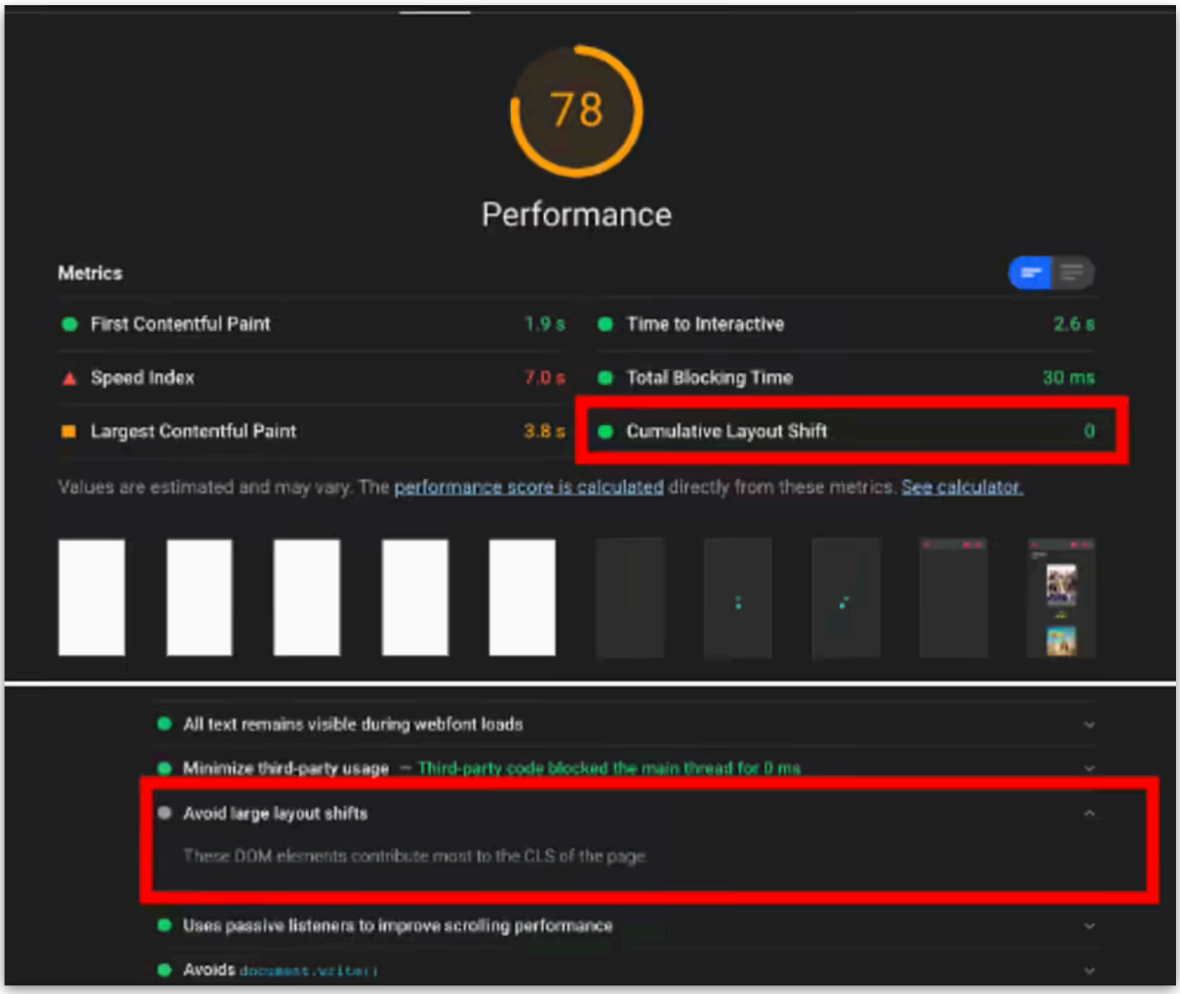
With this change, we were able to observe a slight change of 2% to 5% in FCP, LCP, and TTI. The performance improved from 79% to 81% for the page.

Aspect Ratio for Images

The changes we discussed so far helped us to improve the FCP, LCP, TBT, and TTI on different pages. Let us now talk about improving the last parameter on the Lighthouse report, the Cumulative Layout Shift (CLS). For an in-depth understanding of CLS and its causes, refer to my article on optimizing CLS. The Lighthouse report for the movies page before optimization gave us a clear indication of what was causing the CLS.



Even though a CLS of 0.016 is well below the threshold, we did experience the shift when loading the page, especially on a mobile 3G connection. So we worked on the elements that were causing the layout shift as reported. Instead of setting image dimensions, we used the aspect-ratio-boxes technique for setting the aspect ratio for images. This helps to reserve the required space for the image while the page is still loading so that there is no shift once the image is loaded. Using this technique we were able to bring the CLS for the page down to 0, the image suggestions for layout shifts were eliminated and there was a perceptible improvement in user experience. Note: Browser support for CSS aspect ratio improved after we worked on the Movies application, but if we were building it today we would likely use that feature.



Preconnects

Preconnects allow you to provide hints to the browser on what resources are going to be required by the page shortly. Adding "`rel=preconnect`" informs the browser that the page will need to establish a connection to another domain so that it can start the process sooner. The hints help to load resources quicker because the browser may have already set up the connection by the time the resources are required.

There was a small but discernible difference in the values of performance parameters after this change as tabulated here.

Performance Metric	FCP (s)	Speed Index (s)	LCP (s)	TTI (s)	TBT (ms)	CLS	Performance (%)
Before	0.9	3.9	3.43	2.93	60	0	88
After	0.83	3.5	2.86	2.63	53.33	0	93.33
% Change	7.77	10.25	16.61	10.23	6.67	0	

Optimize the API call sequence

Being a TMDB client, the movies app makes several API calls to get the list of movies, genres, cast, and other details along with related images. The principle used to optimize the API call sequence should ensure that calls to fetch data to be used for rendering the main page area are not put off until the other API calls have finished. With this in mind, we changed our sequence of execution as follows.

Before	After
Fetch the metadata like genres and configuration while the API call for movie posters was put off until they were finished.	Fetch the metadata (used for populating the side menu) and simultaneously fetch the movie poster data.
Fetch the movie poster data	Render the home page with the fetched movie poster data.
Render the home page with the fetched movie poster data.	

Preloading API response

When a user visits the home page of the Movies app for the first time, we already know that we will be showing them page 1 of the 'Popular' movies list. The actual list itself comes from the TMDB API, but the API call can be created based on these two values `Genre = "popular"` and `page = 1`

With this knowledge, we were able to preload the data for the home page as follows.

```
<link
  rel='preload'
  as='fetch'
  href='https://api.themoviedb.org/3/movie/popular?api_key=...5&page=1'
  crossOrigin='true'
/>
```

This was used only on the home page as we cannot predict what the users will click/pick on the other pages. If the preloaded data is not used, it will be a waste of resources resulting in a warning like this which can be seen in Chrome Dev Tools - "`The resource https://api.themoviedb.org/3/movie/popular?api_key=844dba0bfd8f3a4f3799f6130ef9e335&page=1 was preloaded using link preload but not used within a few seconds from the window's load event. Please make sure it has an appropriate as value and it is preloaded intentionally.`"

The LCP and TTI improved by 12.65% and 7.76% respectively after this change while the overall performance went up from 91% to 94% for the home page.

Preloading the logo and the TMDB trademark

The logo and TMDB trademark are displayed on all pages and we found the performance after preloading these to be improved. These were preloaded using a media query.

```
<link
  rel='preload'
  href={LOGO_IMAGE_PATH}
  as='image'
  media='(min-width: 80em)'
/>
<link
  rel='preload'
  href={DARK_TMDB_IMAGE_PATH}
  as='image'
  media='(prefers-color-scheme: dark) and (min-width: 80em)'
/>
<link
  rel='preload'
  href={LIGHT_TMDB_IMAGE_PATH}
  as='image'
  media='(prefers-color-scheme: light) and (min-width: 80em)'
/>
```

This resulted in a 5-6% improvement in FCP and Speed Index.

Making the site responsive

The movies app uses Next.js SSR to render the wrapper for the UI. Since the app can be accessed on both desktop and mobile devices, responsive design was essential. Combining responsive design with SSR has been a challenge because:

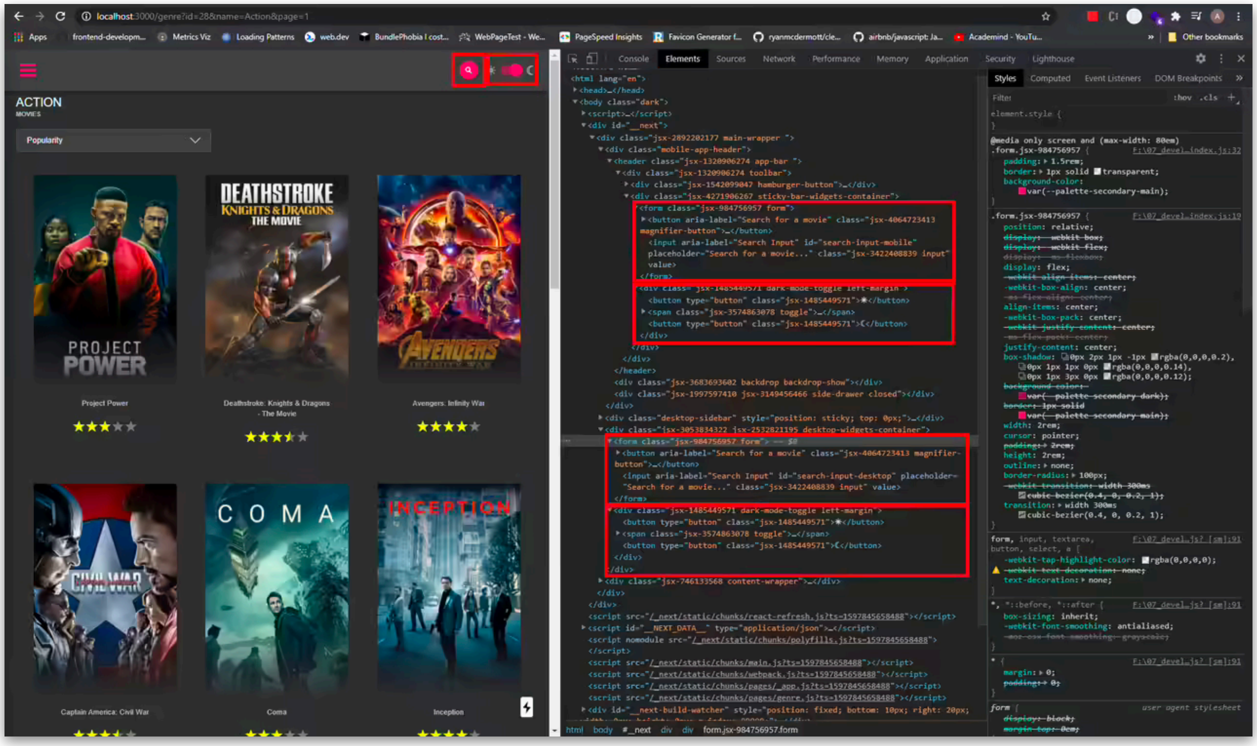
1. The server where the content is rendered does not recognize the client `window` element. Thus methods like `window.matchmedia()` cannot be used to determine client details. Additionally, client hints are not supported across all browsers.

2. Using CSS media query would result in rendering all of the elements regardless of whether they are used either on desktop or mobile.

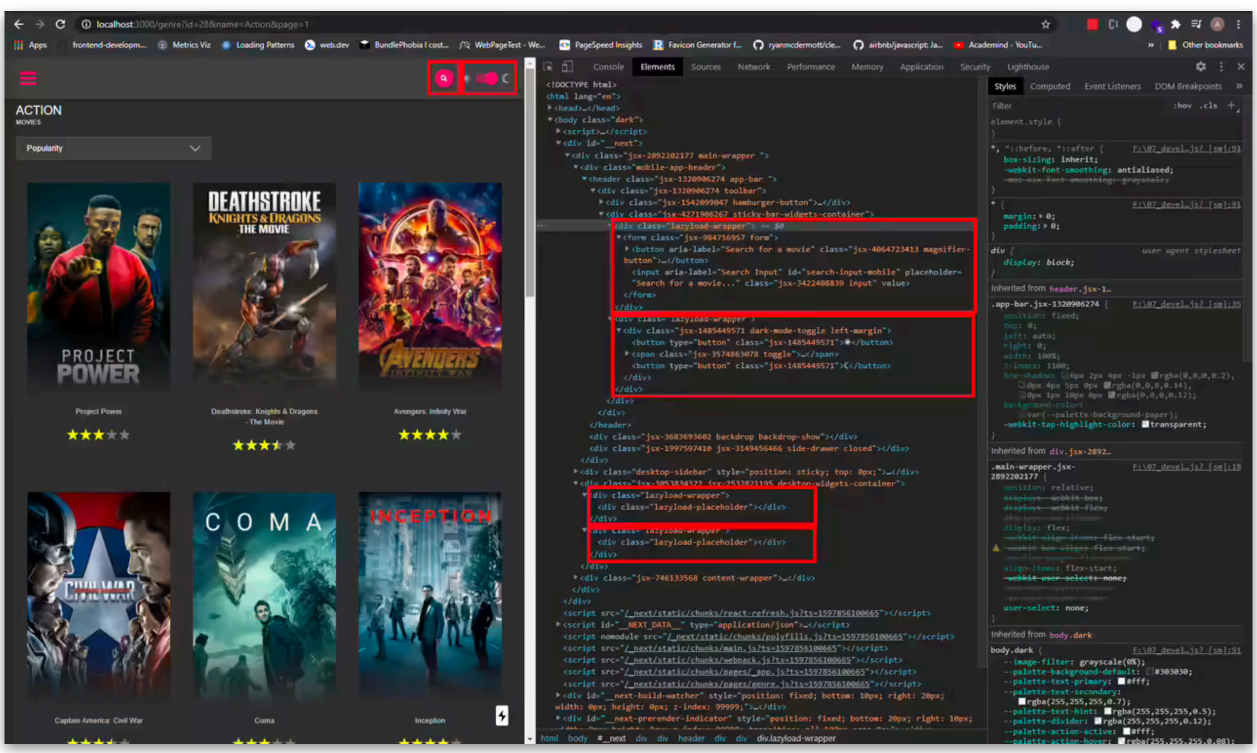
To address these challenges we used the `@artsy/fresnel` library. The approach used here is that the server would still render all elements in the DOM with CSS breakpoints. Only components that match the breakpoints would be mounted. We were thus able to avoid duplicate markup and unnecessary rendering

The following images compare the difference in markup rendered before and after the change for the same content.

Before



After



Following is the change in Lighthouse performance observed after the change.

Performance Parameter	FCP (s)	Speed Index (s)	LCP (s)	TTI (s)	TBT (ms)	CLS	Performance (%)
Before	0.93	3.73	2.6	2.63	60	0.001	94.33
After	1.06	3.23	2.66	2.66	63.33	0	95
% Change	13.97	13.4	2.3	1.14	5.55	100	

While there is some regression in FCP, LCP, TTI, and TBT, the speed index and performance have improved. The chunk size has increased due to the contribution of the artsy/fresnel bundle. However, the reduction in markup may make this a good trade-off.

Enable Google Analytics

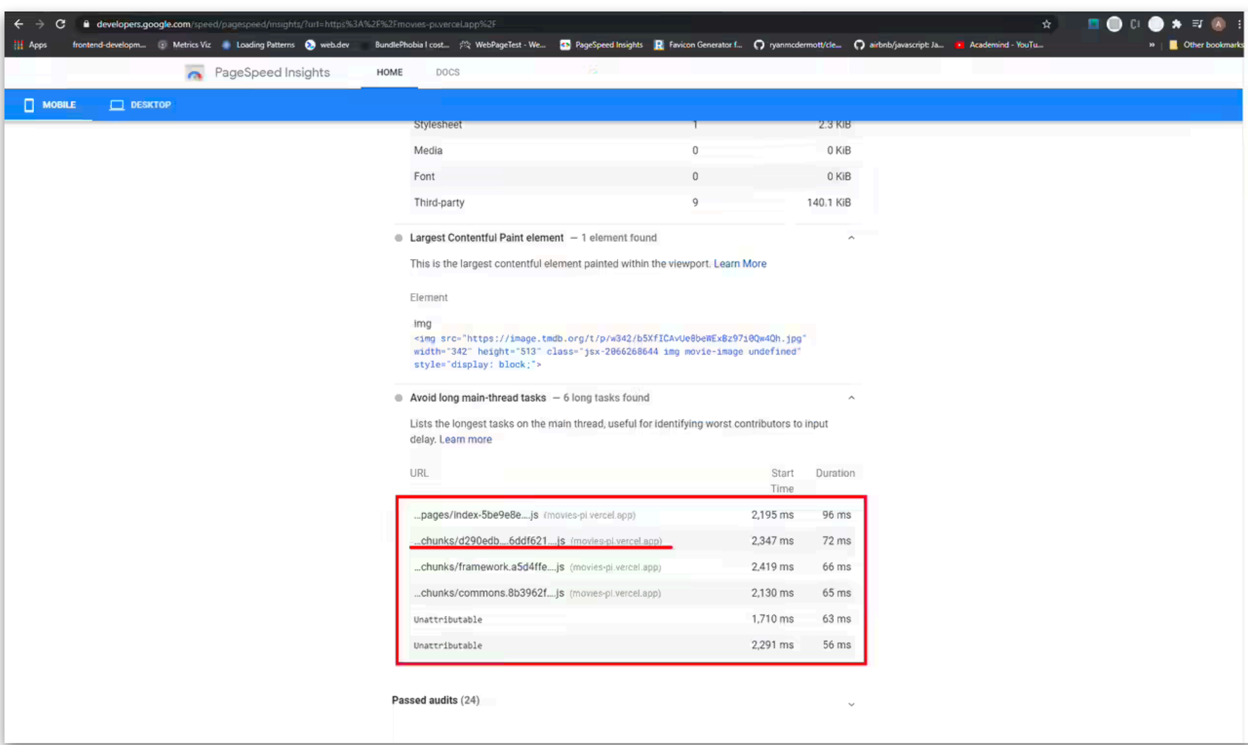
Google analytics was included on the site so that we can get a better picture of how the app engages with its users. Some regression was expected after including Google Analytics. The change in performance was captured as per our process to track performance variations for the code changes. There was some regression as expected due to the inclusion of the analytics component.

Performance Parameter	FCP (s)	Speed Index (s)	LCP (s)	TTI (s)	TBT (ms)	CLS	Performance (%)
Before	0.8	3.4	2.53	1.8	26.66	0	95.66
After	0.95	3.7	2.93	2.13	35	0	92.75
% Change	18.75	8.82	15.61	18.05	31.28	0	

Ideas that did not help

Based on the Lighthouse report's feedback, there were some alternatives and ideas that we tried but gave up because there were no performance benefits.

1. We are using the `react-lazyload` package for lazy loading images. This was listed in the long main thread tasks, along with the scrolling and rating components.



We tried replacing this with native image lazy-loading. Based on subsequent testing, we noticed that TBT increased from 10 ms to 117 ms for a negligible reduction in LCP. It is possible that native image lazy loading loads a few images that are near the viewport while react lazy-load only loads those that are within the viewport causing this difference in TBT.

Today, one could also use the Next.js Image Component to implement this functionality. However, since the component uses JS internally, using an HTML + CSS-based solution may perform better.

1. Before setting the aspect ratio for images, we had tried to improve CLS by setting image dimensions. Even though it is one of the recommended approaches for reducing CLS, setting image dimensions did not work so well as the aspect ratio technique that we finally implemented.

2. Tried out server-side rendering to reduce LCP but it brought about regression rather than improvement. This could be because the movie-related data and images required to render pages were fetched through TMDB API calls. This caused the server response to be slow because all API requests/responses were processed on the server.

Ideas that might help

There are a few additional opportunities for performance improvement that we might try out in the future. These range from replacing individual components with lighter alternatives to implementing full-fledged SSR. Here's what we could explore to check if it contributes to the performance of the app.

1. Implement responsive images with preloading as discussed here
2. Introduce caching using service-workers.
3. Currently, the `_app.js` file is slightly bloated as it includes redux-related logic eg., actions, reducers, etc. Individual pages do not need all of these files when landing. We could try eliminating redux or apply code-splitting for redux logic.
4. Implement SSR without redux and try SSR caching.
5. Replace `react-modal-video` with a lightweight alternative.
6. Use `keen-slider` instead of `react-slider`.
7. Use `react-cool-inview` instead of `react-lazyload`.
8. Apply lazy-loading/code-splitting techniques to load third party libraries using different React loading patterns
9. Image post-processing to preload the first few images like the hero-image.
10. Replace the SVG loading spinner with something that uses CSS animation.
11. Use lighter components that use HTML and CSS for rendering images instead of component that uses JavaScript internally.

Conclusion

Performance optimization is an ongoing process. Over the last 6 months, we covered a lot of ground with these changes to not only incorporate but also test many recommended best practices. We could always do more. However, at some point, you have to decide whether the gain in performance is justified by time spent on testing different alternatives. The loop will of course be repeated as and when new features are added. We however wanted to capture our takeaways from this journey so that they serve as a manual for our future endeavors as well as yours.

With special thanks to Anton Karlovskiy and Leena Sohoni-Kasture for their contributions to this article.

Islands Architecture

The islands architecture encourages small, focused chunks of interactivity within server-rendered web pages

•

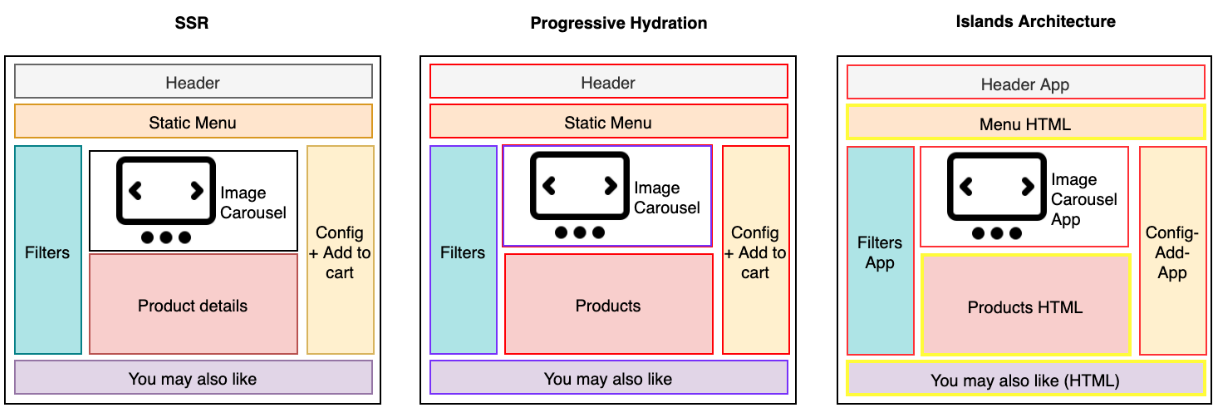
he islands architecture encourages small, focused chunks of interactivity within server-rendered web pages. The output of islands is progressively enhanced HTML, with more specificity around how the enhancement occurs. Rather than a single application being in control of full-page rendering, there are multiple entry points. The script for these "islands" of interactivity can be delivered and hydrated independently, allowing the rest of the page to be just static HTML.

Loading and processing excess JavaScript can hurt performance. However, some degree of interactivity and JavaScript is often required, even in primarily static websites. We have discussed variations of Server Side Rendering (SSR) that enable you to build applications that try to find the balance between:

- Interactivity comparable to Client-Side Rendered (CSR) applications
- SEO benefits that are comparable to SSR applications.

The core principle for SSR is that HTML is rendered on the server and shipped with necessary JavaScript to rehydrate it on the client. Rehydration is the process of regenerating the state of UI components on the client-side after the server renders it. Since rehydration comes at a cost, each variation of SSR tries to optimize the rehydration process. This is mainly achieved by partial hydration of critical components or streaming of components as they get rendered. However, the net JavaScript shipped eventually in the above techniques remains the same.

The term Islands architecture was popularized by Katie Sylor-Miller and Jason Miller to describe a paradigm that aims to reduce the volume of JavaScript shipped through "islands" of interactivity that can be independent delivered on top of otherwise static HTML. Islands are a component-based architecture that suggests a compartmentalized view of the page with static and dynamic islands. The static regions of the page are pure non-interactive HTML and do not need hydration. The dynamic regions are a combination of HTML and scripts capable of rehydrating themselves after rendering.



Render all components together and hydrate

Render all components, hydrate key components first and then progressively hydrate others

Static components are server rendered HTML. Script is required only for interactive components

Let us explore the Islands architecture in further detail with the different options available to implement it at present.

Islands of dynamic components

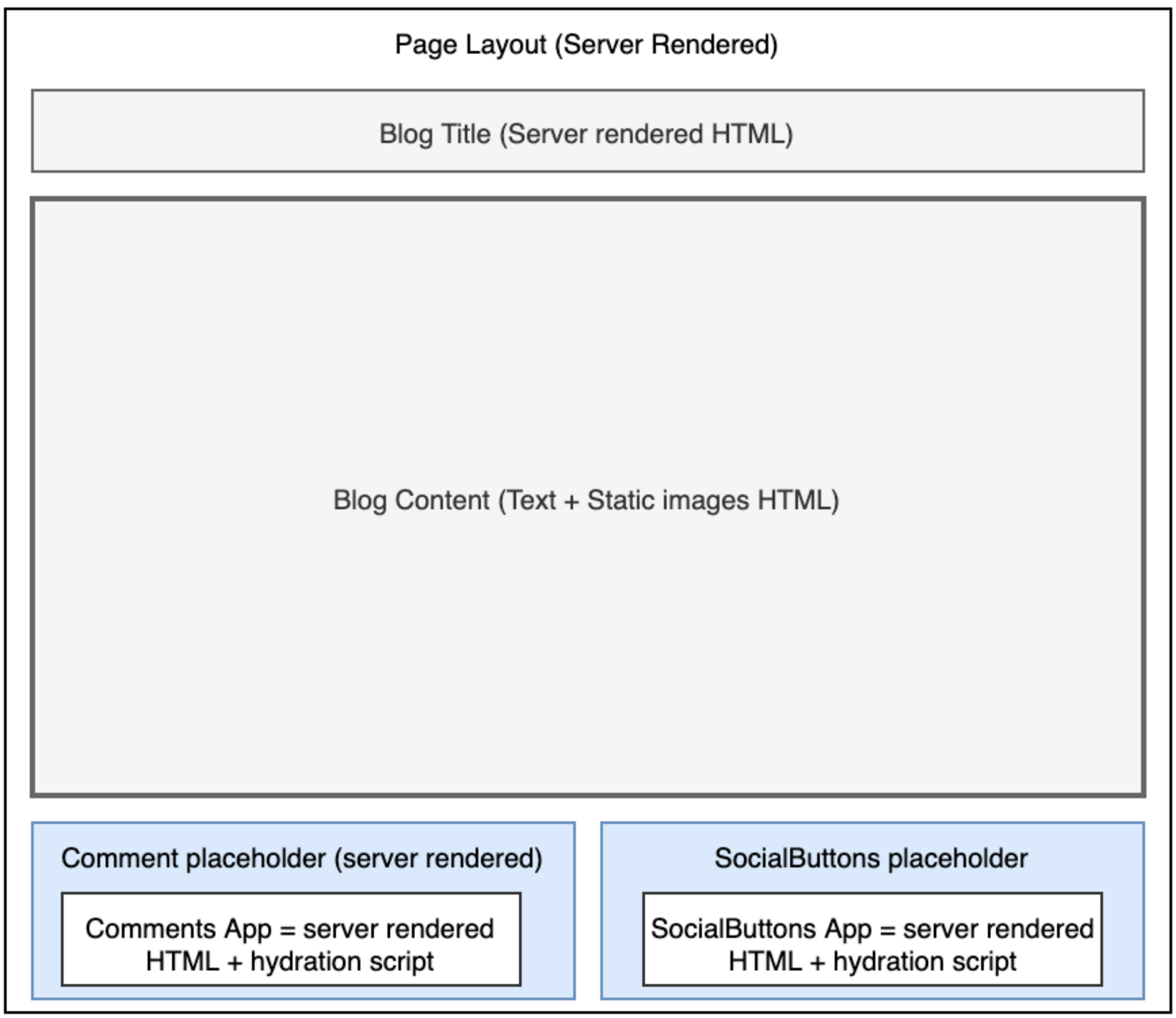
Most pages are a combination of static and dynamic content. Usually, a page consists of static content with sprinkles of interactive regions that can be isolated. For example;

- Blog posts, news articles, and organization home pages contain text and images with interactive components like social media embeds and chat.
- Product pages on e-commerce sites contain static product descriptions and links to other pages on the app. Interactive components such as image carousels and search are available in different regions of the page.
- A typical bank account details page contains a list of static transactions with filters providing some interactivity.

Static content is stateless, does not fire events, and does not need rehydration after rendering. After rendering, dynamic content (buttons, filters, search bar) has to be rewired to its events. The DOM has to be regenerated on the client-side (virtual DOM). This regeneration, rehydration, and event handling functions contribute to the JavaScript sent to the client.

The Islands architecture facilitates server-side rendering of pages with all of their static content. However, in this case, the rendered HTML will include placeholders for dynamic content. The dynamic content placeholders contain self-contained component widgets. Each widget is similar to an app and combines server-rendered output and JavaScript used to hydrate the app on the client.

In progressive hydration, the hydration architecture of the page is top-down. The page controls the scheduling and hydration of individual components. Each component has its hydration script in the Islands architecture that executes asynchronously, independent of any other script on the page. A performance issue in one component should not affect the other.



Implementing Islands

The Island architecture borrows concepts from different sources and aims to combine them optimally. Template-based static site generators such as Jekyll and Hugo support the rendering of static components to pages. Most modern JavaScript frameworks also support isomorphic rendering, which allows you to use the same code to render elements on the server and client.

Jason's post suggests the use of requestIdleCallback() to implement a scheduling approach for hydrating components. Static isomorphic rendering and scheduling of component level partial hydration can be built into a framework to support Islands architecture. Thus, the framework should

- Support static rendering of pages on the server with zero JavaScript.
- Support embed of independent dynamic components via placeholders in static content. Each dynamic component contains its scripts and can hydrate itself using requestIdleCallback() as soon as the main thread is free.
- Allow isomorphic rendering of components on the server with hydration on the client to recognize the same component at both ends.

You can use one of the out-of-the-box options discussed next to implement this.

Frameworks

Different frameworks today are capable of supporting the Islands architecture. Notable among them are

- **Marko**: Marko is an open-source framework developed and maintained by eBay to improve server rendering performance. It supports Islands architecture by combining streaming rendering with automatic partial hydration. HTML and other static assets are streamed to the client as soon as they are ready. Automatic partial hydration allows interactive components to hydrate themselves. Hydration code is only shipped for interactive components, which can change the state on the browser. It is isomorphic, and the Marko compiler generates optimized code depending on where it will run (client or server).

- **Astro**: Astro is a static site builder that can generate lightweight static HTML pages from UI components built in other frameworks such as React, Preact, Svelte, Vue, and others. Components that need client-side JavaScript are loaded individually with their dependencies. Thus it provides built-in partial hydration. Astro can also lazy-load components depending on when they become visible. We have included a sample implementation using Astro in the next section.

- **Eleventy + Preact:** Markus Oberlehner demonstrates the use of Eleventy, a static site generator with isomorphic Preact components that can be partially hydrated. It also supports lazy hydration. The component itself declaratively controls the hydration of the component. Interactive components use a `WithHydration` wrapper so that they are hydrated on the client.

Note that Marko and Eleventy pre-date the definition of Islands provided by Jason but contain some of the features required to support it. **Astro**, however, was built based on the definition and inherently supports the Islands architecture. In the following section, we demonstrate the use of Astro for a simple blog page example discussed earlier.

Sample implementation

The following is a sample blog page that we have implemented using Astro. The page SamplePost imports one interactive component, SocialButtons. This component is included in the HTML at the required position via markup.

SamplePost.astro

```
---
// Component Imports
import { SocialButtons } from '../../components/SocialButtons.tsx';
---

<html lang="en">
 <head>
   <link rel="stylesheet" href="/blog.css" />
 </head>

 <body>
   <div class="layout">
     <article class="content">
       <section class="intro">
         <h1 class="title">Post title (static)</h1>
         <br/>
         <p>Post sub-title (static)</p>
       </section>
       <section class="intro">
           <p>This is the  post content with images that is rendered by the server.</p>
           <img src="https://source.unsplash.com/user/c_v_r/200x200" />
           <p>The next section contains the interactive social buttons component which
includes its script.</p>
       </section>
       <section class="social">
           <div>
           <SocialButtons client:visible></SocialButtons>
           </div>
       </section>
     </article>
   </div>
 </body>
</html>
```

The `SocialButtons` component is a Preact component with its HTML, and corresponding event handlers included.

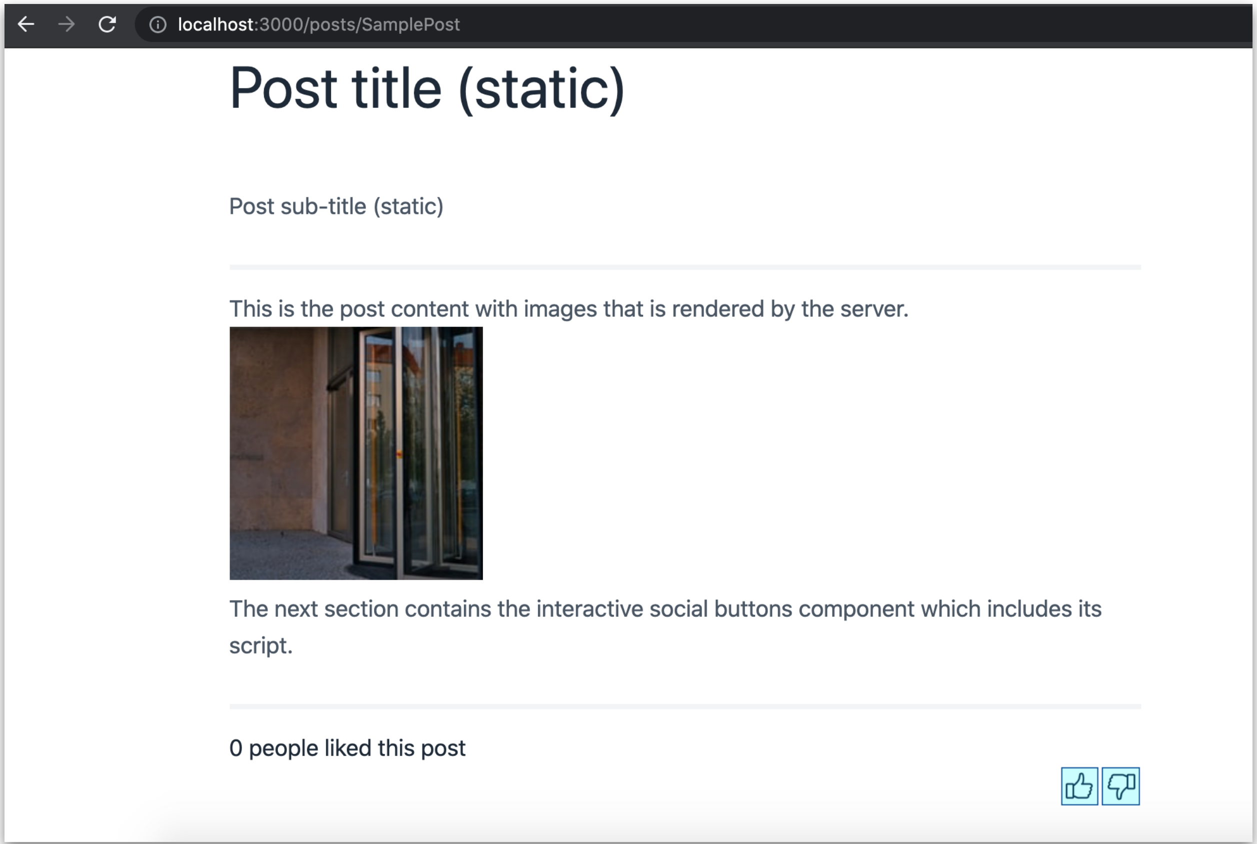
SocialButtons.tsx

```
import { useState } from 'preact/hooks';

/** a counter written in Preact */
export function SocialButtons() {
 const [count, setCount] = useState(0);
 const add = () => setCount((i) => i + 1);
 const subtract = () => setCount((i) => i - 1);

 return (
   <>
     <div>
       {count} people liked this post
     </div>
     <div align="right">
       <img src="/like.png" width="32" height="32" onclick={add}></img>
       <img src="/unlike.png" width="32" height="32" onclick={subtract}></img>
     </div>
   </>
 );
}
```

The component is embedded in the page at run time and hydrated on the client-side so that the click events function as required.



Astro allows for a clean separation between HTML, CSS, and scripts and encourages component-based design. It is easy to install and start building websites with this framework.

Pros and Cons

The Islands architecture combines ideas from different rendering techniques such as server-side rendering, static site generation, and partial hydration. Some of the potential benefits of implementing islands are as follows.

- **Performance**: Reduces the amount of JavaScript code shipped to the client. The code sent only consists of the script required for interactive components, which is much less than the script needed to recreate the virtual DOM for the entire page and rehydrate all the elements on the page. The smaller size of JavaScript automatically corresponds to faster page loads and Time to Interactive (TTI).

Comparisons for Astro with documentation websites created for Next.js and Nuxt.js have shown an 83% reduction in JavaScript code. Other users have also reported performance improvements with Astro.

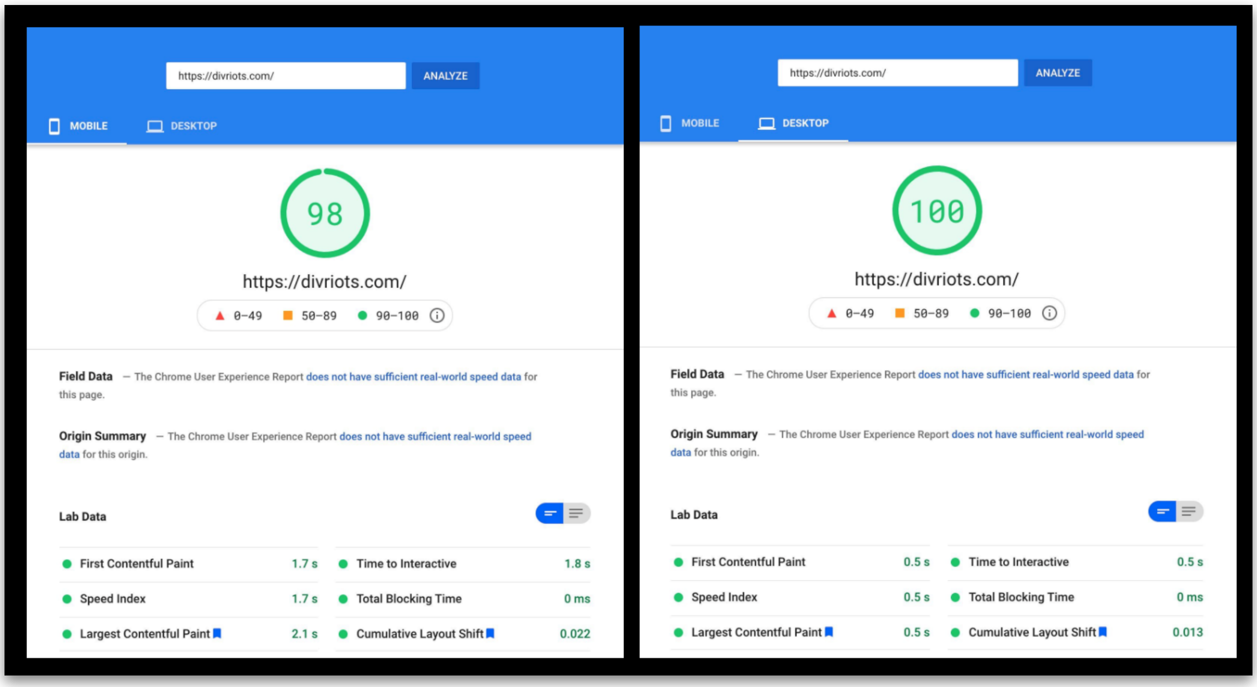


Image Courtesy: https://divriots.com/blog/our-experience-with-astro/

- **SEO:** Since all of the static content is rendered on the server; pages are SEO friendly.

- **Prioritizes important content:** Key content (especially for blogs, news articles, and product pages) is available almost immediately to the user. Secondary functionality for interactivity is usually required after consuming the key content becomes available gradually.

- **Accessibility:** The use of standard static HTML links to access other pages helps to improve the accessibility of the website.

- **Component-based:** The architecture offers all advantages of component-based architecture, such as reusability and maintainability.

Despite the advantages, the concept is still in a nascent stage. The limited support results in some disadvantages.

- The only options available to developers to implement Islands are to use one of the few frameworks available or develop the architecture yourself. Migrating existing sites to Astro or Marko would require additional efforts.

- Besides Jason's initial post, there is little discussion available on the idea.

- New frameworks claim to support the Islands architecture making it difficult to filter the ones which will work for you.

- The architecture is not suitable for highly interactive pages like social media apps which would probably require thousands of islands.

The Islands architecture concept is relatively new but likely to gain speed due to its performance advantages. It underscores the use of SSR for rendering static content while supporting interactivity through dynamic components with minimal impact on the page's performance. We hope to see many more players in this space in the future and have a wider choice of implementation options available.

PERFORMANCE

Optimize your loading sequence

Learn how to optimize your loading sequence to improve how quickly your app is usable

Note: This article is heavily influenced by insights from the Aurora team in Chrome, in particular Shubhie Panicker who has been researching the optimal loading sequence.

In every successful web page load, some critical components and resources become available at just the right time to give you a smooth loading experience. This ensures users perceive the performance of the application to be excellent. This excellent user experience should generally also translate to passing the Core Web Vitals.

Key metrics such as First Content Paint, Largest Contentful Paint, First Input Delay, etc used to measure performance are directly dependent on the loading sequence of critical resources. For example, the page cannot have its LCP if a critical resource like the hero image is not loaded. This article talks about the relationship between the loading sequence of resources and web vitals. Our objective is to provide clear guidance on how to optimize the loading sequence for better web vitals.

Before we establish an ideal loading sequence, let us first try to understand why it is so difficult to get the loading sequence right.

Why is optimal loading difficult to achieve?

We have had the unique opportunity to work on performance analysis for many of our partner's websites. We identified multiple similar issues that plagued the efficient loading of pages across different partner sites.

There is often a critical gap between developers' expectations and how the browser prioritizes resources on the page. This often results in sub-optimal performance scores. We analyzed further to discover what caused this gap and the following points summarize the essence of our analysis.

Sub-optimal sequencing
Web Vitals optimization requires not only a good understanding of what each metrics stands for but also the order in which they occur and how they relate to different critical resources. FCP occurs before LCP which occurs before FID. As such, resources required for achieving FCP should be prioritized over those required by LCP followed by those required by FID.

Resources are often not sequenced and pipelined in the correct order. This may be because developers are not aware of the dependency of metrics on resource loads. As a result, relevant resources are sometimes not available at the right time for the corresponding metric to trigger.

Examples:
a) By the time FCP fires, the hero image should be available for firing LCP.
b) By the time LCP fires, the JavaScript (JS) should be downloaded, parsed and ready (or already executing) to unblock interaction (FID).

Network/CPU Utilization

Resources are also not pipelined appropriately to ensure full CPU and Network utilization. This results in "Dead Time" on the CPU when the process is network bound and vice versa.

A great example of this is scripts that may be downloaded concurrently or sequentially. As the bandwidth gets divided during concurrent download, the total time for downloading all scripts is the same for both sequential and concurrent downloads. If you download scripts concurrently, the CPU is underutilized during the download. However, if you download the scripts sequentially, the CPU can start processing the first one as soon as it is downloaded. This results in better CPU and Network utilization.

Third-Party (3P) Products

3P libraries are often required to add common features and functionality to the website. Third parties include ads, analytics, social widgets, live chat, and other embeds that power a website. A third party library comes with its own JavaScript, images, fonts etc.

3P products don't usually have an incentive to optimize for and support the consumer site's loading performance. They could have a heavy JavaScript execution cost that delays interactivity, or gets in the way of other critical resources being downloaded.

Developers who include 3P products may tend to focus more on the value they add in terms of features rather than performance implications. As a result, 3P resources are sometimes added haphazardly, without full consideration in terms of how it fits into the overall loading sequence. This makes them hard to control and schedule.

Platform Quirks

Browsers may differ in how they prioritize requests and implement hints. Optimization is easier if you have a deep knowledge of the platform and its quirks. Behavior particular to a specific browser makes it difficult to achieve the desired loading sequence consistently.

An example of this is the preload bug on the chromium platform.
The Preload (`<link rel=preload>`) instruction can be used to tell the browser to download key resources as soon as possible. It should only be used when you are sure that the resource will be used on the current page. The bug in Chromium causes it to behave such that requests issued via `<link rel=preload>` always start before other requests seen by the preload scanner even if those have higher priority. Issues such as these put a wrench in optimization plans.

HTTP2 Prioritization

The protocol itself does not provide many options or knobs for adjusting the order and priority of resources. Even if better prioritization primitives were to be made available, there are underlying problems with HTTP2 prioritization that make optimal sequencing difficult. Mainly, we cannot predict in what order servers or CDN's will prioritize requests for individual resources. Some CDN's re-prioritize requests while others implement partial, flawed, or no prioritization.

Resource level optimization

Effective sequencing needs that the resources that are being sequenced to be served optimally so that they will load quickly. Critical CSS should be inlined, Images should be sized correctly and JS should be code-split and delivered incrementally.

The framework itself is lacking constructs that allow code-splitting and serve JS and data incrementally. Users must rely on one of the following to split large chunks of 1P JS

1. Modern React (Suspense / Concurrent mode / Data Fetching) - This is still available for experimentation only
2. Lazy loading using dynamic imports - This is not intuitive and developers need to manually identify the boundaries along which to split the code.

When code-splitting, developers need to achieve just the right granularity of chunks because of a granularity vs performance trade-off.

Higher granularity is desirable because it
1. Minimizes JS needed for individual route and on subsequent user interactions
2. Allows for caching of common dependencies. This ensures that a change in the library doesn't require re-fetching of the entire bundle.

At the same time too much granularity when code-splitting can be bad because too many small chunks lower compression rates for individual chunks and affect browser performance.

Resource optimization also requires the elimination of dead or unused code. Unnecessary or obsolete JS may be often shipped to modern browsers which negatively affects performance. JS transpiled to ES5 and bundled with polyfills is unnecessary for modern browsers. Libraries and npm packages are often not published in ES module format. This makes it hard for bundlers to tree shake and optimize.

As you might have noticed, these issues are not limited to a particular set of resources or platforms. To work around these problems, one requires an understanding of the entire tech stack and how different resources can be coalesced to achieve optimal metrics. Before we define an overall optimization strategy, let us look at how individual resource requirements can defeat our purpose.

More on Resources - Relations, Constraints, and Priorities

In the previous section, we gave a few examples of how certain resources are required for a specific event like FCP or LCP to fire. Let us try to understand all such dependencies first before we discuss a way to work with them. Following is a resource-wise list of recommendations, constraints, and gotchas that need to be considered before we define an ideal sequence.

Critical CSS

Critical CSS refers to the minimum CSS required for FCP. It is better to inline such CSS within HTML rather than import it from another CSS file. Only the CSS required for the route should be downloaded at any given time and all critical CSS should be split accordingly.

If inlining is not possible, critical CSS should be preloaded and served from the same origin as the document. Avoid serving critical CSS from multiple domains or direct use of 3rd party critical CSS like Google Fonts. Your own server could serve as a proxy for 3rd party critical CSS instead.

Delay in fetching CSS or incorrect order of fetching CSS could impact FCP and LCP. To avoid this, non-inlined CSS should be prioritized and ordered above 1P JS and ABT images on the network.

Too much inlined CSS can cause HTML bloating and long style parsing times on the main thread. This can hurt the FCP. As such identifying what is critical and code-splitting are essential.

Inlined CSS cannot be cached. One workaround for this is to have a duplicate request for the CSS that can be cached. Note however, that this can result in multiple full-page layouts which could impact FID.

Fonts

Like critical CSS, the CSS for critical fonts should also be inlined. If inlining is not possible the script should be loaded with a preconnect specified. Delay in fetching fonts, e.g., google fonts or fonts from a different domain can affect

FCP. Preconnect tells the browser to set up connections to these resources earlier.

Inlining fonts can bloat the HTML significantly and delay initiating other critical resource fetches. Font fallback may be used to unblock FCP and make the text available. However, using font fallback can affect CLS due to jumping fonts. It can also affect FID due to a potentially large style and layout task on the main thread when the real font arrives.

Above the Fold (ABT) Images

This refers to images that are initially visible to the user on page load because they are within the viewport. A special case for ABT images is the hero image for the page. All ABT images should be sized. Unsized images hurt the CLS metric because of the layout shift that occurs when they are fully rendered. Placeholders for ABT images should be rendered by the server.

Delayed hero image or blank placeholders would result in a late LCP. Moreover, LCP will re-trigger, if the placeholder size does not match with the intrinsic size of the actual hero image and the image is not overlaid on replacement. Ideally, there should be no impact on FCP due to ABT images but in practice, an image can fire FCP.

Below the Fold (BTF) Images

These are images that are not immediately visible to the user on page load. As such they are ideal candidates for lazy loading. This ensures that they do not contend with 1P JS or important 3P needed on the page. If BTF images were to be loaded before 1P JS or important 3P resources, FID would get delayed.

1P JavaScript

1P JS impacts the interaction readiness of the application. It can get delayed on the network behind images & 3P JS and on the main thread behind 3P JS. As such it should start loading before ABT images on the network and execute before 3P JS on the main thread. 1P JS does not block FCP and LCP in pages that are rendered on the server-side.

3P JavaScript

3P sync script in HTML head could block CSS & font parsing and therefore FCP. Sync script in the head also blocks HTML body parsing. 3P script execution on the main thread can delay 1P script execution and push out hydration and FID. As such, better control is required for loading 3P scripts.

These recommendations and constraints would generally apply irrespective of the tech stack and browser. Note, how something that is a recommendation can also become a constraint. For example, inlining fonts and CSS is great, but too much of it can cause bloating. The trick is to find a balance between ‘Too little Too late' and ‘Too much Too soon’.

The following chart gives us an understanding of Chrome's priorities for loading different resources. Combining the information on priorities and the discussion on resource types will help to better understand the loading sequence that is proposed in the next section.

	Layout-blocking	Load in layout-blocking phase	Load one-at-a-time in layout-blocking phase		
Net Priority	**Highest**	**Medium**	**Low**	**Lowest**	**Idle**
Blink Priority	**VeryHigh**	**High**	**Medium**	**Low**	**VeryLow**
DevTools Priority	**Highest**	**High**	**Medium**	**Low**	**Lowest**
	Main Resource				
	CSS (match)				CSS (mismatch)
		Script (early** or not from preload scanner)	Script (late**)	Script (async)	
	Font	Font (preload)			
		Import			
		Image (in viewport)		Image	
				Media	
				SVG Document	
					Prefetch
		Preload*			
		XSL			
	XHR (sync)	XHR/fetch* (async)			
			Favicon		

Following are the key takeaways from this table.

- CSS and Fonts are loaded with the highest priority. This should help us prioritize critical CSS and fonts.
- Scripts get different priorities based on where they are in the document and whether they are async, defer, or blocking. Blocking scripts requested before the first image (or an image early in the document) are given higher priority over blocking scripts requested after the first image is fetched.

  Async/defer/injected scripts, regardless of where they are in the document, have the lowest priority. Thus we can prioritize different scripts by using the appropriate attributes for async and defer.

- Images that are visible and in the viewport have a higher priority (Net: Medium) than those that are not in the viewport (Net: Lowest). This helps us prioritize ABT images over BTF images.

Let us now see how all of the above details can be put together to define an optimal loading sequence.

What is the Ideal Loading Sequence

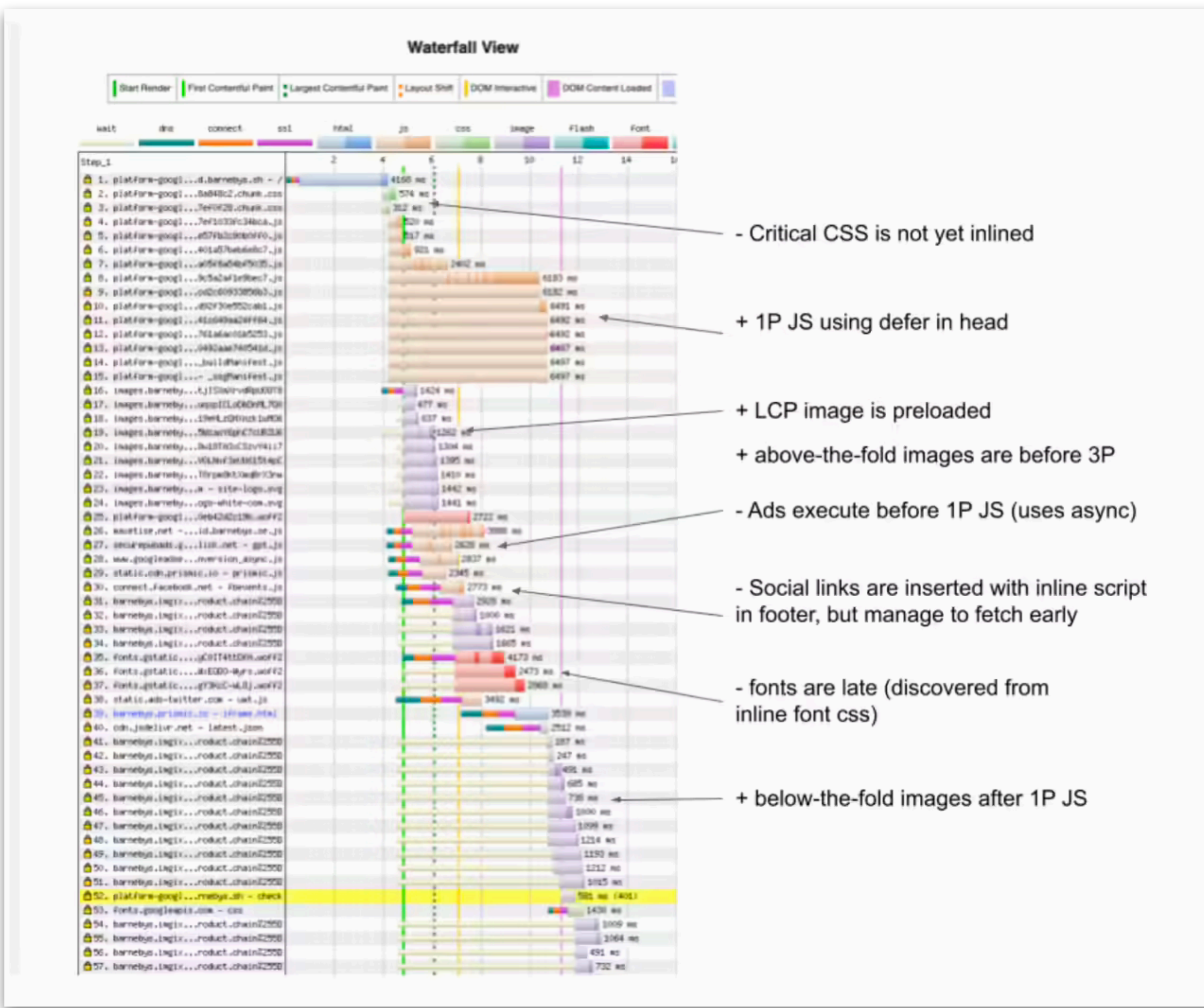
With that background, we can now propose a loading sequence that should optimize the loading of both 1P and 3P resources. The proposed sequence uses Next.js Server Side Rendering (SSR) as a reference for optimization.

Current State

Based on our experience, the following is the typical loading sequence we have observed for a Next.js SSR application before optimization.

CSS	CSS is preloaded before JS but is not inlined
JavaScript	1P JS is preloaded 3P JS is not managed and can still be render-blocking anywhere in the document.
Fonts	Fonts are neither in-lined nor do they use preconnect Fonts are loaded via external stylesheets which delays the loading Fonts may or may not be display blocking.
Images	Hero images are not prioritized Both ABT and BTF images are not optimized

Following is an example of one such sequence from one of our partner sites. The positives and negatives about the loading sequence are included as annotations.



Proposed Sequence without 3P

Following is a loading sequence that takes into account all of the constraints discussed previously. Let us first tackle a sequence without 3P. We will then see how 3P resources can be interleaved in this sequence. Note that, we have considered Google Fonts as 1P here.

Sequence of events on the main browser thread		**Sequence of requests on the network.**	
1	Parse the HTML	Small inline 1P scripts.	1
2	Execute small inline 1P scripts	Inlined critical CSS (Preload if external)	2
		Inlined critical Fonts (Preconnect if external)	3
3	Parse FCP resources (critical CSS, font)	LCP Image (Preconnect if external)	4
First Contentful Paint (FCP)		Fonts (triggered from inline font-css (Preconnect)	5
4	Render LCP resources (Hero image, text)	Non-critical (async) CSS	6
		First-party JS for interactivity	7
		Above the fold images (preconnect)	8
Largest Contentful Paint (LCP)		Below the fold images	9
5	Render important ABT images		
Visually Complete			

6	Parse Non-critical (async) CSS		
7	Execute 1P JS and hydrate	Lazy-loaded JS chunks	1(
First Input Delay (FID)			

While some parts of this sequence may be intuitive, the following points will help to justify it further.

1. We recommend avoiding preload as much as possible because it forces manual preload on every preceding resource and also causes manual curation of ordering. Preload should be especially avoided on fonts, as it is tricky to detect critical fonts.
2. Font-CSS should be ideally inlined. Fonts from another origin should be fetched using preconnect.
3. Preconnect is recommended for all resources from another origin. This will ensure that a connection is established in advance for downloading these resources.
4. Non-critical CSS should be fetched before user interaction begins (FID). This would avoid styling problems due to subsequent rendering of such CSS.
5. Start fetching first-party JS before ABT images on the network. It will take some time to download and parse the JS.
6. Parsing of the HTML on the main thread and download of ABT images can continue in parallel while 1P JS is parsed.

Proposed Sequence with 3P

Finally, we have reached the stage where we can propose a sequence for all key resources that are commonly loaded in a modern web application. Following is what the sequence for events on the main browser thread and network fetch requests will look like with 3P resources in the picture.

Sequence of events on the main browser thread		**Sequence of requests on the network.**	
1	Parse the HTML	FCP blocking 3P resources	1
		Small inline 1P scripts.	2
2	Execute small inline 1P scripts	Inlined critical CSS (Preload if external)	3
3	Parse FCP blocking 3P resources	Inlined critical Fonts (Preconnect if external)	4
4	Parse FCP resources (critical CSS, font)	3P personalized ABT image required for LCP	5
First Contentful Paint (FCP)		LCP Image (Preconnect if external)	6

5	Render 3P personalized ABT image required for LCP	Fonts (triggered from inline font-css (Preconnect)	7
		Non-critical (async) CSS	8
6	Render LCP resources (Hero image, text)	3P that must execute before first user interaction	9
		First-party JS for interactivity	1
Largest Contentful Paint (LCP)		Above the fold images (preconnect)	1
7	Render important ABT images	Default 3P JS	1
8	Parse Non-critical (async) CSS		
9	Execute 3P required for first user interaction	Below the fold images	1
10	Execute 1P JS and hydrate	Lazy-loaded JS chunks	1
First Input Delay (FID)		Less important 3P JS	1

The main concern here is how do you ensure that 3P scripts are downloaded optimally and in the required sequence.
Since the script request goes to another domain, preconnect is recommended for the following 3P requests. This helps to optimize the download.

#1 - FCP blocking 3P resources
#5 - 3P personalized ABT image required for LCP
#9 - 3P that must execute before first user interaction
#12 - Default 3P JS

To achieve the desired sequence, we recommend using the ScriptLoader component for Next. This component is designed to "optimize the critical rendering path and ensure external scripts don't become a bottleneck to optimal page load." The feature most relevant to our discussion is Loading Priorities. This allows us to schedule the scripts at different milestones to support different use cases. Following are the loading priority values available **After-Interactive**: Loads the specific 3P script after the next hydration. This can be used to load Tag-managers, Ads, or Analytics scripts that we want to execute as early as possible but after 1P scripts.

Before-Interactive: Loads the specific 3P script before hydration. It can be used in cases where we want the 3P script to execute before the 1P script. Eg., polyfill.io, bot detection, security and authentication, user consent management (GDPR), etc.

Lazy-Onload: Prioritize all other resources over the specified 3P script and lazy load the script. It can be used for CRM components like Google Feedback or Social Network specific scripts like those used for share buttons, comments, etc.

Thus, preconnect, script attributes and ScriptLoader for Next.js together can help us get the desired sequence for all our scripts.

Conclusion

The responsibility of optimizing apps falls on the shoulders of the creators of the platforms used as well as the developers who use it. Common issues need to be addressed. We aim to make sequencing easier from the inside out.

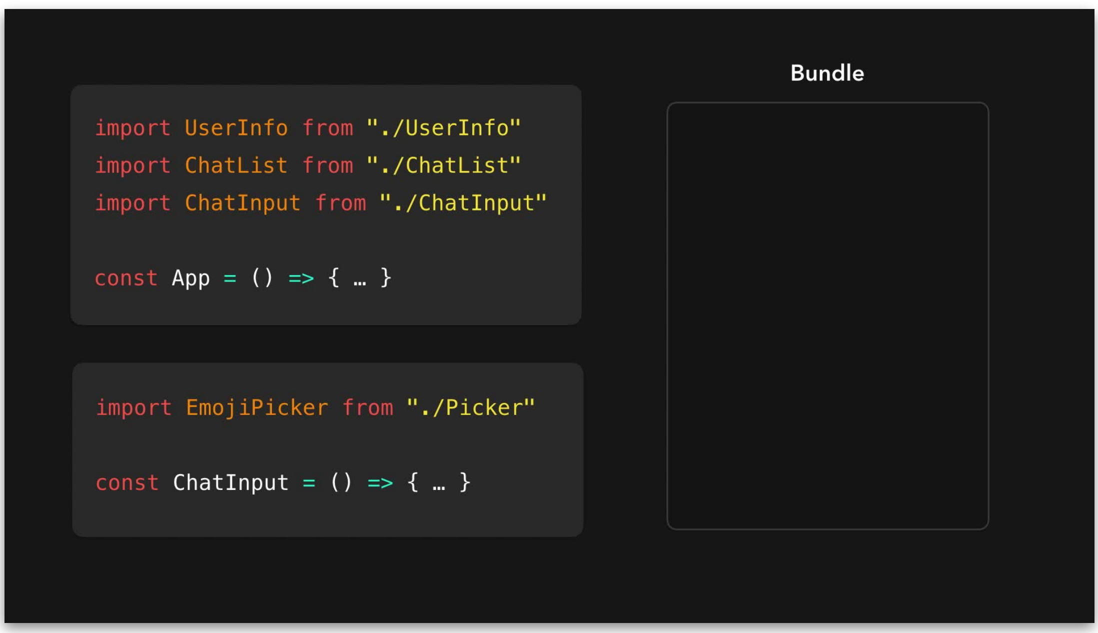
A tried and tested set of recommendations for different use cases and initiatives like the Script Loader help to achieve this for the React-Next.js stack. The next step would be to ensure that new apps conform to the recommendations above.

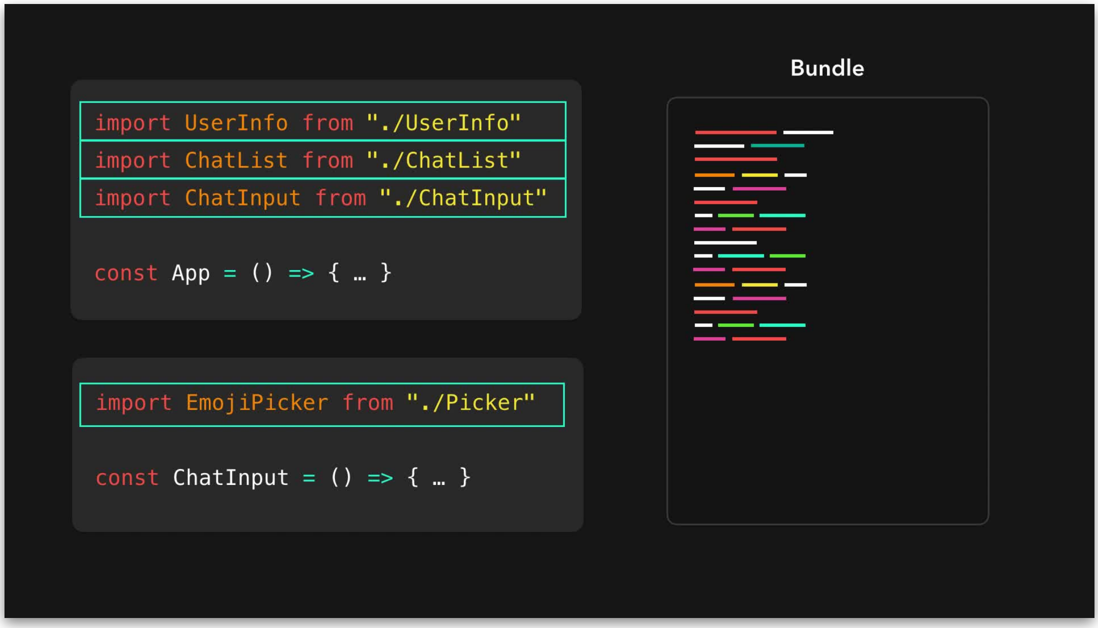
With special thanks to Leena Sohoni (Technical Analyst/Writer), for all her contributions to this write-up.

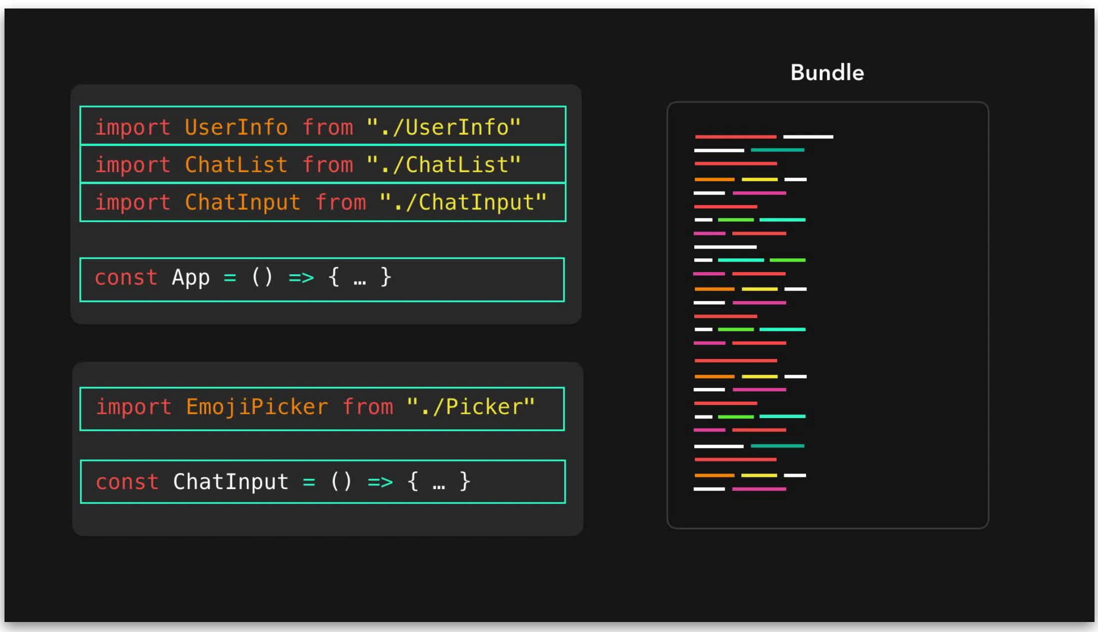
Static Import

Import code that has been exported by another module

The import keyword allows us to import code that has been exported by another module. By default, all modules we're statically importing get added to the initial bundle. A module that is imported by using the default ES2015 import syntax, import module from 'module', is statically imported.




Bundle
import UserInfo from "./UserInfo"
import ChatList from "./ChatList"
import ChatInput from "./ChatInput"
const App = () => { … }
import EmojiPicker from "./Picker"
const ChatInput = () => { … }


Bundle
import UserInfo from "./UserInfo"
import ChatList from "./ChatList"
import ChatInput from "./ChatInput"
const App = () => { … }
import EmojiPicker from "./Picker"
const ChatInput = () => { … }

Let's look at an example! A simple chat app contains a `Chat` component, in which we're statically importing and rendering three components: `UserProfile`, a `ChatList`, and a `ChatInput` to type and send messages! Within the `ChatInput` module, we're statically importing an `EmojiPicker` component to show be able to show the user the emoji picker when the user toggles the emoji.

```
import React from "react";

// Statically import Chatlist, ChatInput and UserInfo
import UserInfo from "./components/UserInfo";
import ChatList from "./components/ChatList";
import ChatInput from "./components/ChatInput";

import "./styles.css";

console.log("App loading", Date.now());

const App = () => (
  <div className="App">
    <UserInfo />
    <ChatList />
    <ChatInput />
  </div>
);
```

The modules get executed as soon as the engine reaches the line on which we import them. When you open the console, you can see the order in which the modules have been loaded!

Since the components were statically imported, Webpack bundled the modules into the initial bundle. We can see the bundle that Webpack creates after building the application.

```
Asset             Size      Chunks            Chunk Names
main.bundle.js    1.5 MiB    main   [emitted]  main
```

Our chat application's source code gets bundled into one bundle: `main.bundle.js`. A large bundle size can affect the loading time of our application significantly depending on the user's device and network connection. Before the App component is able to render its contents to the user's screen, it first has to load and parse all modules.

Luckily, there are many ways to speed up the loading time! We don't always have to import all modules at once: maybe there are some modules that should only get rendered based on user interaction, like the `EmojiPicker` in this case, or rendered further down the page. Instead of importing all component statically, we can dynamically import the modules after the App component has rendered its contents and the user is able to interact with our application.

Dynamic Import

Import parts of your code on demand

In our chat application, we have four key components: `UserInfo`, `ChatList`, `ChatInput` and `EmojiPicker`. However, only three of these components are used instantly on the initial page load: `UserInfo`, `ChatList and ChatInput`

The `EmojiPicker` isn't directly visible, and may not even be rendered at all if the user won't even click on the emoji in order to toggle the `EmojiPicker`. This would mean that we unnecessarily added the `EmojiPicker` module to our initial bundle, which potentially increased the loading time!

In order to solve this, we can dynamically import the `EmojiPicker` component. Instead of statically importing it, we'll only import it when we want to show the `EmojiPicker`.

An easy way to dynamically import components in React is by using React Suspense. The `React.Suspense` component receives the component that should be dynamically loaded, which makes it possible for the App component can render its contents faster by suspending the import of the `EmojiPicker` module!

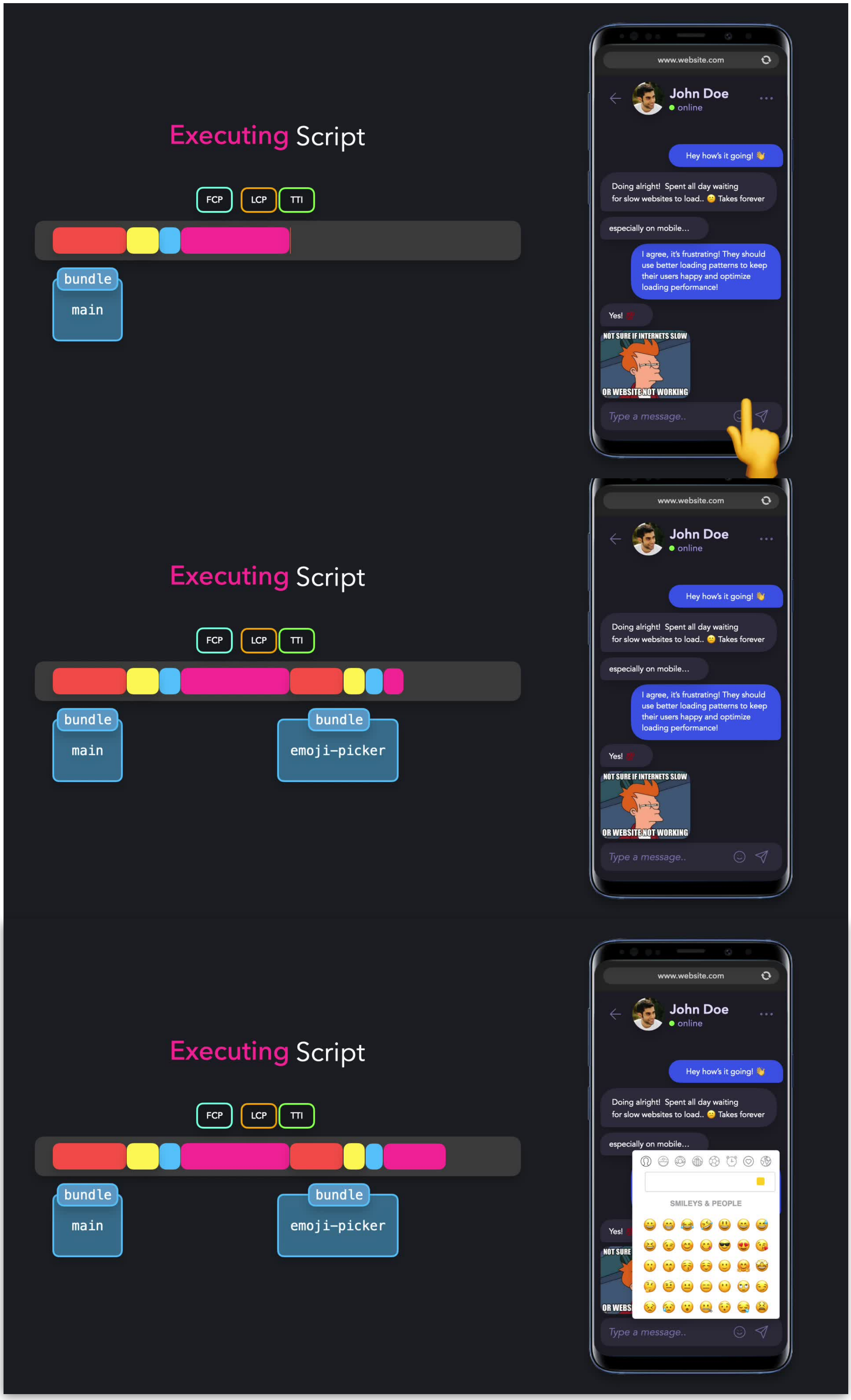
When the user clicks on the emoji, the `EmojiPicker` component gets rendered for the first time. The `EmojiPicker` component renders a `Suspense` component, which receives the lazily imported module:

the `EmojiPicker` in this case. The `Suspense` component accepts a fallback prop, which receives the component that should get rendered while the suspended component is still loading!

Instead of unnecessarily adding `EmojiPicker` to the initial bundle, we can split it up into its own bundle and reduce the size of the initial bundle! A smaller initial bundle size means a faster initial load: the user doesn't have to stare at a blank loading screen for as long. The fallback component lets the user know that our application hasn't frozen: they simply need to wait a little while for the module to be processed and executed.

```
Asset                              Size          Chunks             Chunk Names
emoji-picker.bundle.js             1.48 KiB      1     [emitted]    emoji-picker
main.bundle.js                     1.33 MiB      main  [emitted]    main
vendors~emoji-picker.bundle.js     171 KiB       2     [emitted]    vendors~emoji-picker
```

Whereas previously the initial bundle was `1.5 MiB`, we've been able to reduce it to `1.33 MiB` by suspending the import of the `EmojiPicker`!


Executing Script
FCP
LCP
TTI
bundle
main
www.website.com
John Doe
online
Hey how's it going!
Doing alright! Spent all day waiting for slow websites to load.. Takes forever
especially on mobile...
I agree, it's frustrating! They should use better loading patterns to keep their users happy and optimize loading performance!
Yes!
NOT SURE IF INTERNETS SLOW
OR WEBSITE NOT WORKING
Type a message..
Executing Script
FCP
LCP
TTI
bundle
main
bundle
emoji-picker
www.website.com
John Doe
online
Hey how's it going!
Doing alright! Spent all day waiting for slow websites to load.. Takes forever
especially on mobile...
I agree, it's frustrating! They should use better loading patterns to keep their users happy and optimize loading performance!
Yes!
NOT SURE IF INTERNETS SLOW
OR WEBSITE NOT WORKING
Type a message..
Executing Script
FCP
LCP
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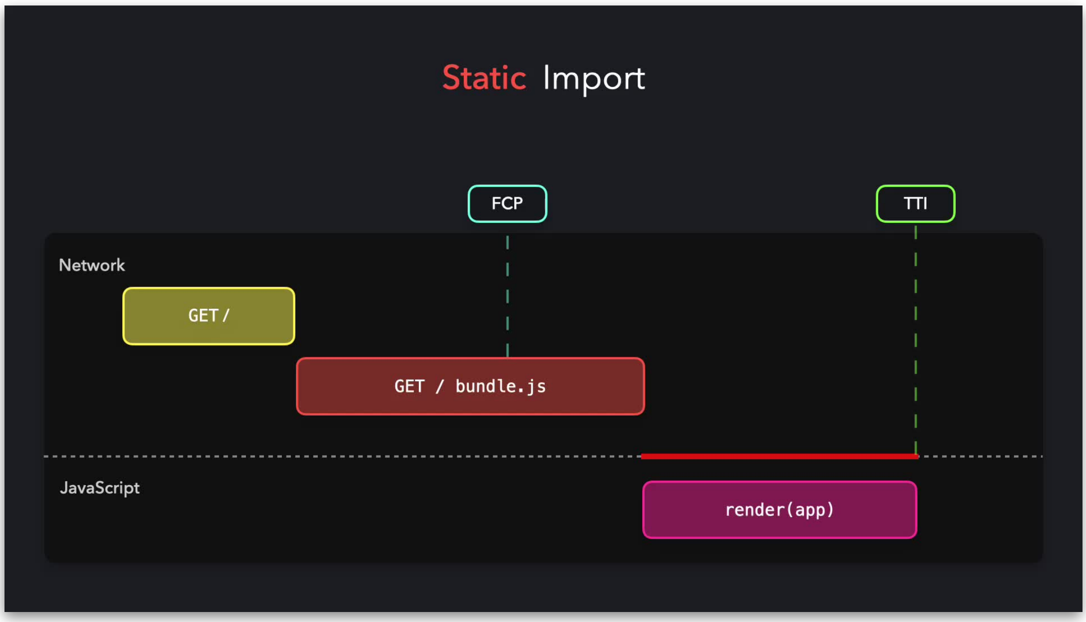
bundle
main
bundle
emoji-picker
www.website.com
John Doe
online
Hey how's it going!
Doing alright! Spent all day waiting for slow websites to load.. Takes forever
especially on mobile...
SMILEYS & PEOPLE
Yes!
Type a message..

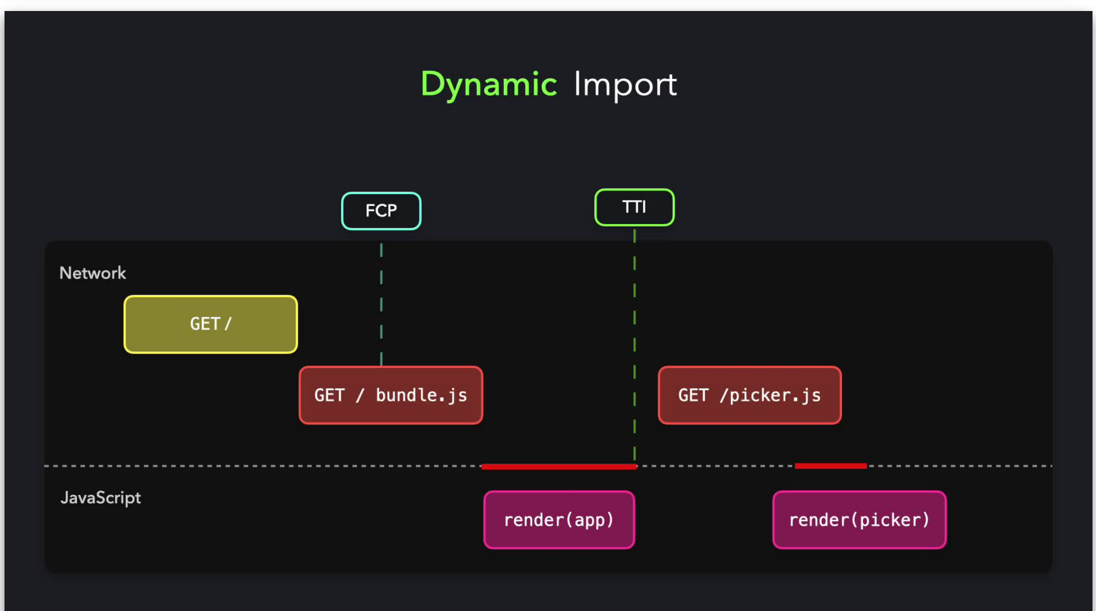
In the console, you can see that the `EmojiPicker` doesn't get executed until we've toggled the `EmojiPicker`!

```
import React, { Suspense, lazy } from "react";
  // import Send from "./icons/Send";
  // import Emoji from "./icons/Emoji";
  const Send = lazy(() =>
    import(/*webpackChunkName: "send-icon" */ "./icons/Send")
  );
  const Emoji = lazy(() =>
    import(/*webpackChunkName: "emoji-icon" */ "./icons/Emoji")
  );
  // Lazy load EmojiPicker  when <EmojiPicker /> renders
  const Picker = lazy(() =>
    import(/*webpackChunkName: "emoji-picker" */ "./EmojiPicker")
  );

  const ChatInput = () => {
    const [pickerOpen, togglePicker] = React.useReducer(
      state => !state, false
    );

    return (
      <Suspense fallback={<p id="loading">Loading...</p>}>
        <div className="chat-input-container">
          <input type="text" placeholder="Type a message..." />
          <Emoji onClick={togglePicker} />
          {pickerOpen && <Picker />}
          <Send />
        </div>
      </Suspense>
    );
  };

  console.log("ChatInput loaded", Date.now());

  export default ChatInput;
```

When building the application, we can see the different bundles that Webpack created.

By dynamically importing the `EmojiPicker` component, we managed to reduce the initial bundle size from `1.5MiB` to `1.33MiB`! Although the user may still have to wait a while until the `EmojiPicker` has been fully loaded, we have improved the user experience by making sure the application is rendered and interactive while the user waits for the component to load.





Loadable Components

Server-side rendering doesn't support React Suspense (yet). A good alternative to React Suspense is the loadable-components library, which can be used in SSR applications.

```
import React from "react";
import loadable from "@loadable/component";

import Send from "./icons/Send";
import Emoji from "./icons/Emoji";

const EmojiPicker = loadable(() => import("./EmojiPicker"), {
  fallback: <div id="loading">Loading...</div>
});

const ChatInput = () => {
  const [pickerOpen, togglePicker] = React.useReducer(state => !state, false);

  return (
    <div className="chat-input-container">
      <input type="text" placeholder="Type a message..." />
      <Emoji onClick={togglePicker} />
      {pickerOpen && <EmojiPicker />}
      <Send />
    </div>
  );
};

export default ChatInput;
```

Similar to React Suspense, we can pass the lazily imported module to the loadable, which will only import the module once the `EmojiPicker` module is being requested! While the module is being loaded, we can render a fallback component.

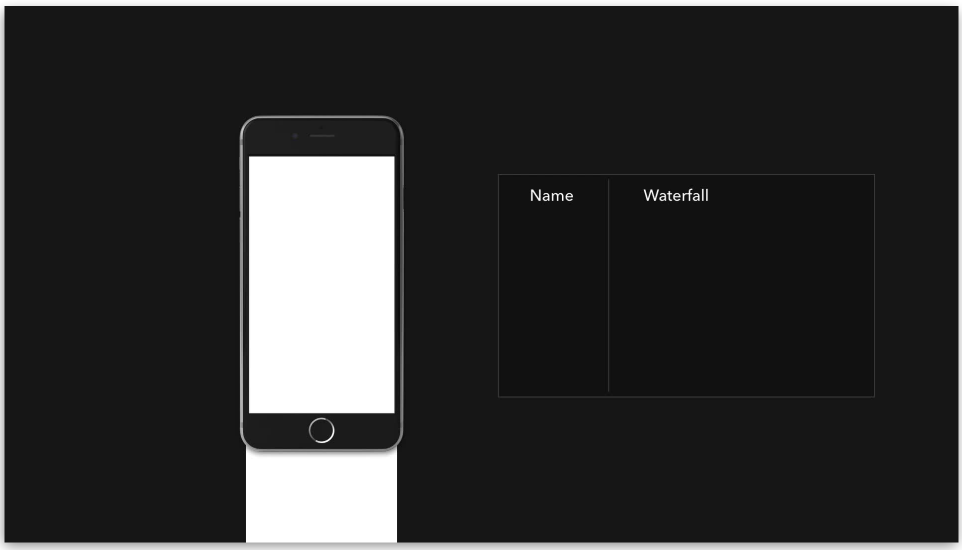
```
import React from "react";
import Send from "./icons/Send";
import Emoji from "./icons/Emoji";
import loadable from "@loadable/component";

const EmojiPicker = loadable(() => import("./components/EmojiPicker"), {
  fallback: <p id="loading">Loading...</p>
});

const ChatInput = () => {
  const [pickerOpen, togglePicker] = React.useReducer(state => !state, false);

  return (
    <div className="chat-input-container">
      <input type="text" placeholder="Type a message..." />
      <Emoji onClick={togglePicker} />
      {pickerOpen && <EmojiPicker />}
      <Send />
    </div>
  );
};

console.log("ChatInput loaded", Date.now());

export default ChatInput;
```

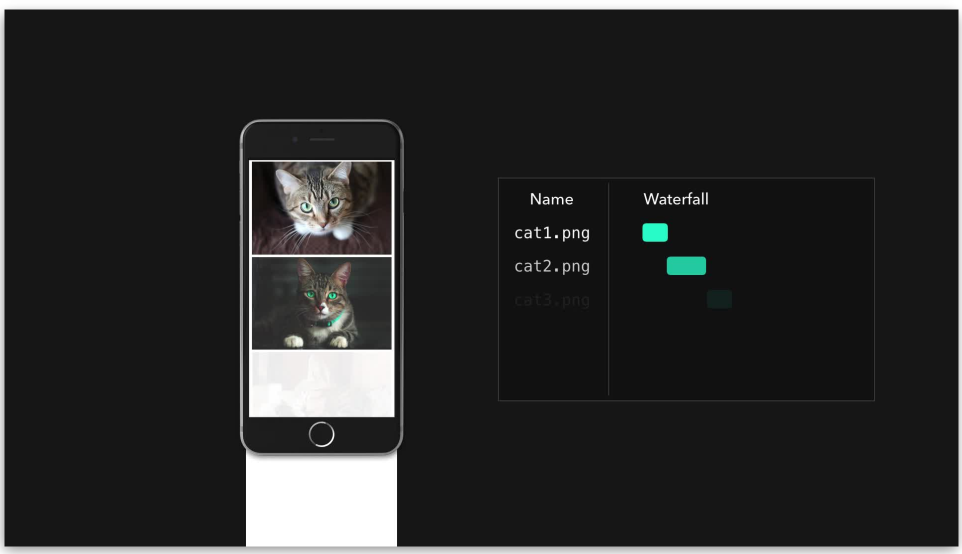
Although loadable components are a great alternative to React Suspense for SSR applications, they're also useful in CSR applications in order to suspend the import of modules.

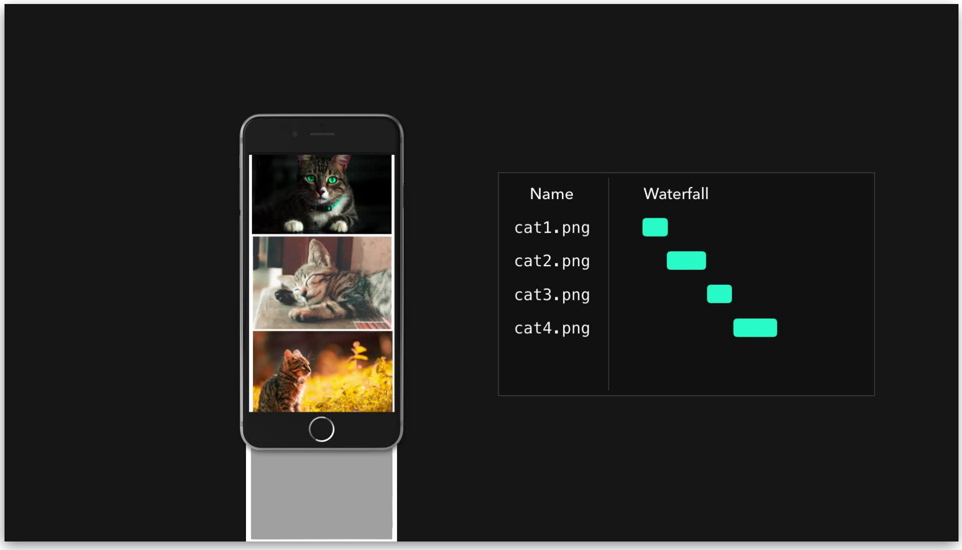
Import on Visibility

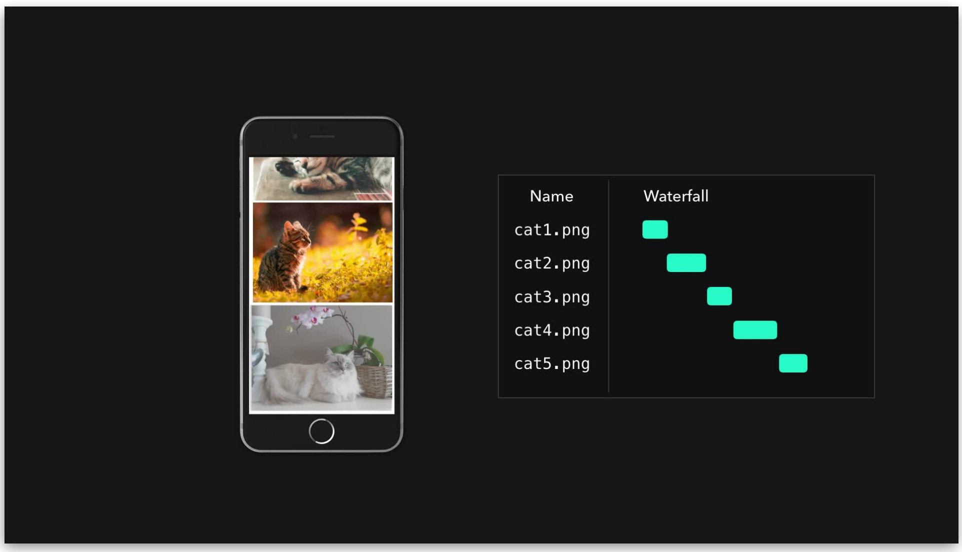
Load non-critical components when they are visible in the viewport

Besides user interaction, we often have components that aren't visible on the initial page. A good example of this is lazy loading images that aren't directly visible in the viewport, but only get loaded once the user scrolls.





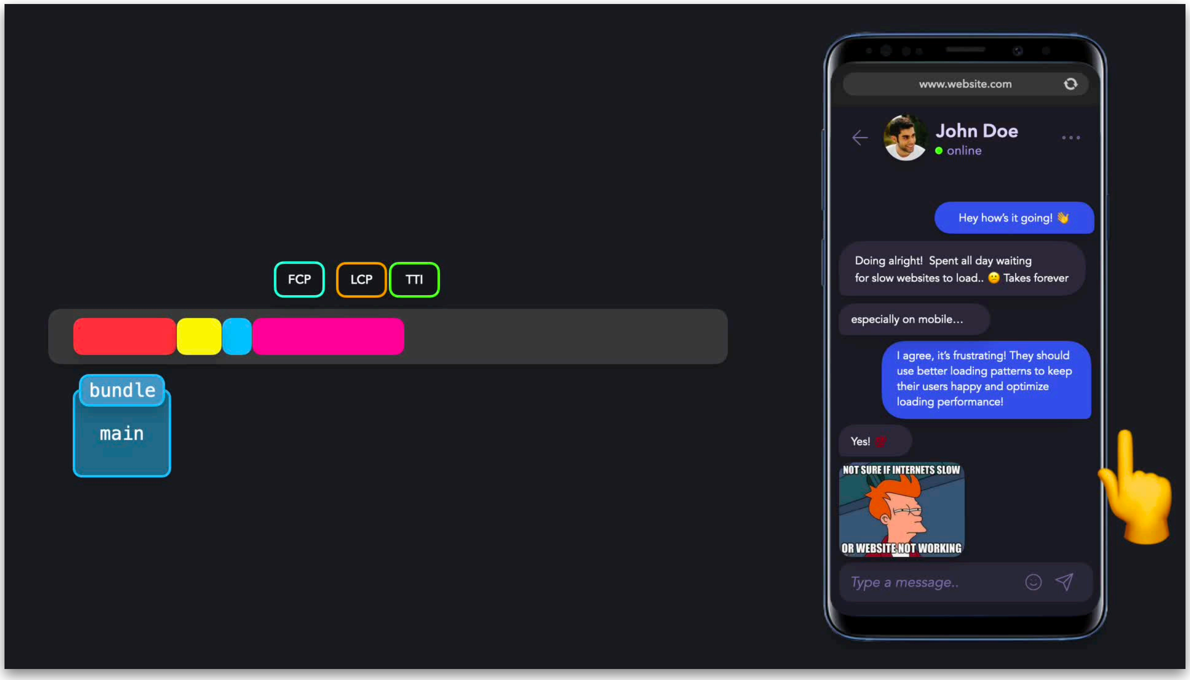




As we're not requesting all images instantly, we can reduce the initial loading time. We can do the same with components! In order to know whether components are currently in our viewport, we can use the `IntersectionObserver API`, or use libraries such as `react-lazyload` or `react-loadable-visibility` to quickly add import on visibility to our application.

```
import React from "react";
import Send from "./icons/Send";
import Emoji from "./icons/Emoji";
import LoadableVisibility from "react-loadable-visibility/react-loadable";

const EmojiPicker = LoadableVisibility({
  loader: () => import("./EmojiPicker"),
  loading: <p id="loading">Loading</p>
});

const ChatInput = () => {
  const [pickerOpen, togglePicker] = React.useReducer(state => !state, false);

  return (
    <div className="chat-input-container">
      <input type="text" placeholder="Type a message..." />
      <Emoji onClick={togglePicker} />
      {pickerOpen && <EmojiPicker />}
      <Send />
    </div>
  );
};

console.log("ChatInput loading", Date.now());

export default ChatInput;
```

Whenever the `EmojiPicker` is rendered to the screen, after the user clicks on the Gif button, `react-loadable-visibility` detects that the `EmojiPicker` element should be visible on the screen. Only then, it will start importing the module while the user sees a loading component being rendered.


FCP
LCP
TTI
bundle
main
www.website.com
John Doe
online
Hey how's it going!
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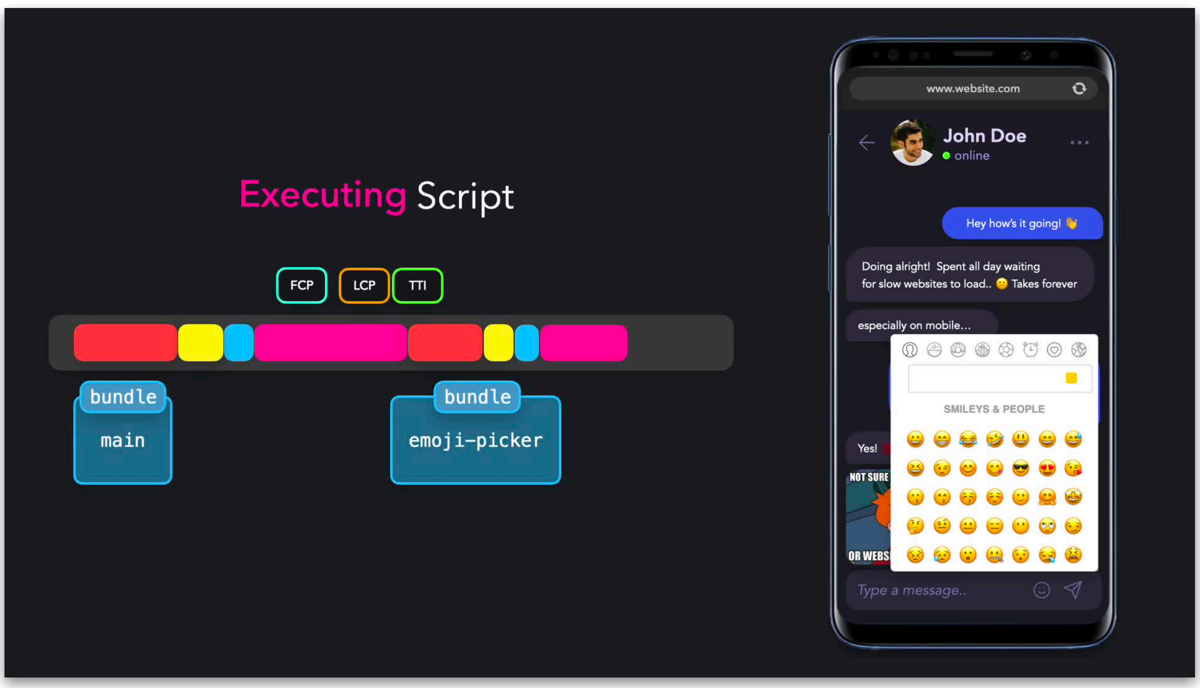
especially on mobile...
I agree, it's frustrating! They should use better loading patterns to keep their users happy and optimize loading performance!
Yes!
NOT SURE IF INTERNETS SLOW
OR WEBSITE NOT WORKING
Type a message..


Executing Script
FCP
LCP
TTI
bundle
main
bundle
emoji-picker
www.website.com
John Doe
online
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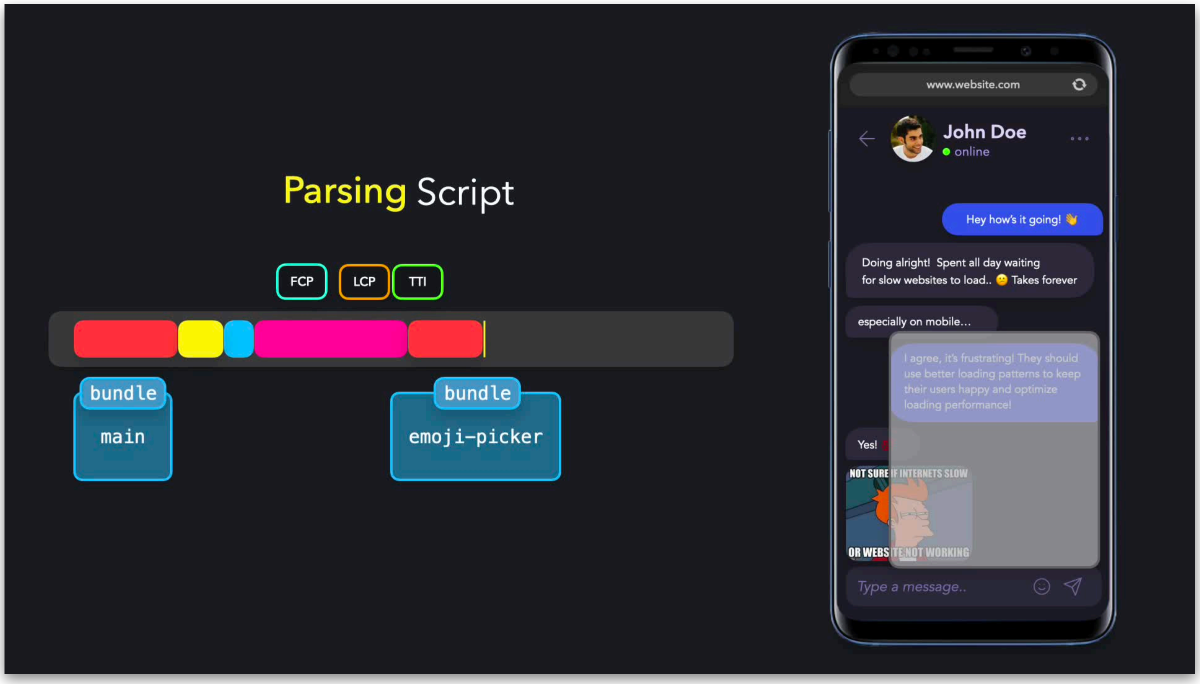
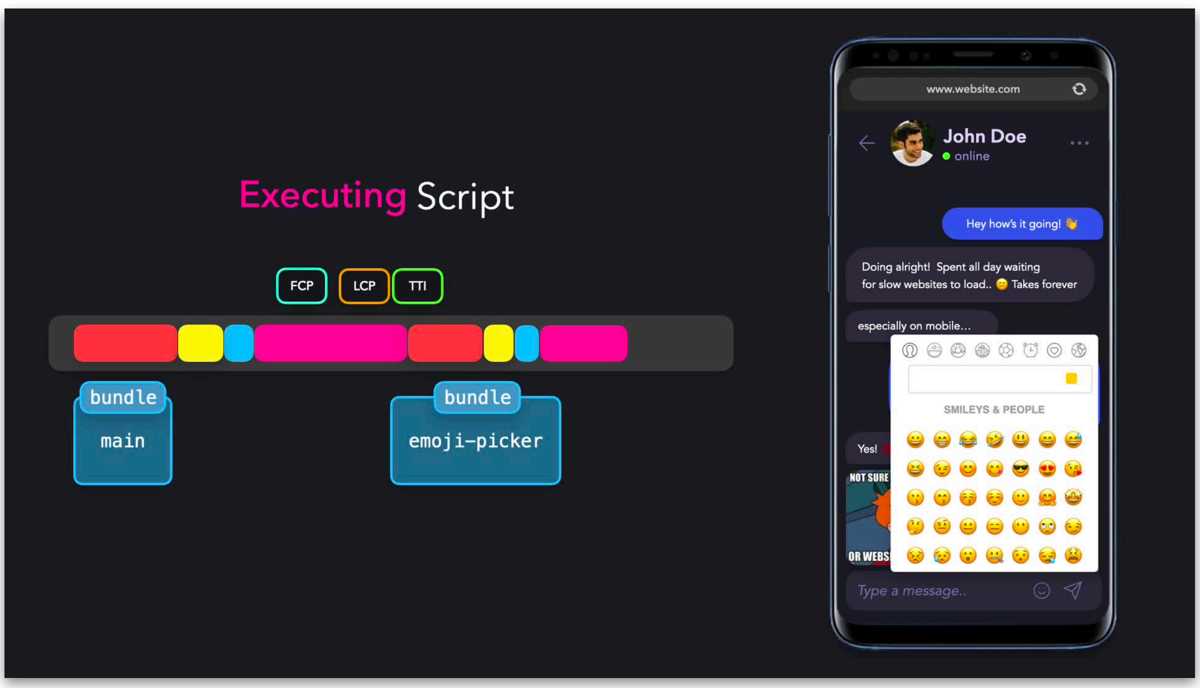
especially on mobile...
SMILEYS & PEOPLE
Yes!
Type a message..





The fallback component lets the user know that our application hasn't frozen: they simply need to wait a short while for the module to be loaded, parsed, compiled, and executed!

Import on Interaction

Load non-critical resources when a user interacts with UI requiring it

Your page may contain code or data for a component or resource that isn’t immediately necessary. For example, part of the user-interface a user doesn't see unless they click or scroll on parts of the page. This can apply to many kinds of first-party code you author, but this also applies to third-party widgets such as video players or chat widgets where you typically need to click a button to display the main interface.

Loading these resources eagerly (right away) can block the main thread if they are costly, pushing out how soon a user can interact with more critical parts of a page. This can impact interaction readiness metrics like **First Input Delay**, **Total Blocking Time** and **Time to Interactive.** Instead of loading these resources immediately, you can load them at a more opportune moment, such as:

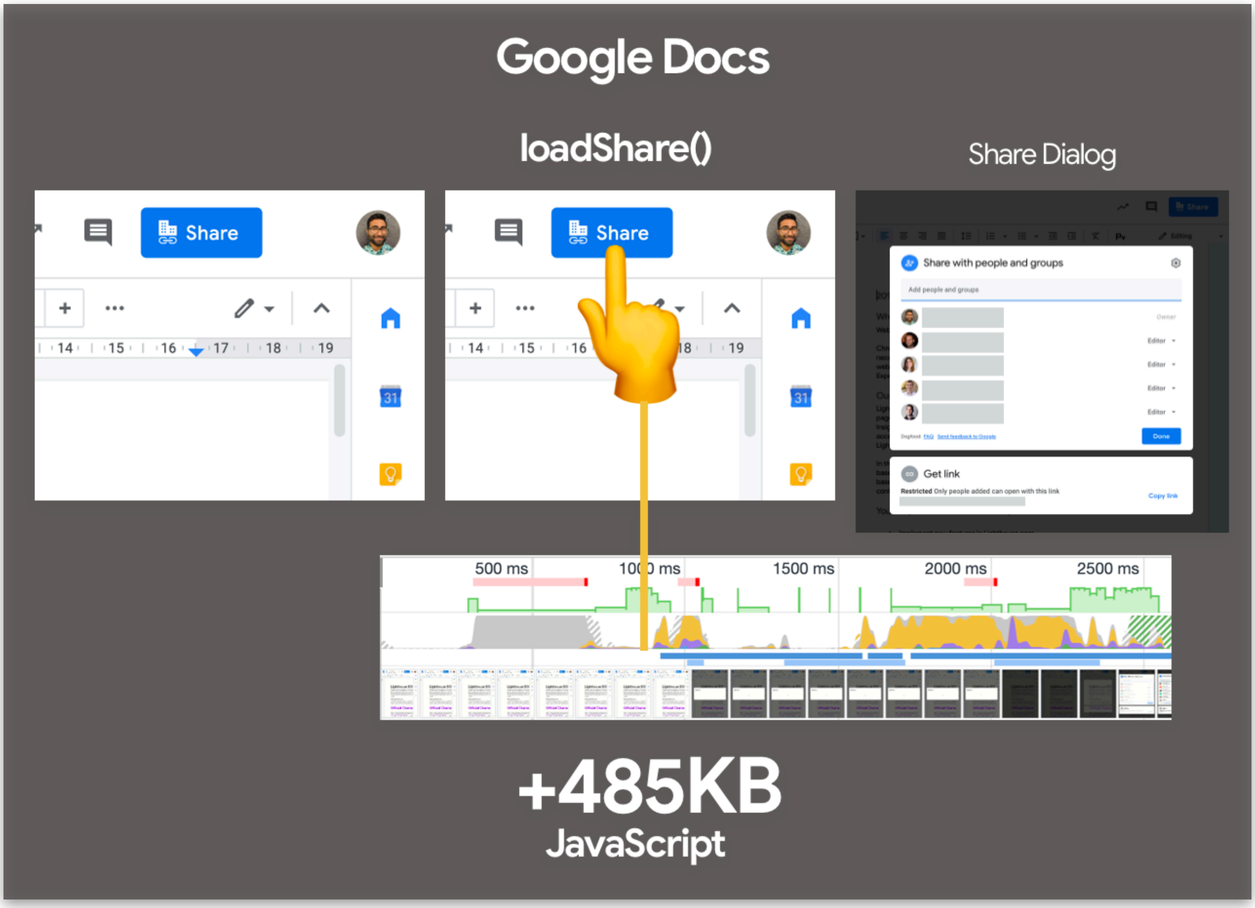
- When the user clicks to interact with that component for the first time
- The component scrolls into view
- Deferring load of that component until the browser is idle (via requestIdleCallback).

The different ways to load resources are, at a high-level:

- **Eager:** load resource right away (the normal way of loading scripts)
- **Lazy (Route-based):** load when a user navigates to a route or component
- **Lazy (On interaction):** load when the user clicks UI (e.g Show Chat)
- **Lazy (In viewport):** load when the user scrolls towards the component
- **Prefetch:** load prior to needed, but after critical resources are loaded
- **Preload:** eagerly, with a greater level of urgency

Import on interaction for first-party code should only be done if you're unable to prefetch resources prior to interaction. The pattern is however very relevant for third-party code, where you generally want to defer it if non-critical to a later point in time. This can be achieved in many ways (defer until interaction, until the browser is idle or using other heuristics).

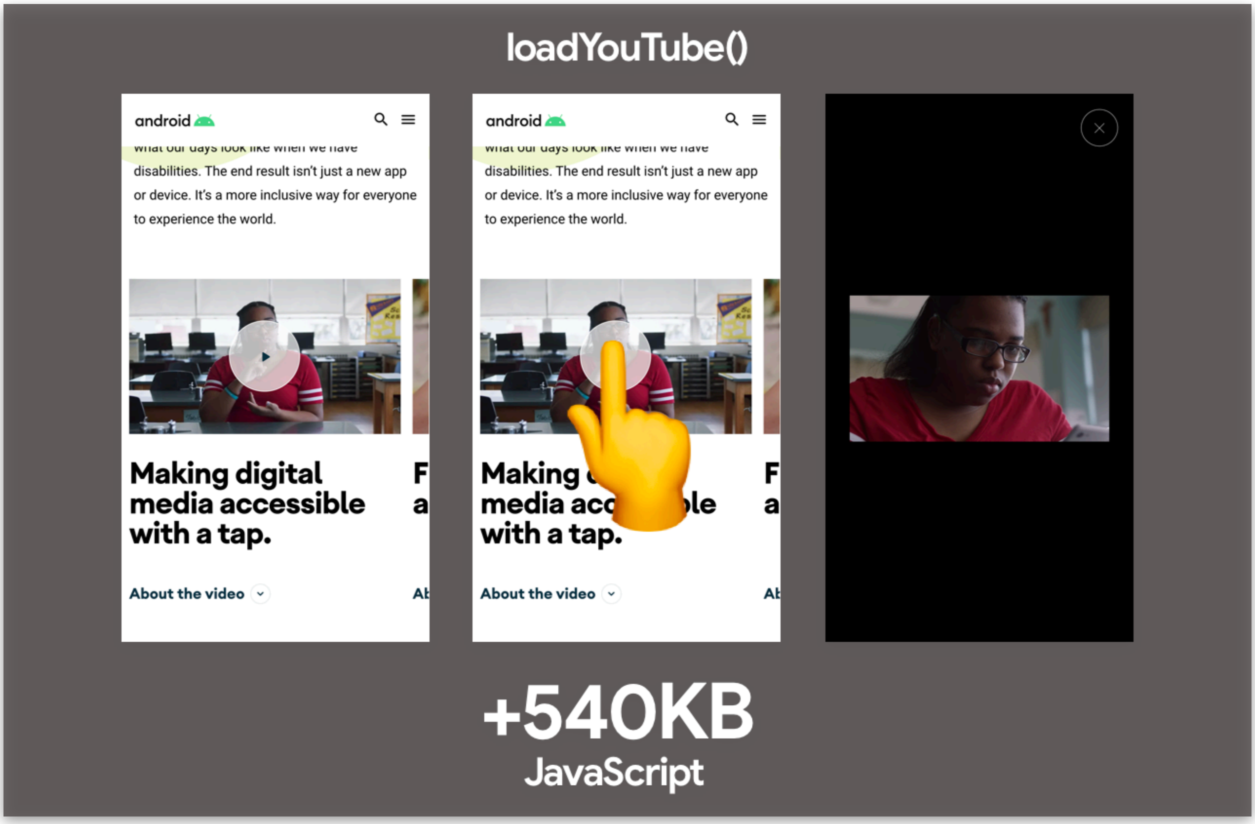
Lazily importing feature code on interaction is a pattern used in many contexts we will cover in this post. One place you may have used it before is Google Docs, where they save loading 500KB of script for the share feature by deferring its load until user-interaction.



Another place where import-on-interaction can be a good fit is loading third-party widgets.

"Fake" loading third-party UI with a facade

You might be importing a third-party script and have less control over what it renders or when it loads code. One option for implementing load-on-interaction is straight-forward: use a facade. A facade is a simple "preview" or "placeholder" for a more costly component where you simulate the basic experience, such as with an image or screenshot. It's terminology we've been using for this idea on the Lighthouse team.

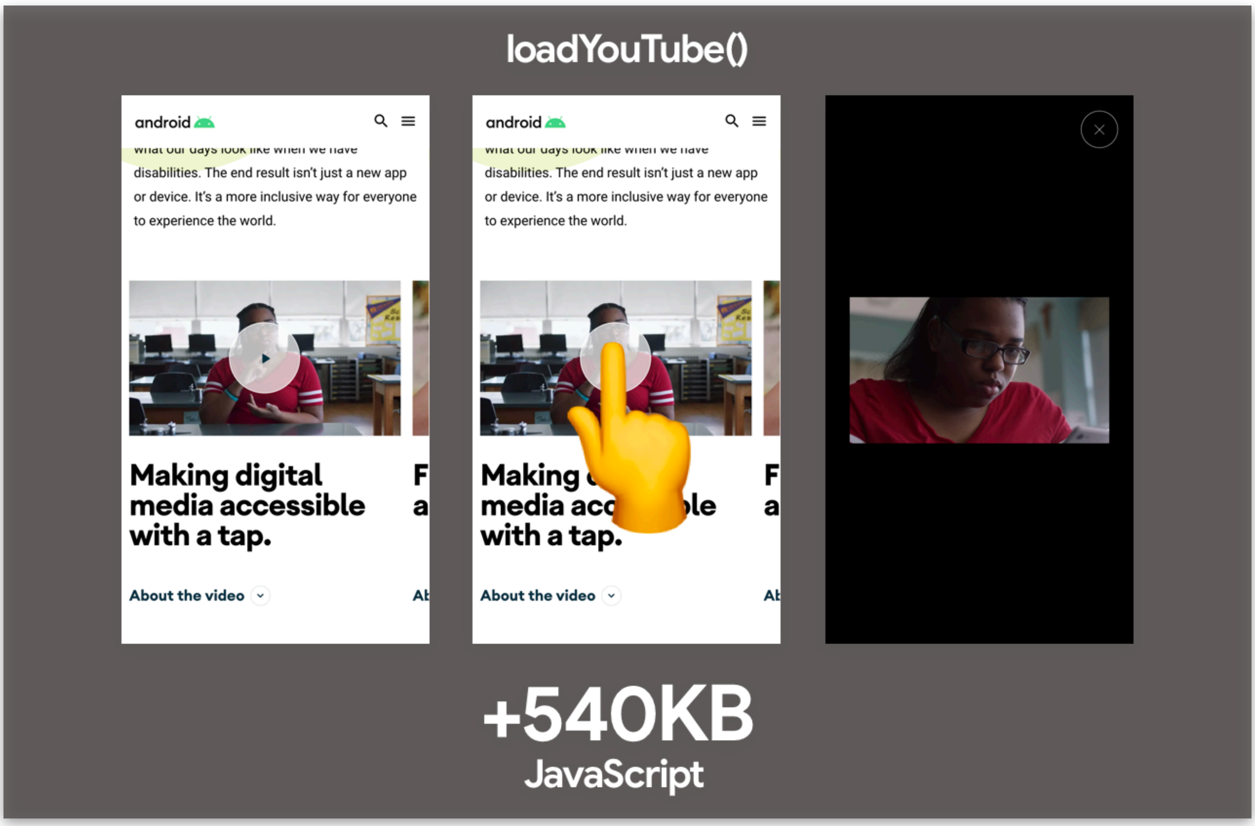


When a user clicks on the "preview" (the facade), the code for the resource is loaded. This limits users needing to pay the experience cost for a feature if they're not going to use it. Similarly, facades can preconnect to necessary resources on hover.

Third-party resources are often added to pages without full consideration for how they fit into the overall loading of a site. Synchronously-loaded third-party scripts block the browser parser and can delay hydration. If possible, 3P script should be loaded with async/defer (or other approaches) to ensure 1P scripts aren't starved of network bandwidth. Unless they are critical, they can be a good candidate for shifting to deferred late-loading using patterns like import-on-interaction.

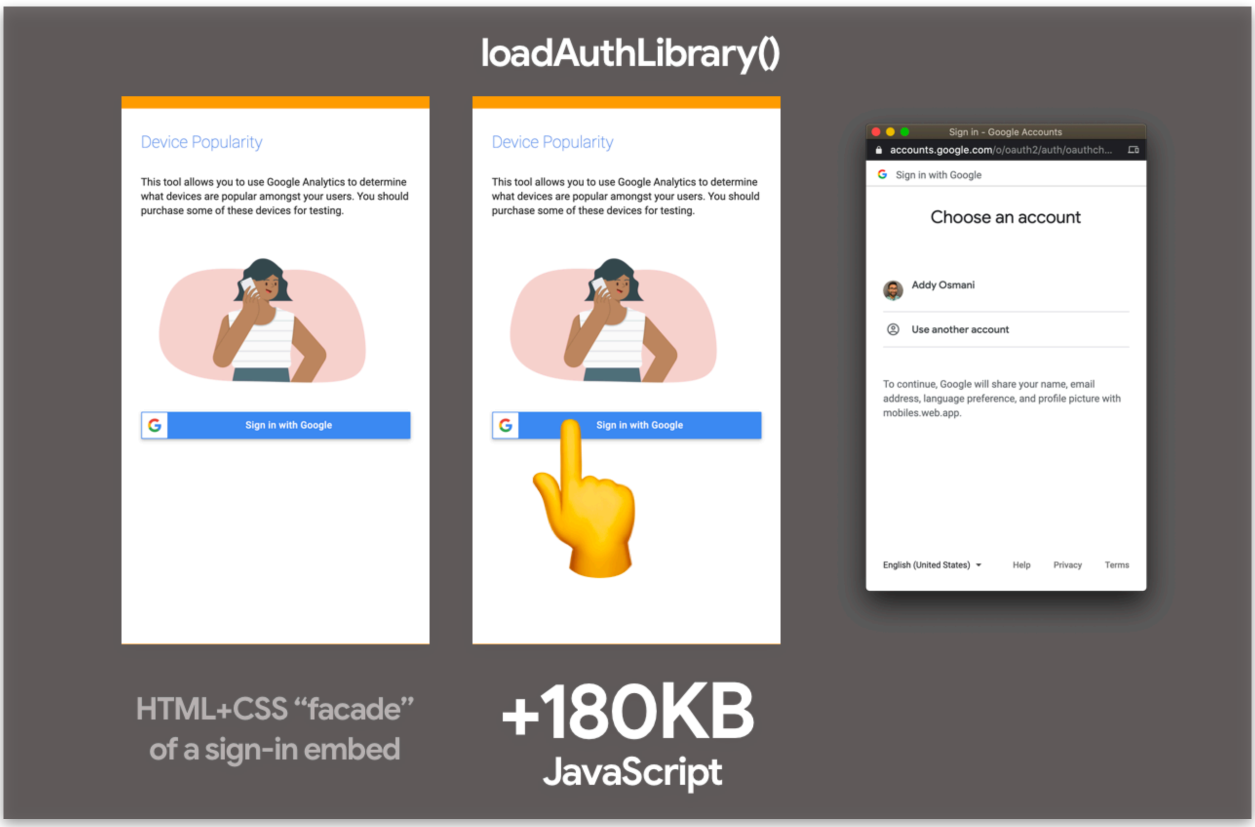
Video Player Embeds

A good example of a "facade" is the YouTube Lite Embed by Paul Irish. This provides a Custom Element which takes a YouTube Video ID and presents a minimal thumbnail and play button. Clicking the element dynamically loads the full YouTube embed code, meaning users who never click play don’t pay the cost of fetching and processing it.



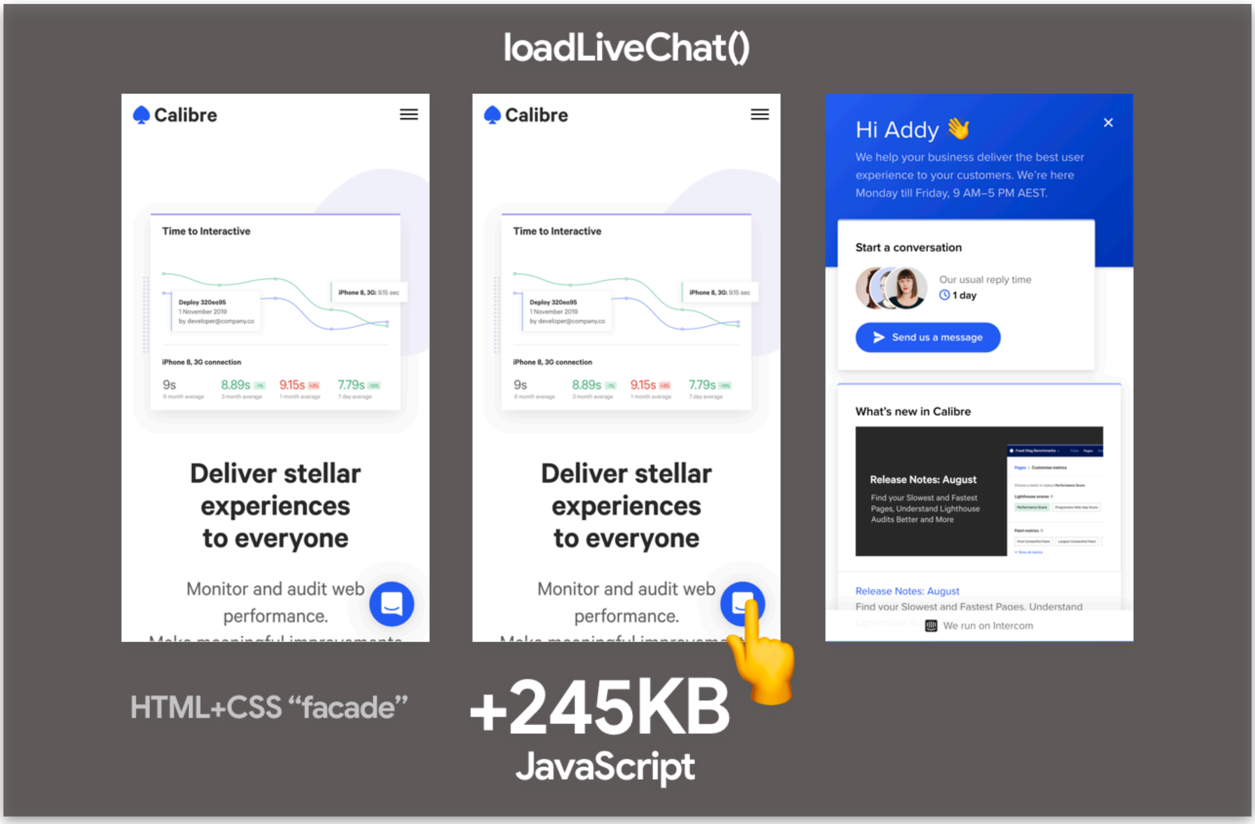
Authentication

Apps may need to support authentication with a service via a client-side JavaScript SDK. These can occasionally be large with heavy JS execution costs and one might rather not eagerly load them up front if a user isn't going to login. Instead, dynamically import authentication libraries when a user clicks on a "Login" button, keeping the main thread more free during initial load.

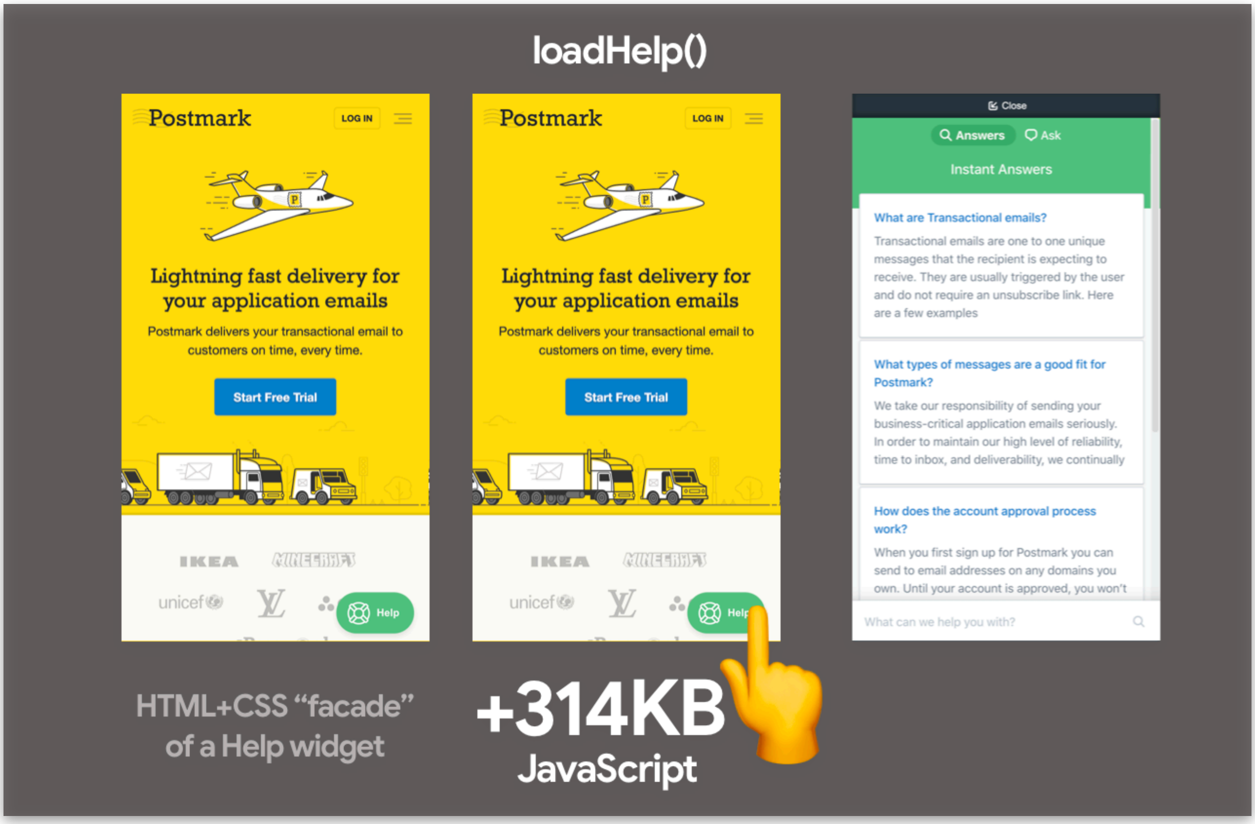


Chat Widgets

Calibre app improved performance of their Intercom-based live chat by 30% through usage of a similar facade approach. They implemented a "fake" fast loading live chat button using just CSS and HTML, which when clicked would load their Intercom bundles.



Postmark noted that their Help chat widget was always eagerly loaded, even though it was only occasionally used by customers. The widget would pull in 314KB of script, more than their whole home page. To improve user-experience, they replaced the widget with a fake replica using HTML and CSS, loading the real-thing on click. This change reduced Time to Interactive from 7.7s to 3.7s.



Vanilla JavaScript

In JavaScript, dynamic import() enables lazy-loading modules and returns a promise and can be quite powerful when applied correctly. Below is an example where dynamic import is used in a button event listener to import the lodash.sortby module and then use it.

```
const btn = document.querySelector('button');

btn.addEventListener('click', e => {
  e.preventDefault();
  import('lodash.sortby')
    .then(module => module.default)
    .then(sortInput()) // use the imported dependency
    .catch(err => { console.log(err) });
});
```

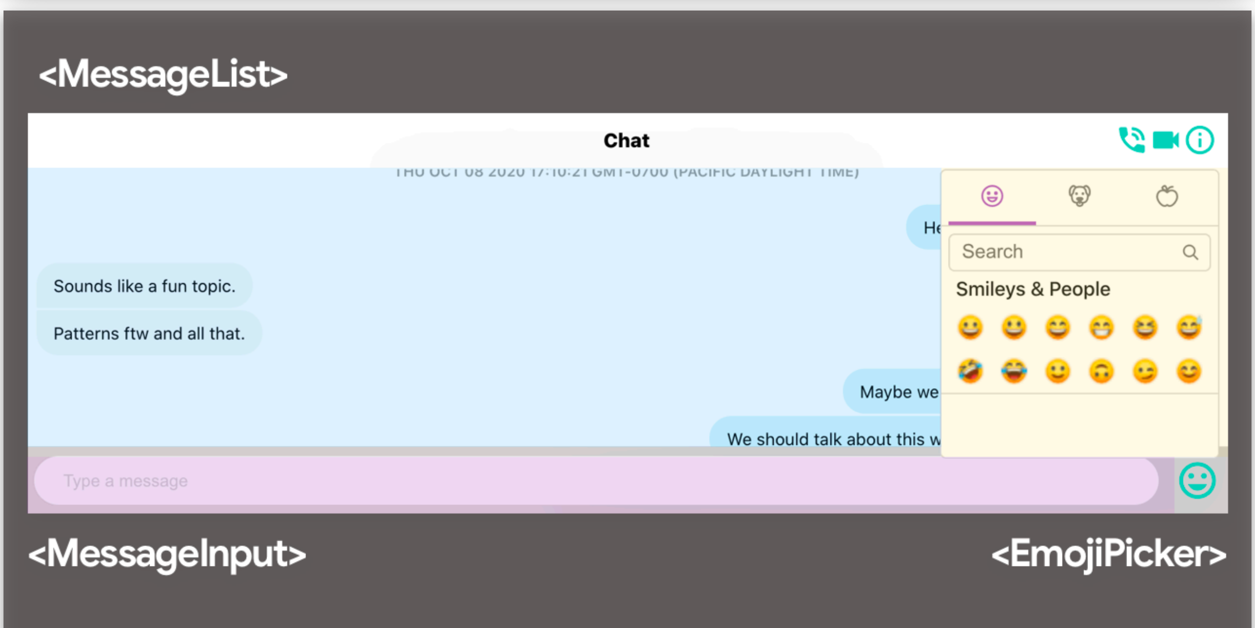
Prior to dynamic import or for use-cases it doesn’t fit as well, dynamically injecting scripts into the page using a Promise-based script loader was also an option.

```
const loginBtn = document.querySelector('#login');

loginBtn.addEventListener('click', () => {
  const loader = new scriptLoader();
  loader.load([
      '//apis.google.com/js/client:platform.js?onload=showLoginScreen'
  ]).then(({length}) => {
      console.log(`${length} scripts loaded!`);
  });
});
```

React

Let's imagine we have a Chat application which has a `MessageList`, `MessageInput` and an `EmojiPicker` component (powered by `emoji-mart`, which is 98KB minified and gzipped). It can be common to eagerly load all of these components on initial page-load.

```
import MessageList from './MessageList';
import MessageInput from './MessageInput';
import EmojiPicker from './EmojiPicker';

const Channel = () => {
  ...
  return (
    <div>
      <MessageList />
      <MessageInput />
      {emojiPickerOpen && <EmojiPicker />}
    </div>
  );
};
```



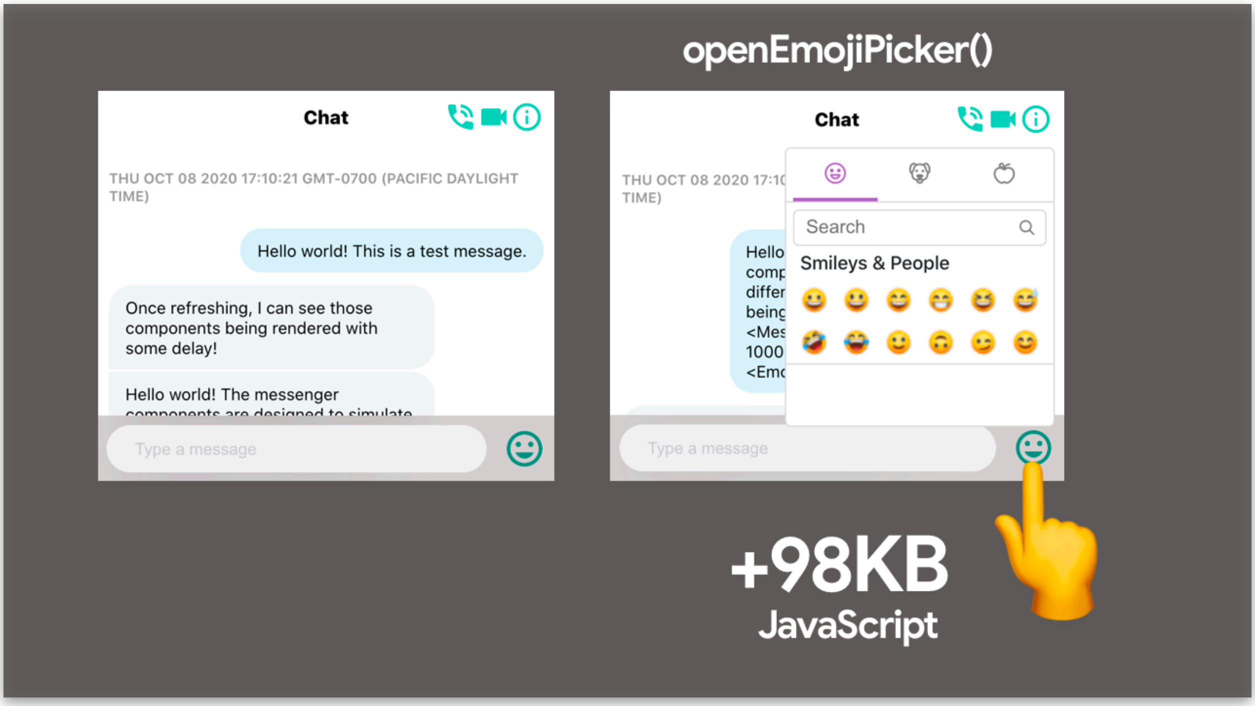
Breaking the loading of this work up is relatively straight-forward with code-splitting. The `React.lazy` method makes it easy to code-split a React application on a component level using dynamic imports.

The `React.lazy` function provides a built-in way to separate components in an application into separate chunks of JavaScript with very little legwork. You can then take care of loading states when you couple it with the `Suspense` component.

```
import React, { lazy, Suspense } from 'react';
import MessageList from './MessageList';
import MessageInput from './MessageInput';

const EmojiPicker = lazy(
  () => import('./EmojiPicker')
);

const Channel = () => {
  ...
  return (
    <div>
      <MessageList />
      <MessageInput />
      {emojiPickerOpen && (
        <Suspense fallback={<div>Loading...</div>}>
          <EmojiPicker />
        </Suspense>
      )}
    </div>
  );
};
```

We can extend this idea to only import code for the `EmojiPicker` component when the Emoji icon is clicked in a `MessageInput`, rather than eagerly when the application initially loads:

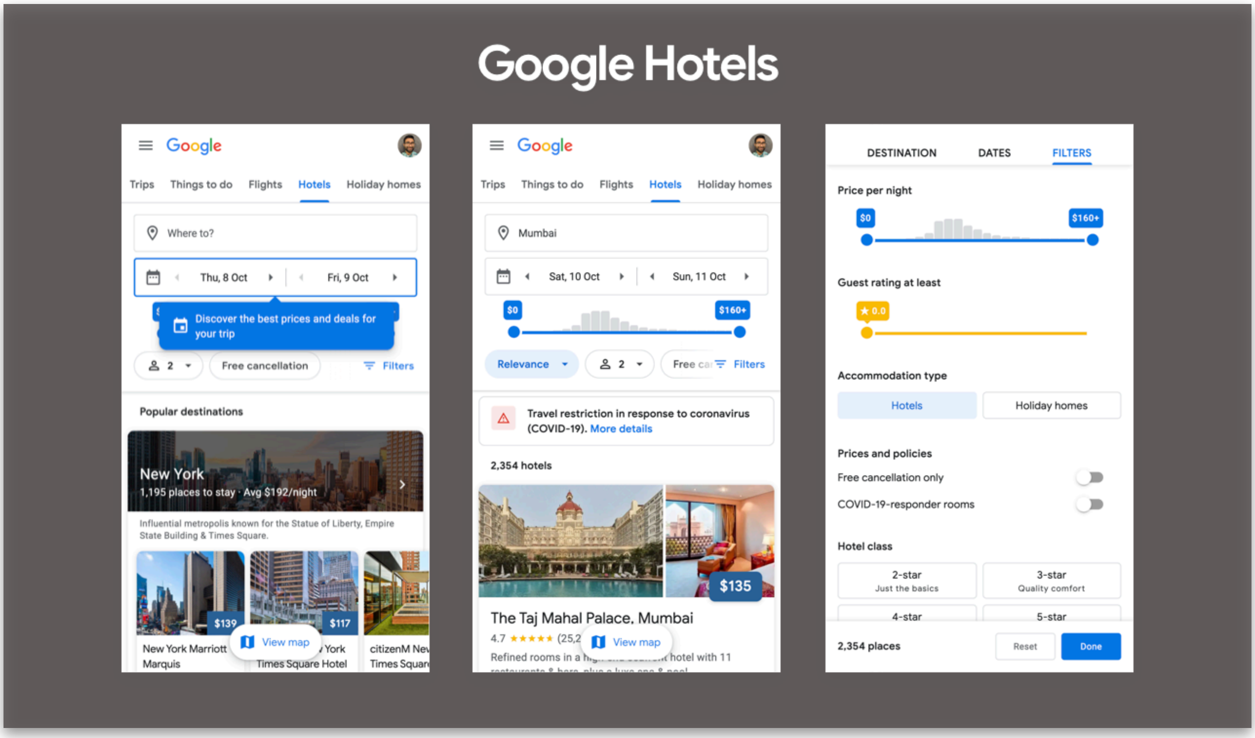
```
import React, { useState, createElement } from 'react';
import MessageList from './MessageList';
import MessageInput from './MessageInput';
import ErrorBoundary from './ErrorBoundary';

const Channel = () => {
  const [emojiPickerEl, setEmojiPickerEl] = useState(null);

  const openEmojiPicker = () => {
    import(/* webpackChunkName: "emoji-picker" */ './EmojiPicker')
      .then(module => module.default)
      .then(emojiPicker => {
        setEmojiPickerEl(createElement(emojiPicker));
      });
  };

  const closeEmojiPickerHandler = () => {
    setEmojiPickerEl(null);
  };

  return (
    <ErrorBoundary>
      <div>
        <MessageList />
        <MessageInput onClick={openEmojiPicker} />
        {emojiPickerEl}
      </div>
    </ErrorBoundary>
  );
};
```



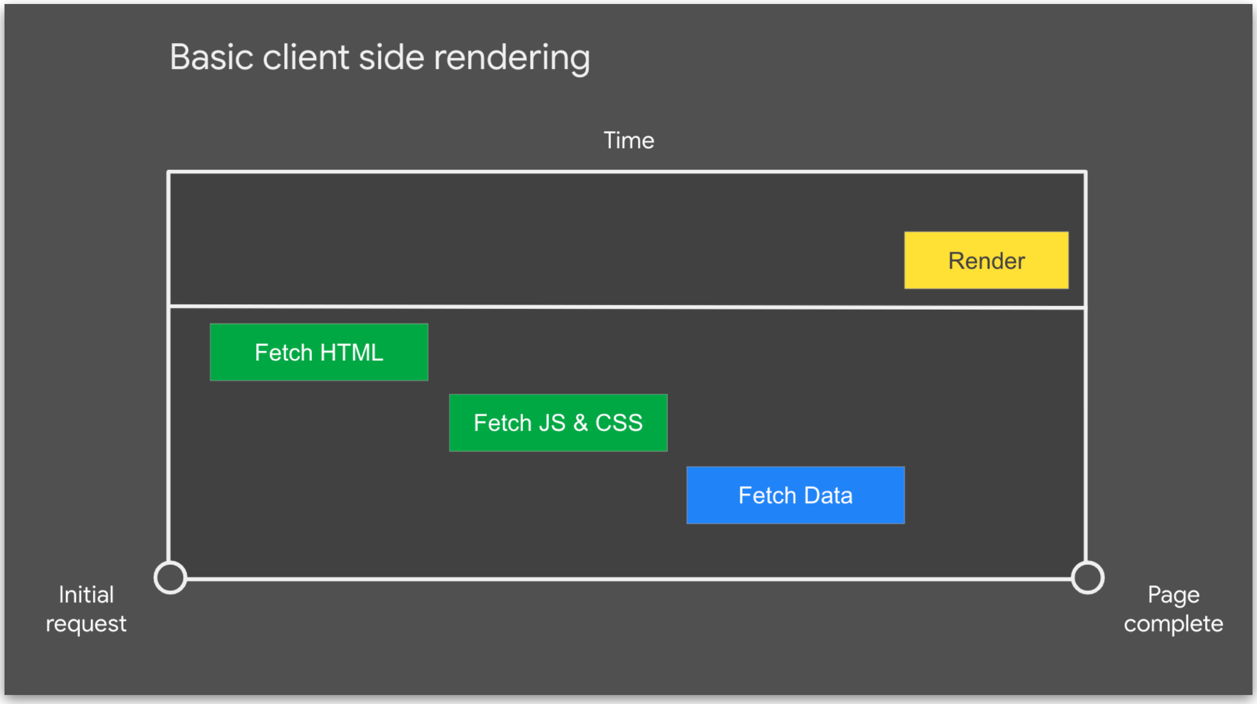
Import-on-interaction for first-party code as part of progressive loading

Loading code on interaction also happens to be a key part of how Google handles progressive loading in large applications like Flights and Photos. To illustrate this, let's take a look at an example previously presented by Shubhie Panicker.

Imagine a user is planning a trip to Mumbai, India and they visit Google Hotels to look at prices. All of the resources needed for this interaction could be loaded eagerly upfront, but if a user hasn't selected any destination, the HTML/CSS/JS required for the map would be unnecessary.



In the simplest download scenario, imagine Google Hotels is using naive client-side rendering (CSR). All the code would be downloaded and processed upfront: HTML, followed by JS, CSS and then fetching the data, only to render once we have everything. However, this leaves the user waiting a long time with nothing displayed on-screen. A big chunk of the JavaScript and CSS may be unnecessary.



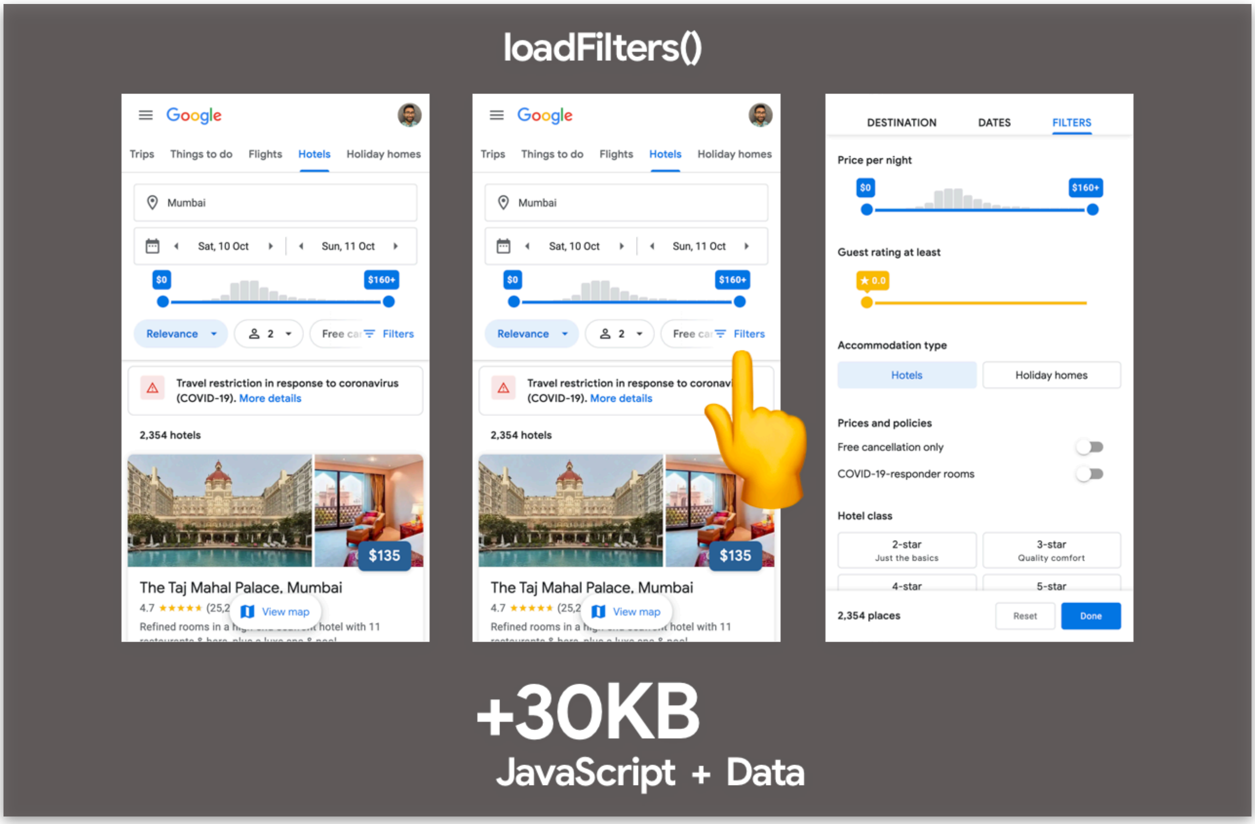
Next, imagine this experience moved to server-side rendering (SSR). We would allow the user to get a visually complete page sooner, which is great, however it wouldn't be interactive until the data is fetched from the server and the client framework completes hydration.

SSR can be an improvement, but the user may have an uncanny valley experience where the page looks ready, but they are unable to tap on anything. Sometimes this is referred to as rage clicks as users tend to click over and over again repeatedly in frustration.

Returning to the Google Hotels search example, if we zoom in to the UI a little we can see that when a user clicks on "more filters" to find exactly the right hotel, the code required for that component is downloaded.

Only very minimal code is downloaded initially and beyond this, user interaction dictates which code is sent down when.

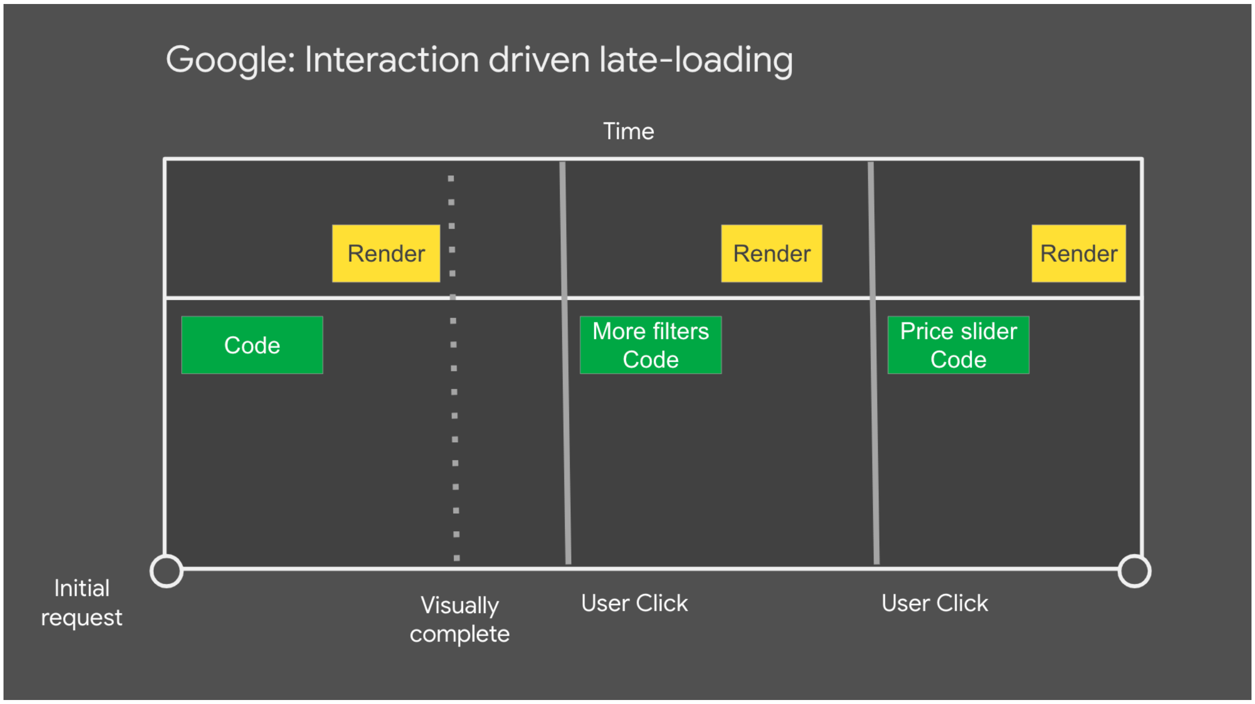
Let's take a closer look at this loading scenario.



There are a number of important aspects to interaction-driven late-loading:

First, we download the minimal code initially so the page is visually complete quickly.

Next, as the user starts interacting with the page we use those interactions to determine which other code to load. For example loading the code for the "more filters" component. This means code for many features on the page are never sent down to the browser, as the user didn't need to use them.



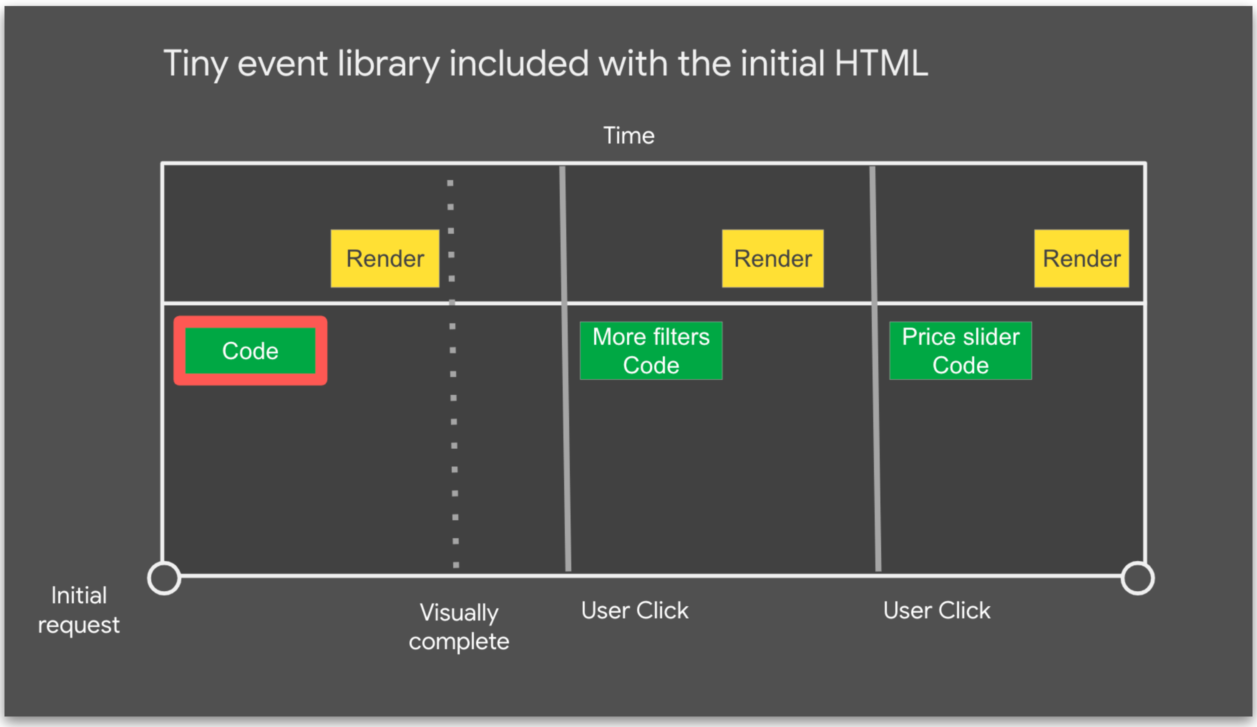
How do we avoid losing early clicks?

In the framework stack used by these Google teams, we can track clicks early because the first chunk of HTML includes a small event library (JSAction) which tracks all clicks before the framework is bootstrapped. The events are used for two things:

- Triggering download of component code based on user interactions
- Replaying user interactions when the framework finishes bootstrapping

Other potential heuristics one could use include, loading component code:

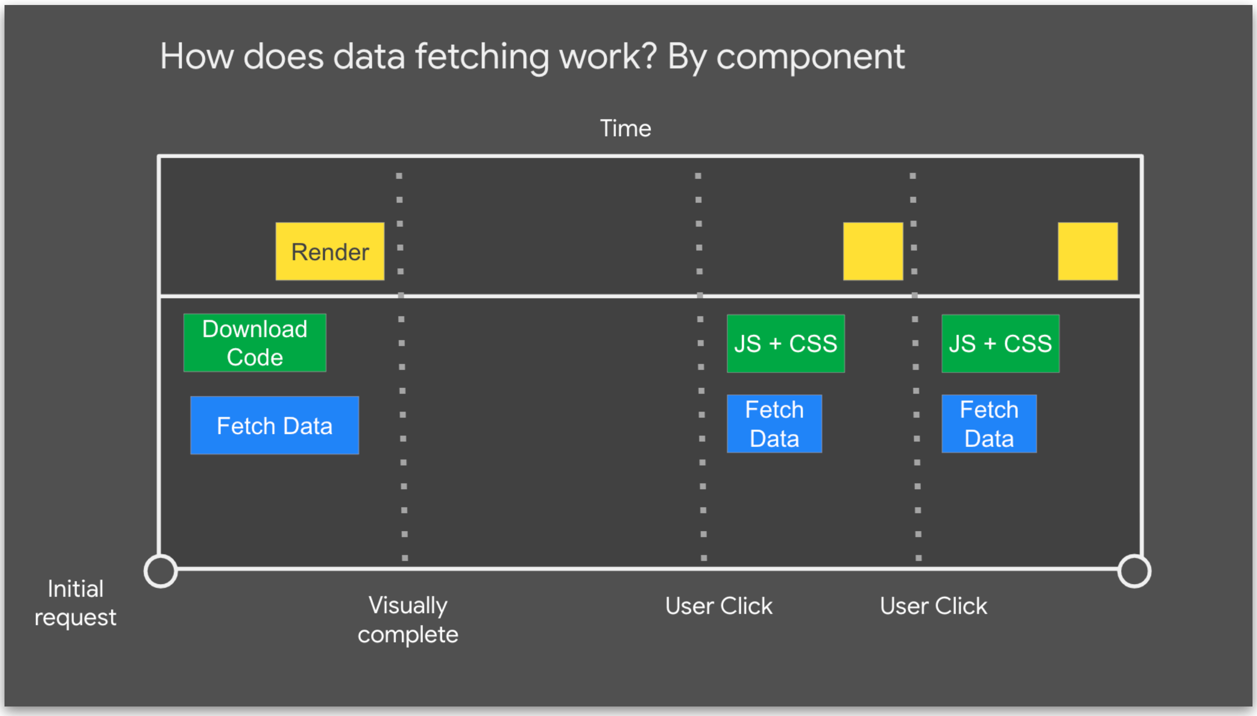
- A period after idle time
- On user mouse hover over the relevant UI/button/call to action
- Based on a sliding scale of eagerness based on browser signals (e.g network speed, Data Saver mode etc).



What about data?

The initial data which is used to render the page is included in the initial page's SSR HTML and streamed. Data that is late loaded is downloaded based on user interactions as we know what component it goes with.

This completes the import-on-interaction picture with data-fetching working similar to how CSS and JS function. As the component is aware of what code and data it needs, all of its resources are never more than a request away.



This functions as we create a graph of components and their dependencies during build time. The web application is able to refer to this graph at any point and quickly fetch the resources (code and data) needed for any component. It also means we code-split based on the component rather than the route.

For a walkthrough of the above example, see Elevating the Web Platform with the JavaScript Community.

Trade-offs

Shifting costly work closer to user-interaction can optimize how quickly pages initially load, however the technique is not without trade-offs.

What happens if it takes a long time to load a script after the user clicks?

In the Google Hotels example, small granular chunks minimize the chance a user is going to wait long for code and data to fetch and execute. In some of the other cases, a large dependency may indeed introduce this concern on slower networks.

One way to reduce the chance of this happening is to better break-up the loading of, or prefetch these resources after critical content in the page is done loading. I'd encourage measuring the impact of this to determine how much it's a real application in your apps.

What about lack of functionality before user interaction?

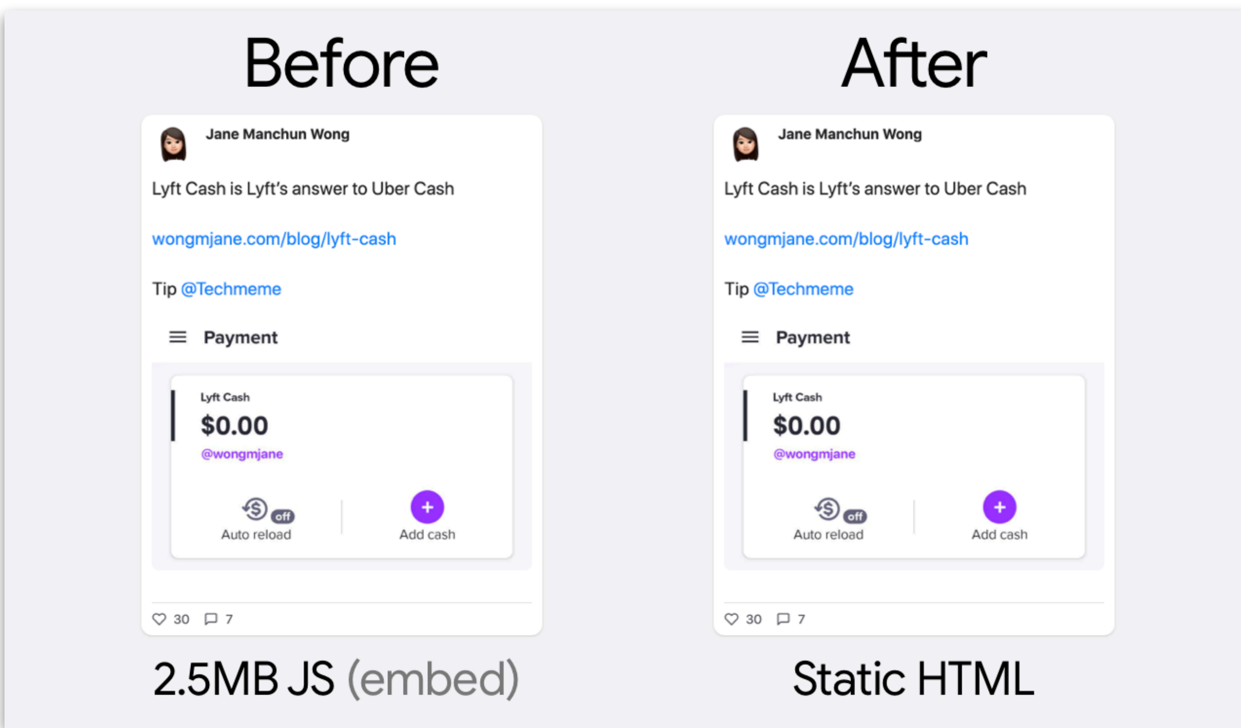
Another trade-off with facades is a lack of functionality prior to user interaction. An embedded video player for example will not be able to autoplay media. If such functionality is key, you might consider alternative approaches to loading the resources, such as lazy-loading these third-party iframes on the user scrolling them into view rather than deferring load until interaction.

Replacing interactive embeds with a static variant

We have discussed the import-on-interaction pattern and progressive loading, but what about going entirely static for the embeds use-case?.

The final rendered content from an embed may be needed immediately in some cases e.g a social media post that is visible in the initial viewport. This can also introduce its own challenges when the embed brings in 2-3MB of JavaScript. Because the embed content is needed right away, lazy-loading and facades may be less applicable.

If optimizing for performance, it's possible to entirely replace an embed with a static variant that looks similar, linking out to a more interactive version (e.g the original social media post). At build time, the data for the embed can be pulled in and transformed into a static HTML version.



This is the approach *@wongmjane* leveraged on their blog for one type of social media embed, improving both page load performance and removing the Cumulative Layout Shift experienced due to the embed code enhancing the fallback text, causing layout shifts.

While static replacements can be good for performance, they do often require doing something custom so keep this in mind when evaluating your options.

Conclusions

First-party JavaScript often impacts the interaction readiness of modern pages on the web, but it can often get delayed on the network behind non-critical JS from either first or third-party sources that keep the main thread busy.

In general, avoid synchronous third-party scripts in the document head and aim to load non-blocking third-party scripts after first-party JS has finished loading. Patterns like import-on-interaction give us a way to defer the loading of non-critical resources to a point when a user is much more likely to need the UI they power.

With special thanks to Shubhie Panicker, Connor Clark, Patrick Hulce, Anton Karlovskiy and Adam Raine for their input.

Route Based Splitting

Dynamically load components based on the current route

We can request resources that are only needed for specific routes, by adding route-based splitting. By combining React Suspense with libraries such as `react-router`, we can dynamically load components based on the current route.

```
import React, { lazy, Suspense } from "react";
import { render } from "react-dom";
import { Switch, Route, BrowserRouter as Router } from "react-router-dom";

const App = lazy(() => import(/* webpackChunkName: "home" */ "./App"));
const Overview = lazy(() =>
  import(/* webpackChunkName: "overview" */ "./Overview")
);
const Settings = lazy(() =>
  import(/* webpackChunkName: "settings" */ "./Settings")
);

render(
  <Router>
    <Suspense fallback={<div>Loading...</div>}>
      <Switch>
        <Route exact path="/">
          <App />
        </Route>
        <Route path="/overview">
          <Overview />
        </Route>
        <Route path="/settings">
          <Settings />
        </Route>
      </Switch>
    </Suspense>
  </Router>,
  document.getElementById("root")
);
```

By lazily loading the components per route, we're only requesting the bundle that contains the code that's necessary for the current route. Since most people are used to the fact that there may be some loading time during a redirect, it's the perfect place to lazily load components!

Bundle Splitting

Split your code into small, reusable pieces

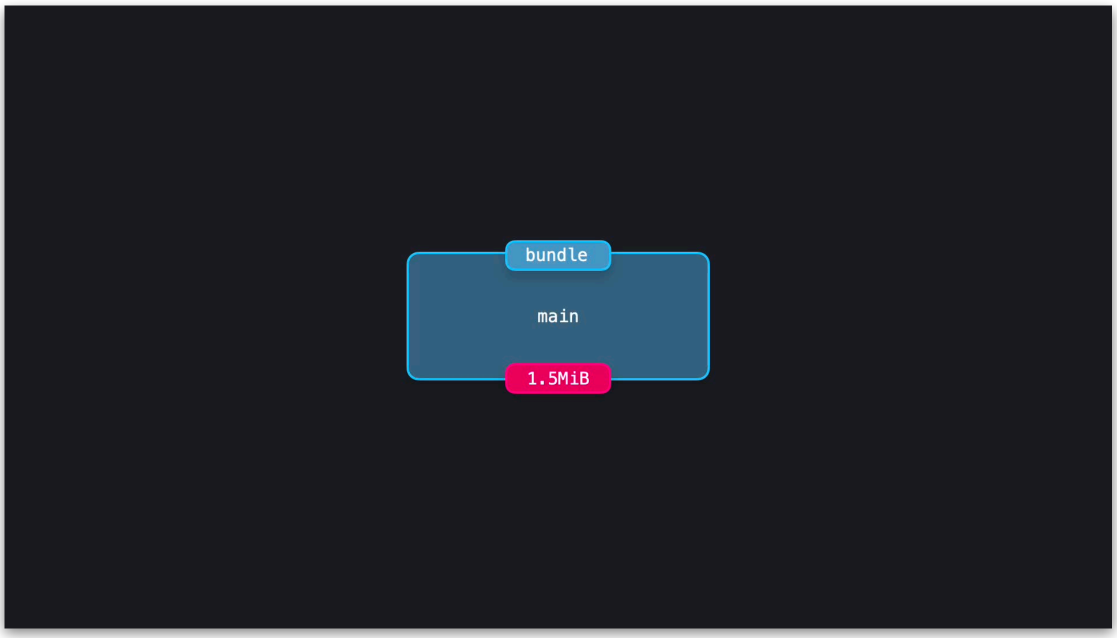
When building a modern web application, bundlers such as Webpack or Rollup take an application's source code, and bundle this together into one or more bundles. When a user visits a website, the bundle is requested and loaded in order to display the data to the user's screen.

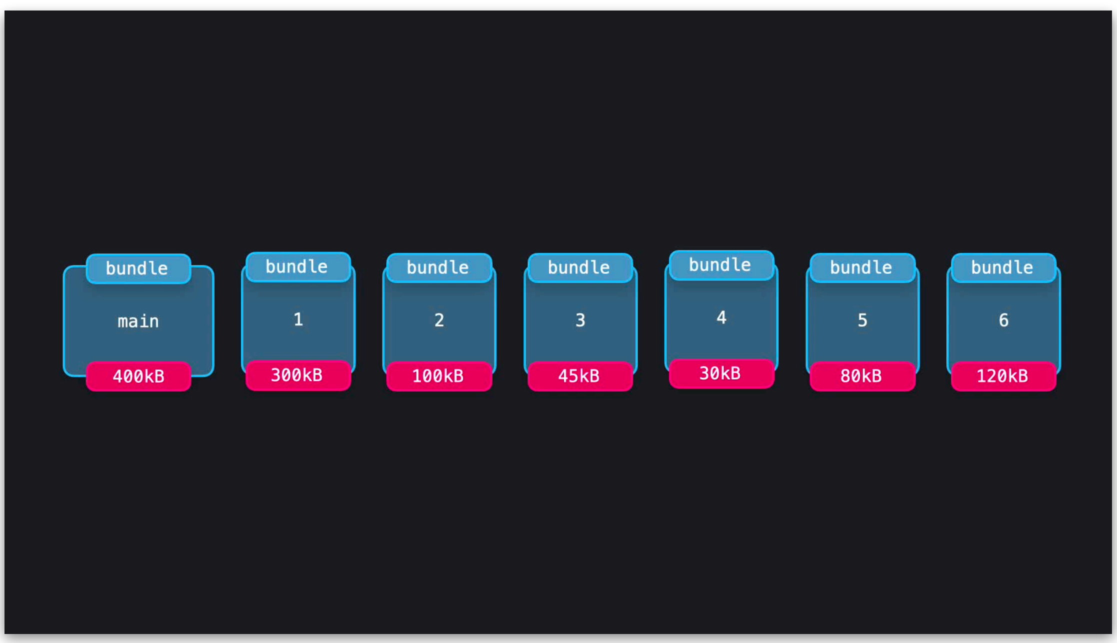
JavaScript engines such as V8 are able to parse and compile data that's been requested by the user as it's being loaded. Although modern browsers have evolved to parse and compile the code as quickly and performant as possible, the developer is still in charge of optimizing two steps in the process: the loading time and execution time of the requested data. We want to make sure we're keeping the execution time as short as possible to prevent blocking the main thread

Even though modern browsers are able to stream the bundle as it arrives, it can still take a significant time before the first pixel is painted on the user's device. The bigger the bundle the longer it can take before the engine reaches the line on which the first rendering call has been made. Until that time, the user has to stare at a blank screen for quite some time, which can be.. highly frustrating!

We want to display data to the user as quickly as possible. A larger bundle leads to an increased amount of loading time, processing time, and execution time. It would be great if we could reduce the size of this bundle, in order to speed things up.

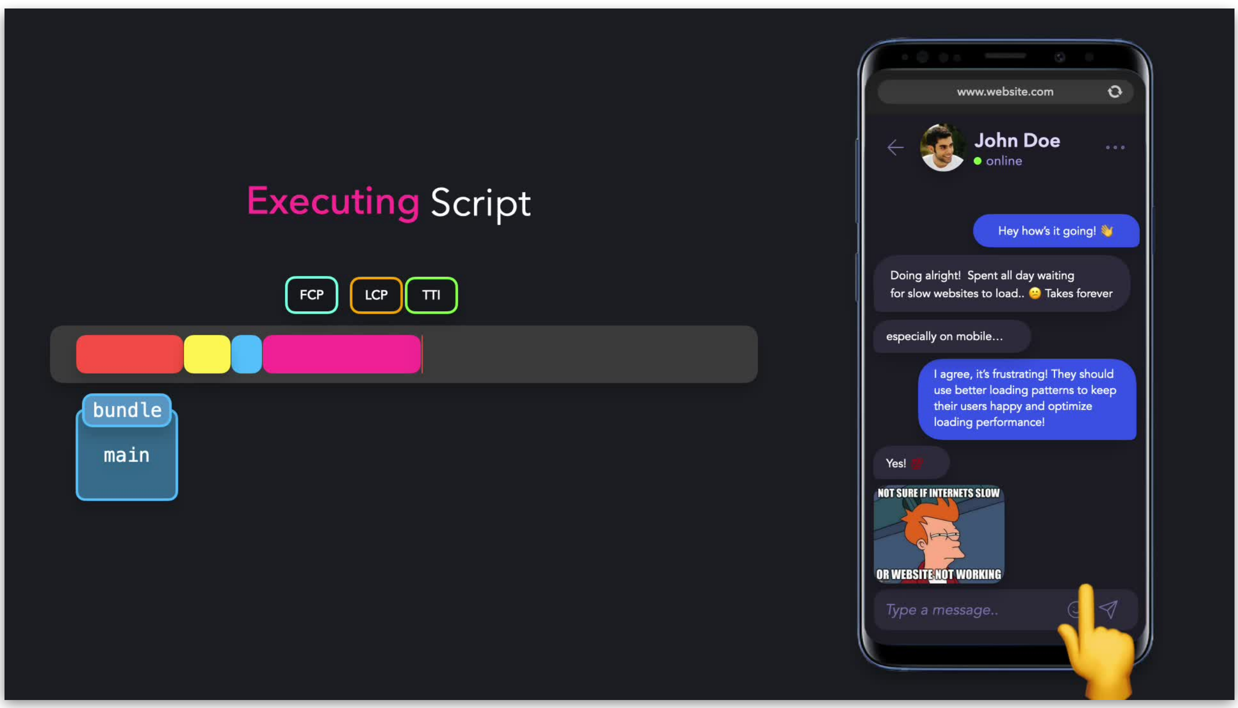
Instead of requesting one giant bundle that contains unnecessary code, we can split the bundle into multiple smaller bundles!

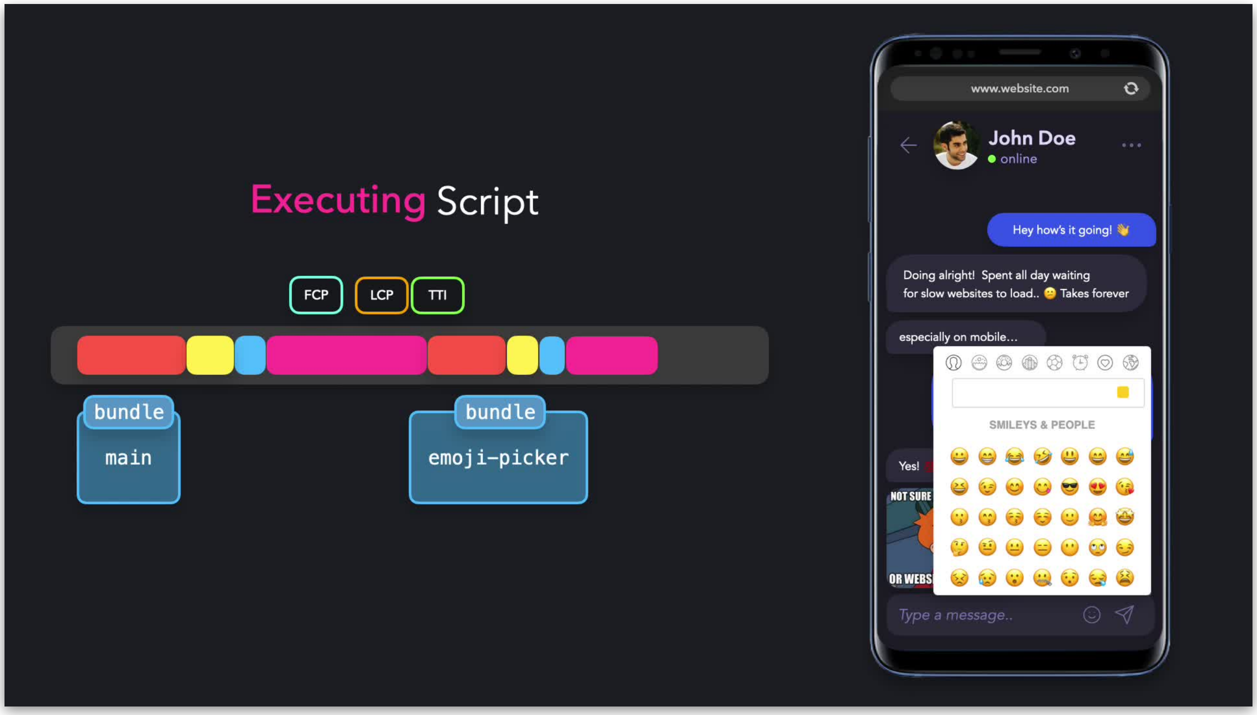




By bundle-splitting the application, we can reduce the time it takes to load, process and execute a bundle! By reducing the loading and execution time, we can reduce the time it takes before the first content has been painted on the user's screen, the First Contentful Paint, and the time it takes before the largest component has been rendered to the screen, the Largest Contentful Paint.

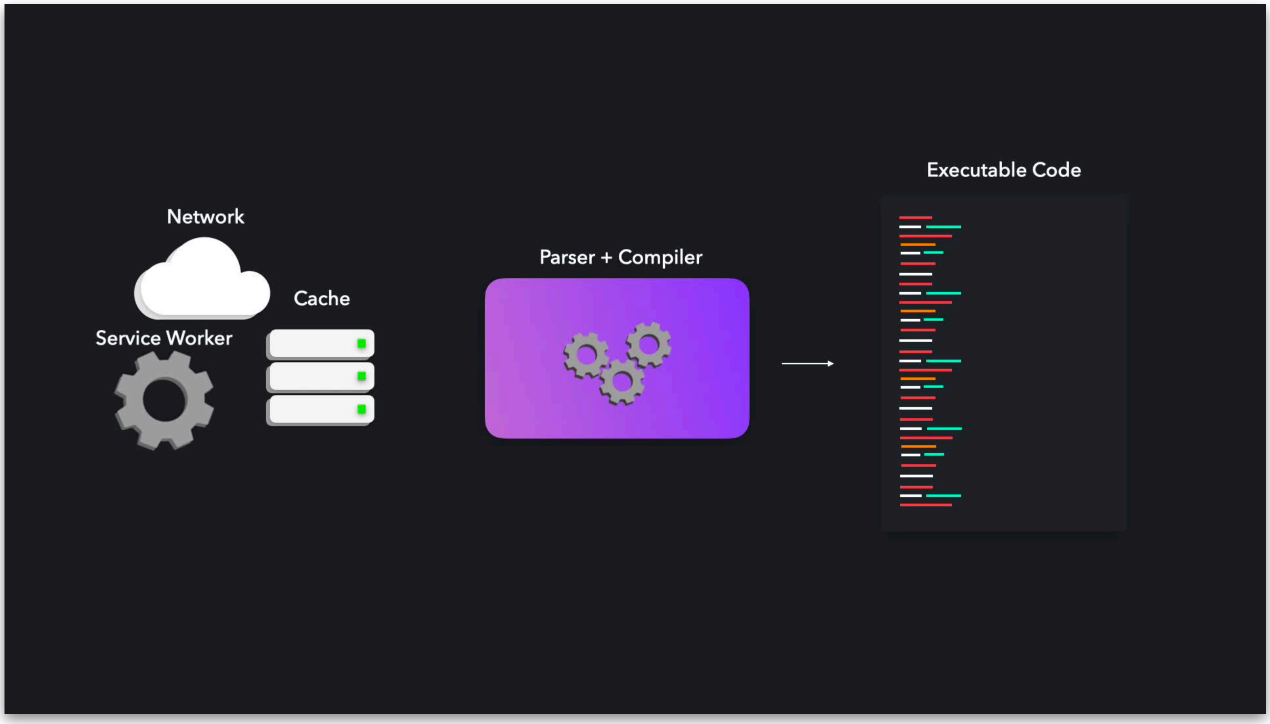
Although being able to see data on our screen is great, we don't just want to see the content. In order to have a fully functioning application, we want users to be able to interact with it as well! The UI only becomes interactive after the bundle has been loaded and executed. The time it takes before all content has been painted to the screen and has been made interactive, is called the Time To Interactive.

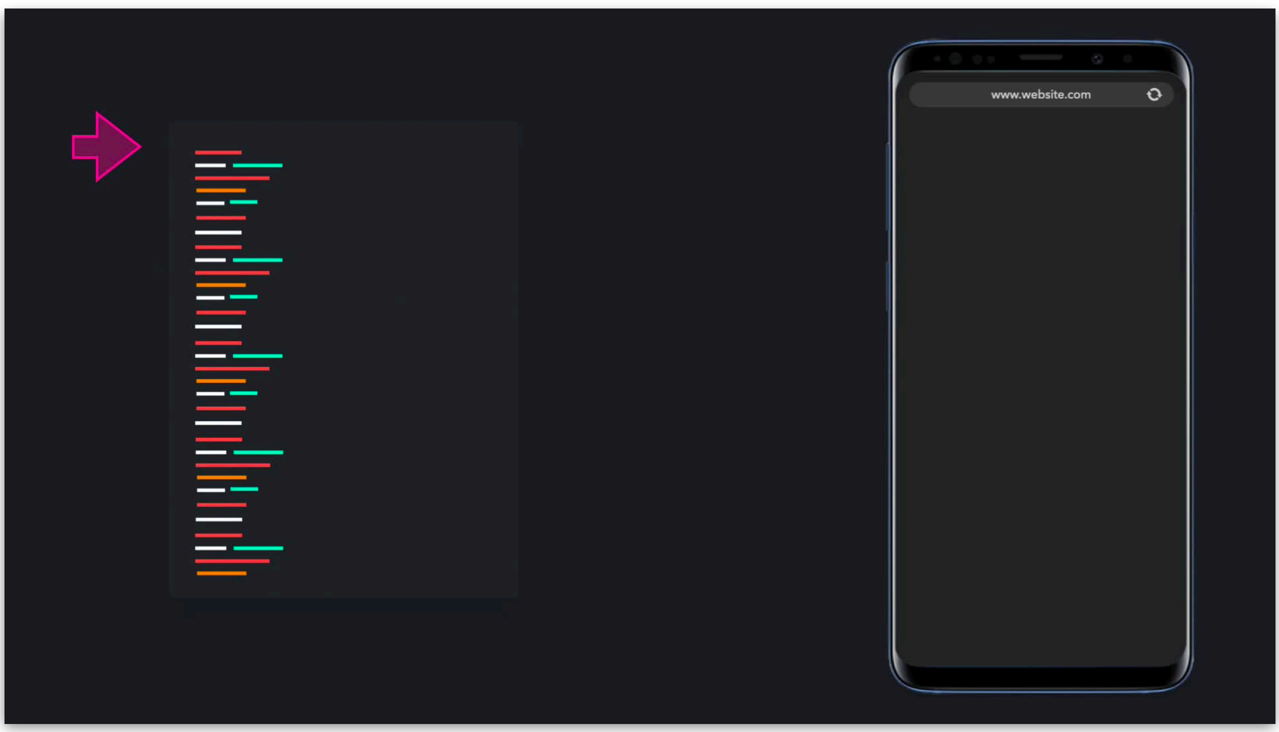


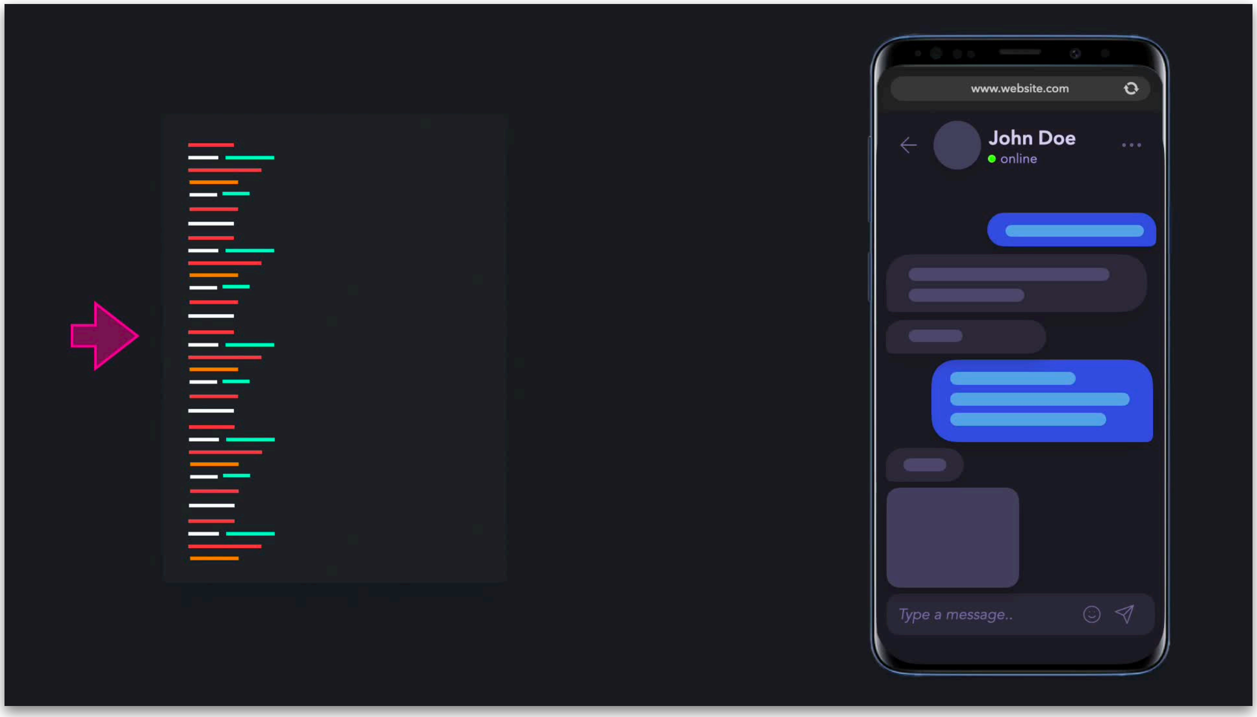


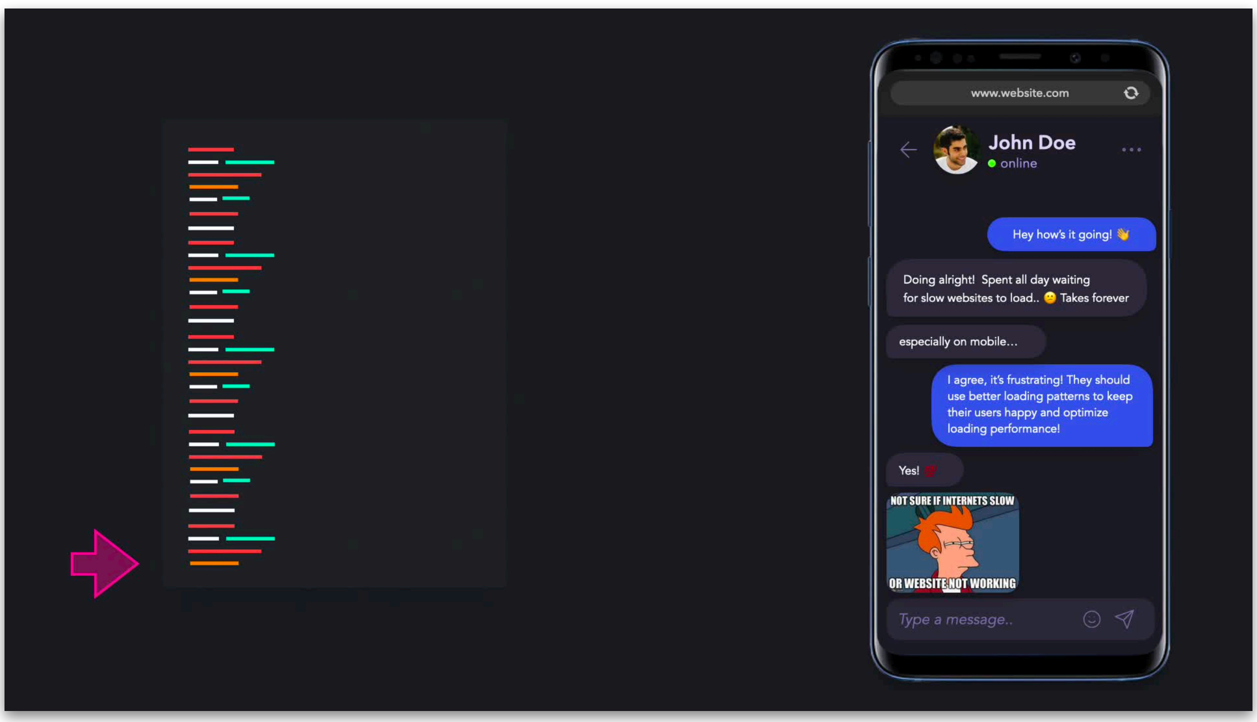
A bigger bundle doesn't necessarily mean a longer execution time. It could happen that we loaded a ton of code that the user won't even use! Maybe some parts of the bundle will only get executed on a certain user interaction, which the user may or may not do!

The engine still has to load, parse and compile code that's not even used on the initial render before the user is able to see anything on their screen. Although the parsing and compilation costs can be practically ignored due to the browser's performant way of handling these two steps, fetching a larger bundle than necessary can hurt the performance of your application. Users on low-end devices or slower networks will see a significant increase in loading time before the bundle has been fetched.

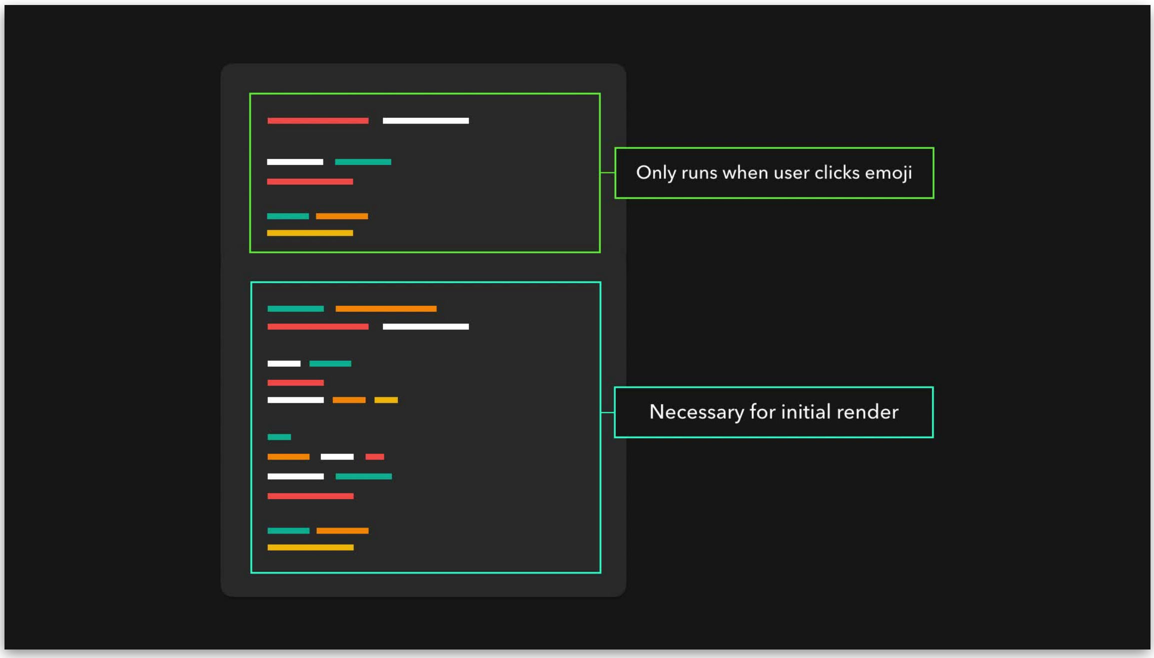

Network
Cache
Service Worker
Parser + Compiler
Executable Code


www.website.com


www.website.com
John Doe
online
Type a message..

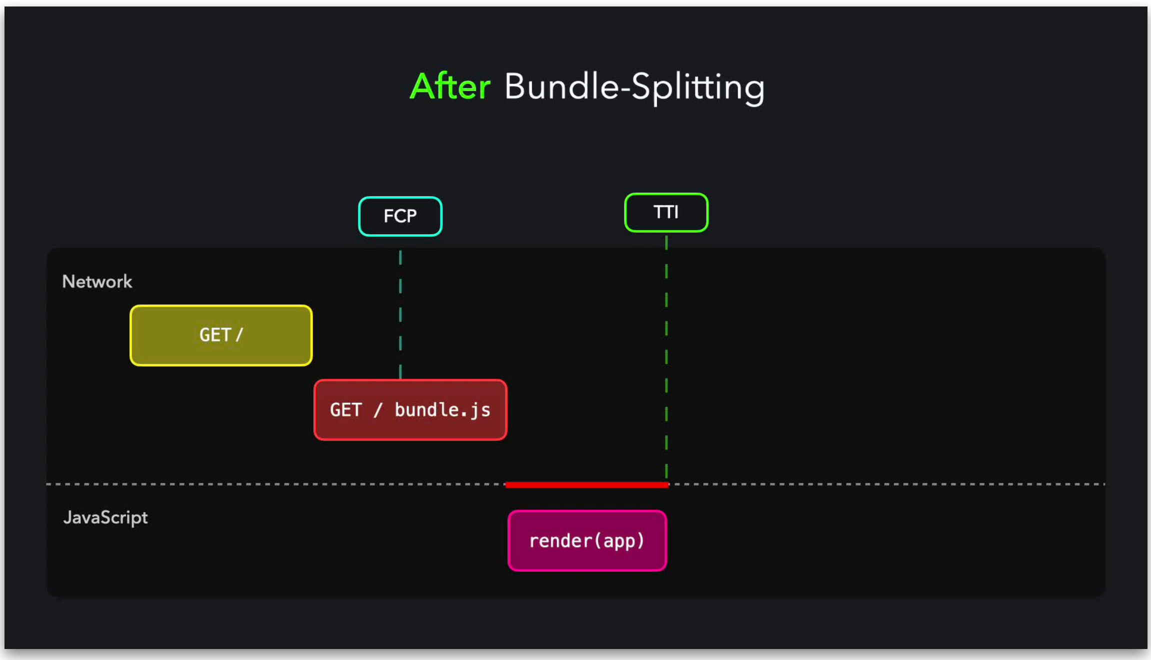

www.website.com
John Doe
online
Hey how's it going!
Doing alright! Spent all day waiting for slow websites to load.. Takes forever
especially on mobile...
I agree, it's frustrating! They should use better loading patterns to keep their users happy and optimize loading performance!
Yes!
NOT SURE IF INTERNETS SLOW
OR WEBSITE NOT WORKING
Type a message..

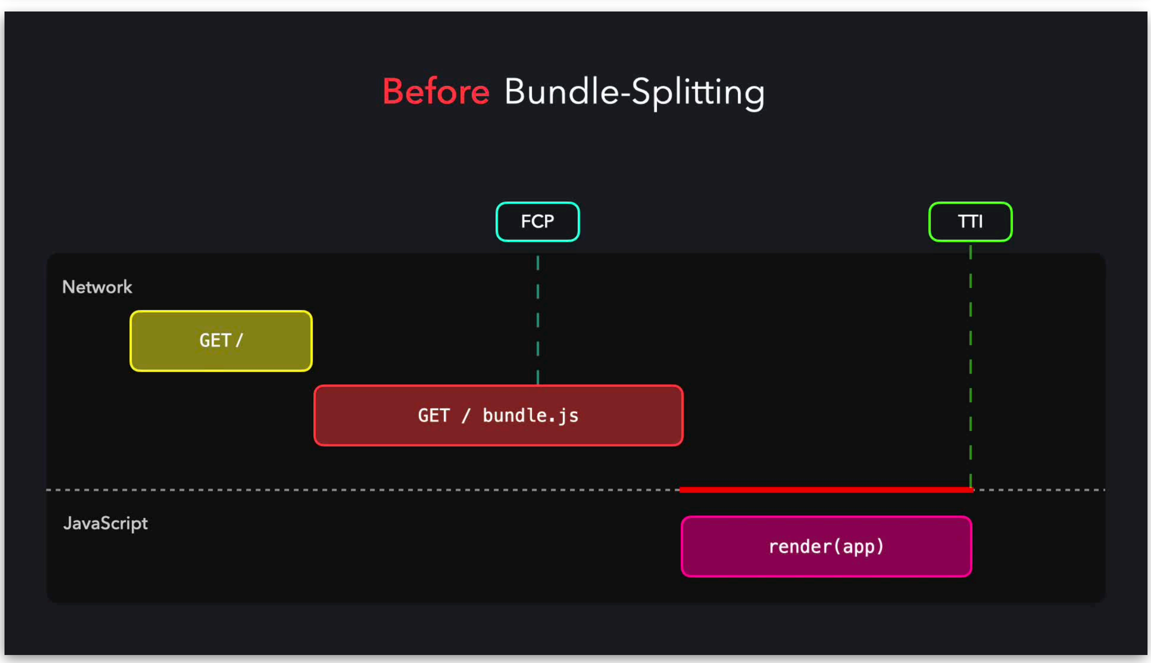
The first part still had to be loaded and processed, even though the engine only used the last part of the file in order to . Instead of intially requesting parts of the code that don't have a high priority in the current navigation, we can separate this code from the code that's needed in order to render the initial page.



By bundle-splitting the large bundle into two smaller bundles, `main.bundle.js` and `emoji-picker.bundle.js`, we reduce the initial loading time by fetching a smaller amount of data.

In this project, we'll cover some methods that allow us to bundle-split our application into multiple smaller bundles, and load the resources in the most efficient and performant ways.





PRPL Pattern

Optimize initial load through precaching, lazy loading, and minimizing roundtrips

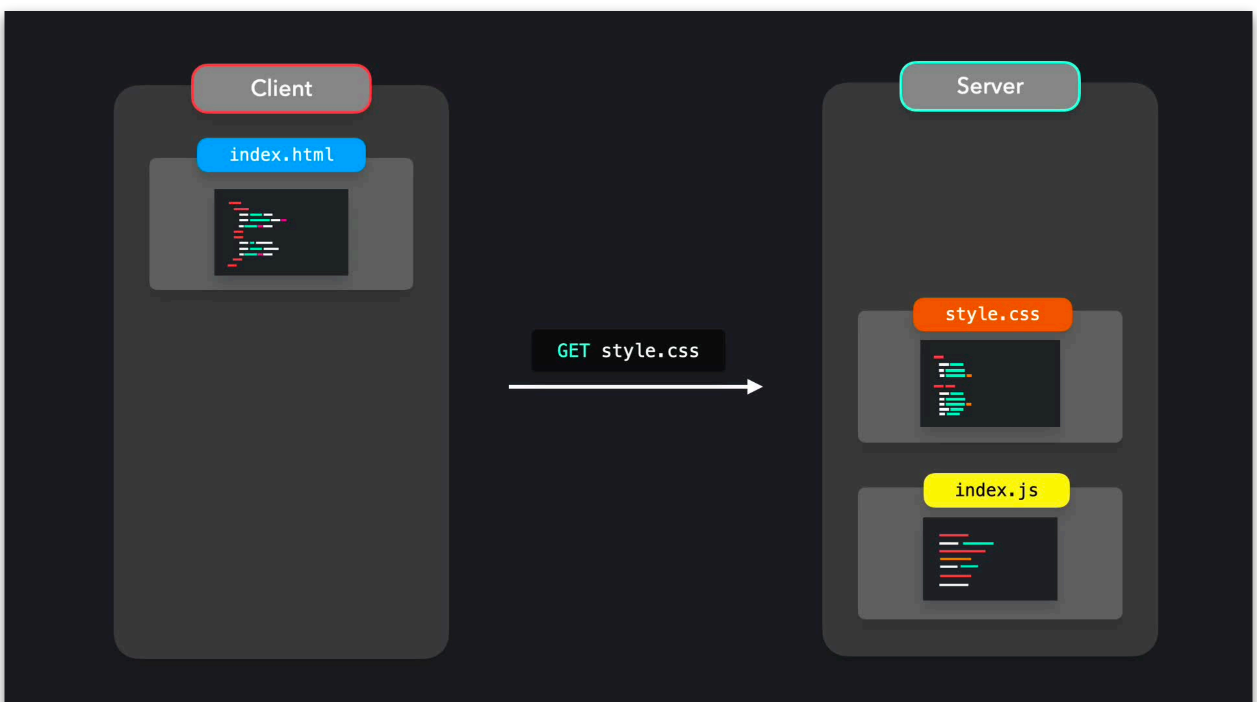
Making our applications globally accessible can be a challenge! We have to make sure the application is performant on low-end devices and in regions with a poor internet connectivity. In order to make sure our application can load as efficiently as possible in difficult conditions, we can use the PRPL pattern.

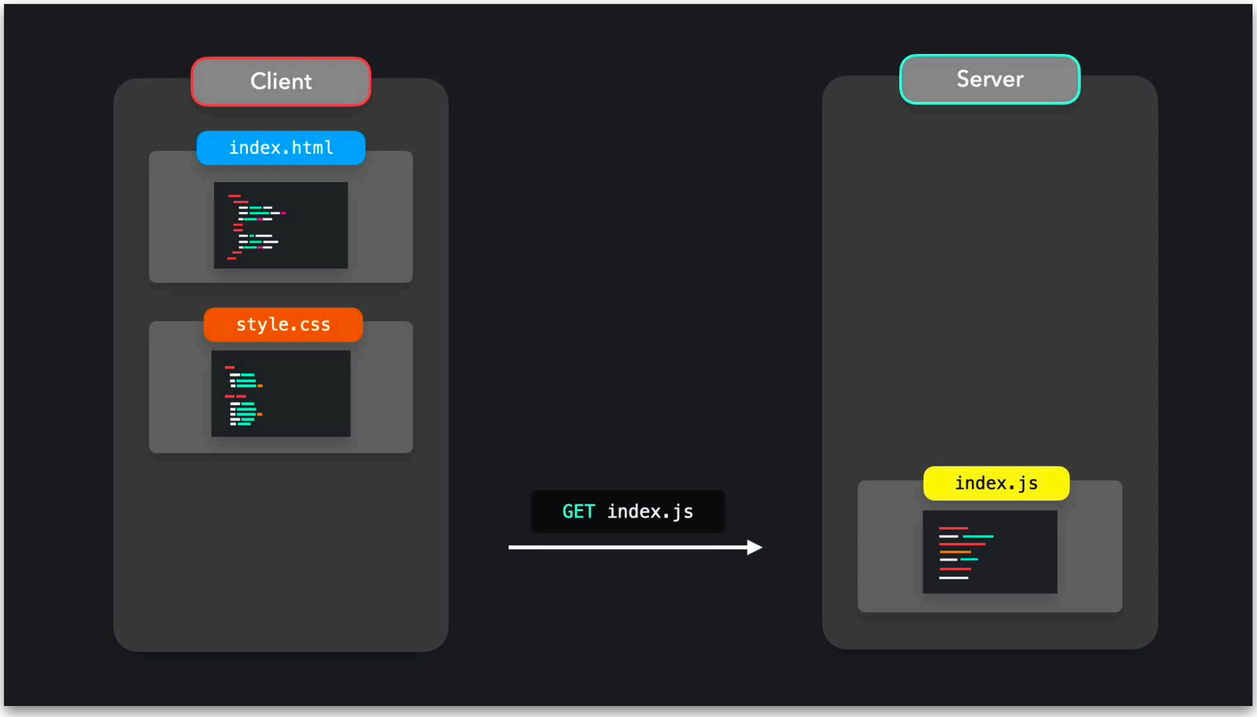
The PRPL pattern focuses on four main performance considerations:

- Pushing critical resources efficiently, which minimizes the amount of roundtrips to the server and reducing the loading time.
- Rendering the initial route soon as possible to improve the user experience
- Pre-caching assets in the background for frequently visited routes to minimize the amount of requests to the server and enable a better offline experience
- Lazily loading routes or assets that aren't requested as frequently

When we want to visit a website, we first have to make a request to the server in order to get those resources. The file that the entrypoint points to gets returned from the server, which is usually our application's initial HTML file!

The browser's HTML parser starts to parse this data as soon as it starts receiving it from the server. If the parser discovers that more resources are needed, such as stylesheets or scripts, another HTTP request is sent to the server in order to get those resources!





Having to repeatedly request the resources isn't optimal, as we're trying to minimize the amount of round trips between the client and the server!

For a long time, we used HTTP/1.1 in order to communicate between the client and the server. Although HTTP/1.1 introduced many improvement compared to HTTP/1.0, such as being able to keep the TCP connection between the client and the server alive before a new HTTP requests gets sent with the keep-alive header, there were still some issues that had to be solved!

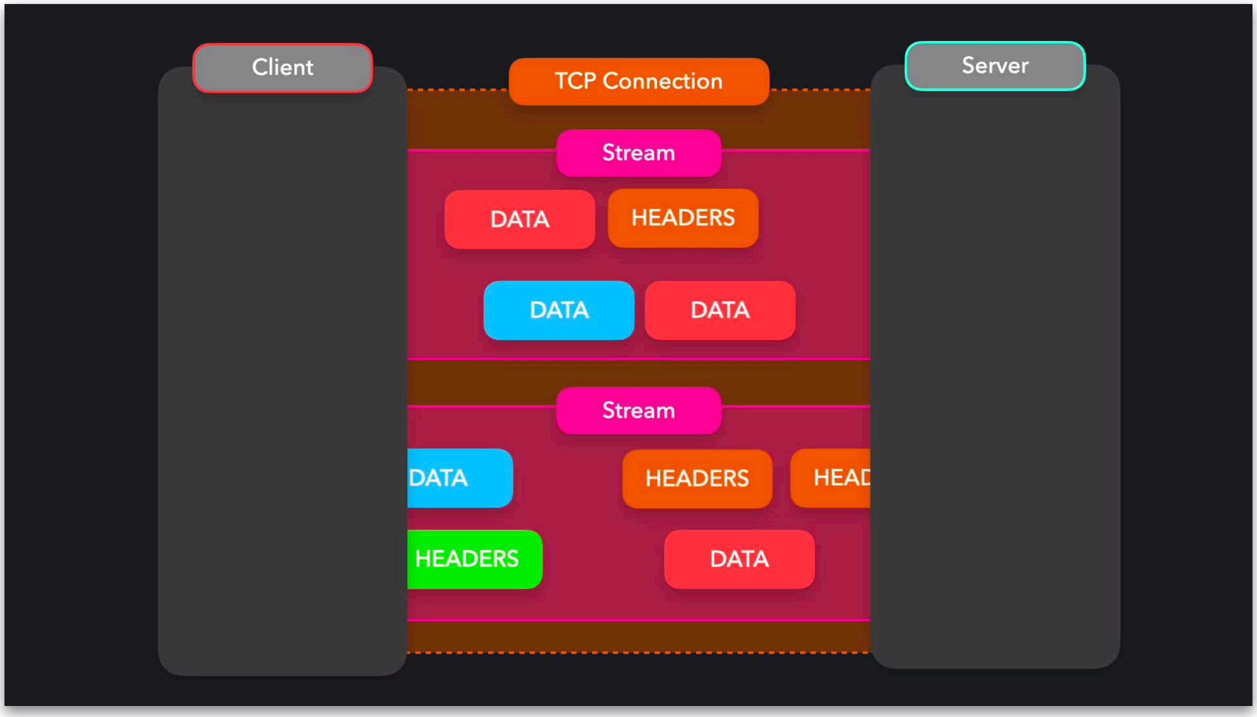
HTTP/2 introduced some significant changes compared to HTTP/1.1, which make it easier for us to optimize the message exchange between the client and the server.

Whereas HTTP/1.1 used a newline delimited plaintext protocol in the requests and responses, HTTP/2 splits the requests and responses up in smaller pieces called frames. An HTTP request that contains headers and a body field gets split into at least two frames: a headers frame, and a data frame!

HTTP/1.1 had a maximum amount of 6 TCP connections between the client and the server. Before a new request can get sent over the same TCP connection, the previous request has to be resolved! If the previous request is taking a long time to resolve, this request is blocking the other requests from being sent. This common issue is called head of line blocking, and can increase the loading time of certain resources!

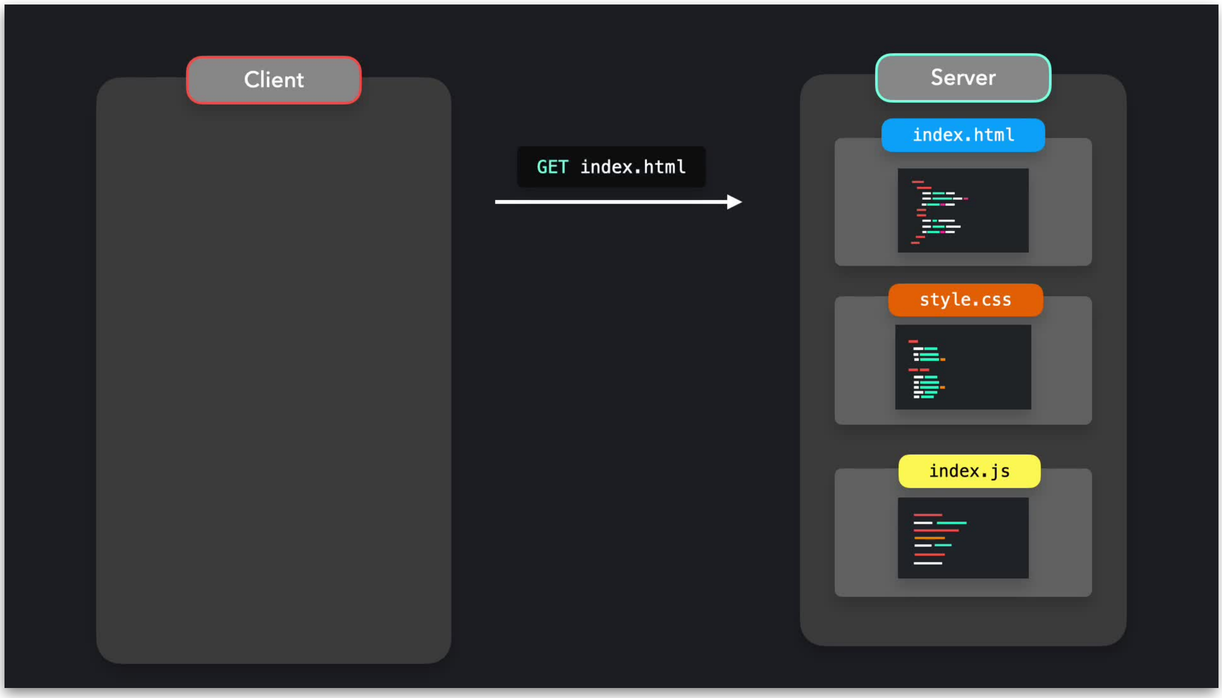
HTTP/2 makes use of bidirectional streams, which makes it possible to have one single TCP connection that includes multiple bidirectional streams, which can carry multiple request and response frames between the client and the server!

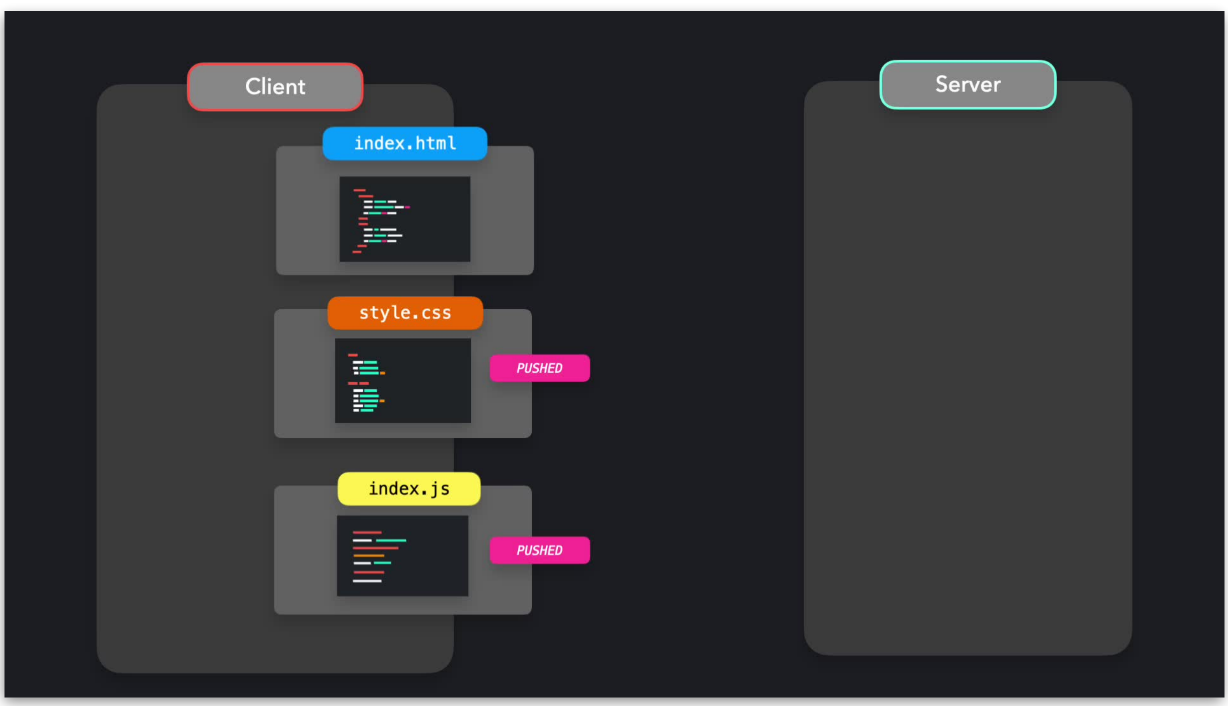
Once the server has received all request frames for that specific request, it reassembles them and generates response frames. These response frames are sent back to the client, which reassembles them. Since the stream is bidirectional, we can send both request and response frames over the same stream.

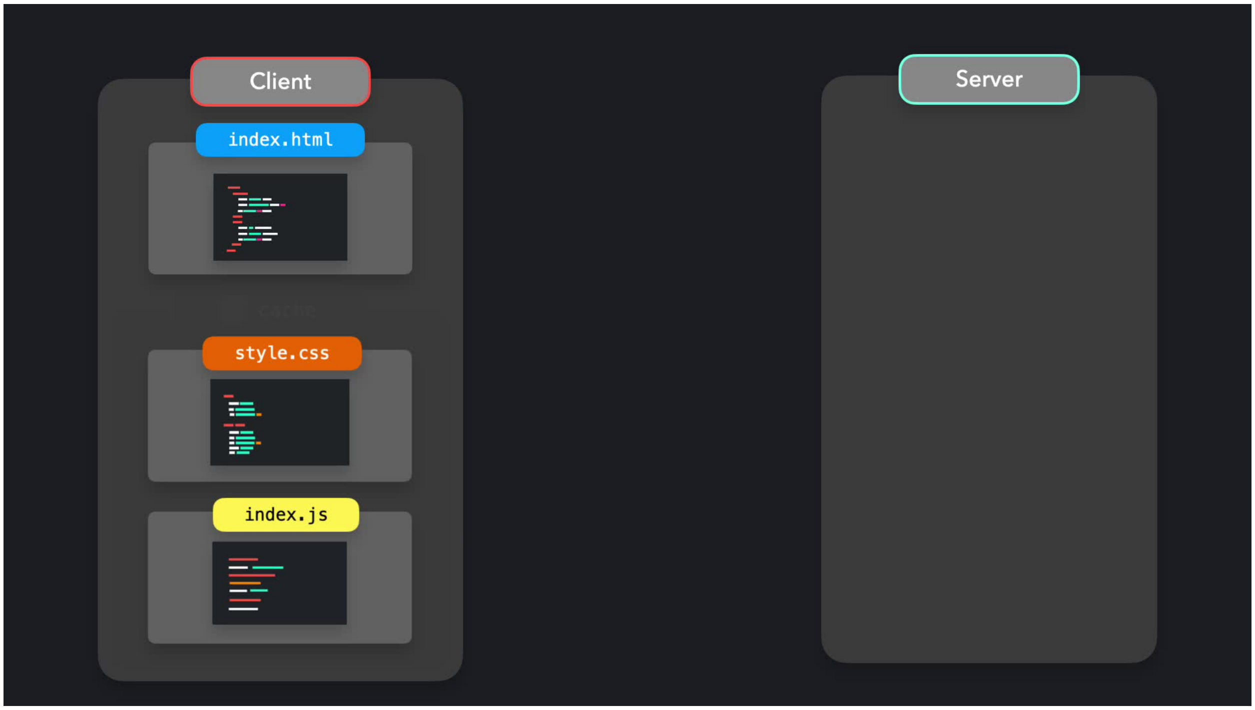


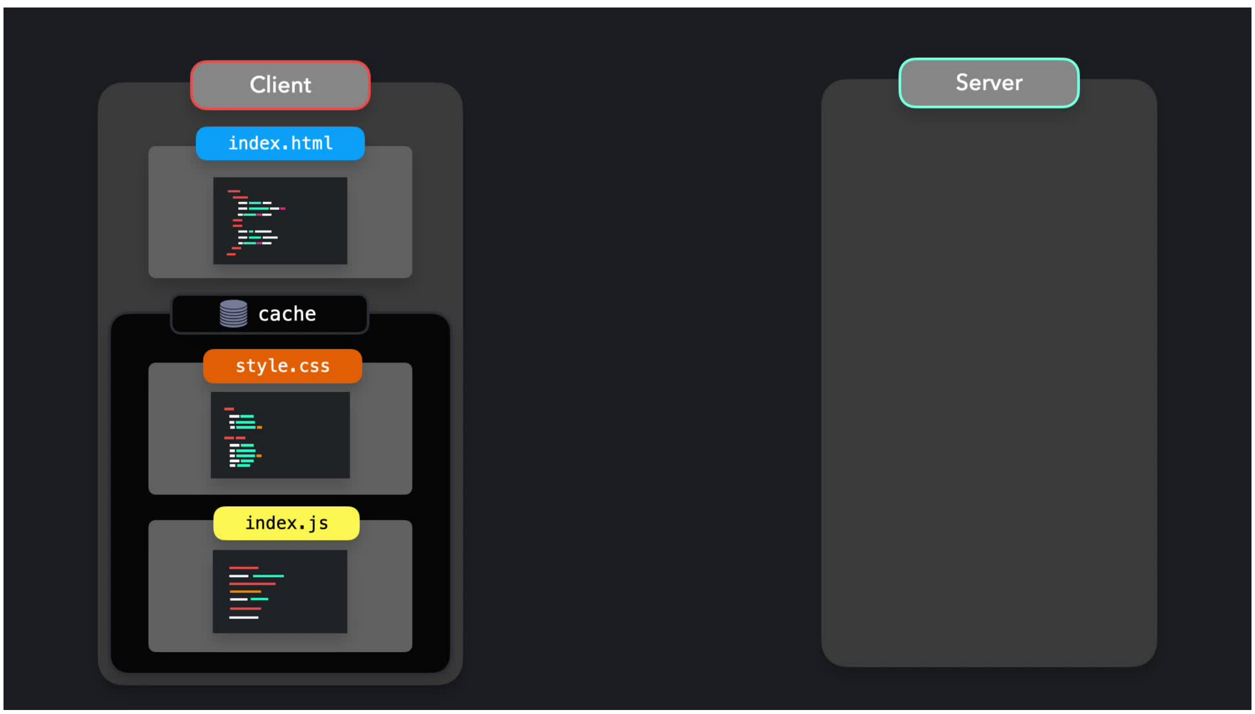
HTTP/2 solves head of line blocking by allowing multiple requests to get sent on the same TCP connection before the previous request resolves!

HTTP/2 also introduced a more optimized way of fetching data, called server push. Instead of having to explicitly ask for resources each time by sending an HTTP request, the server can send the additional resources automatically, by "pushing" these resources.









After the client has received the additional resources, the resources will get stored in browser cache. When the resources get discovered while parsing the entry file, the browser can quickly get the resources from cache instead of having to make an HTTP request to the server!

Although pushing resources reduces the amount of time to receive additional resources, server push is not HTTP cache aware! The pushed resources won’t be available to us the next time we visit the website, and will have to be requested again. In order to solve this, the PRPL pattern uses service workers after the initial load to cache those resources in order to make sure the client isn’t making unnecessary requests.

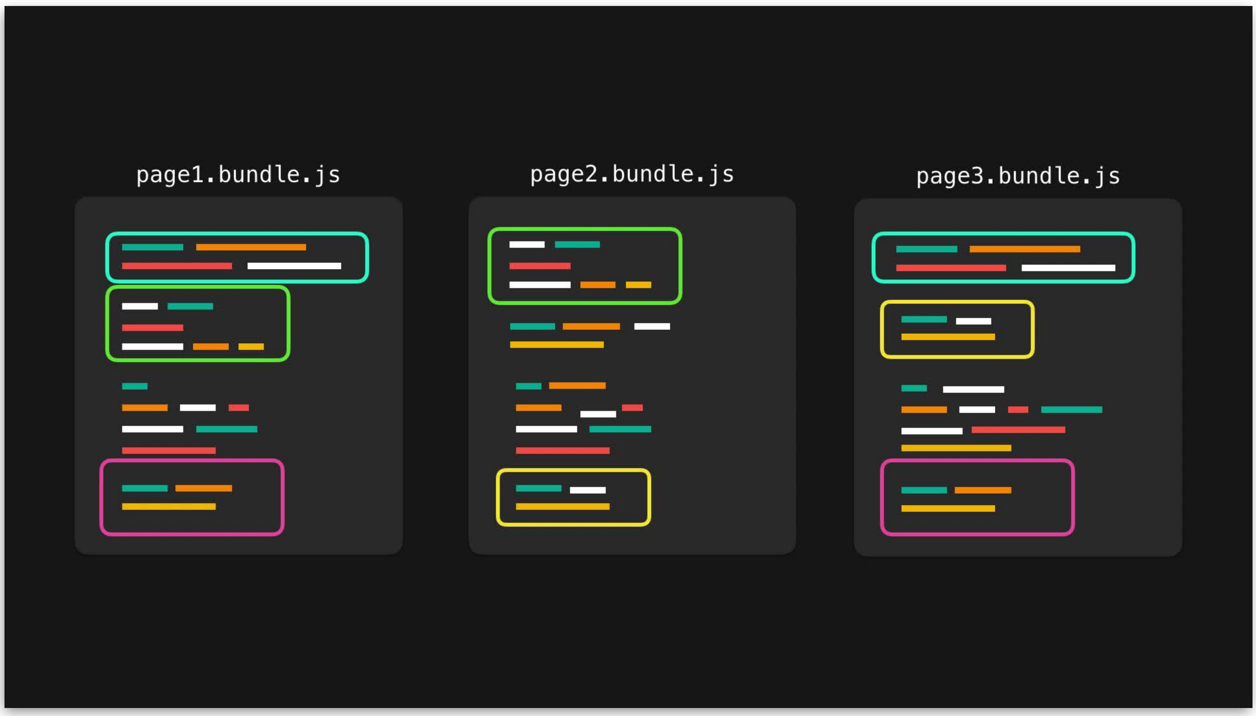
As the authors of a site, we usually know what resources are critical to fetch early on, while browsers do their best to guess this. Luckily, we can help the browser by adding a preload resource hint to the critical resources!

By telling the browser that you’d like to preload a certain resource, you’re telling the browser that you would like to fetch it sooner than the browser would otherwise discover it! Preloading is a great way to optimize the time it takes to load resources that are critical for the current route.

Although preloading resources are a great way to reduce the amount of roundtrips and optimize loading time, pushing too many files can be harmful. The browser’s cache is limited, and you may be unnecessarily using bandwidth by requesting resources that weren’t actually needed by the client.

The PRPL pattern focuses on optimizing the initial load. No other resources get loaded before the initial route has loaded and rendered completely!

We can achieve this by code-splitting our application into small, performant bundles. Those bundles should make it possible for the users to only load the resources they need, when they need it, while also maximizing cachability! Caching larger bundles can be an issue. It can happen that multiple bundles share the same resources.

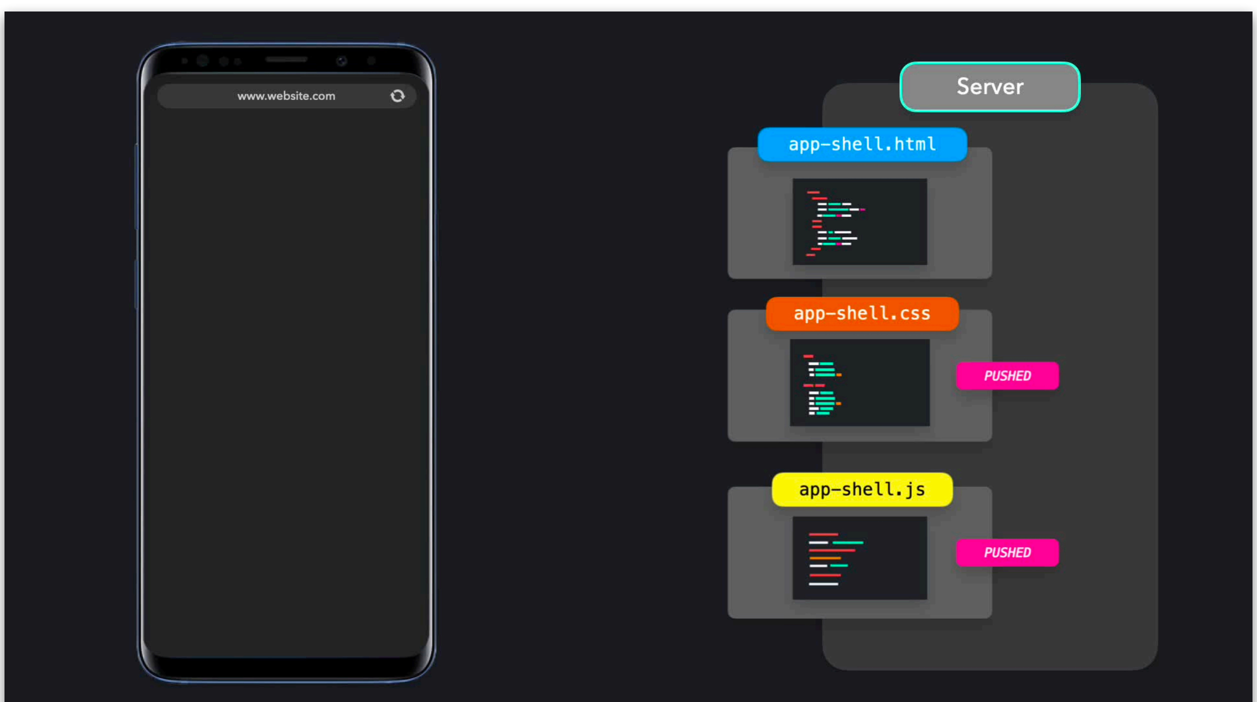


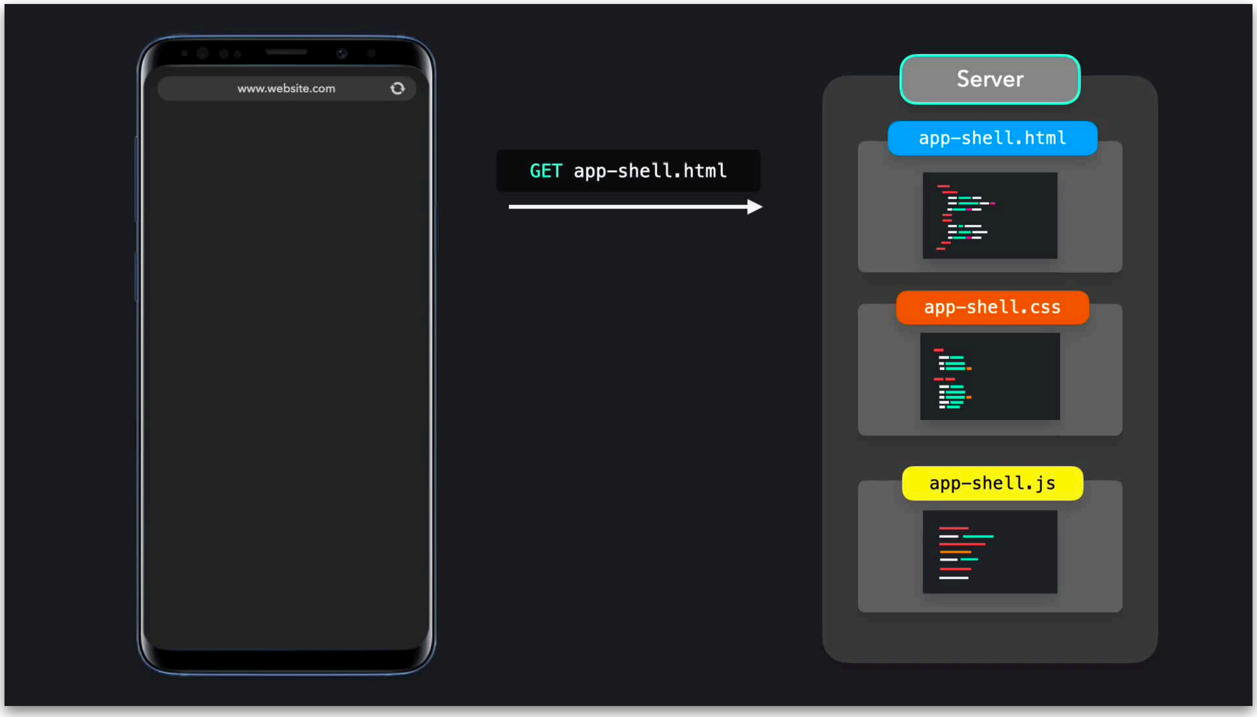
A browser has a hard time identifying which parts of the bundle are shared between multiple routes, and can therefore not cache these resources. Caching resources is important to reduce the number of roundtrips to the server, and to make our application offline-friendly!

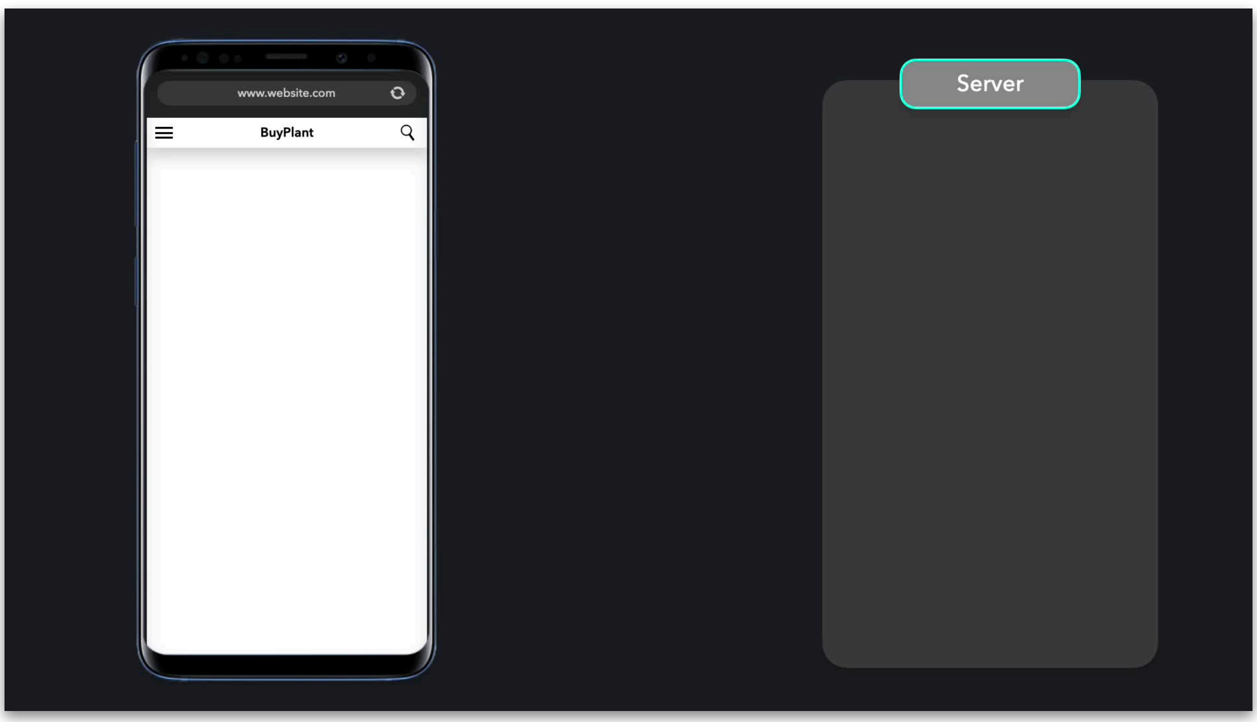
When working with the PRPL pattern, we need to make sure that the bundles we're requesting contain the minimal amount of resources we need at that time, and are cachable by the browser. In some cases, this could mean that having no bundles at all would be more performant, and we could simply work with unbundled modules!

The benefit of being able to dynamically request minimal resources by bundling an application can easily be mocked by configuring the browser and server to support HTTP/2 push, and caching the resources efficiently. For browsers that don't support HTTP/2 server push, we can create a build that is optimized to minimize the amount of roundtrips. The client doesn't have to know whether it's receiving a bundled or unbundled resource: the server delivers the appropriate build for each browser.

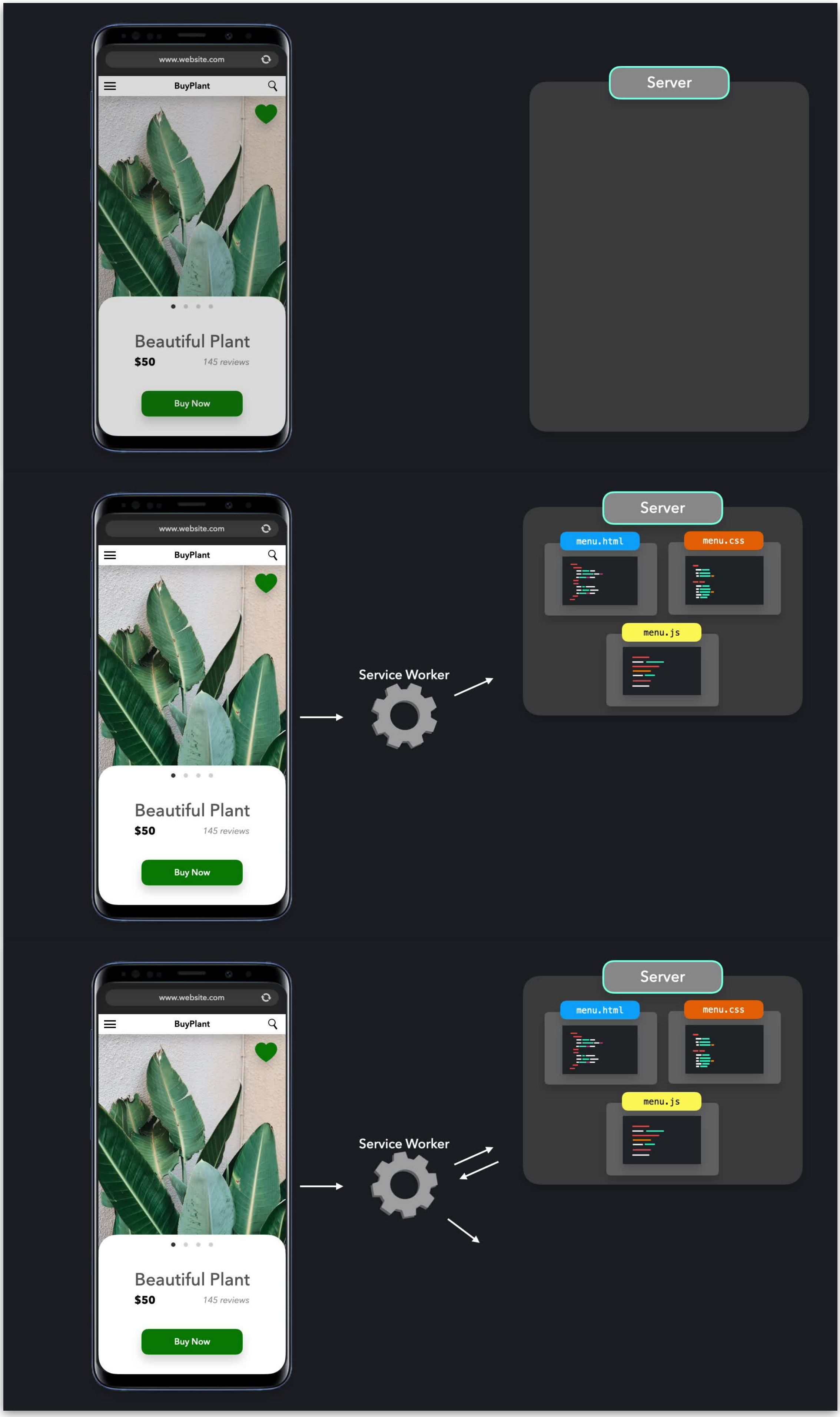
The PRPL pattern often uses an app shell as its main entry point, which is a minimal file that contains most of the application's logic and is shared between routes! It also contains the application's router, which can dynamically request the necessary resources.




www.website.com
GET app-shell.html
Server
app-shell.html
app-shell.css
app-shell.js


www.website.com
BuyPlant
Server

The PRPL pattern makes sure that no other resources get requested or rendered before the initial route is visible on the user's device. Once the initial route has been loaded successfully, a server worker can get installed in order to fetch the resources for the other frequently visited routes in the background!


www.website.com
BuyPlant
Beautiful Plant
$50
145 reviews
Buy Now
Server
www.website.com
BuyPlant
Beautiful Plant
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145 reviews
Buy Now
Service Worker
Server
menu.html
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www.website.com
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menu.html
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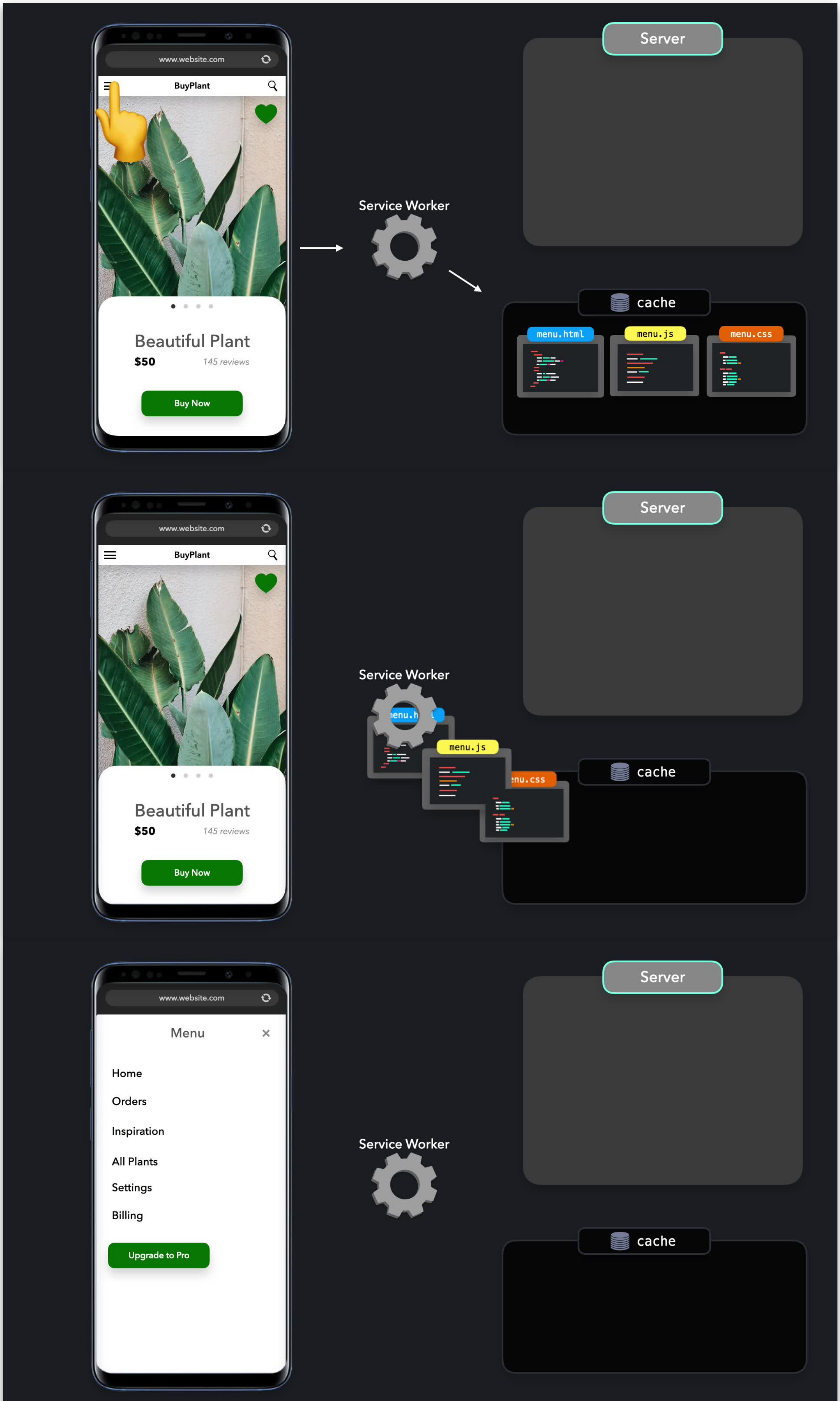
menu.js



www.website.com
BuyPlant
Beautiful Plant
$50
145 reviews
Buy Now
Service Worker
Server
cache
menu.html
menu.js
menu.css
www.website.com
BuyPlant
Beautiful Plant
$50
145 reviews
Buy Now
Service Worker
menu.js
Server
cache
www.website.com
Menu
Home
Orders
Inspiration
All Plants
Settings
Billing
Upgrade to Pro
Service Worker
Server
cache

Since this data is being fetched in the background, the user won't experience any delays. If a user wants to navigate to a frequently visited route that's been cached by the service worker, the service worker can quickly get the required resources from cache instead of having to send a request to the server.

Resources for routes that aren't as frequently visited can be dynamically imported.

Tree Shaking

Reduce the bundle size by eliminating dead code

It can happen that we add code to our bundle that isn't used anywhere in our application. This piece of dead code can be eliminated in order to reduce the size of the bundle, and prevent unnecessarily loading more data! The process of eliminating dead code before adding it to our bundle, is called tree-shaking

Although tree-shaking works for simple modules like the math module, there are some cases in which tree-shaking can be tricky.

Concepts

Tree shaking is aimed at removing code that will never be used from a final JavaScript bundle. When done right, it can reduce the size of your JavaScript bundles and lower download, parse and (in some cases) execution time. For most modern JavaScript apps that use a module bundler (like webpack or Rollup), your bundler is what you would expect to automatically remove dead code.

Consider your application and its dependencies as an abstract syntax tree (we want to "shake" the syntax tree to optimize it). Each node in the tree is a dependency that gives your app functionality. In Tree shaking, input files are treated as a graph. Each node in the graph is a top level statement which is called a "part" in the code. Tree shaking is a graph traversal which starts from the entry point and marks any traversed paths for inclusion.

Every component can declare symbols, reference symbols, and rely on other files. Even the "parts" are marked as having side effects or not. For example, the statement `let firstName = 'Jane'` has no side effects because the statement can be removed without any observed difference if nothing needs foo. But the statement `let firstName = getName()` has side effects, because the call to `getName()` can not be removed without changing the meaning of the code, even if nothing needs `firstName`.

Imports

Only modules defined with the ES2015 module syntax (import and export) can be tree-shaken. The way you import modules specifies whether the module can be tree-shaken or not.

Tree shaking starts by visiting all parts of the entry point file with side effects, and proceeds to traverse the edges of the graph until new sections are reached. Once the traversal is completed, the JavaScript bundle includes only the parts that were reached during the traversal. The other pieces are left out. Let's say we define the following `utilities.js` file:

```
export function read(props) {
    return props.book
}

export function nap(props) {
    return props.winks
}
```

Then we have the following `index.js` file:

```
import { read } from 'utilities';

eventHandler = (e) => {
    read({ book: e.target.value })
}
```

In this example, `nap()` isn't important and therefore won't be included in the bundle.

Side Effects

When we're importing an ES6 module, this module gets executed instantly. It could happen that although we're not referencing the module's exports anywhere in our code, the module itself affects the global scope while it's being executed (polyfills or global stylesheets, for example). This is called a side effect. Although we're not referencing the exports of the module itself, if the module has exported values to begin with, the module cannot be tree-shaken due to the special behavior when it's being imported!

The Webpack documentation gives a clear explanation on tree-shaking and how to avoid breaking it.

Preload

Inform the browser of critical resources before they are discovered

Preload (`<link rel="preload">`) is a browser optimization that allows critical resources (that may be discovered late) to be to be requested earlier. If you are comfortable thinking about how to manually order the loading of your key resources, it can have a positive impact on loading performance and metrics in the Core Web Vitals. That said, preload is not a panacea and requires an awareness of some trade-offs.

```html
<html>
  <head>
    <link rel="preload" href="emoji-picker.js" as="script">
  </head>
  <body>
    ...
    <script src="stickers.js" defer></script>
    <script src="video-sharing.js" defer></script>
    <script src="emoji-picker.js" defer></script>
  </body>
</html>
```

When optimizing for metrics like Time To Interactive or First Input Delay, preload can be useful to load JavaScript bundles (or chunks) that are necessary for interactivity. Keep in mind that great care is needed when using preload as you want to avoid improving interactivity at the cost of delaying resources (like hero images or fonts) necessary for First Contentful Paint or Largest Contentful Paint.

If you are trying to optimize the loading of first-party JavaScript, you can also consider using `<script defer>` in the document `<head>` vs. `<body>` to help with early discover of these resources.

Preload in single-page apps

While prefetching is a great way to cache resources that may be requested some time soon, we can preload resources that need to be used instantly. Maybe it's a certain font that is used on the initial render, or certain images that the user sees right away.

Say our `EmojiPicker` component should be visible instantly on the initial render. Although it should not be included in the main bundle, it should get loaded in parallel. Just like prefetch, we can add a magic comment in order to let Webpack know that this module should be preloaded.

```
const EmojiPicker = import(/* webpackPreload: true */ "./EmojiPicker");
```

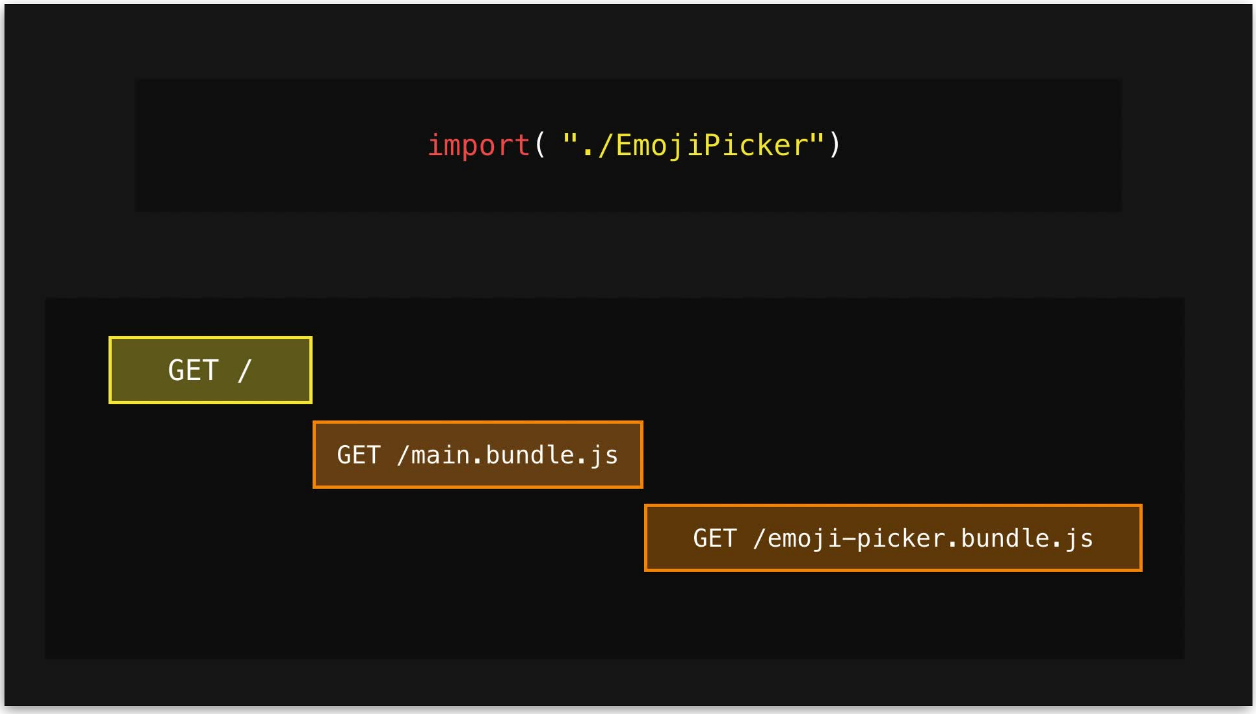
ChatInput.js

```
import React, { Suspense, lazy } from "react";
import Send from "./icons/Send";
import Emoji from "./icons/Emoji";

const EmojiPicker = lazy(() => import("./EmojiPicker"));
const ChatInput = () => {
  const [pickerOpen, togglePicker] = React.useReducer(state => !state, true);

  return (
    <div className="chat-input-container">
      <input type="text" placeholder="Type a message..." />
      <Emoji onClick={togglePicker} />
      {pickerOpen && (
        <Suspense fallback={<p id="loading">loading</p>}>
          <EmojiPicker />
        </Suspense>
      )}
      <Send />
    </div>
  );
};

console.log("ChatInput loading", Date.now());

export default ChatInput;
```

webpack.config.js

```
const path = require("path");
const HTMLWebpackPlugin = require("html-webpack-plugin");
const PreloadWebpackPlugin = require("preload-webpack-plugin");

module.exports = {
  entry: {
    main: "./src/index.js",
    emojiPicker: "./src/components/EmojiPicker.js"
  },
  module: { ... },
  resolve: {... },
  output: { ... },
  plugins: [
    new HTMLWebpackPlugin({
      template: path.resolve(__dirname, "dist", "index.html")
    }),
    new PreloadWebpackPlugin({
      rel: "preload",
      as: "script",
      include: ["emojiPicker"]
    })
  ]
};
```

Webpack 4.6.0+ allows preloading of resources by adding `/* webpackPreload: true */` *to the import. In order to make preloading work in older versions of webpack, you'll need to add the* `preload-webpack-plugin` *to your webpack config.*


import("./EmojiPicker")
GET /
GET /main.bundle.js
GET /emoji-picker.bundle.js


import(/* webpackPreload: true */ "./EmojiPicker")
GET /
GET /main.bundle.js
GET /emoji-picker.bundle.js

After building the application, we can see that the `EmojiPicker` will be prefetched.

```
 Asset                              Size       Chunks                          Chunk Names
    emoji-picker.bundle.js          1.49 KiB   emoji-picker [emitted]          emoji-picker
    vendors~emoji-picker.bundle.js 171 KiB     vendors~emoji-picker [emitted]  vendors~emoji-picker
    main.bundle.js                  1.34 MiB   main  [emitted]                 main

Entrypoint main = main.bundle.j
(preload: vendors~emoji-picker.bundle.js emoji-picker.bundle.js)
```

The actual output is visible as a `link` tag with `rel="preload"` in the head of our document.

```
<link rel="preload" href="emoji-picker.bundle.js" as="script" />
<link rel="preload" href="vendors~emoji-picker.bundle.js" as="script" />
```

The preloaded `EmojiPicker` could be loaded in parallel with the initial bundle. Unlike prefetch, where the browser still had a say in whether it think it's got a good enough internet connection and bandwidth to actually prefetch the resource, a preloaded resource will get preloaded no matter what.

Instead of having to wait until the `EmojiPicker` gets loaded after the initial render, the resource will be available to us instantly! As we're loading assets with smarter ordering, the initial loading time may increase significantly depending on your users device and internet connection. Only preload the resources that have to be visible ~1 second after the initial render.

Preload + the async hack

Should you wish for browsers to download a script as high-priority, but not block the parser waiting for a script, you can take advantage of the `preload` + `async` hack below. The download of other resources may be delayed by the preload in this case, but this is a trade-off a developer has to make:

```
<link rel="preload" href="emoji-picker.js" as="script">
<script src="emoji-picker.js" async>
```

Conclusions

Again, use preload sparingly and always measure its impact in production. If the preload for your image is earlier in the document than it is, this can help browsers discover it (and order relative to other resources). When used incorrectly, preloading can cause your image to delay First Contentful Paint (e.g CSS, Fonts) - the opposite of what you want. Also note that for such reprioritization efforts to be effective, it also depends on servers prioritizing requests correctly.

You may also find `<link rel="preload">` to be helpful for cases where you need to fetch scripts without executing them.

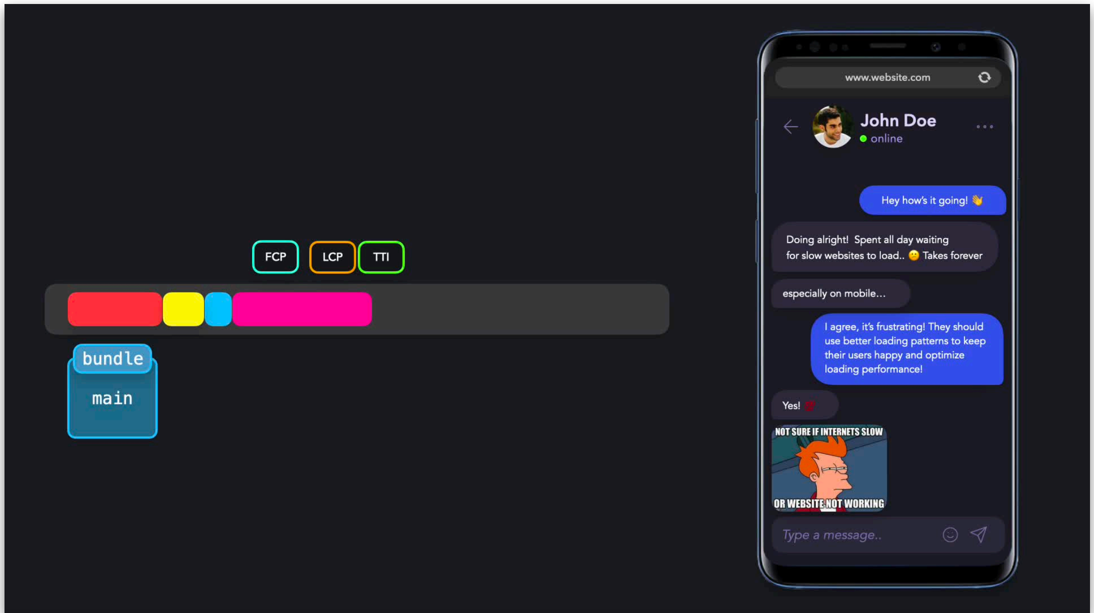
Prefetch

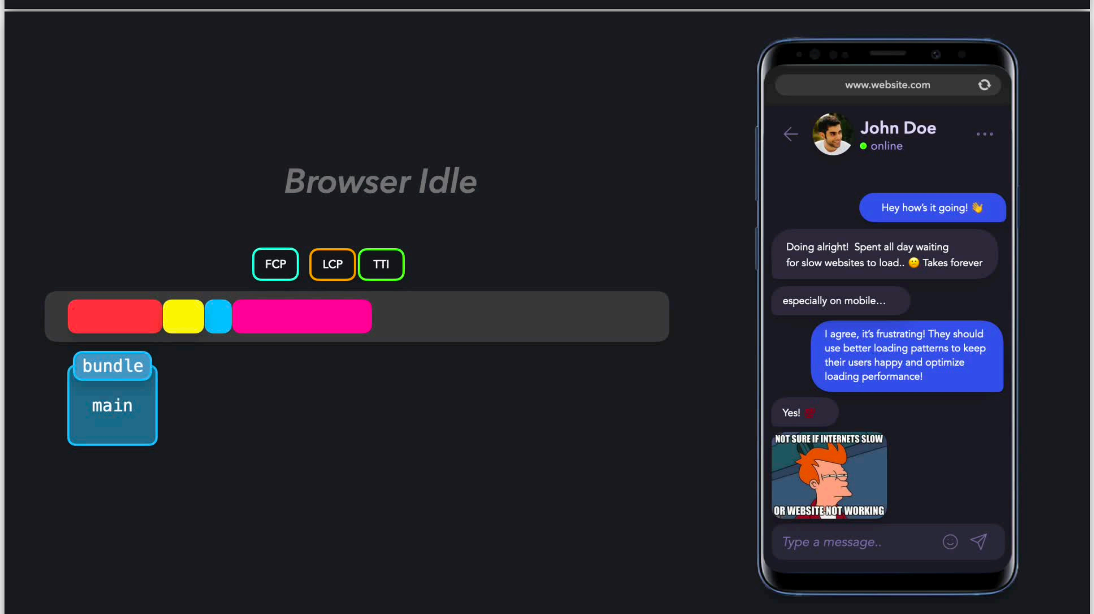
Fetch and cache resources that may be requested some time soon

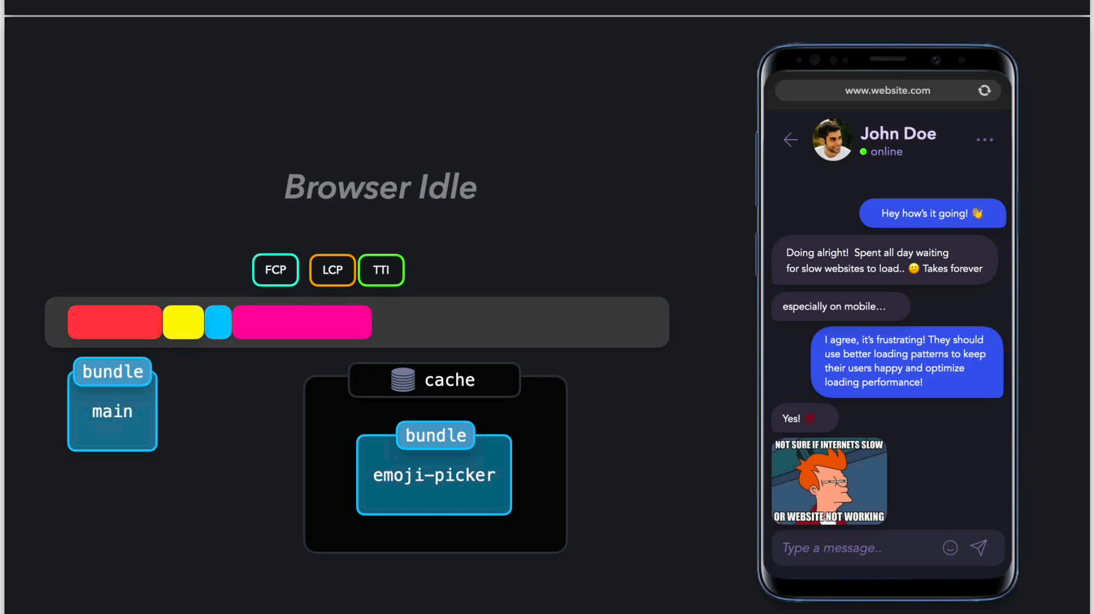
Prefetch (`<link rel="prefetch">`) is a browser optimization which allows us to fetch resources that may be needed for subsequent routes or pages before they are needed. Prefetching can be achieved in a few ways. It can be done declaratively in HTML (such as in the example below), via a HTTP Header (`Link: </js/chat-widget.js>; rel=prefetch`), Service Workers or via more custom means such as through Webpack.

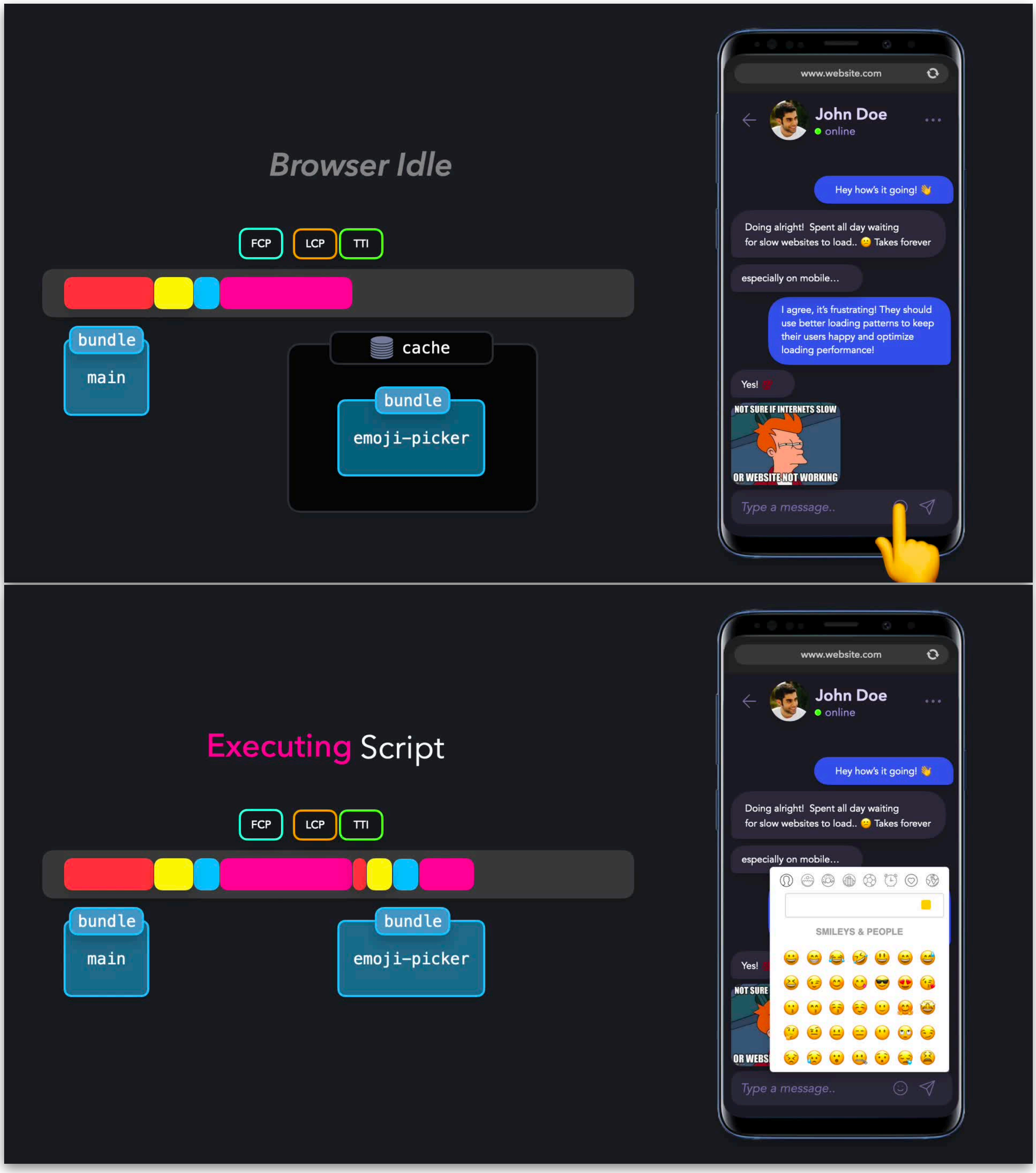
```html
<link rel="prefetch" href="/pages/next-page.html">
<link rel="prefetch" href="/js/emoji-picker.js">
```

In the examples showing how we can import modules based on visibility or interaction, we saw that there was often some delay between clicking on the button in order to toggle the component, and showing the actual component on the screen. This happened, since the module still had to get requested and loaded when the user clicked on the button!


FCP
LCP
TTI
bundle
main
www.website.com
John Doe
online
Hey how's it going!
Doing alright! Spent all day waiting for slow websites to load.. Takes forever
especially on mobile...
I agree, it's frustrating! They should use better loading patterns to keep their users happy and optimize loading performance!
Yes!
NOT SURE IF INTERNETS SLOW
OR WEBSITE NOT WORKING
Type a message..


Browser Idle
FCP
LCP
TTI
bundle
main
www.website.com
John Doe
online
Hey how's it going!
Doing alright! Spent all day waiting for slow websites to load.. Takes forever
especially on mobile...
I agree, it's frustrating! They should use better loading patterns to keep their users happy and optimize loading performance!
Yes!
NOT SURE IF INTERNETS SLOW
OR WEBSITE NOT WORKING
Type a message..


Browser Idle
FCP
LCP
TTI
bundle
main
cache
bundle
emoji-picker
www.website.com
John Doe
online
Hey how's it going!
Doing alright! Spent all day waiting for slow websites to load.. Takes forever
especially on mobile...
I agree, it's frustrating! They should use better loading patterns to keep their users happy and optimize loading performance!
Yes!
NOT SURE IF INTERNETS SLOW
OR WEBSITE NOT WORKING
Type a message..



In many cases, we know that users will request certain resources soon after the initial render of a page. Although they may not visible instantly, thus shouldn't be included in the initial bundle, it would be great to reduce the loading time as much as possible to give a better user experience!

Components or resources that we know are likely to be used at some point in the application can be prefetched. We can let Webpack know that certain bundles need to be prefetched, by adding a magic comment to the import statement: `/* webpackPrefetch: true */`.

```
const EmojiPicker = import(/* webpackPrefetch: true */ "./EmojiPicker");
```

After building the application, we can see that the EmojiPicker will be prefetched.

```
<link rel="prefetch" href="emoji-picker.bundle.js" as="script" />
<link rel="prefetch" href="vendors~emoji-picker.bundle.js" as="script" />
```

The actual output is visible as a link tag with rel="prefetch" in the head of our document.

```
 Asset                              Size       Chunks                          Chunk Names
    emoji-picker.bundle.js          1.49 KiB   emoji-picker [emitted]          emoji-picker
    vendors~emoji-picker.bundle.js  171 KiB    vendors~emoji-picker [emitted]  vendors~emoji-picker
    main.bundle.js                  1.34 MiB   main  [emitted]                 main

Entrypoint main = main.bundle.js
(prefetch: vendors~emoji-picker.bundle.js emoji-picker.bundle.js)
```

Modules that are prefetched are requested and loaded by the browser even before the user requested the resource. When the browser is idle and calculates that it's got enough bandwidth, it will make a request in order to load the resource, and cache it. Having the resource cached can reduce the loading time significantly, as we don't have to wait for the request to finish after the user has clicked the button. It can simply get the loaded resource from cache.

Although prefetching is a great way to optimize the loading time, don't overdo it. If the user ended up never requesting the EmojiPicker component, we unnecessarily loaded the resource. This could potentially cost a user money, or slow down the application. Only prefetch the necessary resources.

List Virtualization

Optimize list performance with list virtualization

In this guide, we will discuss list virtualization (also known as windowing). This is the idea of rendering only visible rows of content in a dynamic list instead of the entire list. The rows rendered are only a small subset of the full list with what is visible (the window) moving as the user scrolls. This can improve rendering performance.

If you use React and need to display large lists of data efficiently, you may be familiar with react-virtualized. It's a windowing library by Brian Vaughn that renders only the items currently visible in a list (within a scrolling "viewport"). This means you don't need to pay the cost of thousands of rows of data being rendered at once. A video walkthrough of list virtualization with react-window accompanies this write-up.

How does list virtualization work?

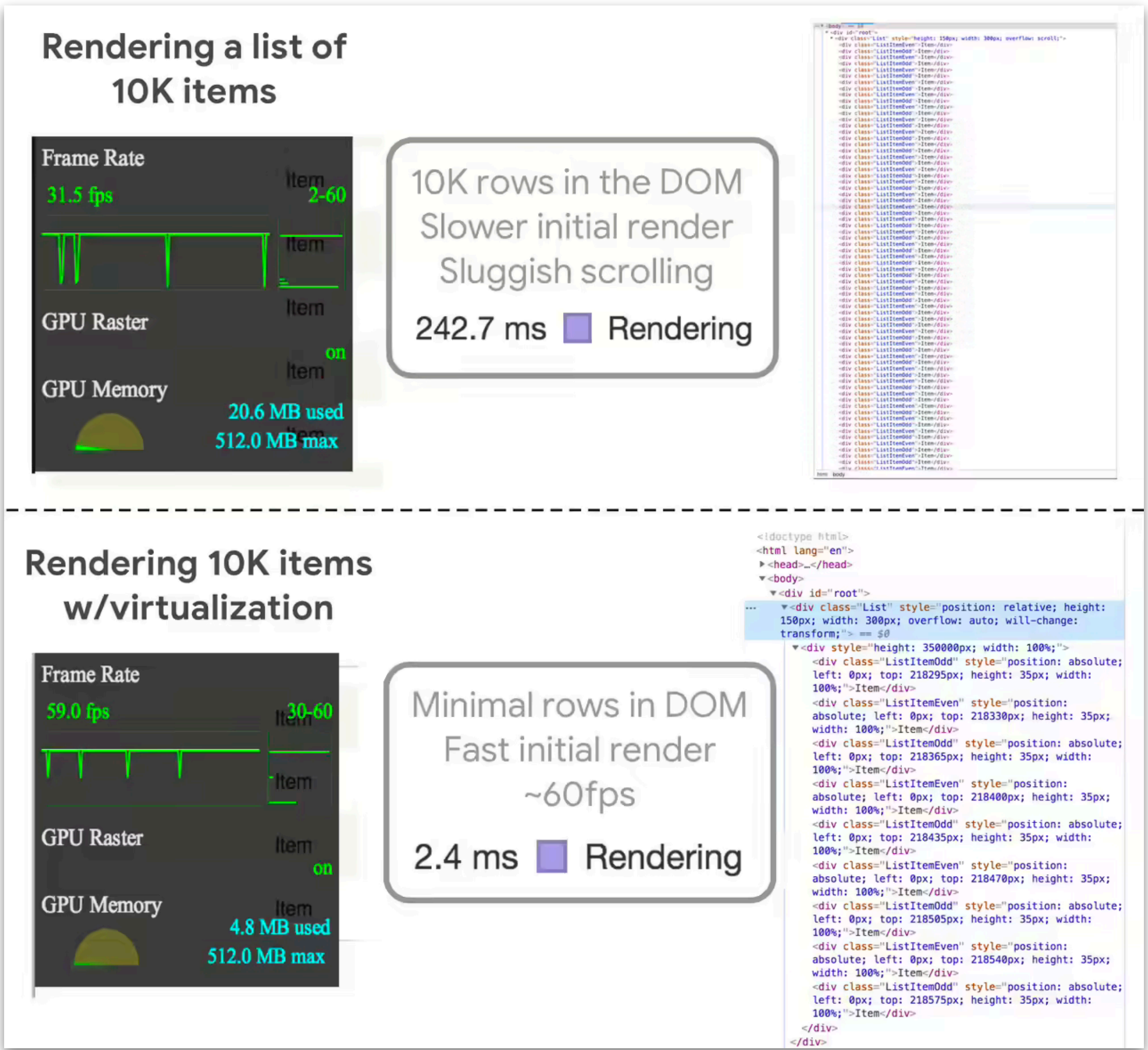
"Virtualizing" a list of items involves maintaining a window and moving that window around your list. Windowing in react-virtualized works by:

- Having a small container DOM element (e.g `<ul>`) with relative positioning (window)

- Having a big DOM element for scrolling

- Absolutely positioning children inside the container, setting their styles for top, left, width and height.

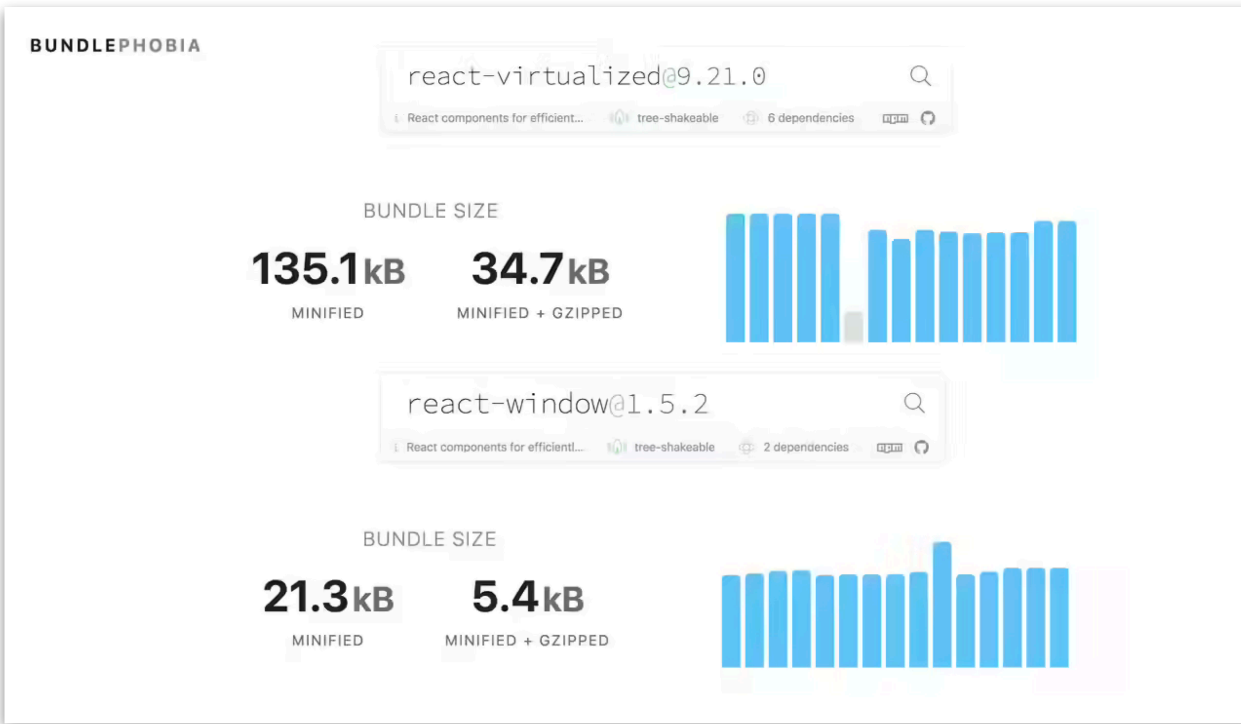
Rather than rendering 1000s of elements from a list at once (which can cause slower initial rendering or impact scroll performance), virtualization focuses on rendering just items visible to the user.



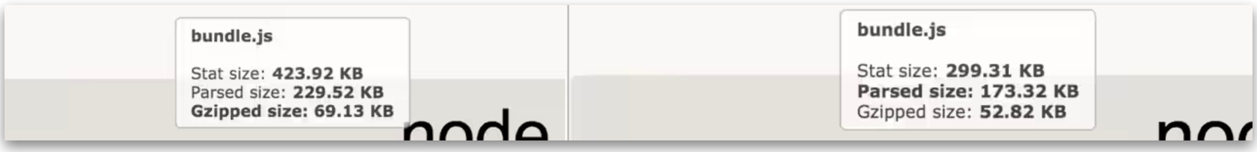
This can help keep list rendering fast on mid to low-end devices. You can fetch/display more items as the user scrolls, unloading previous entries and replacing them with new ones.

A smaller alternative to react-virtualized

`react-window` is a rewrite of `react-virtualized` by the same author aiming to be smaller, faster and more tree-shakeable.



In a tree-shakeable library, size is a function of which API surfaces you

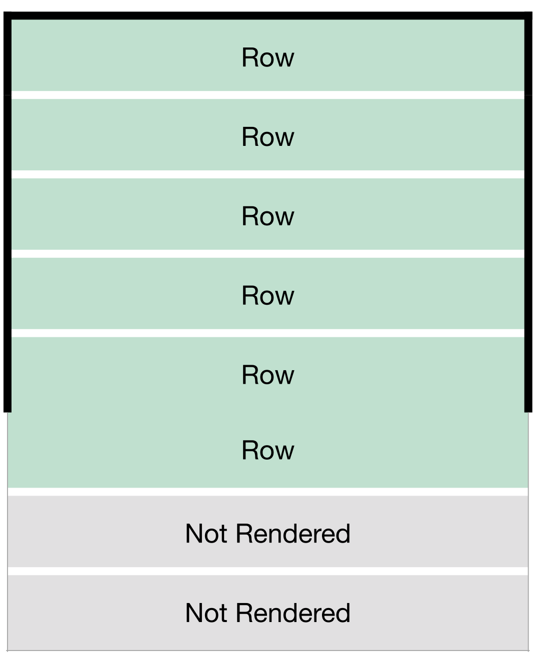


choose to use. I've seen `~20-30KB` (gzipped) savings using it in place of `react-virtualized`:

The APIs for both packages are similar and where they differ, react-window tends to be simpler. react-window's components include:

List

Lists render a windowed list (row) of elements meaning that only the visible rows are displayed to users (e.g `FixedSizeList`, `VariableSizeList`). Lists use a `Grid` (internally) to render rows, relaying props to that inner `Grid`.



Rendering a list of data using React

Here's an example of rendering a list of simple data (`itemsArray`) using React:

```
import React from "react";
import ReactDOM from "react-dom";

const itemsArray = [
  { name: "Drake" },
  { name: "Halsey" },
  { name: "Camillo Cabello" },
  { name: "Travis Scott" },
  { name: "Bazzi" }
];

const Row = ({ index, style }) => (
  <div className={index % 2 ? "ListItemOdd" : "ListItemEven"} style={style}>
    {itemsArray[index].name}
  </div>
);

const Example = () => (
  <div className="List">
    {itemsArray.map((item, index) => Row({ index }))}
  </div>
);

ReactDOM.render(<Example />, document.getElementById("root"));
```

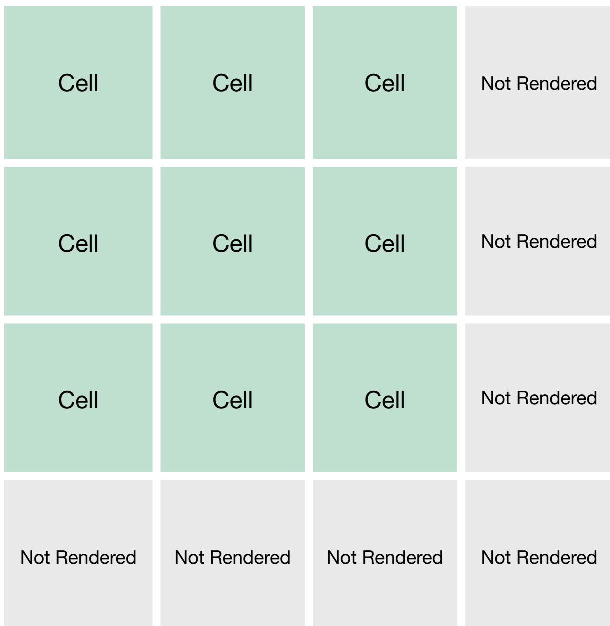
Rendering a list using `react-window`

...and here's the same example using react-window's FixedSizeList, which takes a few props (`width`, `height`, `itemCount`, `itemSize`) and a row rendering function passed as a child:

```
import React from "react";
import ReactDOM from "react-dom";
import { FixedSizeList as List } from "react-window";

const itemsArray = [...]; // our data

const Row = ({ index, style }) => (
  <div className={index % 2 ? "ListItemOdd" : "ListItemEven"} style={style}>
    {itemsArray[index].name}
  </div>
);

const Example = () => (
  <List
    className="List"
    height={150}
    itemCount={itemsArray.length}
    itemSize={35}
    width={300}
  >
    {Row}
  </List>
);

ReactDOM.render(<Example />, document.getElementById("root"));
```

Grid

Grid renders tabular data with virtualization along the vertical and horizontal axes (e.g `FizedSizeGrid`, `VariableSizeGrid`). It only renders the `Grid` cells needed to fill itself based on current horizontal/vertical scroll positions.



If we wanted to render the same list as earlier with a grid layout, assuming our input is a multi-dimensional array, we could accomplish this using `FixedSizeGrid` as follows:

```jsx
import React from 'react';
import ReactDOM from 'react-dom';
import { FixedSizeGrid as Grid } from 'react-window';

const itemsArray = [
  [{},{},{},...],
  [{},{},{},...],
  [{},{},{},...],
  [{},{},{},...],
];

const Cell = ({ columnIndex, rowIndex, style }) => (
  <div
    className={
      columnIndex % 2
        ? rowIndex % 2 === 0
          ? 'GridItemOdd'
          : 'GridItemEven'
        : rowIndex % 2
          ? 'GridItemOdd'
          : 'GridItemEven'
    }
    style={style}
  >
    {itemsArray[rowIndex][columnIndex].name}
  </div>
);

const Example = () => (
  <Grid
    className="Grid"
    columnCount={5}
    columnWidth={100}
    height={150}
    rowCount={5}
    rowHeight={35}
    width={300}
  >
    {Cell}
  </Grid>
);

ReactDOM.render(<Example />, document.getElementById('root'));
```

More in-depth react-window examples

Scott Taylor implemented an open-source Pitchfork music reviews scraper (src) using `react-window` and `FixedSizeGrid`.

Pitchfork scraper uses `react-window-infinite-loader` (demo) which helps break large data sets down into chunks that can be loaded as they are scrolled into view. Here's a snippet of how `react-window-infinite-loader` is incorporated in this app:

```
import React, { Component } from 'react';
import { FixedSizeGrid as Grid } from 'react-window';
import InfiniteLoader from 'react-window-infinite-loader';
...
  render() {
    return (
      <InfiniteLoader
        isItemLoaded={this.isItemLoaded}
        loadMoreItems={this.loadMoreItems}
        itemCount={this.state.count + 1}
      >
        {({ onItemsRendered, ref }) => (
          <Grid
            onItemsRendered={this.onItemsRendered(onItemsRendered)}
            columnCount={COLUMN_SIZE}
            columnWidth={180}
            height={800}
            rowCount={Math.max(this.state.count / COLUMN_SIZE)}
            rowHeight={220}
            width={1024}
            ref={ref}
          >
            {this.renderCell}
          </Grid>
        )}
      </InfiniteLoader>
    );
  }
}
```

What if we have even more complex needs for a grid virtualization solution? We found a The Movie Database demo app that used react-virtualized and Infinite Loader under the hood.

```
return (
  <InfiniteLoader
    isItemLoaded={this.isItemLoaded}
    loadMoreItems={this.loadMoreItems}
    itemCount={this.state.count}
  >
    {({ onItemsRendered, ref }) => (
      <section>
        <FixedSizeList
        itemCount={this.state.count}
        itemSize={ROW_HEIGHT}
        onItemsRendered={onItemsRendered}
        height={this.state.height}
        width={this.state.width}
        ref={ref}
        >
          {this.renderCell}
        </FixedSizeList>
      </section>
    )}
  </InfiniteLoader>
);
```

Porting it over to react-window and react-window-infinite-loader didn't take long, but we did discover a few components were not yet supported. Regardless, the final functionality is pretty close. The missing components were WindowScroller and AutoSizer...which we'll look at next.

```
...
  return (
    <section>
      <AutoSizer disableHeight>
        {({width}) => {
          const {movies, hasMore} = this.props;
          const rowCount = getRowsAmount(width, movies.length, hasMore);
          ...
          return (
            <InfiniteLoader
              ref={this.infiniteLoaderRef}
              ...
              {({onRowsRendered, registerChild}) => (
                <WindowScroller>
                  {({height, scrollTop}) => (
```

What's missing from `react-window`?

react-window does not yet have the complete API surface of `react-virtualized`, so do check the comparison docs if considering it. What's missing?

- `WindowScroller` - This is a `react-virtualized` component that enables Lists to be scrolled based on the window's scroll positions. There are currently no plans to implement this for react-window so you'll need to solve this in userland.

- `AutoSizer` - HOC that grows to fit all of the available space, automatically adjusting the width and height of a single child. Brian implemented this as a standalone package. Follow this issue for the latest.
- `CellMeasurer` - HOC automatically measuring a cell's content by rendering it in a way that is not visible to the user. Follow here for discussion on support.

That said, we found react-window sufficient for most of our needs with what it includes out of the box.

Improvements in the web platform

Some modern browsers now support CSS content-visibility. `content-visibility:auto` allows you to skip rendering & painting offscreen content until needed. If you have a long HTML document with costly rendering, consider trying the property out.

For rendering lists of dynamic content, I still recommend using a library like react-window. It would be hard to have a `content-visbility: hidden` version of such a library that beats a version aggressively using `display: none` or removing DOM nodes when offscreen like many list virtualization libraries may do today.

Conclusions

That's a wrap for our book! We hope you've enjoyed it as much as we did writing it.

Patterns are time-tested templates for writing code. They can be really powerful, whether you're a seasoned developer or beginner, bringing a valuable level of resilience and flexibility to your codebase.

Keep in mind that patterns are not a silver bullet. Take advantage of them when you have a practical need to solve a problem and when you can use them to write better code. Otherwise, be careful to avoid applying patterns arbitrarily. If a problem you're attempting to solve is just hypothetical, maybe it's premature to consider a pattern.

Always keep simplicity in mind. We try to when evaluating these ideas for the apps we write and hope you will too. Ultimately what works best is often a balance of trade-offs.

Understand if a pattern is helping you achieve your goals; whether it's better user-experience, developer-experience or just smarter architecture. When you have a seasoned knowledge of patterns, you'll appreciate when it may be a good time to use one. Otherwise, study patterns and explore if they may be a good fit for the problem you're attempting to solve. Once you've picked a pattern, make sure you're evaluating the trade-offs of using it. If it looks reasonable, you can use it.

Feel free to share "Learning Patterns" with your friends and colleagues. The book is freely available at Patterns.dev and we welcome any feedback you have. Until next time, so long and good luck, friends!

~ Lydia and Addy