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Speakur: Leveraging Web Components for Composable Applications

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Speakur: Leveraging Web Components for Composable Applications

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REPORT

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This report is dedicated to my wife for her patience,

and to my parents for their support and guidance

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Speakur: Leveraging Web Components for Composable Applications

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This report is a case study of applying abstraction, encapsulation, and composition techniques to web application architecture with the use of Web Components, a proposed extension to the HTML5 Document Object Model. I created Speakur, a real-time social discussion plugin for the mobile and desktop web, to show how Web Components can help realize software engineering principles and design patterns, including the composition of applications from components sourced from diverse authors and frameworks.

Web authors can add a Speakur discussion to their page by inserting a simple HTML element at the desired spot to give the page a real-time discussion or feedback system. Speakur uses the Polymer framework's implementation of the draft Web Components standard to achieve the encapsulation of its internal implementation details from the containing page behind a simplified, well defined interface. Web Components are a proposed W3C standard for writing custom HTML tags that take advantage of new

browser technologies like Shadow DOM, package importing, CSS Flexboxes and data-bound templates.

This report reviews Web Components and related technologies and provides a case study for structuring a real-world WC applet that is embedded in a larger app or system. The major research question is whether Web Components offer a viable path towards the encapsulation and composition principles that have largely eluded web engineers thus far. In other words, *are components really the future of the web*? Subsidiary topics include assessing the maturity and performance of current Web Components technologies, and methods of synchronization between user interface components and local and remote data models. My analysis shows that Web Components successfully address many of the key structural and organizational problems faced by web software engineers.

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Chapter 1

Introduction to Speakur and Web Components

1.1 Software Engineering for the Web

This report is a case study of using W3C Web Components, a proposed HTML5 extension, to implement techniques of encapsulation, abstraction, and modularity in web application engineering. I created Speakur, a real-time discussion social plugin for the web, as an experiment to determine the viability and maturity of using Web Components to create modern, highly composable web applications. Figure 3.1 on page 28 shows an example Speakur discussion.

1.1.1 The HTML Document Object Model

Like most web applications, Speakur is written in a combination of HTML markup and the JavaScript programming language. HTML is a declarative markup language used to create documents—web pages—which are viewed with the help of a program called the browser. The Hypertext Markup Language (HTML) standard has proven wildly successful since its introduction in 1993 by British physicist and computer scientist Tim Berners-Lee, with billions and billions of pages served, and hundreds of millions of public and private web sites forming a major part of our information landscape [48]. More than perhaps any other invention, the World Wide Web (WWW) has shaped how we see and use the global network.

Those designing and programming applications for the Web as a computing platform have long dreamed of the ability to mix and match independent, reusable chunks of functionality—components—in their documents without mutual coupling and interference. The Document Object Model (DOM) browser abstraction does not allow for significant decoupling; everything lives together on one big page. Hacks like the `<iframe>` tag let you work around some of these limitations, usually in a inelegant and sometimes insecure fashion.

1.1.2 A Programming Language for the Web

At the time of HTML's introduction, the concept of quickly and easily composing a static web page, much less a full-fledged dynamic application, out of Lego-like reusable building blocks seemed like a distant dream at best. The introduction of the JavaScript[1] (JS) programming language to web browsers in 1995 allowed for a completely new dimension of dynamic behavior that was not previously possible [23]. Eventually web apps like Gmail and Google Docs, powered by JavaScript, rivaled traditional desktop applications in functionality and usability while being instantly accessible from anywhere with an Internet connection. Still, web apps had to be stitched together 'by hand' in ways that carefully ensured the different parts did not step on each other's toes, else disaster frequently ensued. Each component or sub-system could not help but be coupled to the others at some level as a result of the programming model imposed by the DOM and HTML [46].

[1] JavaScript, also rendered as Javascript or JS, has no significant relationship to Sun's (now Oracle's) popular Java programming language. JavaScript is formally standardized as ECMAScript (ES).

1.1.2.1 The Growth of JavaScript

Over the years the dynamic behaviors afforded by JavaScript grew in importance along with the web, and helped contribute to its success. JavaScript is now a ubiquitous programming language and has expanded far beyond the desktop web client. JavaScript interpreters can be found in web servers, mobile phones, industrial controllers, and now the embedded devices that comprise the Internet of Things (IoT) [41]. Its flexible, loosely typed nature can be a boon to the prototyping and initial development process, but the difficulties in building a large application in the DOM soon became apparent. These problems will be explored in detail in Chapter 2.

Over time, a bewildering array of frameworks and libraries sprang up around the HTML/JS ecosystem to help manage this complexity and to provide scaffolding and structure for the client side of web apps. For many years individual JS frameworks seemed to come and go as ephemerally as teenage pop idols [63]. Interoperability between these completing frameworks was virtually non-existent; typically, components from one framework couldn't easily be combined with those from an another. The industry kept searching for the Next Big Thing that would make writing high quality web apps less of bug-ridden, messy chore [63].

1.1.2.2 The Rise of Angular

In recent years (roughly 2011 to 2014) Google's Angular [34] has emerged as a dominant client framework, due in part to its perceived high quality and to the fact that it represents a common point for a fragmented industry to rally around [38]. Facebook's React library with its Virtual DOM is an up-and-comer focused on high performance that

is more complementary in nature to Angular than a true challenger, focusing primarily on the "view" part of the common model-view-controller (MVC) design pattern [22].

Yet despite the emergence of the updated HTML5 standard in 2011 and the recent successes of web frameworks like Angular and React in capturing developer attention, a clear picture still did not exist of how web apps could achieve the encapsulated component model that had become prevalent in other areas of software engineering. That is, until engineers from Google[2] and Mozilla[3] and other organizations got together in 2012 under a W3C Web Applications Working Group [70] to draft a new standard called **Web Components** that will extend and enhance HTML5 in ways that could have a significant long-term impact [52]. For example, as of the time of this writing, a rewrite of Angular called Angular 2.0 is slated to include Web Components as a core architectural element [39].

1.2 Web Components Overview

Fundamentally, the Web Components standard consists of four new core DOM technologies—extensions to the current HTML5 standard. If these standards are accepted by major browser vendors and the World Wide Web Consortium (W3C) which maintains HTML, they will eventually become native browser features and available directly to any web page without needing to use any additional JS frameworks or libraries. The core Web Component technologies are [62]:

[2] As of March 2015, Google's Chrome browser is the most popular desktop browser [72].

[3] The Mozilla Foundation is the sponsor of the popular Firefox web browser. It grew out of Netscape, whose Navigator browser helped bring the web to a mass audience.

- **Custom Elements**: extending HTML with author-created tags
- **Shadow DOM**: a separate document tree completely internal to an element
- **Templates**: scaffolding for instantiating blocks of HTML from inert templates
- **Imports**: packaging for HTML components

1.2.1 Related Technologies

This report also explores several related web standards initiatives that are frequently associated with Web Components but are not formally grouped under them, including mutation observers, model driven views, and the CSS Flexible Boxes and CSS Grid systems [27, 24, 15]. In part because many of these technologies are not yet formally accepted as W3C standards and are not yet widely implemented in typical mobile and desktop browsers, I implemented Speakur using Google's experimental Polymer framework [20]. Polymer provides a JavaScript 'polyfill' library to implement many of the new Web Component features in browsers which would otherwise not support them, similar to the adapter design pattern. Eventually this platform polyfill should become unnecessary, in theory, as WC becomes widely adopted in browsers. Some browsers like Google Chrome have already implemented at least some native Web Component support and the polyfill is effectively a 'no-op' in these areas.

1.2.2 The Componentization of the Web

The move to a component-based DOM architecture is one of the most exciting developments in web engineering in years and follows the overall growth in software-as-a-service (SaaS) and the service oriented architecture model. The conversion of dy-

namic web logic—not mere snippets of plain HTML—into bundles of reusable, extendable, composable services (components) enables web developers to move to a higher level of abstraction than was previously possible.

The shift towards a component-based Web will enable interesting new composite services, mashups, and may help broaden the potential pool of web developers. What previously required a highly integrated, high-overhead development model or lots of tedious glue code can become as simple as importing a custom element and dropping it onto a page. Integrated development environments (IDEs) and other tools that embrace Web Components will be able to assist content authors by, for example, offering name completion on custom elements and the attributes that form their API.

1.3 Structure of This Report

The goal of this report is to demonstrate the application of software engineering design patterns embodied in the W3C proposed Web Components standard such as encapsulating internal logic behind abstraction layers, modular composition, and the real-time synchronization of web application state. This report discusses many of the goals and principles of the Web Components initiative and how a number of different technologies taken together help raise the overall level of abstraction for content authors, web engineers, and application developers—which I will refer to collectively as (web) authors for short.

Chapter 2 gives an introduction to some of the architectural problems inherent in modern web authoring and how Web Components (WC) address them. It provides background on the software engineering design patterns that are embodied in Web Com-

ponents like encapsulation and composition. It describes some of the motivations behind the development of Speakur and some of the specific software engineering design questions it addresses.

Chapter 3 describes the high level software architecture choices behind Speakur and details the specific structures and techniques used when constructing Web Components. It describes how Speakur uses WC to implement encapsulated modules whose internals are protected from unintentional outside influence. It also describes how the choice of the Firebase cloud database service, its WebSocket-based event notification system, and its security subsystem have impacted Speakur's architecture.

In Chapter 4, Implementing a Web Component, I show how applying Web Component principles eases the task of creating a flexible discussion forum for both desktop and mobile browsers. I describe the low level architecture, code flow, and data synchronization process, as well as how to internationalize a JavaScript application so the user interface language (locale) can be switched on the fly. Another important topic in this section is security: how can we implement a largely client-based system while maintaining some kind of data integrity?

This is followed by Chapter 5, Analysis and Lessons Learned, which discusses some of the outcomes as compared to the original goals and also looks at the impact of the selection of Web Components, Polymer, Firebase and several other architectural choices. Finally, the Conclusion summarizes how the Web Components initiative will positively impact the future of software engineering for the web.

1.4 Source Code and Demonstration Resources

The source code for Speakur consists of HTML and JavaScript files located in a Git version control repository. These files constitute an *HTML Import* package that provides a **<speakur-discussion>** custom HTML element for the use of web authors in their own pages. An example of using <speakur-discussion> is given in Chapter 3 and in briefly in Listing 1.1 below.

```
<!-- place this on your page
     where you want a discussion -->
<speakur-discussion
  href="http://example.com/news/web-components-in-action"
  allowAnonymous="false">
</speakur-discussion>
```

Listing 1.1: Speakur custom HTML element.

The Speakur source code and component documentation can be found on the social coding site GitHub.com at [57]:

`https://github.com/Preston-Landers/speakur-discussion`

A demonstration web page that shows off a live embedded Speakur discussion is available at the following location [56]:

`https://preston-landers.github.io/speakur-discussion/components/speakur-discussion/demo.html`

Chapter 2

Background and Motivations

When the Web was first created by Tim Berners-Lee in 1989, web pages were largely envisioned as static *documents* with a single author or a small group of coordinating authors. The idea of composing a large web application out of basic components like snapping together Lego blocks seemed like a distant dream at best. Until recently, web authors were limited to using the predefined HTML layout elements or 'tags' that are listed in the W3C standard and understood by browser programs, such as `<title>` and `<video>`. Letting authors create unique HTML elements with customized behaviors was well beyond the capabilities of the web browsers of the day like Mosaic and Netscape Navigator.

2.1 JavaScript Libraries, Frameworks, and Components

As of early 2015, modern web apps are typically written with a JavaScript framework that provides a cohesive set of structures, design patterns and practices designed to facilitate composing web applications—large or small—from a number of sub-components [38]. Angular, Meteor, and Backbone are three such frameworks. The difference between a 'framework' and a library is somewhat arbitrary, but typically frameworks are more comprehensive than narrowly focused utility libraries. Yet all frameworks must ex-

ist within the confines of the programming model provided by the browser and the Document Object Model. In the DOM, the entire web page or app belongs to a single 'document', constituent parts are not encapsulated or isolated from each other, and authors are limited to working with the predefined HTML tags. These issues make it difficult to create and share generic, reusable *web components*—in the abstract sense—among different users who may not use the same frameworks or follow the same set of assumptions and conventions.

Throughout this report I will refer to both Web Components (the W3C initiative) and to a more general concept of a "software component", or just component for short, which can be anything from a small function or module to a major software package or a collection of web services or APIs. I will also refer to "widgets", which are generic user interface (UI) components like menus and buttons.

2.2 Current Challenges in Web Authoring

In object oriented programming (OOP), encapsulation is typically defined as a "language mechanism for restricting access to some of the object's components" [60, p. 522]. The point of encapsulation is providing an *abstraction* that consumers of the functionality can rely on without knowing the internals. The goals of encapsulation and abstraction include:

> identifying the interface of a data structure ... providing *information hiding* by separating implementation decisions from parts of the program that use the data structure ... and allowing the data structure to be used in many different ways by many different components [60, p. 243].

Among the key benefits of OOP are inheritance and polymorphism, or the ability to treat related types of objects the same way through a shared interface.

2.2.1 DOM Limitations

Although techniques of abstraction and encapsulation have been widespread in object oriented programming for decades, the fundamental web client programming model has not allowed for significant encapsulation of things like the DOM structure and CSS style rules or polymorphic treatment of different components [46]. To illustrate how these problems affect the ability of authors to share and reuse code, let us look at an example from the popular Twitter Bootstrap library [7]. Twitter Bootstrap is a collection of Cascading Style Sheet (CSS) rules and JavaScript user interface components designed to allow web authors to quickly 'bootstrap' an attractive, consistent look-and-feel onto a web page. Bootstrap provides pre-styled user interface (UI) widgets such as menus, buttons, panels, dropdown selectors, alerts, dialogs, and so on, to be used as building blocks to construct web sites or application user interfaces. Because Bootstrap must work within the confines of the DOM and the HTML5 standard, this necessarily exposes a great deal of Bootstrap's internals to its users. For example, to add a Bootstrap site navigation bar to your page, you must essentially copy and paste a large block of HTML and then customize it to your needs as shown in Listing 2.1, adapted from the Bootstrap documentation [7].

```
1 <nav role="navigation" class="navbar navbar-default">
2   <!-- Brand and toggle get grouped for better mobile display -->
3   <div class="navbar-header">
4     <button type="button" data-target="#navbarCollapse"
        data-toggle="collapse" class="navbar-toggle">
5       <span class="sr-only">Toggle navigation</span>
6       <span class="icon-bar"></span>
```

```
7       <span class="icon-bar"></span>
8       <span class="icon-bar"></span>
9     </button>
10    <a href="#" class="navbar-brand">Brand</a>
11  </div>
12  <!-- Collection of nav links and other content for toggling -->
13  <div id="navbarCollapse" class="collapse navbar-collapse">
14    <ul class="nav navbar-nav">
15      <li class="active"><a href="#">Home</a></li>
16      <li><a href="#">Profile</a></li>
17      <li><a href="#">Inbox</a></li>
18    </ul>
19    <ul class="nav navbar-nav navbar-right">
20      <li><a href="#">Login</a></li>
21    </ul>
22  </div>
23</nav>
```

Listing 2.1: Example Twitter Bootstrap navigation bar HTML.

This forces Bootstrap's users to tightly couple the layout of their page with the internal structure required by Bootstrap's navigation bar widget. This coupling hinders a significant refactoring of the navigation widget's internal structure (HTML layout) because that would require the large community of developers to update their applications accordingly. In addition, because CSS rules normally apply across the entire page, the authors of Bootstrap must carefully select the scope and nomenclature of all rules to ensure no unintended side-effects [71]. Even then, conflicts are inevitable when the entire page is treated as a single sandbox and you combine components from many different vendors.

What if instead one could create and share a reusable chunk of functionality—a web component—that hid all of these tedious structural details and encapsulated its private, internal state? What if web authors could create their *own* HTML elements? Using

Bootstrap's navigation bar could be as easy as replacing the code in Listing 2.1 with a custom element like the one in the following example:

```
<twbs-navbar>
  <a toggle href="#">Brand</a>
  <a href="#">Home</a>
  <a href="#">Profile</a>
  <a href="#">Inbox</a>
  <a right href="#">Login</a>
</twbs-navbar>
```

Listing 2.2: Hypothetical custom element version of Bootstrap nav bar.

I wanted my discussion component (Speakur) to follow a similar pattern, both in its external interface and within its internal components, to ensure that internal implementation details were not exposed unnecessarily.

2.2.2 Abstraction, Encapsulation and Composition

The Web Components working group, consisting of software engineers from several major browser vendors, looked at this situation and found that, in practice, browsers already had a suitable model for encapsulating components that hide complexity behind well-defined interfaces. That model was that one used internally by browsers to implement the newer HTML5 tags like the **<video>** element. The <video> element presents a simple interface (API) to HTML authors that hides the complexities of playing high definition video. Internally, browsers implement <video> with a 'shadow' or hidden document inside the object that contains the internal state [50]. For example, an author can write:

```
  <video loop src=...> </video>
```

to cause the video to loop repeatedly.

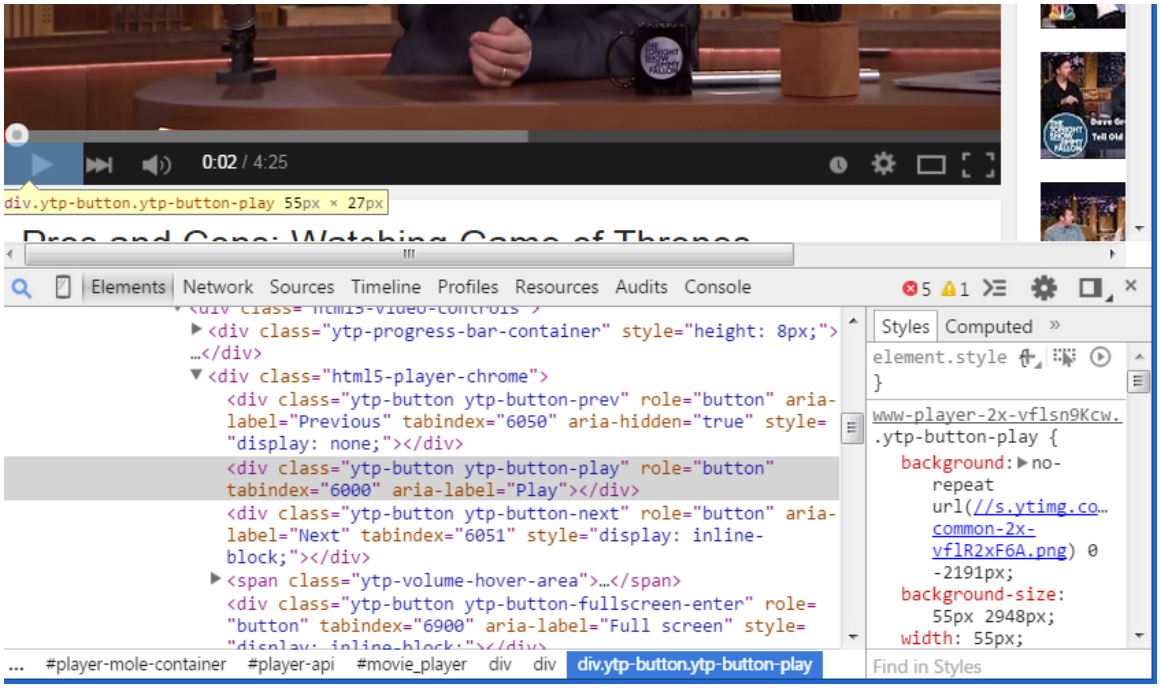

Figure 2.1: Opera's shadow DOM for `<video>` highlighting the Play button.

This shadow Document Object Model inside the `<video>` tag creates the user interface (UI) needed to control video playback such as the volume controls, the timeline bar, and the pause and play buttons. These inner playback controls are themselves built out of HTML, CSS and JS but these details are not exposed to web authors who simply place a `<video>` element on their page. Figure 2.1 illustrates how this works. It shows the shadow (internal) DOM of a `<video>` element on a page with the Play button `<div>` highlighted. A small `#player-api` tag is visible in the DOM path at the bottom of Fig. 2.1. This is an example of the container inside `<video>` using the abstraction of a `#player-api` to encapsulate the details of actually controlling playback within the context of the overall `<video>` interface.

This example illustrates three component design principles that are widely followed in other areas of software engineering [42]:

- Create layers of **abstraction** to represent 'public' details that are relevant to the surrounding code or environment.
- Use **encapsulation** and well defined interfaces to protect private state, hide implementation complexity, and leave implementors free to refactor internals.
- Prefer **composition** or *has-a* relationships over inheritance or *is-a* relationships when building modules to reduce coupling and simplify interface refactoring.

2.2.3 Decoupling Components

Composition helps reduce coupling or structural connections between modules by forcing them to interact using only public interfaces. In the case of the interface for `<video>`, it's composed of simple block elements and scoped CSS roles and the Volume and Play controls aren't particularly special objects, just `<div>` elements with CSS rules and click handlers.

The solution, therefore, to these coupling problems in web authoring is to expose these internal browser APIs for creating elements in a safe and portable fashion. This will allow web authors to create their own rich custom elements using standard portable APIs, encapsulate their internals, and enable easier sharing, composition and integration. The question remains, which specific browser internals must be exposed and standardized in order to support Web Components? The answer to that is the focus of the following section.

2.3 The Web Components Initiative

The Web Components standard consists of two main technologies and two supporting features. HTML Custom Elements and Shadow DOM are the two key players while HTML Imports and Templates support these features. One of the central goals of the Web Components initiative is to maintain interoperability across different browsers and frameworks, so that modules which adhere to the Web Components standard can provide a consistent experience no matter what framework the developer chooses or which browser the user selects. For example, an important benefit of Custom Elements is that they *are* standard HTML elements; they live in the DOM and can be accessed by the usual DOM methods and the majority of standard HTML/JS development tools [62]. They also behave somewhat like objects in traditional object oriented programming in that they have *methods* and hidden internal *state* (data).

2.3.1 HTML Custom Elements

Never before have web authors been able to define their own custom HTML elements that were not found in the official list. Actually, some web frameworks and design tools have been doing exactly that for years, primarily for placing user interface controls that have a complex internal structure like in the Bootstrap nav bar example. These pseudo-custom elements would not get sent to end users because their browsers would not know what to do with them. Instead, preprocessing tools compile these down to standard HTML. In addition, the DOM has long supported creating custom-named elements, but it was not possible to do much interesting with them because they were treated like an ordinary `<span>` element [25]. However, the possibility now exists to create custom

elements in a standard way that will work consistently across browsers with the W3C Custom Element specification [25].

The primary restriction is that all custom elements must have a - character (dash) in their name, such as `<my-element>`. This is to avoid a name collision with future built-in HTML elements. To create a new Custom Element, you must first register it with JavaScript and then you can place your element on the page declaratively in HTML.

```
<script>
 document.registerElement('my-element');
</script>
...
<my-element> hello, world! </my-element>
```

Listing 2.3: Placing a custom element declaratively in HTML.

Or you can create and place custom elements purely in JavaScript:

```
var MyElement = document.registerElement('my-element');

// create a new instance of the element
var thisOne = new MyElement();
document.body.appendChild(thisOne); // add to the <body>
```

Listing 2.4: Placing a custom element imperatively in JavaScript.

In this small example, the result does not look all that different in the browser from a plain `<span>`. To do something more interesting with your custom element you must use the other features in Web Components: Shadow DOM, templates and imports.

2.3.2 Shadow DOM

Shadow DOM encapsulates the internal structure of an element [29]. As we have seen, browsers already use Shadow DOM to encapsulate the private state of standard elements like `<video>` but now this capability is extended to custom-defined elements.

You can think of shadow DOM like an HTML fragment inside an element that describes its external appearance without exposing these structural details[1]. Typically a custom element definition has a template (more on these later) which produces the shadow DOM necessary to render the element. The actual contents of the shadow DOM are just ordinary elements. Any element, whether custom or not, can have zero, one, or more shadow DOM trees attached. A shadow DOM can contain any number of other elements, and those elements can in turn have their own shadow DOMs.

A custom element can wrap regular text, normal HTML elements, other custom elements, or nothing at all, and then project that content through into its shadow DOM, and thus into its visual representation. In the example in Listing 2.2, a **`<twbs-navbar>`** element consumes a set of five **`<a>`** (anchor or link) elements but internally transforms that to something like Listing 2.1, projecting the set of links into the nav menu structure with appropriate wrappers. Speakur follows the same pattern internally when expressing a discussion thread as a list of user comments, each encapsulated into a separate element.

The `<content>` tag is used inside a custom element's template to indicate the spot where the consumed (wrapped) content should be *projected*. This wrapped content is known as *light DOM*, because it's given by the user and projected through into the shadow. Together the shadow DOM and light DOM form the *logical DOM* of a custom element. It is also possible for elements to have multiple shadow DOM sub-trees. This is used particularly for emulating object-oriented-like inheritance relationships between custom elements.

[1] HTML5 Shadow DOM should not be confused with the React framework's **Virtual** DOM, which is conceptually closer to HTML5 Templates in nature than Shadow DOM.

In languages like C# and Java, encapsulation of classes and protection of private object fields are relatively strong guarantees by the language. JavaScript variables can be hidden by scope (*closures*) but shadow DOM and CSS are not completely isolated from the containing page. It is possible to "reach inside" and break encapsulation to at least some degree, but the point is that this must be an intentional act by the developer and not an unexpected side-effect [3].

2.3.3 HTML Imports

One significant problem faced by web developers is the lack of any built-in packaging system for modules in HTML. Prior to Web Components, there was no way to import a snippet of HTML or JavaScript from an external location and insert it exactly one time into the current document, similar to an `#include` directive in the C language or the packaging and import systems in languages like Python and Ruby. JavaScript can always be loaded with a `<script>` tag like usual, but this does not ensure that script resources are executed exactly once, a process known as *de-duping*. A component that uses a certain JS library might be used in two different spots on the page, but that causes the library's script resource to be executed twice, degrading application performance.

Careful design in the library can minimize that impact, but native browser support offers a more consistent and reliable approach. The HTML Imports standard addresses these issues by specifying how bundles of HTML, CSS or JavaScript—components—can be packaged and imported into the current document in a way that ensures automatic de-duping of repeated requests [26]. The major caveat is that de-duping only happens if the resources are named in exactly the same fashion in each case [2].

2.3.4 Templates

The last major piece of the Web Component puzzle is the native HTML5 `<template>` tag. Unlike the rest of Web Components, `<template>` has already become a standard part of the HTML5 specification, although one that is perhaps not widely used yet outside of WC [30]. *Template* is a frequently overloaded word with different meanings in different programming environments. While HTML5 templates have some similarities to the concept of templates popularized by frameworks like Angular and Django, there are some important differences.

HTML5 templates are inert hunks of HTML embedded in the page that can be instantiated into 'real' elements by JavaScript. Their basic function is to give a source input for the shadow DOM when you create a new (custom) element instance and place it on the page. Binding data into templates with special operators[2], also known as a Model-Driven View, is **not** a part of the standard HTML5 template spec. Templates are most useful in combination with 'live' data, not static, unchanging text. The following example of a data-bound template is something that does *not* work with plain Web Components alone:

```
<template>
  The temperature is {{ temp }} in {{ city }} right now.
</template>
```

Listing 2.5: An example of a data-bound template.

Google engineers have advanced a proposal for standardizing Model-Driven Views but it is not yet part of the standard `<template>` element [36]. Instead this functionality

[2]Sometimes called mustaches, handlebars or curly braces.

can be handled by JavaScript frameworks like React or Polymer. Data-bound templates are discussed in more detail in the following chapters.

HTML Templates are useful for providing structure and architecture, but they also help performance. External resources referenced from a template (images, stylesheets, etc.) will not be fetched until the template is actually instantiated. Templates are often used to declare the internal structure (shadow DOM) of custom elements. Therefore the resources needed to use the custom element aren't downloaded until they are actually needed, which is necessary when composing a large application out of numerous distinct components, not all of which are needed immediately. This helps to load the page faster and improves the user experience.

2.4 Related W3C Technologies

There are a number of related W3C initiatives for web standards. Sometimes these are loosely grouped under the label Web Components, and they do support componentization in web application design, but they are a separate part of the HTML5 standard. These include mutation observers, DOM selectors, and so-called 'responsive' attributes designed to adjust the layout automatically according to screen size. All of these techniques have been used extensively in Speakur.

2.4.1 Mutation Observers

For example, *mutation observers* allow a component to register a 'callback' function to observe and react to any state changes of an area of interest in the DOM, whether that change was generated by a user action or another component [27]. This helps de-

couple components by allowing them to react asynchronously to changes in each other's public state without directly interconnecting the components with bound variables. The observers "deliver mutations in batches asynchronously at the end of a micro-task rather than immediately after they occur" [61]. This improves the user experience (UX) by ensuring that callbacks are only called as-needed rather than once for each small change.

2.4.2 Selectors

Another standardization initiative is in the area of DOM / CSS *selectors*, as popularized by the highly successful jQuery library written by John Resig, which as of 2012 was used in half of all major websites [44]. The Selector API was officially standardized in 2013 and browser support is good in current versions [28].

The JS selector API allow you to quickly find DOM elements based on a rule-based description string (the selector) to perform further operations on their state such as reading or modifying data, observing future changes, attaching animations, and so on. The following example shows how to populate a JS variable with the element that has the `id` attribute equal to `some-id`:

```
1  // find an element whose id is equal to 'some-id'
2  var someElem = document.querySelector("#some-id");
3  if (someElem) console.log("Found it!");
4  else console.log("Wasn't there.");
```

Listing 2.6: JavaScript query selector example.

2.4.3 Responsive Layout for Mobile

The rise of smartphones and other mobile devices has accelerated the need for web developers to make their applications responsive to the type of client used to access

it. Creating a web site or application that adjusts to the smaller screen of a mobile phone is often known as *responsive design*. Before the addition of responsive design features to the HTML spec, it was always possible to make manual layout adjustments in JavaScript but this was sometimes brittle and error-prone.

Besides JavaScript, at least three CSS techniques can be used to make a responsive design: the `@media` rule, the Grid layout, and Flexible (Flex) boxes. The CSS `@media` rule allows one to restrict the scope of CSS rules such that they only apply to certain media types including different screen sizes. The CSS Grid layout is intended to control the overall page structure on different device sizes [24]. For example, a 'sidebar' might normally run alongside the main content down the side of the page in a desktop layout, but in a mobile layout the sidebar might come at the end, after the main content. Grid allows for different page layouts for portrait vs. landscape device orientation.

The CSS Flexible Boxes (Flex) model allows individual page components and smaller boxes—user interface widgets—to adjust their layout automatically for different sized screens. Flex boxes are useful for general-purpose user interface (UI) structure, not just device-responsive design, and are widely used in Polymer and in Speakur [19]. Flex boxes are intended to replace the use of the `<table>` tag for formatting and structure, as opposed to semantic tables [15].

2.5 The Polymer Framework

The exciting possibilities offered by Web Components seemed to call for a new framework engineered from the ground-up to take advantage of it. In light of that, a team within Google developed the Polymer framework both to embody the Web Components

architecture [20] and to provide a suite of components and user interface widgets useful for building applications. Because Web Components are a bleeding-edge feature not yet natively implemented in most browsers, the Polymer developers opted to create a *polyfill*, library to fill in these missing features to the degree possible. This polyfill is used in several other Web Components related projects such as X-Tags [32] and Bosonic [8]. Unfortunately polyfills cannot provide a 100% complete Web Components implementation; only native browser support can.

Because Polymer and to a lesser extent Web Components are still experimental and under development, they are both subject to frequent changes. The version of Speakur described in this report is based on Polymer release 0.5. As of the time of this writing, Polymer 0.8 is planned and will contain significant breaking changes to application structure [5]. Small portions of this report pertaining to specific Polymer practices or interfaces are likely to be out of date by the time you read this.

2.6 Speakur: a Discussion Component

My desire to learn more about modern web development led me to investigate web frameworks like Angular and Meteor. I built elementary demos with these two frameworks in particular. Although they certainly let you 'get stuff done', and are used every day to power high-traffic applications, I was unhappy with the non-standard and idiosyncratic nature of these frameworks. They relied on 'proprietary' (even if open source) extensions that were not native to HTML and not easily transportable across different frameworks and architectures. This dissatisfaction led me to learn about the Web Components initiative.

2.6.1 Origins of Speakur

Learning about Web Components quickly led me to the Polymer project. I wanted to create something that demonstrated common use cases for Web Components and also showed off some of the design possibilities provided by Polymer and Material Design [47]. I was also intrigued by the possibilities of a server-free design afforded by Firebase. Some kind of 'live' social plugin like Disqus seemed like a natural fit for the capabilities of Polymer and Firebase, so this led to a discussion plugin for blogs and other articles. My hope was that it would require little or nothing in the way of dedicated server resources in order for other web authors to actually use it, which turned out to be the case.

2.6.2 Motivations and Requirements

I wanted my discussion plugin for web authors to have some of the following attributes:

1. A simple API and usage pattern that abstracted away most of the implementation details. In essence, to demonstrate that it was possible to write an encapsulated plugin for web authors that would fit into a wide variety of application architectures. The question I asked is, how well do Web Components solve this encapsulation and decoupling problem?
2. It should require minimal server resources. Ideally nothing would need to be "installed" and it could be loaded in a cross-origin fashion from online web editors like `https://jsfiddle.net/` and `https://jsbin.com`[3].

[3] See `http://jsbin.com/jubabubazu/10` for a working example.

3. It should be a purely client-side HTML and JavaScript application to the extent possible, with no dedicated server component to deploy. The need for data exchange between users meant that some kind of database service was still required. Therefore it was necessary to delegate some security and validation behaviors to a cloud service or API. Having a client-centric application helped support the first two goals. This made the development of an effective security architecture particularly important in achieving a simple component interface.
4. It should be a 'live' app with a change-event notification system similar to the publish-subscribe (pubsub) design pattern. For example, the interface should automatically update when new replies are posted, or when existing posts are edited.
5. It should support Markdown-formatted comments including syntax highlighting for source code snippets. (The same way that source listings in this report use syntax highlighting.)
6. It should support internationalization and localization features for a global audience. These should be tied to the data synchronization model for immediate updates.
7. If any framework was used at all, it should be based on Web Components. This ruled out the vast majority of frameworks, leaving only Polymer and the less-comprehensive X-Tags [32] and Bosonic [8] projects.

The next chapter discusses some of the high level architectural concerns to be addressed when designing this type of social web plugin, such as creating a scalable database schema, designing a device-responsive user interface, and providing adequate security rules.

Chapter 3

Approach and Software Architecture

This chapter discusses the architectural approach behind Speakur, a social discussion plugin for the desktop and mobile web based on Web Components and the Polymer framework. Web authors can use Speakur to easily add a comment section to their articles or blog posts. Visitors can leave feedback about the article and engage in discussion with each other. Discussions are grouped into topics or 'threads', and within these threads, users can reply to the main article or to each other.

3.1 Functionality and Features

Speakur is a Custom Element (`<speakur-discussion>`) that provides an embeddable discussion forum or comment hosting service for a blog, web page or other web application, similar to the commercial service Disqus[1]. Examples of Speakur's user interface can be found in Figs. 3.1 and 3.2. Placing Speakur inside a web page is straightforward. As shown in Listing 1.1 on page 8, and in Section 4.1 on page 46, the web author simply places the `<speakur-discussion>` element in the HTML at the desired spot. This requires two supporting steps detailed in Section 3.8:

1. loading the Web Components polyfill script,

[1] `https://disqus.com/`

2. then importing the `<speakur-discussion>` element.

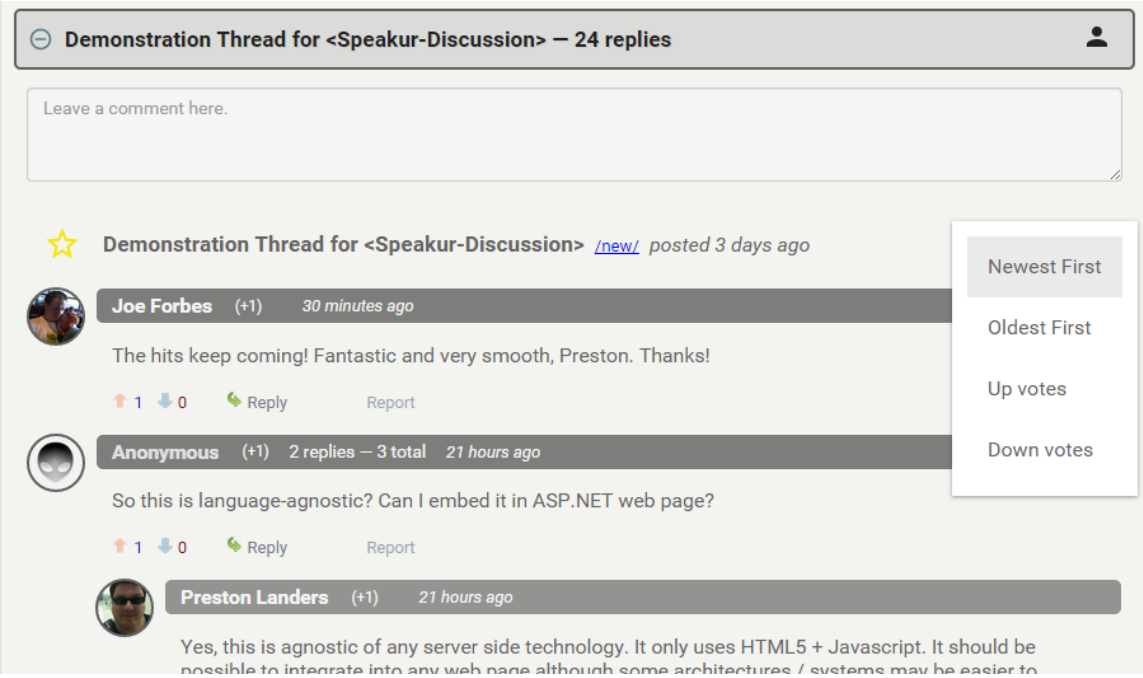

Figure 3.1: A Speakur thread inside a demonstration page.

Once an author imports the element and places it on his page, that site now has an integrated discussion forum for desktop and mobile users as shown in Fig. 3.1. All forum data including user profiles and comment text is stored in an online cloud database called Firebase [10]. The messy details of structuring a discussion forum are abstracted away from the web page author, including the need to deploy a dedicated server component, making Speakur more flexible and component-oriented. The `<speakur-discussion>` element presents a simplified application programming interface (API) to its users. There are only a few options available including the URL of the Firebase instance and the thread target URL (`href`). If you do not provide your own Firebase URL, by default, my demo

database is used instead. Therefore serious users will wish to use their own Firebase account with their own database and resource limits.

In addition to basic commenting features, Speakur offers the ability to vote comments up or down, custom profiles, the ability to use Markdown [12] syntax in comments with source code highlighting for common programming languages, and (rough) user interface translations or localizations into 15 languages as shown in Fig. 3.2.

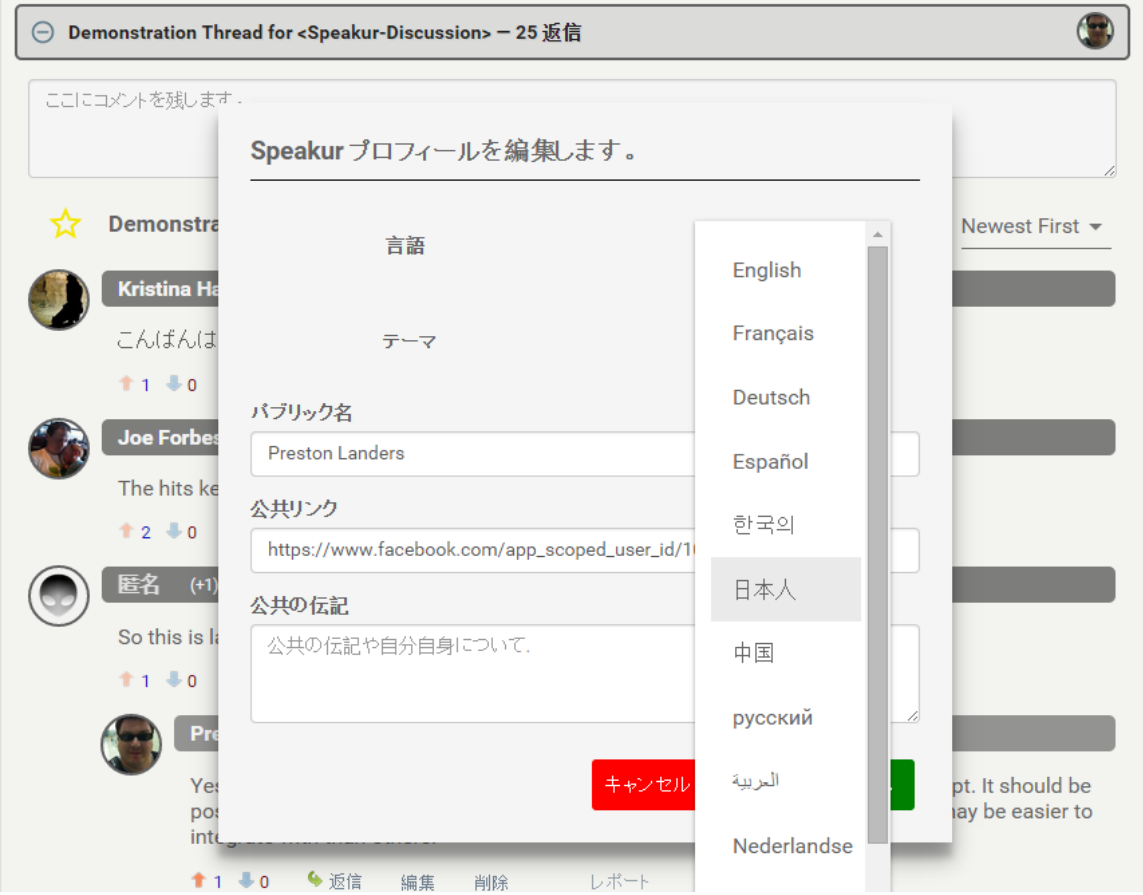

Figure 3.2: Speakur's interface language updates instantly upon selection.

From a technical perspective, one of the more interesting features in Speakur is how Polymer's data-bound templates, also known as Model-Driven Views, allow components to automatically reflect changes in widely separated (decoupled) areas of the application. Also, Firebase's event notification architecture allows all web clients to instantly and transparently reflect any changes in remote clients. Another example of the power of data-bound templates is that all of the user-visible text in the application immediately updates as soon as the user changes his or her locale preference in the dialog in Fig. 3.2. Thanks to data-bound templates, most of the code for this feature is confined to a single translation module, which promotes component decoupling and separation of concerns.

3.2 Software Architecture Overview

It has been said that "any problem in computer science can be solved with another layer of indirection" (usually attributed to David Wheeler). The key to understanding a software package is learning its architecture, which is really a map of these layers of indirection and abstraction. Roy Fielding, the author of the influential REST web architecture, described a software architecture as:

> ...an abstraction of the run-time elements of a software system during some phase of its operation. A system may be composed of many levels of abstraction and many phases of operation, each with its own software architecture.
>
> At the heart of software architecture is the principle of abstraction: hiding some of the details of a system through encapsulation in order to better identify and sustain its properties. A complex system will contain many levels of abstraction, each with its own architecture [40].

The architecture for Speakur is based on client-side (browser) JavaScript code and HTML layout following the Web Components design principles listed in Section 3.4 below. There is no dedicated server component except for the Firebase cloud database service [10]. Speakur is built entirely from plain HTML, JS and CSS files that can be served from a content delivery network (CDN) such as `github.io` or your own server [55]. This low-overhead design allows Speakur to be used on your own website without actually 'installing' any software; just load Speakur directly from `github.io` with an HTML *import* and then insert a tiny bit of HTML markup into your document [55]. This helps fulfill the ease of use requirements #1 and #2 in Section 2.6.2 on page 25.

3.2.1 Speakur's Internal Components

Most of the user interface elements in Speakur—things like dropdown menus and dialogs as well as invisible functional components like expand/collapse elements—are implemented with Polymer's Core and Paper custom element libraries. Speakur presents a simple API through `<speakur-discussion>`, but internally it consists of a number of internal abstraction layers or custom elements. In turn, these internal layers consist of still more focused layers, other Polymer components, simple HTML templates, and wrappers around external JavaScript libraries like `moment.js`. These internal layers are described in Section 4.2 on page 47.

As previously mentioned, in order to make the `<speakur-discussion>` element available for use, you must first load the Web Components polyfill and then *import* the Speakur element, either from `github.io` or your own server. I recommend that you create your own Firebase instance for data security and resource limitation reasons, but even

this is not required. If you don't create your own database, my demonstration instance is used instead. Security for web clients engaging in data manipulation (i.e., posting, editing or deleting comments) is handled entirely through the Firebase authentication and data security rules described below. The simplicity of this arrangement makes it easier to fit Speakur into almost any web application architecture.

3.3 Responsive Design

Although native apps are frequently preferred by mobile users and developers, the mobile web remains an important development platform for the same reason that desktop web apps continue to live alongside native desktop apps; web apps typically do not require installing anything to the device, are always up-to-date, and have a lower barrier to entry for users and developers. Because Speakur is not a standalone application but rather a plug-in designed to be embedded into other web pages or apps, the full document is not under its control. This can affect the mobile user experience, but within these limits, Speakur strives to present a responsive interface to different screen sizes.

The two main techniques used in Speakur for responsive design are CSS flexible (flex) boxes [15] and CSS `@media` rules that apply varied styles to different screen sizes. In addition, Speakur's JavaScript code exposes a `smallScreen` flag to the HTML templates that can trigger layout adjustments, such as moving the user photo to a different location.

The desktop version in Fig. 3.1 (page 28) shows the user photo to the left of the main post area, but the mobile version in Fig. 3.3 above shows how the user photo is moved to the right side of the post header. A CSS `@media` rule for small screens disables the indentation of replies shown at the bottom of Fig. 3.1. The extensive use of CSS flex

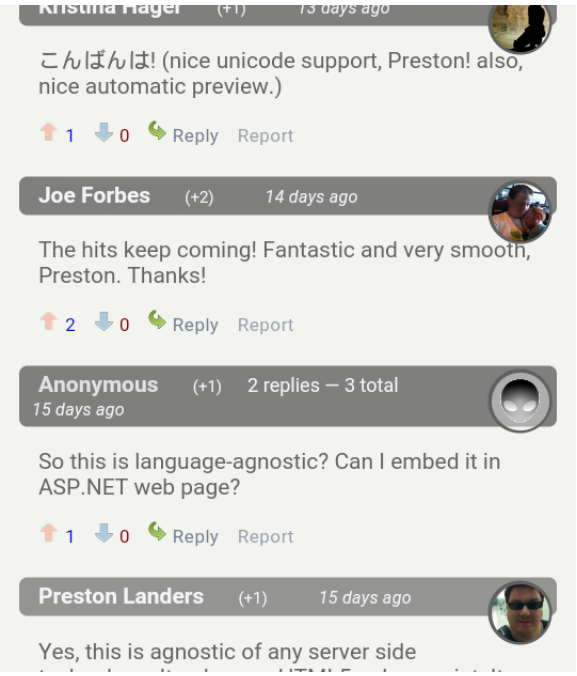

Figure 3.3: Speakur thread on a mobile phone.

box attributes throughout the app ensures that structural elements like headers and toolbars automatically adjust their layout to available space [19]. This is described in more detail in Section 4.7 on page 63.

3.4 Polymer and Web Components

As described in Chapter 2, Web Components are a W3C initiative to expose certain native browser features in a public, standardized way. Polymer is a Google web framework built from the ground up around Web Components. Polymer also provides the crucial polyfill library that is required for Web Component features to work on most current browsers.

In general, Speakur tries to adhere to the core principles laid out by the Web Components developers for general purpose components. It's worth quoting those here in full, because they are applicable to software engineering in general. They are:

1. Address a common need.
2. Do one job really well.
3. Work predictably in a wide variety of circumstances.
4. Be useful right out of the box.
5. Be composable.
6. Be styleable.
7. Be extensible.
8. Think small.
9. Adapt to the user and device.
10. Deliver the key benefit to HTML authors, not just coders [31].

The Polymer project provides two (optional) libraries of Custom Elements for use in your own projects. **Core Elements** includes both user interface widgets and invisible functional elements. Core Elements are minimally styled and can be used directly, but they are also used as base classes for **Paper Elements**, which implement the so-called 'Material Design' look and feel (design language) used by apps for Google's Android mobile operating system [47]. The use of Paper Elements helps give web apps like Speakur a look-and-feel that resembles a native mobile app. Speakur's layout is composed of a combination of native HTML5 elements, Core and Paper Elements, and Speakur's own custom elements which abstract internal implementation details.

3.5 Firebase and Data Synchronization

All persistent data in Speakur is stored in a cloud database called Firebase [10]. Anyone who wants to use Speakur can register for a free account on `firebase.com` and create a database instance to hold Speakur data. No other server component is required. Firebase is a NoSQL-style key-value data store of the kind that has been popularized with the growth of Node.js, a server-side JavaScript environment, and the MongoDB NoSQL database [38].

Firebase provides WebSockets-based event notification and synchronization as well as a security rule description format based on JavaScript Object Notation (JSON) for securing and validating user actions. The use of Firebase as the only server component allows for easy deployment of Speakur with minimal dependencies, helping to adhere to the principles of "think small" and "be useful right out of the box" from the previous section. This also makes Speakur completely dependent on Firebase security rules for authorizing user behavior like deleting posts.

3.5.1 RESTful API

Firebase can be used by itself as the sole provider of data services to an application, as Speakur does, or else it can be used as an auxiliary to other services or REST APIs. One of the key architectural benefits of using Firebase, besides its ease of deployment, is that its data binding and event notification system allows for applications to respond to changes in real-time while maintaining adequate performance.

Firebase itself provides a REST API for data access by programs like Speakur. The term REST or RESTful is sometimes misunderstood, but in Roy Fielding's original

2000 Ph.D. thesis, REST refers to transferring *representations* of application state and using hypertext as the engine of application state[2] [40]. Specifically, 'objects' of whatever type are represented as interlinked hypertext ***resources*** that are operated on by standard HTTP verbs such as `PUT` and `DELETE`. For example, in a Speakur thread, a particular user comment (a post) is an abstract *resource* located at the following uniform resource locator (URL):

`https://YOUR-DB.firebaseio.com/posts/$ParentId/$PostId`

where `$PostId` is an identifier (id) for the post itself, and `$ParentId` is the id of the post this is a reply to, which could be the top-level post (thread id.) In order to delete this post, one would issue an HTTP request to this URL with the `DELETE` verb, as in this `bash` shell script snippet:

```
set DATABASE="https://my-firebase.firebaseio.com"
set POST="fake_post_id"  # the post to delete
set PARENT="parent_post_or_thread_id"

curl --request DELETE $DATABASE/posts/$PARENT/$POST
```

Listing 3.1: Deleting a post with the REST API.

Of course, the server would be expected to check your authorization to delete this resource. Authenticating on the command line is not shown here for simplicity. Viewing (reading) the post is done with a simple `GET` request. Creating a brand new post can be done with `PUT`. Updating an existing post's text is done with the `POST` verb. By default, the resources are *represented* as JSON encoded data, but a client can request an alternative representation such as XML. The storage format for the resource 'at rest' inside the server

[2]Known under the somewhat awkward acronym of HATEOAS.

database is irrelevant from the API perspective.

Areas where typical web APIs fall short of being truly "REST-ful" include:

1. Treating URLs as endpoints for remote procedure calls (RPC) instead of hypertext resources that link to each other in exactly the same way a website starts from the home page and links to various resources which in turn link to other resources.
2. Not closely following HTTP semantics, especially using HTTP verbs inappropriately like using `POST` for all actions including deletion.
3. Not using content-related HTTP headers appropriately for data representations and API versioning [51].

The Firebase API follows typical RESTful patterns in data access, allowing the database and its metadata to be addressed as a set of linked HTTP resources starting from a single root. In addition, Firebase client libraries use a WebSockets connection, a lower-level TCP/IP protocol, to perform event notification and distributed synchronization without the overhead of polling or high-overhead HTTP 1.1 requests. WebSockets are used to enhance performance but all of the data in Firebase (and hence, in Speakur) is accessible from the RESTful HTTP API outside of a WebSocket.

3.5.2 WebSockets

The WebSockets protocol, formally known as RFC 6455, is a TCP/IP protocol that can be used alongside HTTP for persistent data connections between web clients and servers [16]. Its primary purpose is to avoid the overhead of having the client initiate a new HTTP connection to check on the status of something on the server, also known as polling. Aside from the fact that an HTTP connection can be 'upgraded' (protocol

switched) to WebSockets, there is no direct connection or dependency between HTTP and WebSockets. They can be used independently.

Firebase uses WebSockets rather than traditional high-overhead HTTP requests to move data back and forth to the client. This always-on connection allows for sending nearly instant event notifications to all currently active clients with minimal overhead. In practice, this allows the application to update its state in real-time as different users read and write values the database. The Firebase client library 'subscribes' to an area of interest in the database, such as the replies to a particular thread. It then receives notifications when these areas change so it can update the local representations as appropriate. This library also allows authors to register error handler functions to be called in case something goes wrong, but as of this writing, these handlers are not being called due to an internal bug in the `<firebase-element>` wrapper.

3.6 Security Architecture

Because Speakur relies entirely on Firebase for data persistence, its security model is tied heavily to Firebase capabilities. All Speakur code runs inside the client's web browser including the small 'admin' mode. The security architecture of the web is for the most part about protecting the *user* from malicious servers (and other users), not protecting the *server* from the user. It is assumed that servers protect themselves from unauthorized actions. Because Speakur has no 'server' as such, other than the Firebase cloud service, that means the security mechanisms that do things like prevent users from deleting each other's posts must be implemented entirely within Firebase security rules. This is discussed in more detail in Section 4.5.

Firebase implements the two major categories of access control: authentication and authorization. Authentication (sometimes abbreviated *authn*) answers the question "who are you?" while authorization (*authz*) asks "what are you allowed to see and do?" [67]. Confidentiality of in-transit data is handled with Transport Layer Security (TLS), better known as the secure socket layer (SSL) or HTTPS.

The topic of security is important in the context of Web Components because the client web browser is fairly open environment in terms of data exchanges between components. Even with Web Component technologies, data encapsulation is not a hard and fast guarantee. Furthermore, because Speakur attempts to be a self-contained and easy to deploy component, it has no centralized server other than Firebase to enforce data integrity rules. Malicious users can easily step outside of the official Speakur interface and submit commands directly to Firebase. Security is a cross-cutting concern, so this report attempts to demonstrate at least one way to write authentication and authorization rules for a client-centric Web Component that talks to a cloud database.

3.6.1 Authentication

Speakur's authentication and sign-in system is handled through Firebase, specifically Google and Facebook OAuth single-sign on (SSO). Users can sign into a Speakur discussion thread, and hence Firebase, through their Facebook or Google identity. Firebase supports other authorization schemes, including account registration ("simple password"), Twitter and GitHub identities. Site owners who use Speakur can also designate certain threads to allow anonymous commenting.

Every user who registers within a Speakur instance by signing in with one of those

identity providers gets a unique identifier—the `uid` or user ID. This `uid` is used extensively in the database to refer to the user, including in the security (authorization) rules that are external to the actual database (i.e., security metadata). Thread owners also have the option of allowing anonymous posts by users who are not signed in.

3.6.2 Authorization

Firebase lets developers write security authorization rules determine what level of access a user has within the system and what they are allowed to do or see. Speakur's security rules are described in more detail in Section 4.5. The set of security rules for a Speakur database lives in a JSON encoded file that contains expressions that determined whether a given database read or write (change) is allowed. This file resides on the Firebase server, which evaluates the rules when authorizing actions. For example, I defined rules for Speakur which prohibit anyone from editing or deleting an existing post unless they are the original post author or an authorized administrator as shown here:

```
1  "posts": {
2    ".read": true, // anyone can read posts
3    ".write": false,  // deny modification by default
4    "$parentId": {
5      "$childId": {
6        // must be admin or post owner to modify a post.
7        ".write": "data.exists() ? ( auth.uid === data.child('author').
             child('uid').val() || root.child('admins').child(auth.uid).
             child('scope').val() === '*' ) : true",
8        // validate structure of new posts
9        ".validate": "newData.hasChildren([ 'threadId', 'text', 'author'
              ]) && newData.child('timestamp').val() > 1"
10     }
11   }
12 }
```

Listing 3.2: Security rules for the `posts` table (user messages).

The rule structure is dictated by the architecture of Firebase. This setup has certain pros and cons that can be seen in Listing 3.2. On one hand, it's logically designed, and the expressions provide a powerful and fairly comprehensive way to specify the security and authorization logic for your database. On the other hand, non-trivial rule expressions can get awkwardly long and in complex cases can devolve into a maze of nested ternary operators. Having one big file with all the JSON formatted security expressions needed for a database works great for simpler cases but may become unwieldy in a more complex application without the assistance of additional tools.

3.7 Data Flow and Event Handling

One important area of Speakur's architecture is the flow of data within the system and responding asynchronously to local and remote user events. To understand the general flow of information in Speakur (and Polymer), imagine the component as an inverted tree, with the 'root' at the top being the main `<speakur-discussion>` element, and the nodes and leaves under that being the internal parts such as the headers, the posts, and other user interface controls as shown in Fig. 4.3. In this model, information flows *down* through data bindings and bubbles *up* through events.

Data binding is one of the most important extensions to standard DOM provided by the Polymer framework. This ties (or 'binds') a variable from the data model to one or more spots in the shadow DOM, or else to an input or output from some other component, so that any change in the variable is reflected in the bound locations. Two primary uses of data bindings are binding a custom element's representation (shadow DOM template) to live data, and sending data to other elements or components [17]. Data binding

helps provide separation or decoupling between the user interface or *view* and the underlying data *model,* a design pattern that is commonly known as Model-View-Controller (MVC). A short example can be found in Listing 2.5 on page 20. Sections 4.4.1 and 4.4.2 discuss data binding and data-bound templates in more detail.

Although Polymer does support 2-way bindings, experience has shown that when exchanging data with external components, 1-way (top-down) bindings are easier to reason about and should be preferred. Bound variables should flow in one direction, generally parent to child as mentioned above. So how should a child communicate changes back to the parent? The parent (or any other interested party) can register a DOM mutation observer to be notified when the child value changes, or the child can fire an *event* that the parent can respond to.

As mentioned in Section 2.4.1, mutation observers are a standard way to register a callback to be run when some area of the page (DOM) changes. A callback in this case is a function that reacts to a change in some other part of the system. This doesn't necessarily have to be tied to a specific variable like with data-bound templates and can reflect any change in any DOM attribute for standard *and* custom elements.

3.8 Deploying Speakur

Speakur is designed to be easy to deploy. Adding a discussion forum to a blog or web app is as simple as altering the page to:

1. load Polymer's Web Components polyfill,
2. import the `<speakur-discussion>` element,

3. then place `<speakur-discussion>` on the page at the desired location.

Because steps 1 and 2 above can load these resources from an external service or content delivery network, Speakur does not require installing any software to the web server. The HTML, CSS, and JavaScript files, plus associated resources like images and JSON language files, can all be loaded from a different web host. This is known as cross-origin resource sharing, or CORS. Speakur avoids a common security restriction associated with CORS known as Same-Origin Policy, which is used to prevent a class of attacks called Cross-site Request Forgery (CSRF) [14]. It does this by relying entirely on Firebase for live data, which in turn uses WebSockets, which are not subject to Same-Origin Policy restrictions on asynchronous JavaScript HTTP requests (also known as AJAX or `XMLHttpRequest`). This allows Speakur to be used on a site without that site having installed a copy of its files or directly serving them to clients, making it a more flexible component.

3.8.1 Software Dependencies

Like most applications, Speakur relies heavily on other libraries and frameworks to implement some of its underlying behaviors. Some of these libraries in turn depend on other libraries. Collectively, all of the third party modules required to run Speakur are called *dependencies*. For example, safe HTML rendering of user-supplied Markdown-style text is handled by the excellent Marked library [49]. See Appendix A on page 76 for the full list of Speakur's direct dependencies.

Taking advantage of the de-duping feature of HTML Imports requires that you name the path to your resources and dependencies in a consistent fashion. In other

words, if Component A and Component B both require Component Z, both A and B must use the same URL when requesting (importing) Component Z. Furthermore, each of Z's dependencies must also follow this same pattern when importing their own dependencies in order to fully realize de-duping. Therefore Speakur follows the recommendation of the Polymer framework and uses Bower to manage dependencies [9]. Speakur only needs to list which packages it requires, either by name or their Git repository address, and Bower handles downloading these to a managed component directory alongside Speakur itself.

3.8.2 Vulcanize

One possible 'problem' with adopting Web Components architecture is that it encourages the partition of a large application into numerous smaller components or files. Of course, this is really a *feature* designed to enhance code organization, encapsulation and productivity, but it has one important side effect: under the HTTP 1.1 protocol that currently powers the web, each small component requires a separate request which degrades page loading times. Techniques like `Keep-Alive` headers can help, and the HTTP 2.0 protocol addresses this question more comprehensively but is not yet finalized or widely adopted.

In the meantime, the Polymer project provides a tool called Vulcanize which concatenates and minifies your web components into a single file. The result is functionally the exact same but takes less time to transfer. Minification removes all comments, whitespace and non-essential elements from the code to compact it and reduce transfer times. Concatenation combines all of the required text resources (HTML, CSS, and JavaScript

files) into a single[3] file to reduce the number of HTTP requests. Whether using Vulcanize results in an overall faster site ultimately depends on a number of factors including how and when the components are used. For that reason, empirical testing is needed to know whether it should be used in production on a real site [21]. Table 4.3 on page 65 illustrates how Vulcanize helps improve loading performance in three browsers. Every time I release a new version of Speakur, I update the `gh-pages` branch in its Git repository with a Vulcanized edition that includes everything needed to run it, including Polymer and all of its other dependencies. This publishes it to the `github.io` CDN and makes it available to users.

[3] Except when Content Security Policy (CSP) requires the enforced separation of HTML, CSS, and JS. In this case, three files are used.

Chapter 4

Implementing a Web Component

4.1 Overview

Speakur is an HTML5 web application that uses the Polymer framework's implementation of Web Components. It is primarily a client side application with no dedicated server component other than Firebase. It is delivered as a single Custom Element, `<speakur-discussion>`. You import the tag with `<link rel=import href=...>` to make it available to place on the page. This element has a data-bound `<template>` that provides the element's visual representation (shadow DOM). Actually, a custom element's representation, or logical DOM, may consist of both encapsulated shadow DOM as well as light DOM that is supplied by the *user* of the custom element and *projected* into the shadow DOM as discussed in Section 2.3.2. In Speakur's case, the discussion forum is self-contained in terms of content; light DOM is not needed or used in the top-level element. Speakur's options or parameters are controlled with attributes like this:

```
<speakur-discussion
  firebaseLocation="https://speakur-demo.firebaseio.com"
  xtitle="This is the thread's (initial) title."
  href="demo1"
  initiallyOpen="true"
  allowAnonymous="true">
</speakur-discussion>
```

Listing 4.1: Using HTML attributes to set Speakur options.

4.2 Layout and Structure

Structurally, Speakur consists of JavaScript, HTML, and CSS files, along with a few other resource types like images and JSON language files. All of the these internal resources and components are hidden from consumers who only have to import and place the main `<speakur-discussion>` element as discussed in Section 4.8 on page 64. The rest of the components are brought in by internal imports inside `<speakur-discussion>`.

Internally, Speakur is composed of a number of sub-components, a partial list of which is found in Table 4.1. These components are listed in three broad categories: structural containers, logical services, and user interface elements. The structural elements provide a container and abstraction layer for a group of related child elements. For example, `<speakur-card>` provides a Material Design-styled generic 'card' consisting of a styled header, body, and footer. These containers may have certain visible elements such as lines around their border, but most of their representation comes from the components inside.

The logical service elements do not have any direct visual representation. They perform data-related services, provide APIs, and wrap external libraries. It is often useful to provide a custom element wrapper around a non-WC-aware library. For example, the Firebase client library is a general purpose JavaScript library, and is not specifically adapted to Web Components or custom elements. For this reason the Polymer project maintains `<firebase-element>` as a wrapper around the main Firebase library [18]. Within Speakur, each component gets its data either directly from its own `<firebase-element>`, or else from a data binding from an immediate parent element that has its own `<firebase-element>`.

Name	Function
Structural containers	
`<speakur-discussion>`	Top-level public component.
`<speakur-thread-view>`	Container for the comments displayed in an entire thread.
`<speakur-card>`	Provides a Material Design 'card' container.
`<speakur-post-set>`	A container for a list of posts such as replies to a specific post.
Logical services	
`<firebase-element>`	Polymer's Web Component wrapper around Firebase.
`<speakur-base>`	Base-class for most other Speakur components.
`<speakur-i18next>`	My Web Component wrapper around the i18next library [13].
`<speakur-profile>`	Users' session data and preferences.
`<speakur-post-vote>`	Controller for voting posts up or down.
User Interface	
`<speakur-compose>`	Composing replies and posts.
`<speakur-post>`	Displays a single user post/comment.
`<speakur-login-button>`	Login/logout button and dropdown.
`<speakur-theme>`	Base class for all themes, mainly CSS rules.
`<speakur-theme-blue>`	A specific theme.
`<speakur-dialog-profile>`	Dialog to edit user preferences.
`<speakur-lang-select>`	Dropdown to choose the UI language.

Table 4.1: Partial list of Speakur's internal components.

Figure 4.1 shows a partial listing of the internal component files. One of these is abstraction layer for an internationalization library. Following the `<firebase-element>` example, I created a simple custom element wrapper around the **i18next** JavaScript library [13]. This wrapper is called `<speakur-i18next>`. It tells i18next where to find Speakur's translation files and creates a Polymer *filter* to perform translations from data-bound templates. See Section 4.6 below for details. Logical elements are also used to provide abstract 'controllers' (in the MVC sense), base classes, adapters, facades, and other design patterns.

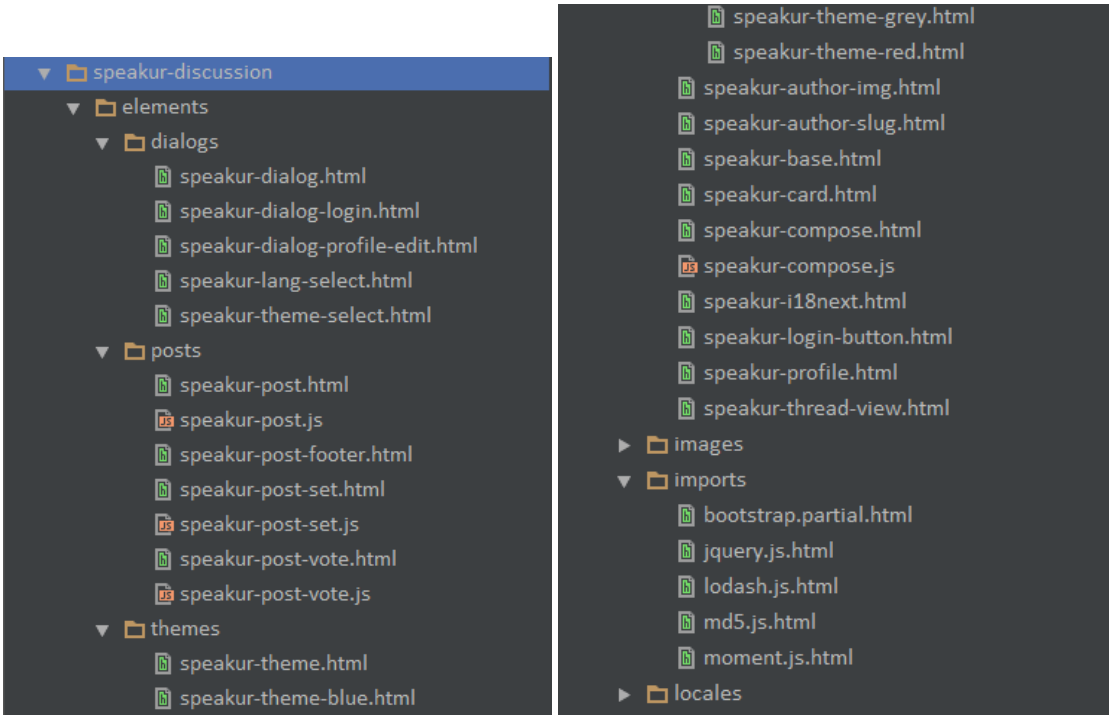

Figure 4.1: Internal elements file layout (partial).

In addition to structural and logical elements, Speakur has a number of user interface (UI) custom elements to do things like display an individual user post or show the

post composition editor. Elements are also reused extensively in different contexts; for example `<speakur-post>` is used for a 'live editor preview' inside `<speakur-compose>` as well as for showing posts in the main `<speakur-thread-view>.`

Some of Speakur's internal components like `<speakur-theme>` are also base classes for other elements in a way that is similar but not identical to classes in object oriented programming (OOP)[1]. Although composition or *has-a* relationships are generally preferred, inheritance or *is-a* relationships can make sense when you truly want to be able to substitute one instance for another interchangeably. JavaScript does not have the concept of a formal interface contract, which puts the burden of type checking on developers and unit tests, but HTML elements (including custom elements) have formally specified interfaces in the form of declared attributes.

4.3 Database Design

Speakur uses Firebase for NoSQL-style database storage. Traditional relational databases (SQL) have emphasized data normalization – the removal of informational redundancies from databases such that a given *fact* is only recorded in a single place. While this helps ensure data integrity, it can adversely affect query time and scalability as additional joins are required to bring in the necessary facts. One of the defining characteristics of the NoSQL movement is denormalization—that is, the principle of eliminating redundancy is sacrificed in order to gain performance [66]. Facts can be defined in more than

[1]Note that JavaScript itself is *prototype*-based and does not have traditional classes or inheritance. Similar behavior is obtained by using regular object instances (instead of classes) as the prototype for instantiating new objects.

Table Name	Function	Key Structure
`admins`	Administrator authorizations	`$uid`
`posts`	User posts	`$parent->$child`
`postvotes`	Public vote counts for posts	`$parent->$child`
`profile`	User data and preferences	`$uid`
`threads`	Discussion thread definitions	`$threadId`
`uservotes`	User votes for posts	`$uid->$parent->$child`

Table 4.2: Speakur's database tables.

one place to speed up queries by reducing the number of read operations.

For example, some information about a post's author such as their public username, id, and photo url is saved inside each post they write so that it's not necessary to look up this information separately just to display the post. One consequence of this is that changing your public name doesn't retroactively change the name on all of your previous posts, just new posts going forward. Certainly, if that name updating was deemed necessary according to business requirements it could be accomplished.

The logical interface presented by Firebase resembles a single JavaScript object which can contain other objects and lists nested up to 32 levels deep [10]. A JavaScript object is fundamentally a `key->value` mapping, also known as a hash map or (in Python) as a dictionary. Although this nested object structure doesn't correspond exactly to traditional relational database (SQL) tables, it is convenient to refer to the top (first) level of nested objects as "tables". The leaf node objects are "records" with data fields, and the intermediate objects are keys within the table. Like most NoSQL databases, Firebase is forgiving with regard to structure and fields; a given record is not guaranteed to follow

any particular structure unless this is required by the security and validation rules.

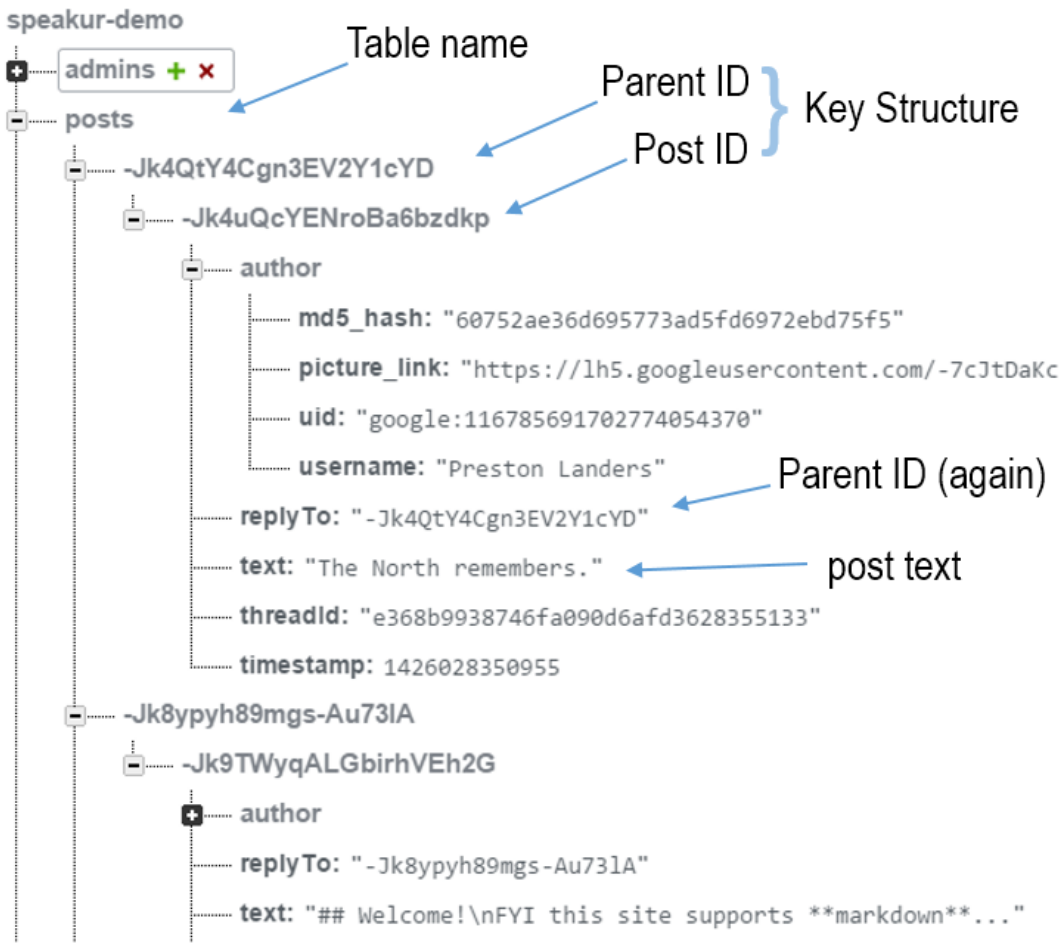

Figure 4.2: Structure of the `posts` table.

The key structure column in Table 4.2 signifies the meaning of the keys underneath a table. For example, the main `posts` table has a `$parent->$child` key structure. The first layer of keys beneath `posts` are post *parent* ids: the id of the post that this is a reply to, or the thread id in the case of a 'top-level' post. The next object down the key hierarchy is the *child* id, which is the id of the actual post itself. The keys beneath that are

the 'fields' of the table, such as the `text` and `replyTo` values. Figure 4.2 shows Firebase's administrative view of the database. The `posts` table is expanded, showing the parent and child id layers and the actual post object nested within. Deeply nested data structures are not good for scalability; relatively flat tables are best [10, 66]. The key structure will become important when we apply security rules in Section 4.5.

In addition to denormalizing the data as necessary, sometimes it is convenient for security reasons to keep related bits of data in separate tables in order to apply different security rules. For instance, we want users to be able to modify a post's vote count without being able to modify the post itself. The nested and denormalized structure of the tables helps ensure that we only fetch what we need, when we need it. The flip side is that we need to be aware of these data duplications and update them as necessary, which can be difficult in a more sophisticated application. But in the post vote count example, even if a malicious user sets a false count on the globally-visible value, we can always recalculate the true count later using the individual user vote records.

4.4 Component Synchronization

Speakur consists of a number of Polymer components which break down the problem of presenting a discussion forum into smaller tasks. Some of these components are listed in Table 4.1 on page 48. They form a hierarchy with `<speakur-discussion>` at the top (root). Figure 4.3 illustrates this, with many components omitted for brevity.

The general data flow is that bindings carry information *down* from parent to child, and changes flow *up* in the form of events and observed mutations. Two-way bindings are possible in that a child element can modify a bound variable and the value would

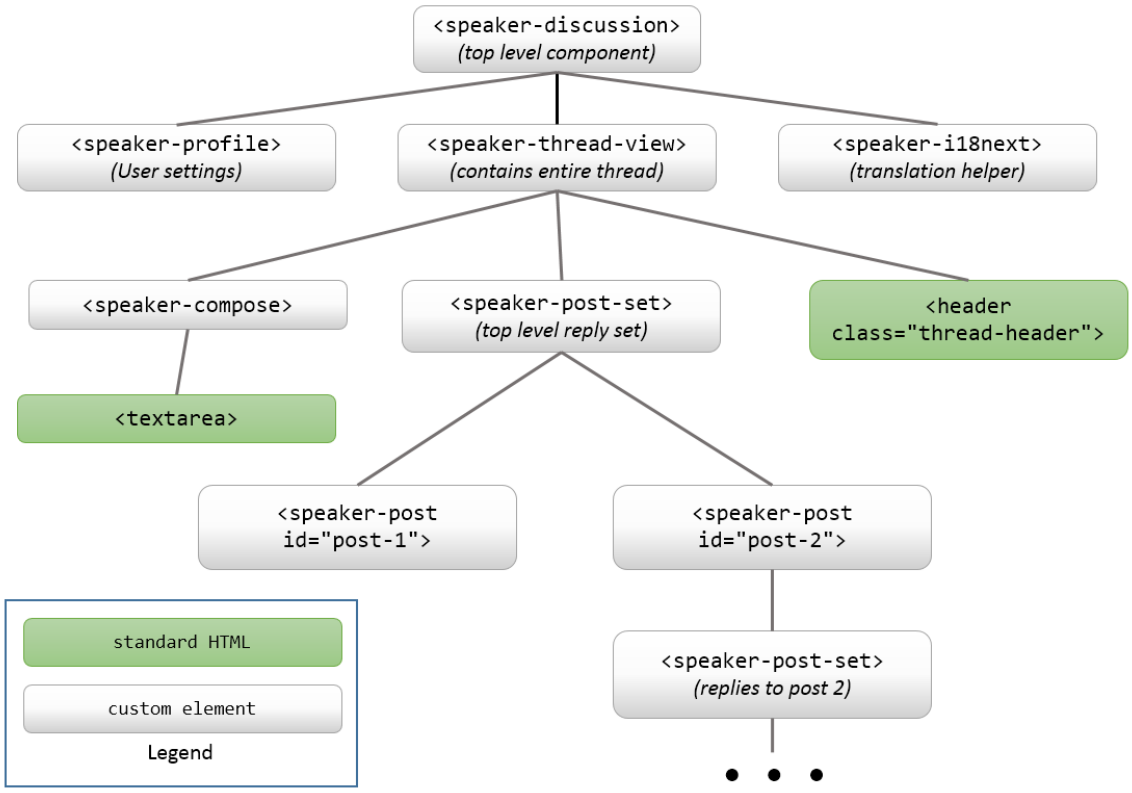

Figure 4.3: Speakur component hierarchy (partial).

be reflected in the parent and vice-versa, but in some scenarios this makes it difficult to determine an 'authoritative' value or causes other circularity problems. For this reason, bindings should be used one-way across component lines, but two-way bindings are useful within a component to update its data model automatically from user input [17].

Each component keeps its own `<firebase-element>` to pull data from Firebase as needed, or in some cases the relevant object is passed in as a binding from a parent element that has its own `<firebase-element>`. This keeps database specific knowledge localized to each component, helping it "be composable". Speakur as a whole doesn't

know or care what storage solution its individual components use, whether Firebase or another API.

4.4.1 Data Bindings and Events

From an MVC viewpoint, a Polymer element with instance variables is the 'model'. The element's data-bound `<template>` is the 'view', and the JavaScript code is the 'controller'. Data bindings carry data information down from parent to child while DOM events propagate upwards.

Using `<firebase-element>` isolates each component from direct interaction with the general purpose Firebase JavaScript library and ties the database directly into the Polymer data binding system. Persisting a change is incredibly easy; writing a new value to a variable not only saves it to the database but pushes the change to all other 'subscribers'—whoever is viewing that post or other object at the time. The `data=` attribute on `<firebase-element>` allows binding a variable in a component to a remote database object:

```
1 <!-- from speakur-post.html -->
2 <firebase-element
3    data="{{ post }}"
4    location="{{ fbLocation(firebaseLocation, 'posts', parentId,
        postId) }}">
5 </firebase-element>
```

Listing 4.2: Binding the `post` variable to a database record.

In the example above, the data retrieved by the `<firebase-element>` is bound by the `{{ }}` operators to the component's `post` variable. Any changes to this database object, whether locally or remotely initiated, will be reflected in the `post` variable and

any associated data-bound `<template>`s, and vice-versa. The `location=` attribute (the database source URL) for this `<firebase-element>` is bound to an expression which finds the location with the `fbLocation` method. Any changes in the variables `firebaseLocation`, `parentId` or `postId` will cause `fbLocation` to be recomputed, which could in turn cause `post` to pull from a different location. Notice that `location=` has the same structure as the resource path in the `DELETE` example from Listing 3.1.

DOM events carry state changes up from children to elements above it. Polymer provides the `fire()` method to trigger a named event with extra data attached. This is a convenience wrapper since it can be done with pure JavaScript. An example of using `fire()` can be found in the language selection dialog from Fig. 3.2. The language selection UI is handled in the `<speakur-lang-select>` component, which is only concerned with presenting the language chooser and not with handling the actual localization, reinforcing separation of concerns. When the user selects a new language it fires an event that bubbles up to the top level `<speakur-discussion>` element:

```
// from speakur-lang-select.js
domReady: function () {
    // listen for core-select event fired by the dropdown menu
    this.$.menu.addEventListener('core-select', function (e) {
        if (e.detail.isSelected) {
            var oldLocale = this.locale;
            var newLocale = e.detail.item.id;

            // Tell container(s) the language selection changed
            this.fire('speakur-locale-change',
               {oldLocale: oldLocale, newLocale: newLocale});
        }
    });
}
```

Listing 4.3: Firing a language change event.

A handler in the top level container (`<speakur-discussion>`) responds to this named event (`speakur-locale-change`) and tells the internationalization component to update the language. This in turn sets the **`lc`** (locale) property in the base element. This property is then used in translation expressions as discussed in Section 4.6.

4.4.2 Data-Bound Templates

Speakur translates internal variables (the model) into visible output with the use of data-bound templates. This is similar in effect to the model-view-controller design pattern. As mentioned above, the custom element itself is the 'model' and its `<template>` is the view. This allows embedding variables directly in the HTML representation of a component as shown in Listing 2.5 on page 20 and here:

```
<!-- from speakur-post-footer.html -->
<div on-click="{{editPost}}" hidden?=
    "{{!canEditPost(post, globals.profile, globals.isAdmin)}}">
  {{ "Edit" | $$(lc) }}
</div>
```

Listing 4.4: User interface control with data bindings (edit post link).

There are three data bindings with `{{ }}` in Listing 4.4:

1. The `hidden?=` attribute (provided by Polymer) binds to `canEditPost` to determine if the Edit link should be shown under a post. In other words, is this user allowed to edit this post? If not, hide this Edit `<div>`.
2. The `<div>` binds its click event to `editPost` so it functions as a link. The `editPost` method of this component will be called when the Edit link is clicked.
3. The inner content of the `<div>` (its light DOM) is bound to a Polymer filter expression that translates the word "Edit" to the current language.

The `{{ }}` operators are not limited to binding to simple variables. Polymer supports a rich expression language within binding operators. That said, keeping `<template>` expressions simple and moving more complex logic to methods in the JavaScript controller helps uphold separation of concerns between controller and view.

4.5 Data Security

Because Firebase is Speakur's only 'server', most of its security rests in Firebase's authentication and authorization rules. Obviously the user interface should be crafted such that undesirable actions are not presented as options for the user, but one also has to consider malicious users stepping outside of the allowed interface and/or directly accessing the REST API. Authentication ensures that we know the identity of anyone making database changes, and the Firebase security rules enforce authorization requirements.

4.5.1 OAuth Authentication

Speakur supports signing in (authenticating) users with two popular single sign-on services: Google and Facebook. This avoids the need to create a dedicated user registration and password system. In this scenario, Google or Facebook is an OAuth identity provider (IdP), and Firebase (standing in for Speakur) is a service provider (SP). The identity provider gives the service provider a limited selection of personal information, generally their name, profile picture, and email address. The user authenticates directly to the chosen IdP (e.g. Facebook) and their password is never sent to Firebase or Speakur. Future versions may support additional identity providers like GitHub and Twitter as well as Firebase's own simple user registration system.

Inside Speakur, authentication is handled by the `<firebase-login>` element, provided by `<firebase-element>` [18]. A binding is set up between that and the `user` variable in `<speakur-discussion>` so that when user authentication is completed, the `user` variable contains an object with user properties like their full name and authentication ID. The authentication session is automatically used by any `<firebase-element>` anywhere on the page provided that their `location=` points to the same database base URL.

4.5.2 Firebase Security Rules

Authorization to perform any given action in the Speakur database is determined by consulting the nested rules in the JSON-formatted security object, whose documentation can be found at [11]. These rules can be entered directly into the Firebase administrative console and a reference copy can be found in the Speakur source code repository under the file `security-rules.json` [56]. These rules are enforced by the Firebase service itself, not my application code.

The structure of the security rule object mirrors the nested hierarchy of the Firebase database itself. Each top level key maps to rules for a particular database "table" like `posts`. These fall into three categories: read, write, and validation rules. These are each structured as boolean expressions (predicates) that determine whether the given action is allowed. Example rules are given in Listing 3.2 on page 40.

1. `.read` rules determine whether a given record can be retrieved by the current user.
2. `.write` rules authorize the creation, modification and deletion of a record.
3. `.validate` rules check whether a record is correctly *structured*.

Write rules determine whether a given create, modify or delete is allowed. Validate rules are run after a write rule has passed in order to check whether the new version is correctly structured per business rules or requirements. Each expression has access to several pre-defined variables including snapshots of the database as it exists both before and after the change would be applied. For example, Listing 3.2 (page 40) shows rules for the `posts` table. The `.write` rule asserts that anyone can create a new post, but modifying an existing post requires that you (`auth.uid`) are either the post owner or an administrator. The `.validate` rule ensures that all posts contain at least 4 keys: `threadId`, `text`, `author`, and `timestamp`. More sophisticated rules and validations are possible, and rules can be nested, but it can be unwieldy to fit a large set of rules into a single predicate expression, making them more difficult to understand and maintain.

4.6 Internationalization and Localization

Adapting an application for different languages and customs is called internationalization (i18n) and localization (l10n)[2]. Speakur offers UI translations for 15 languages. The user can select a new language from the Profile dialog and the interface updates immediately. String substitution with the currently selected language is handled by the i18next JavaScript library, which is abstracted with a custom element wrapper `<speakur-i18next>` [13]. This wrapper provides a Polymer filter named `$$` which is used in `{{ }}` expressions in data-bound templates to translate user-visible UI strings. Of course, the users' posts themselves are not translated; just the application's interface strings.

[2] *Internationalization* refers to the process of **enabling** an app to be localized, and *localization* refers to adapting it to a **specific** locale.

The i18next library loads strings out of JSON files, one for each supported language. I obtained translations by creating an English language file and then passing it through the Microsoft Translation API using 'Eurgh!', a Python program that I wrote for another project [54]. The i18next library includes variable interpolation (insertion points for data) and pluralization rules that are important for grammatically correct text. Here is a short excerpt from the English file followed by the Russian version:

```
// from speakur-en.json
{
  "View Comments": null,
  "replies_count": "__count__ reply",
  "replies_count_plural": "__count__ replies"
}
// from speakur-ru.json
{
  "View Comments": "Посмотреть комментарии",
  "replies_count": "ответ __count__",
  "replies_count_plural": "__count__ ответы"
}
```

Listing 4.5: String resources for internationalization.

This example shows that with the `'View Comments'` key, the corresponding value can be null if the key itself can serve as the text. The other two keys illustrate variable interpolation and pluralization logic where different grammatical forms can be selected based on a numeric variable, in this case, the number of replies that a post has. These translation strings would be used in a template like:

```
<!-- from speakur-post.html -->
<div class='post-replies-count'>
  {{ 'replies' | $$({count: replyCount}, lc) }}
</div>
```

Listing 4.6: Internationalizing a data-bound template.

The `i18next` library sees that a `count` variable is provided to `$$` and looks for that key (`replies`) with either a `_count` or a `_count_plural` suffix depending on the cardinality of `count`. In this expression the `lc` variable (the second parameter to the `$$` call) reflects the user's current language setting, such as `lc=en` for English or `lc=ru` for Russian. Interestingly, the `lc` variable is *not* required by the `$$` filter because it already knows the current locale. Instead, `lc` is included in the expression merely to register a value dependency with Polymer such that when the locale is changed elsewhere, all dependent expressions are recalculated, or in this example, the strings are re-translated to the current locale[3]. In this case it would output something like "1 reply" or "2 replies" as needed. Otherwise Polymer wouldn't bother to recalculate this expression when the locale (`lc`) changed because none of its direct clauses had acquired different values. Adding `lc` to this expression ensures that the text is updated when the language changes.

Another powerful internationalization feature is provided by the moment.js library, a general purpose date/time library that also provides date-related localization services. Unlike the general UI strings, the date translations are not provided by Speakur, but are included in moment.js itself. In addition to formatting dates and times (like the time of a post) according to local conventions, it also provides a `fromNow` function that outputs a localized "ago" string—the amount of time elapsed since a certain point such as "10 seconds ago" or "3 weeks ago". Speakur uses this in post headers to show how long ago they were posted, and ties them to a timer-based value dependency such that the "ago time" updates automatically on the page as time passes. For example, immediately after posting a new reply, its header will say "posted a few moments ago." After a minute it

[3]Polymer expression dependencies are implemented internally with DOM mutation observers [17].

will say “posted a minute ago”, and so on in idiomatic fashion appropriate to the current language. This text has a tooltip which gives the full localized date such as “Wednesday, March 11th 2015 7:53 pm”.

4.7 Device-Responsive Design

As mentioned in Section 3.3, Speakur uses several techniques to achieve a design that automatically responds to different devices and screen sizes, including mobile phones. The three main responsive design techniques used in Speakur are:

1. Using CSS `@media` rules to apply different styles such as sizes and margins to different screen sizes.
2. Using CSS Flexible boxes (a.k.a. ‘flex’) layout with `wrap` options to create structures like toolbars while allowing them to gracefully rearrange on smaller screens.
3. Using a JavaScript variable (`smallScreen`) to control the behavior of data-bound templates and provide a different experience on smaller devices.

In Speakur’s style sheets, a small screen is treated as the base case and larger tablet or desktop-style devices are given extra rules with `@media`. For example, the following rule gives the main Speakur container more padding on large screen devices:

```
<!-- from speakur-discussion.css -->
@media only screen and (min-device-width : 800px) {
  :host .speakur-body-container {
    margin: 4px;
    padding: 8px;
  }
}
```

Listing 4.7: CSS @media rule for large screen devices.

In summary, CSS Flexible boxes let you give `<div>` and other elements 'flex layout' attributes that provide guidance to browsers about how to align the contents inside and adjust for available space. Polymer provides convenient layout shortcuts for the standard CSS attributes [19].

4.8 Publishing and Deployment

Speakur is published to `github.io`, a static web host and content delivery network for GitHub projects. This allows users to import the component without hosting it themselves. Web authors can also host Speakur's files on their own server if desired. This makes it very easy to deploy Speakur in a wide variety of system architectures. Speakur is provided in two versions; the 'development' version where each resource is provided as a separate, raw, non-minified file, and a 'production' or Vulcanized version where all necessary resources are combined into a single file for faster loading speeds [21].

In a relatively small application like Speakur the difference is not huge, especially on Google Chrome which already supports Web Components natively, because the HTML component transfer times are largely dwarfed by the cost of loading the actual discussion from the database. Future protocol enhancements like HTTP 2 may eliminate this discrepancy. That said, using Vulcanize does offer current benefits, as shown in Table 4.3 which compares the time (in milliseconds) to initially display the Speakur component and then fully load a thread with 25 comments in three popular desktop browsers. These figures partly reflect the degree to which each of these browsers natively supports Web Components at this time. At the moment Firefox does not natively support as many Web Component features as Google Chrome or Opera, so the polyfill must do more work, neg-

State	Raw	Vulcanized	Reduction
Google Chrome			
visible	2200	1150	47.7%
complete	4200	2900	31.0%
Mozilla Firefox			
visible	7400	6050	18.2%
complete	12000	10500	12.5%
Opera			
visible	2800	1100	60.7%
complete	7000	2800	60.0%

Table 4.3: Loading time (in milliseconds) in three desktop browsers.

atively impacting load times on that browser. I expect that browser support will improve greatly over the next few years after the Web Components standard is finalized.

Chapter 5

Analysis and Lessons Learned

This report aims to demonstrate how certain traditionally difficult problems in web development have been addressed by Web Components. The principles underlying Web Components and Polymer are summarized by the list in Section 3.4 taken from [31]. I have tried to make Speakur adhere to these principles both internally and externally, and to demonstrate the application of abstraction and encapsulation patterns to creating flexible, composable, reusable, sharable components. My goal is to understand how the W3C Web Component initiative will impact web application engineering in the future. By all appearances, the long term impact will be substantial.

5.1 Web Components Architecture Analysis

Web Component's essential benefit is that it allows decoupling of components, separation of concerns, and the encapsulation of internal structure. This raises bundles of discrete functionality or 'components' to a higher level of abstraction and will help open up a new ecosystem of reusable, extendable, sharable modules. The Web Component principles from Section 3.4 emphasize thinking small, breaking the problem down into manageable chunks and being adaptable, extendable and composable. Web developers were already doing this in many cases, but without formal support from the browser.

Perhaps the most interesting piece of advice is to "deliver the key benefit to HTML authors, not just coders" [31]. It underscores that, fundamentally, the web consists of *documents* with *authors*, a fact that is sometimes forgotten by the myriad of JavaScript libraries and frameworks. The components that will find the most success will be those which focus first and foremost on providing convenience and benefit to HTML authors and content developers, not just the software engineers who maintain the libraries and frameworks behind the scenes. Speakur aims to provide as small a deployment surface as possible to web authors so they can easily add a discussion forum to their site without embedding a big blob of HTML. The growth of social coding sites like GitHub will further encourage the sharing and reuse of Web Components designed along these principles.

At least initially, Web Components and closely aligned frameworks like Polymer will be 'just another framework' in an already crowded scene. However the fact that the Web Components standard is, or will be, baked into the browser gives it something of a unique position in the marketplace, unless it somehow fails to gain W3C certification or widespread native browser adoption. Although official approval seems likely, support from vendors like Apple and Microsoft will be slow to materialize and receive wide deployment, perhaps in part due to the infamous *Not-Invented-Here* syndrome, and partly due to inertia. For that reason, Web Components will be a niche player in the JavaScript ecosystem in the near-term. Even if full browser support is slow to arrive, the Web Components architecture has already begun to influence the future direction of popular development frameworks like Angular. The componentization principles outlined in Section 3.4 constitute solid advice for almost any type of software project. Prefer to err on the side of smallness, simplicity, and predictability, rather than completeness.

5.2 Writing Web Components with Polymer

This section details some of the lessons learned developing Speakur on top of Google's Polymer framework.

5.2.1 Using Data-Bound Templates

Polymer's data bindings are a powerful feature for driving 'live' web applications. Their utility extends well beyond user interface views. A 3-way automatic binding between the local model, the UI view, and the remote database is an extremely powerful abstraction, even more so when combined with Firebase's WebSocket-based event notification system. JavaScript variables can automatically update to reflect changes made by users on the other side of the world. Of course, care must be taken to design the interface so the user doesn't accidentally make changes that are immediate and can't be undone. For example, Speakur's user preferences screen doesn't commit changes to the database until the user clicks the Save button. Editing the text of an existing post also saves a copy of the previous version.

5.2.2 Decoupling Components

Data bindings and synchronization are discussed in Section 4.4. In general, two-way data bindings should only be used *within* a component. Across component boundaries, use a one-way binding to send data down to a child, and fire events to notify containers of state changes. DOM Mutation Observers can be useful for making one component react to a change in another without directly tying their code together. As the example with `lc` (locale) in Section 4.6 showed, sometimes it is necessary to 'shoehorn' certain

variables into a Polymer binding expression to ensure that the expression is recalculated when that variable changes.

5.2.3 Optimizing Polymer Performance

Component load times are currently one problem area for Web Components. The Vulcanize tool offers definite benefits for load times as seen in Table 4.3, but Speakur is a relatively simple application where all 20 or so components are used more or less immediately. The Vulcanize tool must be applied at the level of the site or app, not by the individual component authors. Larger single page applications (SPAs) will face more complex challenges when trying to optimize load times, and performance in general, before Web Components are fully native in browsers, especially when combining frameworks.

The `<template>` element is a powerful new tool for web authors, but current implementations can have performance issues when rendering large lists of items, such as with a long list of comments. Polymer's `<core-list>` is more optimized for this use case. Also, the `if=` attribute on nested `<template>` elements should not be used in those cases where you could use the `hidden?=` attribute on the inner content instead. There are several reasons for this, including performance and the fact that Polymer's handy `this.$` `id`-to-object map is not dynamic; that is, element objects created conditionally in inner templates are not automatically added to `this.$`.

5.2.4 Inheritance in Polymer

I recommend avoiding the use of Polymer's inheritance unless there is a clear case for providing polymorphism-like behavior. One reason for that is that (as of this writing)

when a base class provides computed properties, these property definitions have to be repeated in any subclasses if any new ones are required, which violates the "don't repeat yourself" (DRY) principle. Speakur uses Polymer inheritance in its CSS theme components; most of the functionality is defined in the base class and the subclasses mainly provide numeric parameters for things like colors and margins. Composition could achieve these behaviors almost as easily.

5.3 Lessons Learned

When I started this project, I wasn't sure where it would take me. I was particularly unsure about the extent to which I could leverage the vast existing library of JavaScript frameworks and libraries when writing a new-style Web Component. Here are some of the lessons I learned while developing Speakur:

- **Web Components provide powerful abstractions.**

  Using Web Components, and particularly the data-bound templates provided by Polymer, greatly reduced the amount of effort needed to code a responsive, live web app compared to my previous efforts, yet the result is still flexible and works in a variety of software architectures. It's difficult to estimate that difference in terms of lines of code, but it is clear that Web Components offer better tools for code organization, separation of concerns, and modularization than were previously available.

- **Web Components are standardized.**

  Web Components follow standard HTML and HTTP semantics better than

many previous JavaScript frameworks. A consistent component packaging and import system, the use of HTML attributes for API specification, and the lack of a required compilation or preprocessing step all help Web Components fit cleanly into the architecture of the web.

- **Use Firebase as an adjunct.**

  Firebase is excellent for what it is, but for a really substantial or business-critical application it's probably best to treat it as a handy side-channel for data synchronization and event notification, rather than as the main business data repository. Aside from cost factors or the security issues inherent in storing your data in the cloud, running your own server remains the best way to ensure effective data integrity, control and validation.

- **Polymer can have problems with older JavaScript frameworks.**

  The ease of combining Polymer-based components with other frameworks and non-Web-Component-aware libraries ("legacy code") depends heavily on what they do. Using pure-CSS libraries (like `bootstrap.css`) with Polymer/WC is safe and easy to control by limiting their scope to a particular component.

  Writing a Polymer component that directly uses legacy JavaScript libraries (like `bootstrap.js`) is not nearly as easy in many cases. I tried to use several Bootstrap JavaScript widgets but quickly ran into incompatibilities with treatment of the document model, event handling, and so on. The Twitter Bootstrap developers, perhaps understandably, don't care that much about adding compatibility hacks for relatively immature projects like Polymer. Libraries that provide purely logical services like i18next, instead of document or interface-related features like

Bootstrap, are much easier to integrate.

- **Include mobile early in the development cycle.**

  For example, be careful where you apply margins when designing for mobile. If you have a group of interface widgets that form a logical unit, like a toolbar, and you want some separation between this group and what's above it, don't apply `margin-top` to the whole group container. Instead apply it separately to each item inside the unit, so if some items wrap to the next line they will still have the appropriate top margin. It's best to identify these types of issues early on.

5.4 The Future of Web Components

Polymer and Web Components are extremely powerful tools. They are relatively immature as a technology but quickly improving. Those who wish to deploy a large, full-featured web application based on these technologies may face some bumps in the road, at least until the standard is finalized and browser support is improved. A project version below 1.0 is a general indicator of how ready its authors feel it is for production deployment. Polymer's current version is at 0.5, soon to be 0.8, which suggests that 1.0 is not that far off. Even the massively popular Angular framework has announced that the controversial 2.0 re-write will be based on the Web Components standard, so it appears that Web Components are here to stay [39].

The Web Components initiative is much larger than just Polymer. The draft is due to be formally adopted as an official HTML5 standard by the World Wide Web Consortium. Although it will be a long time before full-speed native Web Component support exists in a majority of browsers worldwide, polyfill libraries can help bring these capabili-

ties to current browsers. However, the prospect of forcing visitors to download a several hundred KB library just to use basic DOM functionality is not very appealing to most web engineers from a performance and user experience perspective. The lack of native browser support may be a limiting factor in Web Component adoption in the near term.

In essence, Web Component's key problem at the moment is that one has to download a large JavaScript framework in order to use it, yet one of its main premises is that it frees you from needing a JavaScript framework. Of course, the path out of this chicken-and-egg problem is for browser vendors to fully implement native Web Components in their products, a process which won't be complete until well after the standard is finalized by the W3C. Given the enormous size of the job that the polyfill library must accomplish, the results obtained so far are impressive. Speakur has demonstrated that it's possible to create focused, extensible, yet full-featured Web Components right now with the help of tools like Polymer and Firebase.

Chapter 6

Conclusion

Web Components are a powerful addition to the web developer's arsenal. Their fundamental premise is that web content can be componentized, encapsulted, and abstracted behind well-defined APIs. Eventually this functionality will be delivered directly by the browser without needing a dedicated JavaScript framework. But for the immediate future, using Web Components in your application means that your clients must download a large blob of JavaScript library code—the polyfill—to enable its features: Custom Elements, shadow DOM, templates, and the component import system.

Web Components have set out on the right path to becoming a mature, widely deployed technology. Newer frameworks like Polymer provide powerful abstractions but are still undergoing rapid evolution. Older, more established frameworks like Angular have already begun the process of adapting to the new Web Component world. Success will be found at the end of this road as long as framework and component authors remain mindful of the guiding principles of Web Components: to be small, focused, extensible, adaptive, and most of all, to deliver the key benefits not only to the software engineers who make the web run, but to the content *authors* that have made it the indispensable communications medium of the modern age.

Appendix

Appendix A

Open Source Credits

Speakur would not have been possible without the following open source components. The components listed here are the direct Bower dependencies. Some of these may install other dependencies in turn.

- Polymer framework [20]:

  Web Components polyfill, core library, Core Elements and Paper Elements.
- Firebase database service and client library [10]
- Marked library [49]
- highlight.js library
- i18next library [13]
- moment.js library
- lodash.js library
- jQuery.js library
- js-md5 library
- pvc-globals custom element

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