

In that vein, I should also thank Jan Kubasiewicz at MassArt’s [Dynamic Media Institute](#). Back in 2007, Jan encouraged me to check out something called [Processing](#), which eventually led me to a whole new career in code-driven arts, data visualization, and now this book.

It has been a pleasure working with my editor, Meghan Blanchette, and everyone else on the team at O’Reilly. Thanks to Meghan and her crew for shepherding this project all the way through, from concept to an actual, physical, chunk of paper with words and strange diagrams printed on it.

Special thanks to [Mike Bostock](#), [Jen Lowe](#), [Anna Powell-Smith](#), and [Daisy Vincent](#) for agreeing to tech review the book and sending incredibly valuable feedback. The final product is vastly improved, thanks to their input. That said, if you find an error or confusing code example, it is because they begged me to rewrite it, and I steadfastly refused.

Mike gets an extra-special thanks for developing D3 in the first place. Without this elegant piece of software, the community of data visualization practitioners wouldn’t be quite as vibrant, enthusiastic, and standards-compliant as it is today.

Speaking of community, many other people—including [Jérôme Cukier](#), [Lynn Cherny](#), [Jason Davies](#), [Jeff Heer](#), [Santiago Ortiz](#), [Kim Rees](#), [Moritz Stefaner](#), [Jan Willem Tulp](#), and others who I have forgotten to mention—on the D3 list and in nearby orbits have also directly contributed to my thinking and process. Thank you for your support. I am lucky to get to collaborate with so many talented people.



## Why Data Visualization?

Our information age more often feels like an era of information overload. Excess amounts of information are overwhelming; raw data becomes useful only when we apply methods of deriving insight from it.

Fortunately, we humans are intensely visual creatures. Few of us can detect patterns among rows of numbers, but even young children can interpret bar charts, extracting meaning from those numbers' visual representations. For that reason, data visualization is a powerful exercise. Visualizing data is the fastest way to communicate it to others.

Of course, visualizations, like words, can be used to lie, mislead, or distort the truth. But when practiced honestly and with care, the process of visualization can help us see the world in a new way, revealing unexpected patterns and trends in the otherwise hidden information around us. At its best, data visualization is expert storytelling.

More literally, visualization is a process of *mapping* information to visuals. We craft rules that interpret data and express its values as visual properties. For example, the humble bar chart in [Figure 1-1](#) is generated from a very simple rule: larger values are *mapped* as taller bars.

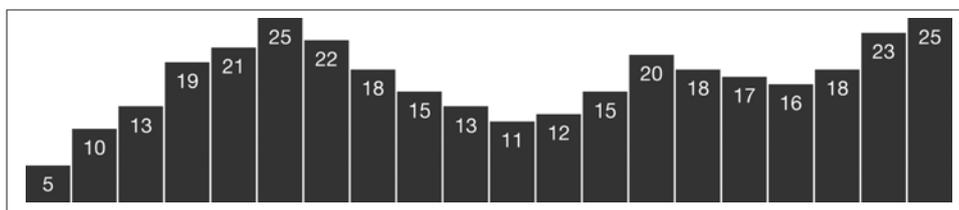


Figure 1-1. Data values mapped to visuals

More complex visualizations are generated from datasets more complex than the sequence of numbers shown in [Figure 1-1](#) and more complex sets of mapping rules.

## Why Write Code?

Mapping data by hand can be satisfying, yet is slow and tedious. So we usually employ the power of computation to speed things up. The increased speed enables us to work with much larger datasets of thousands or millions of values; what would have taken years of effort by hand can be mapped in a moment. Just as important, we can rapidly experiment with *alternate mappings*, tweaking our rules and seeing their output re-rendered immediately. This loop of write/render/evaluate is critical to the iterative process of refining a design.

Sets of mapping rules function as *design systems*. The human hand no longer executes the visual output; the computer does. Our human role is to conceptualize, craft, and write out the rules of the system, which is then finally executed by software.

Unfortunately, software (and computation generally) is extremely bad at understanding what, exactly, people want. (To be fair, many humans are also not good at this challenging task.) Because computers are binary systems, everything is either on or off, yes or no, this or that, there or not there. Humans are mushier, softer creatures, and the computers are not willing to meet us halfway—we must go to them. Hence the inevitable struggle of learning to write software, in which we train ourselves to communicate in the very limited and precise syntax that the computer can understand.

Yet we continue to write code because seeing our visual creations come to life is so rewarding. We practice data visualization because it is exciting to see what has never before been seen. It is like summoning a magical, visual genie out of an inscrutable data bottle.

## Why Interactive?

Static visualizations can offer only precomposed “views” of data, so multiple static views are often needed to present a variety of perspectives on the same information. The number of dimensions of data are limited, too, when all visual elements must be present on the same surface at the same time. Representing multidimensional datasets fairly in static images is notoriously difficult. A fixed image is ideal when alternate views are neither needed nor desired, and required when publishing to a static medium, such as print.

Dynamic, interactive visualizations can empower people to explore the data for themselves. The basic functions of most interactive visualization tools have changed little since 1996, when Ben Shneiderman of the University of Maryland first proposed a

“Visual Information-Seeking Mantra”: *overview first, zoom and filter, then details-on-demand.*

This design pattern is found in most interactive visualizations today. The combination of functions is successful, because it makes the data accessible to different audiences, from those who are merely browsing or exploring the dataset to those who approach the visualization with a specific question in search of an answer. An interactive visualization that offers an overview of the data alongside tools for “drilling down” into the details may successfully fulfill many roles at once, addressing the different concerns of different audiences, from those new to the subject matter to those already deeply familiar with the data.

Of course, interactivity can also encourage engagement with the data in ways that static images cannot. With animated transitions and well-crafted interfaces, some visualizations can make exploring data feel more like playing a game. Interactive visualization can be a great medium for engaging an audience who might not otherwise care about the topic or data at hand.

## Why on the Web?

Visualizations aren’t truly visual unless they are *seen*. Getting your work out there for others to see is critical, and publishing on the Web is the quickest way to reach a global audience. Working with web-standard technologies means that your work can be seen and experienced by anyone using a recent web browser, regardless of the operating system (Windows, Mac, Linux) and device type (laptop, desktop, smartphone, tablet).

Best of all, everything covered in this book can be done with freely accessible tools, so the only investment required is your time. And everything we’ll talk about uses open source, web-standard technologies.

By avoiding proprietary software and plug-ins, you can ensure that your projects are accessible on the widest possible range of devices, from typical desktop computers to tablets and even phones. The more accessible your visualization, the greater your audience and your impact.

## What This Book Is

This book is a practical introduction to merging three practices—data visualization, interactive design, and web development—using D3, a powerful tool for custom, web-based visualization.

These chapters grew out of my own process of learning how to use D3. Many people, including myself, come to D3 with backgrounds in design, mapping, and data visualization, but not programming and computer science.

D3 has a bit of an unfair reputation for being hard to learn. D3 itself is not so complicated, but it operates in the domain of the Web, and the Web *is* complicated. Using D3 comfortably requires some prior knowledge of the web technologies with which it interacts, such as HTML, CSS, JavaScript, and SVG. Many people (myself included) are self-taught when it comes to web skills. This is great, because the barrier to entry is so low, but problematic because it means we probably didn't learn each of these technologies from the ground up—more often, we just hack something together until it seems to work, and call it a day. Yet successful use of D3 requires understanding some of these technologies in a fundamental way.

Because D3 is written in JavaScript, learning to use D3 often means learning a lot about JavaScript. For many datavis folks, D3 *is* their introduction to JavaScript (or even web development generally). It's hard enough to learn a new programming language, let alone a new tool built on that language. D3 will enable you to do great things with JavaScript that you never would have even attempted. The time you spend learning both the language and the tool will provide an incredible payoff.

My goal is to reduce that learning time, so you can start creating awesome stuff sooner. We'll take a ground-up approach, starting with the fundamental concepts and gradually adding complexity. I don't intend to show you how to make specific kinds of visualizations so much as to help you understand the workings of D3 well enough to take those building blocks and generate designs of your own creation.

## Who You Are

You may be an absolute beginner, someone new to datavis, web development, or both. (Welcome!) Perhaps you are a journalist interested in new ways to communicate the data you collect during reporting. Or maybe you're a designer, comfortable drawing static infographics but ready to make the leap to interactive projects on the Web. You could be an artist, interested in generative, data-based art. Or a programmer, already familiar with JavaScript and the Web, but excited to learn a new tool and pick up some visual design experience along the way.

Whoever you are, I hope that you:

- Have heard of this new thing called the “World Wide Web”
- Are a bit familiar with HTML, the DOM, and CSS
- Might even have a little programming experience already
- Have heard of jQuery or written some JavaScript before
- Aren't scared by unknown initialisms like CSV, SVG, or JSON
- Want to make useful, interactive visualizations

If any of those things are unknown or unclear, don't fear. You might just want to spend more time with [Chapter 3](#), which covers what you really need to know before diving into D3.

## What This Book Is Not

That said, this is definitely not a computer science textbook, and it is not intended to teach the intricacies of any one web technology (HTML, CSS, JavaScript, SVG) in depth.

In that spirit, I might gloss over some technical points, grossly oversimplifying important concepts fundamental to computer science in ways that will make true software engineers recoil. That's fine, because I'm writing for artists and designers here, not engineers. We'll cover the basics, and then you can dive into the more complex pieces once you're comfortable.

I will deliberately *not* address every possible approach to a given problem, but will typically present what I feel is the simplest solution, or, if not the simplest, then the most understandable.

My goal is to teach you the fundamental concepts and methods of D3. As such, this book is decidedly *not* organized around specific example projects. Everyone's data and design needs will be different. It's up to you to integrate these concepts in the way best suited to your particular project.

## Using Sample Code

If you are a mad genius, then you can probably learn to use D3 without ever looking at any sample code files, in which case you can skip the rest of this section.

If you're still with me, you are probably still very bright but not mad, in which case you should undertake this book with the full set of accompanying code samples in hand. Before you go any further, please download the sample files from [GitHub](#).

Normal people will want to click the ZIP link to download a compressed ZIP archive with all the files. Hardcore geeksters will want to clone the repository using Git. If that last sentence sounds like total gibberish, please use the first option.

Within the download, you'll notice there is a folder for each chapter that has code to go with it:

```
chapter_04
chapter_05
chapter_06
chapter_07
chapter_08
...
```

Files are organized by chapter, so in **Chapter 9** when I reference *01\_bar\_chart.html*, know that you can find that file in the corresponding location: *d3-book/chapter\_9/01\_bar\_chart.html*.

You are welcome to copy, adapt, modify, and reuse the example code in these tutorials for any noncommercial purpose.

## Thank You

Finally, this book has been handcrafted, carefully written, and pedagogically fine-tuned for maximum effect. Thank you for reading it. I hope you learn a great deal, and even have some fun along the way.

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## CHAPTER 2

# Introducing D3

D3—also referred to as D<sup>3</sup> or d3.js—is a JavaScript library for creating data visualizations. But that kind of undersells it.

The abbreviation D3 references the tool’s full name, *Data-Driven Documents*. The *data* is provided by you, and the *documents* are web-based documents, meaning anything that can be rendered by a web browser, such as HTML and SVG. D3 does the *driving*, in the sense that it connects the data to the documents.

Of course, the name also functions as a clever allusion to the network of technologies underlying the tool itself: the W3, or World Wide Web, or, today, simply “the Web.”

D3’s primary author is the brilliant [Mike Bostock](#), although there are a few other dedicated contributors. The project is entirely open source and freely available on [GitHub](#).

D3 is released under a BSD license, so you may use, modify, and adapt the code for noncommercial or commercial use at no cost.

D3’s official home on the Web is [d3js.org](http://d3js.org).

## What It Does

Fundamentally, D3 is an elegant piece of software that facilitates generation and manipulation of web documents with data. It does this by:

- *Loading* data into the browser’s memory
- *Binding* data to elements within the document, creating new elements as needed

- *Transforming* those elements by interpreting each element’s bound datum and setting its visual properties accordingly
- *Transitioning* elements between states in response to user input

Learning to use D3 is simply a process of learning the syntax used to tell it how you want it to load and bind data, and transform and transition elements.

The *transformation* step is most important, as this is where the *mapping* happens. D3 provides a structure for applying these transformations, but, as we’ll see, you define the mapping rules. Should larger values make taller bars or brighter circles? Will clusters be sorted on the x-axis by age or category? What color palette is used to fill in countries on your world map? All of the visual design decisions are up to you. You provide the concept, you craft the rules, and D3 executes it—without telling you what to do. (Yes, it’s like the opposite of Excel’s pushy “Chart Wizard.”)

## What It Doesn’t Do

Here is a list of things D3 does not do:

- D3 doesn’t generate predefined or “canned” visualizations for you. This is on purpose. D3 is intended primarily for *explanatory* visualization work, as opposed to *exploratory* visualizations. Exploratory tools help you discover significant, meaningful patterns in data. These are tools like [Tableau](#) and [ggplot2](#), which help you quickly generate multiple views on the same data set. That’s an essential step, but different from generating an *explanatory* presentation of the data, a view of the data that highlights what you’ve already discovered. Explanatory views are more constrained and limited, but also focused, and designed to communicate only the important points. D3 excels at this latter step, but is not ideal for the former. (For ideas on other tools, see the section “[Alternatives](#)” on [page 10](#) later in this chapter.)
- D3 doesn’t even try to support older browsers. This helps keep the D3 codebase clean and free of hacks to support old versions of Internet Explorer, for example. The philosophy is that by creating more compelling tools and refusing to support older browsers, we encourage more people to upgrade (rather than forestall the process, thereby requiring us to continue to support those browsers, and so on—a vicious cycle). D3 wants us to move forward.
- D3’s core functionality doesn’t handle bitmap map tiles, such as those provided by Google Maps or Cloudmade. D3 is great with anything vector—SVG images or GeoJSON data—but wasn’t originally intended to work with traditional map tiles. (*Bitmap* images are made up of pixels, so resizing them larger or smaller is difficult without a loss in quality. *Vector* images are defined by points, lines, and curves—mathematical equations, really—and can be scaled up or down without a loss in quality.) This is starting to change, with the introduction of the [d3.geo.tile](#) plug-

in. Prior to this plug-in, geomapping with D3 meant either going all-SVG and avoiding tiles or using D3 to create SVG visuals *on top of* a base layer of map tiles (which would be managed by another library, like Leaflet or Polymaps—see the section “[Alternatives](#)” on page 10 later in this chapter). This question of how to integrate bitmap tiles and vector graphics comes up a lot in the D3 community. As of today, there is no super-simple and perfect answer, but I think you can expect to see lots of work done in this area, and possibly the new tile-handling methods integrated into the D3 core at some point in the future.

- D3 doesn’t hide your original data. Because D3 code is executed on the client side (meaning, in the user’s web browser, as opposed to on the web server), the data you want visualized must be sent to the client. If your data can’t be shared, then don’t use D3. Alternatives include using proprietary tools (like Flash) or prerendering visualizations as static images and sending those to the browser. (If you’re not interested in sharing your data, though, why would you bother visualizing it? The purpose of visualization is to communicate the data, so you might sleep better at night by choosing openness and transparency, rather than having nightmares about [data thieves](#).)

## Origins and Context

The first web browsers rendered static pages; interactivity was limited to clicking links. In 1996, Netscape introduced the first browser with JavaScript, a new scripting language that could be interpreted *by the browser while the page was being viewed*.

This doesn’t sound as groundbreaking as it turned out to be, but this enabled web browsers to evolve from merely passive *browsers* to dynamic frames for interactive, networked experiences. This shift ultimately enabled every intrapage interaction we have on the Web today. Without JavaScript, D3 would never exist, and web-based data visualizations would be limited to prerendered, noninteractive GIFs. (Yuck. Thank you, Netscape!)

Jump ahead to 2005, when Jeffrey Heer, Stuart Card, and James Landay introduced [prefuse](#), a toolkit for bringing data visualization to the Web. [prefuse](#) (spelled with all lowercase letters) was written in Java, a compiled language, with programs that could run in web browsers via a Java plug-in. (Note that *Java* is a completely different programming language than *JavaScript*, despite their similar names.)

[prefuse](#) was a breakthrough application—the first to make web-based visualization accessible to less-than-expert programmers. Until [prefuse](#) came along, any datavis on the Web was very much a custom affair.

Two years later, Jeff Heer introduced [Flare](#), a similar toolkit, but written in ActionScript, so its visualizations could be viewed on the Web through Adobe’s Flash Player. [Flare](#),

like *prefuse*, relied on a browser plug-in. *Flare* was a huge improvement, but as web browsers continued to evolve, it was clear that visualizations could be created with native browser technology, no plug-ins required.

By 2009, Jeff Heer had moved to Stanford, where he was advising a graduate student named Michael Bostock. Together, in Stanford's Vis Group, they created **Protovis**, a JavaScript-based visualization toolkit that relied exclusively on native browser technologies. (If you have used Protovis, be sure to reference Mike's [introduction to D3 for Protovis users](#).)

Protovis made generating visualizations simple, even for users without prior programming experience. Yet to achieve this, it created an abstract representation layer. The designer could address this layer using Protovis syntax, but it wasn't accessible through standard methods, so debugging was difficult.

In 2011, Mike Bostock, Vadim Ogievetsky, and Jeff Heer **officially announced D3**, the next evolution in web visualization tools. Unlike Protovis, D3 operates directly on the web document itself. This means easier debugging, easier experimentation, and more visual possibilities. The only downside to this approach is a potentially steeper learning curve, but this book will make that as painless as possible. Plus, all the skills you gain while learning about D3 will prove useful even beyond the realm of datavis.

If you're familiar with any of these groundbreaking tools, you'll appreciate that D3 descends from a prestigious lineage. And if you have any interest in the philosophy underlying D3's elegant technical design, I highly recommend Mike, Vadim, and Jeff's [InfoVis paper](#), which clearly articulates the need for this kind of tool. The paper encapsulates years' worth of learning and insights made while developing visualization tools.

## Alternatives

D3 might not be perfect for every project. Sometimes you just need a quick chart and you don't have time to code it from scratch. Or you might need to support older browsers and can't rely on recent technologies like SVG.

For those situations, it's good to know what other tools are out there. Here is a brief, noncomprehensive list of D3 alternatives, all of which use web-standard technologies (mostly JavaScript) and are free to download and use.

### Easy Charts

#### *DataWrapper*

A beautiful web service that lets you upload your data and quickly generate a chart that you can republish elsewhere or embed on your site. This service was originally intended for journalists, but it is helpful for everyone. *DataWrapper* displays in-

teractive charts in current browsers and static images for old ones. (Brilliant!) You can also download all the code and run it on your own server instead of using theirs.

### *Flot*

A plotting library for jQuery that uses the HTML canvas element and supports older browsers, even all the way back to Internet Explorer 6. It supports limited visual forms (lines, points, bars, areas), but it is easy to use.

### *Google Chart Tools*

Having evolved from their earlier [Image Charts API](#), Google's Chart Tools can be used to generate several standard chart types, with support for old versions of IE.

### *gRaphaël*

A charting library based on Raphaël (see later in this chapter) that supports older browsers, including IE6. It has more visual flexibility than Flot, and—some might say—it is prettier.

### *Highcharts JS*

A JavaScript-based charting library with several predesigned themes and chart types. It uses SVG for modern browsers and **falls back on VML** for old versions of IE, including IE6 and later. The tool is free only for noncommercial use.

### *JavaScript InfoVis Toolkit*

The JIT provides several preset visualization styles for your data. It includes lots of examples, but the documentation is pretty technical. The toolkit is great if you like one of the preset styles, but browser support is unclear.

### *jqPlot*

A plug-in for charting with jQuery. This supports very simple charts and is great if you are okay with the predefined styles. jqPlot supports IE7 and newer.

### *jQuery Sparklines*

A jQuery plug-in for generating sparklines, typically small bar, line, or area charts used inline with text. Supports most browsers, even back to IE6.

### *Peity*

A jQuery plug-in for very simple and very *tiny* bar, line, and pie charts that supports only recent browsers. Did I mention that this makes only very *tiny* visualizations? +10 cuteness points.

### *Timeline.js*

A library specifically for generating interactive timelines. No coding is required; just use the code generator. There is not much room for customization, but hey, timelines are really hard to do well. Timeline.js supports only IE8 and newer.

### *YUI Charts*

The Charts module for the Yahoo! User Interface Library enables creation of simple charts with a goal of wide browser support.

## Graph Visualizations

A “graph” is just data with a networked structure (for example, B is connected to A, and A is connected to C).

### *Arbor.js*

A library for graph visualization using jQuery. Even if you never use this, you should check out how the documentation is presented as a graph, using the tool itself. (It’s so *meta*.) It uses the HTML canvas, so it works only in IE9 or current browsers, although some workarounds are available.

### *Sigma.js*

A very lightweight library for graph visualization. You have to visit this website, move your mouse over the header graphic, and then play with the demos. Sigma.js is beautiful and fast, and it also uses canvas.

## Geomapping

I distinguish between *mapping* (all visualizations are maps) and *geomapping* (visualizations that include geographic data, or geodata, such as traditional maps). D3 has a lot of geomapping functionality, but you should know about these other tools.

### *Kartograph*

A JavaScript-and-Python combo for gorgeous, entirely vector-based mapping by Gregor Aisch with must-see demos. Please go look at them now. I promise you’ve never seen online maps this beautiful. Kartograph works with IE7 and newer.

### *Leaflet*

A library for tiled maps, designed for smooth interaction on both desktop and mobile devices. It includes some support for displaying data layers of SVG on top

of the map tiles. (See Mike’s demo “[Using D3 with Leaflet](#)”.) Leaflet works with IE6 (barely) or IE7 (better!) and of course all current browsers.

### *Modest Maps*

The granddaddy of tiled map libraries, Modest Maps has been succeeded by Polymaps, but lots of people still love it, as it is lightweight and works with old versions of IE and other browsers. Modest Maps has been adapted for ActionScript, Processing, Python, PHP, Cinder, openFrameworks...yeah, basically everything. File this under “oldie, but goodie.”

### *Polymaps*

A library for displaying tiled maps, with layers of data on top of the tiles. Polymaps relies on SVG and thus works best with current browsers.

## Almost from Scratch

These tools, like D3, provide methods of drawing visual forms, but without predesigned visual templates. If you enjoy the creative freedom of starting from scratch, you might enjoy these.

### *Processing.js*

A native JavaScript implementation of [Processing](#), the fantastic programming language for artists and designers new to programming. Processing is written in Java, so exporting Processing sketches to the Web traditionally involved clunky Java applets. Thanks to Processing.js, regular Processing code can run natively, in the browser. It renders using canvas, so only modern browsers are supported.

### *Paper.js*

A framework for rendering vector graphics to canvas. Also, its website is one of the most beautiful on the Internet, and their demos are unbelievable. (Go play with them now.)

### *Raphaël*

Another library for drawing vector graphics, popular due to its friendly syntax and support for older browsers.

## Three-Dimensional

D3 is not the best at 3D, simply because web browsers are historically two-dimensional beasts. But with increased support for WebGL, there are now more opportunities for 3D web experiences.

### *PhiloGL*

A WebGL framework specifically for 3D visualization.

### *Three.js*

A library for generating any sort of 3D scene you could imagine, produced by Google's Data Arts team. You could spend all day exploring the mind-blowing demos on their site.

## **Tools Built with D3**

When you want to use D3 without actually writing any D3 code, you can choose one of the many tools built on top of D3!

### *Crossfilter*

A library for working with large, multivariate datasets, written primarily by Mike Bostock. This is useful for trying to squeeze your “big data” into a relatively small web browser.

### *Cubism*

A D3 plug-in for visualizing time series data, also written by Mike Bostock. (One of my favorite demos.)

### *Dashku*

An online tool for data dashboards and widgets updated in real time, by Paul Jensen.

### *dc.js*

The “dc” is short for *dimensional charting*, as this library is optimized for exploring large, multidimensional datasets.

### *NVD3*

Reusable charts with D3. NVD3 offers lots of beautiful examples, with room for visual customizations without requiring as much code as D3 alone.

### *Polychart.js*

More reusable charts, with a range of chart types available. Polychart.js is free only for noncommercial use.

### *Rickshaw*

A toolkit for displaying time series data that is also very customizable.

### *Tributary*

A great tool for experimenting with live coding using D3, by Ian Johnson.

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# Technology Fundamentals

Solid familiarity with the following concepts will make your time with D3 a lot less frustrating and a lot more rewarding. Consider this a brief refresher course on Web-Making 101.



Beware! This is a pretty dense chapter, packed with years' worth of web development knowledge, and nothing in here is specific to D3. I recommend skimming just the sections on information that is new to you, and skipping the rest. You can always reference this chapter later as questions arise.

## The Web

If you're brand new to making web pages, you will now have to think about things that regular people blissfully disregard every day, such as this: How does the Web actually work?

We think of the Web as a bunch of interlinked pages, but it's really a collection of conversations between web servers and web clients (browsers).

The following scene is a dramatization of a typical such conversation that happens whenever you or anyone else clicks a link or types an address into your browser (meaning, this brief conversation is had about 88 zillion times every day):

CLIENT: I'd really like to know what's going on over at *somewebsite.com*. I better call over there to get the latest info. [Silent sound of Internet connection being established.]

SERVER: Hello, unknown web client! I am the server hosting *somewebsite.com*. What page would you like?

CLIENT: This morning, I am interested in the page at *somewebsite.com/news/*.

SERVER: Of course, one moment.

*Code is transmitted from SERVER to CLIENT.*

CLIENT: I have received it. Thank you!

SERVER: You're welcome! Would love to stay on the line and chat, but I have other requests to process. Bye!

Clients contact servers with *requests*, and servers respond with data. But what is a server and what is a client?

*Web servers* are Internet-connected computers running server software, so called because they *serve* web documents as requested. Servers are typically always on and always connected, but web developers often also run *local* servers, meaning they run on the same computer that you're working on. *Local* means here; *remote* means somewhere else, on any computer but the one right in front of you.

There are lots of different server software packages, but Apache is the most common. Web server software is not pretty, and no one ever wants to look at it.

In contrast, web *browsers* can be very pretty, and we spend a lot of time looking at them. Regular people recognize names like Firefox, Safari, Chrome, and Internet Explorer, all of which are browsers or *web clients*.

Every web page, in theory, can be identified by its URL (Uniform Resource Locator) or URI (Uniform Resource Identifier). Most people don't know what *URL* stands for, but they recognize one when they see it. By obsolete convention, URLs commonly begin with *www*, as in <http://www.calmingmanatee.com>, but with a properly configured server, the *www* part is wholly unnecessary.

Complete URLs consist of four parts:

- An indication of the *communication protocol*, such as HTTP or HTTPS
- The *domain name* of the resource, such as [calmingmanatee.com](http://calmingmanatee.com)
- The *port number*, indicating over which port the connection to the server should be attempted
- Any additional locating information, such as the path of the requested file, or any query parameters

A complete URL, then, might look like this: <http://alignedleft.com:80/tutorials/d3/>.

Typically, the port number is excluded, as web browsers will try to connect over port 80 by default. So the preceding URL is functionally the same as the following: <http://alignedleft.com/tutorials/d3/>

Note that the protocol is separated from the domain name by a colon and two forward (regular) slashes. Why two slashes? No reason. The inventor of the Web **regrets the error**.

HTTP stands for Hypertext Transfer Protocol, and it's the most common protocol for transferring web content from server to client. The "S" on the end of HTTPS stands for *Secure*. HTTPS connections are used whenever information should be encrypted in transit, such as for online banking or e-commerce.

Let's briefly step through the process of what happens when a person goes to visit a website.

1. User runs the web browser of her choice, then types a URL into the address bar, such as *alignedleft.com/tutorials/d3/*. Because she did not specify a protocol, HTTP is assumed, and "http://" is prepended to the URL.
2. The browser then attempts to connect to the server behind *alignedleft.com* across the network, via port 80, the default port for HTTP.
3. The server associated with *alignedleft.com* acknowledges the connection and is taking requests. ("I'll be here all night.")
4. The browser sends a request for the page that lives at */tutorials/d3/*.
5. The server sends back the HTML content for that page.
6. As the client browser receives the HTML, it discovers references to *other files* needed to assemble and display the entire page, including CSS stylesheets and image files. So it contacts the same server again, once per file, requesting the additional information.
7. The server responds, dispatching each file as needed.
8. Finally, all the web documents have been transferred over. Now the client performs its most arduous task, which is to *render* the content. It first parses through the HTML to understand the structure of the content. Then it reviews the CSS selectors, applying any properties to matched elements. Finally, it plugs in any image files and executes any JavaScript code.

Can you believe that all that happens every time you click a link? It's a lot more complicated than most people realize, but it's important to understand that client/server conversations are fundamental to the Web.

## HTML

Hypertext Markup Language is used to structure content for web browsers. HTML is stored in plain text files with the *.html* suffix. A simple HTML document looks like this:

```
<!DOCTYPE html>
<html>
  <head>
    <title>Page Title</title>
  </head>
  <body>
```

```
<h1>Page Title</h1>
<p>This is a really interesting paragraph.</p>
</body>
</html>
```

HTML is a complex language with a rich history. This overview will address only the current iteration of HTML (formerly known as HTML5) and will touch on only what is immediately relevant for our practice with D3.

## Content Plus Structure

The core function of HTML is to enable you to “mark up” content, thereby giving it structure. Take, for example, this raw text:

```
Amazing Visualization Tool Cures All Ills A new open-source tool designed for
visualization of data turns out to have an unexpected, positive side effect:
it heals any ailments of the viewer. Leading scientists report that the tool,
called D3000, can cure even the following symptoms: fevers chills general
malaise It achieves this end with a patented, three-step process. Load in data.
Generate a visual representation. Activate magic healing function.
```

Reading between the lines, we can infer that this is a very exciting news story. But as unstructured content, it is very hard to read. By adding structure, we can differentiate between the headline, for example, and the body of the story.

### Amazing Visualization Tool Cures All Ills

A new open-source tool designed for visualization of data turns out to have an unexpected, positive side effect: it heals any ailments of the viewer. Leading scientists report that the tool, called D3000, can cure even the following symptoms:

- fevers
- chills
- general malaise

It achieves this end with a patented, three-step process.

1. Load in data.
2. Generate a visual representation.
3. Activate magic healing function.

That has the same raw text content, but with a *visual structure* that makes the content more accessible.

HTML is a tool for specifying *semantic structure*, or attaching hierarchy, relationships, and *meaning* to content. (HTML doesn’t address the visual representation of a

document’s structure—that’s CSS’ job.) Here is our story with each chunk of content replaced by a *semantic description* of what that content is.

### Headline

Paragraph text

- Unordered list item
- Unordered list item
- Unordered list item

Paragraph text

1. Numbered list item
2. Numbered list item
3. Numbered list item

This is the kind of structure we specify with HTML markup.

## Adding Structure with Elements

“Marking up” is the process of adding *tags* to create *elements*. HTML tags begin with `<` and end with `>`, as in `<p>`, which is the tag indicating a paragraph of text. Tags usually occur in pairs, in which case adding an opening and closing pair of tags creates a new *element* in the document structure.

Closing tags are indicated with a slash that closes or ends the element, as in `</p>`. Thus, a paragraph of text may be marked up like the following:

```
<p>This is a really interesting paragraph.</p>
```

Some elements can be *nested*. For example, here we use the `em` element to add *emphasis*.

```
<p>This is a <em>really</em> interesting paragraph.</p>
```

Nesting elements introduces hierarchy to the document. In this case, `em` is a child of `p` because it is contained by `p`. (Conversely, `p` is `em`’s parent.)

When elements are nested, they cannot overlap closures of their parent elements, as doing so would disrupt the hierarchy. For example:

```
<p>This could cause <em>unexpected</p>  
<p>results</em>, and is best avoided.</p>
```

Some tags never occur in pairs, such as the `img` element, which references an image file. Although HTML no longer requires it, you will sometimes see such tags written in *self-closing* fashion, with a trailing slash before the closing bracket:

```

```

As of HTML5, the self-closing slash is optional, so the following code is equivalent to the preceding code:

```

```

## Common Elements

There are hundreds of different HTML elements. Here are some of the most common. We'll cover additional elements in later chapters. (Reference the excellent [Mozilla Developer Network documentation](#) for a complete listing.)

`<!DOCTYPE html>`

The standard document type declaration. Must be the first thing in the document.

`html`

Surrounds all HTML content in a document.

`head`

The document head contains all metadata about the document, such as its `title` and any references to external stylesheets and scripts.

`title`

The title of the document. Browsers typically display this at the top of the browser window and use this title when bookmarking a page.

`body`

Everything not in the head should go in the body. This is the primary visible content of the page.

`h1, h2, h3, h4`

These let you specify headings of different levels. `h1` is a top-level heading, `h2` is below that, and so on.

`p`

A paragraph!

`ul, ol, li`

Unordered lists are specified with `ul`, most often used for bulleted lists. Ordered lists (`ol`) are often numbered. Both `ul` and `ol` should include `li` elements to specify list items.

`em`

Indicates emphasis. Typically rendered in *italics*.

`strong`

Indicates additional emphasis. Typically rendered in **boldface**.

`a`

A link. Typically rendered as underlined, blue text, unless otherwise specified.

`span`

An arbitrary span of text, typically within a larger containing element like `p`.

`div`

An arbitrary *division* within the document. Used for grouping and containing related elements.

Our earlier example could be given semantic structure by marking it up using some of these element's tags:

```
<h1>Amazing Visualization Tool Cures All Ills</h1>
<p>A new open-source tool designed for visualization of data turns out to have
an unexpected, positive side effect: it heals any ailments of the viewer.
Leading scientists report that the tool, called D3000, can cure even the
following symptoms:</p>
<ul>
  <li>fevers</li>
  <li>chills</li>
  <li>general malaise</li>
</ul>
<p>It achieves this end with a patented, three-step process.</p>
<ol>
  <li>Load in data.</li>
  <li>Generate a visual representation.</li>
  <li>Activate magic healing function.</li>
</ol>
```

When viewed in a web browser, that markup is rendered as shown in [Figure 3-1](#).

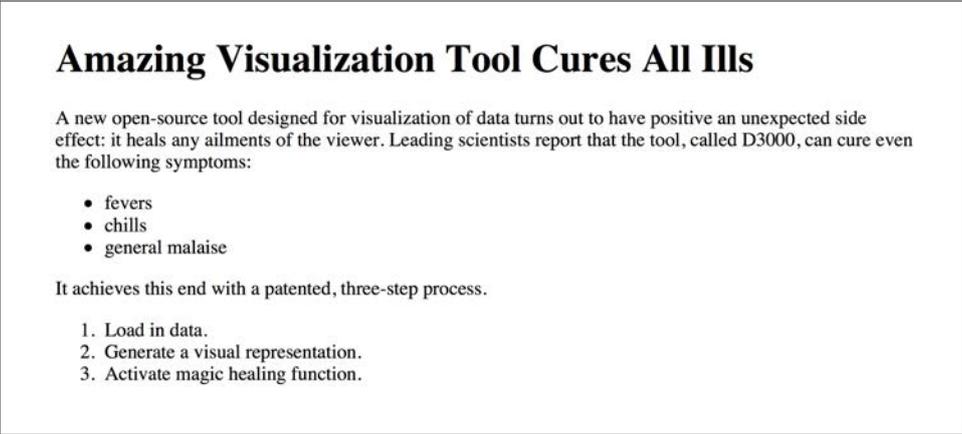


Figure 3-1. Typical default rendering of simple HTML

Notice that we specified only the *semantic* structure of the content; we didn't specify any visual properties, such as color, type size, indents, or line spacing. Without such instructions, the browser falls back on its *default styles*, which, frankly, are not too exciting.

## Attributes

All HTML elements can be assigned *attributes* by including property/value pairs in the opening tag.

```
<tagname property="value"></tagname>
```

The name of the property is followed by an equals sign, and the value is enclosed within double quotation marks.

Different kinds of elements can be assigned different attributes. For example, the `a` link tag can be given an `href` attribute, whose value specifies the URL for that link. (`href` is short for "HTTP reference.")

```
<a href="http://d3js.org/">The D3 website</a>
```

Some attributes can be assigned to *any* type of element, such as `class` and `id`.

## Classes and IDs

Classes and IDs are extremely useful attributes, as they can be referenced later to identify specific pieces of content. Your CSS and JavaScript code will rely heavily on classes and IDs to identify elements. For example:

```
<p>Brilliant paragraph</p>
<p>Insightful paragraph</p>
<p class="awesome">Awe-inspiring paragraph</p>
```

These are three very uplifting paragraphs, but only one of them is truly awesome, as I've indicated with `class="awesome"`. The third paragraph becomes part of a *class* of *awesome* elements, and it can be selected and manipulated along with other class members. (We'll get to that in a moment.)

Elements can be assigned multiple classes, simply by separating them with a space:

```
<p class="uplifting">Brilliant paragraph</p>
<p class="uplifting">Insightful paragraph</p>
<p class="uplifting awesome">Awe-inspiring paragraph</p>
```

Now, all three paragraphs are *uplifting*, but only the last one is both *uplifting* and *awesome*.

IDs are used in much the same way, but there can be only one ID per element, and each ID value can be used only once on the page. For example:

```
<div id="content">
  <div id="visualization"></div>
  <div id="button"></div>
</div>
```

IDs are useful when a single element has some special quality, like a `div` that functions as a button or as a container for other content on the page.

As a general rule, if there will be only *one* such element on the page, you can use an `id`. Otherwise, use a `class`.



Class and ID names cannot begin with numerals; they must begin with alphabetic characters. So `id="1"` won't work, but `id="item1"` will. The browser will not give you any errors; your code simply won't work, and you will go crazy trying to figure out why.

## Comments

As code grows in size and complexity, it is good practice to include comments. These are friendly notes that you leave for yourself to remind you why you wrote the code the way you did. If you are like me, you will revisit projects only weeks later and have lost all recollections of it. Commenting is an easy way to reach out and provide guidance and solace to your future (and very confused) self.

In HTML, comments are written in the following format:

```
<!-- Your comment here -->
```

Anything between the `<!--` and `-->` will be ignored by the web browser.

## DOM

The term Document Object Model refers to the hierarchical structure of HTML. Each pair of bracketed tags (or, in some cases, a single tag) is an *element*, and we refer to elements' relative relationships to each other in human terms: parent, child, sibling, ancestor, and descendant. For example, in this HTML:

```
<html>
  <body>
    <h1>Breaking News</h1>
    <p></p>
  </body>
</html>
```

body is the parent element to both of its children, h1 and p (which are siblings to each other). All elements on the page are descendants of html.

Web browsers parse the DOM to make sense of a page's content. As coders building visualizations, we care about the DOM, because our code must navigate its hierarchy to apply styles and actions to its elements. We don't want to make *all* the div elements blue; we need to know how to select just the divs of the class sky and make *them* blue.

## Developer Tools

In the olden days, the web development process went like this:

1. Write some code in a text editor.
2. Save the files.
3. Switch to a browser window.
4. Reload the page, and see if your code worked.
5. If it didn't work, take a guess at what went wrong inside the magical black box of the web browser, then go back to step 1.

Browsers were notoriously secretive about what went on *inside* the rendering engine, which made debugging a total nightmare. (Seriously, in the late 1990s and early 2000s, I literally had nightmares about this.) Fortunately, we live in a more enlightened age, and every modern-day browser has built-in *developer tools* that expose the inner workings of the beast and enable us to poke around under the hood (to mix incompatible metaphors).

All this is to say that developer tools are a big deal and you will rely on them heavily to both test your code and, when something breaks, figure out what went wrong.

Let's start with the simplest possible use of the developer tools: viewing the raw source code of an HTML page (see [Figure 3-2](#)).

Every browser supports this, although different browsers hide this option in different places. In Chrome 23.0, it's under View→Developer→View Source. In Firefox 17.0, look under Tools→Web Developer→Page Source. In Safari 6.0, it's under Develop→Show Page Source (although you must first set the “Develop” menu to display under Safari→Preferences→Advanced). Going forward, I'm going to assume that you're using the newest version of whatever browser you choose.

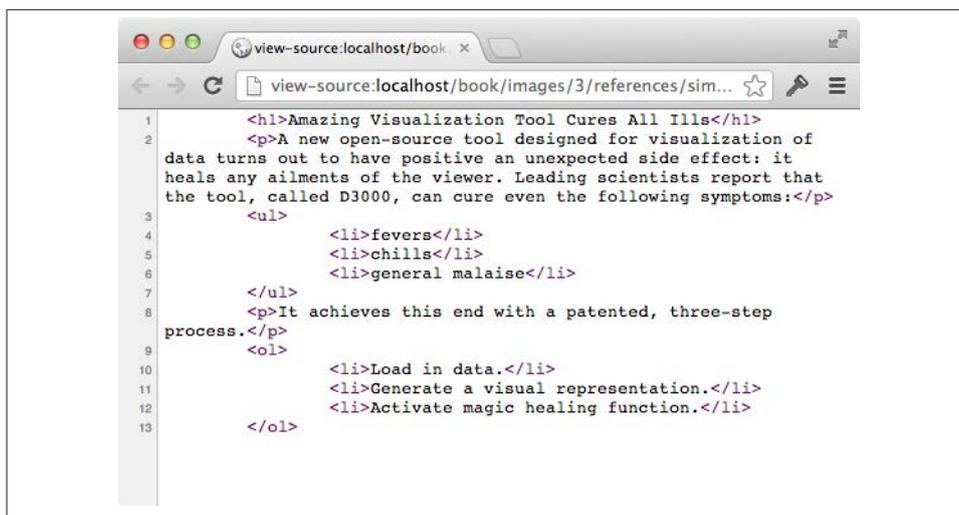


Figure 3-2. Looking at the source code in a new window

That gets you the raw HTML, but if any D3 or JavaScript code has been executed, the current DOM may be vastly different.

Fortunately, your browser's developer tools enable you to see the current state of the DOM. And, again, the developer tools are different in every browser. In Chrome, find them under View→Developer→Developer Tools. In Firefox, try Tools→Web Developer. In Safari, first enable the developer tools (in Safari→Preferences→Advanced). Then, in the Develop menu, choose Show Web Inspector. In any browser, you can also use the corresponding keyboard shortcut (as shown adjacent to the menu item) or right-click and choose “inspect element” or something similar.

Until recently, Safari and Chrome shared the same developer tools, but with Safari 6.0, Apple completely redesigned their dev tools, much to the dismay of many web-developing Safari fans. (The new tools are very hard to navigate, and I don't think I'm the only one who feels that way.) Whichever browser you use might look a bit different from my screenshots, but the functionality will be very similar.

Figure 3-3 shows the Elements tab of Chrome’s web inspector. Here we can see the current state of the DOM. This is useful because your code will modify DOM elements dynamically. In the web inspector, you can watch elements as they change.

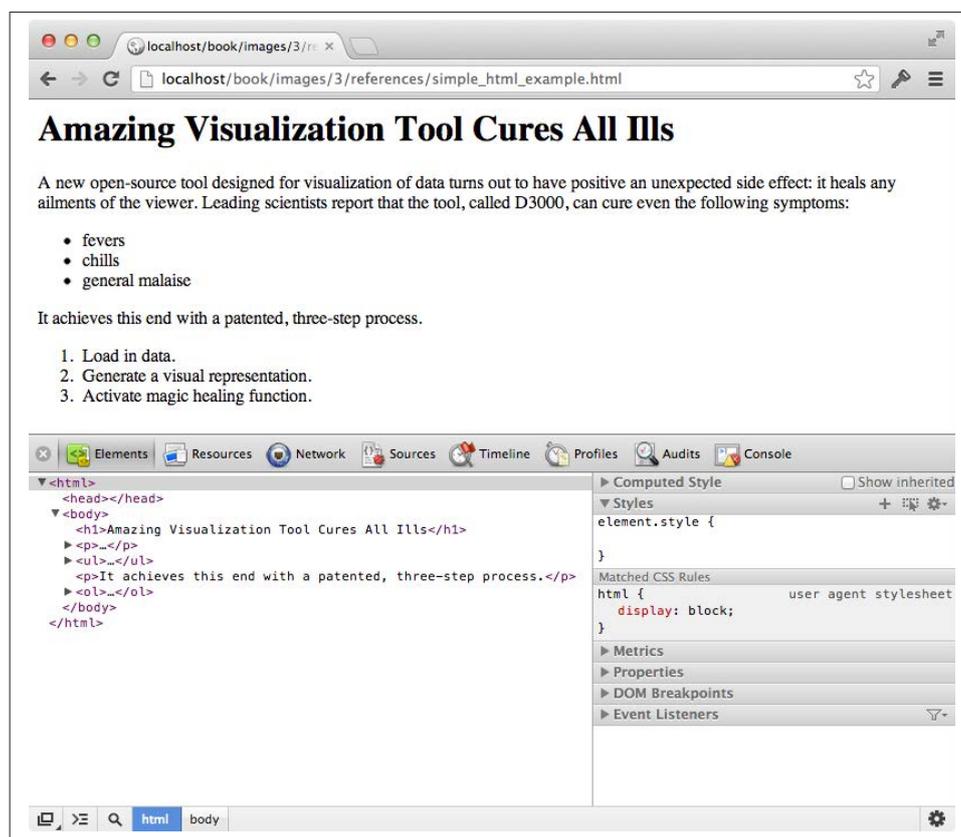


Figure 3-3. Chrome’s web inspector

If you look closely, you’ll already see some differences between the raw HTML and the DOM, including the fact that Chrome generated the required `html`, `head`, and `body` elements. (I was lazy and didn’t include them in my original HTML.)

One more thing: why am I focusing on Chrome, Firefox, and Safari? Why not Internet Explorer, Opera, or the many other browsers out there? For one, it's best to develop your projects using a browser with the broadest support for web standards. Internet Explorer made huge progress with versions 9 and 10, but Chrome, Firefox, and Safari are understood to have the broadest standards support, and they are updated more frequently.

Second, you're going to spend a lot of time using the developer tools, so you should develop with a browser that has tools you enjoy using. I was pretty devoted to Safari until the 6.0 update changed everything. Now I'm going back and forth between Chrome and Firefox's new dev tools. I recommend you try them all and decide what works best for you.

## Rendering and the Box Model

*Rendering* is the process by which browsers, after parsing the HTML and generating the DOM, apply visual rules to the DOM contents and draw those pixels to the screen.

The most important thing to keep in mind when considering how browsers render content is this: to a browser, everything is a box.

Paragraphs, `divs`, `spans`—all are boxes in the sense that they are two-dimensional rectangles, with properties that any rectangle can have, such as width, height, and positions in space. Even if something looks curved or irregularly shaped, rest assured, to the browser, it is merely another rectangular box.

You can see these boxes with the help of the web inspector. Just mouse over any element, and the box associated with that element is highlighted in blue, as shown in [Figure 3-4](#).

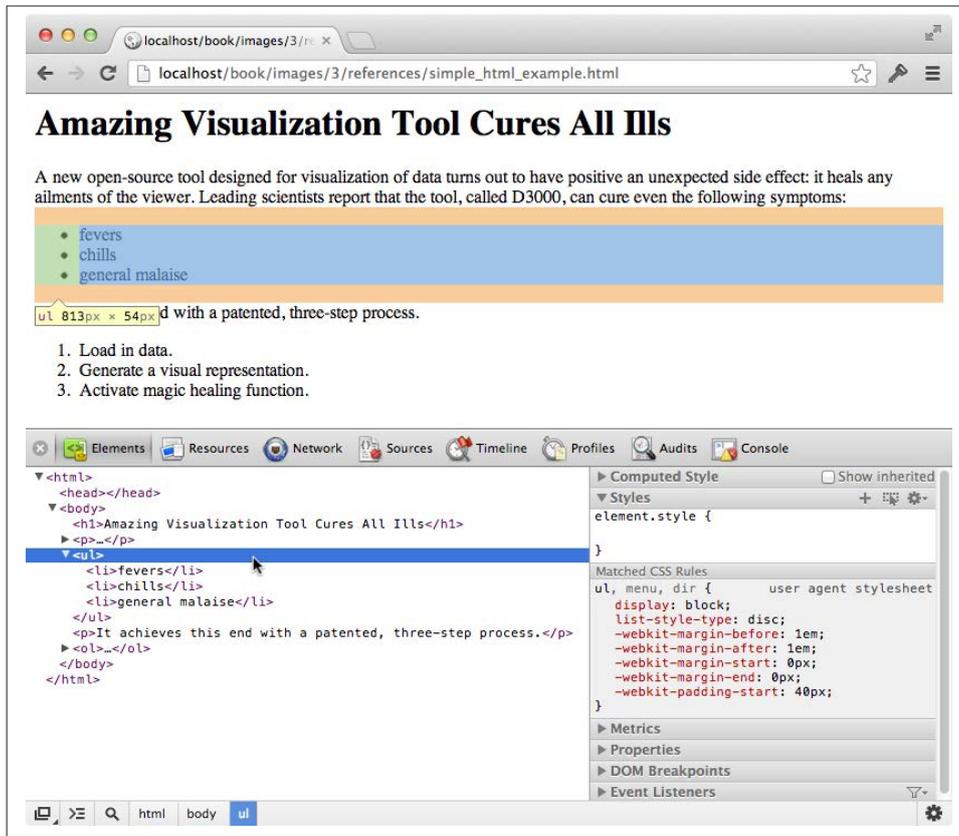


Figure 3-4. Inspector with element box highlighted

There's a lot of information about the `ul` unordered list here. Note that the list's total dimensions (width and height) are shown in the yellow box at the element's lower-left corner. Also, the list's position in the DOM hierarchy is indicated in the lower-left corner of the inspector: `html > body > ul`.

The box for the `ul` expands to fill the width of the entire window because it is a *block-level* element. (Note how under "Computed Style" is listed `display: block;`) This is in contrast to *inline* elements, which rest *in line* with each other, not stacked on top of each other like blocks. Common inline elements include `strong`, `em`, `a`, and `span`.

By default, block-level elements expand to fill their container elements and force any subsequent sibling elements further down the page. Inline elements do not expand to fill extra space, and happily exist side by side, next to their fellow inline neighbors. (Discussion question: what kind of element would you rather be?)

# CSS

Cascading Style Sheets are used to style the visual presentation of DOM elements. A simple CSS stylesheet looks like the following:

```
body {  
  background-color: white;  
  color: black;  
}
```

CSS styles consist of *selectors* and *properties*. Selectors are followed by properties, grouped in curly brackets. A property and its value are separated by a colon, and the line is terminated with a semicolon, like the following:

```
selector {  
  property: value;  
  property: value;  
  property: value;  
}
```

The same properties can be applied to multiple selectors at once by separating the selectors with a comma, as in the following:

```
selectorA,  
selectorB,  
selectorC {  
  property: value;  
  property: value;  
  property: value;  
}
```

For example, you might want to specify that both `p` paragraphs and `li` list items should use the same font size, line height, and color.

```
p,  
li {  
  font-size: 12px;  
  line-height: 14px;  
  color: orange;  
}
```

Collectively, this whole chunk of code (selectors and bracketed properties) is called a *CSS rule*.

## Selectors

D3 uses CSS-style selectors to identify elements on which to operate, so it's important to understand how to use them.

Selectors identify specific elements to which styles will be applied. There are several different kinds of selectors. We'll use only the simplest ones in this book.

### Type selectors

These are the simplest. They match DOM elements with the same name:

```
h1      /* Selects all level 1 headings      */
p       /* Selects all paragraphs              */
strong  /* Selects all strong elements           */
em      /* Selects all em elements              */
div     /* Selects all divs                    */
```

### Descendant selectors

These match elements that are contained by (or “descended from”) another element. We will rely heavily on descendant selectors to apply styles:

```
h1 em   /* Selects em elements contained in an h1 */
div p   /* Selects p elements contained in a div */
```

### Class selectors

These match elements of any type that have been assigned a specific class. Class names are preceded with a period, as shown here:

```
.caption /* Selects elements with class "caption" */
.label  /* Selects elements with class "label"  */
.axis   /* Selects elements with class "axis"   */
```

Because elements can have more than one class, you can target elements with multiple classes by stringing the classes together, as in the following:

```
.bar.highlight /* Could target highlighted bars      */
.axis.x       /* Could target an x-axis              */
.axis.y       /* Could target a y-axis                */
```

`.axis` could be used to apply styles to both axes, for example, whereas `.axis.x` would apply only to the x-axis.

### ID selectors

These match the single element with a given ID. (Remember, IDs can be used only once each in the DOM.) IDs are preceded with a hash mark.

```
#header /* Selects element with ID "header"    */
#nav   /* Selects element with ID "nav"       */
#export /* Selects element with ID "export"   */
```

Selectors get progressively more useful as you combine them in different ways to target specific elements. You can string selectors together to get very specific results. For example:

```
div.sidebar /* Selects divs with class "sidebar", but
              not other elements with that class */
#button.on /* Selects element with ID "button", but
              only when the class "on" is applied */
```

Remember, because the DOM is dynamic, classes and IDs can be added and removed, so you might have CSS rules that apply only in certain scenarios.

For details on additional selectors, see the [Mozilla Developer Network](#).

## Properties and Values

Groups of property/value pairs cumulatively form the styles:

```
margin: 10px;
padding: 25px;
background-color: yellow;
color: pink;
font-family: Helvetica, Arial, sans-serif;
```

At the risk of stating the obvious, notice that each property expects a different kind of information. `color` wants a color, `margin` requires a measurement (here in px or pixels), and so on.

By the way, colors can be specified in several different formats:

- Named colors: orange
- Hex values: #3388aa or #38a
- RGB values: `rgb(10, 150, 20)`
- RGB with alpha transparency: `rgba(10, 150, 20, 0.5)`

You can find [exhaustive lists of properties online](#); I won't try to list them here. Instead, I'll just introduce relevant properties as we go.

## Comments

```
/* By the way, this is what a comment looks like
   in CSS. They start with a slash-asterisk pair,
   and end with an asterisk-slash pair. Anything
   in between will be ignored. */
```

## Referencing Styles

There are three common ways to apply CSS style rules to your HTML document.

### Embed the CSS in your HTML.

If you embed the CSS rules in your HTML document, you can keep everything in one file. In the document head, include all CSS code within a `style` element.

```
<html>
  <head>
    <style type="text/css">

      p {
        font-size: 24px;
```

```

        font-weight: bold;
        background-color: red;
        color: white;
    }

</style>
</head>
<body>
    <p>If I were to ask you, as a mere paragraph, would you say that I
    have style?</p>
</body>
</html>

```

That HTML page with CSS renders as shown in [Figure 3-5](#).

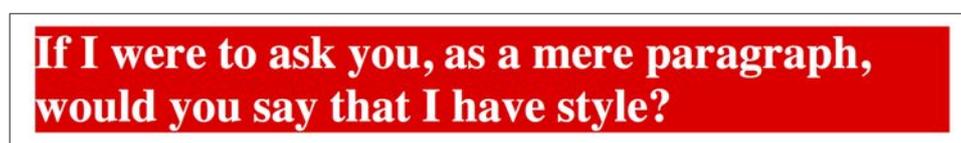


Figure 3-5. Rendering of an embedded CSS rule

Embedding is the simplest option, but I generally prefer to keep different kinds of code (for example, HTML, CSS, JavaScript) in separate documents.

### Reference an external stylesheet from the HTML.

To store CSS outside of your HTML, save it in a plain-text file with a `.css` suffix, such as `style.css`. Then use a `link` element in the document head to reference the external CSS file, like so:

```

<html>
  <head>
    <link rel="stylesheet" href="style.css">
  </head>
  <body>
    <p>If I were to ask you, as a mere paragraph, would you say that
    I have style?</p>
  </body>
</html>

```

This example renders exactly the same as the prior example.

### Attach inline styles.

A third method is to attach style rules *inline* directly to elements in the HTML. You can do this by adding a `style` attribute to any element. Then include the CSS rules within the double quotation marks. The result is shown in [Figure 3-6](#).

```
<p style="color: blue; font-size: 48px; font-style: italic;">Inline styles  
are kind of a hassle</p>
```

*Inline styles are kind of a hassle*

Figure 3-6. Rendering of an inline CSS rule

Because inline styles are attached directly to elements, there is no need for selectors.

Inline styles are messy and hard to read, but they are useful for giving special treatment to a single element, when that style information doesn't make sense in a larger stylesheet. We'll learn how to apply inline styles programmatically with D3 (which is much easier than typing them in by hand, one at a time).

## Inheritance, Cascading, and Specificity

Many style properties are *inherited* by an element's descendants unless otherwise specified. For example, this document's style rule applies to the `div`:

```
<html>  
  <head>  
    <title></title>  
    <style type="text/css">  
  
      div {  
        background-color: red;  
        font-size: 24px;  
        font-weight: bold;  
        color: white;  
      }  
  
    </style>  
  </head>  
  <body>  
    <p>I am a sibling to the div.</p>  
    <div>  
      <p>I am a descendant and child of the div.</p>  
    </div>  
  </body>  
</html>
```

Yet when this page renders, the styles intended for the `div` (red background, bold text, and so on) are *inherited* by the second paragraph, as shown in [Figure 3-7](#), because that `p` is a descendant of the styled `div`.



Figure 3-7. Inherited style

Inheritance is a great feature of CSS, as children adopt the styles of their parents. (There’s a metaphor in there somewhere.)

Finally, an answer to the most pressing question of the day: why are they called Cascading Style Sheets? It’s because selector matches cascade from the top down. When more than one selector applies to an element, the later rule generally overrides the earlier one. For example, the following rules set the text of all paragraph elements in the document to be blue *except* for those with the class of `highlight` applied, which will be black *and* have a yellow background, as shown in Figure 3-8. The rules for `p` are applied first, but then the rules for `p.highlight` override the less specific `p` rules.

```
p {  
  color: blue;  
}  
  
p.highlight {  
  color: black;  
  background-color: yellow;  
}
```

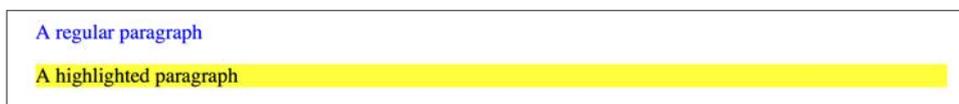


Figure 3-8. CSS cascading and inheritance at work

Later rules generally override earlier ones, but not always. The true logic has to do with the *specificity* of each selector. The `p.highlight` selector would override the `p` rule even if it were listed first, simply because it is a more specific selector. If two selectors have the same specificity, then the later one will be applied.

This is one of the main causes of confusion with CSS. The rules for calculating specificity are inscrutable, and I won’t cover them here. To save yourself headaches later, keep your selectors clear and easy to read. Start with general selectors on top, and work your way down to more specific ones, and you’ll be all right.