

# Elm IN ACTION

Richard Feldman



MANNING

# *Elm in Action*

RICHARD FELDMAN



MANNING  
SHELTER ISLAND

For online information and ordering of this and other Manning books, please visit [www.manning.com](http://www.manning.com). The publisher offers discounts on this book when ordered in quantity. For more information, please contact

Special Sales Department  
Manning Publications Co.  
20 Baldwin Road  
PO Box 761  
Shelter Island, NY 11964  
Email: [orders@manning.com](mailto:orders@manning.com)

©2020 by Manning Publications Co. All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by means electronic, mechanical, photocopying, or otherwise, without prior written permission of the publisher.

Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in the book, and Manning Publications was aware of a trademark claim, the designations have been printed in initial caps or all caps.

- ⊗ Recognizing the importance of preserving what has been written, it is Manning's policy to have the books we publish printed on acid-free paper, and we exert our best efforts to that end. Recognizing also our responsibility to conserve the resources of our planet, Manning books are printed on paper that is at least 15 percent recycled and processed without the use of elemental chlorine.



Manning Publications Co.  
20 Baldwin Road  
PO Box 761  
Shelter Island, NY 11964

Acquisitions editor: Mike Stephens  
Development editor: Elesha Hyde  
Senior technical development editor: Al Scherer  
Technical development editor: Marius Butuc  
Review editor: Aleksandar Dragosavljević  
Production editor: Anthony Calcaro  
Copy editor: Sharon Wilkey  
Proofreader: Katie Tennant  
Technical proofreader: Mathias Polligkeit  
Typesetter and cover designer: Marija Tudor

ISBN 9781617294044

Printed in the United States of America

*To Mom and Dad,  
who have given me more love and wisdom  
than I could ever return*



# *brief contents*

---

<b>PART 1</b>	<b>GETTING STARTED . .....</b>	<b>1</b>
1	▪ Welcome to Elm	3
2	▪ Your first Elm application	29
3	▪ Compiler as assistant	55
<b>PART 2</b>	<b>PRODUCTION-GRADE ELM . .....</b>	<b>89</b>
4	▪ Talking to servers	91
5	▪ Talking to JavaScript	125
6	▪ Testing	167
<b>PART 3</b>	<b>BUILDING BIGGER . .....</b>	<b>203</b>
7	▪ Data modeling	205
8	▪ Single-page applications	246



# *contents*

---

*preface* xi  
*acknowledgments* xiii  
*about this book* xv  
*about the author* xix  
*about the cover illustration* xx

## PART 1 GETTING STARTED ..... 1

### 1 *Welcome to Elm* 3

1.1 How Elm fits in 5  
1.2 Expressions 7  
    *Using elm repl* 7 ▪ *Building expressions* 8 ▪ *Booleans and conditionals* 11

1.3 Functions 13  
    *Defining functions* 14 ▪ *Importing functions* 15 ▪ *Creating scope with let-expressions* 18 ▪ *Anonymous functions* 19  
    *Operators* 20

1.4 Collections 22  
    *Lists* 23 ▪ *Records* 24 ▪ *Tuples* 26

### 2 *Your first Elm application* 29

2.1 Rendering a page 30  
    *Describing a page using the Html module* 31 ▪ *Building a project* 37

2.2	Handling user input with The Elm Architecture	40
	<i>Representing application state with a model</i>	40
	<i>Handling events with messages and updates</i>	48

## 3 Compiler as assistant 55

3.1	Documenting guarantees with type annotations	56
	<i>Adding optional type annotations</i>	56
	<i>Annotating functions with type variables</i>	58
	<i>Reusing annotations with type aliases</i>	61
	<i>Annotating longer functions</i>	62
3.2	Using case-expressions and custom types	65
	<i>Using case-expressions</i>	65
	<i>Enumerating possibilities with custom types</i>	67
	<i>Holding data in custom types</i>	71
	<i>Representing flexible messages with custom types</i>	74
3.3	Generating random numbers with commands	77
	<i>Describing random values with Random.Generator</i>	77
	<i>Introducing commands to The Elm Architecture</i>	78
	<i>Generating random values with Random.generate</i>	80

# PART 2 PRODUCTION-GRADE ELM ..... 89

## 4 Talking to servers 91

4.1	Preparing for server-loaded data	92
	<i>Modeling incremental initialization</i>	92
	<i>Resolving data dependencies</i>	95
4.2	Fetching data from a server	100
	<i>Describing HTTP requests</i>	100
	<i>Sending HTTP requests</i>	104
4.3	Decoding JSON	111
	<i>Decoding JSON strings into results</i>	111
	<i>Decoding JSON collections</i>	112
	<i>Decoding JSON HTTP responses</i>	117

## 5 Talking to JavaScript 125

5.1	Using custom elements	126
	<i>Importing custom elements</i>	127
	<i>Handling custom events</i>	133
	<i>Responding to slider changes</i>	137
5.2	Sending data to JavaScript	141
	<i>Creating a command by using a port</i>	141
	<i>Receiving data from Elm</i>	146
	<i>Timing DOM updates</i>	150

5.3 Receiving data from JavaScript	152
<i>Receiving real-time data from JavaScript via ports</i>	152
<i>Receiving initialization arguments via flags</i>	156

## 6 Testing 167

6.1 Writing unit tests	168
<i>Introducing tests</i>	168
<i>Unit testing a JSON decoder</i>	172
<i>Narrowing test scope</i>	176
6.2 Writing fuzz tests	180
<i>Converting unit tests to fuzz tests</i>	180
<i>Testing update functions</i>	184
<i>Creating multiple tests with one function</i>	186
6.3 Testing views	188
<i>Testing DOM structure</i>	189
<i>Fuzzing view tests</i>	193
<i>Testing user interactions</i>	196

## PART 3 BUILDING BIGGER ..... 203

## 7 Data modeling 205

7.1 Storing values by keys in dictionaries	206
<i>Setting up the page</i>	207
<i>Storing photos by URL in a dictionary</i>	209
7.2 Modeling trees by using recursive custom types	218
<i>Defining trees by using custom types</i>	218
<i>Recursive messages</i>	223
<i>Event handlers with recursive messages</i>	226
7.3 Decoding graphs and trees	228
<i>Decoding dictionaries</i>	228
<i>Decoding recursive JSON</i>	231
<i>Accumulating while decoding</i>	235

## 8 Single-page applications 246

8.1 Framing the page	247
<i>Creating Main.elm</i>	247
<i>Rendering the header and footer</i>	249
<i>Skipping unnecessary renders with Html.Lazy</i>	253
8.2 Routing	258
<i>Handling the initial URL</i>	258
<i>Parsing URL paths</i>	263
<i>Handling URL changes</i>	267
8.3 Delegating pages	272
<i>Revising module structure</i>	272
<i>Initializing page states</i>	275
<i>Delegating page logic</i>	279

- appendix A Getting set up* 291  
*appendix B Installing Elm packages* 294  
*appendix C Html.Lazy's change check* 298  
*index* 303

# ****preface****

---

Shortly after I gave my first conference talk about Elm, I got an email from Manning Publications. It said Manning was interested in publishing a book on Elm, and asked if I had time for a phone call with a guy named Mike to talk about Elm and maybe recommend some potential authors. I hopped on the call and gave Mike a few names. Then—I couldn’t help myself—I launched into a stream of unsolicited advice about how I thought this hypothetical book should be done.

From start to finish, the book should be about building things. The world is bursting at the seams with books on typed pure functional programming that focus on theory first, second, and third, and then get to “Hello World” around chapter 7. Elm is part of that family of languages, but Elm is for building things! A great Elm book, I told Mike, should have the reader building an interactive application by chapter 3 at the latest.

Having both taught and participated in my fair share of Elm workshops, I didn’t stop there. “The book should introduce types only after the reader has built something. That’s really important! Otherwise, what happens is . . . ” Pretty soon I was gesturing with my free hand as I paced alone around my apartment.

At some point, I realized I was describing the book I wished I’d had back when I first set out to learn functional programming. By the end of the call, I wanted that book to exist so badly, I volunteered to write it. This, I assume, was the desired outcome of the “Hey, could you recommend another author to us?” call. If so, then well played!

When I got that first email, most of my time with Elm had still been as a happy hobbyist. I’d spent less than a year with it at work—using it “in anger,” as the saying goes. I knew Elm as a fun language, and my coworkers were loving it so far, but it remained to

be seen how the language would fare in the long run, especially in the pressure cooker of a small startup with ambitious goals.

Now that I can reflect on the four years since our company first started using Elm, our decision to adopt it was without a doubt the most positive technical change I've seen any team make in my entire career. Over the years, I've heard other companies tell similar stories about their experience with Elm—in blog posts, conference talks, and sometimes enthusiastically in person.

Fast-forward a few years—and 10 Elm conferences—from that first phone call, and *Elm in Action* now exists! It has become the book I excitedly described on that call: the book I wished I'd had as a beginner. If you want to build things for web browsers, and you want them to be both reliable and delightful to maintain, then you're the person I had in mind when writing this book. I hope you enjoy exploring this wonderful language as much as I have!

# *acknowledgments*

---

I wrote this book at a pace that could charitably be described as “glacial,” so first and foremost I’d like to acknowledge the patient folks at Manning who supported me through all the written and rewritten (and, let’s be honest, sometimes rewritten another time or two) chapters—in particular, Elesha Hyde, my editor, who claims not to be a programmer but who has repeatedly spotted bugs in my code examples, and Marius Butuc, who reviewed every snippet of source code and uncovered more mistakes than I’d prefer to count. Much love to my patient wife, Kristy, for putting up with all my late nights spent writing this thing!

It goes without saying that this book would not exist without Evan Czaplicki, since he created Elm. More than that, though, this book wouldn’t have turned out nearly as well as it did without his involvement and feedback on the early drafts. Thank you so much, Evan! Further thanks go to Brian Hicks, Luke Westby, Robin Heggelund Hansen, MEAP readers who commented on Manning’s liveBook discussion forum, and to everyone else who gave detailed feedback on early chapter drafts. It made a huge difference to me.

I’ve learned from many people over the years, and I want to acknowledge a few who taught me things I needed to know to write this book. In particular, thanks go to Aditya “Deech” Siram for setting me on the path to learn typed functional programming, to Al Adams for teaching me I can bite off more than I can chew and get it down anyway, and to Amy Weiss—both for introducing me to the depth of prose and for, in 2005, looking me in my novice eye and exclaiming, “You’re a writer!” Lastly, thanks again to Evan Czaplicki for . . . I’m not sure how I could put into words all the things you’ve taught me about programming, so maybe I should have paid closer attention in Amy Weiss’s class.

I'd also like to thank all the book's formal reviewers, including Amit Lamba, Andy Kirsch, Bryce Darling, Damian Esteban, Daniel Carl, Daut Morina, Giovanni Ornaghi, Jake Romer, Jeff Smith, Jeffrey "jf" Lim, Jose Samonte, Kariem Ali, Keith Donaldson, Kent Spillner, Kumar Unnikrishnan, Lance Halvorsen, Mathias Polligkeit, Matt Audesse, Peter Hampton, Rob Bazinet, Tahir Awan, Thomas Ballinger, and Ubaldo Pescatore.

Finally, I'd like to thank the incredible friends and colleagues who have shaped the course of my life, including but by no means limited to Jack Stover, Rob Owen, Paul Bender, Tom "T Money" Mooney, Zac Hill, Josh Leven, Michael "Glass" Glass, Jeff Scheur, Marcos "Dui" Toledo, and my amazing sister, Janet Feldman. I love you all.

# *about this book*

---

*Elm in Action* teaches you how to build applications using the Elm programming language. It starts with an introduction to the language’s basic syntax and semantics, then moves on to building the beginnings of a photo-sharing application. In each of the following chapters, you build on that application—adding features, improving code quality, and writing tests—and learn more about Elm in the process. By the end of the final chapter, you’ll have scratch-built a complete single-page application with routing, tests, client-server communication, and JavaScript interoperation.

## **Who should read this book**

This book is written for people who know at least one programming language. This means, for example, that the book does not explain what a function is, or what `if` does. That said, the book does not expect you to have prior experience with types, functional programming, or any particular language syntax.

You don’t need to be a web programmer to learn Elm through this book. However, because Elm runs in the browser, in many places the book assumes you have some high-level familiarity with web concepts such as browsers, servers, HTTP, HTML, CSS, and JavaScript. If you are unfamiliar with these, you may find yourself glossing over a paragraph or diagram here and there, but by the end of the book, you can still expect to understand Elm almost as well as someone who was familiar with those technologies going in.

An exception to this rule is chapter 5, which is about how Elm code can interoperate with JavaScript code. Understanding some parts of that chapter naturally requires an understanding of JavaScript, but even that chapter contains only a few small snippets of JS code. Even if you don’t know JS, you may still be able to generally follow what the JS code is doing in the context of the chapter.

### How this book is organized: a roadmap

*Elm in Action* is divided into three parts and eight chapters. The first three chapters cover the basics; by the end of them, you will have learned the core concepts of the language and will have built a small Elm application. The next three chapters cover intermediate topics that come up in more fully featured Elm projects. The final two are about techniques that let you build larger and more advanced Elm applications.

- *Chapter 1*—“Welcome to Elm” covers the basic syntax and concepts of the language. It teaches you to “speak Elm” but not yet to do much with it.
- *Chapter 2*—“Your first Elm application” introduces the Elm Architecture, which is the foundation on which all Elm applications are built. By the end of the chapter, you’ll have used the Elm Architecture to build a working application.
- *Chapter 3*—“Compiler as assistant” covers Elm’s compiler and type system and shows how you can use it to make the application you built in chapter 2 easier to maintain.
- *Chapter 4*—“Talking to servers” shows how to use JSON decoders and commands to communicate between your application and a web server.
- *Chapter 5*—“Talking to JavaScript” introduces subscriptions over the course of adding some JavaScript interoperation to your application.
- *Chapter 6*—“Testing” shows how to use `elm-test`’s unit-testing and fuzz-testing features to make your application more reliable through automated tests.
- *Chapter 7*—“Data modeling” details recursive data modeling techniques, which give you the ability to build a wider variety of applications.
- *Chapter 8*—“Single-page applications” brings all the code from the previous chapters together, connecting your application’s two separate pages through a single-page application architecture, including handling routing and sharing code between pages.

Each chapter builds on concepts introduced in the ones before it, so the book is designed to be read in normal chapter order rather than jumping around. Every line of code in the application is introduced in one chapter or another, so if you do decide to skip around, it might help to look at the code listings at [www.manning.com/books/elm-in-action](http://www.manning.com/books/elm-in-action) to see where the application’s code base stands at the beginning of that chapter.

### About the code

This book contains many examples of source code in numbered listings and in line with normal text. In both cases, source code is formatted in a fixed-width font like this to separate it from ordinary text. Sometimes code is also in **bold** to highlight code that has changed from previous steps in the chapter, such as when a new feature adds to an existing line of code.

In many cases, the original source code has been reformatted; we’ve added line breaks and reworked indentation to accommodate the available page space in the

book. Code annotations accompany many of the listings, highlighting important concepts.

The code listings in each chapter fall into two categories: independent examples related to a particular concept, and code changes for the application whose development begins in chapter 2 and continues through chapter 8.

The complete source code for the application is available online on the Manning website at [www.manning.com/books/elm-in-action](http://www.manning.com/books/elm-in-action) and on GitHub at [github.com/rtfeldman/elm-in-action](https://github.com/rtfeldman/elm-in-action). The end of each chapter also includes a final listing indicating where any changes to the application ended up, including annotations that comment on relevant details. The independent code examples (the ones unrelated to the application) are not included in the online repository.

The book was developed with Elm version 0.19.1, which is available for free and runs on Windows, macOS, and Linux. Appendix A has instructions on how to install Elm, as well as some supplemental free tools used in chapters 6 and 8.

### ***liveBook discussion forum***

Purchase of *Elm in Action* includes free access to a private web forum run by Manning Publications where you can make comments about the book, ask technical questions, and receive help from the author and from other users. To access the forum, go to <https://livebook.manning.com/#!/book/elm-in-action/discussion>. You can learn more about Manning’s forums and the rules of conduct at <https://livebook.manning.com/#!/discussion>.

Manning’s commitment to our readers is to provide a venue where a meaningful dialogue between individual readers and between readers and the author can take place. It is not a commitment to any specific amount of participation on the part of the author, whose contribution to the forum remains voluntary (and unpaid). We suggest you try asking him some challenging questions lest his interest stray! The forum and the archives of previous discussions will be accessible from the publisher’s website as long as the book is in print.

### ***Other online resources***

The following are additional Elm resources:

- [guide.elm-lang.org](https://guide.elm-lang.org)—The official Elm guide is a fantastic resource that will always be an up-to-date language reference whenever a new version of Elm is released.
- [github.com/rtfeldman/elm-spa-example](https://github.com/rtfeldman/elm-spa-example)—This code repository contains a sizeable (roughly 4,000 lines of code) single-page application the author wrote in Elm as an example of good practices as he sees them. It can give you a sense of what a larger Elm application than the one you’ll build over the course of this book might look like.
- [frontendmasters.com/courses/elm](https://frontendmasters.com/courses/elm)—The author recorded both an “Introduction to Elm” and an “Advanced Elm” video workshop course for Frontend

Masters. The Introduction course covers topics similar to those in this book, but with different examples and exercises. The Advanced course is intended for people who have spent a few months with Elm, so you might find it a nice next step if you've finished this book and are looking for more advanced topics.

## *about the author*

---

Richard has spent 24 years programming, almost half of them professionally. Most of his career has been as a web programmer, where he has often found himself pushing the browser to its limit in the pursuit of ambitious user interfaces. He first used JavaScript before jQuery came out, was among the earliest contributors to React after it was open sourced, and started writing Elm before it had a core team.

Today Richard is a member of the Elm core team, is a frequent conference speaker on the topic of Elm, and is the organizer of the Philadelphia Elm Meetup. He is also an instructor for Frontend Masters, where he teaches an “Introduction to Elm” as well as an “Advanced Elm” course. He maintains several widely used open source Elm projects, including elm-test, elm-css, elm-spa-example, and elm-json-decode-pipeline.

Some have said he’s “into Elm,” but he’s not sure where they got that wild idea.

## *about the cover illustration*

---

### **Turkey/Ottoman Empire collection**

The illustration of the woman on the cover of *Elm in Action* is titled “An Egyptian Arab.” The illustration is taken from a collection of costumes of the Ottoman Empire published on January 1, 1802, by William Miller of Old Bond Street, London. The title page is missing from the collection, and we have been unable to track it down to date. The book’s table of contents identifies the figures in both English and French, and each illustration bears the names of two artists who worked on it, both of whom would no doubt be surprised to find their art gracing the front cover of a computer programming book ... 200 years later.

The collection was purchased by a Manning editor at an antiquarian flea market in the “Garage” on West 26th Street in Manhattan. The seller was an American based in Ankara, Turkey, and the transaction took place just as he was packing up his stand for the day. The Manning editor didn’t have on his person the substantial amount of cash that was required for the purchase, and a credit card and check were both politely turned down. With the seller flying back to Ankara that evening, the situation was getting hopeless. What was the solution? It turned out to be nothing more than an old-fashioned verbal agreement sealed with a handshake. The seller simply proposed that the money be transferred to him by wire, and the editor walked out with the bank information on a piece of paper and the portfolio of images under his arm. Needless to say, we transferred the funds the next day, and we remain grateful and impressed by this unknown person’s trust in one of us. It recalls something that might have happened a long time ago.

We at Manning celebrate the inventiveness, the initiative, and, yes, the fun of the computer business with book covers based on the rich diversity of regional life of two centuries ago, brought back to life by the pictures from this collection.

## *Part 1*

# *Getting started*

The first three chapters cover the fundamentals of building a user interface in Elm. By the end of chapter 3, you'll have built a basic Elm application from scratch, having learned how to read and write Elm syntax, use The Elm Architecture to build interactive user interfaces, and leverage Elm's compiler to get strong guarantees about your code.

Chapter 1 introduces the basics of Elm syntax and some basic operations. It focuses on small, self-contained examples and shows you how to run them. It sets the stage for chapter 2, where you begin by rendering a single page in the browser, and then make it interactive using The Elm Architecture.

Finally, chapter 3 builds on the application you wrote in chapter 2. You'll extend it by adding some documentation and new functionality, learning some helpful techniques that will come in handy throughout the rest of the book. Once you complete chapter 3, you'll know enough to be able to build a basic Elm project on your own



# Welcome to Elm

---

## This chapter covers

- Introducing Elm to a project
- Using `elm repl`
- Building expressions
- Writing and importing functions
- Working with collections

Back in 2014, I set out to rewrite a side project and ended up with a new favorite programming language. Not only was the rewritten code faster, more reliable, and easier to maintain, but writing it was the most fun I'd had in over a decade of writing code. Ever since that project, I've been hooked on Elm.

The rewrite in question was a writing application I'd built even longer ago, in 2011. Having tried out several writing apps over the course of writing a novel, and being satisfied with none, I decided to scratch my own itch and build my dream writing app. I called it Dreamwriter.

For those keeping score: yes, I was indeed writing code in order to write prose better.

Things went well at first. I built the basic web app, started using it, and iterated on the design. Months later I'd written over fifty thousand words in Dreamwriter. If I'd been satisfied with that early design, the story might have ended there. However, users always want a better experience—and when the user and the developer are the same person, further iteration is inevitable.

The more I revised Dreamwriter, the more difficult it became to maintain. I'd spend hours trying to reproduce bugs that knocked me out of my writing groove. At some point, the copy and paste functions stopped working, and I found myself resorting to the browser's developer tools whenever I needed to move paragraphs around.

Right around when I'd decided to scrap my unreliable code base and do a full rewrite, a blog post crossed my radar. After reading it, I knew three things:

- The Elm programming language compiled to JavaScript, just like Babel or TypeScript. (I already had a compile step in my build script, so this was familiar territory.)
- Elm used the same rendering approach as React.js—which I had recently grown to love—except Elm had rendering benchmarks that outperformed React's!
- Elm's compiler would catch a lot of the errors I'd been seeing before they could harm me in production. I did not yet know just how many it would catch.

I'd never built anything with a functional programming language like Elm before, but I decided to take the plunge. I didn't really know what I was doing, but the compiler's helpful error messages kept picking me up whenever I stumbled. Eventually, I got the revised version up and running, and began to refactor.

The refactoring experience blew me away. I revised the Elm-powered Dreamwriter gleefully, even recklessly—and no matter how dramatic my changes, the compiler always had my back. It would point out whatever corner cases I'd missed, and I'd go through and fix them. As soon as the code compiled, lo and behold, everything worked again. I felt *invincible*.

I related my Elm experience to my coworkers at NoRedInk, and they were curious but understandably cautious. How could we find out if the team liked it without taking a big risk? A full rewrite may have been fine for Dreamwriter, but it would have been irresponsible to attempt that for our company's entire frontend.

So we introduced Elm gently, by rewriting just one portion of one production feature in Elm. It went well, so we did a bit more. And then more.

Today our frontend programmers code almost exclusively in Elm, and our team has never been happier. Our test suites are smaller, yet our product is more reliable. Our feature set has grown more complex, yet refactoring remains delightful. We swap stories with other companies using Elm about how long our production code has run without throwing a runtime exception. In this book, we'll explore all of these benefits.

After learning some basics, we'll begin building an Elm single-page web application called *Photo Groove*. Building it will involve learning concepts that apply to any Elm application, not just single-page apps—concepts like rendering, state management, testing, talking to servers, interoperating with JavaScript, and performance optimization.

We'll build this application the way teams typically do: ship a basic version that works, but has minimal features and some technical debt. As we advance through the chapters, we'll expand and refactor our code, adding features and paying off technical debt as we learn more about Elm. By the end of the book, we will have transformed our application into a more featureful product, with a more maintainable code base, than the one we initially shipped.

With any luck, we'll have a lot of fun doing it. Welcome to Elm!

## 1.1 How Elm fits in

Elm can be used either as a replacement for in-browser JavaScript code or as a complement to it. You write some .elm files, run them through Elm's compiler, and end up with plain old .js files that the browser runs as it normally would. If you have separate stylesheets that you use alongside JavaScript, they'll work the same way alongside Elm.

Figure 1.1 illustrates this process.

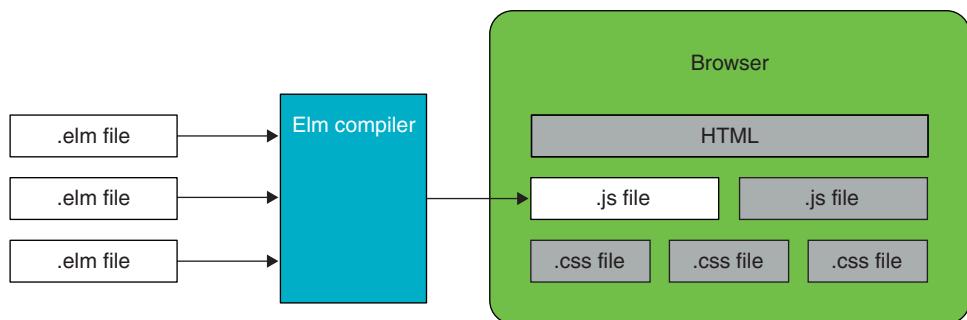


Figure 1.1 Elm files are compiled to plain old JavaScript files.

The appropriate Elm-to-JavaScript ratio can vary by project. Some projects may want primarily JavaScript and only a touch of Elm for business logic or rendering. Others may want a great deal of Elm but just a pinch of JavaScript to leverage its larger ecosystem. No single answer applies to every project.

What distinguishes Elm from the many flavors of JavaScript is *reliability*. Handwritten JavaScript code is notoriously prone to runtime crashes like “undefined is not a function.” TypeScript has improved on this, but there are enough loopholes and escape hatches in its design that the surrounding ecosystem is often regarded with caution.

In contrast, Elm programmers consistently describe the *confidence* Elm's compiler inspires in them. Elm applications have a reputation for never throwing runtime exceptions in practice! This reliability extends to the entire Elm package ecosystem, which is built around a small set of simple primitives like expressions, immutable values, and managed effects—all verified by the compiler.

Elm’s compiler also has a reputation for user-friendliness. Not only does it infer the types of entire programs without requiring the handwritten type annotations that many languages do—in chapter 2 we’ll build an entire application, and then in chapter 3 we’ll see how to add optional annotations to it—but when the compiler does find problems, it reports them with such clarity that it has made a name for itself even among legendary programmers.

*That should be an inspiration for every error message.*

—John Carmack, after seeing one of Elm’s compiler errors

Having this level of compiler assistance makes Elm code dramatically easier to refactor and debug, especially as code bases grow larger. There is an up-front cost to learning and adopting Elm, but you reap more and more maintainability benefits the longer the project remains in active development.

**TIP** Most teams that use Elm in production say they used a “planting the seed” approach. Instead of waiting for a big project where they could build everything in Elm from the ground up, they rewrote a small part of their existing JavaScript or TypeScript code base in Elm. This was low-risk and could be rolled back if things did not go as planned, but having that small seed planted in production meant they could grow their Elm code at a comfortable pace from then on.

Although Elm is in many ways a simpler language than JavaScript, it’s also much younger. This means Elm has fewer off-the-shelf solutions available for any given problem. Elm code can interoperate with JavaScript code to piggyback the larger JavaScript library ecosystem, but Elm’s design differs enough from JavaScript’s that incorporating JavaScript libraries takes effort.

Balancing these trade-offs depends on the specifics of a given project. Let’s say you’re on a team where people are comfortable with JavaScript or TypeScript, but are new to Elm. Here are some projects I expect would benefit from the team learning and using Elm:

- Feature-rich web applications whose code bases are large or will grow large
- Individual features that will be revised and maintained over an extended period of time
- Projects where most functionality comes from in-house code, not off-the-shelf libraries

In contrast, I might choose a more familiar language and toolset for projects like these:

- Time-crunched projects where learning a language is unrealistic given the deadline
- Projects that will consist primarily of gluing together off-the-shelf components
- Quick proof-of-concept prototypes that will not be maintained long-term

We'll explore these trade-offs in more detail throughout the course of the book.

## 1.2 Expressions

To get our feet wet with Elm, let's tap into one of the most universal traits across the animal kingdom: the innate desire to *play*. Researchers have developed many theories as to why we play, including to learn, to practice, to experiment, and, of course, for the pure fun of it.

These researchers could get some high-quality data by observing a member of the *homo sapiens programmerus* species in its natural environment for play—the read-eval-print loop, or REPL. You'll be using Elm's REPL to play as you take your first steps as an Elm programmer.

### 1.2.1 Using elm repl

The Elm Platform includes a nice REPL called `elm repl`, so if you have not installed the Elm Platform yet, head over to appendix A to get hooked up.

Once you're ready, enter `elm repl` at the terminal. You should see this prompt:

```
---- Elm 0.19.1 -----
Say :help for help and :exit to exit!
----- >
```

Alexander Graham Bell invented the telephone over a century ago. There was no customary greeting back then, so Bell suggested one: lift the receiver and bellow out a rousing “Ahoy!” Thomas Edison later proposed the alternative “Hello,” which stuck, and today programmers everywhere append “World” as the customary way to greet a new programming language.

Let's spice things up a bit, shall we? Enter this at the prompt:

```
> "Ahoy, World!"
```

You should see this response from `elm repl`:

```
"Ahoy, World!" : String
```

Congratulations—you are now an Elm programmer!

**NOTE** To focus on the basics, for the rest of this chapter I'll omit the type annotations that `elm repl` prints. For example, the previous code snippet would have omitted the `: String` portion of `"Ahoy, World!" : String`. We'll get into these annotations in chapter 3.

If you're the curious sort, by all means feel free to play as we continue. Enter things that occur to you and see what happens! Whenever you encounter an error you don't understand yet, picture yourself as a tiger cub building intuition for physics through experimentation: adorable for now, but powerful in time.

## 1.2.2 Building expressions

Let's rebuild our "Ahoy, World!" greeting from two parts and then play around from there. Try entering these into `elm repl`.

### Listing 1.1 Combining strings

```
> "Ahoy, World!"
"Ahoy, World!"

> "Ahoy, " ++ "World!"
"Ahoy, World!"

> "Pi is " ++ String.fromFloat pi ++ " (give or take)" ←
"Pi is 3.141592653589793 (give or take)"
```

**String.fromFloat** is a standalone function, not a method associated with a particular object. We will cover it later.

In Elm, we use the `++` operator to combine strings, instead of the `+` operator JavaScript uses. At this point, you may be wondering: does Elm even have a `+` operator? What about the other arithmetic operators? Let's find out by experimenting in `elm repl`!

### Listing 1.2 Arithmetic expressions

```
> 1234 + 103
1337

> 12345 - (5191 * -15) ←
90210
          Nests expressions via parentheses

> 2 ^ 11
2048

> 49 / 10
4.9

> 49 // 10 ←
4
          Integer division (decimals get truncated)
```

Sure enough, Elm has both a `++` and a `+` operator. They're used for different things:

- The `++` operator is for appending. Using it on a number is an error.
- The `+` operator is for addition. It can be used *only* on numbers.

You'll see this preference for *being explicit* often in Elm. If two operations are sufficiently different—in this case, adding and appending—Elm implements them separately, so each implementation can *do one thing well*.

### STRINGS AND CHARACTERS

Elm also distinguishes between *strings* and their individual UTF-8 *characters*. Double quotes in Elm represent string literals, just as in JavaScript, but single quotes in Elm represent character literals. Table 1.1 shows a few examples of strings and characters.

**Table 1.1 Strings and characters**

Elm literal	Result
"a"	A string with a length of 1.
'a'	A single character.
"abc"	A string with a length of 3.
'abc'	<i>Error:</i> Character literals must contain exactly one character.
""	An empty string.
::	<i>Error:</i> Character literals must contain exactly one character.

## COMMENTS

There are two ways to write comments in Elm:

- Use -- for single-line comments (like // in JavaScript).
- Use {- to begin a multiline comment, and -} to end it (like /\* and \*/ in JS).

Let's see these in action!

### Listing 1.3 Characters, comments, and named values

```

> 'a'  -- This is a single-line comment. It will be ignored. ←
'a'                                         | JavaScript
                                           | comment: //

> "a"  {- This comment could span multiple lines. -} ←
"a"                                         | JavaScript
                                           | comment: /* ... */

> milesPerHour = 88                         ←
88                                         | JavaScript: const
                                           | milesPerHour = 88;

> milesPerHour
88

```

## ASSIGNING NAMES TO VALUES

In the last two lines of code in the preceding listing, we did something new: we assigned the name `milesPerHour` to the value 88.

**NOTE** Normally, once we assign a name to a value, that name cannot be reassigned later to a different value in the same scope. Assignment in Elm works like JavaScript's `const` keyword, as opposed to `var` or `let`. The only exception to this is in `elm repl`, where you can override a previous assignment for convenience.

There are a few things to keep in mind when assigning names to values:

- The name must begin with a lowercase letter. After that, it can be a mix of letters, numbers, and underscores.

- By convention, all letters should be in one uninterrupted sequence. For example, `map4` is a reasonable name, but `map4ever` is not, as the sequence of letters is interrupted by the `4`.
- Because of the previous two rules, you should never use `snake_case` or `SCREAMING_SNAKE_CASE` to name values. Use `camelCase` instead.
- If you absolutely must know whether the compiler will accept `some_rad__TH1NG__` as a valid name, remember: what happens in `elm repl` stays in `elm repl`.

### ASSIGNING NAMES TO EXPRESSIONS

You can assign names not only to literal values, but also to expressions.

**DEFINITION** An *expression* is anything that evaluates to a single value.

Table 1.2 lists some expressions we've seen so far.

**Table 1.2 Examples of Elm expressions**

Expression	Evaluates to
<code>"Ahoy, " ++ "World!"</code>	<code>"Ahoy, World!"</code>
<code>2 ^ 11</code>	<code>2048</code>
<code>pi</code>	<code>3.141592653589793</code>
<code>42</code>	<code>42</code>

**NOTE** Since an expression is anything that evaluates to a value, literal values like `"Ahoy, World!"` and `42` are expressions too—just expressions that have already been fully evaluated.

Expressions are the basic building block of Elm applications. This is different from JavaScript, which offers many features as statements instead of expressions.

Consider these two lines of JavaScript code:

```
label = (num > 0) ? "positive" : "negative" // ternary expression
label = if (num > 0) { "positive" } else { "negative" } // if-statement
```

The first line is a ternary *expression*. As an expression, it evaluates to a value, and JavaScript happily assigns that value to `label`.

The second line is an *if-statement*, and since statements do not evaluate to values, trying to assign it to `label` yields a syntax error.

This distinction does not exist in Elm, as Elm programs express logic by using expressions only. As such, Elm has *if-expressions* instead of if-statements. As you will see in chapter 2, every Elm application is essentially one big expression built up from many smaller ones!

### 1.2.3 Booleans and conditionals

There aren't many Boolean values out there—just the two, really—and working with them in Elm is similar to working with them in JavaScript. There are a few differences, though:

- You write `True` and `False` instead of `true` and `false`.
- You write `/=` instead of `!==`.
- To negate values, you use Elm's `not` function instead of JavaScript's `!` prefix.

Let's try them out!

**Listing 1.4 Boolean expressions**

```
> 1 + 1 == 2           ← JavaScript: 1 + 1 === 2
True                  ← JavaScript: true

> 1 + 1 /= 2          ← JavaScript: 1 + 1 !== 2
False                 ← JavaScript: false

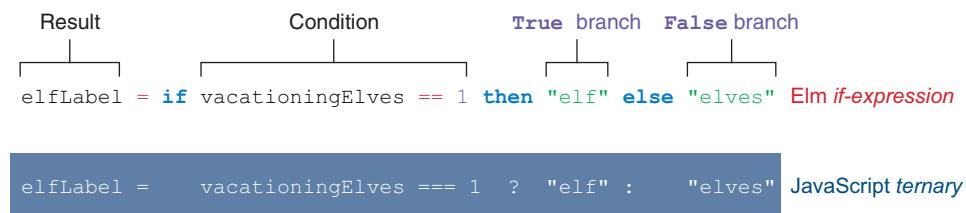
> not (1 + 1 == 2)   ← JavaScript:
False                | !(pi === pi)

> pi <= 0 || pi >= 10
False

> 3 < pi && pi < 4   ← 3 < pi < 4
True                  ← would be an error
```

Now let's say it's a lovely afternoon at the North Pole, and we're in Santa's workshop writing a bit of user interface (UI) logic to display how many elves are currently on vacation. The quick-and-dirty approach would be to add the string "`elves`" after the number of vacationing elves, but then when the count is 1, we'd display "`1 elves`", and we're better than that.

Let's polish our user experience with the if-expression shown in figure 1.2.



**Figure 1.2 Comparing an Elm if-expression to a JavaScript ternary**

Like JavaScript ternaries, Elm if-expressions require three ingredients:

- A condition
- A branch to evaluate if the condition passes
- A branch to evaluate otherwise

Each ingredient must be an expression, and the whole if-expression evaluates to the result of whichever branch got evaluated. You'll get an error if any of these three ingredients is missing, so make sure to specify an `else` branch every time!

**NOTE** JavaScript has a concept of “truthiness,” where conditionals can be values other than `true` and `false`. Elm doesn’t have truthiness. Conditions can be either `True` or `False`, and that’s it. Life is simpler this way.

Now let's say we modified our pluralization conditional to include a third case:

- If we have one Elf, evaluate to `"elf"`.
- Otherwise, if we have a positive number of elves, evaluate to `"elves"`.
- Otherwise, we must have a negative number of elves, so evaluate to `"anti-elves"`.

In JavaScript, you may have used `else if` to continue branching conditionals like this. It's common to use `else if` for the same purpose in Elm, but it's worth noting that `else if` in Elm is nothing more than a stylish way to combine the concepts we learned a moment ago. Check it out!

### Listing 1.5 Using `else if`

```
if elfCount == 1 then
    "elf"
else
    (if elfCount >= 0 then "elves" else "anti-elves")
```

```
if elfCount == 1 then
    "elf"
else (if elfCount >= 0 then
    "elves"
else
    "anti-elves")
```

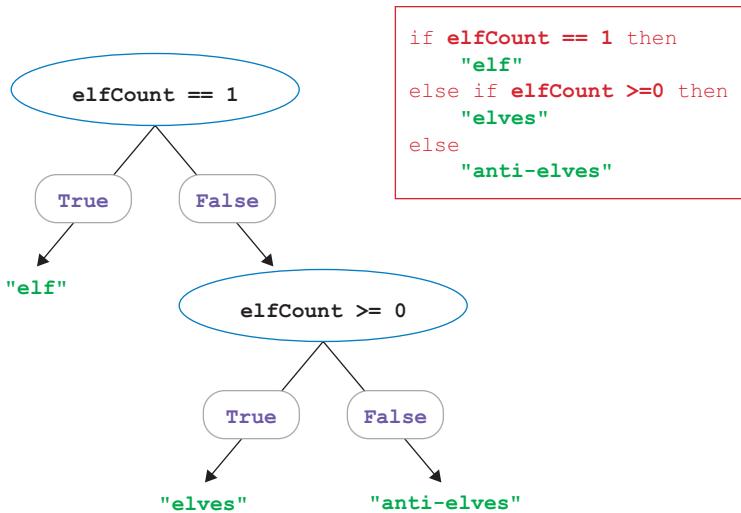
```
if elfCount == 1 then
    "elf"
else if elfCount >= 0 then
    "elves"
else
    "anti-elves"
```

Uses an if-expression inside `else`

Rearranges some whitespace

Drops the parentheses

This works because the `else` branch of an if-expression must be an expression, and it just so happens that if-expressions themselves are expressions. As shown in figure 1.3,



**Figure 1.3** The `else-if` technique: use an `if-expression` as the `else` branch of another `if-expression`.

all it takes is putting an `if-expression` after another one's `else`, and voilà! Additional branching achieved.

Nesting expressions is a recurring theme in Elm, and you'll see plenty more recipes like `else if` throughout the book.

Chapter 3 will add a powerful new conditional to our expression toolbox, one that has no analogue in JavaScript: the *case-expression*.

## 1.3 Functions

Earlier we wrote this expression:

```
elfLabel = if vacationingElves == 1 then "elf" else "elves"
```

Suppose it turns out that a general-purpose singular/plural labeler would be really useful, and we want to reuse similar logic across the code base at Santa's workshop. Search results might want to display "1 result" and "2 results" as appropriate, for example. We can write a *function* to make this pluralization logic easily reusable.

**DEFINITION** Elm *functions* represent reusable logic. They are not objects. They have no fields, no prototypes, and no ability to store state. All they do is accept values as arguments and then return a value.

If you thought expressions would be a recurring theme in Elm, wait 'til you see functions!

### 1.3.1 Defining functions

Let's define our first function: `isPositive`. It will take a number and then do the following:

- Return `True` if the number is greater than zero
- Return `False` otherwise

We can define `isPositive` in `elm repl` and try it out right away.

#### Listing 1.6 Defining a function

```
> isPositive num = num > 0      ← JavaScript: function
<function>
                                         isPositive(num) { return num > 0; }

> isPositive 2                  ← JavaScript:
                                         isPositive(2)

> (isPositive 2)                ← JavaScript:
                                         (isPositive(2))
True

> isPositive (2 - 10)           ← JavaScript:
                                         isPositive(2 - 10)
False
```

As you can see, in Elm we put the function parameter name before the `=` sign. We also don't surround the function body with `{ }`. And did you notice the `return` keyword is nowhere to be seen? That's because Elm doesn't have one! In Elm, a function body is a single expression, and since an expression evaluates to a single value, Elm uses that value as the function's return value. This means all Elm functions return values!

For our `isPositive` function, the expression `num > 0` serves as the function's body and provides its return value.

#### Refactoring out an early return

In JavaScript, `return` is often used to exit a function early. This is harmless when used responsibly, but can lead to unpleasant surprises when used in the middle of large functions. Elm does not support these unpleasant surprises, because it has no `return` keyword.

Let's refactor the early `return` out of this JavaScript function:

```
function capitalize(str) {
    if (!str) {
        return str;          ← Early
    }                                return
                                    str[0].toUpperCase() + str.slice(1);
}
```

Without making any other changes, we can refactor this early `return` into a ternary:

```
function capitalize(str) {
    return !str ? str : str[0].toUpperCase() + str.slice(1);
}
```

*Poof!* There it goes. Since JavaScript's ternaries are structurally similar to Elm's if-expressions, this code is now much more straightforward to rewrite in Elm. More-convoluted JavaScript functions may require more steps than this, but it is always possible to untangle them into plain old conditionals.

Removing an early `return` is one of many quick refactors you can do to ease the transition from legacy JavaScript to Elm, and we'll look at more of them throughout the book. When doing these, do not worry if the intermediate JavaScript code looks ugly! It's intended to be a stepping-stone to nicer Elm code, not something to be maintained long-term.

Let's use what you just learned to generalize our previous elf-labeling expression into a reusable `pluralize` function. Our function this time will have a longer definition than last time, so let's use multiple lines to give it some breathing room. In `elm repl`, you can enter multiple lines by pressing Enter to insert a line break as normal. If you do, you'll need to press Enter twice when you're finished entering everything.

**NOTE** Indent with spaces only! Tab characters are syntax errors in Elm.

#### Listing 1.7 Using multiple REPL lines

```
> pluralize singular plural count =
|   if count == 1 then singular else plural    ←
<function>

> pluralize "elf" "elves" 3      ←
"elves"                                ← No commas
                                         between arguments!

> pluralize "elf" "elves" (round 0.9)    ←
"elf"                                    ← (round 0.9)
                                         returns 1.
```

**Don't forget to press Enter twice when you're done.**

When passing multiple arguments to an Elm function, separate the arguments with whitespace and not commas. That last line of code is an example of passing the result of one function call, namely `round 0.9`, as an argument to another function. Think about what would happen if we did not put parentheses around `(round 0.9)`—how many arguments would we then be passing to `pluralize`?

### 1.3.2 Importing functions

So far, we've used only basic operators and functions we wrote ourselves. Now let's expand our repertoire of functions by using one from an external module.

**DEFINITION** A *module* is a named collection of Elm functions and other values.

The `String` module is a core module that ships with Elm. Additional modules can be obtained from Elm's official package repository, copying and pasting code from elsewhere, or through a back-alley rendezvous with a shadowy figure known as Dr. Deciduous. Chapter 4 covers the former, but neither the author nor Manning Publications endorses obtaining Elm modules through a shadowy back-alley rendezvous.

Let's import the `String` module and try out some of its functions.

### Listing 1.8 Importing functions

```
> String.toLowerCase "Why don't you make TEN louder?"
"why don't you make ten louder?"

> String.toUpperCase "These go to eleven."
"THESE GO TO ELEVEN."

> String.fromFloat 44.1
"44.1"

> String.toInt 531
"531"
```

The `String.fromFloat` and `String.toInt` functions convert *floats* (numbers that may be fractions) and *integers* (numbers that may not be fractions) to strings.

In JavaScript, both are handled by the catchall `toString` method, whereas Elm generally uses separate functions to convert between different types of values. This way, Elm can (and will) give an error if you accidentally call `String.fromFloat` on a function instead of a number, rather than cheerfully displaying gibberish to a very confused user who was expecting to see their account balance.

#### USING FUNCTIONS FROM THE STRING MODULE

Observant readers may note a striking resemblance between Elm's `String.toUpperCase` function and the `toUpperCase()` method one finds on JavaScript strings. This is the first example of a pattern we will encounter many times!

JavaScript has several ways of organizing string-related functionality: fields on a string, methods on a string, or methods on the `String` global itself.

In contrast, Elm strings have neither fields nor methods. As detailed in table 1.3, the `String` module houses the standard set of string-related features, and exposes them in the form of plain old functions like `toLowerCase` and `toUpperCase`.

**Table 1.3** String functionality comparison

JavaScript	Elm
<code>"storm".length</code>	<code>String.length "storm"</code>
<code>"dredge".toUpperCase()</code>	<code>String.toUpperCase "dredge"</code>
<code>String.fromCharCode(someChar)</code>	<code>String.fromChar someChar</code>

This organizational pattern is consistent not only within the `String` module, but also across Elm. Want a function related to sets? Look no further than the functions in the `Set` module. Debugging functions? Hit up the `Debug` module.

Methods are never the answer in Elm; over here it's all vanilla functions, all the time.

**TIP** Complete documentation for String, Set, Debug, and other tasty modules can be found in the elm/core section of the <https://package.elm-lang.org> website.

You'll learn more about modules in the coming chapters, including how to write your own!

### USING STRING.FILTER TO FILTER OUT CHARACTERS

Another useful function in the String module is filter. It lets us filter out unwanted characters from a string, such as non-numeric digits from a phone number.

To do this, we'll pass filter a function that specifies which characters to keep. The function will take a single character as an argument and return True if we should keep that character, or False if we should chuck it. Figure 1.4 illustrates using String.filter to remove dashes from a US telephone number.

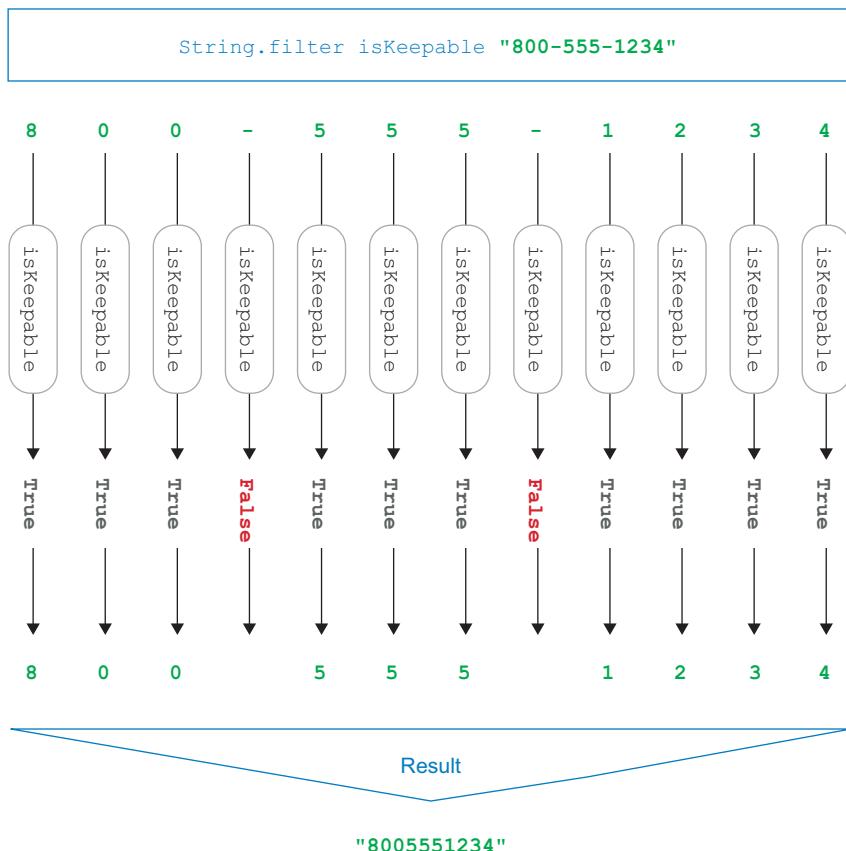


Figure 1.4 Using String.filter to remove dashes from a US phone number

Elm functions are first-class values that can be passed around just like any other value. This lets us provide `filter` with the function it expects by defining that function and then passing it in as a plain old argument.

#### **Listing 1.9 Filtering with a named function**

```
> isKeepable character = character /= '-'           ← A function describing
<function>                                         which characters to keep

> isKeepable 'z'
True

> isKeepable '-'
False

> String.filter isKeepable "800-555-1234"
"8005551234"                                     ← Passing our function
                                                    to String.filter
```

This code normalizes these telephone numbers splendidly. Alexander Graham Bell would be proud!

`String.filter` is one of the *higher-order functions* (functions that accept other functions as arguments) that Elm uses to implement customizable logic like this.

### **1.3.3 Creating scope with let-expressions**

Let's say we find ourselves removing dashes from phone numbers so often that we want to make a reusable function for the operation. We can do that with our trusty `isKeepable` function:

```
withoutDashes str = String.filter isKeepable str
```

This works, but in a larger Elm program, it might be annoying having `isKeepable` in the global scope like this. After all, its implementation is useful only to `withoutDashes`. Can we avoid globally reserving such a nicely self-documenting name?

Absolutely! We can scope `isKeepable` to the implementation of `withoutDashes` by using a *let-expression*.

**DEFINITION** A *let-expression* adds locally scoped named values to an expression.

Figure 1.5 shows how to implement `withoutDashes` by using a single *let-expression*.

The diagram illustrates the structure of the `withoutDashes` function using a *let-expression*. The code is shown in a light blue box:

```
withoutDashes str =
  let
    dash and isKeepable → dash =
      are inaccessible → ' - '
      outside this →
        let-expression. → isKeepable character =
          character /= dash
          in
          String.filter isKeepable str
```

Annotations explain the components:

- An arrow points from `dash` to the text "dash and `isKeepable` are inaccessible outside this *let-expression*".
- An arrow points from `isKeepable` to the text "isKeepable character = `character /= dash`".
- A large green arrow labeled "let-expression" points from the entire *let-expression* block to the final line `String.filter isKeepable str`.
- An annotation at the bottom left states: "The entire *let-expression* evaluates to this. → `String.filter isKeepable str`".

Figure 1.5 Anatomy of the wild let-expression

The code in figure 1.5 does very nearly the same thing as entering the following in elm repl:

```
> dash = '-'
> isKeepable character = character /= dash
> withoutDashes str = String.filter isKeepable str
```

In both versions, the implementation of `withoutDashes` boils down to `String.filter isKeepable str`. The only difference between the two is the scope of `dash` and `isKeepable`:

- In the elm repl version, `dash` and `isKeepable` are in the global scope.
- In figure 1.5, `dash` and `isKeepable` are scoped locally to the let-expression.

You can mentally replace any let-expression with the part after its `in` keyword—in this case, `String.filter isKeepable str`. All the named values between `let` and `in` are intermediate values that are no longer in scope once the expression after `in` gets evaluated.

**NOTE** The indentation you see in figure 1.5 is no accident! In a multiline let-expression, the `let` and `in` keywords must be at the same indentation level, and all other lines in the let-expression must be indented further than they are.

Anywhere you'd write a normal expression, you can swap in a let-expression instead. Because of this, you don't need to learn anything new to define locally scoped named values inside function bodies, branches of if-expressions, or anywhere else.

Wherever you want some local scope, reach for a refreshing let-expression!

#### 1.3.4 Anonymous functions

*Anonymous functions* work like named functions, except they don't have a name. The following listing compares named and anonymous functions in JavaScript and in Elm.

**Listing 1.10** Named and anonymous functions

<pre>function area(w, h) { return w * h; }  function(w, h) { return w * h; }  area w h = w * h  \w h -&gt; w * h</pre>	<div style="display: flex; justify-content: space-between;"> <div style="text-align: center;"> <p>JavaScript named function</p> </div> <div style="text-align: center;"> <p>JavaScript anonymous function</p> </div> <div style="text-align: center;"> <p>Elm named function</p> </div> <div style="text-align: center;"> <p>Elm anonymous function</p> </div> </div>
--	---

Elm's anonymous functions differ from named functions in three ways:

- They have no names.
- They begin with a \symbol{symbol}.
- Their parameters are followed by a `->` symbol instead of an `=` symbol.

Once defined, anonymous functions and named functions work the same way; you can always use one in place of the other. For example, the following do exactly the same thing:

```
isKeepable char = char /= '-'
isKeepable = \char -> char /= '-'
```

Let's use an anonymous function to call `String.filter` in one line instead of two, and then see if we can improve the business logic! For example, we can try using `Char.isDigit` to cast a wider net, filtering out any nondigit characters instead of just dashes.

### Listing 1.11 Filtering with anonymous functions

```
> String.filter (\char -> char /= '-') "800-555-1234"
"8005551234"

> String.filter (\char -> char /= '-') "(800) 555-1234"
"(800) 5551234"                                     Our simple filter
                                                        fell short here.

> String.filter (\char -> Char.isDigit char) "(800) 555-1234"
"8005551234"                                         Much
                                                        better!

> String.filter Char.isDigit "(800) 555-1234"      ← Refactor of previous
"8005551234"                                         approach
```

Anonymous functions are often used with higher-order functions like `String.filter`.

## 1.3.5 Operators

So far, we've seen functions such as `String.filter`, as well as operators such as `++`, `-`, and `==`. How do operators and functions relate?

As it turns out, Elm's operators *are* functions! There are a few things that distinguish operators from normal functions:

- Operators must always accept exactly two arguments—no more, no fewer.
- Normal functions have names that begin with a letter. You typically call them by writing the name of the function followed by its arguments. This is *prefix-style* calling.
- Operators have names that contain neither letters nor numbers. You typically call them by writing the first argument, followed by the operator, followed by the second argument. This is *infix-style* calling.
- Wrapping an operator in parentheses treats it as a normal function—prefix-style calling and all! Figure 1.6 illustrates calling the `(-)` operator in both infix style and prefix style.

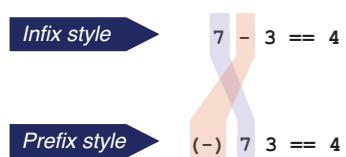


Figure 1.6 Calling the `-` operator in both infix style and prefix style

Let's play with some operators in `elm repl`.

### Listing 1.12 Showing that operators are functions

```
> (/)
<function>

> divideBy = (/)
<function>

> 7 / 2           ← Infix-style
3.5               calling

> (/) 7 2         ← Prefix-style
3.5               calling

> divideBy 7 2
3.5
```

#### OPERATOR PRECEDENCE

Try entering an expression involving both arithmetic operators and `(==)` into `elm repl`:

```
> 3 + 4 == 8 - 1
True : Bool
```

Now consider how we'd rewrite this expression in prefix style:

```
> (==) ((+) 3 4) ((-) 8 1)
True : Bool
```

Notice anything about the order in which these operators appear?

- Reading the *infix-style* expression from left to right, we see `+`, then `==`, and finally `-`.
- The *prefix-style* expression has a different order: first we see `==`, then `+`, and finally `-`.

How come? They get reordered because `(==)`, `(+)`, and `(-)` have different *precedence* values, illustrated in figure 1.7.

**DEFINITION** In any expression containing multiple operators, the operators with higher *precedence* get evaluated before those with lower precedence. This applies only to *infix-style* calls, as all *prefix-style* calls implicitly have the same precedence.

There isn't much formal documentation on operators' relative precedence values, but operators that appear in many programming languages (such as the `(==)`, `(+)`, and `(-)` operators) tend to work similarly in Elm as they do everywhere else.

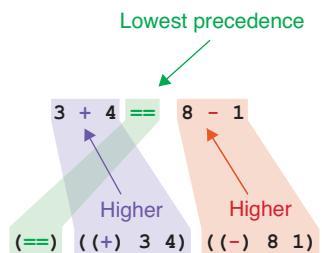


Figure 1.7 `(==)` gets evaluated after `(+)` and `(-)` because it has lower precedence.

### NORMAL FUNCTION CALLS HAVE TOP PRECEDENCE

Here are two ways to write the same thing:

```
> negate 1 + negate 5
-6

> (negate 1) + (negate 5)
-6
```

These two are equivalent because plain function calls have higher precedence than any operator. This means anytime you want to pass the results of two plain function calls to an operator, you won't need to add any parentheses! You'll still get the result you wanted.

### OPERATOR ASSOCIATIVITY

Besides precedence, the other factor that determines evaluation order for operators called in *infix style* is whether the operators are *left-associative*, *right-associative*, or *nonassociative*. Every operator is one of these.

An easy way to think about operator associativity is in terms of where the implied parentheses go, as shown in table 1.4. Infix expressions involving left-associative operators, such as arithmetic operators, have implied parentheses that cluster on the left.

**Table 1.4** Implied parentheses for the (-) operator

Parentheses shown	Expression	Result
None	10 - 6 - 3	1
Assuming <i>left-associative</i>	((10 - 6) - 3)	1
Assuming <i>right-associative</i>	(10 - (6 - 3))	7

If (-) were right-associative,  $10 - 6 - 3$  would have parentheses clustering on the right, meaning it would evaluate to  $(10 - (6 - 3))$  and the undesirable result of  $10 - 6 - 3 == 7$ . Good thing arithmetic operators are left-associative!

Nonassociative operators cannot be chained together. For example, `foo == bar == baz` does not result in clustered parentheses; it results in an error!

## 1.4

### Collections

Elm's most basic *collections* are lists, records, and tuples. Each has varying degrees of similarity to JavaScript's arrays and objects, but one way in which they differ from JavaScript collections is that Elm collections are always *immutable*.

**DEFINITION** An *immutable* value cannot be modified in any way once created.

This is in contrast to JavaScript, where some values (like strings and numbers) are immutable, but collections (like arrays and objects) can be mutated.

### 1.4.1 Lists

An Elm *list* has many similarities to a JavaScript array:

- You can create one with a square bracket literal; for example, `[ "one fish", "two fish" ]`.
- You can ask for its first element.
- You can ask for its length.
- You can iterate over its elements in various ways.

An Elm list does have some differences, though:

- It is immutable.
- It has no fields or methods. You work with it by using functions from the `List` module.
- Because it is a *linked list*, you can ask for its first element, but not for other individual elements. (If you need to ask for elements at various positions, you can first convert from an Elm `List` to an Elm `Array`. We'll discuss Elm arrays in chapter 3.)
- All elements in an Elm list must have a consistent type. For example, it can be a “list of numbers” or a “list of strings,” but not a “list where strings and numbers intermingle.” (Making a list containing both strings and numbers involves first creating wrapper elements for them, using a feature called *custom types* that we'll cover in chapter 3.)

Although Elm supports both (immutable) lists and (also immutable) arrays, Elm lists are much more commonly used in practice. Table 1.5 shows some examples of how Elm lists and JavaScript arrays differ.

**Table 1.5 Contrasting JavaScript arrays and Elm lists**

JavaScript array	Elm list
<code>[ 1, 2, 3 ].length</code>	<code>List.length [ 1, 2, 3 ]</code>
<code>[ "one fish", "two fish" ][0]</code>	<code>List.head [ "one fish", "two fish" ]</code>
<code>[ "one fish", "two fish" ][1]</code>	No arbitrary position-based element access.
<code>[ 1, 2 ].concat([ 3, 4 ])</code>	<code>[ 1, 2 ] ++ [ 3, 4 ]</code>
<code>[ 1, 2 ].push(3)</code>	Cannot be modified; use, for example, <code>append</code> instead.
<code>[ 1, "Paper", 3 ]</code>	All elements in a list must have a consistent type.

Let's focus on that last one. Why must all elements in an Elm list have a consistent type?

To understand how this requirement benefits us, let's delve into the `List.filter` function, which works like the `String.filter` function we used earlier.

We saw earlier that `String.filter` takes a function that returns `True` when the given character should be kept, and `False` when it should be dropped. `List.filter` differs only in that the function you provide doesn't necessarily receive characters—instead, it receives elements from the list, whatever they may be.

Let's see that in action. Quick! To `elm repl`!

### Listing 1.13 Filtering lists

```
> List.filter (\char -> char /= '-') [ 'Z', '-', 'Z' ]    ← Same function we passed  
['Z','Z'] to String.filter earlier

> List.filter (\str -> str /= "-") [ "ZZ", "-", "Top" ]   ← Strings instead  
["ZZ","Top"] of characters

> List.filter Char.isDigit [ '7', '-', '9' ]      ← Works just as with  
['7','9'] String.filter

> List.filter (\num -> num > 0) [ -2, -1, 0, 1, 2 ]   ← Keeps only the  
[1,2] positive numbers
```

Here's how we would rewrite that last line of code in JavaScript:

```
[ -2, -1, 0, 1, 2 ].filter(function(num) { return num > 0; })
```

This looks straightforward enough, but JavaScript arrays permit inconsistent element types. Without looking it up, can you guess what happens if we change it to the following?

```
[ -2, "0", "one", 1, "+02", "(3)" ].filter(function(num) { return num > 0; })
```

Will it crash? Will it happily return numbers? What about strings? It's a bit of a head-scratcher.

Because Elm requires consistent element types, this is a no-brainer: in Elm it would be an error. Even better, it would be an error at build time—meaning you can rest easy knowing that whatever surprises would result from executing this code will not inflict pain on your users. Requiring consistent element types means all lists in Elm guarantee this level of predictability.

By the way, the preceding `filter()` call returns `[ 1, "+02" ]`. (Like, *duh*, right?)

## 1.4.2 Records

We've now seen how JavaScript's mutable arrays resemble Elm's immutable lists. In a similar vein, JavaScript's mutable objects resemble Elm's immutable *records*.

**DEFINITION** A *record* is a collection of named fields, each with an associated value.

Array and list literals in the two languages are syntactically identical. But whereas JavaScript object literals use `:` to separate fields and values, Elm record literals use `=` instead. Let's get a sense of some of their other differences in table 1.6.

**Table 1.6 Comparing JavaScript objects and Elm records**

JavaScript object	Elm record
{ name: "Li", cats: 2 }	{ name = "Li", cats = 2 }
({ name: "Li", cats: 2 }).cats	({ name = "Li", cats = 2 }).cats
({ name: "Li", cats: 2 })["cats"]	Fields can be accessed only directly, using a dot.
({ name: "Li", cats: 2 }).cats = 3	Cannot be modified. (New cat? New record!)
{ NAME: "Li", CATS: 2 }	Field names can't start with uppercase letters.
({ name: "Li", cats: 2 }).__proto__	No prepackaged fields, only the ones you define.
Object.keys({ name: "Li", cats: 5 })	No listing of field names is available on demand.
Object.prototype	Records have no concept of inheritance.

Wow—compared to objects, records sure don’t do much! It’s like all they do is sit around holding onto the data we gave them. (Yep.) Personally, I’ve found Elm’s records a welcome reprieve from the intricacies of JavaScript’s `this` keyword.

### RECORD UPDATES

*Record updates* let us concisely obtain a new record by copying the old one and changing only the specified values. (Because records are immutable, Elm will reuse values from the existing record to save time and memory, rather than copying *everything*.)

Let’s use this technique to represent someone obtaining an extra cat, going from `{ name = "Li", cats = 2 }` to `{ name = "Li", cats = 3 }` by way of a record update.

#### **Listing 1.14 Record updates**

```
> catLover = { name = "Li", cats = 2 }
{ name = "Li", cats = 2 }

> catLover
{ name = "Li", cats = 2 }

> withThirdCat = { catLover | cats = 3 }           ↪ Record
{ name = "Li", cats = 3 }                           update syntax

> withThirdCat
{ name = "Li", cats = 3 }

> catLover
{ name = "Li", cats = 2 }                         ↪ Original record unmodified!

> { catLover | cats = 88, name = "LORD OF CATS" }   ↪ Updates multiple fields
{ name = "LORD OF CATS", cats = 88 }               (order doesn't matter)
```

Record updates let us represent this incremental evolution without mutating our records or re-creating them from scratch. In chapter 2, we'll represent our application state with a record, and use record updates to make changes based on user interaction.

### 1.4.3 Tuples

Lists let us represent collections of *varying size*, whose elements share a *consistent type*. Records let us represent collections of *fixed fields*—that is, fields that cannot be added or removed at runtime—but the values corresponding to those fields may have *varied types*.

*Tuples* introduce no new capabilities to this mix, as there is nothing a tuple can do that a record can't. Compared to records, though, what tuples bring to the party is conciseness.

**DEFINITION** A *tuple* is a record-like value whose fields are accessed by position rather than by name.

In other words, tuples are for when you want a record but don't want to bother naming its fields. They are often used for things like key-value pairs, where writing out { key = "foo", value = "bar" } would add verbosity but not much clarity. Let's try some out!

### **Listing 1.15 Using tuples**

```
> ( "Tech", 9 )
("Tech",9)

> Tuple.first ( "Tech", 9 )
"Tech"

> Tuple.second ( "Tech", 9 )
9
```

↳ Returns first element (works only on two-element tuples)

↳ Returns second element (works only on two-element tuples)

You can use the `Tuple.first` and `Tuple.second` functions only on tuples that contain two elements. If they have three elements, you can use *tuple destructuring* to extract their values.

**DEFINITION** *Tuple destructuring* extracts the values inside a tuple and assigns them to names in the current scope.

Let's use tuple destructuring to implement a function that takes a tuple of three elements.

### **Listing 1.16 Tuple destructuring**

```
> multiply3d ( x, y, z ) = x * y * z           ← Destructuring a tuple into  
<function>                                         three named values: x, y, and z  
  
> multiply3d ( 6, 7, 2 )  
84
```

```
> multiply2d someTuple = let ( x, y ) = someTuple in x * y
<function>
```

Destructuring a tuple  
inside a let-expression

As demonstrated here, once you have named the values inside the tuple, you can use them just as you would any other named value.

**TIP** Mind the difference between a tuple and a parenthetical function call! `( foo, bar )` is a tuple, whereas `( foo bar )` is a call to the `foo` function, passing `bar` as an argument. A simple mnemonic to remember the difference is “comma means tuple.”

Table 1.7 compares the feature sets of lists, records, and tuples.

**Table 1.7 Comparing lists, records, and tuples**

List	Record	Tuple
Can add or remove elements at runtime	Cannot add or remove fields at runtime	Cannot add or remove elements at runtime
Can iterate over	Cannot iterate over	Cannot iterate over
No names	Named fields	No names
Immutable	Immutable	Immutable

Because any tuple can be represented using a record instead, Elm does not support tuples of more than three elements. For those situations, it’s better to use a record! When you need only two or three elements, though, choose tuples or records based on whichever would yield more readable code; their performance characteristics are equivalent.

## Summary

We’re off to a fantastic start! First, we discussed some of the toughest problems web programmers face: crashing is too easy in JavaScript, and maintenance is too error-prone even with a boost from TypeScript. Then, you learned how Elm addresses these problems, with a design that prioritizes maintainability and a helpful compiler that catches would-be runtime exceptions before they can cause user pain. From there, you dove in and wrote your first Elm code in `elm repl`.

Here is a brief review of things we covered along the way:

- The `++` operator combines strings, whereas the `+` operator is for addition only.
- Double quotes refer to strings. Single quotes refer to individual UTF-8 characters.
- Let-expressions introduce scoped named values to an expression.
- There is no concept of “truthiness” in Elm, just `True` and `False`.
- `if foo /= bar then "different" else "same"` is an *if-expression*. Like JavaScript ternaries, if-expressions require an `else` branch and always evaluate to a value.

- Lists like [ 3, 1, 4 ] are immutable. Their elements must share a consistent type.
- List.filter ( $\lambda \text{num} \rightarrow \text{num} > 0$ ) numbersList returns a list containing all the positive numbers in the original numbersList.
- catLover = { name = "Li", cats = 2 } assigns a record to the name catLover. Once assigned, names cannot be reassigned.
- { catLover | cats = 3 } returns a new record that is the same as the catLover record, except the cats value is now 3.
- ( foo, bar ) destructures a tuple such as ( 2, 3 ). In this example, foo would be 2, and bar would be 3.

Table 1.8 summarizes some of the differences between JavaScript and Elm.

**Table 1.8 Differences between JavaScript and Elm**

JavaScript	Elm
// This is an inline comment	-- This is an inline comment
/* This is a block comment */	{- This is a block comment -}
true && false	True && False
"Ahoy, " + "World!"	"Ahoy, " ++ "World!"
"A spade" === "A spade"	"A spade" == "A spade"
"Calvin" !== "Hobbes"	"Calvin" /= "Hobbes"
Math.pow(2, 11)	2 ^ 11
Math.trunc(-49 / 10)	-49 // 10
n > 0 ? "positive" : "not"	if n > 0 then "positive" else "not"
nums.filter(function(n) { ... })	List.filter ( $\lambda \text{n} \rightarrow \text{n} > 0$ ) nums
function pluralize(s, p, c) { ... }	pluralize singular plural count = ...

You also learned about several differences between plain functions and operators, as shown in table 1.9.

**Table 1.9 Differences between plain functions and operators**

Function	How to identify one	Calling style	Examples
Plain	Name begins with a letter	Prefix style	negate, not, pluralize
Operator	Name has no letters or numbers	Infix style	(++), (*), (==)

In chapter 2, we'll expand on what you've learned here to create a working Elm application. Let's go build something!

# Your first Elm application



## This chapter covers

- Declaratively rendering a page
- Managing state with Model-View-Update
- Handling user interaction

Elm applications are built to last. They have a reputation for being scalable, easy to refactor, and difficult to crash unexpectedly. Because JavaScript applications have . . . well . . . a different reputation, it stands to reason that Elm must be doing things differently. And so it is!

Whereas each line of code in a JavaScript application could result in a change or effect—like “update that text!” or “send this to the server!”—the code in an Elm application builds up a *description* of what the program should do in response to various inputs. Elm’s compiler translates this description into the appropriate JavaScript code for the browser to run at the appropriate times, and the end user may have no idea Elm was involved at all.

In this chapter, you’ll build your first Elm application: *Photo Groove*, a simple photo-browsing web app where users select thumbnails to view larger versions.

We'll create a user interface by using declarative rendering, and manage state by using The Elm Architecture. By the end of the chapter, we will have a fully functioning application—and a code base we can build on for the rest of the book!

## 2.1 Rendering a page

Since the very early days of the web, browsers have been translating HTML markup into a Document Object Model (or DOM, for short) that represents the structure of the current page. The DOM consists of *DOM nodes*, and it's only by changing these nodes that web applications can modify the current page on the fly.

In this chapter, we'll work with the two most common types of DOM nodes:

- *Elements*—These have a `tagName` (such as "button" or "img"), and may have child DOM nodes.
- *Text nodes*—These have a `textContent` property instead of a `tagName`, and are childless.

As figure 2.1 shows, elements and text nodes can freely intermingle inside the DOM.

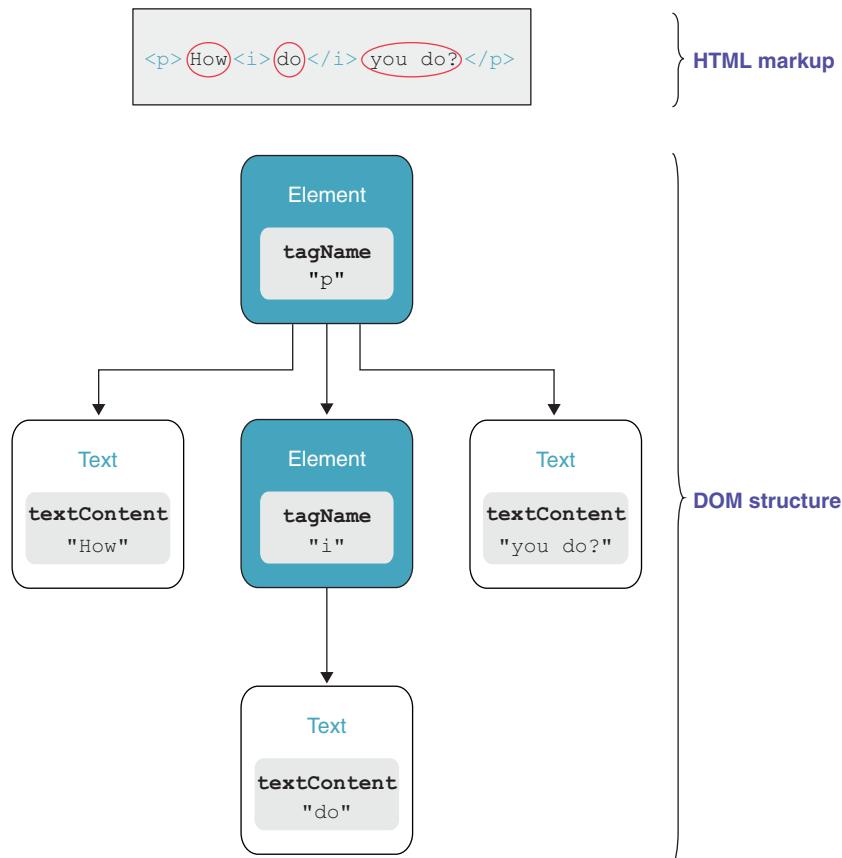


Figure 2.1 Intermingling element DOM nodes and text nodes

Here we've pulled back the curtain on the markup `<p>How <i>do</i> you do?</p>` to see that despite its two element tags—namely, `<p>` and `<i>`—we are actually working with five DOM nodes here! The other three are not elements, but rather text nodes.

### 2.1.1 Describing a page using the `Html` module

When describing how a page looks in Elm, we don't write markup. Instead, we call functions to create representations of DOM nodes. The most flexible of these functions is called `node`, and as figure 2.2 shows, its arguments line up neatly with the analogous markup.

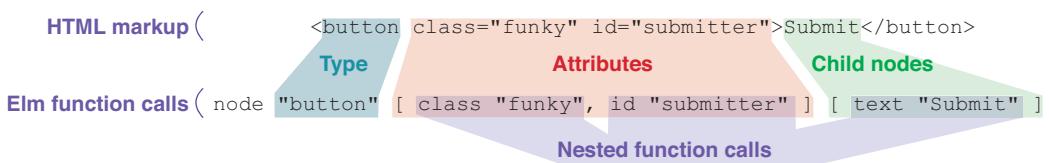


Figure 2.2 Representing a button using HTML markup (top) and Elm's `node` function (bottom)

This line of Elm code contains four function calls. Can you spot them?

- A call to the `node` function, passing three arguments: the string `"button"`, a list of attributes, and a list of child nodes
- A call to the `class` function, passing `"funky"`
- A call to the `id` function, passing `"submitter"`
- A call to the `text` function, passing `"Submit"`

These are plain old Elm functions. Each returns a representation of a portion of the DOM: a `button` element, a text node, and some `class` and `id` attributes. You can call these functions anytime you like, and pass their return values to other functions as usual.

In Elm, we usually refer to a “virtual DOM node” as “`Html`” for short. This name comes from the `Html` module, which provides a variety of intuitively named functions that let you avoid calling `node` directly. For example, the `Html` module’s `img` function is shorthand for calling `node` and passing `"img"` as the first argument. The following two lines are equivalent:

```
node "img" [ src "logo.png" ] []
     img  [ src "logo.png" ] []
```

It's best practice to use functions like `img` as much as possible, and to fall back on `node` only when no alternative is available. (For example, you may notice that there is no equivalent of the `img` function for the deprecated `<blink>` element. I'm not saying you should call `node "blink" [] [ text "<BLINK> LIVES AGAIN" ]`, but I'm not *not* saying that, either.)

## RENDERING A PAGE

Let's use what you've learned to render your first page with Elm! For the rest of this chapter, we'll be building the Photo Groove application. Eventually, we'll add features like applying filters and viewing larger versions, but first we need to render a basic page labeled "Photo Groove" across the top, with some thumbnail images below.

Because our output is visual this time, `elm repl` won't get us very far. Instead, let's kick things off with our first .elm file:

- 1 Make a new directory called `PhotoGroove` and open it in a terminal.
- 2 Run `elm init` and enter `y` when prompted. This will create a file called `elm.json`, which Elm needs to build our project. If you're curious about `elm.json`, take a look at appendix B.
- 3 `elm init` will have created a directory called `src`. Create a file called `PhotoGroove.elm` inside this `src` directory.

Now that our file structure is set up, enter the following into the `src/PhotoGroove.elm` file.

### Listing 2.1 src/PhotoGroove.elm

```
module PhotoGroove exposing (main)
    ← Declares a new module
import Html exposing (div, h1, img, text)
import Html.Attributes exposing (...)

    ← Imports other modules

view model =
    div [ class "content" ]
        [ h1 [] [ text "Photo Groove" ] ← h1 element with an
          ← empty attributes list
        , div [ id "thumbnails" ]
            [ img [ src "http://elm-in-action.com/1.jpeg" ] []
            , img [ src "http://elm-in-action.com/2.jpeg" ] []
            , img [ src "http://elm-in-action.com/3.jpeg" ] []
            ]
        ]
    ← Put commas at the start of the line.

main = ← We'll discuss "main" later.
    view "no model yet"
```

**Put commas at the start of the line.**

## DECLARING THE PHOTOGROOVE MODULE

By writing `module PhotoGroove exposing (main)` at the top of our `PhotoGroove.elm` file, we define a new module. This means future modules in our project will be able to import this `PhotoGroove` module just as they would the `String` or `Html` modules; for example, like so:

```
import PhotoGroove exposing (main)
```

Because we wrote `exposing (main)` after `module PhotoGroove`, we are exposing only one of our two top-level values—`main` but not `view`—for other modules to import.

This means another module that imported PhotoGroove would get an error if it tried to access PhotoGroove.view. Only exposed values can be accessed by other modules. As a general rule, it's best for our modules to expose as little as possible.

## Why commas in front?

When writing a multiline literal in JavaScript, the usual convention is to put commas at the end of each line. Consider the following code:

```
rules = [
    rule("Do not talk about Sandwich Club."),
    rule("Do NOT talk about Sandwich Club.")
    rule("No eating in the common area.")
]
```

Did you spot the mistake? A comma is missing after the second call to `rule`, meaning this is not syntactically valid JavaScript. Running this code will result in a `SyntaxError`.

Now consider the equivalent Elm code, with the same missing comma:

```
rules = [
    rule "Do not talk about Sandwich Club.",
    rule "Do NOT talk about Sandwich Club."
    rule "No eating in the common area."
]
```

The mistake is just as easy to overlook, but harder to fix because this is syntactically valid Elm code—but not the code you intended to write!

The missing comma means the preceding code is essentially equivalent to the following:

```
rules = [
    (rule "Do not..."),
    (rule "Do NOT..." rule "No eating...")
]
```

Instead of calling `rule` three times, each time with one argument, here the second call to `rule` is receiving three arguments—and there is no third call. Instead of the syntax error JavaScript gave you, you'll get a seemingly nonsensical error about functions being called with the wrong number of arguments.

Now try to make this mistake when writing in a commas-first style:

```
rules =
  [ rule "Do not talk about Sandwich Club."
    rule "Do NOT talk about Sandwich Club."
    , rule "No eating in the common area."
  ]
```

This style makes it blindingly obvious that a comma is missing. Now we don't even need to compile our code to identify the problem!

It may feel different at first, but the commas-first style gives you one less potential error to worry about once you get used to it.

Now that we have our PhotoGroove module, it's time to see what it looks like in a browser. Still inside the same directory as the one where we ran `elm init`, run this:

```
elm reactor
```

This will start up a local server running at <http://localhost:8000> that can compile and serve our Elm files. Open <http://localhost:8000/src/PhotoGroove.elm> in your browser, and you should see the results of the compiled PhotoGroove.elm file. The page should look like the screenshot in figure 2.3.

## Photo Groove



Figure 2.3 Viewing <http://localhost:8000/src/PhotoGroove.elm>

Congratulations! You've rendered your first user interface in Elm. Figure 2.4 shows the DOM structure of the interface we just rendered.

Notice how the functions that create elements—in this case, `div`, `h1`, and `img`—take exactly two arguments in all cases:

- *A list of attributes*—If an element has no attributes, we pass `[]` like so:

```
h1 [] [ text "Photo Groove" ]
```

- *A list of child DOM nodes*—If an element has no children, we pass `[]` like so:

```
img [ src "1.jpeg" ] []
```

If an element has neither attributes nor children? In that case, we pass `[] []` like this:

```
br [] []
```

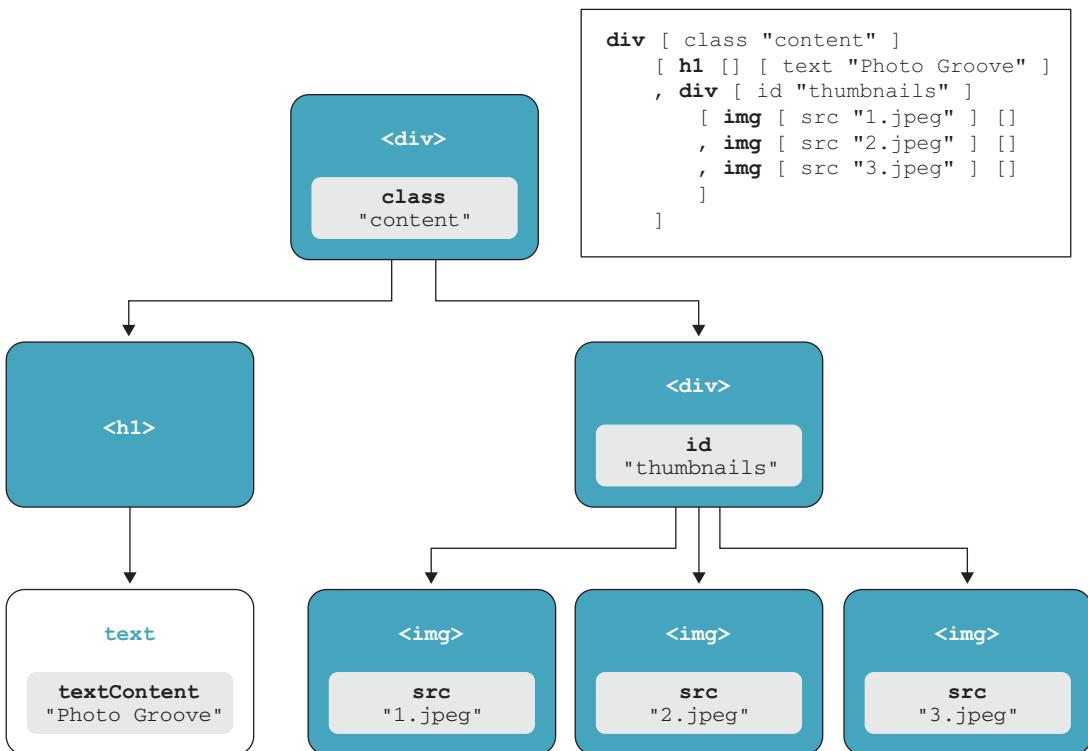


Figure 2.4 The DOM structure of our first Elm user interface

This two-argument pattern is consistent throughout the `Html` module, and it's worth following if you ever decide to make a custom element of your own by using the `node` function. We'll see more of the `node` function in chapter 5.

#### IMPORTING UNQUALIFIED VALUES WITH EXPOSING

We've now used several functions from the `Html` module, but we wrote them in a style different from that of chapter 1. Back then, we wrote functions like `String.filter` in a *qualified* style—that is, we included the `String` module's name right there in the function call. With the `Html` module's functions, we used an *unqualified* style—we wrote `div` instead of `Html.div`, we wrote `h1` instead of `Html.h1`, and so forth.

We could do this because we used `exposing` when we imported the `Html` module:

```
import Html exposing (div, h1, img, text)
```

This line of code both imports the `Html` module so we can use its contents, and brings `Html.div`, `Html.h1`, `Html.img`, and `Html.text` into the global scope. That lets us refer to them as `div`, `h1`, `img`, and `text` without the prefix of `Html`.

We could have achieved essentially the same result by assigning them names directly:

```
import Html

div = Html.div
h1 = Html.h1
img = Html.img
text = Html.text
```

However, since this pile of code can be replaced by a single line—`import Html exposing (div, h1, img, text)`—it's normal to use `exposing` for this purpose instead.

### **EXPOSING EVERYTHING WITH (...)**

When we imported the `Html` module, we listed exactly which values we wanted to expose: `div`, `h1`, `img`, and `text`. For the `Html.Attributes` module, we wrote this instead:

```
import Html.Attributes exposing (...)
```

Using `exposing (...)` means “expose everything,” which lets us use every value in the `Html.Attributes` module in an unqualified style. Let’s change our first `import` to use `exposing (...)` instead:

```
import Html exposing (...)
```

Now we won’t need to extend the list of `div`, `h1`, `img`, and `text` whenever we want to use a new element type. Everything the `Html` module has to offer is now in our global scope.

### **Why is the qualified style the better default choice?**

In chapter 1, we wrote out `String.toUpperCase` and `List.filter`, instead of `toUpperCase` and `filter`. Here we’re doing the opposite, writing `img` and `div` instead of `Html.img` and `Html.div`.

This raises the question: when is it a good idea to use the qualified style (with the module name prefixed) over the unqualified style? The unqualified style is more concise, so why not use `exposing (...)` every time?

Unqualified imports have two primary downsides. One is that unqualified names can become ambiguous. Try this in `elm repl`:

```
> import String exposing (...)
> import List exposing (...)
> reverse
```

You’ll get an error saying that `reverse` is ambiguous. After importing and exposing both `String.reverse` and `List.reverse`, it’s no longer clear which of the two

you meant. (In cases like this, you can still use the qualified style to resolve the ambiguity, so if you now put `String.reverse` or `List.reverse` into `elm repl`, they will still work as usual.)

Unqualified imports are also less self-documenting. Suppose you come across code that says `partition foo bar`, and you've never seen `partition` before. Naturally, you wonder: "How can I find out what `partition` does? Is it defined in this file?" You search through the file and can't find it, so it must come from an `import`. You scroll up to the imports and discover a long list of `exposing (...)` declarations. Argh! `partition` could be in any of those!

This could take a while. . . .

Suppose instead you see the code `List.partition foo bar`. You want to know what `List.partition` does, so you bring up the documentation for the `List` module on <https://package.elm-lang.org>. You learn about `List.partition`, then get on with your day.

Scenarios like this are why it's best practice to write things in a *qualified* way by default.

Still, sometimes there's a good reason to prefer the unqualified style—for example, unqualified `Html` functions are designed to resemble HTML markup. In these cases, it's best to limit yourself to one `exposing (...)` (or perhaps one "family" of them, such as `Html` and `Html.Attributes`) per file. This way, if you encounter an unfamiliar function of mysterious origin, you'll have the fewest modules to hunt through to find its documentation.

## 2.1.2 Building a project

Now that we have something on the screen, let's add some styles!

**TIP** There are many ways to style a web page, each with its own trade-offs. The two most popular Elm-specific choices are `rtfeldman/elm-css`, a package for writing CSS directly in Elm, and the groundbreaking `mdgriffith/elm-ui`, which provides a way to style pages without writing CSS at all. Comparing styling alternatives is outside the scope of this book, but both of these can be found at <https://package.elm-lang.org>.

We could style our page by using a separate Elm package, or by writing inline CSS styles using the `Html.Attributes.style` attribute, but instead we're going to organize things by writing our CSS declarations in a separate `.css` file.

The only way to get multiple files involved in the same web page is to give a browser some HTML markup, so our first step in the process of styling our application will be to create a `.html` file.

Let's create a file named `index.html` in the same directory as our `elm.json` file (the one where we ran `elm init` back in section 2.1.1) and put the following content inside it.

### Listing 2.2 index.html

```
<!doctype html>
<html>
    <head>
        <style>
            body { background-color: rgb(44, 44, 44); color: white; }
            img { border: 1px solid white; margin: 5px; }
            .large { width: 500px; float: right; }
            .selected { margin: 0; border: 6px solid #60b5cc; }
            .content { margin: 40px auto; width: 960px; }
            #thumbnails { width: 440px; float: left; }
            h1 { font-family: Verdana; color: #60b5cc; }
        </style>
    </head>

    <body>
        <div id="app"></div>           ← Our Elm application  
will render into this div.
        <script src="app.js"></script>           ← PhotoGroove.elm will  
get compiled into app.js.
        <script>
            Elm.PhotoGroove.init({node: document.getElementById("app")});
        </script>
    </body>
</html>
```

The markup we put in this file covers things like these:

- The standard `<!doctype>`, `<html>`, and `<body>` tags
- Whatever `<head>` inclusions we need—styles, metadata, `<title>`, and so on
- Importing a file called `app.js`, which we will have Elm's compiler generate in a moment

The line `Elm.PhotoGroove.init({node: document.getElementById ("app")});` starts our Elm code running in the `<div id="app"></div>` element we included in `index.html`.

### COMPILING TO JAVASCRIPT

Next, it's time to compile our Elm code into JavaScript. Run this in the terminal:

```
elm make src/PhotoGroove.elm --output app.js
```

This will compile our `PhotoGroove.elm` file into the JavaScript file the browser will read. (That generated JavaScript file will be called `app.js`, because we passed `--output app.js` to `elm make`.) Now our HTML file has a compiled `app.js` file to load up.

## THE ELM RUNTIME AND MAIN

When Elm compiles our code into JavaScript, it includes an extra bit of JavaScript known as the *Elm Runtime*. The Elm Runtime is behind-the-scenes code that quietly handles things like the following:

- Adding and removing event listeners for any events our code depends on
- Efficiently scheduling tasks like HTTP requests and DOM updates
- Storing and managing application state

When we called `Elm.PhotoGroove.init` from `index.html`, we told the Elm Runtime to use the top-level `main` value in the `PhotoGroove` module as the application's entry point. If we did not have a module called `PhotoGroove`, or if it did not define a top-level value named `main`, we'd receive an error.

This means when the browser runs our compiled code, `view "no model yet"` will be the first line of code executed, because that's what we assigned to `main`. If we renamed the `PhotoGroove` module to `CubeDraft`, we'd have to call `Elm.CubeDraft.init` instead, but otherwise everything would still work. If the `CubeDraft` module did not define a value named `main`, however, the application would not start. There's no renaming `main`!

If you open `index.html` in a browser, you should see the application displaying as it does in figure 2.5. Fantastic! Next, we'll make it interactive.

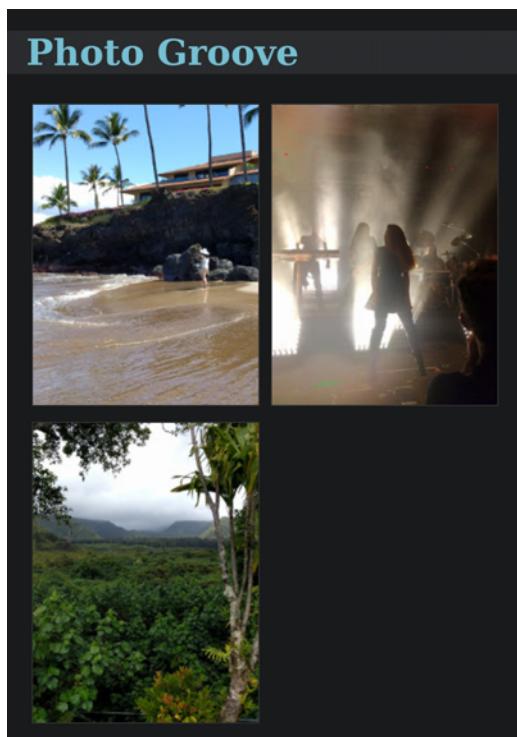


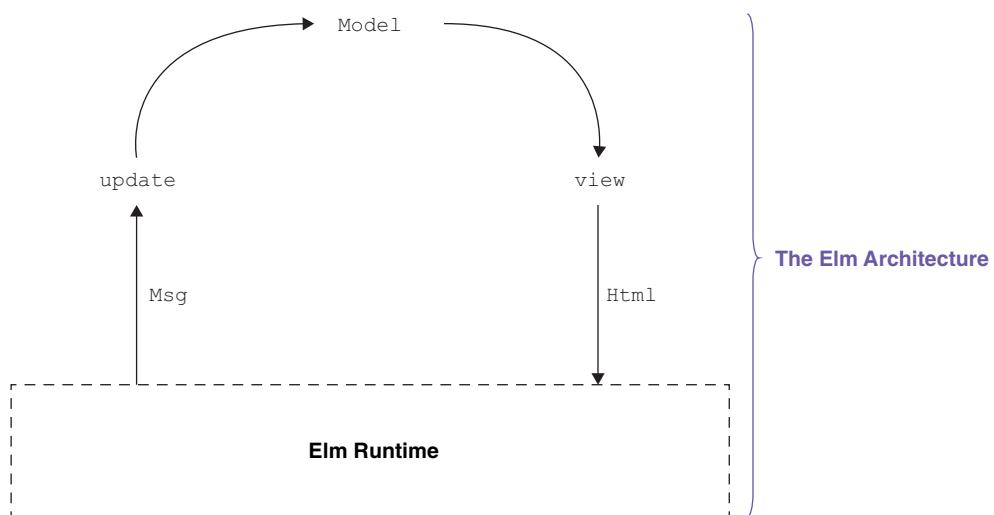
Figure 2.5 Rendering the application

## 2.2 Handling user input with The Elm Architecture

So far, we haven't had much data flowing through our application. Okay, we haven't had *any*—all we did was generate some `Html` and render it. That will soon change, as we're about to start handling user input! This brings us to a common question that every growing application faces sooner or later: how will we keep data flow manageable as our code base grows?

JavaScript offers a staggering selection of data flow architectures to choose from, but Elm has just one. It's called *The Elm Architecture*, and the Elm Runtime is optimized for applications that follow it. We'll learn about The Elm Architecture as we add interactivity to Photo Groove.

Figure 2.6 shows a preview of the architecture we'll be building toward in this chapter. Don't worry if this does not make sense yet! We'll get there, one step at a time.



**Figure 2.6** The Elm Runtime uses The Elm Architecture to manage data flow.

Let's begin where data flow naturally begins in an application: with the application's *state*.

### 2.2.1 Representing application state with a model

Back in the Wild West days of the web, it was common to store application state primarily in the DOM itself. Is that menu expanded or collapsed? Check whether one of its DOM nodes has `class="expanded"` or `class="collapsed"`. Need to know what value a user has selected in a drop-down menu? Query it out of the DOM at the last possible instant.

This approach turned out not to scale very well, especially as applications grew more complex. Today it's common practice to store application state completely outside the DOM, and to propagate changes from that independent state over to the DOM as necessary. This is how we do it in The Elm Architecture.

### DECLARING A MODEL

We're going to store our application state separately from the DOM, and we'll refer to that state as our *model*.

**DEFINITION** The *model* represents the state of an Elm application.

Remember how earlier we wrote this code?

```
main =
    view "no model yet"
```

Let's replace that code with the contents of the following listing.

#### Listing 2.3 Adding a model

```
initialModel =
[ { url = "1.jpeg" }
, { url = "2.jpeg" }
, { url = "3.jpeg" }
]
```

**We'll add more fields beyond url later.**

```
main =
    view initialModel
```

**Passes our new initialModel record to view**

Excellent! Now we have an initial model to work with. So far, it contains a list of photos, each of which is represented by a record containing a `url` string.

### WRITING A VIEW FUNCTION

Next, we'll render a thumbnail for each photo in our list. At the top level of a typical Elm application is a single *view function*, which accepts our current model as an argument and then returns some `Html`. The Elm Runtime takes the `Html` returned by this view function and alters the page's actual DOM to match it.

By pure coincidence, we've already written just such a view function—it's the function we had the foresight to name `view`. Unfortunately, our current `view` implementation ignores the `model` argument it receives, which means changing our model won't result in a change visible to the end user. Let's fix that! `view` should base its return value on its `model` argument.

It'll be easier to do this if we first write a separate *viewThumbnail helper function*, which renders a single thumbnail as `Html`.

**DEFINITION** A *helper function* helps another function do its job. Here, the `viewThumbnail` helper function will help `view` do its job.

Let's replace our view implementation with the code in the following listing.

#### Listing 2.4 Splitting out viewThumbnail

```
urlPrefix =
    "http://elm-in-action.com/" | We'll prepend this to
                                strings like "1.jpeg".

view model =
    div [ class "content" ]
        [ h1 [] [ text "Photo Groove" ]
        , div [ id "thumbnails" ] []
        ]

viewThumbnail thumb =
    img [ src (urlPrefix ++ thumb.url) ] [] | Prepend urlPrefix to get a complete URL
                                                like "http://elm-in-action.com/1.jpeg".
```

Figure 2.7 illustrates how our current model and view connect to the Elm Runtime.

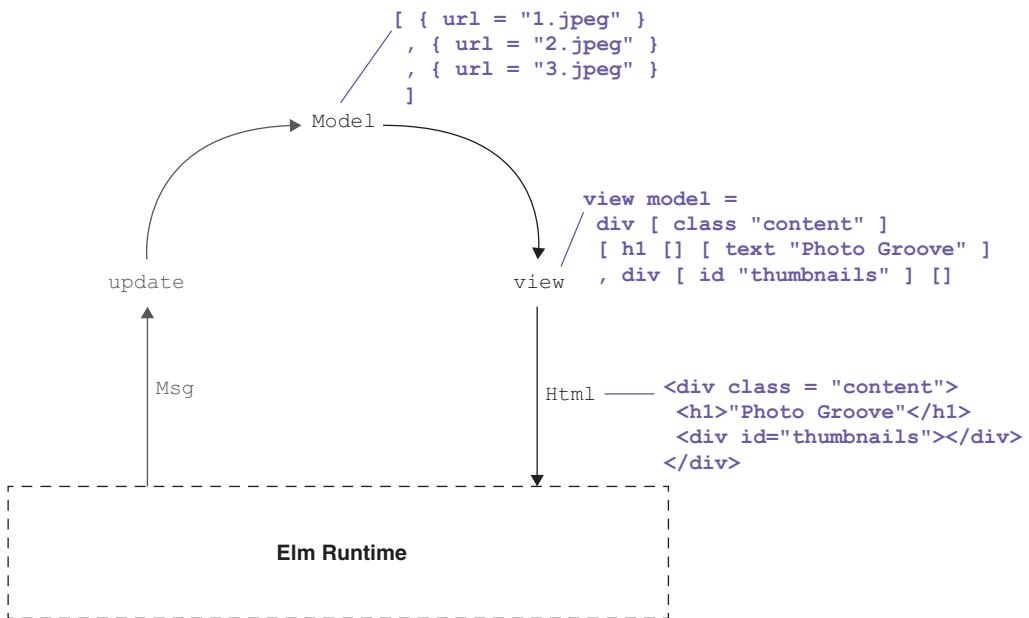


Figure 2.7 Model and view connecting with the Elm Runtime

Next, we'll iterate over our list of photo records and call `viewThumbnail` on each one, in order to translate it from a dusty old record to a vibrant and inspiring `img`. Fortunately, the `List.map` function does exactly this!

## USING LIST.MAP

`List.map` is another *higher-order* function similar to the `List.filter` function we used in chapter 1. We pass `List.map` a translation function and a list, and it runs that translation function on each value in the list. Once that's done, `List.map` returns a new list containing the translated values. Take a look at figure 2.8 to see `List.map` do its thing for `viewThumbnail`.

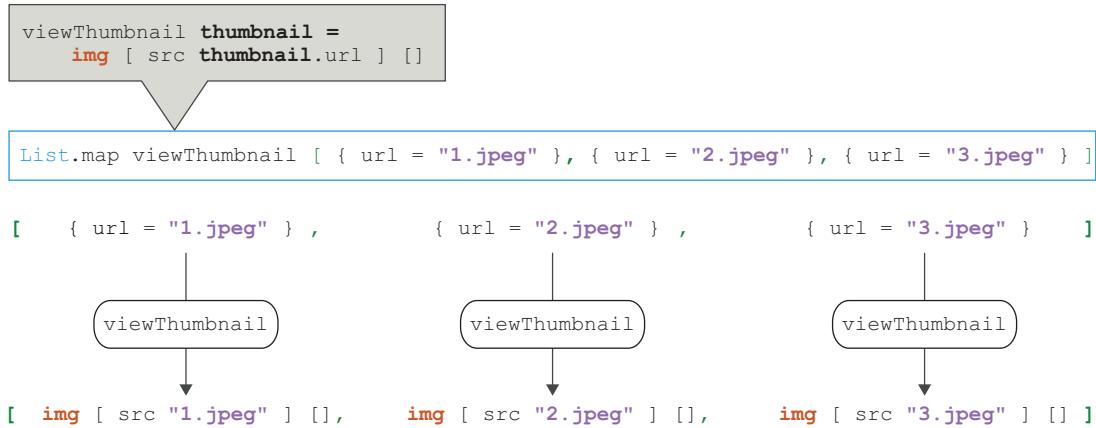


Figure 2.8 Using `List.map` to transform photo records into `img` nodes

Because `div` is a plain Elm function that accepts two lists as arguments—first a list of attributes, followed by a list of child nodes—we can swap out our entire hardcoded list of child `img` nodes with a single call to `List.map`! Let's do that now:

```

view model =
  div [ class "content" ]
    [ h1 [] [ text "Photo Groove" ]
    , div [ id "thumbnails" ] (List.map viewThumbnail model)
    ]

viewThumbnail thumb =
  img [ src (urlPrefix ++ thumb.url) ] []
  
```

If you run `elm make src/PhotoGroove.elm --output app.js` again to recompile this code, you should see the same result as before. The difference is that now we have a more flexible internal representation, setting us up to add interactivity in a way that was impossible before we connected `model` and `view`.

## EXPANDING THE MODEL

Now let's add a feature: when the user clicks a thumbnail, it will become selected—indicated by a blue border surrounding it—and we'll display a larger version of it beside the thumbnails.

To do this, we first need to store which thumbnail is selected. That means we'll want to convert our model from a list to a record, so we can store both the list of photos and the current `selectedUrl` value at the same time.

### Listing 2.5 Converting the model to a record

```
initialModel =
  { photos =
    [ { url = "1.jpeg" }
    , { url = "2.jpeg" }
    , { url = "3.jpeg" }
    ]
  , selectedUrl = "1.jpeg" }
```



Next, let's update `viewThumbnail` to display the blue border for the selected thumbnail. That's easier said than done! `viewThumbnail` accepts only one argument—`thumbnail`—so it has no way to access the model. That, in turn, means it can't possibly know the current value of `selectedUrl`—but without knowing which thumbnail is selected, how can it know whether to return a selected or unselected `img`? It can't! We'll have to pass that information along from `view` to `viewThumbnail`.

Let's rectify this situation by passing `selectedUrl` into `viewThumbnail` as an additional argument. Armed with that knowledge, `viewThumbnail` can situationally return an `img` with the `"selected"` class—which our CSS has already styled to display with a blue border—if the `url` of the given thumbnail matches `selectedUrl`:

```
viewThumbnail selectedUrl thumb =
  if selectedUrl == thumb.url then
    img
      [ src (urlPrefix ++ thumb.url)
      , class "selected"
      ]
      []
  else
    img
      [ src (urlPrefix ++ thumb.url) ]
      []
```

Comparing our `then` and `else` cases, we see quite a bit of code duplication. The only thing different about them is whether `class "selected"` is present. Can we trim down this code?

Absolutely! We can use the `Html.classList` function. It builds a `class` attribute by using a list of tuples. Each tuple contains, first, the desired class name, and, second, a Boolean indicating whether to include the class in the final class string.

Let's refactor the preceding code to the following, which does the same thing:

```
viewThumbnail selectedUrl thumb =
  img
    [ src (urlPrefix ++ thumb.url)
```

```
, classList [ ( "selected", selectedUrl == thumb.url ) ]
]
[]
```

Now all that remains is to pass in `selectedUrl`, which we can do with an anonymous function. While we're at it, let's also add another `img` to display a larger version of the selected photo.

#### Listing 2.6 Rendering a selected thumbnail via an anonymous function

```
view model =
    div [ class "content" ]
        [ h1 [] [ text "Photo Groove" ]
        , div [ id "thumbnails" ]
            (List.map
                (\photo -> viewThumbnail model.selectedUrl photo)
                model.photos
            )
        , img
            [ class "large"
            , src (urlPrefix ++ "large/" ++ model.selectedUrl)
            ]
            []
        ]
]
```

Displays a larger version  
of the selected photo

If you recompile with the same `elm make` command as before, the result should now look like figure 2.9. Looking good!

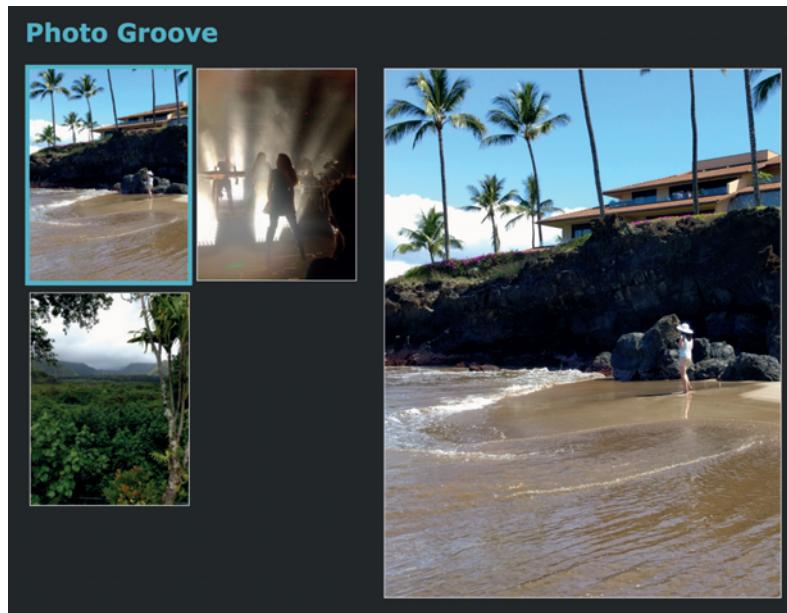


Figure 2.9 Rendering a larger version alongside the selected thumbnail

### REPLACING ANONYMOUS FUNCTIONS WITH PARTIAL APPLICATION

Although the way we've written this works, it's not quite idiomatic Elm code. The idiomatic style would be to remove the anonymous function like so:

```
Before: List.map (\photo -> viewThumbnail model.selectedUrl photo)
  model.photos
After: List.map (viewThumbnail model.selectedUrl)
  model.photos
```

Whoa! Does the revised version still work? Do these two lines somehow do the same thing? It totally does, and they totally do! This is because calling `viewThumbnail` without passing all of its arguments is an example of *partially applying* a function.

**DEFINITION** *Partially applying* a function means passing it some of its arguments—but not all of them—and getting back a new function that will accept the remaining arguments and finish the job.

When we called `viewThumbnail model.selectedUrl photo`, we provided `viewThumbnail` with both of the arguments it needed to return some `Html`. If we call it without that second `photo` argument, what we get back is not `Html`, but rather a function—specifically, a function that accepts the missing `photo` argument and *then* returns some `Html`.

Let's think about how this would look in JavaScript, where functions don't support partial application by default. If we'd written `viewThumbnail` in JavaScript, and wanted it to support partial application, it would have had to look like this:

```
function viewThumbnail(selectedUrl) {
  return function(thumb) {
    if (selectedUrl === thumb.url) {
      // Render a selected thumbnail here
    } else {
      // Render a non-selected thumbnail here
    }
  };
}
```

Functions that can be partially applied, such as the one in this JavaScript code, are known as *curried functions*.

**DEFINITION** A *curried function* is a function that can be partially applied.

All Elm functions are curried. That's why when we call `(viewThumbnail model.selectedUrl)`, we end up partially applying `viewThumbnail`, not getting an `undefined` argument or an error.

In contrast, JavaScript functions are not curried by default. They are instead *tupled*, which is to say they expect a complete “tuple” of arguments. (In this case, *tuple* refers to “a fixed-length sequence of elements,” not specifically one of Elm's tuple values.)

Elm and JavaScript both support either curried or tupled functions. The difference is in which they choose as the default:

- In JavaScript, functions are tupled by default. If you'd like them to support partial application, you can first curry them by hand—as we did in our JavaScript `viewThumbnail` implementation in the preceding code.
- In Elm, functions are curried by default. If you'd like to partially apply them, go right ahead. They're already set up for it. If you'd like a tupled function, write a curried function that accepts a single tuple as its argument, and then destructure that tuple.

Table 2.1 shows how to define and use both curried and tupled functions in either language.

**Table 2.1 Curried functions and tupled functions in Elm and JavaScript**

	Elm	JavaScript
Curried function	<code>splitA separator str =     String.split separator str</code>	<code>function splitA(sep) {     return function(str) {         return str.split(sep);     } }</code>
Tupled function	<code>splitB ( separator, str ) =     String.split separator str</code>	<code>function splitB(sep, str) {     return str.split(sep); }</code>
Total application	<code>splitB ( "-", "867-5309" )</code>	<code>splitB("-", "867-5309")</code>
Total application	<code>splitA "-" "867-5309"</code>	<code>splitA("-")("867-5309")</code>
Partial application	<code>splitA "-"</code>	<code>splitA("-")</code>

We can use our newfound powers of partial application to make `view` more concise. We now know we can replace our anonymous function with a partial application of `viewThumbnail`:

```
Before: List.map (\photo -> viewThumbnail model.selectedUrl photo) model.photos
After:  List.map      (viewThumbnail model.selectedUrl) model.photos
```

**TIP** In Elm, an anonymous function like `(\foo -> bar baz foo)` can always be rewritten as `(bar baz)` by itself. Keep an eye out for this pattern; it comes up surprisingly often.

Here's how our updated `view` function should look.

### Listing 2.7 Rendering a selected thumbnail via a partial application

```

view model =
    div [ class "content" ]
        [ h1 [] [ text "Photo Groove" ]
        , div [ id "thumbnails" ]
            (List.map (viewThumbnail model.selectedUrl) model.photos)
        , img
            [ class "large"
            , src (urlPrefix ++ "large/" ++ model.selectedUrl)
            ]
        []
    ]

```

**Partially applies  
viewThumbnail with  
model.selectedUrl**


Because all Elm functions are curried, it's common to give a function more information by adding an argument to the *front* of its arguments list. For example, when `viewThumbnail` needed access to `selectedUrl`, we made this change:

<b>Before:</b> <code>List.map viewThumbnail</code>	<code>model.photos</code>
<b>After:</b> <code>List.map (viewThumbnail model.selectedUrl)</code>	<code>model.photos</code>

Fortunately, we added the new `selectedUrl` argument to the front. This let us pass it in using partial application instead of an anonymous function. This is a common technique in Elm code.

**NOTE** *Currying* is named after acclaimed logician Haskell Brooks Curry. The Haskell programming language is also named after him. Whether the Brooks Brothers clothing company is named after his middle name is left as an exercise for the reader.

## 2.2.2 Handling events with messages and updates

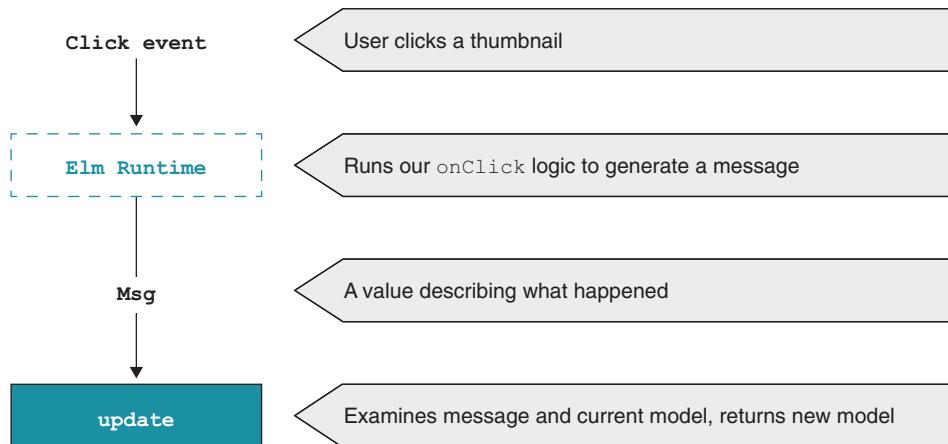
Now that we can properly render which thumbnail is selected, we need to change the appropriate part of the model whenever the user clicks a different thumbnail. If we were writing JavaScript, we might implement this logic by attaching an event listener to each thumbnail like so:

```
thumbnail.addEventListener("click", function() { model.selectedUrl = url; });
```

Elm wires up event handlers a bit differently. Similarly to the way we wrote a `view` function that translated our current `model` into a desired DOM structure, we're now going to write an `update` function that translates *messages* into our desired `model`.

**DEFINITION** A *message* is a value used to pass information from one part of the system to another.

When the user clicks a thumbnail, a message will be sent to an `update` function, as illustrated in figure 2.10.



**Figure 2.10** Handling the event when a user clicks a thumbnail

The message should describe *what happened*—for example, “the user clicked a photo”—but the format of our message is entirely up to us. We could represent it as a string, or a list, or a number, or anything else we please. Here’s a message implemented as a record:

```
{ description = "ClickedPhoto", data = "2.jpeg" }
```

This record is a message that conveys the following: “The user clicked the 2.jpeg photo.” It will be up to our update function to decide what to do with this information. In general, when update receives a message, it will do the following:

- 1 Look at the message it received
- 2 Look at our current model
- 3 Use these two values to determine a new model, and then return it

We can implement our “select photo” logic by adding this update function right above main:

```
update msg model =
    if msg.description == "ClickedPhoto" then
        { model | selectedUrl = msg.data }

    else
        model
```

Notice that if we receive an unrecognized message, we return the original model unchanged. This is important! Whatever else happens, the update function must always return a new model, even if it happens to be the same as the old model.

### ADDING ONCLICK TO VIEWTHUMBNAIL

We can declare that a `ClickedPhoto` message should be sent to update whenever the user clicks a thumbnail, by adding an `onClick` attribute to `viewThumbnail`. To do this, we'll first need to import the `Html.Events` module, since that's where `onClick` lives.

Our imports now look like this:

```
import Html exposing (...)
import Html.Attributes exposing (...)
import Html.Events exposing (onClick)
```

Now that we've imported `onClick`, let's introduce it to `viewThumbnail` like so:

```
viewThumbnail selectedUrl thumb =
    img
        [ src (urlPrefix ++ thumb.url)
        , classList [ ( "selected", selectedUrl == thumb.url ) ]
        , onClick { description = "ClickedPhoto", data = thumb.url }
        ]
        []
```

The Elm Runtime takes care of managing event listeners behind the scenes, so this one-line addition is the only change we need to make to our view. We're ready to see this in action!

### THE MODEL-VIEW-UPDATE LOOP

To wire our Elm Application together, we're going to change `main = view model` to the following, which incorporates `update` according to how we've set things up so far. First, we'll add one final import to the top of our imports list:

```
import Browser
```

This module gives us access to the `Browser.sandbox` function, which we can use to describe an interactive Elm application like so:

```
main =
    Browser.sandbox
        { init = initialModel
        , view = view
        , update = update
        }
```

The `Browser.sandbox` function takes a record with three fields:

- `model`—A value that can be anything you please
- `view`—A function that takes a model and returns an `Html` node
- `update`—A function that takes a message and a model, and returns a new model

It uses these arguments to return a description of a program, which the Elm Runtime sets in motion when the application starts up. Before we got the `Browser` module involved, `main` could render only static views. `Browser.sandbox` lets us specify how to react to user input. Figure 2.11 shows how data flows through our revised application.

Notice that `view` builds fresh `Html` values after every update. That might sound like a lot of performance overhead, but in practice, it's almost always a performance *benefit!*

This is because Elm doesn't actually re-create the entire DOM structure of the page every time. Instead, it compares the `Html` it got this time to the `Html` it got last time and updates only the parts of the page that are different between the two requested representations.

This approach to *virtual DOM* rendering, popularized by the JavaScript library React, has several benefits over manually altering individual parts of the DOM:

- Updates are batched to avoid expensive repaints and layout reflows.
- Application state is far less likely to get out of sync with the page.
- Replaying application state changes effectively replays user interface changes.

Let's compile once more with `elm make src/PhotoGroove.elm --output app.js`. If you open `index.html`, you should now be able to click a thumbnail to select it. You

```
update msg model =
    if msg.description == "ClickedPhoto" then
        { model | selectedUrl = msg.data }
    else
        model
```

```
{ description = "ClickedPhoto"
, data = "2.jpeg"
}
```

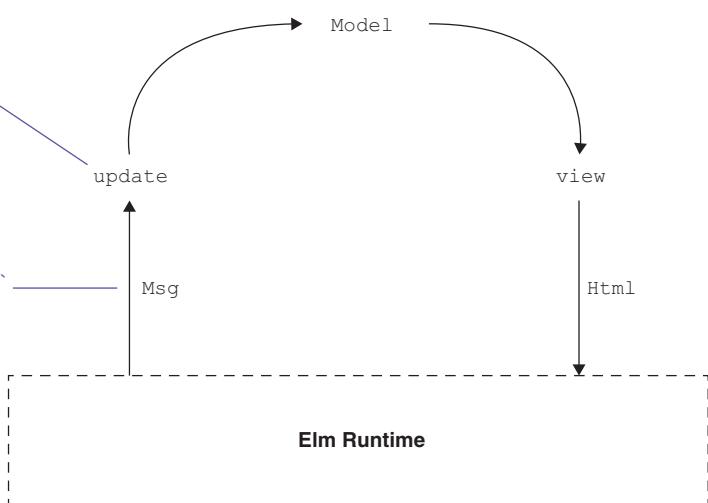


Figure 2.11 Data flowing from the start of the program through the Model-View-Update loop

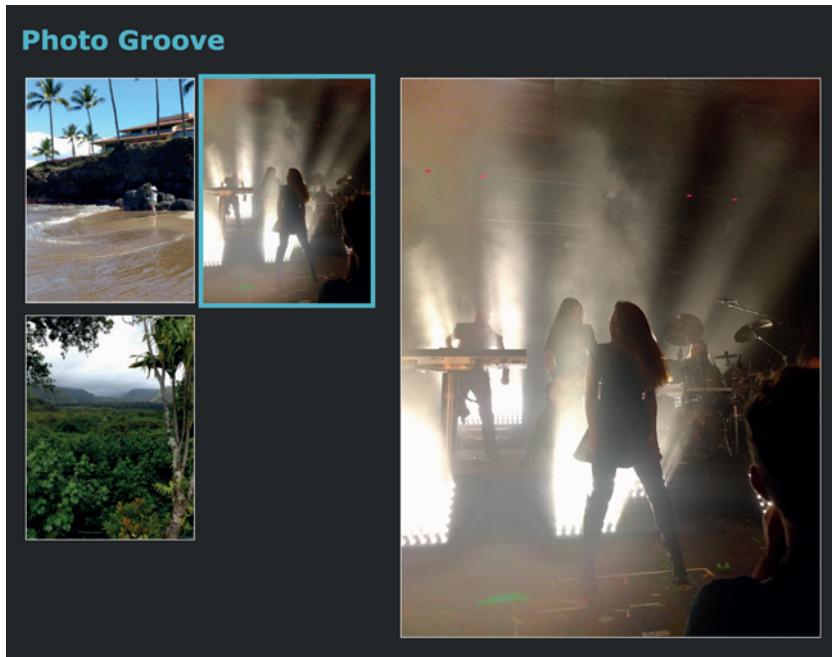


Figure 2.12 Our final Photo Groove application

can tell it worked by the outline that appears around the selected photo, like the one in figure 2.12. Huzzah!

At this point, we've also worked our way through the complete Elm Architecture diagram from the beginning of section 2.2. Figure 2.13 shows where things ended up.

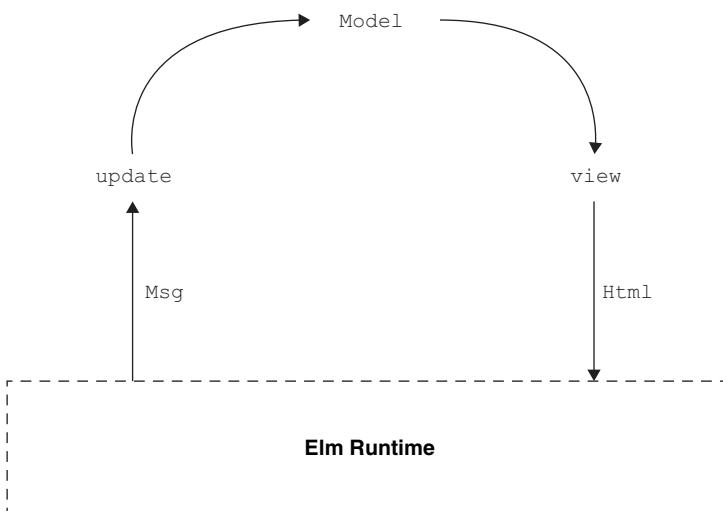


Figure 2.13 Our final Elm Architecture setup

Congratulations on a job well done!

## Summary

In this chapter, you learned three ways to handle interactions, each of which differs from the JavaScript way of handling the same. Table 2.2 summarizes these differences.

**Table 2.2** Handling interactions in JavaScript compared to Elm

Interaction	JavaScript approach	Elm approach
Changing the DOM	Directly alter DOM nodes	Return some <code>Html</code> from a view function
Reacting to user input	Attach a listener to an element	Specify a message to send to update
Changing application state	Alter an object in place	Return a new model in update

We covered many other concepts in the course of building our first Elm application, including the following:

- A model represents our application state.
- A view function takes a model and returns a list of `Html` nodes.
- User events such as clicks get translated into message values.
- Messages get run through the `update` function to produce a new model.
- After an update, the new model is sent to the view function to determine the new DOM.
- `Browser.sandbox` wires together model, view, and update.
- `List.map` is a higher-order function that translates one list into another.
- All Elm functions are curried, which means they can be partially applied.

Here's the complete `src/PhotoGroove.elm` file we ended up with.

**Listing 2.8** `PhotoGroove.elm` with a complete Model-View-Update in place

```
module PhotoGroove exposing (main)
    import Browser
    import Html exposing (..)
    import Html.Attributes exposing (..)
    import Html.Events exposing (onClick)

urlPrefix =
    "http://elm-in-action.com/"

view model =
    div [ class "content" ]
```

The diagram shows annotations for the code listing:

- A bracket on the left side of the code, spanning the module definition and imports, is labeled "The name of our module".
- A bracket on the right side of the imports, spanning the entire list, is labeled "The other modules we're importing".
- A bracket at the bottom, spanning the entire view function, is labeled "The view function takes the current model and returns some HTML".

```

[ h1 [] [ text "Photo Groove" ]
, div [ id "thumbnails" ]
    (List.map (viewThumbnail model.selectedUrl) model.photos) ←
, img
    [ class "large"
    , src (urlPrefix ++ "large/" ++ model.selectedUrl)
    ]
    []
]

viewThumbnail selectedUrl thumb =
img
[ src (urlPrefix ++ thumb.url)
, classList [ ( "selected", selectedUrl == thumb.url ) ]
, onClick { description = "ClickedPhoto", data = thumb.url } ←
]
[]

initialModel =
{ photos =
[ { url = "1.jpeg" }
, { url = "2.jpeg" }
, { url = "3.jpeg" }
]
, selectedUrl = "1.jpeg"
}

update msg model =
if msg.description == "ClickedPhoto" then ← Changes the selected URL to
    { model | selectedUrl = msg.data } ← the photo the user clicked
else
    model

main =
Browser.sandbox ← Browser.sandbox describes
{ init = initialModel
, view = view
, update = update
}
our complete application.

```

In the next chapter, we'll get into ways to improve the application we've made so far, both adding features and refactoring to make it easier to maintain. Onward!

# Compiler as assistant

## This chapter covers

- Documenting guarantees with type annotations
- Implementing multiway conditionals with case-expressions
- Storing flexible data with custom types
- Using `Array` and `Maybe` for positional element access
- Generating random numbers by using commands

In chapter 2, we built your first Elm application. It doesn't do much yet, but it has potential! So far, it displays thumbnails of three photos, and lets users click one to view a larger version.

We showed it to our manager, who was thrilled with what we made: "Wow, this is looking *incredible*. The part where you click the thumbnail and it shows the bigger version? Just brilliant. I'm going to get some more team members working with you on this."

Nice! Quite a vote of confidence. Sure, we have no tests or documentation to help get these new teammates up to speed, but there's no time like the present to clean up our code.

Our manager also has a couple of feature requests: “Let’s give users the ability to choose between viewing small, medium, or large thumbnails. Also, for this next version, I want to kick the fun factor into overdrive. Let’s add a button that says *Surprise Me!*, and when you click it, it selects one of the photos—at random.”

We resist the urge to tell our manager, “Whoa there, that might be too much fun,” and instead review the tasks we’ve just received:

- Improve code quality to help new team members get up to speed.
- Let users choose between small, medium, and large thumbnails.
- Add a Surprise Me! button that randomly selects a photo.

Improving code quality *while* adding new features is often a tall order—even more so because these particular features involve aspects of Elm you have not yet encountered. Fortunately, we have an assistant to help us out: Elm’s compiler.

In this chapter, you’ll learn how the compiler can help you improve documentation, refactor without introducing regressions, and accomplish both while introducing new features. Let’s get to it!

## 3.1 Documenting guarantees with type annotations

One of the quickest ways we can make our code nicer for incoming teammates is to add comments that document what our code does. Although comments are simple and flexible, they’re also notoriously unreliable. Sometimes they’re written inaccurately. Other times they start out accurate but become inaccurate as the code base changes out from under them.

*Code never lies. Comments sometimes do.*

—Ron Jeffries

Elm gives us access to a permanently trustworthy form of documentation: type annotations.

### 3.1.1 Adding optional type annotations

In chapter 2, we assigned the constant `urlPrefix` to `"http://elm-in-action.com"`. Let’s edit our `PhotoGroove.elm` file to add a type annotation on top of that `urlPrefix` assignment, as shown in figure 3.1.

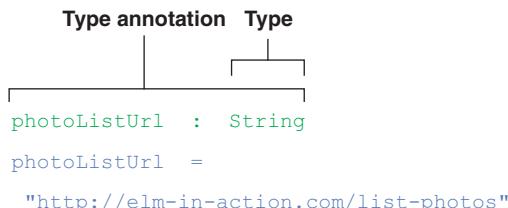


Figure 3.1 Adding a type annotation to `urlPrefix`

This annotation is saying, “`urlPrefix` is a `String`,” and it’s not kidding around with that. Elm’s compiler will check our entire code base to verify this claim. If it finds even one incidence where `urlPrefix` is not used as a `String`, it will give us an error at compile time. This means if our code compiles, we can be certain `urlPrefix` is a `String` absolutely everywhere it’s used!

This guarantee is even more useful for annotated functions. When teammates are new to the code base, being able to reliably tell at a glance what a function expects and what it returns can be an incredible time saver.

## ANNOTATING FUNCTIONS

We can annotate functions by writing `->` between their arguments and return values:

```
isEmpty : String -> Bool  
isEmpty str = str == ""
```

This annotation says, “`isEmpty` takes a `String` and returns a `Bool`.” `Bool` refers to one of those `True` or `False` Boolean values that we can use as the condition of an if-expression.

## ANNOTATING RECORDS

Record annotations use : instead of = but otherwise look about the same as record values:

```
selectPhoto : { description : String, data : String }
selectPhoto = { description = "ClickedPhoto", data = "1.jpeg" }
```

This annotation says, “`selectPhoto` is a record with a `description` field and a `data` field, and each of those fields is a `String`.” We can add a similar annotation to our `initialModel`:

```
initialModel =  
  { photos = [ { url = "1.jpeg" }, { url = "2.jpeg" }, { url = "3.jpeg" } ]  
  , selectedUrl = "1.jpeg"  
}
```

Ah, but this record has a list in it! How do we annotate lists?

## ANNOTATING LISTS

In chapter 1, you learned that all elements in an Elm list must have a consistent type. This is reflected in their type annotations. For example, Elm represents a list of strings with the type annotation `List String`, and a list of Booleans with the type annotation `List Bool`. Let's play around with some lists to see their type annotations in `elm repl`.

### **Listing 3.1 Annotating lists**

```
> [ "funk", "soul" ]  
["funk", "soul"] : List String
```

## A list of strings

```
> [ [ "thanks", "for" ], [ "all", "the", "fish" ] ]  
[[["thanks","for"], ["all"], "the", "fish"]]: List (List
```

## A list of lists of strings

```
> [ { url = "1.jpeg" }, { url = "2.jpeg" } ]
[ { url = "1.jpeg" }, { url = "2.jpeg" } ] : List { url : String }
```

A list of records

Notice anything about the structure of that last example? It looks just like the list of photos in our model. This means we can use it to write an annotation for our model. Let's do that:

```
initialModel : { photos : List { url : String }, selectedUrl : String }
initialModel =
...
```

Model annotations are among the most helpful forms of documentation for new teammates, because they concisely (and reliably!) describe the structure of our entire application state.

### 3.1.2 **Annotating functions with type variables**

Functions, records, and lists served us well in chapter 2, but implementing the Surprise Me! button will involve a collection we haven't used before.

#### LISTS AND ARRAYS

Chapter 1 mentioned that Elm supports arrays as well as lists. Both are sequential collections of varying length, whose elements share a consistent type. However, arrays and lists differ in a few ways:

- Lists can be created with square bracket literals, whereas arrays have no literal syntax in Elm. We always create arrays by calling functions.
- Lists perform better in typical Elm use cases. This makes them the standard choice for representing a sequence of values, in contrast to JavaScript (where arrays are standard).
- Arrays are better for arbitrary positional access. That means it's quick and easy to say, "Give me the third element in this array." Lists have no first-class way to do this.

Randomly choosing a photo involves arbitrary positional access. As such, we've found ourselves in exactly the sort of situation where an array will serve us better than a list.

#### **ARRAY.FROMLIST**

The most common way to obtain an array is by calling `Array.fromList` on an existing list. Table 3.1 shows the results of a few calls to `Array.fromList`.

**Table 3.1** Translating a list into an array by using `Array.fromList`

Expression	Result
<code>Array.fromList [ 2, 4, 6 ]</code>	Array containing three elements: 2, 4, and 6
<code>Array.fromList [ "foo" ]</code>	Array containing one element: "foo"
<code>Array.fromList []</code>	Array containing zero elements

## TYPE VARIABLES

How would we write a type annotation for `Array.fromList`? It's a bit different from the functions we've annotated so far, as it returns a different type depending on what you pass it. Table 3.2 shows some examples of the types of values it can return.

**Table 3.2** `Array.fromList`'s return type depends on its input

Given one of these	<code>Array.fromList</code> returns one of these
<code>List Float</code>	<code>Array Float</code>
<code>List String</code>	<code>Array String</code>
<code>List { url : String }</code>	<code>Array { url : String }</code>

Notice the pattern? Whatever type of list we pass in, that's what type of array we get out. We can capture this pattern in a type annotation like so:

```
fromList : List elementType -> Array elementType
```

In this annotation, `elementType` is a *type variable*.

**DEFINITION** A *type variable* represents more than one possible type. Type variables have lowercase names, making them easy to differentiate from *concrete types* like `String`, which are always capitalized.

When you call `Array.fromList`, passing a list, the type variable `elementType` gets replaced by that list's element type. Table 3.3 shows this process in action.

**Table 3.3** Replacing `Array.fromList`'s type variable

When we pass this in . . .	... <code>elementType</code> becomes ...	... and we get this back
<code>List Float</code>	<code>Float</code>	<code>Array Float</code>
<code>List String</code>	<code>String</code>	<code>Array String</code>
<code>List { url : String }</code>	<code>{ url : String }</code>	<code>Array { url : String }</code>

## CHOOSING NAMES FOR TYPE VARIABLES

When annotating `fromList`, we can choose a different name for its type variable besides `elementType`. Because a type variable serves as a placeholder for a concrete type like `String` or `List Int`, it can have just about any name, so long as it's lowercase and we use it consistently. For example, we could annotate `Array.fromList` in any of the following ways:

- `List elementType -> Array elementType`
- `List foo -> Array foo`
- `List a -> Array a`

In contrast, *none* of the following would work as annotations for `Array.fromList`:

- `List elementType -> Array blah`
- `List foo -> Array bar`
- `List a -> Array b`

These three annotations are saying, “`Array.fromList` takes a list containing elements of one type and returns an array that potentially contains elements of another type.”

That just ain’t so! `Array.fromList` can return only an array whose elements have the same type as the list it receives. Its type annotation must reflect that, by having the same type variable for both the `List` it accepts and the `Array` it returns.

**NOTE** Elm has three type variable names that have special meanings—`number`, `appendable`, and `comparable`—which we’ll dive into later. For now, avoid choosing any of those as your type variable names.

By the way, you’ll often encounter type variables in documentation with single-letter names like `a`, `b`, `c`, and so on. (For example, the official documentation for `Array.fromList` annotates it as `List a -> Array a`.) You are by no means obliged to do the same. Feel free to use the most self-descriptive names you can think of for your own type variables.

#### CREATING AN ARRAY OF PHOTOS

Because we want to access our photos by position, we’ll be using `Array.fromList` on our `model.photos` list to translate it into an array. Let’s add this code below our `initialModel` definition in `PhotoGroove.elm`:

```
photoArray : Array { url : String }
photoArray =
    Array.fromList initialModel.photos
```

If we tried to compile this right now, we’d get an error because we have not imported the `Array` module. Let’s add it to the top of our imports list:

```
import Array exposing (Array)
```

Nice. Let’s verify that our code still compiles by running `elm make src/PhotoGroove.elm --output app.js` once more before proceeding.

#### Exposing imported types

Notice how we wrote `exposing (Array)` there? If we’d written `import Array` without the `exposing (Array)` part, we’d need to refer to the `Array` type in a qualified style, like so:

```
photoArray : Array.Array { url : String }
```

`Array.Array` refers to “the `Array` type from the `Array` module,” just as `Array.fromList` refers to “the `fromList` function from the `Array` module.” Kinda verbose, right?

By writing exposing (Array) after import Array, we get to skip the Array. prefix and use the more concise annotation:

```
photoArray : Array { url : String }
Lovely!
```

### 3.1.3 Reusing annotations with type aliases

Now that we've created photoArray, we can see that our annotations for initialModel and photoArray have a bit of code duplication going on: they both include { url : String }:

```
initialModel : { photos : List { url : String }, selectedUrl : String }
photoArray : Array { url : String }
```

We can replace this duplication with shared code by using a type alias.

**DEFINITION** A *type alias* assigns a name to a type. Anywhere you would refer to that type, you can substitute this name instead.

Let's create a type alias called Photo, and then use that in place of { url : String }.

#### Listing 3.2 Creating a type alias called Photo

<pre>type alias Photo =     { url : String }</pre>	<b>“Whenever I say Photo, I mean { url : String }”</b>
--	--

```
initialModel : { photos : List Photo, selectedUrl : String }
initialModel =
    ...
photoArray : Array Photo
photoArray =
    Array.fromList initialModel.photos
```

This makes our initialModel annotation not only more concise, but also easier to maintain! Now if we add a new field to our Photo record, we can change the type alias in one place instead of having to hunt down several individual annotations.

#### ANNOTATING INITIALMODEL BY USING A TYPE ALIAS

Since initialModel, view, and update all involve our model record, let's add a type alias for Model as well, and then revise initialModel's type annotation to use it:

```
type alias Model =
    { photos : List Photo
    , selectedUrl : String
    }

initialModel : Model
```

That takes care of initialModel. What about view?

### HTML'S TYPE VARIABLE

We know `view` takes a `Model` and returns `Html`, but we can't just write "view returns `Html`" and call it a day. This is because, just like `List` and `Array`, the `Html` type has a type variable.

`Html`'s type variable reflects the type of message it sends to update in response to events from handlers like `onClick`. Table 3.4 compares the type variables for `List` to the ones in `Html`.

Table 3.4 Comparing type variables for `List` and `Html`

Value	Type	Description
[ "foo" ]	List String	List of String elements
[ 3.14 ]	List Float	List of Float elements
div [ onClick "foo" ] []	Html String	Html producing String messages
div [ onClick 3.14 ] []	Html Float	Html producing Float messages
div [ onClick { x = 3.3 } ] []	Html { x : Float }	Html producing { x : Float } messages

Because our `onClick` handler produces messages in the form of records that have a `description` string and a `data` string, our `view` function's return type is as follows:

```
Html { description : String, data : String }
```

That's pretty verbose! Even though it won't remove any code duplication yet, it's perfectly fine to introduce a type alias to make `view`'s annotation more concise. Let's add one above `view`:

```
type alias Msg =
    { description : String, data : String }

view : Model -> Html Msg
```

Excellent! Next, we'll look into annotating `view`'s helper function, `viewThumbnail`.

#### 3.1.4 Annotating longer functions

We've now seen a few type annotations for functions that take a single argument, but none for functions that take multiple arguments. Our `viewThumbnail` function will be the first.

To learn how to annotate a multi-argument function, let's play around with one that has a simpler return type: the humble `padLeft` function. `padLeft` makes sure strings meet a certain minimum length. You give it a minimum length, a *filler character*, and a string. If the string is not at least the given length, `padLeft` adds filler characters to its left until the string reaches that length.

We can try it out in `elm repl`, because `padLeft` is included in Elm's core `String` module:

```
> String.padLeft 9 '.."not!"  
".....not!" : String  
  
> String.padLeft 2 '.."not!"  
"not!" : String
```

We can see that `String.padLeft` takes three arguments—an `Int`, a `Char`, and a `String`—and then returns another `String`. How can we annotate a function like that?

Believe it or not, you've already seen the answer! It's one of those answers that likes to hide in plain sight.

#### **ANNOTATING A PARTIALLY APPLIED FUNCTION**

Let's think back to chapter 2, where you learned that all functions in Elm are *curried*. That means they all support *partial application*—the practice of calling a function without passing all the arguments it requires. If we call `padLeft`, passing only one of its three arguments, the result will be a function that takes the remaining arguments and “finishes the job.”

Here's a partial application of `padLeft`. What would the annotation for this be?

```
padNine = String.padLeft 9
```

`padLeft 9` is a partial application, so we know `padNine` must be a function. That's a start!

We also know that `padLeft` takes a `Char` as its next argument after the `9`. That gives us enough information to rough out some pseudocode:

```
padNine : Char -> (a function of some sort)  
padNine = String.padLeft 9
```

Now let's suppose we gave this `padNine` function the `Char` it wants. Passing a `'.'` character to `padNine` would be the same as passing `9` and then `'.'` to the original `padLeft`, like so:

```
padNineDots = String.padLeft 9 '..'
```

How would we annotate `padNineDots`? Because it gives `padLeft` two of three arguments, only one more argument is needed to finish the job. That last argument is a `String`, so `padNineDots` must *take a String and return a String*. We know how to write that one!

```
padNineDots : String -> String  
padNineDots = String.padLeft 9 '..'
```

We now know the following:

- `padNine` takes a `Char` and returns a function (of some type).
- If you pass `padNine` a `Char`, it returns a `String -> String` function.

Putting those two together, our mystery function must be a `String -> String`! That tells us we can annotate `padNine` like so:

```
padNine : Char -> (String -> String)
padNine = String.padLeft 9
```

Now let's unwind our original partial application. If we cease partially applying the 9, we can follow the pattern we saw here to arrive at a valid annotation for the original `padLeft` itself:

```
padLeft : Int -> (Char -> (String -> String))
```

This is a perfectly accurate annotation, but it's a bit heavy on the parentheses, yeah? Fortunately, we can be more concise. Elm's syntax lets us omit the parentheses here, so the following two annotations are equivalent:

```
padNine : Int -> (Char -> (String -> String))
padNine : Int -> Char -> String -> String
```

Either style works just as well as the other, but the latter is considered best practice. You can see `elm repl` use this annotation style in the following listing, as we partially apply `String.padLeft` step by step, until it has no more arguments to accept and finally returns a `String`.

### **Listing 3.3 Multi-argument function annotations**

```
> String.padLeft
<function:padLeft> : Int -> Char -> String -> String

> String.padLeft 9
<function> : Char -> String -> String

> String.padLeft 9 '.'
<function> : String -> String

> String.padLeft 9 '.' "not!"
".....not!" : String
```

Notice that each time we partially applied `padLeft`, our annotation got shorter, as shown in table 3.5.

**Table 3.5 Type annotations changing as a function gets partially applied**

Function	Type annotation
<code>String.padLeft</code>	<code>Int -&gt; Char -&gt; String -&gt; String</code>
<code>String.padLeft 9</code>	<code>Char -&gt; String -&gt; String</code>
<code>String.padLeft 9 .'</code>	<code>String -&gt; String</code>
<code>String.padLeft 9 '.' "not!"</code>	<code>String</code>

If you think about it, this means, technically, *every Elm function takes only one argument*. After all, any function that *appears* to take multiple arguments is ultimately calling out to single-argument functions behind the scenes. The fact that Elm lets you omit the parentheses for these nested calls is just a syntactic convenience.

**TIP** You can now tell your friends that, in chapter 2, you wrote an entire working Elm application in which every function took only a single argument. This sounds like some really hardcore programming unless your friends are familiar with currying.

### ANNOTATING VIEWTHUMBNAIL

Armed with this knowledge, we can follow this pattern to annotate `viewThumbnail` like so:

```
viewThumbnail : String -> Photo -> Html Msg
viewThumbnail selectedUrl thumb =
```

**TIP** Searching for "viewThumbnail :" in your editor is now a quick way to jump to `viewThumbnail`'s definition.

Splendid! Our code is getting easier and easier for teammates to pick up at a glance.

## 3.2 Using case-expressions and custom types

Now that our documentation situation is looking better, let's shift gears to work on those two new features: the Surprise Me! button and the Thumbnail Size Chooser.

We'll introduce these iteratively, first adding the visual elements with only a token level of interactivity, and then circling back to make them work properly afterward.

### 3.2.1 Using case-expressions

Let's start by adding the Surprise Me! button to our view, right above the thumbnails `div`:

```
, button
  [ onClick { description = "ClickedSurpriseMe", data = "" } ]
  [ text "Surprise Me!" ]
, div [ id "thumbnails" ]
```

Next, let's revise our `update` function to add a quick `else if` branch for our new `"ClickedSurpriseMe"` message, and a shiny new type annotation while we're at it:

```
update : Msg -> Model -> Model
update msg model =
  if msg.description == "ClickedPhoto" then
    { model | selectedUrl = msg.data }

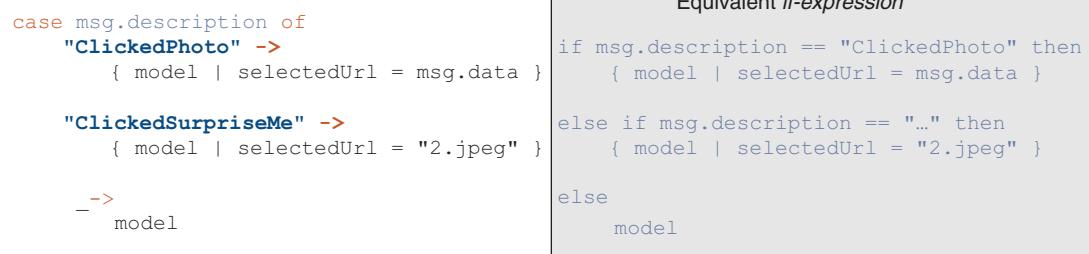
  else if msg.description == "ClickedSurpriseMe" then
    { model | selectedUrl = "2.jpeg" }

  else
    model
```

This implementation always selects the second photo. That's not much of a *surprise*, granted, but we'll get there. For now, let's smooth out that code duplication we just introduced.

### REFACTORING AN IF-EXPRESSION INTO A CASE-EXPRESSION

We now have two conditionals that do nothing more than compare `msg.description` to a string. Let's express this more cleanly by rewriting these if-expressions as a *case-expression*, as shown in figure 3.2.



**Figure 3.2** Refactoring an if-expression into a case-expression

Whereas an *if-expression* is a two-way conditional, a *case-expression* is a multiway conditional. It lets us compare something to a wider range of values than just `True` or `False`.

Just as with a JavaScript switch-statement, we begin a case-expression by providing a value that will be run through a series of comparisons. Here we wrote `case msg.description of` because we want to run `msg.description` through these comparisons. Following the `case` are a series of *branches* such as the following:

```
"ClickedPhoto" ->
  { model | selectedUrl = msg.data }
```

This says that if `msg.description` is equal to `"ClickedPhoto"`, then the branch after the `->` will be evaluated, and the entire case-expression will evaluate to that branch's result.

If `msg.description` is not equal to `"ClickedPhoto"`, the next branch (in this case, the `"ClickedSurpriseMe" ->` branch) will be checked in the same way, and so on. Elm has no equivalent of JavaScript's `break` statement, because case-expression branches don't "fall through" like branches in JavaScript's switch-statements do.

Just like if-expressions, case-expressions must always evaluate to a single value, meaning exactly one branch must always be chosen for evaluation. When we're writing if-expressions, we have `else` to ensure that we end up with a value no matter what, whereas in case-expressions, we can use the default branch of `_ ->` for the same purpose.

**NOTE** In a case-expression, every branch must be indented the same amount—similar to what you saw in chapter 1 with let-expressions. Indentation level is significant only with let-expressions and case-expressions.

Our code is really shaping up! Let's copy the case-expression from figure 3.2 into PhotoGroove.elm, and then run `elm make` once more to recompile it.

#### TRYING OUT THE SURPRISE ME! BUTTON

Before we open up index.html and view our progress, we have one last change to make. While we've been hard at work on code quality and new functionality, one of our new teammates has been busy improving our stylesheets. Let's edit index.html to make use of their work, by changing its `<head>` to the following:

```
<head>
    <link rel="stylesheet" href="http://elm-in-action.com/styles.css">
</head>
```

Lovely! Now we can open our revised index.html to see the new button in all its glory, as shown in figure 3.3.

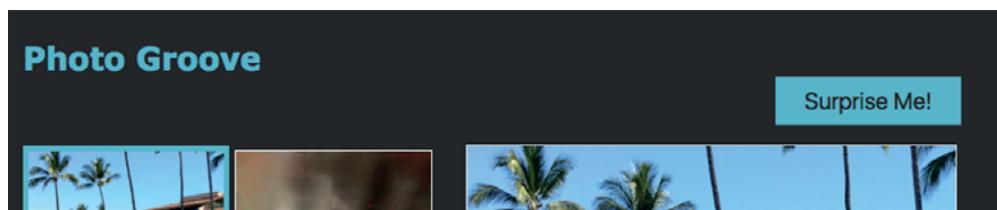


Figure 3.3 The new Surprise Me! button

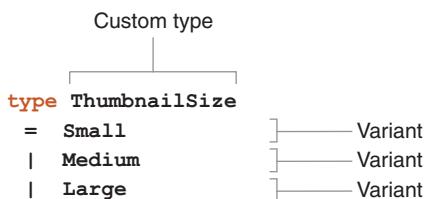
In addition to styling the Surprise Me! button, our helpful teammate went ahead and added styles for the Thumbnail Size Chooser too. How about we introduce some logic to go with those styles?

#### 3.2.2 *Enumerating possibilities with custom types*

Our second feature lets users choose one of three thumbnail sizes: small, medium, or large. The first step toward implementing it will be storing the current `chosenSize` in our model.

In JavaScript, we might represent `chosenSize` as a `String`—perhaps setting it to either "SMALL", "MEDIUM", or "LARGE". But in Elm, we can do better with custom types.

**DEFINITION** A *custom type* is one you define by specifying the values it can contain.



**Figure 3.4** Defining an enumeration of values with a custom type called `ThumbnailSize`

One use for a custom type is as an enumeration of values. Figure 3.4 illustrates how we can define a custom type to represent the thumbnail size choices we'll support.

This is saying, “Define a new type called `ThumbnailSize` with three possible values: `Small`, `Medium`, and `Large`.” Let’s add this code to `PhotoGroove.elm`, right above `type alias Msg`.

We’ll add the definition of `ThumbnailSize` in figure 3.4 to our code, right above `type alias Photo`. We can now define `chosenSize` in one of the following ways:

```

chosenSize : ThumbnailSize
chosenSize = Small

chosenSize : ThumbnailSize
chosenSize = Medium

chosenSize : ThumbnailSize
chosenSize = Large
  
```

Notice that in each of these examples, the type of `chosenSize` is `ThumbnailSize`. These new values we’ve created—`Small`, `Medium`, and `Large`—aren’t “actually integers under the hood” or “just strings behind the scenes.” We really have scratch-built a brand-new type here! Trying to compare a `ThumbnailSize` to a number, string, or any other type (using `==` or any other comparison) will yield an error at build time. This is different from `type alias`, which gives a *name* to an existing type—much as a variable gives a name to an existing value.

These custom type values are also unique. The expression `Medium == Medium` is `True`. But put absolutely any other value (besides `Medium`) on either side of that `==`, and the expression will no longer be `True`. The same can be said of `Small == Small` and `Large == Large`.

**NOTE** Boolean values in Elm are capitalized because `Bool` is a custom type.  
Its definition looks like this: `type Bool = True | False`.

Let’s add the `chosenSize` field to our model and initialize it to `Medium` in `initialModel`:

```

type alias Model =
    { photos : List Photo
    , selectedUrl : String
    , chosenSize : ThumbnailSize
    }

initialModel : Model
initialModel =
  
```

```
{ photos = ...
, selectedUrl = "1.jpeg"
, chosenSize = Medium
}
```

Great! Next, we'll render some radio buttons to let users change the chosen size.

### RENDERING A THUMBNAIL-SIZE RADIO BUTTON

We can use our newfound knowledge of custom types and case-expressions to write a helper function that takes a `ThumbnailSize` and renders a radio button for choosing that size. Let's add the following to `PhotoGroove.elm`, right below `viewThumbnail`.

**Listing 3.4** Rendering a thumbnail-size radio button

```
viewSizeChooser : ThumbnailSize -> Html Msg
viewSizeChooser size =
    label []
        [ input [ type_ "radio", name "size" ] []
        , text (sizeToString size)
        ]

sizeToString : ThumbnailSize -> String
sizeToString size =
    case size of
        Small ->
            "small" | Evaluates to “small”
                    if size == Small
        Medium ->
            "med" | Evaluates to “med”
                    if size == Medium
        Large ->
            "large" | Evaluates to “large”
                    if size == Large
```

**NOTE** The underscore in that `type_` attribute is very important! As you've seen, `type` is a reserved keyword in Elm (used to define custom types), which means it can't be used for an `Html` attribute name. The `Html.Attributes` module names the attribute `type_` to work around this.

Notice anything missing from that case-expression? It has no default branch! We accounted for the cases where `size` is `Small`, `Medium`, and `Large`—but what if `size` has another value, such as `null`, `undefined`, or `"halibut"`?

Can't happen! `sizeToString`'s type annotation tells us that `size` is guaranteed to be a `ThumbnailSize`, and a `ThumbnailSize` can be only `Small`, `Medium`, or `Large`. It can't be `null` or `undefined` because those don't exist in Elm, and it can't be `"halibut"` because that's a `String`, not a `ThumbnailSize`.

Elm's compiler knows we've covered every possibility here, so it doesn't require a default branch. In fact, if we tried to add one, the compiler would politely inform us that we'd written unreachable code.

### RENDERING THREE RADIO BUTTONS

We can now call this `viewSizeChooser` function three times, passing `Small`, `Medium`, and `Large`, to render the three radio buttons on the page. Let's do that right above thumbnails:

```
, h3 [] [ text "Thumbnail Size:" ]
, div [ id "choose-size" ]
  [ viewSizeChooser Small, viewSizeChooser Medium, viewSizeChooser Large ]
, div [ id "thumbnails" ]
  (List.map (viewThumbnail model.selectedUrl) model.photos)
```

Once again we see some code duplication: we're calling the same function (`viewSizeChooser`) on every element in a list. Anytime we're calling the same function on every element in a list, there's a good chance we can make our code cleaner with `List.map`.

This is absolutely one of those times. Let's refactor our `choose-size` element to this:

```
, div [ id "choose-size" ]
  (List.map viewSizeChooser [ Small, Medium, Large ])
```

This refactor not only reduces duplication, but also makes our code more concise.

### RENDERING DIFFERENT THUMBNAIL SIZES

Rendering the interface for *choosing* a thumbnail size is great, but it's only half the battle! We still need to actually render our thumbnails differently based on what the user has chosen.

Thanks to our coworker having written a stylesheet for us, we can implement this by adding one of the classes "`small`", "`med`", or "`large`" to our thumbnails container. Because those classes conveniently correspond to the results of our `sizeToString` function, we can go ahead and replace our current `div [ id "thumbnails" ]` with the following:

```
div [ id "thumbnails", class (sizeToString model.chosenSize) ]
```

**TIP** It would be best practice to write a separate `sizeToClass` function and use it here in place of `sizeToString`, even if their implementations were identical for the time being. Having separate functions means if someone later changes the text on the radio buttons, our thumbnail classes won't accidentally break.

Let's see how it looks! Because we haven't implemented the radio button logic yet, try changing the `chosenSize` value in `initialModel` to `Large` and then recompile to see how that affects the way the page looks. Then try recompiling again with `Small`, and finally back to `Medium`. You should be able to see a range of thumbnail sizes this way, as shown in figure 3.5.

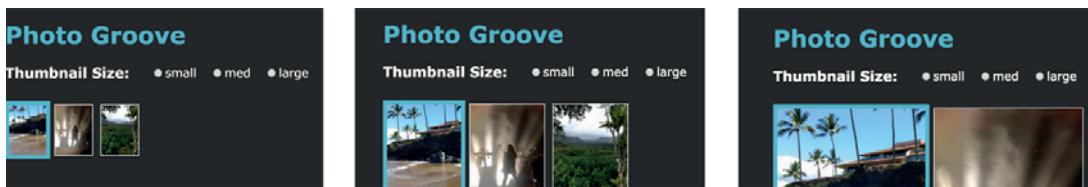


Figure 3.5 Recompiling with `chosenSize = Small`, `chosenSize = Medium`, and `chosenSize = Large`

Cool! Now that we have our interface rendering, it's time to start making the logic work.

### 3.2.3 Holding data in custom types

Making the Surprise Me! button change our model's `selectedUrl` field to a random photo's `url` means we'll need to access a random photo from our `photoArray`. In JavaScript, we might implement reading a photo from an array as follows:

```
var photos = [ ...maybe there are photos here, but maybe not... ];
var selectedId = photos[2].url; // Select the third photo
```

What happens if `photos` doesn't have at least three elements? In that case, `photos[2]` would evaluate to `undefined`, and `photos[2].url` would throw an angry runtime exception such as this:

```
Uncaught TypeError: Cannot read property 'url' of undefined
```

Elm avoids this runtime exception by handling this situation differently, in three ways:

- In Elm, you call `Array.get` to get an element in an array; there is no `[2]` accessor.
- `Array.get` never returns `undefined` or `null`, because Elm has neither of these.
- `Array.get` always returns a container value called a `Maybe`.

What's a `Maybe`? Glad you asked!

**DEFINITION** A `Maybe` is a container like a `List`, except it can hold one element at most.

`Maybe` is implemented as a custom type, but a flavor of custom type you haven't covered yet: one that holds data. Its definition looks like this:

```
type Maybe value
  = Just value
  | Nothing
```

#### MAYBE VERSUS UNDEFINED

The most common use for `Maybe` is to represent the potential absence of a value. It provides a *container-based* alternative to JavaScript's *drop-in replacements* of `null` and

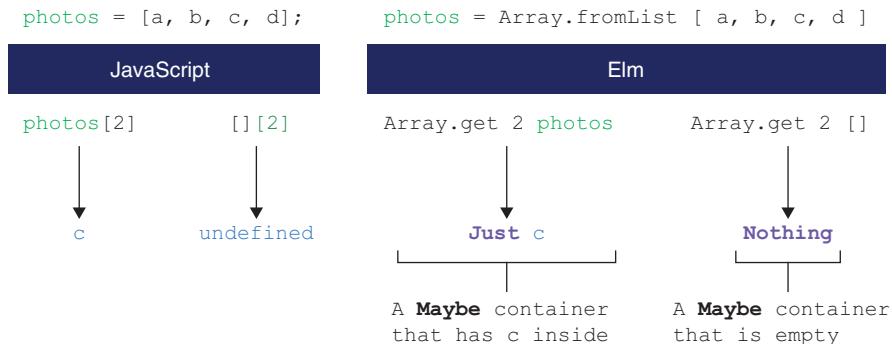


Figure 3.6 Comparing Elm’s `Maybe` to JavaScript’s `undefined`

`undefined`. Figure 3.6 compares Elm’s `Array.get` and `Maybe` to JavaScript’s `[2]` and `undefined`.

`Array.get 2 photos` expresses the desire to access the third element of an array called `photos`. However, the `photos` array may have fewer than three elements in it. If the index 2 is outside the bounds of `photos`, then `Array.get 2 photos` will return `Nothing`.

On the other hand, if 2 is inside its bounds, then `Array.get` will return `Just c`—where `c` is the element at index 2 in the `photos` array.

### MAYBE’S TYPE VARIABLE

As we’ve seen before with `List`, `Array`, and `Html`, the `Maybe` type has a type variable. We chose to name it `value` in the definition we gave for `Maybe`’s custom type earlier:

```
type Maybe value
  = Just value
  | Nothing
```

Just as you can have a `List String` or a `List Photo`, you can also have a `Maybe String` or `Maybe Photo`. The difference is that whereas `List Photo` means “a list of photos,” `Maybe Photo` means “either a `Photo` or nothing at all.” Put another way, `Maybe` is a container that can hold at most one element.

Now that we know `Just "1.jpeg"` is a `Maybe String`, what is the type of `Just` itself?

### "JUST" IS A FUNCTION

Argh, that heading totally gave away the answer. Oh well.

As the heading suggests, whereas `Nothing` is a `Maybe` value, `Just` is a *function* that returns a `Maybe` value. We can confirm this in `elm repl`:

```
> Nothing
Nothing : Maybe a

> Just
<function> : a -> Maybe a
```

```
> Just "dance"
Just ("dance") : Maybe String
```

Chapter 1 noted that when you write a function by hand, its name must be lowercase. Yet here we see that custom type variants (like `Just`) are functions with capitalized names. What makes them so special?

A capital question! The answer is right around the corner.

### DESTRUCTURING CUSTOM TYPES

In chapter 1, you learned how to *destructure* tuples to both extract and name their values:

```
multiply3d ( x, y, z ) = x * y * z
```

As it turns out, we can also destructure custom type variants such as `Just` in the branches of case-expressions. This destructuring is what sets variants apart from other functions. Let's use what you've learned about `Array.get` and `Maybe` to add this `getPhotoUrl` function right above our update function.

#### Listing 3.5 Selecting a photo by index

```
getPhotoUrl : Int -> String
getPhotoUrl index =
    case Array.get index photoArray of
        Just photo -> photo.url
        Nothing -> ""
```

Here, `Just photo ->` is saying two things:

- This branch matches a `Maybe` value that was created using the `Just` variant.
- We're extracting the value that was passed to `Just` and naming it `photo`.

**NOTE** This is where the distinction between capitalized and uncapitalized functions matters. By comparing their capitalizations, Elm's compiler can tell that `Just photo ->` refers to a type variant called `Just` that holds a value we've chosen to name `photo`. If we'd instead written `Just True ->`, the compiler would know we meant “the `Just` variant holding *exactly* the value `True`.”

Notice that this case-expression did not need a `_ ->` branch. This is because its branches already cover all possible values of `Maybe`. One branch covers `Nothing`, and the other covers any values created with `Just`. Because `Nothing` and `Just` are the only ways to obtain a `Maybe`, these branches have every possibility covered.

Also notice that because `Array.get` returns a `Maybe`, you can't help but remember to handle the case where `index` is outside the bounds of `photoArray`. This design means that you'll always be doing the minimal amount of coding necessary to handle error cases. You don't need to defensively check whether something is `null` or `undefined`, because Elm's compiler has your back in cases where the value you want might not be available.

### 3.2.4 Representing flexible messages with custom types

We've made so much progress! We've updated our views to render the new interfaces, expanded our model to hold our new `chosensize` field, and introduced helper functions for `photoArray`. Now it's time to wire all that together with changes to update.

Let's start by updating that `chosensize` field, which currently gets initialized to `Medium` and then never changes. We'll want to update it whenever the user clicks a radio button.

This might seem like the obvious change to make to `viewSizeChooser`:

```
viewSizeChooser : ThumbnailSize -> Html Msg
viewSizeChooser size =
    ...
        onClick { description = "ClickedSize", data = size }
```

There's just one problem: this is a type mismatch! Remember our type alias for `Msg`?

```
type alias Msg =
    { description : String, data : String }
```

This says the `data` field of a `Msg` needs to be a `String`, not a `ThumbnailSize`. To preserve backward compatibility with existing code, we need a `Msg` type that can accommodate both `ThumbnailSize` and `String`. One way we could do this would be to add a new field called `size`:

```
type alias Msg =
    { description : String, data : String, size : ThumbnailSize }
```

This solves one problem while creating another. Now our existing `onClick` handler will no longer compile, because it's missing a field. Here's how we wrote it back in chapter 2:

```
onClick { description = "ClickedPhoto", data = thumb.url }
```

Without specifying a value for that new `size` field, this record is no longer a valid `Msg`. We'd need to change it to something like this:

```
onClick { description = "ClickedPhoto", data = thumb.url, size = Small }
```

Yuck. Having to set `size = Small` for a message that doesn't care about `size`? That doesn't smell right. And are we really planning to add a field to every `Msg` in our program whenever we need it to support a new data type? This doesn't seem like it will scale well. Is there a better way?

#### IMPLEMENTING MSG AS A CUSTOM TYPE

There totally is! Implementing `Msg` as a custom type will work much better. Here's the plan:

- 1 Replace our type alias `Msg` declaration with a type `Msg` declaration.
- 2 Revise `update` to use a case-expression that destructures our new custom type.
- 3 Change our `onClick` handler to pass a type variant instead of a record.

The following listing shows the first two changes: replacing type alias `Msg` with type `Msg`, and revising `update` accordingly. Let's edit `PhotoGroove.elm` to incorporate these changes.

### Listing 3.6 Implementing `Msg` as a custom type

```

type Msg
    = ClickedPhoto String
    | ClickedSize ThumbnailSize
    | ClickedSurpriseMe

update : Msg -> Model -> Model
update msg model =
    case msg of
        ClickedPhoto url ->
            { model | selectedUrl = url }
        ClickedSurpriseMe ->
            { model | selectedUrl = "2.jpeg" }

```

Annotations for Listing 3.6:

- `type Msg` → Replaces our earlier declaration of type alias `Msg`
- `= ClickedPhoto String` → Replaces our `ClickedPhoto` message
- `| ClickedSize ThumbnailSize` → Our new message: user clicked a thumbnail size
- `| ClickedSurpriseMe` → Replaces our `ClickedSurpriseMe` message
- `ClickedPhoto url ->` → Previous condition: `msg.description == "ClickedPhoto"`
- `{ model | selectedUrl = url }` → Nothing to destructure for Surprise Me!

This change means our `onClick` handlers now expect type variants instead of records. We'll need to make this change in view:

```

Old: onClick { description = "ClickedSurpriseMe", data = "" }
New: onClick ClickedSurpriseMe

```

Let's also make this change in `viewThumbnail`:

```

Old: onClick { description = "ClickedPhoto", data = thumb.url }
New: onClick (ClickedPhoto thumb.url)

```

#### THE MISSING-PATTERNS ERROR

If we recompile, we'll see a type of error we haven't seen before: a *missing-patterns* error:

```

-- MISSING PATTERNS ----- src/PhotoGroove.elm

This `case` does not have branches for all possibilities.
...
Missing possibilities include:

```

```
    ClickedSize _
```

I would have to crash if I saw one of those. Add branches for them!

Oops! The compiler noticed we handled only `ClickedPhoto` and `ClickedSurpriseMe` in our `update` function's case-expression; we never wrote the logic for `ClickedSize`. Fortunately, that problem will never reach our end users because the compiler *didn't let us forget*.

**TIP** Anytime you use the default case `_ ->` in a case-expression, you cannot get this error. That is not a good thing! The missing-patterns error is your friend. When you see it, it's often saving you from a bug you would have had to hunt down later. Try to use `_ ->` only as a last resort, so you can benefit from as many missing-pattern safeguards as possible.

Let's add this to our `update` function, right above the `ClickedSurpriseMe` branch:

```
ClickedSize size ->
  { model | chosenSize = size }

ClickedSurpriseMe index ->
  { model | selectedUrl = "2.jpeg" }
```

Finally, we need to add a new `onClick` handler to our radio button in `viewSizeChooser`:

```
Old: input [ type_ "radio", name "size" ] []
New: input [ type_ "radio", name "size", onClick (ClickedSize size) ] []
```

If we recompile and click the radio buttons, we can now see the thumbnail sizes change.

**TIP** We could improve user experience in at least two ways here. One way is to make the Medium option display as selected on page load. Another is to use a broader event handler than `onClick`—one that detects whenever the radio state changes, even if it's not from a click. Try implementing these improvements sometime for practice.

Using custom types for `Msg` has two major advantages over records:

- The compiler can save us from typos. Before, if we wrote `ClickedPhoti` instead of `ClickedPhoto`, our code would silently fail and we'd have to hunt down the cause. Now, if we write `ClickedPhoti` instead of `ClickedPhoto`, Elm's compiler will give us an error at build time—including the line number of the typo. No bug hunting necessary!
- Each flavor of `Msg` now holds only the minimum amount of data it needs. `ClickedPhoto` holds only a `String`, and `ClickedSize` holds only a `ThumbnailSize`. Best of all, `ClickedSurpriseMe` doesn't need to hold any data at all—and so it doesn't!

To sum up, implementing `Msg` as a custom type has made our code more reliable, more concise, and easier to scale. These advantages make custom types the typical choice for representing messages in production Elm applications, and they're what we will use for the rest of the book. Now all that remains is to introduce random number generation into Surprise Me!

### 3.3 Generating random numbers with commands

Currently, our Surprise Me! button always selects the second photo, but we want it to select a random photo instead. Here's how we're going to do that:

- 1 Generate a random integer between 0 and 2. This will be our index.
- 2 Ask `photoArray` for the photo it's storing at that index.
- 3 Set our model's `selectedUrl` to be that photo's `url`.

We'll start by generating the random integer.

#### 3.3.1 Describing random values with `Random.Generator`

In JavaScript, `Math.random()` is the typical starting point for generating random values. Calling `Math.random()` gives you a random `Float` between 0 and 1. To randomly generate an `Int` or a `String`, you manually convert that `Float` into the value you actually want.

In Elm, we start with a `Random.Generator`, which specifies the type of value we want to randomly generate. For example, the `Random.int` function takes a lower bound and an upper bound, and returns a `Random.Generator` that generates a random `Int` between those bounds.

Here's a `Generator` that randomly generates integers between 0 and 2:

```
randomPhotoPicker : Random.Generator Int
randomPhotoPicker =
    Random.int 0 2
```

Notice that the type annotation says `Random.Generator Int`. This means, “We have a `Random.Generator` that produces `Int` values.” If we'd used `Random.bool` instead of `Random.int`, it would have returned a `Random.Generator Bool` instead.

#### GENERATING A RANDOM PHOTO INDEX

Because `randomPhotoPicker` generates random integers between 0 and 2, and `photoArray` has three photos in it, we could use this generator to pick an index within `photoArray` to select. That would work, but it would be brittle because it relies on `photoArray` having exactly three photos.

We can improve it by replacing the hardcoded 2 with `(Array.length photoArray - 1)`. Let's add the following after our `getPhotoUrl` declaration:

```
randomPhotoPicker : Random.Generator Int
randomPhotoPicker =
    Random.int 0 (Array.length photoArray - 1)
```

#### INSTALLING PACKAGE DEPENDENCIES

We also need to add the `Random` module to the end of our imports:

```
import Random
```

This won't quite compile yet, because although we've added `import Random`, the `Random` module is not among the standard modules that were installed when we ran `elm init` in chapter 2. For `import Random` to work, we first need to install the package that contains the `Random` module.

**DEFINITION** An Elm *package* is an installable collection of modules.

The `elm install` command downloads and installs packages when you give it the name of the package you want. Package names consist of a username followed by a / and then the package name; in this case, the package we seek is named `elm/random`.

Let's use `elm install` to get some `Random` going. Run this command in the terminal:

```
elm install elm/random
```

You should see something like this:

Here is my plan:

```
Add:  
elm/random    1.0.0
```

Would you like me to update your `app.js` accordingly? [Y/n] :

Answer `y`, and you should shortly see the text `Dependencies ready`.

**TIP** If you'd like to know more details about package installation, see appendix B. It covers the `app.js` file, Elm's versioning system, and more.

Now that we've described the `random` value we want by using a `Random.Generator`, added `import Random` to access the module where `Random.Generator` lives, and used `elm install` to obtain the `elm/random` package that houses that module, our code will compile again. We're ready to generate some random values!

### 3.3.2 **Introducing commands to The Elm Architecture**

If you call JavaScript's `Math.random()` five times, you'll probably get back five different numbers. Elm functions are more consistent. If you call any Elm function five times with the same arguments, you can expect to get the same return value each time. This is no mere guideline, but a language-level guarantee! Knowing that all Elm functions have this useful property makes bugs easier to track down and reproduce.

Because Elm forbids functions from returning different values when they receive the same arguments, it's not possible to write an inconsistent function like `Math.random` as a plain Elm function. Instead, Elm implements random number generation by using a command.

**DEFINITION** A *command* is a value that describes an operation for the Elm Runtime to perform. Unlike calling a function, running the same command multiple times can have different results.

When the user clicks the Surprise Me! button, we'll use a command to translate our `Random.Generator Int` into a randomly generated `Int`, which will represent our new selected photo index.

#### RETURNING COMMANDS FROM UPDATE

Remember how we specified what `onClick` should do in terms of a message that got sent to our `update` function? We didn't say, "Add this click event listener to the DOM right away." We said, "I want this `Msg` to get sent to my `update` function whenever the user clicks here."

Commands work similarly. We don't say, "Generate a random number right this instant." We say, "I want a random number, so please generate one and send it to my `update` function gift-wrapped in a `Msg`." As with `onClick`, we let `update` take it from there—and if we so desire, `update` can return new commands that trigger new calls to `update` when they complete. Figure 3.7 shows how commands flow through The Elm Architecture.

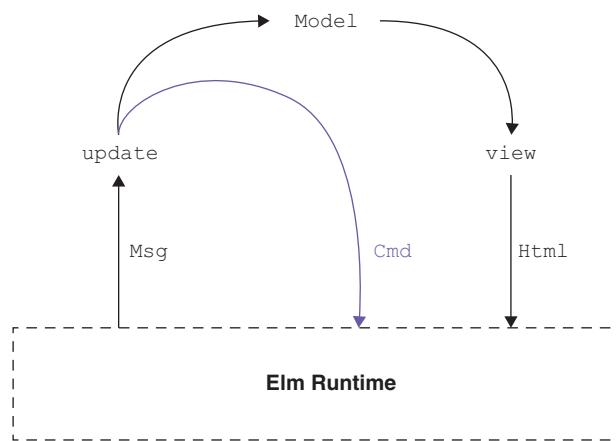


Figure 3.7 How commands flow through The Elm Architecture

Importantly, the addition of commands has not altered the fundamental structure of The Elm Architecture you learned in chapter 2. All of the following still hold true:

- Our `Model` value is still the single source of truth for the application state.
- Our `update` function is still the only way to alter that model.
- Sending a `Msg` to `update` remains the only way for the runtime to tell `update` what happened.

All we've done is give `update` some new powers: the ability to run logic that can have inconsistent results, such as generating a random number. As you will soon see, the key to unlocking these powers is upgrading from `Browser.sandbox` to `Browser.element`.

### RUNNING COMMANDS IN RESPONSE TO USER INPUT

We want to generate our random number in response to a click event, so we'll need to alter our `update` function a bit. Specifically, we'll have `update` return a tuple containing not only the new `Model` we want, but also whatever commands we want the Elm Runtime to execute.

Before we edit `update`'s implementation, let's revise its type annotation to guide our work:

```
update : Msg -> Model -> ( Model, Cmd Msg )
```

As you can see, tuple annotations look just like tuple values. `( Model, Cmd Msg )` means "a tuple where the first element is a `Model` and the second is a `Cmd Msg`."

**NOTE** We write `Cmd Msg` instead of just `Cmd` for the same reason that we write `Html Msg` instead of `Html`. Like `Html`, the `Cmd` type also has a type variable, and for a familiar reason: whenever a `Cmd` finishes, a `Msg` value is what gets sent to `update` for further processing.

Let's revise our `update` implementation to reflect this new reality:

```
update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
    case msg of
        ClickedPhoto url ->
            ( { model | selectedUrl = url }, Cmd.none )

        ClickedSize size ->
            ( { model | chosenSize = size }, Cmd.none )

        ClickedSurpriseMe ->
            ( { model | selectedUrl = "2.jpeg" }, Cmd.none )
```

A fine start! Next, we'll replace that `Cmd.none` in `ClickedSurpriseMe`'s branch with a command to randomly generate the index of the photo we want to select.

#### 3.3.3 Generating random values with `Random.generate`

The `Random.generate` function returns a command that generates random values wrapped up in messages. It's just what the doctor ordered here! `Random.generate` takes two arguments:

- A `Random.Generator`, which specifies the type of random value we want
- A function that can wrap the resulting random value in one of our `Msg` values

The `randomPhotoPicker` we created earlier will do nicely for `Random.Generator`, so all we're missing is a way to wrap these randomly generated integers in a `Msg`. We can introduce one by adding a new variant to `Msg` and a new branch to `update`:

```
type Msg
    = ClickedPhoto String
    | GotSelectedIndex Int
    ...
```

```

update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
    case msg of
        GotSelectedIndex ->
            ( { model | selectedUrl = getPhotoUrl index }, Cmd.none )

...

```

Great! Next, we'll get `Random.generate` to produce one of these `GotSelectedIndex` messages.

### CALLING RANDOM.GENERATE

When a user clicks the Surprise Me! button, the `ClickedSurpriseMe ->` branch of our `update` function's case-expression runs. Currently, that returns a `Cmd.none`, but now we want it to return a different command: one that generates a random `Int` and sends it back to `update` wrapped in a `GotSelectedIndex`. We'll obtain this command by calling `Random.generate`. Earlier we noted that `Random.generate` needs two ingredients:

- A `Random.Generator`, which specifies the type of random value we want. (We'll use `randomPhotoPicker`, our `Random.Generator Int`, for this.)
- A function that can wrap the resulting random value in one of our `Msg` values. (We'll use our `GotSelectedIndex` variant for this, since it's a function that returns a `Msg`.)

Let's revise our `ClickedSurpriseMe` branch to return an unchanged model, and to call `Random.generate` instead of returning `Cmd.none`:

```
ClickedSurpriseMe ->
    ( model, Random.generate GotSelectedIndex randomPhotoPicker )
```

Figure 3.8 illustrates how this would cause data to flow through our application, assuming the Elm Runtime randomly generated a 2 after the user clicked our Surprise Me! button.

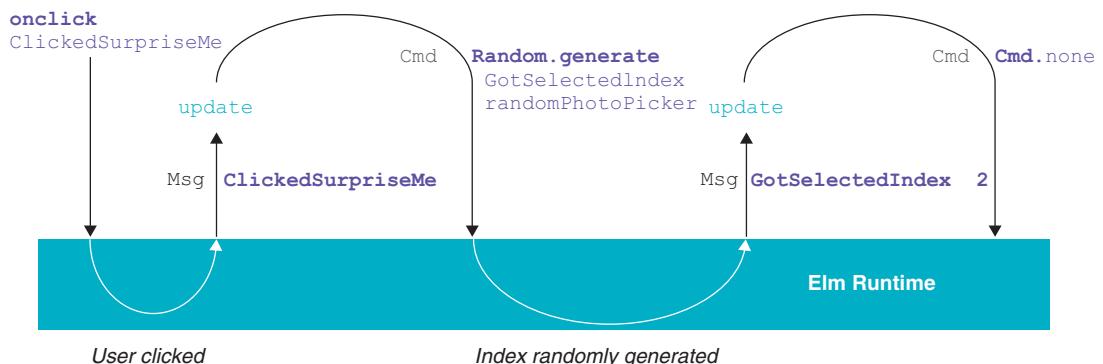


Figure 3.8 Data flowing through our application, assuming the Elm Runtime randomly generated a 2

**TIP** Because update returns a tuple of a new Model and a command, it's possible for the same update branch to change the Model and to run a command as well. In such a case, first Model would change, then view would get run on the new Model to update the page, and finally the command would run.

Calling `Random.generate GotSelectedIndex randomPhotoPicker` returns a command that does the following:

- 1 Randomly generates an `Int` between 0 and 2, because that's the type of random value `randomPhotoPicker` specified it should generate
- 2 Takes that randomly generated `Int`, passes it to `GotSelectedIndex` (which is an `Int -> Msg` function), and runs the resulting `Msg` through `update`

We could write a type annotation for `Random.generate` like so:

```
generate : (randomValue -> msg) -> Random.Generator randomValue -> Cmd msg
```

**NOTE** Capitalization is important! There is a big difference between `Msg` and `msg` here. A function that returns `Msg` returns an instance of the exact `Msg` custom type we defined in `PhotoGroove.elm`. In contrast, `msg` is a type variable. A function that returns `msg` could return anything at all!

Table 3.6 shows how the expressions involved in our call to `Random.generate` relate to the parameters and type variables in this annotation.

**Table 3.6 Types involved in calling `Random.generate`**

Expression	Type	Type in original annotation
<code>GotSelectedIndex</code>	<code>(Int -&gt; Msg)</code>	<code>(randomValue -&gt; msg)</code>
<code>randomPhotoPicker</code>	<code>Random.Generator Int</code>	<code>Random.Generator randomValue</code>
<code>Random.generate GotSelectedIndex randomPhotoPicker</code>	<code>Cmd Msg</code>	<code>Cmd msg</code>

**NOTE** Because it takes a function as an argument, `Random.generate` is another *higher-order function* like `List.map` or `String.filter`.

### UPGRADING MAIN TO USE `BROWSER.ELEMENT`

We're almost done, but if we compile our code right now, we'll get an error. This is because `Browser.sandbox` wants `update` to return a `Model`, whereas our `update` function now returns a `( Model, Cmd Msg )` tuple. Fortunately, `sandbox`'s older sibling, `Browser.element`, expects just such a tuple. Let's replace our `main` declaration with this:

```
main =
  Browser.element
    { init = \flags -> ( initialModel, Cmd.none )
```

```

, view = view
, update = update
, subscriptions = \model -> Sub.none
}

```

We're passing two things differently from what we passed to `Browser.sandbox`:

- 1 The `init` record has been replaced by a function that takes `flags` and returns a tuple. We'll revisit `flags` in chapter 5; let's focus on the tuple for now. The first element in that tuple is our initial `Model`, and the second is a command to run when the application loads. (`init` is the only place besides `update` that can specify commands to run.) Because we have nothing to run on startup, we write `Cmd.none`.
- 2 We've added a `subscriptions` field. Like `flags`, we'll also dive into that in chapter 5; for now, let's disregard it.

### ANNOTATING MAIN

Finally, we'll give `main` the following type annotation:

```
main : Program () Model Msg
```

Whoa! What's that funky `()` thing? The `()` value is known as *unit*. It contains no information whatsoever. It's both a value and a type; the `()` type can be satisfied only with the `()` value. We could use it to write a function like this:

```

getUltimateAnswer : () -> Int
getUltimateAnswer unit =
    40 + 2

```

The only way to call `getUltimateAnswer` would be to pass `()` to it; because it accepts `()` as an argument, no other value but `()` will do. A function that takes only `()` as an argument returns the same exact value every time it's called, making it a very boring function.

The reason we see `()` in our `Program` annotation is that `Program`'s three type parameters represent the following pieces of information:

- Our `flags` type. `flags` refers to the argument `init` receives, which we aren't currently using. Using `()` for our `flags` type indicates that we don't accept any flags.
- Our model's type. We can have any type of model we like—it could be a `String`, or an `Int`, or any number of other types. In our case, our model has the type `Model`.
- The type of the message that both `update` and `view` will use. In our case, that type is `Msg`.

Putting these together, we can read `Program () Model Msg` as “an Elm `Program` with no `flags`, whose model type is `Model` and whose message type is `Msg`.”

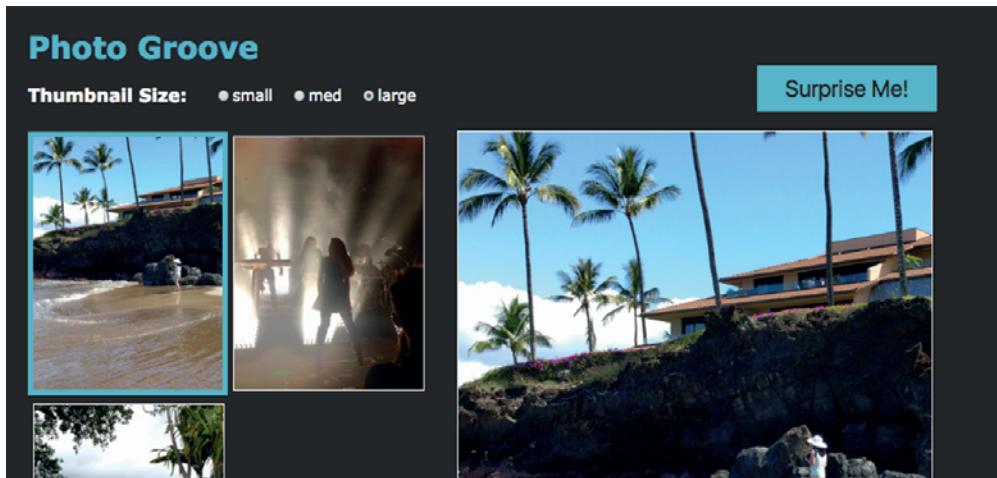


Figure 3.9 Randomly choosing the initially selected photo

### THE FINAL BUILD

If you recompile with `elm make` and open `index.html`, you should experience a gloriously functional application. Try clicking `Surprise Me!` to watch it randomly pick a different photo, as shown in figure 3.9.

Ain't it grand? Even after all the changes we made, once it compiled, it just worked—no regressions! Not only that, but our code never came anywhere near causing a runtime exception. This is a normal experience with Elm, yet it never seems to get old.

Compared to where we were at the end of chapter 2, our revised application is not only more feature rich, but also more reliable and better documented. It does more, it does it better, and the code is easier to maintain. Huzzah!

### Summary

We've now improved on our application from chapter 2 in several ways:

- We added documentation in the form of type annotations.
- Users can now select from one of three thumbnail sizes.
- It has a `Surprise Me!` button that selects a thumbnail at random.
- From now on, whenever we add a new `Msg` value, the compiler will give us a missing-patterns error if we forget to handle it (as when we didn't account for `ClickedSize`).

Along the way, we covered many new concepts:

- Type variables represent concrete types that have not been specified yet.
- A `type alias` declaration assigns a name to a type, much as a constant assigns a name to a value.
- A `type` declaration defines a new custom type, one that did not exist before.

- Custom types can hold more-flexible data than records or tuples can.
- Custom type variants can be either values that are instances of that custom type, or functions that return instances of that custom type.
- You can destructure custom type variants in case-expressions to extract their data.
- If you don't write a fallback `_ ->` branch in a case-expression, you'll get a compiler error unless your code handles all possible cases.
- `Array.get` prevents runtime crashes by returning a `Maybe` instead of a normal element.
- The `()` type (known as *unit*) is both a type and a value. The only value of type `()` is the value `()`.
- The type `Program () Model Msg` refers to an Elm Program with no flags, whose model type is `Model` and whose message type is `Msg`.

You also learned some differences between comments and type annotations, as shown in table 3.7.

**Table 3.7 Documenting code with comments and type annotations**

Comment	Type annotation
Arbitrary string, can describe anything	Can describe only a thing's type
Can be inaccurate or become out of date	Compiler guarantees it's accurate and up to date
Can be written just about anywhere	Always goes on the line above the thing it documents

Finally, you learned about `Maybe`, the container value that `Array.get` returns to represent the potential absence of a value. Table 3.8 compares `Maybe` and `List`.

**Table 3.8 Comparing Maybe and List**

Container contents	List	Maybe
Empty	<code>[] : List a</code>	<code>Nothing : Maybe a</code>
One value	<code>[ "foo" ] : List String</code>	<code>Just "foo" : Maybe String</code>
Two values	<code>[ "foo", "bar" ] : List String</code>	<code>Not possible!</code>

In chapter 4, we'll take our application *to the extreme*, by talking to a server to obtain our list of photos to display. Stay tuned!

#### Listing 3.7 The complete PhotoGroove.elm

```
module PhotoGroove exposing (main)

import Array exposing (Array)
import Browser
import Html exposing (...)
```

```

import Html.Attributes exposing(..)
import Html.Events exposing(onClick)
import Random

urlPrefix : String
urlPrefix =
    "http://elm-in-action.com/"

type Msg
    = ClickedPhoto String
    | GotSelectedIndex Int
    | ClickedSize ThumbnailSize
    | ClickedSurpriseMe

view : Model -> Html Msg
view model =
    div [ class "content" ]
        [ h1 [] [ text "Photo Groove" ]
        , button
            [ onClick ClickedSurpriseMe ]
            [ text "Surprise Me!" ]
        , h3 [] [ text "Thumbnail Size:" ]
        , div [ id "choose-size" ]
            (List.map viewSizeChooser [ Small, Medium, Large ])
        , div [ id "thumbnails", class (sizeToString model.chosenSize) ]
            (List.map (viewThumbnail model.selectedUrl) model.photos)
        , img
            [ class "large"
            , src (urlPrefix ++ "large/" ++ model.selectedUrl)
            ]
        []
    ]

viewThumbnail : String -> Photo -> Html Msg
viewThumbnail selectedUrl thumb =
    img
        [ src (urlPrefix ++ thumb.url)
        , classList [ ( "selected", selectedUrl == thumb.url ) ]
        , onClick (ClickedPhoto thumb.url)
        ]
        []

viewSizeChooser : ThumbnailSize -> Html Msg
viewSizeChooser size =
    label []
        [ input [ type_ "radio", name "size", onClick (ClickedSize size) ] []
        , text (sizeToString size)
        ]

```

The type of urlPrefix is String.

Msg is a custom type with four variants.

These variants are containers. Each holds a different type of value.

This variant is not a container. It holds no extra information.

view is a function that takes a Model and returns an Html Msg value.

The ClickedSurpriseMe variant is not a function.

Arguments are separated by -> because they can be partially applied.

The ClickedPhoto variant is a function. Its type is String -> Msg.

```
sizeToString : ThumbnailSize -> String
sizeToString size =
  case size of
    Small ->
      "small"
    Medium ->
      "med"
    Large ->
      "large"
```

This case-expression has no default branch because these three branches already cover all possibilities.

```
type ThumbnailSize
= Small
| Medium
| Large
```

```
type alias Photo =
{ url : String }
```

A type alias gives a name to a type. Anywhere we see the Photo type, we could have written this instead.

```
type alias Model =
{ photos : List Photo
, selectedUrl : String
, chosenSize : ThumbnailSize
}
```

Type aliases can use other type aliases like Photo, as well as custom types like ThumbnailSize.

```
initialModel : Model
initialModel =
{ photos =
  [ { url = "1.jpeg" }
  , { url = "2.jpeg" }
  , { url = "3.jpeg" }
  ]
, selectedUrl = "1.jpeg"
, chosenSize = Medium
}
```

```
photoArray : Array Photo
photoArray =
  Array.fromList initialModel.photos
```

```
getPhotoUrl : Int -> String
getPhotoUrl index =
  case Array.get index photoArray of
    Just photo ->
      photo.url
    Nothing ->
      ""
```

Array.get returns a Maybe because it's possible that there is no value at that index.

```
randomPhotoPicker : Random.Generator Int
randomPhotoPicker =
    Random.int 0 (Array.length photoArray - 1)
```

This Random.Generator Int describes a random number generator that produces integers.

```
update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
    case msg of
        GotSelectedIndex index ->
            ( { model | selectedUrl = getPhotoUrl index }, Cmd.none )
```

Tuples are similar to records.  
( Model, Cmd Msg ) is a tuple with two elements.

```
ClickedPhoto url ->
    ( { model | selectedUrl = url }, Cmd.none )
```

Random.generate returns a Cmd that generates a random value, wraps it in GotSelectedIndex, and passes it to update.

```
ClickedSize size ->
    ( { model | chosenSize = size }, Cmd.none )
```

```
ClickedSurpriseMe ->
    ( model, Random.generate GotSelectedIndex randomPhotoPicker )
```

```
main : Program () Model Msg
main =
    Browser.element
        { init = \flags -> ( initialModel, Cmd.none )
        , view = view
        , update = update
        , subscriptions = \model -> Sub.none
        }
```

An Elm program with no flags, with Model for its model type and Msg for its message type

## *Part 2*

# *Production-grade Elm*

I

In the next three chapters, you'll learn techniques that can be found in most Elm applications in the wild: talking to servers, talking to JavaScript, and testing. Strictly speaking, not every Elm application needs these, but in practice, all three are used very widely.

In chapter 4, you'll learn how to communicate with servers. This involves commands, a new concept within The Elm Architecture. Chapter 5 teaches how to communicate with JavaScript, which turns out to be very similar to communicating with servers. Chapter 5 also introduces the last foundational concept of The Elm Architecture: subscriptions.

Just as part 1 of the book ended with a chapter on how to make your code more reliable, so too does part 2, by teaching how to write automated tests for the code you've written in the preceding chapters. You'll learn about Elm's unit tests, fuzz tests, and how to test the user interface itself. By the end, you'll know enough to use Elm professionally.



# *Talking to servers*



## ***This chapter covers***

- Using decoders to validate and translate JSON
- Handling descriptive errors with results
- Communicating over HTTP with commands

We've made great progress! Users of our Photo Groove application can now do quite a bit:

- Select a thumbnail to view a larger version
- Choose Small, Medium, or Large thumbnail sizes
- Click the Surprise Me! button to select a random thumbnail

Our manager is impressed with our progress but has even more in mind: "It's time to take Photo Groove to the next level. The highest level. The cloud level. That's right, we're going to have Photo Groove start getting its photo information from our servers!"

As with last time, our manager has one more minor feature request: "There's also going to be some metadata associated with each photo—specifically, download size and an optional caption. We can have it show those on top of the big photo, right?"

Sure, since you asked so nicely.

In this chapter, we'll teach our application how to talk to servers. We'll validate and translate JSON data, communicate over HTTP using The Elm Architecture, and reliably handle errors in client-server communication. Let's get to it!

## 4.1 Preparing for server-loaded data

Now that we're going to be loading our initial list of photos from the server, our data-modeling needs will change.

### 4.1.1 Modeling incremental initialization

Right now, our `initialModel` looks like this:

```
initialModel : Model
initialModel =
    { photos = [ { url = "1.jpeg" }, { url = "2.jpeg" }, { url = "3.jpeg" } ]
    , selectedUrl = "1.jpeg"
    , chosenSize = Medium
    }
```

Once we start loading our photos from the server, we'll no longer have any photos when the page loads. Instead, we'll immediately send a request to the server to retrieve them, and once we hear back, we'll either have some photos to display . . . or an error message for the user. Let's translate these new considerations into some changes to our data model.

#### MODELING LOADED DATA

Our photos can now be in three possible states:

- We're still loading them. This will be our initial state when the program begins.
- There was a server error. In this case, we'll have an error message to display.
- We successfully loaded the data. Now we have photos, and possibly one is selected.

A custom type is the perfect way to represent these distinct possibilities! Let's introduce this custom type right above our `type alias Model` declaration:

```
type Status
    = Loading
    | Loaded (List Photo) String
    | Errorred String
```

This neatly represents all three possibilities. We'll begin in the `Loading` state, and then we'll transition to either `Loaded` or `Errorred`, depending on whether the server gave us some photos or an error. If we're in the `Errorred` state, we have an error message to display, and we have a `List Photo` (and the `String` of which URL is selected) only if the photos `Loaded` successfully.

**NOTE** Another way to model this would be using a *list zipper* data structure.

We won't dive into list zippers in this book, but they're worth knowing about!

A list zipper is like a `List` that has exactly one of its elements marked as

selected. We could replace `Loaded (List Photo) String` with a `Loaded` variant that contains a single value; namely, a list zipper.

Let's replace the `List Photo` in our `Model` and `initialModel` with `Status`:

```
type alias Model =
    { status : Status
    , chosenSize : ThumbnailSize
    }

initialModel : Model
initialModel =
    { status = Loading
    , chosenSize = Medium
    }
```

### PROPAGATING CHANGES

Now that we've revised our `Model`, we can lean on the compiler to tell us what parts of our code base were affected by this revision. This will let us reliably propagate these changes throughout our code base!

If we recompile, we'll see three type mismatches: one in `photoArray`, one in `update`, and one in `view`. Let's start with `view`.

### FIXING VIEW

`view` has some code that references the obsolete `model.photos`:

```
(List.map (viewThumbnail model.selectedUrl) model.photos)
```

We'll fix this by introducing a case-expression on `model.status`, and moving the code in question to that case-expression's `Loaded` branch—because now our photos are available in only that state. Our new `view` will look like this:

```
view : Model -> Html Msg
view model =
    div [ class "content" ]
        (case model.status of
            Loaded photos selectedUrl ->
                viewLoaded photos selectedUrl model.chosenSize

            Loading ->
                []

            Errored errorMessage ->
                [ text ("Error: " ++ errorMessage) ]
        )

viewLoaded : List Photo -> String -> ThumbnailSize -> List (Html Msg)
viewLoaded photos selectedUrl chosenSize = ...
```

Here we have a case-expression in the middle of our `view`, and we're passing its output to `div [ class "content" ]`. We can totally do that! Using a conditional expression in rendering logic might seem unfamiliar if you're used to HTML (or a restricted

templating system), but remember, Elm views are plain old functions. They get to use the language to its fullest!

Each branch in this case-expression evaluates to a `List (Html Msg)`, which will serve as the list of child nodes for the `div [ class "content" ]` at the top of `view`. The `Loading` branch returns `[]`, which means it won't display anything. (This would also be a reasonable place to display a loading spinner.) The `Errored` branch only displays the error message, and the `Loaded` branch calls `viewLoaded`—which is where most of the action will happen.

### RENDERING THE LOADED PHOTOS

The `viewLoaded` helper function will look almost the same as what we previously had in `view`. The only difference is that it takes three arguments instead of the one `Model`, and it returns a `List (Html Msg)` instead of `Html Msg`. (After all, view functions can return whatever is most helpful to us!)

Let's move that code over from the old `view` and replace any obsolete mentions of `model` with direct references to the arguments instead:

```
viewLoaded : List Photo -> String -> ThumbnailSize -> List (Html Msg)
viewLoaded photos selectedUrl chosenSize =
    [ h1 [] [ text "Photo Groove" ]
    , button
        [ onClick ClickedSurpriseMe ]
        [ text "Surprise Me!" ]
    , h3 [] [ text "Thumbnail Size:" ]
    , div [ id "choose-size" ]
        (List.map viewSizeChooser [ Small, Medium, Large ])
    , div [ id "thumbnails", class (sizeToString chosenSize) ]
        (List.map (viewThumbnail selectedUrl) photos)
    , img
        [ class "large"
        , src (urlPrefix ++ "large/" ++ selectedUrl)
        ]
    []
]
```

Spectacular! If we recompile, we'll now see two type mismatches remaining instead of three. Before we fix the next one, though, there's a quick refactor we can make.

### USING THE <| OPERATOR

Let's zoom in on our call to `div`:

```
div [ class "content" ]
(case model.status of
    ...
)
```

This code works fine, but it could be shorter if we used the `<|` operator. “What does that thing do?” I hear you ask, followed immediately by, “Is it a slice of pizza?”

To answer both questions: it is not a slice of pizza, but rather a ~~slice of cake~~ an operator that calls a function. In Elm, these two lines of code do the same thing:

```
String.toUpperCase (String.reverse "hello")
String.toUpperCase <| String.reverse "hello"
```

The `<|` operator takes a function and another value, and passes the value to the function. That might not sound like it does much, but it's handy for situations like the one we have here—where an infix operator would look nicer than parentheses. We can use it to refactor our `div`, as shown in table 4.1.

**Table 4.1 Eliminating parentheses by using the `<|` operator**

Parentheses	<code>&lt;  Operator</code>
<code>div [ class "content" ]   (case model.status of     ...   )</code>	<code>div [ class "content" ] &lt;    case model.status of     ...</code>

Lovely! Once we've implemented that refactor, we're ready to resolve our next type mismatch. This one will be a bit more involved.

### 4.1.2 Resolving data dependencies

The cause of our next type mismatch is that two branches of `update`'s case-expression reference `model.selectedUrl`, which no longer exists:

```
GotSelectedIndex index ->
  ( { model | selectedUrl = getPhotoUrl index }, Cmd.none )

ClickedPhoto url ->
  ( { model | selectedUrl = url }, Cmd.none )
```

Because the selected URL now lives in `model.status`, we'll need to change this logic accordingly.

#### FIXING UPDATE

Let's add a `selectUrl` helper function below `update` to help us out with this:

```
selectUrl : String -> Status -> Status
selectUrl url status =
  case status of
    Loaded photos _ ->
      Loaded photos url

    Loading ->
      status thought

    Errorred errorMessage ->
      status
```

This function doesn't do much. If it's passed a `Status` that is in the `Loaded` state, it returns an updated version of that `Status` that has the thumbnails' `selectedUrl` set to the given URL. Otherwise, it returns the `Status` unchanged.

**TIP** This function could be made more robust. Currently, if it gets a photo URL to select before the photos have loaded, it ignores that error and proceeds as if nothing has gone wrong. A more robust implementation might return a `Maybe Status`, so that `update` could fire off a `Cmd` to record the error in a logging service. We won't use a logging service in this book, but although it's good to recover from errors that shouldn't have happened, additionally logging that they happened gives you a way to later investigate what went wrong.

### The underscore placeholder

You may have noticed that `Loaded.photos _ ->` uses an underscore instead of a descriptive name like `selectedUrl`. The underscore is no ordinary name. It is a special placeholder indicating that there is a value here, but we're choosing not to use it. Attempting to reference `_` in our logic would be a compile error.

One handy feature of `_` is that you can use it multiple times in the same pattern. For example:

```
Loaded _ _ ->
    status
```

You can use `_` in case-expression branches as well as in function arguments:

```
functionThatTakesThreeArguments _ _ _ =
    "I ignore all three of my arguments and return this string!"
```

In contrast to choosing a name like `unusedValue`, the underscore makes it clearer that the value is never used.

Let's use our tasty new `selectUrl` helper function to fix the type mismatch in `update` like so:

```
case msg of
    GotSelectedIndex index ->
        ( { model | status = selectUrl (getPhotoUrl index) model.status }
        , Cmd.none
        )

    ClickedPhoto url ->
        ( { model | status = selectUrl url model.status }, Cmd.none )
```

If we recompile, we can see that we're now down from two type mismatches to one.

### REPLACING PHOTOARRAY

The final type mismatch occurs because our top-level `photoArray` is still based on `initialModel.photos`. This was perfectly reasonable back when `initialModel.photos` had a bunch of hardcoded photos in it, but now that we're loading them on the fly, we need a new approach.

Let's start by deleting our existing `photoArray` definition, along with the `getPhotoUrl` and `randomPhotoPicker` declarations that went with it. This will remove our previous compile error, but will reveal two more once we recompile. This is good! The top-level `photoArray` was only a symptom; now we're getting closer to the actual cause.

### DIRECTLY CHOOSING A RANDOM PHOTO

One way we could fix this is by creating `photoArray` on the fly. However, this is a good opportunity to step back and see if we can find a nicer approach.

In chapter 3, we created an `Array Photo` to help us choose a photo at random. We then used a `Random.Generator Int` to get a random index into that array, and `Array.get` with that index to obtain the `Photo` we desired. Is there some way we could randomly choose a `Photo` without the intermediate `Array`? Indeed there is: the `Random.uniform` function!

```
Random.uniform : elem -> List elem -> Random.Generator elem
```

This function produces a `Random.Generator` that randomly picks one of the `elem` values we passed it. It's called `uniform` because it has the same chance of randomly producing any of the elements; their probabilities have a *uniform* distribution.

Why does it take both an `elem` argument as well as a `List elem`? Why not take a `List elem` alone? Because `List elem` could be empty, and it would be impossible for `uniform` to pick one element from a list of zero elements.

**NOTE** Conceptually, `Random.uniform` "takes a non-empty list." The reason Elm's standard libraries don't include a dedicated `NonEmptyList` type is that it's simple enough for a function that needs one to follow `Random.uniform`'s design: accept a mandatory `elem` as well as a `List elem` of optional additional values. Similarly, a function can "return a non-empty list" by returning an `( elem, List elem )` tuple.

We'll use `Random.uniform` to fix the `ClickedSurpriseMe` branch, which depended on the `randomPhotoPicker` value that no longer exists. Let's change the `Clicked-SurpriseMe` branch like so:

```
ClickedSurpriseMe ->
  case model.status of
    Loaded (firstPhoto :: otherPhotos) _ ->
      ( model
      , Random.generate GotRandomPhoto
        (Random.uniform firstPhoto otherPhotos)
      )

    Loading ->
      ( model, Cmd.none )

    Errorred errorMessage ->
      ( model, Cmd.none )
```

These two `Loaded` branches use some patterns we haven't seen before.

### THE :: PATTERN

Let's zoom in on the first pattern:

```
Loaded (firstPhoto :: otherPhotos) _ ->
```

The `firstPhoto :: otherPhotos` pattern matches `List` values that have at least one element. Their first element is named `firstPhoto` (because it came before the `::` symbol), and the remaining elements are in a list called `otherPhotos`. If we were to annotate their types, we'd write `firstPhoto : Photo` and `otherPhotos : List Photo`.

Now that we have a `Photo` and a `List Photo`, we can pass them as the arguments to `Random.uniform` to get a `Random.Generator Photo` value.

**TIP** When you encounter a function like `Random.uniform` that takes a “non-empty list,” using the `::` pattern in a case-expression is often a good way to obtain the two arguments it needs.

### GOTRANDOMPHOTO

Now that we're generating a random photo instead of a random index, our call to `Random.generate` will use a message variant named `GotRandomPhoto` instead of the previous `GotSelectedIndex`. We'll need to change our `Msg` type to reflect this. Let's remove the `GotSelectedIndex Int` variant and add this at the end of our type `Msg` definition:

```
| GotRandomPhoto Photo
```

Then we'll replace the `GotSelectedIndex` branch in `update` with this:

```
GotRandomPhoto photo ->
  ( { model | status = selectUrl photo.url model.status }, Cmd.none )
```

Fantastic! Now our Surprise Me! logic will work with photos loaded from the server, and not only that, we refactored our way out of a dependency. Because we are no longer using `Array`, we can remove `import Array` from the top of our module.

### MISSING PATTERNS

If we try to recompile, we'll see one final error:

```
-- MISSING PATTERNS ----- src/PhotoGroove.elm
```

Whoops! Our `case model.status` does not handle the possibility that we are in the `Loaded` state with an empty list of photos. The `Loaded (firstPhoto :: otherPhotos) _ ->` branch represents only the situation where we got at least one photo, so we'll need to add a second `Loaded` branch for the situation where the server gave us zero photos.

### THE [ ] PATTERN

Let's introduce a new branch right below the existing `Loaded` branch:

```
Loaded [] _ ->
  ( model, Cmd.none )
```

This pattern will match `Loaded` variants where the `List Photo` value is empty. It says that if the user clicks Surprise Me! and we loaded zero photos, then the Surprise Me! button does nothing. Thanks to this change, our code compiles again!

### USING THE PIPELINE OPERATOR

We have one more change to make: a stylistic one. We're going to express the first `Loaded` branch as a *pipeline* of sequential operations by using `Tuple.pair` and the `|>` operator.

Let's look at `Tuple.pair` first. It's a function that takes two arguments and returns them in a tuple. So writing `Tuple.pair a b` returns `(a, b)`. It works nicely with the `|>` operator, like so:

```
Loaded (firstPhoto :: otherPhotos) _ ->
    Random.uniform firstPhoto otherPhotos
    |> Random.generate GotRandomPhoto
    |> Tuple.pair model
```

The `|>` operator is purely stylistic. This expression is exactly equivalent to writing `Tuple.pair model (Random.generate GotRandomPhoto (Random.uniform firstPhoto otherPhotos))` except it's expressed in a different style. Figure 4.1 compares these two ways to write the same expression.

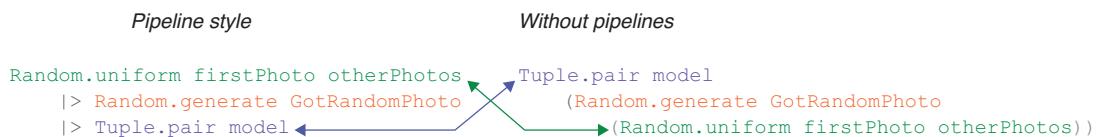


Figure 4.1 The same expression, with and without pipelines

The pipelined code is saying the following:

- 1 Call `Random.uniform firstPhoto otherPhotos`.
- 2 Pass its return value as the final argument to `Random.generate GotRandomPhoto`.
- 3 Pass that return value as the final argument to `Tuple.pair model`.

Pipelines can make it easier to read and to modify sequences of transformations like this. We'll be using them later in this chapter and throughout the rest of the book. Go ahead and switch to the pipeline version before we move on.

**NOTE** Before Elm's compiler generates JavaScript code, it quietly rewrites pipelines into normal function calls. So `"foo" |> String.reverse` compiles to the same thing as `String.reverse "foo"`. Since they compile to the same thing, there's no performance cost to choosing one over the other. Choose whichever makes for nicer code.

### THE COMPLETED REFACTOR

Let's review the code changes we've made:

- 1 Our data model now represents three distinct states: `Loading`, `Loaded`, and `Errored`.
- 2 We begin in the `Loading` state, but now we access photos or `selectedUrl` only when in the `Loaded` state. (Because we now store those values in the `Loaded` variant, we've guaranteed that we can't possibly access them in any other state.)
- 3 When the user clicks the Surprise Me! button, we randomly select a photo without creating an intermediate `Array`.

Although our code compiles, it no longer does much. We begin in the `Loading` state, but we never transition out of it. Fortunately, our data model is now prepared for us to make that transition using photos we receive from the server. It's time to get some HTTP going!

## 4.2 Fetching data from a server

One of our helpful coworkers has set up a simple server endpoint that returns a comma-separated list of photo filenames. The list doesn't yet contain the metadata that we'll ultimately need, but it'll give us a good starting point toward that goal. Let's send an HTTP GET request to fetch that comma-separated string from a server.

### 4.2.1 Describing HTTP requests

We'll be using the `Http` module to send HTTP requests to our server. Since `Http` is not one of Elm's core modules, we need to install the `elm/http` package to gain access to it. We'll do that the same way we installed the `elm/browser` package in chapter 2:

```
elm install elm/http
```

Answer `y` when prompted, and we'll be ready to go!

#### MANAGED EFFECTS INSTEAD OF SIDE EFFECTS

In chapter 3, we saw how generating random numbers in Elm must be done with a `Cmd` rather than a plain function call. Whereas JavaScript's `Math.random()` can return a different random number each time you call it, Elm functions must be more consistent. When you pass an Elm function the same arguments, it's guaranteed to return the same value.

There's another rule that applies to all Elm functions, and this one affects the HTTP requests we're about to make. The rule is that Elm functions cannot have *side effects*.

**DEFINITION** An *effect* is an operation that modifies external state. A function that modifies external state when it executes has a *side effect*.

HTTP requests can always modify external state—because even a GET request can result in a server changing values in a database—so performing an HTTP request is an

effect. This means if we execute a function and it performs an HTTP request, that function has a side effect.

The following listing shows a few JavaScript functions that consistently return the same value, but that have side effects because they modify external state along the way. None of these could be written as plain Elm functions.

#### Listing 4.1 JavaScript functions that have side effects

```
function storeStuff() {
    localStorage.stuff = "foo";
    return 1;
}

function editField(object) {
    object.foo = "bar";
    return object;
}

var something = 1;

function editVar() {
    something = 2;
    return 0;
}
```

<code>function storeStuff() {     localStorage.stuff = "foo";     return 1; }  function editField(object) {     object.foo = "bar";     return object; }  var something = 1;  function editVar() {     something = 2;     return 0; }</code>	<b>Modifies the contents of localStorage</b>  <b>Modifies the object it receives</b>  <b>Modifies an external variable</b>
--	--

If you look through all the code we've written for Photo Groove, you won't find a single function that has a side effect. All effects are performed by the Elm Runtime itself; our code only *describes* which effects to perform, by returning values from `update`.

**NOTE** Calling `update` does not directly alter any state. All `update` does is return a tuple. If you wanted to, you could call `update` a hundred times in a row, and all it would do is give you back a hundred tuples.

This system of *managed effects*, in which the Elm Runtime is in charge of performing all effects, means that Elm programs can be written entirely in terms of data transformations. In chapter 6, you'll see how nice this makes Elm code to test.

To perform an HTTP request, we'll do what we did with random number generation in chapter 3: use `Cmd` to tell the Elm Runtime to perform that effect.

#### HTTP.GET

The `Http.get` function returns a `Cmd` representing the HTTP request we want to make. It has this type:

```
Http.get : { url : String, expect : Expect msg } -> Cmd msg
```

We pass `Http.get` a URL string, along with an `Expect` value that describes what we expect to get back. Just as in chapter 3 with random number generation, once this `Cmd` completes, it will send a `Msg` to `update` telling us what happened.

Let's see how it works! Suppose we decided to call it like this:

```
Http.get
  { url = "http://manning.com"
  , expect = Http.expectString toMsg
  }
```

Here's what this code is saying:

- 1 Send an HTTP GET request to <http://manning.com>.
- 2 I expect to get back a String for the response.
- 3 When the response comes back, use this `toMsg` function to translate it into a `Msg`.
- 4 Send that `Msg` to update.

Figure 4.2 illustrates this process.



Figure 4.2 The Elm Runtime executing a Cmd from `Http.get`

Next, we'll take a look at how to process that response properly.

#### **HTTP.EXPECTSTRING**

Let's take a closer look at that `Http.expectString` function. What exactly is it looking for in that `toMsg` function?

```
Http.expectString : (Result Http.Error String -> msg) -> Expect msg
```

Unlike the random number generation effect we performed in chapter 3, a lot can go wrong with an HTTP request! What if we send the server an invalid URL? Or an unrecognized one? What if the server has been unplugged by a mischievous weasel?

If the request fails for any reason, we'll want to know what went wrong so we can try to recover—and possibly inform the user. `Http.expectString` uses a value that accounts for this possibility: a `Result`.

## RESULT AND MAYBE

To get a feel for how `Result` works, let's compare it to its cousin `Maybe`. In chapter 3, we saw how `Array.get` returned a `Maybe` to account for the possibility of a missing value. The definition of `Maybe` looks like this:

```
type Maybe value
  = Just value
  | Nothing
```

Elm has a similar custom type for representing the *result* of an operation that can fail, such as performing an HTTP request. It's called `Result`, and it looks like this:

```
type Result errValue okValue
  = Err errValue
  | Ok okValue
```

As we can see, `Result` has two type variables:

- `okValue` represents the type of value we'll get if the operation succeeded. For example, if we are trying to obtain a `String` from the server, then `okValue` would be `String`.
- `errValue` represents the type of error we'll get if the operation failed. In our case, `errValue` will refer to a custom type that enumerates various mishaps that can befall HTTP requests. That custom type is called `Http.Error`.

Just as `Maybe` requires that we write logic to handle both the `Just` and `Nothing` cases, so too does `Result` require that we handle both the `Ok` and `Err` cases.

## HTTP.GET AND HTTP.EXPECTSTRING

Putting it all together, we can see how `Http.get` and `Http.expectString` work together to provide the ingredients we need to describe a request:

```
expectString : (Result Http.Error String -> msg) -> Expect msg
get        : { url : String, expect : Expect msg } -> Cmd msg
```

Between the two of them, we have the following:

- A URL string
- The `Msg` that should be sent to update if the request fails (meaning we got the `Err` variant of `Result Http.Error String`, which holds an `Http.Error` we can inspect)
- The `Msg` that should be sent to update if the request succeeds (meaning we got the `Ok` variant of `Result Http.Error String`, which holds the `String` the server sent back)

Now that you know how to put an HTTP request together, you're ready to send it!

## 4.2.2 Sending HTTP requests

To handle the response from our freshly described HTTP request, we'll start by importing the `Http` module. Let's add this right before `import Random`:

```
import Http
```

Next, let's add a `Msg` variant to handle the `Result` value we'll get from `Http.get`:

```
type Msg
    = ClickedPhoto String
    | ClickedSize ThumbnailSize
    | ClickedSurpriseMe
    | GotRandomPhoto Photo
    | GotPhotos (Result Http.Error String)
```

You'll learn more about the `Http.Error` type in a bit. For now, let's add a branch to our update function's case-expression for this new `Msg`. We'll start with something like this:

```
GotPhotos result ->
    case result of
        Ok responseStr ->
            ...translate responseStr into a list of Photos for our Model...
        Err httpError ->
            ( { model | status = Errored "Server error!" }, Cmd.none )
```

With that basic skeleton in place, we can implement these two cases one at a time. We'll start with the `Ok responseStr` case, where the server gave us a valid response and all is well.

### READING PHOTO FILENAMES WITH STRING.SPLIT

Remember earlier, when I mentioned how we have a server endpoint that returns a comma-separated list of photo filenames? If not, here it is again:

*One of our helpful coworkers has set up a simple server endpoint that returns a comma-separated list of photo filenames.*

—This book, earlier

Sure enough, if we visit this endpoint at <http://elm-in-action.com/photos/list>, we can see the list of filenames. It's a plain old string:

```
"1.jpeg,2.jpeg,3.jpeg,4.jpeg"
```

We wrote `Ok responseStr` a moment ago—that `responseStr` value will refer to exactly this string! Now we can split `responseStr` into a list of individual filenames by using Elm's `String.split` function. It has this type:

```
split : String -> String -> List String
```

We give `String.split` a separator (in this case, a comma) and a string to split, and it gives us back a list of all the strings it found between those separators. Table 4.2 shows what `String.split ", "` will do to the string we get from the server.

**Table 4.2** Calling `String.split ", "` on a string

<code>stringFromServer</code>	<code>String.split ", "</code> <code>stringFromServer</code>
<code>"1.jpeg,2.jpeg,3.jpeg,4.jpeg"</code>	<code>[ "1.jpeg", "2.jpeg", "3.jpeg", "4.jpeg" ]</code>

Once we have this list of filename strings, we can use it to set the `photos : List Photo` field in our `Model` as in the following listing.

**Listing 4.2 Incorporating `responseStr` into the Model**

```
Ok responseStr ->
  let
    urls =
      String.split "," responseStr           ← Splits the String
                                              into a List String
    photos =
      List.map (\url -> { url = url }) urls ← Translates the List
                                              String into a List Photo
    firstUrl =
      List.head photos           ← Gets the first
                                  photo in the list
  in
    ( { model | status = Loaded photos firstUrl }, Cmd.none ) ← Sets the photos
                                                               in the model
```

Now when we successfully receive a `String` response from the server, we'll translate it into a list of `Photo` records, along with a `firstUrl` to use as our `selectedUrl`, and store them both in our `Model`. Now we recompile everything, and . . .

**LIST.HEAD**

... *Whoops!* This code doesn't compile.

The source of the trouble is our call to `List.head`. That function's type looks like this:

```
List.head : List elem -> Maybe elem
```

`List.head` and `Array.get 0` serve essentially the same purpose: returning `Nothing` when passed an empty collection, or `Just whatever` if the collection had anything in it. Unfortunately for us, this means that our `firstUrl` is not a `String` like the `Loading (List Photo) String` variant expects, but rather a `Maybe String`!

**USING THE “AS” KEYWORD**

We can use the `::` pattern you learned in section 4.1.2 to remedy this situation. Let's rewrite our `Ok responseStr` branch like so:

```
Ok responseStr ->
  case String.split "," responseStr of
    (firstUrl :: _) as urls ->
      let
        photos =
          List.map (\url -> { url = url }) urls
```

```

in
( { model | status = Loaded photos firstUrl }, Cmd.none )

[] ->
( { model | status = Errored "0 photos found" }, Cmd.none )

```

This pattern has something you haven't seen before!

```
(firstUrl :: _) as urls ->
```

The `as urls` part of this pattern means “give the name `urls` to this entire `List`, while also subdividing it into its first element—which we will name `firstUrl`—and its remaining elements, which we will decline to name by using the `_` placeholder.”

**TIP** You can also use `as` when destructuring function arguments. For example, `doSomethingWithTuple (( first, second ) as tuple) = ...` or perhaps `doSomethingWithRecord ({ username, password } as record) = ...`

Now everything should compile once again. Notice that we now treat it as an error case if the server returns zero photos. In fact, if this happens, we will set our model's `status` to `Errored`, and it will be as if the server had given us back an invalid response.

When Elm's compiler highlights an edge case like this, we often have a choice to make about how we want to handle it. For example, here we could have set `selectedUrl` to `" "` and called it a day. (If we wanted to go that route, though, it would have been better to be more explicit about the possibility of not having a selection; for example, by changing the type of `selectedUrl` to a `Maybe String`.) We decided not to, but it would have worked fine to take either path.

**NOTE** Because we now know our `List Photo` in the `Loaded` variant will never be empty, we could change the type of `Loaded` to hold a non-empty list instead of a `List Photo`. For example, its type could be `Loaded Photo (List Photo) String`. We won't make that change here, but try it out if you have time.

Before we move on, let's pause for a quick refactor.

#### USING TYPE ALIASES TO CREATE RECORDS

Declaring type alias `Photo = { url : String }` does more than give us a `Photo` type we can use in type annotations. It also gives us a convenience function whose job is to build `Photo` record instances. This function is also called `Photo`. Here it is in action:

```
Photo "1.jpeg" == { url = "1.jpeg" }
```

This also works with record type aliases involving multiple fields, like the one for `Model`:

```

type alias Model =
    { status : Status
    , chosenSize : ThumbnailSize
    }

```

This declaration gives us a convenience function called `Model` that builds a record and returns it. Because this record has two fields, whereas `Photo` had only one, the `Model` function accepts two arguments instead of one. The type of the `Model` function looks like this:

```
Model : Status -> ThumbnailSize -> Model
```

The order of arguments matches the order of the fields in the type alias declaration. So if you were to move the `photos : List Photo` declaration to the end of the type alias, then the `Model` function would look like this instead:

```
Model : String -> ThumbnailSize -> List Photo -> Model
```

We can use this knowledge to perform a quick refactor of our `Photo` construction:

```
Old: List.map (\url -> { url = url }) urls
New: List.map Photo urls
```

Lovely!

### PATTERN MATCHING

There's one more refactor we can make here. If you zoom out a bit, you'll notice we have a case-expression nested directly inside another case-expression:

```
case msg of
  ...
  GotPhotos result ->
    case result of
      Ok responseStr ->
        ...
        Err _ ->
          ( model, Cmd.none )
```

In situations like this, we can use concise *pattern matching* to express the same logic:

```
case msg of
  ...
  GotPhotos (Ok responseStr) ->
  ...
  GotPhotos (Err _) ->
    ( model, Cmd.none )
```

**DEFINITION** *Pattern matching* is a way of destructuring values based on how their containers look. In the preceding example, if we have a `GotPhotos` containing an `Ok` containing a value, that value will go into a variable called `responseStr`.

This refactored code is equivalent to what we had before. The difference is that now each of our branches is expressing two conditions at once:

- The `GotPhotos (Ok responseStr)` branch runs if `msg` is a `GotPhotos` variant that contains an `Ok` value.
- The `GotPhotos (Err _)` branch runs if `msg` is a `GotPhotos` variant that contains an `Err` value.

You can nest patterns like these as much as you want, even assembling elaborate creations like `NestAllTheThings (Just (Ok (Listen (This (IsReally "great" _))))`—but try not to overdo it.

### RUNNING A COMMAND ON INIT

At this point, we've assembled all the ingredients necessary to launch our HTTP rocket ship in the direction of our server:

- A URL string and `Expect` value that `Http.get` will use to return a `Cmd Msg` that will send the request
- Logic for the `GotPhotos` message that will handle the response

Let's put it all together to create a new value called `initialCmd` by using this call to `Http.get`:

```
initialCmd : Cmd Msg
initialCmd =
    Http.get
        { url = "http://elm-in-action.com/photos/list"
        , expect = Http.expectString (\result -> GotPhotos result)
        }
```

We'll use this `initialCmd` value to run our HTTP request when the program starts up.

### The type of `initialCmd`

Why does `initialCmd` have the type `Cmd Msg`? Let's look at the type of `Http.get` again:

```
Http.get : { url : String, expect : Expect msg } -> Cmd msg
```

Because `msg` is lowercase, it's a type variable like the ones we saw in chapter 3. This means whatever flavor of `Expect` we pass to `Http.get`, we'll get the same flavor of `Cmd` back. Their type parameters will necessarily be the same!

How can we tell what `Expect`'s type parameter will be in this expression? Let's dig one level deeper and look at `Http.expectString` again:

```
Http.expectString : (Result Http.Error String -> msg) -> Expect msg
```

Once again we see a type variable called `msg`. So the `Expect` will be parameterized on whatever type we return from the `(Result Http.Error String -> msg)` function we pass to `Http.expectString`. In our case, that would be this anonymous function:

```
Http.ExpectString (\result -> GotPhotos result)
```

Because that function returns a `Msg`, the call to `Http.expectString` will return an `Expect Msg`, which in turn means `Http.get` will return `Cmd Msg`.

### SIMPLIFYING INITIALCMD

This will compile, but we can simplify it. Back in section 2.2.1 of chapter 2, we noted that an anonymous function like `(\foo -> bar baz foo)` can always be rewritten as `(bar baz)` by itself. This means we can replace `(\result -> GotPhotos result)` with `GotPhotos` like so:

```
initialCmd : Cmd Msg
initialCmd =
    Http.get
        { url = "http://elm-in-action.com/photos/list"
        , expect = Http.expectString GotPhotos
        }
```

Now we have a `Cmd` to run, but we want to kick this one off a bit differently than last time. We ran our random number generation command from `update` in response to a user click, but we want to run this command right when the program starts up.

We can do that by updating `main` to use `initialCmd` instead of `Cmd.none` on `init`, like so:

```
main : Program Never Model Msg
main =
    Browser.element
        { init = \_ -> ( initialModel, initialCmd )
        , view = view
        , update = update
        , subscriptions = \_ -> Sub.none }
```

**We don't use this argument, so name it.**

While we're at it, we also updated `init` and `subscriptions` to use `_` for their anonymous functions' arguments, because those arguments never get used.

**TIP** An anonymous function that ignores its argument (like the `\_ ->` in the preceding code) kinda looks like a hockey stick.

Figure 4.3 illustrates how our revised `init` kicks off the sequence of events leading up to our `update` function receiving a `GotPhotos` message.



Figure 4.3 Running a `GotPhotos` command on `init`

Now let's recompile and open `index.html`, so we can bask in the glory of our new server-loaded photos! Figure 4.4 shows how the page should now look.

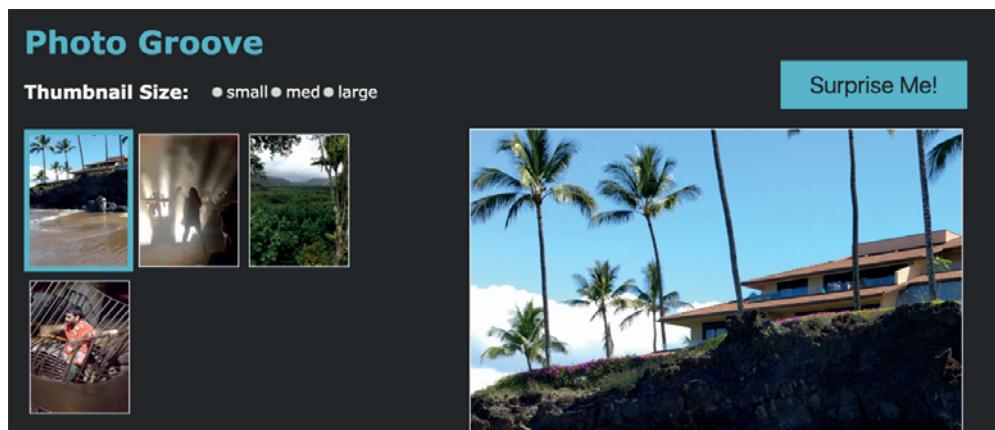


Figure 4.4 The updated application, with an additional photo loaded

Beautiful! Now that we're loading photos from the server, we're ready to take the final step: obtaining the metadata and complete URLs from the server, rather than filenames alone.

## 4.3 Decoding JSON

Browsers can talk to servers in many ways: JSON, XML, RPC, BBQ . . . the list goes on. Regardless, when the browser sends off an HTTP request to a server, the response comes back as a bunch of raw bytes. It's up to the program running in the browser to decode those bytes into a useful representation.

The server with the metadata will be sending us that information via JSON. This means we'll need some way to decode a JSON string into something more useful.

### 4.3.1 Decoding JSON strings into results

To work with JSON, we'll want the `elm/json` package. Run this at the terminal:

```
elm install elm/json
```

We already had this as an indirect dependency (because the `elm/browser` package depends on it, and we depend on `elm/browser` directly), so answer `y` when prompted to move it into our direct dependencies.

**NOTE** We can import modules from only our direct dependencies, not from our indirect dependencies.

#### THE DECODESTRING FUNCTION

Plenty of things can go wrong during the process of decoding JSON. Suppose the server messes up and sends us XML instead of JSON. Our JSON-decoding logic will certainly fail! Or suppose we get back a response that's valid JSON, but a required field is missing. What then?

The `Json.Decode.decodeString` function returns a `Result`. Its complete type is shown here:

```
decodeString : Decoder val -> String -> Result Error val
```

Notice that the `Result` we get back from `decodeString` has one concrete type—namely, that `errValue` is always an `Error`—and one that matches the type of the given decoder's type variable. (`Error` is a custom type that the `Json.Decode` module uses to represent an error that occurred during decoding.) Table 4.3 shows how the decoder passed to `decodeString` affects its return type.

Table 4.3 How the decoder passed to `decodeString` affects its return type

Decoder passed in	<code>decodeString</code> returns	Example success value
<code>Decoder Bool</code>	<code>Result Error Bool</code>	<code>Ok True</code>
<code>Decoder String</code>	<code>Result Error String</code>	<code>Ok "Win!"</code>
<code>Decoder (List Int)</code>	<code>Result Error (List Int)</code>	<code>Ok [ 1, 2, 3 ]</code>

### DECODING PRIMITIVES

The `Json.Decode` module has a Decoder `Bool` called `bool`, which translates a JSON Boolean string (either "true" or "false") into an Elm `Bool` (`True` or `False`). Let's try it in `elm repl`!

#### **Listing 4.3 Using `decodeString bool`**

```
> import Json.Decode exposing(..)

> decodeString Bool "true"
Ok True : Result Error Bool

> decodeString Bool "false"
Ok False : Result Error Bool

> decodeString Bool "42"
Err ... : Result Error Bool

> decodeString Bool "@&!*/%?"
Err ... : Result Error Bool
```

Besides `bool`, the `Json.Decode` module offers other primitive decoders like `string`, `int`, and `float`. They work similarly to `bool`, as we can see in `elm repl`.

#### **Listing 4.4 Using `decodeString` with `int`, `float`, and `string`**

```
> import Json.Decode exposing(..)

> decodeString Float "3.33"
Ok 3.33 : Result Error Float

> decodeString String "\\\"backslashes escape quotation marks\\\""
Ok "backslashes escape quotation marks" : Result Error String

> decodeString Int "76"
Ok 76 : Result Error Int

> decodeString Int "3.33"
Err ... : Result Error Int
```

The only primitive decoders are `bool`, `int`, `float`, `string`, and `null`, because JavaScript's `undefined` is not allowed in valid JSON. As you will soon see, there are other ways of handling `null` besides using this primitive decoder.

### 4.3.2 Decoding JSON collections

You've now seen how to decode primitives like Booleans, integers, and strings from JSON into their Elm counterparts. This is a good start, but JSON also supports arrays and objects, and we'll need to decode both of these types in order to receive our list of photos with metadata.

## DECODING JSON ARRAYS INTO LISTS

Suppose we have the JSON string "[true, true, false]". To decode a list of Booleans from this JSON array, we can write `list Bool`. This will give us a Decoder (List Bool) value.

Here's how `Json.Decode.bool` and `Json.Decode.list` compare:

```
bool : Decoder Bool
list : Decoder value -> Decoder (List value)
```

Whereas `bool` is a decoder, `list` is a *function* that takes a decoder and returns a new one. We can use it in `elm repl` to make decoders for lists of primitives, or even lists of lists!

### Listing 4.5 Using `Json.Decode.list`

```
> import Json.Decode exposing (Decoder, list, bool, string, int)
> list
<function> : Decoder a -> Decoder (List a)    ←
> list bool
<internals> : Decoder (List Bool)               | elm repl chooses "a" for the
                                                    | type variable we called "value".
> list string
<internals> : Decoder (List String)
> list (list int)
<internals> : Decoder (List (List Int))
```

## DECODING OBJECTS

The simplest way to decode an object is with the `field` function. Suppose we write this:

```
decoder : Decoder String
decoder =
    field "email" string
```

When this decoder runs, it performs three checks:

- 1 Are we decoding an Object?
- 2 If so, does that Object have a field called `email`?
- 3 If so, is the Object's `email` field a String?

If all three are true, then decoding succeeds with the value of the Object's `email` field. Table 4.4 shows how this decoder would work on a variety of inputs.

Table 4.4 Decoding objects with field decoders

Decoder	JSON	Result
<code>field "email" string</code>	5	Err ... (the number 5 has no fields)
	<code>{"email": 5}</code>	Err ... (the email field wasn't a string)
	<code>{"email": "cate@nolf.com"}</code>	Ok "cate@nolf.com"

## DECODING MULTIPLE FIELDS

Building a decoder for a single field is all well and good, but typically when decoding objects, we care about more than one of their fields. How do we do that? The simplest is with a function like `map2`, which we can see in table 4.5.

**Table 4.5 Decoding objects with field decoders**

Decoder	JSON	Result
<code>map2</code> <code>(\x y -&gt; ( x, y ))</code> <code>(field "x" int)</code> <code>(field "y" int)</code>	<code>{"x": 5}</code>  <code>{"x": 5, "y": null}</code>  <code>{"x": 5, "y": 12}</code>	<code>Err ... (y was missing)</code>  <code>Err ... (y was null, not int)</code>  <code>Ok ( 5, 12 )</code>

## DECODING MANY FIELDS

The photo information we'll be getting back from our server will be in the form of JSON that looks like this:

```
{"url": "1.jpeg", "size": 36, "title": "Beachside"}
```

This is an object with three fields: two strings and one int. Let's update our `Photo` type alias to reflect this:

```
type alias Photo =
    { url : String
    , size : Int
    , title : String
    }
```

We could decode this by using the technique we just learned, with one slight difference. We'd have to use `map3` instead of `map2`, because we have three fields instead of two:

```
photoDecoder : Decoder Photo
photoDecoder =
    map3
        (\url size title -> { url = url, size = size, title = title })
        (field "url" string)
        (field "size" int)
        (field "title" string)
```

How far can this approach take us? If we added a fourth field, we'd change `map3` to `map4`. The `Json.Decode` module also includes `map5`, `map6`, `map7`, and `map8`, but `map8` is as high as it goes. From there, we can either combine the decoders we've already used . . . or we can introduce a library designed for larger-scale JSON decoding!

## PIPELINE DECODING

The `Json.Decode.Pipeline` module is designed to make life easier when decoding large objects. It comes from a popular third-party package called `NoRedInk/elm-json-decode-pipeline`—so let's quickly install it before we proceed:

```
elm install NoRedInk/elm-json-decode-pipeline
```

Let's also add it to our imports. We'll do that by adding all of this to our imports list, right after `import Http`:

```
import Http
import Json.Decode exposing (Decoder, int, list, string, succeed)
import Json.Decode.Pipeline exposing (optional, required)
```

Now the coast is clear to replace `photoDecoder` with the code in this listing.

#### Listing 4.6 `photoDecoder`

```
photoDecoder : Decoder Photo
photoDecoder =
    succeed buildPhoto
    |> required "url" string
    |> required "size" int
    |> optional "title" string "(untitled)" ← "size" is required and
                                                 must be an integer. ← "title" is optional and
                                                 defaults to "(untitled)". ← If decoding succeeds,
                                                 pass these values to the
                                                 buildPhoto function.

"url" is required
and must
be a string. ← "url" string ← "size" int ← "title" string "(untitled)" ←

buildPhoto : String -> Int -> String -> Photo
buildPhoto url size title =
    { url = url, size = size, title = title }
```

Let's break down what's happening here:

- 1 `succeed buildPhoto` begins the pipeline. It says that our decoder will decode the arguments to `buildPhoto`, one by one, and ultimately the whole decoder will succeed unless any of the steps in this pipeline fails. Because `buildPhoto` accepts three arguments, we'll need three pipeline steps after this. (Otherwise, the compiler will give an error.)
- 2 `required "url" string` says that we need what we're decoding to be a JSON object with the string field `"url"`. We're also saying that if decoding succeeds, we should use this first result as the first argument to `buildPhoto`. Decoding could fail here, either because the `"url"` field is missing, or because the field is present—but is not a string.
- 3 `required "size" int` does the same thing as `required "url" string` except that it decodes to an integer instead of a string.
- 4 `optional "title" string "(untitled)"` is similar to the required steps, but with one important difference: in this example, if the `"title"` field were either missing or null, this decoder will default on that final argument instead of failing decoding—that is, the title string would default to `"(untitled)"`.

Figure 4.5 shows how the `buildPhoto` arguments and `photoDecoder` arguments match up.

```

photoDecoder : Decoder Photo
photoDecoder =
    succeed buildPhoto
        |> required "url" string
        |> required "size" int
        |> optional "title" string "(untitled)"
buildPhoto :
String
-> Int
-> String
-> Photo

```

Figure 4.5 The relationship between photoDecoder and buildPhoto

### How “succeed” and “required” interact

To get a deeper understanding of how this works, let’s take a closer look at how `succeed` and `required` interact here. Let’s start by looking at the type of `Decode.succeed` and `buildPhoto`:

```

succeed : a -> Decoder a
buildPhoto : String -> Int -> String -> Photo

```

Putting the two together, when we call `Decode.succeed buildPhoto`, it returns a decoder of this type:

```
Decoder (String -> Int -> String -> Photo)
```

If we stopped right here, we’d have a pretty unhelpful decoder! It would always succeed, no matter what JSON we gave it, and all it would do is give us that same `buildPhoto` function that we already had to begin with.

We can make this decoder a bit more useful by adding `required`, like so:

```

functionDecoder : Decoder (Int -> String -> Photo)
functionDecoder =
    succeed buildPhoto
        |> required "url" string

```

Whereas the decoder we made with `succeed Photo` would succeed no matter what JSON we gave it, this one will succeed only if we give it a JSON object with a field called `url` that holds a `String`. This decoder also has a slightly different type than the `succeed Photo` one did. It’s shrunk by one argument:

```

Before required: Decoder (String -> Int -> String -> Photo)
After required:  Decoder (           Int -> String -> Photo)

```

The following table shows how each call to `required` applies one more argument to the `Photo` function we started out with. Doing this a few times shrinks our original `Decoder (String -> Int -> String -> Photo)` down to a `Decoder Photo`.

Step	Type
succeed buildPhoto	Decoder (String -> Int -> String -> Photo)
> required "..." string	Decoder (           Int -> String -> Photo)
> required "..." int	Decoder (String -> Photo)
> required "..." string	Decoder Photo

By the way, notice anything familiar about what `buildPhoto` does?

All it does is take one argument for each of the fields in `Photo`, and then assign them uncritically without altering them in any way. We already have a function that does this! It's the `Photo` function, which we got for free because we defined the `Photo` type alias.

Let's delete `buildPhoto` and replace `photoDecoder = succeed buildPhoto` with this:

```
photoDecoder =
  succeed Photo
  |> required "url" ...
```

Much easier! Finally, let's add this `photoDecoder` definition right below type alias `Photo`.

**WARNING** Reordering any function's arguments can lead to unpleasant surprises. Because reordering the fields in the `Model` type alias has the consequence of reordering the `Model` function's arguments, you should be exactly as careful when reordering a type alias as you would be when reordering any function's arguments!

### 4.3.3 Decoding JSON HTTP responses

You've already seen how we can use `Http.expectString` to obtain a `String` from a server, and how we can use `decodeString` and a `Decoder` to translate a `String` into a list of `Photo` records for our `Model`.

Although we could use `Http.expectString` and `decodeString` to populate our `Model` in this way, another function in the `Http` module will take care of both for us.

#### HTTP.EXPECTJSON

The `Http.expectJson` function requests data from a server and then decodes it. Here's how the types of `Http.expectString` and `Http.expectJson` match up:

```
expectString : (Result Http.Error String -> msg)           -> Expect msg
expectJson  : (Result Http.Error val    -> msg) -> Decoder val -> Expect msg
```

Comparing types like this suggests how these functions are similar and how they differ. They both accept a function to translate a `Result` into a `msg`. Both `Result` types have `Http.Error` as their `Err` type. However, whereas `expectString` takes no other arguments and always produces a `String` for its `Result`'s `Ok` type, `getJSON` additionally accepts a `Decoder` `val`, and on success produces an `Ok` `val` result instead of `Ok` `String`.

As you might expect, if we give `Http.expectJson` a decoder of `(list int)`, and the response it gets back is the JSON payload `"[1, 2, 3]"`, then `Http.get` will successfully decode that into `Ok (List Int)`. If decoding fails, we will instead get `Err BadBody`.

### THE BADBODY ERROR

What's `BadBody`? It's a variant of that `Http.Error` type we said we'd get back to. (Sure enough, here we are getting back to it.) `Http.Error` is a custom type that describes various ways an HTTP request can fail. It looks like this:

```
type Error
  = BadUrl String
  | Timeout
  | NetworkError
  | BadStatus Int
  | BadBody String
```

The `BadBody` variant occurs when the body of the HTTP response failed to decode properly. Because `Error` is a custom type, we can run a case-expression on any `Http.Error` value—with different branches for `Timeout`, `NetworkError`, and so on—to do custom error handling based on what went wrong.

**TIP** The lower-level `Http.request` function lets you customize requests in greater depth than `Http.get` does.

### USING EXPECTJSON IN INITIALCMD

We want to decode the JSON from our server into a `List Photo`, and we have a `Decoder Photo`. This means we can use `Http.expectJson` and `Json.Decode.list` to end up with the information we want.

Let's change `initialCmd` to do just that, while referencing a slightly different URL: instead of `/photos/list`, from now on we'll use `/photos/list.json` instead:

```
initialCmd : Cmd Msg
initialCmd =
  Http.get
    { url = "http://elm-in-action.com/photos/list.json"
    , expect = Http.expectJson GotPhotos (list photoDecoder)
    }
```

This means we'll be sending a `List Photo` to `GotPhotos` instead of a `String`, so we'll need to update its definition to match:

```
type Msg
  = SelectByUrl String
  | GotSelectedIndex Int
  | SurpriseMe
  | SetSize ThumbnailSize
  | GotPhotos (Result Http.Error (List Photo))
```

This lets us simplify the `GotPhotos (Ok ...)` branch of `update`'s case-expression quite a bit! Having direct access to `photos` means we no longer need to build that value up by using a let-expression. We can instead use our new friend *pattern matching* like so:

```
GotPhotos (Ok photos) ->
  case photos of
```

```

first :: rest ->
  ( { model | status = Loaded photos first.url }
  , Cmd.none
  )

[] ->
  ( { model | status = Errorred "0 photos found" }, Cmd.none )

```

**NOTE** The `Http.post` and `Http.jsonBody` functions let you easily send JSON data to servers. In chapter 6, you'll see how the `Json.Encode` module provides a nice way to assemble JSON values—it's much simpler than `Json.Decode`.

### RENDERING THE METADATA

Now all that remains is to have our view render the new caption and download size metadata. We can do this by adding one line to `viewThumbnail`:

```

viewThumbnail selectedUrl thumb =
  img
    [ src (urlPrefix ++ thumb.url)
    , title (thumb.title ++ " [" ++ String.fromInt thumb.size ++ " KB]")
    , classList [ ( "selected", selectedUrl == Just thumb.url ) ]
    , onClick (SelectByUrl thumb.url)
    ]
  []

```

Great! At this point, everything should compile, and we can open `index.html` to see the result, shown in figure 4.6.

Now we're reading our list of photos from the server rather than hardcoding them, and we've given ourselves a nice foundation on which to build an even richer application!

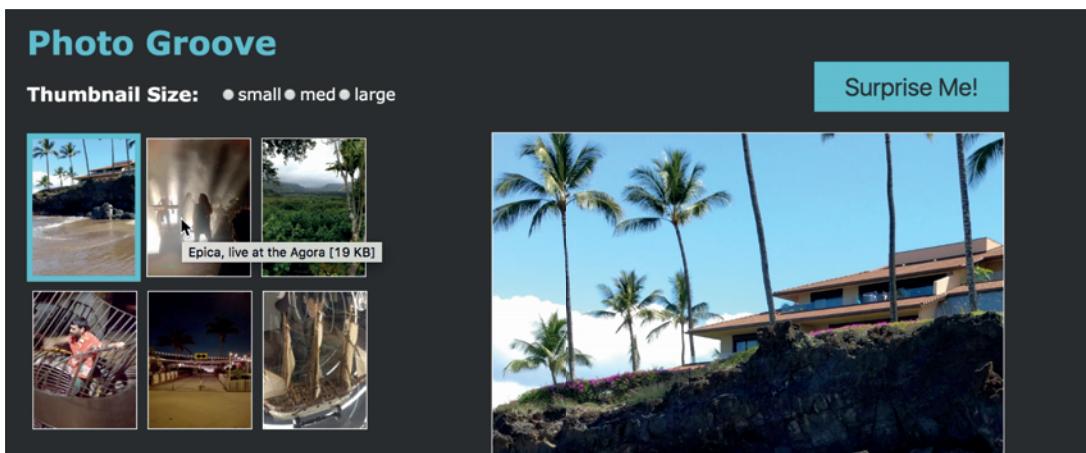


Figure 4.6 The final application

## Summary

You learned quite a few things in the course of making Photo Groove talk to servers:

- A Decoder can validate and translate JSON into an Elm value.
- The `Json.Decode` module provides primitive decoders like `float`, `int`, and `string`.
- The `Json.Decode.list` function turns a `Decoder Bool` into a `Decoder (List Bool)`.
- Pattern matching lets us trade nested case-expressions for longer branch conditions.
- The `<|` operator can replace parentheses. `foo <| bar 5` is the same as `foo (bar 5)`.
- The `Json.Decode.Pipeline` module offers functions to decode objects in pipeline style.
- A `Result` is either `Ok okValue` in case of success, or `Err errValue` in case of failure.
- `String.split` splits a string around a given separator, resulting in a list of strings.
- `Http.get` takes a URL `String` and an `Expect`, and returns a `Cmd` that sends a request.
- `Http.expectString` requests a plain `String` from the server at the given URL.
- `Http.expectJson` works like `expectString`, except it runs a `Decoder` on the result.
- The `init` field passed to `Browser.element` lets us specify a `Cmd` to run on startup.

You also saw how the pipeline operator (`|>`) lets us write expressions by starting with a value and then running a series of transformations on it. Table 4.6 shows an example of this.

**Table 4.6 The same expression with and without pipelines**

Pipeline style	Without pipelines
<pre>model.photos  &gt; Array.fromList  &gt; Array.get index</pre>	<pre>Array.get index (Array.fromList model.photos)</pre>

Now that we've gotten Photo Groove talking to a server, we'll get it talking to JavaScript. This will let us tap into the enormous ecosystem of JavaScript libraries out there. Let's see what that can get us!

**Listing 4.7 The complete PhotoGroove.elm**

```
module PhotoGroove exposing (main)

import Browser
import Html exposing (...)
import Html.Attributes exposing (class, classList, id, name, src, title, type_)
import Html.Events exposing (onClick)
import Http
import Json.Decode exposing (Decoder, bool, int, list, string, succeed)
import Json.Decode.Pipeline exposing (optional, required)
import Random

urlPrefix : String
urlPrefix =
    "http://elm-in-action.com/"

type Msg
    = ClickedPhoto String
    | ClickedSize ThumbnailSize
    | ClickedSurpriseMe
    | GotRandomPhoto Photo
    | GotPhotos (Result Http.Error (List Photo))

view : Model -> Html Msg
view model =
    div [ class "content" ] <| foo (bar baz) == foo <| bar baz
        case model.status of
            Loaded photos selectedUrl ->
                viewLoaded photos selectedUrl model.chosenSize

            Loading ->
                []

            Errorred errorMessage ->
                [ text ("Error: " ++ errorMessage) ]

viewLoaded : List Photo -> String -> ThumbnailSize -> List (Html Msg)
viewLoaded photos selectedUrl chosenSize =
    [ h1 [] [ text "Photo Groove" ]
    , button
        [ onClick ClickedSurpriseMe ]
        [ text "Surprise Me!" ]
    , h3 [] [ text "Thumbnail Size:" ]
    , div [ id "choose-size" ]
        (List.map viewSizeChooser [ Small, Medium, Large ])
```

```
, div [ id "thumbnails", class (sizeToString chosenSize) ]
  (List.map (viewThumbnail selectedUrl) photos)
, img
  [ class "large"
  , src (urlPrefix ++ "large/" ++ selectedUrl)
  ]
  []
]

viewThumbnail : String -> Photo -> Html Msg
viewThumbnail selectedUrl thumb =
  img
    [ src (urlPrefix ++ thumb.url)
    , title (thumb.title ++ " [" ++ String.fromInt thumb.size ++ " KB]")
    , classList [ ( "selected", selectedUrl == thumb.url ) ]
    , onClick (ClickedPhoto thumb.url)
    ]
    []

viewSizeChooser : ThumbnailSize -> Html Msg
viewSizeChooser size =
  label []
  [ input [ type_ "radio", name "size", onClick (ClickedSize size) ] []
  , text (sizeToString size)
  ]

sizeToString : ThumbnailSize -> String
sizeToString size =
  case size of
    Small ->
      "small"

    Medium ->
      "med"

    Large ->
      "large"

type ThumbnailSize
= Small
| Medium
| Large

type alias Photo =
{ url : String
, size : Int
, title : String
}
```

```

photoDecoder : Decoder Photo
photoDecoder =
    succeed Photo
        |> required "url" string
        |> required "size" int
        |> optional "title" string "(untitled)"

The second argument will be the "size" int field.

type Status
= Loading
| Loaded (List Photo) String
| Errored String

type alias Model =
{ status : Status
, chosenSize : ThumbnailSize
}

initialModel : Model
initialModel =
{ status = Loading
, chosenSize = Medium
}

update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
case msg of
    GotRandomPhoto photo ->
        ( { model | status = selectUrl photo.url model.status }, Cmd.none )

    ClickedPhoto url ->
        ( { model | status = selectUrl url model.status }, Cmd.none )

    ClickedSize size ->
        ( { model | chosenSize = size }, Cmd.none )

    ClickedSurpriseMe ->
        case model.status of
            Loaded (firstPhoto :: otherPhotos) _ ->
                Random.uniform firstPhoto otherPhotos
                    |> Random.generate GotRandomPhoto
                    |> Tuple.pair model
Matches only nonempty lists. firstPhoto is a Photo, and otherPhotos is a List Photo.

    Loaded [] _ ->
        ( model, Cmd.none )

    Loading ->
        ( model, Cmd.none )

    Errored errorMessage ->
        ( model, Cmd.none )

```

**Json.Decode.succeed Photo means we'll call the Photo function to create a Photo record when this pipeline completes.**

**The first argument to the Photo function will be the "url" string field on the JSON object.**

**The third argument will be the "title" string field if the JSON object has one; otherwise, "(untitled)".**

**foo (bar baz) == bar baz |> foo.**

**We would get a Missing Patterns error without this branch. The list might be empty!**

```

GotPhotos (Ok photos) ->
    case photos of
        first :: rest ->
            ( { model | status = Loaded photos first.url }
            , Cmd.none
            )

[] ->
    ( { model | status = Errored "0 photos found" }, Cmd.none )

GotPhotos (Err httpError) ->
    ( { model | status = Errored "Server error!" }, Cmd.none )

selectUrl : String -> Status -> Status
selectUrl url status =
    case status of
        Loaded photos _ ->
            Loaded photos url

        Loading ->
            status

        Errored errorMessage ->
            status

initialCmd : Cmd Msg
initialCmd =
    Http.get
        { url = "http://elm-in-action.com/photos/list.json"
        , expect = Http.expectJson GotPhotos (list photoDecoder)
        }

main : Program () Model Msg
main =
    Browser.element
        { init = \flags -> ( initialModel, initialCmd )
        , view = view
        , update = update
        , subscriptions = \_ -> Sub.none
        }

```

This Msg is a GotPhotos variant, and  
the Result it holds is an Ok variant.

Json.Decode.list turns  
photoDecoder : Decoder Photo  
into a Decoder (List Photo).

# 5

# Talking to JavaScript

## This chapter covers

- Rendering custom elements
- Sending data to JavaScript
- Receiving data from JavaScript
- Initializing our Elm application by using data from JavaScript

Now we've gotten Photo Groove loading photos from a server. It's looking better and better! However, our manager has a concern: "We have the photos, and they certainly look sharp. But where is the *groove*? This is Photo Groove, not Photo Browse! You know what we need? *Filters*. You know, the kind that make normal photos look all wacky and messed up? Those!"

Sounds groovy.

We collaborate with our team's visual designer to create a mockup of the filtering feature. The final design calls for a display to report on the current activity of the filtering process, and sliders to control the filters' settings. And not just any sliders! Our designer wants these to match the look and feel of some sliders we're using on a different product.

As luck would have it, we won't have to code either the filter effects or the sliders from scratch. They're both available as open source libraries, but there's a catch: these libraries are written in JavaScript, not Elm.

Fortunately, Elm applications are not limited to using only Elm libraries! In this chapter, we'll expand Photo Groove to include a filtering feature. We'll add sliders that let users apply filters in varying degrees to the large photo. We'll create an activity display that shows information from the JavaScript libraries. Along the way, you'll learn two ways to incorporate JavaScript code into an Elm application: *custom elements* and *ports*. Here we go!

## 5.1 Using custom elements

We'll start with the sliders. We want to create three sliders in total: Hue, Ripple, and Noise. Adjusting each value will transform how the large photo appears to the end user. Figure 5.1 shows how the sliders fit into what we'll be building over the course of this chapter.

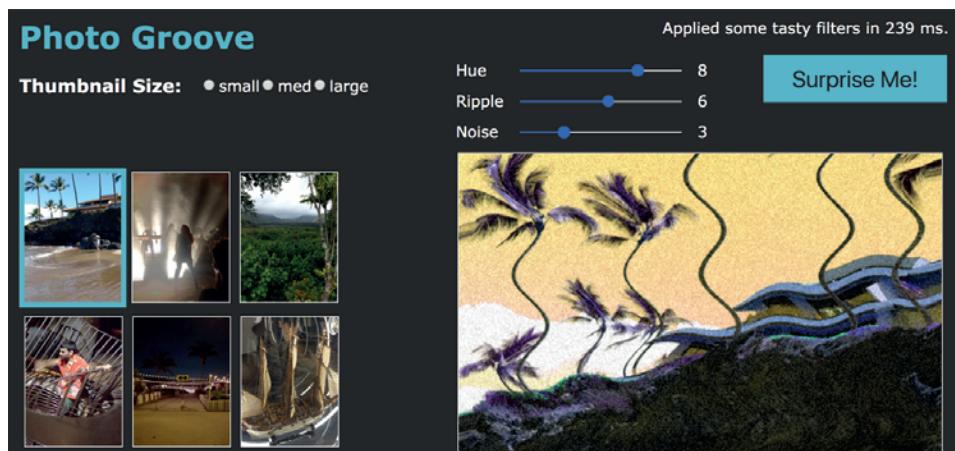


Figure 5.1 Adding sliders that control filtering for the large photo

Each slider controls an integer value that the filtering library will use for the magnitude of the filter effect. Sliding all three to 0 would disable filtering—leaving the photos unaltered, as they look now—whereas setting all three to the maximum value of 11 would apply each filter at full power.

Implementing the sliders by using custom elements will involve three steps:

- 1 Running some JavaScript code before our Elm code executes, to register custom behavior for all `<range-slider>` elements on the page
- 2 Writing Elm code to render these `<range-slider>` elements, using plain `Html` values
- 3 Writing custom event handlers to update our model based on the sliders' states

Along the way, you'll learn a new use for the JSON decoders we saw in chapter 4, and compare two alternative ways of integrating the sliders into our data model.

### 5.1.1 Importing custom elements

To use the third-party JavaScript slider in Elm, we'll first wrap it in a custom element. The slider we'll be importing is written in plain JavaScript with no dependencies, but this Custom Elements Wrapper technique also works with React.js components, jQuery widgets, and just about everything in between!

#### CUSTOM ELEMENTS

*Custom elements* are a part of the Web Components specification. Here's how they work:

- We write some JavaScript to define a new DOM element type. In this case, the new element will be called a `<range-slider>`. (Custom elements must have a dash in their names.)
- We run that JavaScript code when our page loads, to register this custom element with the browser.
- From now on, whenever any code—in JavaScript or in Elm—creates a DOM element whose tag name is "`range-slider`", that element will behave according to this custom logic.

**WARNING** Custom elements are implemented in JavaScript, so they may throw runtime exceptions!

#### REGISTERING CUSTOM ELEMENTS

We'll start by making a custom element that renders a plain old text `<input>` to the page. Then we'll go back and upgrade it to be a proper slider.

Let's start by adding this code right above `</head>` in `index.html`.

#### Listing 5.1 Registering the custom element

```

<script>
    class RangeSlider extends HTMLElement {
        connectedCallback() {
            var input = document.createElement("input");
            this.appendChild(input);
        }
    }
    window.customElements.define("range-slider", RangeSlider);
</script>
</head>

```

Here we're using the `class` keyword that was added to JavaScript in ECMAScript 2015. If you're unfamiliar with `class`, not to worry; in this chapter, all you need to

know about it is that `connectedCallback` declares a new method on the class, and we'll be working inside that method declaration to wire up our `RangeSlider`.

**TIP** Certain older browsers don't support `class`, or for that matter custom elements. Fortunately, the custom elements polyfill offers a solution if you need to support the browsers in question. Visit <https://github.com/web-components/custom-elements> to learn more about it.

Finally, we come to this line:

```
window.customElements.define("range-slider", RangeSlider);
```

This registers the `<range-slider>` on the page. From now on, whenever a DOM element with the tag name "range-slider" appears on this page, it will behave according to the implementation we've imported here.

#### ADDING A <RANGE-SLIDER> TO THE PAGE

Back at the beginning of chapter 2, we saw the `node` function from the `Html` module. It takes three arguments:

- Tag name
- List of attributes
- List of children

Here are two ways to create the same button, one using `node` and the other using `button`:

```
node "button" [ class "large" ] [ text "Send" ]
button [ class "large" ] [ text "Send" ]
```

Functions that create elements like `button`, `label`, and `input` have tiny implementations—they do nothing more than call `node`. For example, `label` and `input` can be implemented like so:

```
label attributes children =
  node "label" attributes children

input attributes children =
  node "input" attributes children
```

**TIP** Because of partial application, we could also have written these as `label = node "label"` and `input = node "input"`. However, it's considered good practice to name all your arguments when defining a named function at the top level like this.

Now that the `<range-slider>` custom element has been registered on the page with our call to `window.customElements.define("range-slider", RangeSlider)`, the only Elm code necessary to use it is to call `node "range-slider"`. Let's add a function that does this, at the end of `PhotoGroove.elm`:

```
rangeSlider attributes children =
  node "range-slider" attributes children
```

This `rangeSlider` function will work the same way as functions like `button`, `div`, and so on. It also has the same type as they do:

```
rangeSlider : List (Attribute msg) -> List (Html msg) -> Html msg
```

Add this type annotation right above that `rangeSlider` implementation.

### VIEWING THE SLIDERS

Next, let's invoke `rangeSlider` to render the sliders. They won't actually work like sliders yet, but we'll make them work properly afterward. For now, add the following code beneath the `view` function.

#### Listing 5.2 `viewFilter`

```
viewFilter : String -> Int -> Html Msg
viewFilter name magnitude =
    div [ class "filter-slider" ]
        [ label [] [ text name ] ]           | Displays the filter's name
        , rangeSlider                      | <range-slider> that goes from 0 to 11
            [ max "11"                   |
            , Html.Attributes.property "val" (Json.Encode.int magnitude) <-
            ]
            []
        , label [] [ text (String.fromInt magnitude) ]   | Sets the slider's "val" to the current magnitude
    ]                                         | Displays the current magnitude
```

That `Json.Encode` module is a new one! Let's add it right above `import Random`, like so:

```
import Json.Encode
import Random
```

### HTML.ATTRIBUTES.PROPERTY

Here we're using `Json.Encode.int` not to encode JSON, as the name might suggest, but rather to encode a JavaScript Value for the `Html.Attributes.property` function:

```
Html.Attributes.property "val" (Json.Encode.int magnitude)
```

This will set a JavaScript *property* on this `<range-slider>` node, so that our custom element can read it later. The property will be named `val`, and it will be set to our `magnitude` value.

The `Json.Encode.int` function specifies what the property's type will be on the JavaScript side. If we had used `(Json.Encode.string (String.fromInt magnitude))` instead, the property would have been set to a JavaScript string instead of a number.

## AMBIGUOUS NAME

If we try to build this code, we'll get a compile error. `max` is ambiguous. It's being exposed by both of these modules:

- `Basics`
- `Html.Attributes`

We're seeing this error because Elm has a built-in math function called `max`. It's in the `Basics` module, and every Elm file has an implicit `import Basics exposing(..)` so that we can use common functions like `negate`, `not`, and `max` without having to qualify them as `Basics.negate`, `Basics.not`, or `Basics.max`.

## RESOLVING AMBIGUOUS NAMES

The compiler is reporting an ambiguity in our code: when we wrote `max`, we might have meant either `Basics.max` or `Html.Attributes.max`, since both `max` functions are exposed in this file. Let's clarify which we meant by fully qualifying `max`:

```
Html.Attributes.max "11"
```

This resolves the compiler error, but `Html.Attributes.max` is pretty verbose. We can shorten it by giving `Html.Attributes` an alias of `Attr`, using the `as` keyword:

```
import Html.Attributes as Attr exposing (class, classList, id, name, src, title, type_)
```

While we're at it, let's give `Json.Encode` the same treatment:

```
import Json.Encode as Encode
```

Now anywhere we would write `Html.Attributes.foo`, we can write `Attr.foo` instead. Similarly, anywhere we would write `Json.Encode.int`, we can now write `Encode.int` instead.

Let's refactor our `rangeSlider` to look like this:

```
, rangeSlider
  [ Attr.max "11"
  , Attr.property "val" (Encode.int magnitude)
  ]
```

Splendid! This should make everything compile neatly.

## RENDERING THREE SLIDERS

Now we can call `viewFilter` in our `viewLoaded` function to get a few sliders rendering. Let's do that right below the code for the Surprise Me! button:

```
viewLoaded photos selectedUrl chosenSize =
  [ h1 [] [ text "Photo Groove" ]
  , button
    [ onClick ClickedSurpriseMe ]
    [ text "Surprise Me!" ]
  , div [ class "filters" ]
    [ viewFilter "Hue" 0
    , viewFilter "Ripple" 0
    , viewFilter "Noise" 0
    ]]
```



Figure 5.2 Adding rangeSliders for Hue, Ripple, and Noise

Figure 5.2 shows how this looks on the page.

#### THE CUSTOM ELEMENT RENDERING PROCESS

Notice that although we rendered three `<range-slider>` elements to the DOM, the browser displays an `<input>` for each of them. Let's recap why that is:

- 1 We defined class `RangeSlider` extends `HTMLElement` in JavaScript.
- 2 We gave it a `connectedCallback` method that creates a new `<input>` node and calls `this.appendChild` on it. This method will be called whenever a `<range-slider>` is added to the DOM.
- 3 We called `window.customElements.define("range-slider", RangeSlider)`, which told the browser to use our `RangeSlider` class as the implementation for all `<range-slider>` nodes on the page.
- 4 In Elm we called node `"rangeSlider"` to add `<range-slider>` nodes to the page.
- 5 When the browser added those `<range-slider>` elements to the DOM, it ran their `connectedCallback` methods from the `RangeSlider` class, which appended the `<input>` nodes we requested as their children.

Now we can replace that `createElement("input")` inside `connectedCallback` with some code to instantiate our third-party custom slider instead of an `<input>`, and we'll be all set!

#### REPLACING `<INPUT>` WITH THE CUSTOM SLIDER

To use the third-party slider, we'll first need to import the code for it. Let's import its stylesheet and JavaScript code inside the `<head>` of our `index.html` file, right below our existing `<link rel="stylesheet">` declaration:

```
<link rel="stylesheet" href="http://elm-in-action.com/styles.css">
<link rel="stylesheet" href="http://elm-in-action.com/range-slider.css">
<script src="http://elm-in-action.com/range-slider.js"></script>
```

These tags load both the JavaScript code and CSS styles necessary to render a range slider element. The particular slider library we will be using is the MIT-licensed *JS Range (JSR)*, by Mateusz Koteja. You can find the source code at [github.com/mm-jsr/jsr](https://github.com/mm-jsr/jsr).

The way JS Range creates a slider is by creating a new `JSR` object and passing it an `<input>` node. We'll use this on the `input` node we conveniently already created in our `connectedCallback` method.

**Listing 5.3 Using JSR to turn the <input> into a slider**

```

connectedCallback() {
  var input = document.createElement("input");
  this.appendChild(input);
  var jsr = new JSR(input, {
    max: this.max,
    values: [this.val],
    sliders: 1,
    grid: false
  });
}

```

Creates a new JSR using the <input> we created

Uses the Attr.max value we set in Elm

Tweaks some other JSR knobs—these aren't important

Uses the Attr.property "val" we set in Elm

Here we've passed JSR the <input> it requires as its first argument, as well as a configuration object. We've configured its max to be `this.max`, and its values to be `this.val`. These correspond to the `Attr.max` and `Attr.property "val"` calls we made in Elm:

```

rangeSlider
  [ Attr.max "11"
  , Attr.property "val" (Encode.int magnitude)
  ]

```

**TIP** Naming this property `val` instead of `value` is no accident. Elm applies special handling to the `value` property, so it's best not to choose that particular name for custom properties.

This is our first example of sending a value from Elm to JavaScript. The `Attr.max` *property* that we set on the Elm side appeared as `this.max` on the JavaScript side, within the custom element's `connectedCallback` method.

**NOTE** The browser treats DOM element *attributes* and *properties* differently. Both properties and attributes have the type `Attribute` in Elm—so that the `node` function can accept a `List` of any combination of them—which means the only way to tell them apart is to read their documentation or source code. This distinction is relevant in custom elements because, although DOM element *properties* like `Attr.max` and `Attr.property` are accessible using `this` within any custom element method, DOM element *attributes* are not.

Let's open up our browser to see our custom elements in all their glory! Figure 5.3 shows how the page should look.

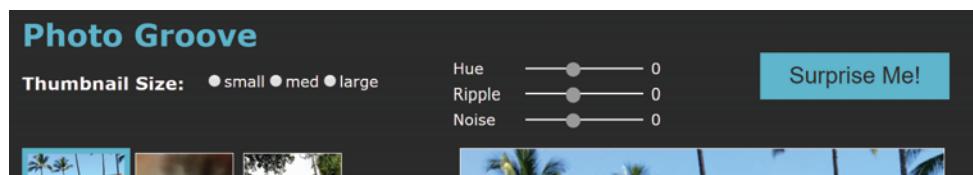


Figure 5.3 Using JSR to instantiate the sliders

**TIP** Custom elements can wrap pretty much any JavaScript library that uses the DOM. For example, you could replace `this.appendChild(input)` with `ReactDOM.render(this)` inside `connectedCallback`.

Those sliders look slick, but they aren't completely operational yet. We want the numbers next to the sliders to change as the user slides their values around. Let's make that happen!

### 5.1.2 Handling custom events

If we take a quick glance at JS Range's documentation, we can see that the slider emits a custom event, called "update", from its `range` object as the user slides. This event reports the slider's current value, so we'd like to listen for it and update our Model with that value.

Our Elm code can't listen to events emitted by the JSR `range` object itself, but it can listen to events from the `<range-slider>` custom element. We can add a quick bit of JavaScript code to listen for the `range` object's `update` event and broadcast its value from the `<range-slider>` so we can hear it over in Elm Land. Let's add this to the end of our `connectedCallback()` method.

#### Listing 5.4 Broadcasting a ChangeEvent

```
connectedCallback() {
    ...
    var rangeSliderNode = this; ← Stores a reference
                                to "this" for later
    jsr.addEventListener("update", function(elem, value) { ← Listens for "update"
        var event = new CustomEvent("slide", { ← Creates a new
            detail: {userSlidTo: value} ← "slide" event
        });
        rangeSliderNode.dispatchEvent(event); ← Stores the value
    }); ← inside that event
}
```

Dispatches the event  
from the <range-slider>

Now whenever the user drags the slider around, our `<range-slider>` element will emit a "slide" event containing the new value they've chosen.

**TIP** Internet Explorer has a slightly different API for creating `CustomEvent` values. That API has been deprecated, and modern browsers may drop support for it, but if you need to support IE, here's what to do: `var event = document.createEvent("CustomEvent"); event.initCustomEvent("slide", true, true, {detail: userSlidTo: value})`.

#### LISTENING FOR CUSTOM EVENTS

Now that we're dispatching this "slide" event, how might we respond to it on the Elm side? `Html.Events` has a variety of built-in event handler functions such as

`onClick`, but there's no `onSlide`. The `Html.Attributes` module has no idea it exists. So how can we specify a handler for it?

### HTML.EVENTS.ON

The `Html.Events.on` function lets us create a custom event handler, just as the `Html.node` function lets us create a custom element and the `Html.Attributes.property` function lets us create a custom property. The `on` function has this type:

```
on : String -> Decoder msg -> Attribute msg
```

The `String` is the name of the event, which in this case is `"slide"`. The `Decoder` argument is a `Json.Decode.Decoder`, the same type of decoder we built in chapter 4 for our HTTP responses. Here we won't be using the `Decoder` on a JSON string coming back from a server, but rather on a JavaScript event object.

### DECODING THE SLIDE EVENT

The `CustomEvent` object JavaScript will dispatch for `"slide"` is shaped something like this:

```
{detail: {userSlidTo: 7}}
```

The `detail` field is what `CustomEvent` objects use to hold their custom information, which in our case holds a single field we decided to name `userSlidTo` in listing 5.4. We can use the `Json.Decode.field` and `Json.Decode.int` functions to write a decoder for this like so:

```
field "detail" (field "userSlidTo" int)
```

Table 5.1 compares this decoder to the example `email` decoder we wrote in chapter 4.

Table 5.1 Decoding objects with field decoders

Decoder	JSON	Result
field "email" string	5	Err "Expected object, got 5"
	{"email": 5}	Err "Expected string for 'email', got 5"
	{"email": "cate@nolf.com"}	Ok "cate@nolf.com"
Decoder	JavaScript	Result
field "detail" (field "userSlidTo" int)	9	Err "Expected object, got 9"
	{"detail": 9}	Err "Expected object for detail, got 9"
	{"detail": {"userSlidTo": 9}}	Ok 9

### JSON.DECODE.AT

There's a convenience function in `Json.Decode` for the case where we want to call `field` on another field like this: `Json.Decode.at`. It takes a list of field strings and traverses them in order. These two decoders do the same thing:

```
field "detail" (field "userSlidTo" int)

at [ "detail", "userSlidTo" ] int
```

### DECODING A MSG

This `Decoder Int` will decode an integer from a JavaScript object such as `{detail: {userSlidTo: 7}}`. But is that what we want? Let's look at the type of `on` again:

```
on : String -> Decoder msg -> Attribute msg
```

Notice that it wants a `Decoder msg` and then returns an `Attribute msg`. That tells us we want it to decode not an integer, but a message. Ah! We have a message type named `Msg`. So how do we convert between the `Decoder Int` that we have and the `Decoder Msg` that `on` expects?

### USING JSON.DECODE.MAP

The `Json.Decode.map` function is just what the doctor ordered! It converts between decoded values, as shown in table 5.2.

**Table 5.2** `Json.Decode.map`

Expression	Description
<code>Json.Decode.map negate float</code>	Decodes a float, then negates it.
<code>Json.Decode.map (\num -&gt; num * 2) int</code>	Decodes an integer, then doubles it.
<code>Json.Decode.map (\_ -&gt; "[[redacted]]") string</code>	Decodes a string, then replaces it with "[[redacted]]" no matter what it was originally. Note that this will still fail if it attempts to decode a nonstring value.

Because `Json.Decode.map` takes a function that converts one decoded value to another, we can use it to convert our decoded `Int` into a `Msg`.

### UPDATING IMPORTS

We'll need to expose the `on` and `at` functions in our imports in order to reference them:

```
import Html.Events exposing (on, onClick)
import Json.Decode exposing (Decoder, at, string, int, list, succeed)
```

Then we'll be ready to add this `onSlide` function to the end of `PhotoGroove.elm`.

### Listing 5.5 `onSlide`

```
onSlide : (Int -> msg) -> Attribute msg
onSlide toMsg =
    let
        detailUserSlidTo : Decoder Int
        detailUserSlidTo =
            at [ "detail", "userSlidTo" ] int
            Decodes the integer located
            at event.detail.userSlidTo

        msgDecoder : Decoder msg
        msgDecoder =
            Json.Decode.map toMsg detailUserSlidTo
            Converts that integer to
            a message using toMsg

    in
    on "slide" msgDecoder
        ↪ Creates a custom event
        ↪ handler using that decoder
```

Notice how `onSlide` takes a `toMsg` function? This is because we need it to be flexible. We plan to have multiple sliders on the page, and we'll want each of them to have a unique `Msg` variant so that we can tell their messages apart. The `toMsg` argument lets us pass in the appropriate variant on a case-by-case basis, which will come in handy later.

#### REFACTORING TO USE PIPELINES

Notice how we assemble this value in three steps (`detailUserSlidTo`, `msgDecoder`, and `on`), and each step's final argument is the previous step's return value? That means we can rewrite this to use the pipeline style you learned in chapter 4! Let's do that refactor:

```
onSlide : (Int -> msg) -> Attribute msg
onSlide toMsg =
    at [ "detail", "userSlidTo" ] int
    |> Json.Decode.map toMsg
    |> on "slide"
```

Try walking through each step in the pipeline and finding the equivalent code in listing 5.5. All the same logic is still there, just reorganized.

#### ADDING EVENT HANDLING TO `viewFilter`

Now that we have `onSlide`, we can use it in our `viewFilter` function. Remember how we made `onSlide` accept an `Int -> msg` function, so that we could pass it a different `Msg` variant on a case-by-case basis? We'll want `viewFilter` to have that same flexibility. The only difference will be that because `viewFilter` returns an `Html Msg`, we won't be using a type variable like `msg`; instead, `viewFilter` will accept an `Int -> Msg` function.

### Listing 5.6 Using `onImmediateValueChange` in `viewFilter`

```
viewFilter : (Int -> Msg) -> String -> Int -> Html Msg
viewFilter toMsg name magnitude =
    div [ class "filter-slider" ]
```

```

[ label [] [ text name ]
, rangeSlider
  [ Attr.max "11"
  , Attr.property "val" (Encode.int magnitude)
  , onSlide toMsg
  ]
[]
, label [] [ text (String.fromInt magnitude) ]
]

```

Calling onSlide just as we did onClick

With this shiny new `viewFilter` implementation completed, our display logic is ready to be connected to our model and update. Once we've revised those to work with `viewFilter`, our shiny new custom elements will be fully integrated into our application!

### 5.1.3 Responding to slider changes

We have three filters, each of which has a name and a magnitude. How should we track their current values in our model? Let's walk through two approaches, comparing the pros and cons of each, and then at the end decide which to use.

The first approach would be to add three fields to the model: one for Hue, one for Ripple, and one for Noise. The alternative would prioritize flexibility, and store the filters as a list of `{ name : String, amount : Int }` records. Table 5.3 shows these approaches side by side.

**Table 5.3 Storing filter data as three Ints versus one list of records**

Three-integers approach	One-list-of-records approach
<pre> type alias Model = { status : Status , chosenSize : ThumbnailSize , hue : Int , ripple : Int , noise : Int }  initialModel : Model initialModel = { status = Loading , chosenSize = Medium , hue = 5 , ripple = 5 , noise = 5 } </pre>	<pre> type alias Model = { status : Status , chosenSize : ThumbnailSize , filters : List { name : String, amount : Int } }  initialModel : Model initialModel = { status = Loading , chosenSize = Medium , filters = [ { name = "Hue", amount = 5 } , { name = "Ripple", amount = 5 } , { name = "Noise", amount = 5 } ] } </pre>

Each model design has its own strengths and weaknesses, which become clearer when we write code that references this part of the model.

Let's consider how our update implementations might compare. In either approach, we'd expand our `Msg` type's variants and then add at least one branch to

our update function's case-expression. Table 5.4 compares how these revisions would look for each approach.

Table 5.4 Updating the model

Three-integers approach	One-list-of-records approach
<pre> type Msg = ClickedPhoto String ...   SlidHue Int   SlidRipple Int   SlidNoise Int  case msg of ... SlidHue hue -&gt; ( { model   hue = hue } , Cmd.none )  SlidRipple ripple -&gt; ( { model   ripple = ripple } , Cmd.none )  SlidNoise noise -&gt; ( { model   noise = noise } , Cmd.none ) </pre>	<pre> type Msg = ClickedPhoto String ...   SlidFilter String Int  case msg of ... SlidFilter name amount -&gt; let   transform filter =     if filter.name == name then       { name = name       , amount = amount       }     else       filter   filters =     model.filters      &gt; List.map transform   in   ( { model   filters = filters }   , Cmd.none   ) </pre>

The list-of-records approach is more flexible. If we decided to add a fourth filter, such as Blur, we could add it to `initialModel`, and boom! It would appear on the page instantly. With the three-integers approach, adding a fourth integer would require not only expanding `initialModel`, but also adding a field to our type alias for `Model`, a variant for our `Msg`, and a branch for `update`'s case-expression. That sure sounds like more work!

Finally, let's compare how rendering would look in table 5.5.

Table 5.5 Viewing filter data from three fields versus one

Three-integers approach	List-of-records approach (assuming <code>viewFilter</code> tweaked)
<pre> , div [ class "filters" ] [ viewFilter SlidHue "Hue" model.hue , viewFilter SlidRipple "Ripple" model.ripple , viewFilter SlidNoise "Noise" model.noise ] </pre>	<pre> , div [ class "filters" ] (List.map viewFilter model.filters) </pre>

In either case, we'd need to change `viewLoaded`'s arguments—either giving it access to `Model` or to a `{ name : String, amount : Int }` record. But after doing that, we could save ourselves a few lines of code with the list-of-records approach, using `List.map` as shown in table 5.5. Once again, a list of records comes out ahead!

### CHOOSING AN APPROACH

So far, we've compared these approaches by conciseness, as well as by the amount of effort it would take to add more filters later. However, our analysis is overlooking a crucial consideration, one that tends to make a much bigger difference in Elm than in JavaScript: *which approach rules out more bugs?*

As we've seen, Elm's compiler gives us certain guarantees that can rule out entire categories of bugs. Some code can better leverage these guarantees than others. We can "help the compiler help us" by taking the compiler into consideration when making decisions like these. What potential future headaches would each approach let the compiler rule out?

### CONSIDERING POTENTIAL BUGS

Suppose we go with the list-of-records approach, and one of our coworkers makes an innocuous typo—writing "`Rippl`" instead of "`Ripple`"—such that a `SlidFilter "Rippl" 5` message comes through our `update` function. That code will compile, but it won't work properly because our `filter.name == "Rippl"` condition will never pass. We'll have to hope our coworker catches this bug in testing.

What if our coworker makes the same typo in the three-integers approach? Attempting to create a `SlidRippl 5` message will be a compiler error, because we named our `Msg` variant `SlidRipple`, not `SlidRippl`; see table 5.6.

**Table 5.6 Making a mistake**

	Three-integers approach	List-of-records approach
Message	<code>SlidRippl 5</code>	<code>SlidFilter "Rippl" 5</code>
Outcome	Elm's compiler tells us we have a naming error.	This compiles, but now we have a bug.

### CONSIDERING FUTURE CHANGES

What about making changes? Suppose in the future we need to rename "`Ripple`" to "`Swirl`".

In the three-integers approach, we can rename our `Msg` variant from `SlidRipple` to `SlidSwirl`, and our `Model` field from `ripple` to `swirl`—and then watch Elm's compiler tell us exactly what other parts of our code base need changing as a result. If we miss anything, we'll get a helpful type mismatch error telling us every spot we overlooked.

With the list-of-records approach, we have to hope none of our coworkers ever wrote code using the hardcoded magic string "`Ripple`" instead of a constant. If they did, and something breaks, the only way we'll find out before the bug reaches

production is if someone also wrote a test that happens to fail when we change "Ripple" to "Swirl".

### CHOOSING RELIABILITY

By using individual fields instead of a list of records, we can rule out the entire category of bugs related to invalid filter names.

Increasing conciseness and saving potential future effort are nice, but preventing bugs in a growing code base tends to be more valuable over time. Verbosity has a predictable impact on a project, whereas the impact of bugs can range from "quick fix" to "apocalyptic progress torpedo." Ruling those out is more valuable than a bit of conciseness!

We'll go with the approach that prevents more bugs. Take a moment to look back at tables 5.3, 5.4, and 5.5, and implement the changes in the first column. Then let's revise our `viewLoaded` function to accept `Model` as its final argument instead of `ChosenSize`, and to use `Model`'s new fields:

```
viewLoaded : List Photo -> String -> Model -> List (Html Msg)
viewLoaded photos selectedUrl model =
  ...
  , div [ class "filters" ]
    [ viewFilter SlidHue "Hue" model.hue
      , viewFilter SlidRipple "Ripple" model.ripple
      , viewFilter SlidNoise "Noise" model.noise
    ]
  ...
  , div [ id "thumbnails", class (sizeToString model.chosenSize) ]
```

Last, but not least, we'll need to change `view` to pass `model` instead of `model.chosenSize` as the final argument to `viewLoaded`:

```
Loaded photos selectedUrl ->
  viewLoaded photos selectedUrl model
```

**TIP** It's generally a good idea to keep our types as narrow as possible, so we'd like to avoid passing `viewLoaded` the entire `Model` if we can. However, that's not a refactor we need to do right now.

When the dust settles, you should be able to recompile with `elm make --output=app.js PhotoGroove.elm` and see the number labels change when the user slides, as shown in figure 5.4.

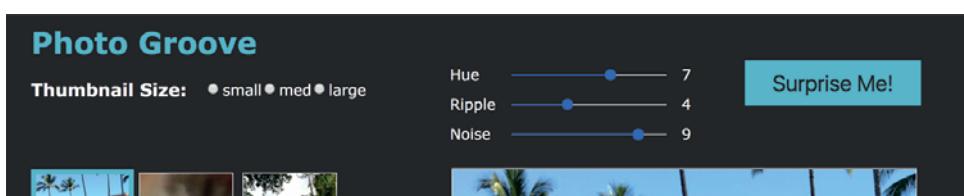


Figure 5.4 Sliding now changes the numbers next to the sliders.

Now that we have our sliders set up, we can move on to introducing the filters themselves!

## 5.2 Sending data to JavaScript

Now our model has all the data it needs to calibrate the filters. We'll use some JavaScript once again to apply the filters, although this time not custom elements. Instead, we'll write code that passes configuration options and a `<canvas>` element to a JavaScript function, which will then proceed to draw groovy pictures on it.

First we'll get a basic proof-of-concept working, to confirm that we're successfully communicating across languages, and then we'll smooth out the implementation details until we're satisfied with how things are working.

### 5.2.1 Creating a command by using a port

You may recall from chapter 4 that an *effect* is an operation that modifies external state. You may also recall that if a function modifies external state when it runs, that function has a *side effect*. Elm functions are not permitted to have side effects, but JavaScript functions are.

#### TALKING TO JAVASCRIPT IS LIKE TALKING TO SERVERS

Because calling any JavaScript function may result in a side effect, Elm functions cannot call JavaScript functions anytime they please; this would destroy the guarantee that Elm functions have no side effects.

Instead, Elm talks to JavaScript the same way it talks to servers: by sending data out through a command, and receiving data in through a message. Figure 5.5 illustrates this.

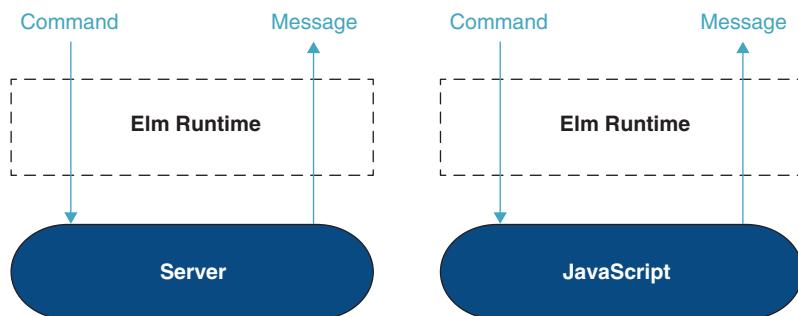


Figure 5.5 Using commands and messages to talk to both servers and JavaScript

This means that talking to JavaScript will have some characteristics in common with what we saw when talking to servers in chapter 4:

- Data can be sent only by using a command.
- Data can be received only by `update`, and that data must be wrapped in a message.
- We can translate and validate this incoming data by using decoders.

**NOTE** In JavaScript, some effects are performed synchronously, with program execution halting until the effect completes. In contrast, an Elm `Cmd` always represents an *asynchronous* effect. This means that when we send data to JavaScript, it's always possible that other JavaScript code might run before data gets sent back to Elm.

### CREATING A COMMAND

Let's create a `Cmd` to send some data to JavaScript. First we'll define a `type alias` for the data we're going to send, right above our `type alias` for `Photo`:

```
type alias FilterOptions =
    { url : String
    , filters : List { name : String, amount : Int }
    }
```

This represents all the information our JavaScript library will need in order to apply the filters: the URL of the photo in question, plus the list of filters and their amounts.

### PORT MODULES

In chapter 4, we created a `Cmd` using the `Http.send` function, but here we'll instead use a language feature designed specifically for talking to JavaScript: the `port` keyword. Any module that uses the `port` keyword must be declared using the `port module` keyword, which means we'll need to change the first line of `PhotoGroove.elm` to this:

```
port module PhotoGroove exposing (...)
```

**TIP** If you're ever wondering whether a given module talks directly to arbitrary JavaScript code, checking to see if it's a `port` module is generally the quickest way.

### USING A PORT TO DEFINE A FUNCTION

Now that we're working with a `port` module, we can use the `port` keyword right above the `type alias` for `FilterOptions` like so:

```
port setFilters : FilterOptions -> Cmd msg
```

This declares a function called `setFilters`. Its type is `(FilterOptions -> Cmd msg)`. We don't write an implementation for this function, because the `port` keyword automatically writes one for us. `port` only needs to look at the type we requested to decide what the function should do.

All `port` functions that send data to JavaScript are defined using a very specific pattern:

- The `port` keyword must be followed by a function name and a type annotation.
- The type annotation must be for a function that takes one argument.
- The function must return `Cmd msg`, and nothing else—not even `Cmd Msg`!

### PORT COMMANDS NEVER SEND MESSAGES

Our new `setFilters` function returns `Cmd msg`, not `Cmd Msg`—but what’s the difference? We know from chapter 3 that the lowercase *m* means `msg` is a *type variable*, like the `val` type variable we saw in `Array.fromList`:

```
fromList : List val -> Array val
```

This `List String -> Cmd msg` function is the first time you’ve seen a function annotation with a type variable in its return type, but no type variable in its parameters. As it turns out, though, we’ve been using a `Cmd msg` for quite some time now! The official documentation for `Cmd.none` shows that it has this type:

```
none : Cmd msg
```

A `Cmd msg` by itself like this is a *command that produces no message after it completes*.

**NOTE** A command that produces no messages has the type `Cmd msg`, a subscription (for example, `Sub.none`) that produces no messages has the type `Sub msg`, and a list that has no elements—that is, `[]`—has the similar type `List val`. Because their type variables have no restriction, you can use a `Cmd msg` anywhere you need any flavor of `Cmd`, just as you can use an empty list anywhere you need any flavor of `List`. Playing around with empty lists in `elm repl` can be a helpful way to see how types like these interact with other types.

Both `Cmd.none` and `setFilters` produce no message after completing. The difference is that `Cmd.none` has no effect, whereas `setFilters` will perform the effect of sending data to JavaScript. (Specifically, it will send the `FilterOptions` value we pass it.) You can think of `setFilters` as a “fire and forget” command. Table 5.7 compares `Cmd Msg` and `Cmd msg` in different expressions.

Table 5.7 Comparing `Cmd Msg` and `Cmd msg`

Expression	Type	Effect	Message sent back to update
<code>list photoDecoder  &gt; Http.get "http://..."  &gt; Http.send GotPhotos</code>	<code>Cmd Msg</code>	Sends HTTP request	GotPhotos
<code>Cmd.none</code>	<code>Cmd msg</code>	(None)	(No message sent back)
<code>setFilters filterOptions</code>	<code>Cmd msg</code>	Sends <code>filterOptions</code> to JavaScript	(No message sent back)

**NOTE** Although HTTP requests can fail, sending data to JavaScript cannot. We don’t miss out on any error-handling opportunities just because `setFilters` sends no message back to update.

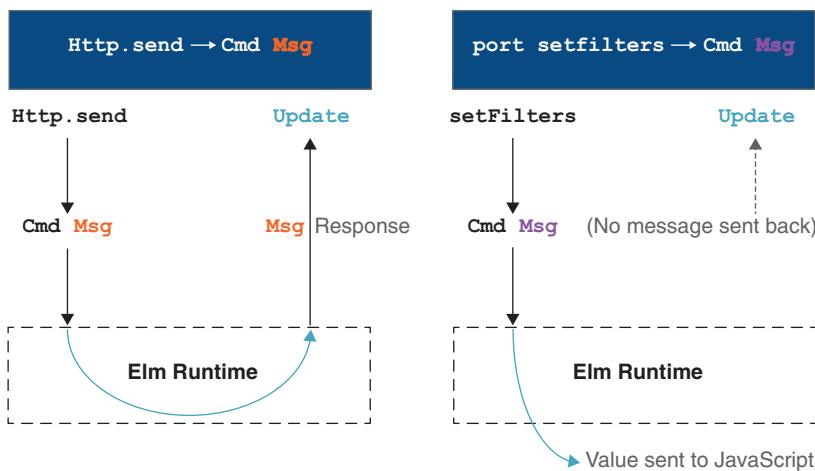


Figure 5.6 Comparing a `Cmd` from `Http.send` to a `Cmd` from a port

Figure 5.6 shows the similarities and differences between a `Cmd` originating from an `Http.send`, and a `Cmd` originating from a port.

#### CALLING SETFILTERS WHEN USERS SELECT PHOTOS

Now that we have our port set up, we need to call `setFilters` in order to send some data to JavaScript. We'll want to apply the filters every time the user selects a photo, so that's when we'll want `update` to return the command we get from `setFilters`. Here's one way we could modify the `ClickedPhoto` branch of `update` to do this.

#### Listing 5.7 ClickedPhoto

```
ClickedPhoto selectedUrl ->
    let
        filters =
            [ { name = "Hue", amount = model.hue }
            , { name = "Ripple", amount = model.ripple }
            , { name = "Noise", amount = model.noise }
            ]
        url =
            urlPrefix ++ "large/" ++ selectedUrl
        cmd =
            setFilters { url = url, filters = filters }
    in
        ( model, cmd )
```

However, the `ClickedPhoto` branch is not the only way a user can select a photo. Users can also click the Surprise Me! button to select a photo at random, and we'll want to apply filters in that situation as well. This means we'll want to reuse the

preceding code in two places: both the `ClickedPhoto` branch of our case-expression as well as the `GotRandomPhoto` branch.

### SHARING CODE BETWEEN UPDATE BRANCHES

Usually, the simplest way to share code is to extract common logic into a helper function and call it from both places. This is just as true for `update` as it is for any function, so let's do that!

**NOTE** The structure of `update` permits clever alternatives to this venerable code-sharing technique—for example, having `update` call itself, passing a different `Msg`. This saves us from writing another function, but it's more error-prone. If we do this, and later a teammate innocently changes how that other `Msg` responds to user input, our code breaks. Having `update` call itself also runs a bit slower because we create an unnecessary `Msg` and run an unnecessary case-expression on it. A helper function not only runs faster; it's less error-prone to maintain because it explicitly signals to future maintainers that code is being reused.

We'll name the helper function `applyFilters`, and add it right below `update`.

#### Listing 5.8 applyFilters

```
applyFilters : Model -> ( Model, Cmd Msg )
applyFilters model =
    case model.status of
        Loaded photos selectedUrl ->
            let
                filters =
                    [ { name = "Hue", amount = model.hue }
                    , { name = "Ripple", amount = model.ripple }
                    , { name = "Noise", amount = model.noise }
                    ]
                url =
                    urlPrefix ++ "large/" ++ selectedUrl
            in
                ( model, setFilters { url = url, filters = filters } )

        Loading ->
            ( model, Cmd.none )

        Errorred errorMessage ->
            ( model, Cmd.none )
```

Now we can have both `ClickedPhoto` and `GotRandomPhoto` call `applyFilters` directly:

```
GotRandomPhoto photo ->
    applyFilters { model | status = selectUrl photo.url model.status }

ClickedPhoto url->
    applyFilters { model | status = selectUrl url model.status }
```

Lovely! Now whenever a user clicks either a photo or the Surprise Me! button, `setFilters` will return a `Cmd` that sends the appropriate `FilterOptions` value over to JavaScript. Next, we'll wire up the logic on the JavaScript side, which will receive that `FilterOptions` value and use it to apply some filters.

### 5.2.2 Receiving data from Elm

Now we're going to write a bit more JavaScript code. Whenever we access a JS library from Elm, it's best to write as little JavaScript as possible. This is because if something crashes at runtime, it's a safe bet that the culprit is somewhere in our JavaScript code—so the less of it we have, the less code we'll have to sift through to isolate the problem.

#### ADDING PASTA

The JavaScript code we need comes from an open source image-filtering library intuitively named Pasta.js. We can import Pasta by adding this `<script>` tag to `index.html`, right before the `<script>` that imports our compiled `app.js` file:

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

<script src="http://elm-in-action.com/pasta.js"></script>
<script src="app.js"></script>
```

This `<script>` adds a global JavaScript function called `Pasta.apply` to the page. It takes two arguments:

- A `<canvas>` element, which is where `apply` will draw the filtered photos
- An options object, which—in a remarkable coincidence—has the same structure as the `FilterOptions` record Elm will be sending to JavaScript via our `setFilters` port.

Let's introduce that `<canvas>`. We can do this with a quick change to `PhotoGroove.elm`, having `viewLoaded` render a `canvas` instead of an `img` for the "large" image. Let's replace our `img [ class "large", ... ] []` in `viewLoaded` with this:

```
canvas [ id "main-canvas", class "large" ] []
```

`Pasta.apply` will take care of drawing the filtered photo onto this `canvas`. (The photo URL to draw will be sent to `Pasta.apply` via the `FilterOptions` we're sending through our port.)

#### RECEIVING DATA FROM THE SETFILTERS PORT

We can set up a callback function that receives data from our `setFilters` function like so:

```
<script src="http://elm-in-action.com/pasta.js"></script>
<script src="app.js"></script>
<script>
  var app = Elm.PhotoGroove.init({node: document.getElementById("app")});

  app.ports.setFilters.subscribe(function(options) {
    Pasta.apply(document.getElementById("main-canvas"), options);
  });
</script>
```

We've never needed the return value of `Elm.PhotoGroove.init()` before, but now we do. This object, typically named `app`, lets us subscribe to data that Elm sends to JavaScript via ports like `setFilters`. When the Elm Runtime executes the `Cmd` returned by `setFilters`, the callback function we've passed to `app.ports.setFilters.subscribe` will run. The `options` argument it accepts is the `FilterOptions` record Elm sent over, but converted from an Elm record to a JavaScript object.

**WARNING** Like custom elements, ports invoke JavaScript code—which may throw runtime exceptions. If we make a mistake in any of our JavaScript code here, Elm's compiler has no way to help us catch it.

Table 5.8 shows how a port translates immutable Elm values (like the `FilterOptions` record) into brand-new (potentially mutable) JavaScript values.

**Table 5.8** Translating Elm values into JavaScript values via ports

Elm value	Elm type	JavaScript value	JavaScript type
"foo"	String	"foo"	string
4.2	Float	4.2	number
True	Bool	true	boolean
( "foo", True, 4.2 )	( String, Bool, Float )	["foo", true, 4.2]	Array
[ "drive", "line" ]	List String	["drive", "line"]	Array
{ name = "Shadow" }	{ password : String }	{"name": "Shadow"}	object
Nothing	Maybe val	null	object

**TIP** Because all Elm values must be immutable, mutable values (such as JavaScript objects and arrays) can't be sent through the port. Instead they automatically get copied into immutable data structures. This process has some overhead. Passing in values like strings and numbers, which are already immutable, has no such overhead.

Because we gave our `<canvas>` an `id` of "main-canvas", we can easily pass it to `Pasta.apply` by calling `document.getElementById("main-canvas")` to find it on the page by `id`.

#### TRYING IT OUT

Let's try it out! If we open the page, we see . . . well, an empty rectangle, as shown in figure 5.7.

That's not what we wanted! We'll figure out that bug later, but first let's see what these sliders do. Crank up that Ripple value, and then . . . hmm, still nothing happens. What's the deal?

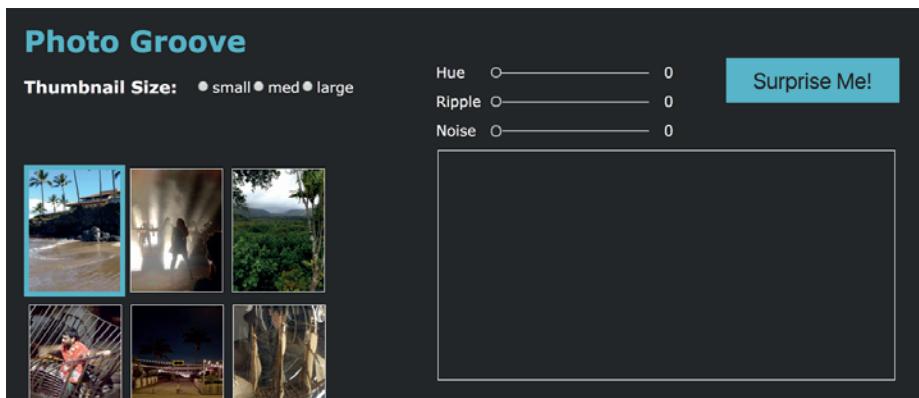


Figure 5.7 An empty rectangle. Yep.

One last idea: maybe try selecting a new photo? Oh hey, look at that! As we can see in figure 5.8, things changed—quite a lot! We are definitely talking to that JavaScript library.

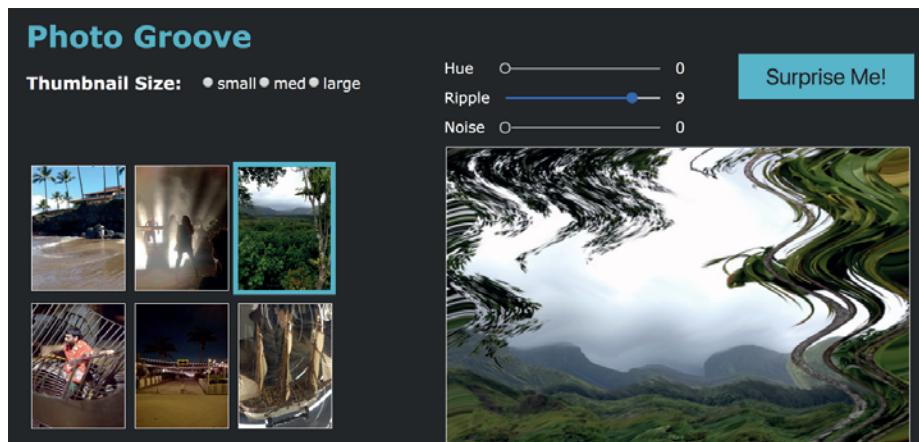


Figure 5.8 Increasing Ripple, then selecting another photo

However, there are some bugs to iron out. Playing around with it some more, we observe the following problems:

- All of the Ripple and Noise values between 1 and 11 have the same effect.
- Changing Hue doesn't seem to do anything.
- When we initially load the page, we see an empty rectangle instead of the first photo.

Clearly, we have some fixing to do!

### CONVERTING THE AMOUNT VALUE TO A PERCENTAGE

The reason Hue isn't working is the same reason that the Ripple and Noise values between 1 and 11 do the same thing: we're not quite using the `Pasta.js` API correctly.

We're sending an `Int` between 1 and 11, but actually `Pasta.js` is expecting a percentage—a `Float` between 0 and 1. Because JavaScript does not draw a distinction between `Int` and `Float`, this mistake does not result in a type mismatch error—not even at runtime!—and instead, our code simply does not work as expected.

We can fix this by dividing our `Model`'s `hue`, `ripple`, and `noise` fields by 11 before sending them to JavaScript. Let's revise our logic in `applyFilters`:

```
filters =
  [ { name = "Hue", amount = toFloat model.hue / 11 }
  , { name = "Ripple", amount = toFloat model.ripple / 11 }
  , { name = "Noise", amount = toFloat model.noise / 11 }
]
```

We need that `toFloat` because Elm's division operator (`/`) works only if you give it two `Float` values. The `Basics.toFloat` function converts an `Int` to a `Float`, so `toFloat model.hue` converts `model.hue` from an `Int` to a `Float`—at which point we can divide it by 11 as normal.

**NOTE** This is another example of Elm's design emphasizing *being explicit*. If JavaScript required similar explicitness, we'd have caught this bug earlier, when we tried to pass an `Int` to an API expecting a `Float`.

We'll also need to update `FilterOptions` to expect a `Float` for the `amount` field:

```
type alias FilterOptions =
  { url : String
  , filters : List { name : String, amount : Float }
  }
```

Now if we recompile and try our sliders again, we see a much more interesting range of Hue, Ripple, and Noise values. Lovely! There are still some bugs left, but we're making progress.

### CHANGING AS WE SLIDE

This will be way more fun if the photos update every time we slide, right? We know that `applyFilters` calls our `setFilters` port, so to apply the filters every time we slide, all we need to do is to run our `applyFilters` command every time we slide:

```
update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
  case msg of
    ...
      SlidHue hue ->
        applyFilters { model | hue = hue }

      SlidRipple ripple ->
        applyFilters { model | ripple = ripple }
```

```
SlidNoise noise ->
    applyFilters { model | noise = noise }
```

Recompile, and . . . presto! We're still greeted with an empty rectangle, but now whenever we slide, the photos update in real time to reflect the new filter settings. Whee! Now let's fix that pesky bug where we see an empty rectangle instead of a photo on page load.

### 5.2.3 Timing DOM updates

Showing the initial photo when the page loads takes two steps—a straightforward step and a tricky step. Let's start with the straightforward one: what we do after loading the photos.

#### APPLYING FILTERS AFTER LOADING PHOTOS

The problem here is that we currently load the photos and then re-render the view, but re-rendering the view is no longer enough to make a photo show up. We now need to call `applyFilters` so that Pasta can render something to the canvas.

To fix this, we need the `GotPhotos` branch of our `update` function's case-expression to call `applyFilters` after updating `model`:

```
GotPhotos (Ok photos) ->
  case photos of
    first :: rest ->
      applyFilters
        { model
          | status =
            case List.head photos of
              Just photo ->
                Loaded photos photo.url

              Nothing ->
                Loaded [] ""
        }
}
```

However, if you recompile and reload, you'll see the same behavior. Why wasn't that enough?

#### TIMING PORTS AND RENDERING

The remaining problem is a matter of timing. Let's break down what is happening:

- 1 We initialize `model.status` to `Loading`.
- 2 We request a list of photos from the server.
- 3 `view` runs, and does not call `viewLoaded` because `model.status` is `Loading`.
- 4 Because `viewLoaded` is never called, the `<canvas>` is never rendered.
- 5 The server responds with our photos, meaning `update` gets a `GotPhotos` message.
- 6 `update` runs its `GotPhotos` branch and returns a new `Model` (with a status that is no longer `Loading`), as well as a `Cmd` that will instruct our JavaScript code to have Pasta render to the `<canvas>`.

See the problem? Step 6 tells Pasta to render to a `<canvas>`, but as we noted in step 4, no such `<canvas>` has been created yet!

This means our JavaScript call to `Pasta.apply(document.getElementById("main-canvas"), options)` will silently fail. Shortly after this happens, `view` will run again with the new model. This time, `model.status` will not be `Loading`—meaning `viewLoaded` will happily ask for a fresh, blank `<canvas>`. Great.

We were so close, though! If Elm would have rendered the `view` before running the `Cmd` that invoked `Pasta`, the `<canvas>` would have been on the DOM before the JavaScript executed, and everything would have been fine. So why doesn't Elm do this?

### OPTIMIZED DOM UPDATES

One reason the Elm Runtime has good performance is that it skips unnecessary renders. See, browsers repaint the DOM as pixels on users' screens only every so often. If the Elm Runtime changes part of the DOM, and then changes it again before the next repaint, the first change will have been wasted time; only the second change will be painted for users to see.

You might think that if your `update` function gets called a million times in a single second, your `view` would also be called a million times. Not so! Although those million updates will result in a million potential `Model` changes, Elm waits until the browser's next repaint to call `view` even once—with whatever value `Model` has at that moment. Invoking `view` more frequently than that would result in DOM updates that the browser wouldn't bother to paint anyway.

### SYNCHRONIZING WITH THE ELM RUNTIME

The JavaScript function `requestAnimationFrame` allows code to run just before the browser's next repaint. Because this is when the Elm Runtime will schedule its next DOM update, we can use `requestAnimationFrame` to delay our call to `document.getElementById("main-canvas")` until after our next `view` has added the `<canvas>` we need to the DOM.

Because `requestAnimationFrame` accepts a single callback function, we can finally fix this bug by wrapping our call to `Pasta.apply` in a `requestAnimationFrame` callback function, like so:

```
app.ports.setFilters.subscribe(function(options) {
  requestAnimationFrame(function() {
    Pasta.apply(document.getElementById("main-canvas"), options);
  });
});
```

**TIP** Anytime you need to trigger some JavaScript port code to run *after the next time* `view` results in a DOM update, you can synchronize things by wrapping your port code in `requestAnimationFrame` like this.

Let's recompile and bring up the page. Now the initial photo loads right after the page does.

## 5.3 Receiving data from JavaScript

Now we're ready for the final piece of the puzzle: the Pasta activity display, which shows information reported by Pasta. First we'll start subscribing to Pasta's real-time activity updates, which Pasta broadcasts as they occur. Then we'll set an initial activity message that displays the version of Pasta we've loaded. Each change involves a different Elm concept we haven't used before: first *subscriptions* and then *flags*. Let's put them to work!

### 5.3.1 Receiving real-time data from JavaScript via ports

Here we'll be receiving real-time data from JavaScript in the same way we receive user input: through a `Msg`. Let's start by adding an `activity` string to our `Model`, `initialModel`, and `Msg`, as shown in table 5.9.

**Table 5.9 Adding an activity string to Model, initialModel, and Msg**

Model	initialModel	Msg
<pre>type alias Model =     { status : Status     , activity : String }</pre>	<pre>initialModel : Model initialModel =     { status = Loading     , activity = "" }</pre>	<pre>type Msg ...   GotRandomPhoto Photo   GotActivity String</pre>

With these in place, our change to `update` is straightforward: set the `activity` field on `model` when we receive a `GotActivity` message:

```
update msg model =
    case msg of
        GotActivity activity ->
            ( { model | activity = activity }, Cmd.none )
```

We'll also need `viewLoaded` to display the activity:

```
, button
    [ onClick ClickedSurpriseMe ]
    [ text "Surprise Me!" ]
, div [ class "activity" ] [ text model.activity ]
, div [ class "filters" ]
```

Nice! We're getting faster at this. Now all that's missing is a source of `GotActivity` messages. We'll get those from JavaScript.

#### SENDING DATA FROM JAVASCRIPT TO ELM

Let's modify `index.html` to add a bit more JavaScript code right below our `setFilters` code:

```
var app = Elm.PhotoGroove.init({node: document.getElementById("app")});

app.ports.setFilters.subscribe(function(options) {
    requestAnimationFrame(function() {
        Pasta.apply(document.getElementById("main-canvas"), options);
    })
});
```

```

    });
}

Pasta.addActivityListener(function(activity) {
  console.log("Got some activity to send to Elm:", activity);
});

```

Pasta calls this function whenever its activity changes.

Logs the new activity value to the developer console

This uses Pasta's `addActivityListener` function to log activity to the browser's JavaScript console. If we reload the page and open the browser's console, we'll see various activity messages flowing through as we play around with the sliders and select photos. Next, we need to send those activity strings to Elm instead of to the console.

### SUBSCRIPTIONS

Earlier in the chapter, we sent data from Elm to JavaScript by using a command. Now we'll do the reverse: send some data from JavaScript to Elm—using, not a command, but a *subscription*.

**DEFINITION** A *subscription* represents a way to translate certain events outside our program into messages that get sent to our `update` function.

One use for subscriptions is handling user inputs that aren't tied to a particular DOM element. For example, we've used `onClick` to translate a click event on a specific element into a message that gets sent to `update`. What if we instead want to detect when the user resizes the entire browser window?

We do this by adding a subscription to our program that translates browser window resize events into messages. Those messages get sent to `update` just as the ones for `onClick` do. The difference is that instead of using `Html.Events.onClick` from the `elm/html` package, we'd use `Browser.onResize` from the `elm/browser` package, as shown in figure 5.9.

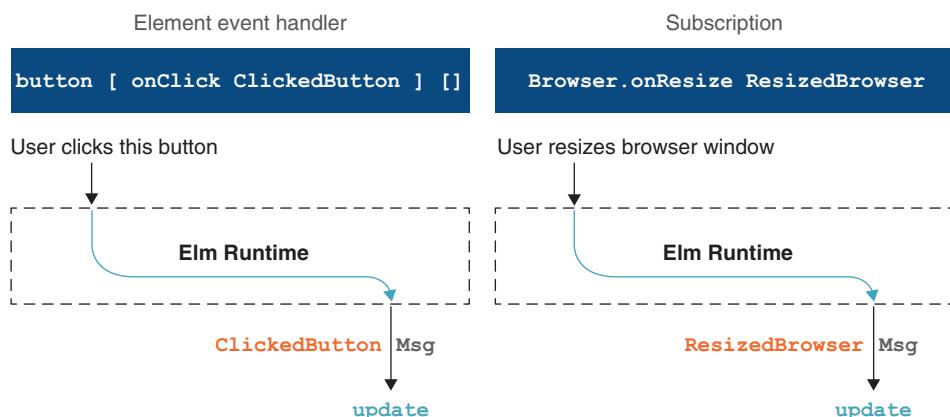


Figure 5.9 A subscription that translates browser window resize events into messages

### DEFINING A SUBSCRIPTION PORT

There are also subscriptions that translate data from JavaScript into messages that are sent to update. We can get one of these subscriptions by using a slightly different port declaration. Let's add another port right below the code that defines `setFilters`:

```
port setFilters : FilterOptions -> Cmd msg
port activityChanges : (String -> msg) -> Sub msg
```

We can already see some similarities and differences between our command port and our subscription port. Both define a function that takes one argument, but whereas the first function returns a command (`Cmd msg`), the second returns a subscription (`Sub msg`).

`Cmd` and `Sub` are both parameterized on the type of message they produce. We noted earlier that `setFilters` returns a `Cmd msg` (as opposed to `Cmd Msg`) because it is a command that produces no message after it completes. In contrast, `activityChanges` returns a `Sub msg`, but here `msg` refers to the type of message returned by the `(String -> msg)` function we pass to `activityChanges`. Table 5.10 shows how various calls to `activityChanges` can yield different return values.

**Table 5.10 Calling the `activityChanges` function**

Function to pass to <code>activityChanges</code>	Expression	Return type
<code>String.length : String -&gt; Int</code>	<code>activityChanges String.length</code>	<code>Sub Int</code>
<code>String.reverse : String -&gt; String</code>	<code>activityChanges String.reverse</code>	<code>Sub String</code>
<code>GotActivity : String -&gt; Msg</code>	<code>activityChanges GotActivity</code>	<code>Sub Msg</code>

**NOTE** Whereas it's normal for `setFilters` to return `Cmd msg`, it would be bizarre for `activityChanges` to return `Sub msg`. After all, a `Cmd msg` is a command that has an effect but never sends a message to update—but subscriptions do not run effects. Their whole purpose is to send messages to update. Subscribing to a `Sub msg` would be like listening to a disconnected phone line: not terribly practical.

If we call `activityChanges GotActivity`, we'll get back a `Sub Msg` subscription. That's all well and good, but what do we do with a `Sub Msg`?

### PASSING SUBSCRIPTIONS TO BROWSER.ELEMENT

We use `Sub Msg` with that `subscriptions` field we set up with `Browser.element`:

```
main : Program () Model Msg
main =
    Browser.element
        { init = _ -> ( initialModel, initialCmd )
        , view = viewOrError
        , update = update
        , subscriptions = subscriptions
        }
```

```
subscriptions : Model -> Sub Msg
subscriptions model =
    activityChanges GotActivity
```

Ever since chapter 3, we've been setting this `subscriptions` field to an anonymous function that always returned `Sub.none`. Now we've made that function return `activityChanges GotActivity` instead, which means that whenever JavaScript sends a string to the `activityChanges` port, it will result in a `GotActivity` message being sent to update.

**NOTE** The argument this anonymous `subscriptions` function accepts is a `Model`. Whenever our model changes, the new model is passed to this function, giving us a chance to return a different `Sub` depending on what's in the new model. This lets us dynamically control which subscriptions our program pays attention to.

Figure 5.10 illustrates how subscriptions fit into Elm programs.

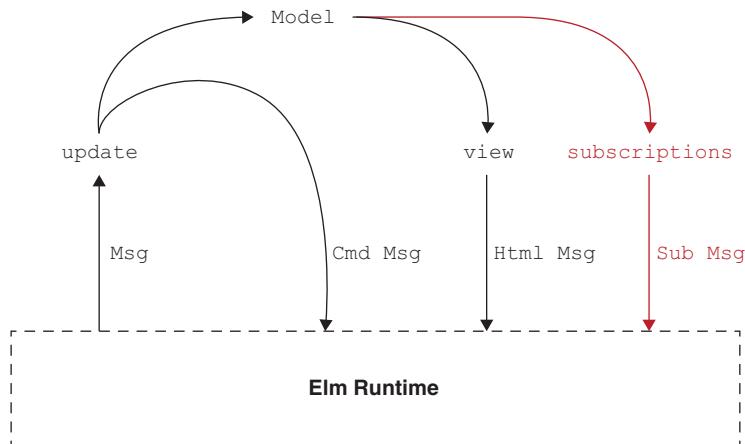


Figure 5.10 How subscriptions fit into Elm programs

Now our `activityChanges` port is fully connected to the rest of our application, meaning we're ready to have our JavaScript code start sending it data!

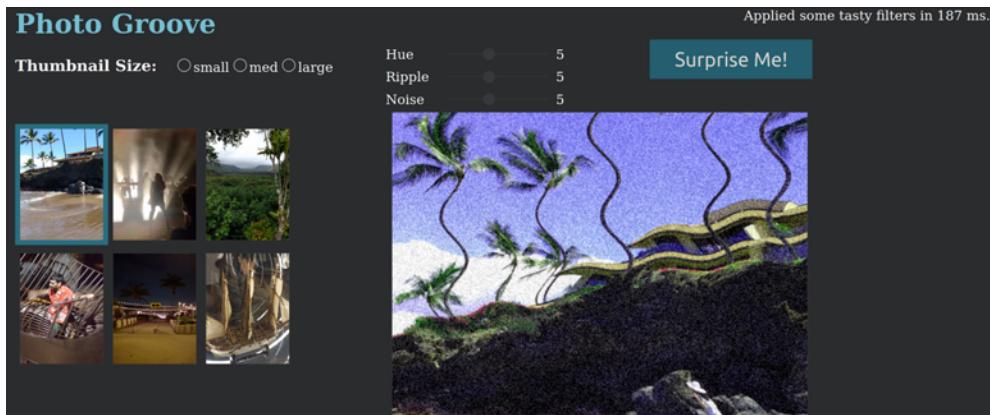
#### CALLING APP.PORTS.ACTIVITYCHANGES.SEND

Much as we used `app.ports.setFilters.subscribe` to receive data from Elm, so too, we can use `app.ports.activityChanges.send` to send data to Elm. Let's replace our `console.log` in `index.html` with a call to `app.ports.activityChanges.send`:

```
Pasta.addActivityListener(function(activity) {
    console.log("Got some activity to send to Elm:", activity);
    app.ports.activityChanges.send(activity);
});
```

Remember, `subscriptions = \_ -> activityChanges GotActivity` specifies that we'll wrap whatever `activity` string we receive from the `activityChanges` port in a `GotActivity` message.

This means that calling `app.ports.activityChanges.send("Reticulating splines")` from JavaScript will ultimately result in a `GotActivity "Reticulating splines"` message being sent to update on the Elm side. At that point, our existing activity-rendering logic should kick in, which we can confirm by recompiling and reopening `index.html` in the browser. Figure 5.11 shows how the page should look.



**Figure 5.11** Showing the activity when filters change

Fantastic! We have just one more problem to address. Right when we refresh the page, at first there is no activity to show, leading to a brief flicker of nothingness before the first activity update arrives. We'll fix this by showing an initial activity message, using data obtained from Pasta prior to the first activity change it sends us.

### 5.3.2 Receiving initialization arguments via flags

We'd like to display an initial activity report that includes the version of Pasta we're using. It will look something like this:

*Initializing with Pasta v4.2...*

We can easily obtain the current version from Pasta in JavaScript; all we have to do is reference `Pasta.version`. But how do we get that value into Elm in time for the initial render, to avoid that flicker of missing content?

#### SENDING INITIALIZATION DATA TO PROGRAM

Calling `app.ports.activityChanges.send(Pasta.version)` won't cut it here. Elm would still render `initialModel` (with `model.activity` being "", resulting in

the flicker of missing content) before receiving a message from `activityChanges` and re-rendering with the new activity.

What we want is a way to give Elm a value from JavaScript that's available right away, early enough to use in our initial render. This means we don't want ports; we want *flags*.

**DEFINITION** *Flags* are values passed from JavaScript to an Elm program's `init` function.

To use flags, we'll revisit the very first piece of configuration we used in our main declaration:

```
main =
  Browser.element
    { init = \flags -> ( initialModel, initialCmd ) }
```

Remember that `flags` argument the `init` function was receiving? The one we renamed to `_` because we weren't using it? We're finally about to use it!

Let's give our initialization logic a bit more room to breathe, by moving `init` from an anonymous function to a named top-level function:

```
main =
  Browser.element
    { init = init
      , view = view
      , update = update
      , subscriptions = \_ -> activityChanges GotActivity
    }

init : Float -> ( Model, Cmd Msg )
init flags =
  let
    activity =
      "Initializing Pasta v" ++ String.fromFloat flags
  in
    ( { initialModel | activity = activity }, initialCmd )
```

**TIP** `String.fromFloat` is like `String.toInt`, but for floats. Okay, maybe calling this a “tip” is a bit of a stretch, but let's go with it.

Changing the type of `init`'s `flags` argument will affect the type of `main` a bit:

```
main : Program () Model Msg
main : Program Float Model Msg
```

`Program () Model Msg` means “a `Program` with `Model` as its model type, `Msg` as its message type, and which has no flags.” `Program Float Model Msg` means the same thing, except that its flags are a `Float`. (For a refresher on the `()` type, see chapter 3, section 3.3.3.)

## The type of `Browser.element`

The complete type of the `Browser.element` function is as follows:

```
{ init : flags -> ( model, Cmd msg )
, view : model -> Html msg
, update : msg -> model -> ( model, Cmd msg )
, subscriptions : model -> Sub msg
}
-> Program flags model msg
```

These three type variables—`flags`, `model`, and `msg`—tie every Elm program together.

Because `view`, `init`, `update`, and `subscriptions` all produce the same `msg` type as the one `update` receives as an argument, you can choose whatever message type you like; `update` will be able to process every message. The Elm Runtime will send messages to `update` only from the sources that you see in this configuration record right here.

Likewise, the `model` that `init` returns has the same type as the one `update` accepts and returns, and the same one `subscriptions` is based on.

Elm has no secret enforcement mechanism behind the scenes making sure all the messages and the `model` fit together properly. It's all done with plain old type variables right here in this type signature.

## SENDING FLAGS TO ELM

Now that our `init` function accepts a `Float` for its `flags`, we're ready to send that `Float` in from JavaScript. We do this by passing an extra argument to the `Elm.PhotoGroove.init` method we've been using to start the program running:

```
var app = Elm.PhotoGroove.init({
  node: document.getElementById("app"),
  flags: Pasta.version
});
```

## Decoding JavaScript values

If we want, we can use the same JSON decoders we used in chapter 4 to translate values from JavaScript into Elm values while gracefully handling errors. In that chapter, we used the `Json.Decode.decodeString` function to decode a `String` of JSON into various Elm values. A similar function, `Json.Decode.decodeValue`, takes a `Json.Decode.Value` instead of a `String`. We can write our `activityChanges` port to expect a `Value` from JavaScript, like so:

```
import Json.Decode exposing (Value)

port activityChanges : (String -> msg) -> Sub msg
port activityChanges : (Value -> msg) -> Sub msg
```

From there, writing a Decoder Msg and passing it to `Json.Decode.decodeValue` will give us a Result String Msg. We can translate that into a Msg by introducing an error-handling Msg that ideally displays a helpful message to end users, explaining that something went wrong.

We can use the same technique for flags:

```
main : Program Value Model Msg
```

Using this decoder style is generally a better choice for production applications. For one thing, it lets us give users a better experience by gracefully handling errors. For another, any incoming type other than `Value` is liable to result in a runtime exception if JavaScript passes in something invalid.

Elm will check this immediately upon receiving the value, and will throw the exception early rather than letting it snake its way through our program, but it's better still to do the error handling ourselves. Besides, because Elm performs the automatic check using decoders anyway, there's no performance penalty for doing it explicitly.

That's it! Now when we start up Photo Groove, we'll see the version number proudly displaying for the briefest of moments before the first photo loads. Figure 5.12 shows the initial activity value, captured using an incredibly high-speed screenshotting camera.



Figure 5.12 Showing the activity on page load

Nicely done!

## Summary

Photo Groove is now substantially groovier than before. Specifically:

- We added some cool sliders by using custom elements written in JavaScript.
- As users slide their values around, we change the filters on the large photo.
- The filters come from a JavaScript library, which Photo Groove talks to like a server.
- When the JS filtering library sends activity reports, Photo Groove displays them.
- The initial activity report includes the JS filtering library's version number.

In the process, you learned some new concepts and techniques for building Elm applications:

- Asking “Which approach rules out more bugs?” is a good way to decide between different ways to model data.
- Once custom elements have been registered on the page, we can access them by using the `Html.node` function.

- The `as` keyword lets us alias imported modules; for example, `import Html.Attributes as Attr` and `import Json.Encode as Encode`.
- The `Html.Events.on` function lets us create a custom event handler by using a `Decoder`.
- `requestAnimationFrame` can delay our JavaScript code's execution until the next time Elm calls `view` and renders the result to the DOM.
- A subscription represents a way to translate certain events outside our program into messages that get sent to our `update` function.
- A `port` module can use the `port` keyword to define functions that return commands and subscriptions that talk to JavaScript.
- `init`'s first argument lets us send initialization flags from JavaScript to Elm.

In chapter 6, we'll crank our application's maintainability into overdrive by building it a hearty suite of automated tests. Listings 5.9 and 5.10 show where `index.html` and `PhotoGroove.elm` ended up.

### Listing 5.9 index.html

```
<!doctype html>
<html>
    <head>
        <link rel="stylesheet" href="http://elm-in-action.com/styles.css">
        <link rel="stylesheet" href="http://elm-in-action.com/range-slider.css">
        <script src="http://elm-in-action.com/range-slider.js"></script>
        <script>
            class RangeSlider extends HTMLElement {
                connectedCallback() {
                    var input = document.createElement("input");
                    this.appendChild(input);

                    var jsr = new JSR(input, {
                        max: this.max,
                        values: [this.val],
                        sliders: 1,
                        grid: false
                    });
                    rangeSliderNode = this;

                    jsr.addEventListener("update", function(elem, value) {
                        var event = new CustomEvent("slide", {
                            detail: {userSlidTo: value}
                        });
                        rangeSliderNode.dispatchEvent(event);
                    });
                }
            }
        </script>
    </head>
    <body>
        <range-slider>
    </body>
</html>
```

**The connectedCallback() method gets called whenever a <range-slider> is added to the DOM.**

**When the slider updates, dispatches a CustomEvent that Elm can listen for**

**Defines a RangeSlider class to be the implementation for <range-slider> later**

**Creates an <input> and adds it to the DOM**

**Uses the JSR library to initialize the <input>**

```

        window.customElements.define("range-slider", RangeSlider); <-
    </script>
</head>
</body>
<div id="app"></div>

<script src="http://elm-in-action.com/pasta.js"></script>
<script src="app.js"></script>
<script>
    var app = Elm.PhotoGroove.init({node:
        document.getElementById("app"), flags: Pasta.version}); <-->
    Run this code
    when the Elm
    Runtime sends a
    setFilters Cmd. <-->
        app.ports.setFilters.subscribe(function(options) {
            requestAnimationFrame(function() {
                Pasta.apply(
                    document.getElementById("main-canvas"),
                    options
                );
            });
        });
    <-->
    Pasta.addActivityListener(function(activity) {
        app.ports.activityChanges.send(activity);
    });
</script>
</body>
</html>

```

Defines <range-slider> to use the RangeSlider class for its logic

Passes Pasta.version in as a flag to the Elm program

Uses requestAnimationFrame to wait for view to be reflected in the real DOM

When Pasta's activity listener fires, sends activity to the activityChanges Sub

### Listing 5.10 PhotoGroove.elm

```

port module PhotoGroove exposing (main)

import Array exposing (Array)
import Browser
import Html exposing (..)
import Html.Attributes as Attr exposing (..)
import Html.Events exposing (on, onClick)
import Http
import Json.Decode exposing (Decoder, at, bool, int, list, string, succeed)
import Json.Decode.Pipeline exposing (optional, required)
import Json.Encode as Encode
import Random

urlPrefix : String
urlPrefix =
    "http://elm-in-action.com/"

type Msg
    = ClickedPhoto String
    | SlidHue Int
    | SlidRipple Int
    | SlidNoise Int

```

```

| ClickedSize ThumbnailSize
| ClickedSurpriseMe
| GotRandomPhoto Photo
| GotActivity String
| GotPhotos (Result Http.Error (List Photo))

view : Model -> Html Msg
view model =
    div [ class "content" ] <|
        case model.status of
            Loaded photos selectedUrl ->
                viewLoaded photos selectedUrl model

            Loading ->
                []

            Errorred errorMessage ->
                [ text ("Error: " ++ errorMessage) ]

viewFilter : (Int -> Msg) -> String -> Int -> Html Msg
viewFilter toMsg name magnitude =
    div [ class "filter-slider" ]
        [ label [] [ text name ]
        , rangeSlider
            [ Attr.max "11"
            , Attr.property "val" (Encode.int magnitude)
            , onSlide toMsg
            ]
            []
        , label [] [ text (String.toInt magnitude) ]
    ]Calls our rangeSlider function. It's a plain function like any other, but resembles the usual functions we use to create Html values.

viewLoaded : List Photo -> String -> Model -> List (Html Msg)
viewLoaded photos selectedUrl model =
    [ h1 [] [ text "Photo Groove" ]
    , button
        [ onClick ClickedSurpriseMe ]
        [ text "Surprise Me!" ]
    , div [ class "activity" ] [ text model.activity ]
    , div [ class "filters" ]
        [ viewFilter SlidHue "Hue" model.hue
        , viewFilter SlidRipple "Ripple" model.ripple
        , viewFilter SlidNoise "Noise" model.noise
        ]
    , h3 [] [ text "Thumbnail Size:" ]
    , div [ id "choose-size" ]
        (List.map viewSizeChooser [ Small, Medium, Large ])
    , div [ id "thumbnails", class (sizeToString model.chosenSize) ]
        (List.map (viewThumbnail selectedUrl) photos)
    , canvas [ id "main-canvas", class "large" ] []
    ]

```

```

viewThumbnail : String -> Photo -> Html Msg
viewThumbnail selectedUrl thumb =
    img
        [ src (urlPrefix ++ thumb.url)
        , title (thumb.title ++ " [" ++ String.fromInt thumb.size ++ " KB]")
        , classList [ ( "selected", selectedUrl == thumb.url ) ]
        , onClick (ClickedPhoto thumb.url)
        ]
        []
[]

viewSizeChooser : ThumbnailSize -> Html Msg
viewSizeChooser size =
    label []
        [ input [ type_ "radio", name "size", onClick (ClickedSize size) ] []
        , text (sizeToString size)
        ]

sizeToString : ThumbnailSize -> String
sizeToString size =
    case size of
        Small ->
            "small"
        Medium ->
            "med"
        Large ->
            "large"

type ThumbnailSize
= Small
| Medium
| Large

port setFilters : FilterOptions -> Cmd msg
port activityChanges : (String -> msg) -> Sub msg
| Creates app.ports.setFilters and
| app.ports.activityChanges. The Elm
| Runtime will create the implementation
| of setFilters and activityChanges.

type alias FilterOptions =
    { url : String
    , filters : List { name : String, amount : Float }
    }

type alias Photo =
    { url : String
    , size : Int
    , title : String
    }

```

```
photoDecoder : Decoder Photo
photoDecoder =
    succeed Photo
        |> required "url" string
        |> required "size" int
        |> optional "title" string "(untitled)"

type Status
= Loading
| Loaded (List Photo) String
| Errorred String

type alias Model =
{ status : Status
, activity : String
, chosenSize : ThumbnailSize
, hue : Int
, ripple : Int
, noise : Int
}

initialModel : Model
initialModel =
{ status = Loading
, activity = ""
, chosenSize = Medium
, hue = 0
, ripple = 0
, noise = 0
}

update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
case msg of
    GotActivity activity ->
        ( { model | activity = activity }, Cmd.none )

    SlidHue hue ->
        applyFilters { model | hue = hue }

    SlidRipple ripple ->
        applyFilters { model | ripple = ripple }

    SlidNoise noise ->
        applyFilters { model | noise = noise }

    GotRandomPhoto photo ->
        applyFilters { model | status = selectUrl photo.url model.status }

    ClickedPhoto url ->
        applyFilters { model | status = selectUrl url model.status }
```

```
ClickedSize size ->
  ( { model | chosenSize = size }, Cmd.none )

ClickedSurpriseMe ->
  case model.status of
    Loaded (firstPhoto :: otherPhotos) _ ->
      Random.uniform firstPhoto otherPhotos
      |> Random.generate GotRandomPhoto
      |> Tuple.pair model

    Loaded [] _ ->
      ( model, Cmd.none )

    Loading ->
      ( model, Cmd.none )

    Errorred errorMessage ->
      ( model, Cmd.none )

GotPhotos (Ok photos) ->
  case photos of
    first :: rest ->
      applyFilters { model | status = Loaded photos first.url }

    [] ->
      ( { model | status = Errorred "0 photos found" }, Cmd.none )

GotPhotos (Err httpError) ->
  ( { model | status = Errorred "Server error!" }, Cmd.none )

applyFilters : Model -> ( Model, Cmd Msg )
applyFilters model =
  case model.status of
    Loaded photos selectedUrl ->
      let
        filters =
          [ { name = "Hue", amount = toFloat model.hue / 11 }
          , { name = "Ripple", amount = toFloat model.ripple / 11 }
          , { name = "Noise", amount = toFloat model.noise / 11 }
          ]

        url =
          urlPrefix ++ "large/" ++ selectedUrl
      in
        ( model, setFilters { url = url, filters = filters } )

    Loading ->
      ( model, Cmd.none )

    Errorred errorMessage ->
      ( model, Cmd.none )
```

```

selectUrl : String -> Status -> Status
selectUrl url status =
    case status of
        Loaded photos _ ->
            Loaded photos url

        Loading ->
            status

        Errorred errorMessage ->
            status


initialCmd : Cmd Msg
initialCmd =
    Http.get
        { url = "http://elm-in-action.com/photos/list.json"
        , expect = Http.expectJson GotPhotos (list photoDecoder)
        }

main : Program Float Model Msg
main =
    Browser.element
        { init = init
        , view = view
        , update = update
        , subscriptions = subscriptions
        }

subscriptions : Model -> Sub Msg
subscriptions model =
    activityChanges GotActivity

init : Float -> ( Model, Cmd Msg )
init flags =
    let
        activity =
            "Initializing Pasta v" ++ String.fromFloat flags
    in
        ( { initialModel | activity = activity }, initialCmd )

rangeSlider : List (Attribute msg) -> List (Html msg) -> Html msg
rangeSlider attributes children =
    node "range-slider" attributes children

```

```

onSlide : (Int -> msg) -> Attribute msg
onSlide toMsg =
    at [ "detail", "userSlidTo" ] int
        |> Json.Decode.map toMsg
        |> on "slide"

```

Creates a  
<range-slider>  
element

Handles the custom  
“userSlidTo” event that  
<range-slider> will emit



# Testing

## This chapter covers

- Writing unit tests
- Writing fuzz tests
- Testing update functions
- Testing view functions

Our Photo Groove application has been delighting users in production for a while now, and things have settled down on the development team. Our manager has left for vacation with vague instructions to “keep the lights on,” and we find ourselves with time to revisit some of the corners we cut when shipping Photo Groove.

At this point, we know we’ll be maintaining this application for the long haul. We’ll need to add new features, improve existing ones, and do both without introducing bugs to the existing feature set. That isn’t easy! The longer our application is around, the more important it will be that the code we write is not just reliable, but also *maintainable*.

As we saw in chapter 3, Elm’s compiler is an invaluable tool for maintainability. It can assist us by finding syntax errors and type mismatches before they can impact our end users, and this is even more helpful after we make a big change to our code.

However, the compiler has no way of knowing how our business logic is supposed to work. We'll need to use a different tool to verify that our business logic is working as expected, and `elm-test` is great for that! In this chapter, you'll learn how to use `elm-test` to write automated tests that verify our business logic, including the following:

- Testing our JSON decoding logic
- Testing our update logic
- Testing our view logic

By the end, we'll have a more maintainable code base that will be easier to build on as we continue to iterate on Photo Groove's feature set in the chapters to come. Let's rock!

## 6.1 **Writing unit tests**

Before you can write your first automated test, we'll need to introduce a new package to our code base: `elm-explorations/test`. Typically, we'd do this using the `elm install` command, but setting up our tests for the first time is a bit more involved. Fortunately, the `elm-test` command-line tool automates this setup for us.

### 6.1.1 **Introducing tests**

Let's begin by running this command from the same directory as our `elm.json` file:

```
elm-test init
```

This will generate three things:

- A new folder called `tests`
- A file inside that folder called `Example.elm`
- A new dependency in our `elm.json` file

**NOTE** Any package that begins with `elm-explorations/` might begin with `elm/` someday. Depending on when you're reading this, the package name might be `elm/test` instead of `elm-explorations/test`!

Figure 6.1 illustrates how our project's new file structure should look.

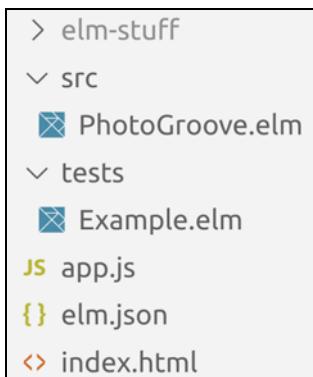


Figure 6.1 Our project's file structure after running `elm-test init`

**NOTE** The elm-stuff folder contains cached files generated by `elm make` to speed up compilation. It should never be checked into source control, and it will be harmlessly regenerated by `elm make` if it gets deleted.

`elm-test init` also installed a package called `elm-explorations/test` as a *test dependency*. A test dependency's modules are available only when running tests—meaning only modules we put in this new `tests/` directory will be able to access them.

**TIP** The application's dependencies and test dependencies are listed in that `elm.json` file. We'll dive into this file in greater depth in appendix B.

We'll use modules from the `elm-explorations/test` package in the `Example.elm` file that was created inside the `tests/` directory.

### RENAMING EXAMPLE.ELM

Let's open up that `Example.elm` file in the `tests/` directory. It should have this line at the top:

```
module Example exposing (...)
```

As vibrant a name as `Example.elm` might be, it doesn't fit very well with our application. Let's rename the file to `PhotoGrooveTests.elm` and change the first line to this:

```
module PhotoGrooveTests exposing (...)
```

**NOTE** Elm module names must match their filenames. If we kept the first line as `module Example` but renamed the file to `PhotoGrooveTests.elm`, we would get an error when we ran our tests.

This module will contain our *tests*, each of which is an expression that verifies something about our application's logic. Although this chapter focuses on using tests to defend against regressions in our existing application code, this is not the only way to do it. It can be helpful to write tests before finishing the initial version of the business logic itself, to guide implementation and help reveal design shortcomings early.

When we use the `elm-test` command to run our tests, each test will either *pass* or *fail*. Failures might indicate that our application code has a problem, or that our tests have a problem—after all, tests can have bugs too! If every test passes, the *test run* as a whole passes. If any test fails, the test run as a whole fails.

### UNIT TESTS

The `suite : Test` value in our `PhotoGrooveTests` module is an example of a unit test in Elm. The term *unit test* means different things depending on who you ask, so let's start by setting a clear definition of what it means in Elm.

**DEFINITION** In Elm, a *unit test* is a test that runs once, and whose test logic does not perform effects. (In chapter 4, you learned that an *effect* is an operation that modifies external state.)

We'll contrast unit tests with fuzz tests in a bit.

## EFFECTS

Every unit test requires a single expression that evaluates to an `Expectation` value.

Here's an `Expectation` that tests whether `1 + 1 == 2`:

```
expectation : Expectation
expectation =
    Expect.equal (1 + 1) 2
```

I have it on good authority that `1 + 1` should be equal to `2`, so it's safe to assume that any test that evaluates to this `Expectation` will pass when we run it.

`Expect.equal` is a function that has the following type:

```
equal : a -> a -> Expectation
```

We pass it two values, and it returns an `Expectation` that claims the two values are equal. If they turn out to be equal, the expectation will pass. If not, it will fail. Failed expectations usually translate to failed tests, as we will see momentarily.

## RUNNING OUR FIRST UNIT TEST

Let's replace the implementation of `suite` in `PhotoGrooveTests.elm` with the following:

```
suite : Test
suite =
    test "one plus one equals two" (\_ -> Expect.equal 2 (1 + 1))
```

Before we get into what this code means, let's run this test and see if it passes.

Run this at the command line:

```
elm-test
```

You should see some output that ends with this:

TEST RUN FAILED Msg Msg

Huzzah! You've written your first passing test!

## BREAKING DOWN OUR FIRST UNIT TEST

Figure 6.2 highlights the two arguments we passed to the `test` function.

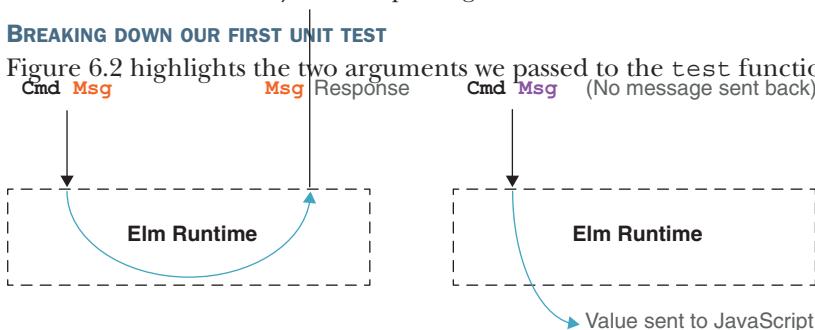


Figure 6.2 Arguments passed to the `test` function

The first argument to `test` is a description of the test. If the test fails, `elm-test` will display this text to let us know which test failed. Because the purpose of these descriptions is to help us identify which test failed, `elm-test` enforces that they must be unique. Now that we've given this test a description of "one plus one equals two", we can't give any other test that same description.

Next, let's look at the argument after the description string:

```
(\_\_ -> Expect.equal 2 (1 + 1))
```

Oh, hey! It's our friend `Expect.equal` from earlier. When the test ran, `Expect.equal` checked whether the two arguments it received were equal. Because they were, it returned a "pass" `Expectation`. (Otherwise, it would have returned a "fail" `Expectation`.)

Since `2 == (1 + 1)`, it returns a "pass" `Expectation`, which is why the test as a whole passed when we ran it.

Notice that the argument the `test` function receives is not an actual `Expectation` value, but rather an anonymous function that *returns* an `Expectation`. This function wrapper is important, but unit tests never need to reference the argument it receives, so we can always safely disregard that argument by naming it "`_`" the way we did here.

## Why the function wrapper?

Although `Expect.equal 2 (1 + 1)` determines whether the test passes, we don't pass that directly to the test function. We wrap it in an anonymous function first; what we actually pass is `(\_\_ -> Expect.equal 2 (1 + 1))` instead.

Why does `test` expect us to pass it a function instead of a plain old `Expectation`? This is done in order to postpone evaluation of the test. Compare these two expressions:

```
totalA = (          10 + 20 + 30)
addNums = (\_\_ -> 10 + 20 + 30)
```

If we run both of these lines of code, `totalA` will immediately add `10 + 20 + 30` to get a result of `60`. However, `addNums` will not do any addition yet. That line of code only defines a function. The addition won't happen until the function gets called later.

The very first release of `elm-test` did not wrap expectations in functions like this, which led to a problem on large test suites. `elm-test` would print something like "Starting test run . . ." followed by a blank screen, followed by a pile of output only after the last test had finished. There was no opportunity to report progress incrementally, because every test in the module began evaluating, one after the other, as soon as the module loaded!

Delaying evaluation lets `elm-test` control when and how to run each test, giving it the flexibility to do things like report incremental progress on a long-running test suite.

**(continued)**

At this point, you might be asking yourself, “Self, what exactly is the throwaway value that gets passed to that function?” Clearly the function takes an argument, because every Elm function must take at least one argument. (There is, in fact, no such thing as a zero-argument Elm function.) So what’s the value that gets passed in?

To answer that, let’s look at the type of the `test` function:

```
test : String -> ((() -> Expectation) -> Test)
```

Remember the `()` value that we discussed back in chapter 3? It’s called *unit*, and we used it near the end of section 3.3.3 to annotate `main` as `Program () Model Msg`.

Here we can see that the anonymous function we’re passing has the type `() -> Expectation`, which means the only possible value it can be passed is `()`. Because a function like that must always return the same value every time it is called, one of the few things it’s useful for is to delay evaluation.

Because we define our test case inside an anonymous `() -> Expectation` function, that code does not get evaluated right away when the program starts. Instead, it will be evaluated only when that `() -> Expectation` function is called. This lets `elm-test` control when tests are executed, which in turn lets it perform optimizations such as running tests in parallel.

Great! Next, you’ll use what you’ve learned to write your first real unit test for Photo Groove.

### 6.1.2 Unit testing a JSON decoder

Take a look back at our `photoDecoder`, which we used to decode `Photo` values from the raw JSON strings our HTTP requests received from the server. `photoDecoder` describes JSON values that have two required fields and one optional field. Here’s how we defined it:

```
photoDecoder : Decoder Photo
photoDecoder =
    decode buildPhoto
        |> required "url" string
        |> required "size" int
        |> optional "title" string "(untitled)"
```

We’ll write a test for this code that checks whether that optional field is serving the purpose we expect—namely, that if the JSON the server sends us doesn’t have a `title` field, the photo ends up with the default title of “`(untitled)`”.

However, our test can’t yet access `photoDecoder`. Let’s add this to the top of `PhotoGrooveTests`, right above `import Test exposing (...)`:

```
import PhotoGroove
```

This will import all values exposed by our `PhotoGroove` module. We can check which values a module exposes by looking at its first line. In our case, that line looks like this:

```
port module PhotoGroove exposing (main)
```

Uh-oh! It looks like we're exposing only `main` at the moment. By default, Elm modules hide their values from the outside world—an excellent default, as we will see in chapter 8!—which means that, at the moment, this module is exposing only `main`. If we want to access `photoDecoder` from `PhotoGrooveTests`, we'll have to expose it too.

We can do this by changing the first line of the `PhotoGroove` module like so:

```
port module PhotoGroove exposing (main, photoDecoder)
```

With that change in place, we can move on to writing the test. First we'll write it using only what you know already, and then you'll learn some new Elm techniques to make it nicer to read.

### WRITING A FAILING TEST FIRST

Let's start by renaming `suite` to `decoderTest`, and implementing it as a failing test so you can see what failed test output looks like.

#### Listing 6.1 decoderTest

```
module PhotoGrooveTests exposing (...)

import Expect exposing (Expectation)
import Json.Decode exposing (decodeString)
import PhotoGroove
import Test exposing (...)

decoderTest : Test
decoderTest =
    test "title defaults to (untitled)" Test description
        (\_ ->
            Sample JSON string [ "url": "fruits.com", "size": 5" Anonymous function wrapper
                |> decodeString PhotoGroove.photoDecoder
                |> Expect.equal
                    (Ok { url = "fruits.com", size = 5, title = "" })
        ) Decoding the JSON
```

You may recall the `decodeString` function from chapter 4. It takes a decoder and a string containing some JSON, then returns a `Result`:

```
decodeString : Decoder val -> String -> Result String val
```

Here we've supplied `photoDecoder` as the decoder, and "`{"url": "fruits.com", "size": 5}`" as the JSON string. That JSON string is pretty noisy with all those backslash-escaped quotes, though. Let's clean that up a bit.

### TRIPLE-QUOTED STRINGS

Elm has a triple-quote syntax for writing longer quotes. Table 6.1 shows how to use that syntax to rewrite the preceding JSON string.

**Table 6.1** Using triple-quote string syntax

Single quote	Triple quote
jsonSingleQuote = <pre>"{\"url\": \"fruits.com\", \"size\": 5}"</pre>	jsonTripleQuote = <pre>"""   {"url": "fruits.com", "size": 5} """</pre>

The triple-quote syntax is more verbose—three quotes is, after all, more than one—but it has two advantages over the more common single-quote syntax:

- Triple-quoted strings can span across multiple lines.
- Triple-quoted strings can contain unescaped quotation marks.

Both of these are particularly useful for JSON strings. For one, they let us dodge a veritable avalanche of backslashes! For another, it's reasonable to have long JSON strings in decoder tests. In those cases, having strings that can span multiple lines really comes in handy.

Because this is a fairly short bit of JSON, we can triple-quote it but keep it on one line. Let's change "`{\"url\": \"fruits.com\", \"size\": 5}`" to "`"""{"url": "fruits.com", "size": 5}"""` and keep moving.

### RUNNING ALL TESTS

Our test expects that decoding this JSON string with `photoDecoder` will return `(Ok { url = "fruits.com", size = 5, title = "" })`. But in a shocking plot twist, it actually will not!

To see what it returns instead, let's rerun `elm-test` and check out the failure message. The `elm-test` command will search our tests directory for `.elm` files, and run all the `Test` values they expose. In our case, `elm-test` will find `PhotoGrooveTests.elm` and an exposed `Test` value called `decoderTest`. If we added a second `.elm` file to our `tests/` directory, its exposed `Test` values would also be included the next time we ran `elm-test`.

**NOTE** The exposing `(...)` in our module `PhotoGrooveTests` exposing `(...)` declaration means our `PhotoGrooveTests` module exposes all of its top-level values—currently just `decoderTest`—so other modules can import them. Later, you'll learn how to reap some major benefits from having our modules intentionally expose less, but for now we'll continue exposing everything.

### INSPECTING FAILURE OUTPUT

Let's run our tests by running this at the command line:

```
elm-test
```

We should see the output in figure 6.3.

```
↓ PhotoGrooveTests
✗ title defaults to (untitled)

Ok { url = "fruits.com", size = 5, title = "(untitled)" }
|
| Expect.equal
|
Ok { url = "fruits.com", size = 5, title = "" }
```

### TEST RUN FAILED

Figure 6.3 Output from the failed test

See the two `Ok` values with the records inside? Those represent the arguments we passed to `Expect.equal`. They differ in that one has `title = "(untitled)"`, whereas the other has `title = ""`.

It's no coincidence that the record on the bottom is the record at the end of our pipeline:

```
"""{"url": "fruits.com", "size": 5}"""
|> decodeString PhotoGroove.photoDecoder
|> Expect.equal
(Ok { url = "fruits.com", size = 5, title = "" })
```

As long as our test code is written in a pipeline style that ends in `| > Expect.equal`, we should be able to look at our code side by side with the test output and see by visual inspection which value `Expect.equal` received as which argument. The value at the top in our test should line up with the value at the top of the console output, and the value on the bottom in our test should line up with the value on the bottom of the console output.

### FIXING THE FAILING TEST

The failing test output also told us why the test failed: we wrote that we expected the `title` field to be `" "`, but actually it was `"(untitled)"`. (You'd think the test description we wrote of `"title defaults to (untitled)"` would have tipped us off ahead of time, but here we are.)

This test will pass after we fix the expectation. Let's change the `Expect.equal` call to this:

```
Expect.equal (Ok { url = "fruits.com", size = 5, title = "(untitled)" })
```

Now let's see if that worked, by running `elm-test` once more. The output should look like this:

### TEST RUN FAILED

Great success!

**TIP** It's useful to start with an intentionally failing test and then fix it. This helps avoid the embarrassing situation of accidentally writing a test that always passes! After you've seen the test fail, and then fixed it—or, even better, fixed the implementation it's testing—you can have more confidence that the test is actually verifying something.

#### REPLACING PARENTHESES WITH THE <| OPERATOR

Our test got easier to read when we switched to the triple-quote syntax, but we still have those clunky parentheses around our anonymous function. We can make things nicer by using the `<|` operator you learned about in chapter 4.

You may recall that the `<|` operator takes a function and another value, and passes the value to the function. We can use it to refactor our test as shown in table 6.2.

Table 6.2 Replacing parentheses with the `<|` operator

Parentheses	Left pipe
<pre>test "title defaults to (untitled)"   (\_ -&gt;    ... )</pre>	<pre>test "title defaults to (untitled)" &lt;    \_ -&gt;   ...</pre>

Nice! Things are looking cleaner now, but we can still improve this test.

### 6.1.3 Narrowing test scope

Our test's description says `"title defaults to (untitled)"`, but we're actually testing much more than that. We're testing the structure of the entire `Photo`!

This means if we update the structure of `Photo`—say, to add a new field—this test will break. We'll have to come back and fix it manually, when we wouldn't have needed to if the test did not rely on the entire `Photo` structure. Even worse, if something breaks about `url` or `size`, we'll get failures not only for the tests that are directly responsible for those, but also for this unrelated test of `title`. Those spurious failures will clutter up our test run output!

#### TESTING ONLY THE TITLE

Here's how our pipeline currently works:

```
"""{"url": "fruits.com", "size": 5}"""
|> decodeString PhotoGroove.photoDecoder
|> Expect.equal (Ok { url = "fruits.com", size = 5, title = "(untitled)" })
```

Let's refactor the test to work with `title` only, by introducing a function called `Result.map`:

```
"""{"url": "fruits.com", "size": 5}"""
|> decodeString PhotoGroove.photoDecoder
```

```
|> Result.map (\photo -> photo.title)
|> Expect.equal (Ok "untitled")
```

We've made two changes here:

- We added a step to our pipeline: `Result.map (\photo -> photo.title)`.
- We changed `(Ok { url = "fruits.com", size = 5, title = "untitled" })` to the narrower test of `(Ok "(untitled)")`.

## RESULT.MAP

You've previously seen two functions—`map`: `List.map` from chapter 2 and `Json.Decode.map` from chapter 5. Now we're adding `Result.map` to your repertoire!

Check out the similarities between the types of `List.map`, `Json.Decode.map`, and `Result.map`:

```
List.map : (a -> b) -> List      a -> List      b
Json.Decode.map : (a -> b) -> Decoder  a -> Decoder  b
Result.map : (a -> b) -> Result x a -> Result x b
```

Pretty similar! Each `map` function does the following:

- 1 Takes a data structure with a type variable we've called `a` here
- 2 Also takes an `(a -> b)` function that converts from `a` to `b`
- 3 Returns a version of the original data structure in which the type variable is `b` instead of `a`

Here are some examples of `map` functions using `String.toInt`. Note how `map` consistently transforms the value inside the container from an integer to a string:

```
List.map  String.toInt          [ 5 ] ==      [ "5" ]
Json.Decode.map  String.toInt  (succeed 5) == (succeed "5")
Result.map  String.toInt       (Ok 5) ==      (Ok "5")
```

Transforming a container's contents is the main purpose of `map`, but in some cases `map` does not transform anything, and returns the original container unchanged:

```
List.map  String.toInt          [] ==      []
Json.Decode.map  String.toInt  (fail "argh!") == (fail "argh!")
Result.map  String.toInt       (Err 1) ==     (Err 1)
```

As we can see, sometimes `map` functions decline to transform an entire classification of values:

- `List.map` has no effect on `[]`.
- `Json.Decode.map` has no effect on decoders created with `fail`.
- `Result.map` has no effect on `Err` variants.

It's up to each `map` implementation to decide how to handle the values it receives, but in general they should fit this familiar pattern of transforming the contents of a container.

## Inferring implementation details from a type

Even without knowing their implementations, we might have been able to guess that `List.map` would not transform empty lists. After all, if a collection is empty, there's nothing to transform!

It's harder to guess that `Result.map` would ignore `Err` values, as there is no equivalent "empty collection" for `Result`. Believe it or not, once you know what to look for, you can find enough information in the type of `Result.map` to be certain that it could not possibly transform `Err` values!

Here's its type again. This time, let's take a closer look at the type variable that refers to `Err`; namely, `x`:

```
Result.map : (a -> b) -> Result x a -> Result x b
```

Suppose the implementation of `Result.map` tried to pass an `x` value to the `(a -> b)` transformation function. That implementation wouldn't compile! `x` and `a` are different types, so passing an `x` value to a function expecting `a` would be a type mismatch. The transformation function can't possibly affect an `Err`, because it can't be passed one.

There is a function that transforms the error, called `Result.mapError`:

```
Result.mapError : (x -> y) -> Result x a -> Result y a
```

Can you spot the difference? `Result.mapError` accepts a transformation function that takes an `x` but not an `a`. It can't transform an `Ok` value because it can't be passed one, and sure enough, `Result.mapError` does nothing when passed an `Ok` value.

Taking this idea even further, have a look at the `identity` function, from the `Basics` module:

```
identity : a -> a
```

This function knows so little about its argument that it can't do anything to it. For example, if it tried to divide whatever it received by 2, it would have to be `identity : Float -> Float` instead. The only way to implement an Elm function with the type `a -> a` is to have it return its argument unchanged:

```
identity : a -> a  
identity a = a
```

Inferring implementation details like this can speed up bug hunting. Sometimes you can tell whether a function a coworker wrote might possibly be the culprit behind a bug you're tracking down just by looking at its type. If the function couldn't possibly affect the problematic value, you know you're clear to move on and search elsewhere.

## USING THE .TITLE SHORTHAND

We can make one more refactor to our test. Take a closer look at the anonymous function we're passing to `Result.map`:

```
""" {"url": "fruits.com", "size": 5}"""
|> decodeString PhotoGroove.photoDecoder
|> Result.map (\photo -> photo.title)
|> Expect.equal (Ok "(untitled)")
```

Functions like this come up enough that Elm has a shorthand for them. Let's replace this entire anonymous function with `.title`:

```
|> Result.map .title
```

Writing `.title` by itself gives us a function that takes a record and returns the contents of its `title` field. It's exactly the same as the `(\photo -> photo.title)` function we had there before, except that it's shorter.

## THE UNIT TEST WITH NARROWED SCOPE

Here's the original test we began with:

```
decoderTest : Test
decoderTest =
    test "title defaults to (untitled)"
        (\_ ->
            """ {"url": "fruits.com", "size": 5}"""
                |> decodeString PhotoGroove.photoDecoder
                |> Expect.equal
                    (Ok { url = "fruits.com", size = 5, title = "" })
        )
```

We refactored it to use triple-quoted strings, to test only the decoded title using `Result.map .title`, and to use the `<|` operator instead of parentheses around our anonymous function. The following listing shows our refactored `decoderTest` in all its glory.

### Listing 6.2 Refactored decoderTest

```
decoderTest : Test
decoderTest =
    test "title defaults to (untitled)" <|
        \_ ->
            """ {"url": "fruits.com", "size": 5}"""
                |> decodeString PhotoGroove.photoDecoder
                |> Result.map .title
                |> Expect.equal (Ok "(untitled)")
```

This works great! We can now rerun `elm-test` to confirm that the refactored test still passes.

However, we're testing only this one particular hardcoded JSON string. Next, we'll use fuzz tests to expand the range of values our test covers, without writing additional tests by hand.

## 6.2 Writing fuzz tests

When writing tests for business logic, it can be time-consuming to hunt down *edge cases*—those unusual inputs that trigger bugs that never manifest with more common inputs. In Elm, *fuzz tests* help us detect edge case failures by writing one test that verifies a large number of randomly generated inputs.

**DEFINITION** Elm’s *fuzz tests* are tests that run several times with randomly generated inputs. Outside Elm, this testing style is sometimes called *fuzzing*, *generative testing*, *property-based testing*, or *QuickCheck-style testing*. `elm-test` went with *fuzz* because it’s concise, suggests randomness, and is fun to say.

Figure 6.4 shows what we’ll be building toward.

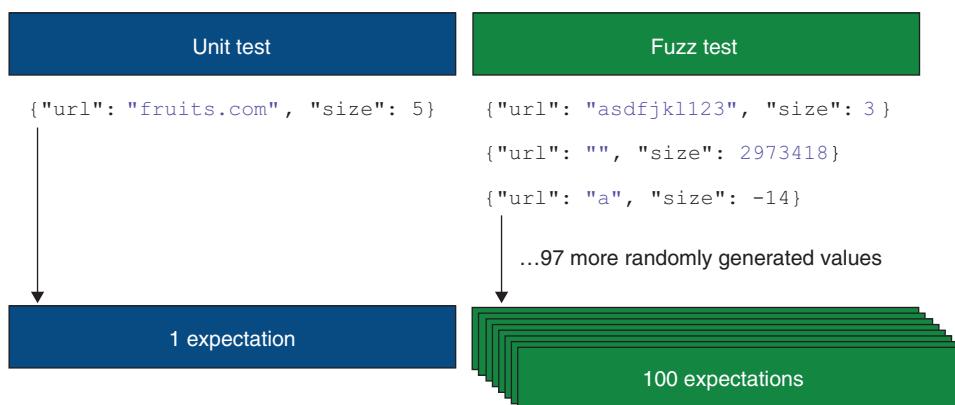


Figure 6.4 Randomly generating inputs with fuzz tests

A common way to write a fuzz test is to start by writing a unit test and then convert it to a fuzz test to help identify edge cases. Let’s dip our toes into the world of fuzz testing by converting our existing unit test to a fuzz test. We’ll do this by randomly generating our JSON instead of hardcoding it, so we can be sure our default title works properly no matter what the other fields are set to!

### 6.2.1 Converting unit tests to fuzz tests

Before we can switch to using randomly generated JSON, we need to replace our hardcoded JSON string with some code to generate that JSON programmatically.

#### BUILDING JSON PROGRAMMATICALLY WITH `Json.Encode`

Just as we use the `Json.Decode` module to turn JSON into Elm values, we can use the `Json.Encode` module to turn Elm values into JSON. Let’s add this to the top of `PhotoGrooveTests.elm`, right after `import Json.Decode exposing (decodeString)`:

```
import Json.Encode as Encode
```

Because JSON encoding is the only type of encoding we'll be doing in this file, that as `Encode` alias lets us write `Encode.foo` instead of the more verbose `Json.Encode.foo`. While we're at it, let's give our `Json.Decode` import the same treatment, and change it to this:

```
import Json.Decode as Decode exposing (decodeString)
```

### JSON.ENCODE.VALUE

Whereas the `Json.Decode` module centers around the `Decoder` abstraction, the `Json.Encode` module centers around the `Value` abstraction. A `Value` (short for `Json.Encode.Value`) represents a JSON-like structure. In our case, we will use it to represent actual JSON, but it can represent objects from JavaScript (like the JavaScript event objects we decoded in chapter 5) as well.

We'll use three functions to build our `{"url": "fruits.com", "size": 5}` JSON on the fly:

- `Encode.int : Int -> Value`
- `Encode.string : String -> Value`
- `Encode.object : List ( String, Value ) -> Value`

`Encode.int` and `Encode.string` translate Elm values into their JSON equivalents. `Encode.object` takes a list of key-value pairs; each key must be a `String`, and each value must be a `Value`. Table 6.3 shows how we can use these functions to create a `Value` representing the same JSON structure as the one our hardcoded string currently represents.

**Table 6.3** Switching from `String` to `Json.Encode.Value`

String	Json.Encode.Value
<code>"""{"url": "fruits.com", "size": 5}"""</code>	<code>Encode.object [ ( "url", Encode.string "fruits.com" ), ( "size", Encode.int 5 ) ]</code>

### JSON.DECODE.DECODEVALUE

After we have this `Value` we want, we could do two things with it:

- Call `Encode.encode` to convert the `Value` to a `String`, and then use our existing `decodeString` `photoDecoder` call to run our decoder on that JSON string.
- Don't bother calling `Encode.encode`, and instead swap out our `decodeString` `photoDecoder` call for a call to `decodeValue` `photoDecoder` instead.

Like `decodeString`, the `decodeValue` function also resides in the `Json.Decode` module. It decodes a `Value` directly, without having to convert to and from an intermediate string representation. That's simpler and will run faster, so we'll do it that way.

Let's start by editing our `import Json.Decode` line to expose `decodeValue` instead of `decodeString`. It should end up looking like this:

```
import Json.Decode as Decode exposing (decodeValue)
```

Then let's incorporate our new encoding and decoding logic into our test's pipeline.

### Listing 6.3 Using programmatically created JSON

```
decoderTest : Test
decoderTest =
    test "title defaults to (untitled)" <|
        \_ ->
            [ ( "url", Encode.string "fruits.com" )
            , ( "size", Encode.int 5 )
            ]
            |> Encode.object
            |> decodeValue PhotoGroove.photoDecoder
            |> Result.map .title
            |> Expect.equal (Ok " (untitled) ")
```

We now call  
decodeValue instead  
of decodeString here.

### FROM TEST TO FUZZ2

Now we're building our JSON programmatically, but we're still building it out of the hardcoded values `"fruits.com"` and `5`. To help our test cover more edge cases, we'll replace these hardcoded values with randomly generated ones.

The Fuzz module will help us do this. Add this after `import Expect exposing (Expectation)`:

```
import Fuzz exposing (Fuzzer, int, list, string)
```

We want a randomly generated string to replace `"fruits.com"`, and a randomly generated integer to replace `5`. To access those, we'll make the substitution shown in table 6.4.

Table 6.4 Replacing a unit test with a fuzz test

Unit test	Fuzz test
<pre>test "title defaults to (untitled)" &lt;      \_ -&gt;</pre>	<pre>fuzz2 string int "title defaults to (untitled)" &lt;      \url size -&gt;</pre>

We've done two things here. First we replaced the call to `test` with a call to `fuzz2 string int`. The call to `fuzz2` says that we want a fuzz test that randomly generates two values. `string` and `int` are *fuzzers* specifying that we want the first generated value to be a string, and the second to be an integer. Their types are `string : Fuzzer String` and `int : Fuzzer Int`.

**DEFINITION** A *fuzzer* specifies how to randomly generate values for fuzz tests.

The other change we made was to our anonymous function. It now accepts two arguments: `url` and `size`. Because we've passed this anonymous function to `fuzz2` string int, `elm-test` will run this function 100 times, each time randomly generating a fresh `String` value and passing it in as `url`, and a fresh `Int` value and passing it in as `size`.

**NOTE** `Fuzz.string` does not generate strings completely at random. It has a higher probability of generating values that are likely to cause bugs: the empty string, very short strings, and very long strings. Similarly, `Fuzz.int` prioritizes generating 0, a mix of positive and negative numbers, and a mix of very small and very large numbers. Other fuzzers tend to be designed with similar priorities.

### USING THE RANDOMLY GENERATED VALUES

Now that we have our randomly generated `url` and `size` values, all we have to do is to use them in place of our hardcoded `"fruits.com"` and `5` values. Here's our final fuzz test.

#### Listing 6.4 Our final complete fuzz test

```
decoderTest : Test
decoderTest =
    fuzz2 string int "title defaults to (untitled)" <|
        \url size ->
            [ ( "url", Encode.string url )
            , ( "size", Encode.int size )
            ]
            |> Encode.object
            |> decodeValue PhotoGroove.photoDecoder
            |> Result.map .title
            |> Expect.equal (Ok "(untitled)")
```

**url and size come from  
the string and int fuzzers  
we passed to fuzz2.**

Great! We can now have considerably more confidence that any JSON string containing only properly set `"url"` and `"size"` fields—but no `"title"` field—will result in a photo whose title defaults to `"(untitled)"`.

**TIP** For even greater confidence, we can run `elm-test --fuzz 5000` to run each fuzz test function 5,000 times instead of the default of 100 times. Specifying a higher `--fuzz` value covers more inputs, but it also makes tests take longer to run. Working as a team can get us more runs without any extra effort. Consider that if each member of a five-person team runs the entire test suite 10 times per day, the default `--fuzz` value of 100 gets us 5,000 runs by the end of the day!

Next, we'll turn our attention to a more frequently invoked function in our code base: `update`.

## 6.2.2 Testing update functions

All Elm programs share some useful properties that make them easier to test:

- The entire application state is represented by a single Model value.
- Model changes only when update receives a Msg and returns a new Model.
- update is a plain old function, so we can call it from tests like any other function.

Let's take a look at the type of update:

```
update : Msg -> Model -> ( Model, Cmd Msg )
```

Because this one function serves as the gatekeeper for all state changes in our application, all it takes to test any change in application state is to do the following:

- 1 Call update in a test, passing the Msg and Model of our choice.
- 2 Examine the Model it returns.

### TESTING CLICKEDPHOTO

Let's use this technique to test one of our simplest state changes: when a SlidHue message—introduced in chapter 5—comes through the application. For reference, here's the branch of update's case-expression that runs when it receives a SlidHue message:

```
SlidHue hue ->
    applyFilters { model | hue = hue }
```

This might seem like a trivial thing to test. It does so little. All it does is update the model's hue field, right?

Not quite! Importantly, this logic also calls applyFilters. What if applyFilters later returns a different model, introducing a bug? Even writing a quick test for SlidHue can give us an early warning against that and potential future regressions in our update implementation. The following listing shows a basic implementation, which combines several concepts we've seen elsewhere in the chapter.

### Listing 6.5 Testing SlidHue

```
slidHueSetsHue : Test
slidHueSetsHue =
    fuzz int "SlidHue sets the hue" <|
        \amount ->
            initialModel
                |> update (SlidHue amount)
                |> Tuple.first
                |> .hue
                |> Expect.equal amount
```

The diagram illustrates the flow of the test code. It starts with a call to `initialModel`, which is annotated with a bracket labeled "Begins with the initial model". This is followed by a call to `update (SlidHue amount)`, which is annotated with a bracket labeled "Calls update directly". The result of `update` is discarded, as indicated by a bracket labeled "Discards the Cmd returned by update". The `Expect` block at the end of the code is annotated with a bracket labeled "Returns the model's hue field". Finally, a large bracket at the bottom labeled "The model's hue should match the amount we gave SlidHue." spans the entire sequence from `initialModel` to the final `Expect` condition.

You may recall `Tuple.first` from chapter 1. It takes a tuple and returns the first element in it. Because `update` returns a `( Model, Cmd Msg )` tuple, calling `Tuple.first` on that value discards the `Cmd` and returns only the `Model`—which is all we care about in this case.

Let's run the test and . . . whoops! It didn't compile!

### EXPOSING VARIANTS

Reading the compiler error message, you might remember that although we previously edited the `PhotoGroove` module to have it expose `photoDecoder`, we haven't done the same for all the values we're using here, like `initialModel` and `update`. Let's change our module declaration to expose these:

```
port module PhotoGroove exposing
    (Model, Msg(..), Photo, initialModel, main, photoDecoder, update)
```

The `(..)` in `Msg(..)` means to expose not only the `Msg` type itself (for use in type annotations such as `Msg -> Model -> Model`), but also its variants. If we'd exposed only `Msg` rather than `Msg(..)`, we still wouldn't be able to use variants like `SlideHue` in our test. In contrast, `Photo` is a type alias, so writing `Photo(..)` would yield an error; `Photo` has no variants to expose.

**NOTE** We also could have written `port module PhotoGroove exposing(..)` instead of separately listing what we want to expose. However, it's best to avoid declaring modules with `exposing(..)`, except in the case of test modules such as `PhotoGrooveTests`. By explicitly listing only the values and types we want to expose, we avoid unintentionally exposing implementation details that would be better kept hidden within the module.

Because we're using `SlideHue` without qualifying it with its module name—which we could have done by writing `PhotoGroove.SlideHue` instead—we'll need to expose some variants in our `import` declaration to bring them into scope. Let's do that for `Msg`, `Photo`, `Model`, and `initialModel` by changing the `import PhotoGroove` line in `PhotoGrooveTests` like so:

```
import PhotoGroove exposing (Model, Msg(..), Photo, initialModel, update)
```

### Making commands testable

As of this writing, `elm-test` does not support testing commands directly. However, you can work around this if you're willing to modify your `update` function. First, make a custom type that represents all the commands your application can run. In our case, that would be the following:

```
type Commands
    = FetchPhotos Decoder String
    | SetFilters FilterOptions
```

**(continued)**

Then change `update` to have this type:

```
update : Msg -> Model -> ( Model, Commands )
```

Next, write a function that converts from `Commands` to `Cmd Msg`:

```
toCmd : Commands -> Cmd Msg
toCmd commands =
    case commands of
        FetchPhotos decoder url ->
            Http.get { url = url, expect = Http.expectJson GotPhotos
decoder }

        Setfilters options ->
            setFilters options
```

Finally, we can use these to assemble the type of `update` that `Browser.element` expects:

```
updateForProgram : Msg -> Model -> ( Model, Cmd Msg )
updateForProgram msg model =
    let
        ( newModel, commands ) =
            update msg model
    in
        ( newModel, toCmd commands )
```

Now we can pass `updateForProgram` to `Browser.element`, and everything will work as before. The difference will be that `update` returns a value we can examine in as much depth as we like, meaning we can test it in as much depth as we like.

This technique is useful, but it is rarely used in practice. The more popular approach is to hold off on testing commands until `elm-test` supports them directly.

Excellent! If you rerun `elm-test`, you should see two passing tests instead of one.

### **6.2.3 *Creating multiple tests with one function***

We've now tested `SlidHue`, but `SlidRipple` and `SlidNoise` are just as prone to mistakes as `SlidHue`. One way to add tests for the other two would be by copying and pasting the `SlidHue` test two more times, and tweaking the other two to use `SlidRipple` and `SlidNoise`. This is a perfectly fine technique! If a test doesn't have another test verifying its behavior, the best verification tool we have is reading the test's code. Sharing code often makes it harder to tell what a test is doing by inspection, which can seriously harm test reliability.

In the case of these sliders, though, we'd like to share code for a different reason than conciseness: they ought to behave the same way. If in the future we changed one test but forgot to change the others, that would almost certainly be a mistake. Sharing code prevents that mistake from happening.

### GROUPING TESTS WITH DESCRIBE

The following listing shows how we can use the `Test.describe` function to make a group of slider tests.

#### Listing 6.6 Testing SlidHue

```

sliders : Test
sliders =
    describe "Slider sets the desired field in the Model"
        [ testSlider "SlidHue" SlidHue .hue
        , testSlider "SlidRipple" SlidRipple .ripple
        , testSlider "SlidNoise" SlidNoise .noise
        ]
    
```

**(toMsg : Int -> Msg)  
will be SlidHue,  
SlidRipple, or SlidNoise.**

```

testSlider : String -> (Int -> Msg) -> (Model -> Int) -> Test
testSlider description toMsg amountFromModel =
    fuzz int description <|
        \amount ->
            initialModel
                |> update (toMsg amount)
                |> Tuple.first
                |> amountFromModel
                |> Expect.equal amount
    
```

**Groups this List  
of Test values under  
one description**

**Uses testSlider's description  
argument as the test's description**

**(amountFromModel : Model -> Int)  
will be .hue, .ripple, or .noise.**

The `Test.describe` function has this type:

```
describe : String -> List Test -> Test
```

When one of the tests in the given list fails, `elm-test` will print out not only that test's description, but also the string passed to `describe` as the first argument here. For example, if a test with a description of "SlidHue" were listed as one of the tests inside a `describe "Slider sets the desired field in the Model"`, its failure output would look like figure 6.5.

↓ PhotoGroveTests  
 ↓ Slider sets the desired field in Model  
 ✘ SlidHue

Figure 6.5 Failure output after using `describe`

### RETURNING TESTS FROM A CUSTOM FUNCTION

The `testSlider` function is a generalized version of our `slidHueSetsHue` test from earlier. Table 6.5 shows them side by side.

Table 6.5 Comparing `slidHueSetsHue` and `testSlider`

slidHueSetsHue	testSlider
<pre>fuzz int "SlidHue sets the hue" &lt;      \amount -&gt;         initialModel              &gt; update (SlidHue amount)              &gt; Tuple.first              &gt; .hue              &gt; Expect.equal amount</pre>	<pre>fuzz int description &lt;      \amount -&gt;         initialModel              &gt; update (toMsg amount)              &gt; Tuple.first              &gt; amountFromModel              &gt; Expect.equal amount</pre>

Have a look at the type of `testSlider`:

```
testSlider : String -> (Int -> Msg) -> (Model -> Int) -> Test
testSlider description toMsg amountFromModel =
```

Its three arguments correspond to what we want to customize about the `SlidHue` test:

- `description` : `String` lets us use descriptions other than "SlidHue sets the hue".
- `toMsg` : `Int -> Msg` lets us use messages other than `SlidHue`.
- `amountFromModel` : `Model -> Int` lets us use `model` fields other than `.hue`.

Because the `testSlider` function returns a `Test`, and `describe` takes a `List Test`, we were able to put these together to obtain our customized hue, ripple, and noise tests like so:

```
describe "Slider sets the desired field in the Model"
  [ testSlider "SlidHue" SlidHue .hue
    , testSlider "SlidRipple" SlidRipple .ripple
    , testSlider "SlidNoise" SlidNoise .noise
  ]
```

This compiles because the `SlidHue` variant is a function whose type is `SlidHue : Int -> Msg`, which is what the `toMsg` argument expects, and because the `.hue` shorthand is a function whose type is `.hue : Model -> Int`, which is what the `amountFromModel` argument expects.

#### RUNNING THE COMPLETE TESTS

Let's take them out for a spin! If you rerun `elm-test`, you should still see four happily passing tests.

**TIP** Notice how `elm-test` always prints "to reproduce these results, run `elm-test --fuzz 100 --seed`" and then a big number? That big number is the random number seed used to generate all the fuzz values. If you encounter a fuzz test that is hard to reproduce, you can copy this command and send it to a collaborator. If they run it on the same set of tests, they will see the same output you do; fuzz tests are deterministic given the same seed.

We've now tested some decoder business logic, confirmed that running a `SlidHue` message through `update` sets `model.hue` appropriately, and expanded that test to test the same logic for `SlidRipple` and `SlidNoise` by using one function that created multiple tests. Next, we'll take the concepts you've learned so far and apply them to testing our rendering logic as well!

### 6.3 *Testing views*

Our application has several rules concerning how we render thumbnail photos. For example:

- Initially, we don't render any thumbnails.

- Once the photos load, we render a thumbnail for each of them.
- When you click a thumbnail, that photo becomes selected.

It's important that these features keep working as we expand our application. By writing tests for each of them, we can guard against not only future business logic regressions in `update`, but also visual regressions in `view`. In the remainder of the chapter, we will write tests to verify all three of these rules.

### 6.3.1 Testing DOM structure

The functions to test DOM structure come from different modules. Let's import the ones we'll be using by adding the following to `PhotoGrooveTests.elm`:

```
import Html.Attributes as Attr exposing (src)
import Test.Html.Query as Query
import Test.Html.Selector exposing (text, tag, attribute)
```

**NOTE** It's common to alias `Test.Html.Query` as `Query` like this for brevity's sake. We'll refer to this as "the `Query` module" in this chapter, even though the fully qualified name would be "`Test.Html.Query` module."

We'll also need to have our `PhotoGroove` module declaration expose `view` so we can import it. While we're at it, let's also expose `Status(..)` and `urlPrefix`, which we'll use in the next section:

```
exposing (Model, Msg(..), Photo, Status(..),
          initialModel, main, photoDecoder, update, urlPrefix, view)
```

We'll also expose them when we import them in `PhotoGrooveTests`:

```
import PhotoGroove exposing (Model, Msg(..), Photo, Status(..),
                             initialModel, update, urlPrefix, view)
```

With these changes in place, we're ready to write our first `view` test!

#### No photos? No thumbnails.

The first rule we'll test is this one:

- Initially, we don't render any thumbnails.

Here's the test we'll write for that:

```
noPhotosNoThumbnails : Test
noPhotosNoThumbnails =
    test "No thumbnails render when there are no photos to render." <|
        \_ ->
            initialModel
                |> PhotoGroove.view
                |> Query.fromHtml
                |> Query.findAll [ tag "img" ]
                |> Query.count (Expect.equal 0)
```

This pipeline has several steps, so let's break them into two parts.

## BUILDING A QUERY.SINGLE

The first part of the pipeline is this:

```
initialModel
|> PhotoGroove.view
|> Query.fromHtml
```

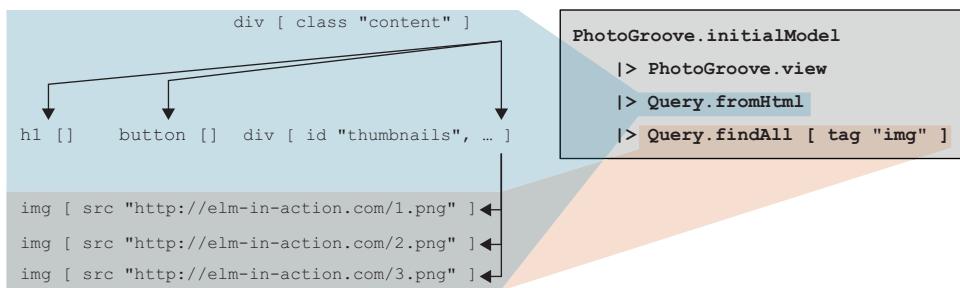
This code kicks things off by building a representation of the DOM that our test can examine. Table 6.6 breaks down the types involved in this expression.

**Table 6.6 Types involved in `initialModel |> view |> Query.fromHtml`**

Expression	Type
<code>initialModel</code>	<code>Model</code>
<code>PhotoGroove.view</code>	<code>Model -&gt; Html Msg</code>
<code>Query.fromHtml</code>	<code>Html msg -&gt; Query.Single msg</code>
<code>initialModel</code>  > <code>PhotoGroove.view</code>  > <code>Query.fromHtml</code>	<code>Query.Single msg</code>

Passing `initialModel` to `view` gives us the `Html` that will display on Photo Groove's initial render. The functions in the `Query` module descend into this `Html`, starting from its root node and proceeding down the tree of DOM nodes it describes. Once we've narrowed it down to the nodes we care about, we call one final function to verify something about them, and produce an `Expectation`.

Figure 6.6 shows the `img` tags `Query.findAll` will find.



**Figure 6.6 Finding all the `img` tags in the DOM**

## QUERYING HTML

Query functions make use of two types as they descend into `Html`:

- `Query.Single`, which represents a single DOM node
- `Query.Multiple`, which represents multiple DOM nodes

Some functions work in terms of `Single` nodes, whereas others work in terms of `Multiple` nodes. Representing these as distinct types makes it easier to tell when we expect a query to have one result versus several. For example, the `Query.count` function takes `Multiple`, whereas the `Query.children` function takes `Single` and returns `Multiple`.

### CONVERTING FROM HTML TO QUERY

The `Query.fromHtml` function begins the process of descending into an `Html` value, by returning a `Single` representing the `Html`'s root node. What is that root node in our case? We can tell by looking at the `view` function that returned that `Html`; namely, `PhotoGroove.view`:

```
view : Model -> Html Msg
view model =
    div [ class "content" ]
```

Because `view` returns a `div` with a `class` of "`content`", when our `Query.fromHtml` function returns a `Query.Single` value, that `Single` value will refer to this `div`.

**NOTE** The complete type of `Query.fromHtml` is `fromHtml : Html msg -> Query.Single msg`. Notice the type variable `msg` in there? Because `view` returns an `Html Msg`, calling `Query.fromHtml` will return a `Query.Single Msg` value.

### CONVERTING FROM QUERY TO EXPECTATION

Now that we have our `Single` value representing the `div [ class "content" ]` at the root of our `Html`, let's look at the rest of the pipeline—where we transform that `Single` into an `Expectation`. Table 6.7 breaks down the types involved in this process.

Table 6.7 Transforming a `Query.Single` into an `Expectation`

Expression	Type
<code>initialModel</code>  > <code>PhotoGroove.view</code>  > <code>Query.fromHtml</code>	<code>Query.Single msg</code>
<code>Query.findAll [ tag "img" ]</code>	<code>Query.Single msg -&gt; Query.Multiple msg</code>
<code>Query.count (Expect.equal 0)</code>	<code>Query.Multiple msg -&gt; Expectation</code>

We've used two functions to get from `Single` to `Expectation`: `Query.findAll` and `Query.count`. Here's the type of `Query.findAll`:

```
findAll : List Selector -> Single msg -> Multiple msg
```

We give it a list of selectors—ways to identify a particular DOM node—and a `Single`, and it returns a `Multiple` representing all the descendant nodes that match the given selectors. We gave it only one selector—`tag "img"`—which means `findAll`

will return all the `img` tags in the DOM tree beneath the `div [ "content" ]` at the root of our `Single` query.

Finally, once we have our `Multiple` nodes, we're ready to make a claim about them. In this case, our test is that we expect no thumbnails to be rendered, so we want to make the claim that the `Multiple` query contains zero nodes. This is where `Query.count` comes in:

```
count : (Int -> Expectation) -> Multiple msg -> Expectation
```

#### PARTIALLY APPLYING EXPECT.EQUAL

Notice that `Query.count` takes an `(Int -> Expectation)` function, which we satisfied by passing it a partially applied `Expect.equal`:

```
Query.count (Expect.equal 0)
```

As you may recall, `Expect.equal` takes two arguments and compares them to verify that they're equal. That means these two expressions are equivalent:

```
Query.count (Expect.equal 0)
Query.count (\count -> Expect.equal 0 count)
```

One way to read `Query.count (Expect.equal 0)` is, “Count the results in the query, and expect that count to equal 0.”

#### COMPLETE VIEW TEST

Here's the complete implementation of our `noPhotosNothumbnails` test once again, from `Model` to `Expectation` by way of `Html` and some `Query` operations.

#### Listing 6.7 noPhotosNothumbnails

```
noPhotosNothumbnails : Test
noPhotosNothumbnails =
    test "No thumbnails render when there are no photos to render." <|
        \_ ->
            initialModel
                |> PhotoGroove.view
                    |> Query.fromHtml
                        |> Query.findAll [ tag "img" ]
                            |> Query.count (Expect.equal 0)
```

Sure enough, when we run the test, it should pass!

**TIP** As our test suites get larger, it can be handy to run only a few tests at a time. Take a look at the `Test.skip` and `Test.only` functions in the documentation for the `elm-explorations/test` package on the <https://package.elm-lang.org> website. We can also run only a few test files at a time by passing them as arguments to `elm-test`; for example, `elm-test tests/DecoderTests.elm` or `elm-test tests/User/*.elm`.

Next, we'll expand this test to verify views resulting not only from the initial model, but also from models that have photos loaded.

### 6.3.2 Fuzzing view tests

The second business rule we want to test is this one:

- Once the photos load, we render a thumbnail for each of them.

#### CHECKING IF A GIVEN THUMBNAIL WAS RENDERED

Let's start by writing a function to check whether a given URL has been rendered as a thumbnail. Add this at the end of PhotoGrooveTests.elm:

```
thumbnailRendered : String -> Query.Single msg -> Expectation
thumbnailRendered url query =
    query
        |> Query.findAll[ tag "img", attribute (Attr.src (urlPrefix ++ url)) ]
        |> Query.count (Expect.atLeast 1)
```

This function starts with a `Query.Single`—which will represent the root of our page's DOM—and finds all the `img` elements within it that have the expected `src` attribute. Then it runs a `Query.count`, which expects that our query found at least one `img` element like that.

**NOTE** It's better to use `Expect.atLeast 1` than `Expect.equal 1` because our business logic permits duplicate thumbnail URLs, and we wouldn't want our test to incorrectly reject repeats as invalid.

We use `(urlPrefix ++ url)` for our `src` check instead of `url` because that's what our `viewThumbnail` implementation does. The `urlPrefix` is `"http://elm-in-action.com/"`, so without prepending that, we would be searching for a `src` of `"foo.jpeg"` when in actuality a `src` of `"http://elm-in-action.com/foo.jpeg"` was rendered—meaning this test would never pass.

#### CHECKING IF ALL THUMBNAILS WERE RENDERED

Now that we have a function to test whether a single thumbnail was rendered, let's use it to build a function that tests whether *all* thumbnails were rendered. We could test this by hardcoding some example photos, but why bother? We can get better test coverage by using fuzz tests to randomly generate URLs, and build photos from those!

We'll start by adding a function to build a photo from a single URL, and then randomly generate a list of URLs. Add this to the end of PhotoGroove.elm:

```
photoFromUrl : String -> Photo
photoFromUrl url =
    { url = url, size = 0, title = "" }
```

Next, we'll want to generate some random strings to use as URLs.

## FUZZING COLLECTIONS

We can call the `Fuzz.list` function, passing `Fuzz.string` to randomly generate a list of strings. This is the type of `Fuzz.list`:

```
list : Fuzzer a -> List (Fuzzer a)
```

If we call `fuzz (list string)`, it will give us a `Fuzzer (List String)` that we could use as our list of URLs:

```
fuzz (list string) "URLs render as thumbnails" <|
  \urls ->
```

However, there's a subtle problem here: the list fuzzer can potentially generate hundreds of elements. That might not sound like a big deal, but let's recap what we want this test to do:

- 1 Generate a list of URLs
- 2 Render a page that creates a thumbnail `Html` element for each of these URLs
- 3 Convert that entire `Html` structure to a `Query.Single`
- 4 Traverse every element inside the `Query.Single`, looking for an `img` with the right `src`
- 5 Repeat the previous step for every single one of the URLs

If the list fuzzer generates 300 URLs on average, that means for each of those 300 URLs, `Query.findAll` has to traverse 300 nodes searching for the one that matches. That's a total of 90,000 nodes to traverse, and we're not even done yet! Remember that fuzz tests run 100 times by default. If those tests generate 300 URLs on average, the total traversal count would be  $300 \times 300 \times 100$ —so we'd be looking at *nine million traversals* in a single test run. That test would take, uh . . . a bit of time to run. So let's not do that!

When test suites start taking a long time to run, it slows down the whole team. Tests accumulate, and it's important to be mindful of their performance characteristics to avoid letting slowdowns accumulate as well.

## CUSTOMIZING LIST SIZES

We can prevent this combinatorial explosion by restricting the sizes of the lists we generate. Let's start our test like this:

```
thumbnailsWork : Test
thumbnailsWork =
  fuzz (Fuzz.intRange 1 5) "URLs render as thumbnails" <|
    \urlCount ->
```

`Fuzz.intRange` will randomly generate an integer from 1 to 5. We'll use it to build a list of one to five elements. (We already have a test covering the zero-elements case: our `noPhotosNoThumbnails` test from earlier.)

Here's how we can convert from `urlCount` to a list of URLs:

```
urls : List String
urls =
    List.range 1 urlCount
        |> List.map (\num -> String.fromInt num ++ ".png")
```

The `List.range` function takes two integers and makes a list containing all the numbers in between. We can see it in action in `elm repl`:

```
> List.range 1 5
[1,2,3,4,5] : List Int
```

Now that we have a reasonably sized list of URLs, we can build photos from them by using the `photoFromUrl` function we wrote earlier. Then we can build a query using a pipeline similar to the one created for our last view test. This time, instead of leaving `initialModel` unchanged, we'll override its `photos` field to be the list of photos we just created using `photoFromUrl` on the fly:

```
{ initialModel | status = Loaded (List.map photoFromUrl urls) "" }
|> view
|> Query.fromHtml
```

This gives us a `Query.Single`, which we can use to create an `Expectation` to complete our test.

### COMBINING EXPECTATIONS WITH EXPECT.ALL

Let's pause and take a look at what we've put together so far:

- A `Query.Single` representing the root DOM node of our page
- A function that checks whether a `Query.Single` renders the given URL as a thumbnail: `thumbnailRendered : String -> Query.Single msg -> Expectation`
- A list of URLs: `urls : List String`

We can distill these down to a single `Expectation` by using the `Expect.all` function:

```
Expect.all : List (subject -> Expectation) -> subject -> Expectation
```

The purpose of `Expect.all` is to run a series of checks on a single subject value, and return a passing `Expectation` only if they all pass. In our case, the `subject` will be the `Query.Single` value we've built up, meaning we need to pass `Expect.all` a list with this type:

```
List (Query.Single msg -> Expectation)
```

We can use `thumbnailRendered` to get just such a list! Let's take a look at its type again:

```
thumbnailRendered : String -> Query.Single msg -> Expectation
```

We can get our list of checks by partially applying `thumbnailRendered` like so:

```
thumbnailChecks : List (Query.Single msg -> Expectation)
thumbnailChecks =
    List.map thumbnailRendered urls
```

Because we've passed a `List String` to `List.map`, it will pass each `String` in that list as the first argument to `thumbnailRendered`. The result of this `List.map` is the `List (Query.Single msg -> Expectation)` we needed for `Expect.all`.

### THE FINAL TEST

Putting it all together, here's what we get.

#### Listing 6.8 The complete thumbnail test

```
thumbnailsWork : Test
thumbnailsWork =
    fuzz (Fuzz.intRange 1 5) "URLs render as thumbnails" <|
        \urlCount ->
            let
                urls : List String
                urls =
                    List.range 1 urlCount
                    |> List.map (\num -> String.fromInt num ++ ".png")

                thumbnailChecks : List (Query.Single msg -> Expectation)
                thumbnailChecks =
                    List.map thumbnailRendered urls
            in
                { initialModel | status = Loaded (List.map photoFromUrl urls) ""
                }
                |> view
                |> Query.fromHtml
                |> Expect.all thumbnailChecks
```

Now that we've verified that the thumbnails display as expected, we can move on to testing that they work properly when a user clicks one.

### 6.3.3 Testing user interactions

The final piece of business logic we'll be testing is this:

- When you click a thumbnail, that photo becomes selected.

Here we can benefit from the test coverage we've obtained through tests we wrote earlier in the chapter. We already have tests that verify the following:

- When the photos load, the first one gets selected.
- Whenever `update` receives a `ClickedPhoto` message, that photo becomes selected.

Having that logic independently verified simplifies what it takes to test this requirement: all we need to do is test that when the user clicks a thumbnail, the Elm Runtime will send an appropriate `ClickedPhoto` message to `update`.

## FUZZ.MAP

Once again, we'll want a list of URLs, and once again we'll want to avoid a combinatorial explosion by limiting the number of photos we generate to only a handful. Now that we have multiple tests that want a short list of URL strings, we can avoid code duplication by creating a custom Fuzzer (List String) value that has these characteristics, using `Fuzz.map`.

Earlier in the chapter, you learned about `Result.map`, and saw how it compared to `List.map` and `Json.Decode.map`. Buckle up, because `Fuzz.map` is going to be *super duper different* from those other map functions:

```
Fuzz.map : (a -> b) -> Fuzzer    a -> Fuzzer    b
Json.Decode.map : (a -> b) -> Decoder  a -> Decoder  b
List.map : (a -> b) -> List      a -> List      b
Result.map : (a -> b) -> Result x a -> Result x b
```

Okay, not really. `Fuzz.map` works the same way as these other map functions do: it takes a function that converts from one contained value to another. The following listing shows how we can use `Fuzz.map` to implement our custom fuzzer.

### Listing 6.9 Custom fuzzer with `Fuzz.map`

```
urlFuzzer : Fuzzer (List String)
urlFuzzer =
  Fuzz.intRange 1 5
  |> Fuzz.map urlsFromCount

urlsFromCount : Int -> List String
urlsFromCount urlCount =
  List.range 1 urlCount
  |> List.map (\num -> String.fromInt num ++ ".png")
```

Now that we have this fuzzer, we can refactor our `thumbnailsWork` test to use it. First we'll remove the `urls` definition from inside its let-expression, and then we'll replace the test definition with this:

```
thumbnailsWork =
  fuzz urlFuzzer "URLs render as thumbnails" <|
    \urls ->
```

## SIMULATING CLICK EVENTS

Next, we'll write a fuzz test that renders a list of photos and simulates clicking one of them. Let's think about the structure of that test. It needs two ingredients:

- A list of one or more photos
- Knowing which photo in that list to click

One way we could set this test up is the same way we did with `thumbnailsWork` previously:

```
fuzz urlFuzzer "clicking a thumbnail selects it" <|
  \urls ->
```

There's a problem with this approach. What if `urlFuzzer` happens to generate an empty list? We'd have no photo to click!

### GENERATING A NON-EMPTY LIST

We can fix this by generating a single URL, plus a list of other URLs to go after it. It's okay if that second list happens to be empty, because we'll still have the single URL to work with:

```
fuzz2 string urlFuzzer "clicking a thumbnail selects it" <|
  \urlToSelect otherUrls ->
  let
    photos =
      [ urlToSelect ] ++ otherUrls
```

### THE :: OPERATOR

Incidentally, when we have a single element to add to the front of a list like this, the `::` operator is both more concise and more efficient than what we've done here. The following two expressions produce the same list, but the version that uses `::` is more efficient because it does not create an extra list in the process:

```
[ urlToSelect ] ++ otherUrls
  urlToSelect :: otherUrls
```

### CHOOSING WHICH PHOTO TO CLICK

This test is looking better, but there's another problem. How do we decide which photo to click? We could decide to choose the first one every time, but then our test wouldn't be very complete. We'd be testing only that clicking the *first* thumbnail works, not that clicking *any* thumbnail works.

Could we select which photo to click at random? Well, as we saw in chapter 3, generating random numbers is an effect (represented in Elm as a `Cmd`), and `elm-test` tests are not permitted to run effects.

What we can do instead is to generate two lists at random: one list to go before the URL we'll click, and another to go after it:

```
fuzz3 urlFuzzer string urlFuzzer "clicking a thumbnail selects it" <|
  \urlsBefore urlToSelect urlsAfter ->
  let
    photos =
      urlsBefore ++ urlToSelect :: urlsAfter
```

We almost have the list we want, but not quite. Because we want to make sure we click the right one, its URL needs to be unique within the list of photos. We can do this by giving it a different extension from the others; we used `".png"` in our `urlFuzzer` definition, so we'll use `".jpeg"` here:

```
url =
  urlToSelect ++ ".jpeg"

photos =
  urlsBefore ++ url :: urlsAfter
```

## HTML.TEST.EVENT

It's time to simulate the click event! We'll use the `Html.Test.Event` module to do this, so let's add it at the top of `PhotoGrooveTests` and alias it to `Event` for brevity:

```
import Test.Html.Event as Event
```

This gives us access to a function called `Event.simulate` that simulates user events, such as clicks, and checks whether they result in the expected message being sent to update. Here's how we'll use it.

### Listing 6.10 `Event.simulate`

```
clickThumbnail : Test
clickThumbnail =
    fuzz3 urlFuzzer string urlFuzzer "clicking a thumbnail selects it" <|
        \urlsBefore urlToSelect urlsAfter ->
            let
                url =
                    urlToSelect ++ ".jpeg"

                photos =
                    (urlsBefore ++ url :: urlsAfter)
                    |> List.map photoFromUrl

                srcToClick =
                    urlPrefix ++ url
            in
                { initialModel | status = Loaded photos "" }  

                    |> view  

                    |> Query.fromHtml  

                    |> Query.find [ tag "img", attribute (Attr.src srcToClick) ]  

                    |> Event.simulate Event.click  

                    |> Event.expect (ClickedPhoto url)
```

Simulates that  
a user clicked  
this img

Expects that this message  
was sent to update

Those last three lines are new! Here's what's different about them:

- We used `Query.find` instead of `Query.findAll`. This is different in that `Query.find` expects to find exactly one node, and returns a `Single` instead of a `Multiple`. If it finds zero nodes, or multiple nodes, it immediately fails the entire test.
- `Event.simulate Event.click` simulates a click event on the node returned by `Query.find`. It returns an `Event` value, representing what the Elm Runtime will produce in response to that click event.
- `Event.expect (ClickedPhoto url)` converts the `Event` into an `Expectation`, by checking that the event resulted in a `(ClickedPhoto url)` message being sent to update.

If we run all this, sure enough, it works!

## FINAL TESTS

With this test in place, we have now covered all three cases of our rendering logic that we set out to cover:

- Initially, we don't render any thumbnails.
- Once the photos load, we render a thumbnail for each of them.
- When you click a thumbnail, that photo becomes selected.

Marvelous!

## Summary

You've learned plenty in this chapter, including the following:

- How to introduce tests to an existing Elm application
- The similarities between `Result.map`, `Fuzz.map`, `List.map`, and `Json.Decode.map`
- Building JSON values using `Json.Encode`
- How to use `Json.Decode.decodeValue` instead of `decodeString`
- Describing expectations using `Expect.equal`, `Expect.atLeast`, and `Expect.all`
- Writing unit tests using the `test` function
- Writing fuzz tests by passing fuzzers to `fuzz`, `fuzz2`, and `fuzz3`
- Testing the update function by passing handcrafted messages to it in tests
- Assembling `Html` values and querying them with `Test.Html.Query`
- Descending through the DOM by using `Query.findAll`
- Simulating sending events to rendered `Html` by using `Event.simulate`

Here's the final `PhotoGrooveTests.elm` file.

### Listing 6.11 PhotoGrooveTests.elm

```
module PhotoGrooveTests exposing
    (clickThumbnail, decoderTest, photoFromUrl, sliders, testSlider,
     thumbnailRendered, thumbnailsWork, urlFuzzer, urlsFromCount)

import Expect exposing (Expectation)
import Fuzz exposing (Fuzzer, int, list, string)
import Html.Attributes as Attr exposing (src)
import Json.Decode as Decode exposing (decodeValue)
import Json.Encode as Encode
import PhotoGroove
    exposing
        ( Model
        , Msg(..)
        , Photo
        , Status(..)
        , initialModel
        , update
        )
```

The `(..)` means to expose not only the type—so we can use it in type annotations—but also the variants, so we can use them in expressions.

```

        , urlPrefix
        , view
    )
import Test exposing (..)
import Test.Html.Event as Event
import Test.Html.Query as Query
import Test.Html.Selector exposing (attribute, tag, text)

decoderTest : Test
decoderTest =
    fuzz2 string int "title defaults to (untitled)" <|
        \url size ->
            [ ( "url", Encode.string url )
            , ( "size", Encode.int size )
            ]
            |> Encode.object
            |> decodeValue PhotoGroove.photoDecoder
            |> Result.map .title
            |> Expect.equal (Ok "(untitled)")

Result.map is similar
to List.map and
Json.Decode.map. → |> Expect.equal (Ok "(untitled)") url will be a string, and
size will be an int, because
of fuzz2 string int.

sliders : Test
sliders =
    describe "Slider sets the desired field in the Model"
        [ testSlider "SlidHue" SlidHue .hue
        , testSlider "SlidRipple" SlidRipple .ripple
        , testSlider "SlidNoise" SlidNoise .noise
        ]

testSlider : String -> (Int -> Msg) -> (Model -> Int) -> Test
testSlider description toMsg amountFromModel =
    fuzz int description <|
        \amount ->
            initialModel
                |> update (toMsg amount)
                |> Tuple.first
                |> amountFromModel
                |> Expect.equal amount

.toMsg will be SlidHue, SlidRipple,
or SlidNoise, each of which is a
function with the type (Int -> Msg).
amountFromModel will be
.hue, .ripple, or .noise.

thumbnailsWork : Test
thumbnailsWork =
    fuzz (Fuzz.intRange 1 5) "URLs render as thumbnails" <|
        \urlCount ->
            let
                urls : List String
                urls =
                    List.range 1 urlCount
                    |> List.map (\num -> String.fromInt num ++ ".png")

.intRange prevents us from
getting huge URL lists that
would slow our test way down.

thumbnailChecks : List (Query.Single msg -> Expectation)
thumbnailChecks =
    List.map thumbnailRendered urls

```

```

in
{ initialModel | status = Loaded (List.map photoFromUrl urls) "" }
    |> view
    |> Query.fromHtml
    |> Expect.all thumbnailChecks

```

**Expect.all runs each of the given expectations on the given subject.**

**view converts a Model to Html Msg, and Query.fromHtml converts Html to a Query.Single, which we can run checks on.**

```

thumbnailRendered : String -> Query.Single msg -> Expectation
thumbnailRendered url query =
    query
        |> Query.findAll [ tag "img", attribute (Attr.src (urlPrefix ++ url))]
    ]
        |> Query.count (Expect.atLeast 1)

```

```

photoFromUrl : String -> Photo
photoFromUrl url =
    { url = url, size = 0, title = "" }

```

```

urlFuzzer : Fuzzer (List String)
urlFuzzer =
    Fuzz.intRange 1 5
        |> Fuzz.map urlsFromCount

```

```

urlsFromCount : Int -> List String
urlsFromCount urlCount =
    List.range 1 urlCount
        |> List.map (\num -> String.toInt num ++ ".png")

```

```

clickThumbnail : Test
clickThumbnail =
    fuzz3 urlFuzzer string urlFuzzer "clicking a thumbnail selects it" <|
        \urlsBefore urlToSelect urlsAfter ->
            let
                url =
                    urlToSelect ++ ".jpeg"

```

**url :: urlsAfter operator adds the url String to the beginning of the urlsAfter List of Strings.**

```

photos =
    (urlsBefore ++ url :: urlsAfter) <-
        |> List.map photoFromUrl

srcToClick =
    urlPrefix ++ url
in
{ initialModel | status = Loaded photos "" }
    |> view
    |> Query.fromHtml
    |> Query.find [ tag "img", attribute (Attr.src srcToClick) ]
    |> Event.simulate Event.click
    |> Event.expect (ClickedPhoto url)

```

**Simulates a click on the img, and checks that the appropriate ClickedPhoto message was sent to update**

## *Part 3*

# *Building bigger*

T

he final two chapters deal with more advanced topics: data modeling and single-page applications. These chapters build on everything you've learned so far, and introduce new concepts such as routing, working with recursive data, and a powerful performance optimization technique.

In chapter 7, you'll learn how to model an interactive folder tree, involving two important data structures: dictionaries and recursive custom types. It also introduces a second page to the application. Chapter 8 then connects this page with the page you built in chapters 1 through 6, creating a single-page application with routing and navigation. It also introduces the most common performance optimization technique in Elm.

By the end of these two chapters, you'll know enough to dive into just about any Elm project and be able to make changes to it. There might be some unfamiliar terms or techniques here and there, but everything else in Elm involves variations on what you've learned in this book. You'll know everything you need to build your next fully featured user interface in Elm.





# *Data modeling*

## ***This chapter covers***

- Storing values with associated keys by using dictionaries
- Building interactive trees by using recursive custom types
- Using intermediate representations to decode JSON incrementally
- Decoding recursive data structures with recursive JSON decoders

Our manager is back from vacation and eager to tell the team about a poolside revelation for a new Photo Groove feature: Photo Folders. (The original name was “Photo Pholders” but Marketing said *no*.) As our users’ photo collections grow, they’ve been asking for ways to organize them. Folders are a tried-and-true way to offer exactly that!

To build this feature, we’ll introduce a second page to Photo Groove. It will let users navigate through a folder hierarchy, with each folder potentially holding several photos as well as several other folders.

This Photo Folders page will also showcase a new feature one of our coworkers built: Related Photos. This feature automatically analyzes a user’s photos, detects which ones are related to which others, and tags those photos as related on the server. The Photo Folders page will be the first to display these new Related Photos relationships. When the user selects a photo in a particular folder, we’ll show them a larger version of the photo, as well as thumbnails of its related photos.

As we implement all this, I’ll introduce new concepts you haven’t seen before. To implement the Selected Photo display, we’ll try out a new data structure: a *dictionary*. Once we’re done with that, we’ll see how to build our Folders display by using a *recursive custom type*, and how to model its expanding and collapsing by using *recursive messages*. Finally, we’ll write some JSON decoders to load all this from the server, using *intermediate representations* and *recursive decoders* to handle the nested JSON format our server will send us for this page.

Let’s get started!

## 7.1 Storing values by keys in dictionaries

The new Photo Folders page we’ll be building will have two main sections: the folders themselves, followed by a large display of the selected photo and its related photos. When the user clicks a photo in either the Folders display or in the Related display, that photo will become the selected photo that we show in the Selected Photo display, along with its related photos. Figure 7.1 shows the page we’ll be building in this chapter.

Because we can’t implement a “click to select a photo” functionality for the Folders display until the Selected Photo display exists, we’ll implement the Selected Photo display first and build the Folders display afterward.

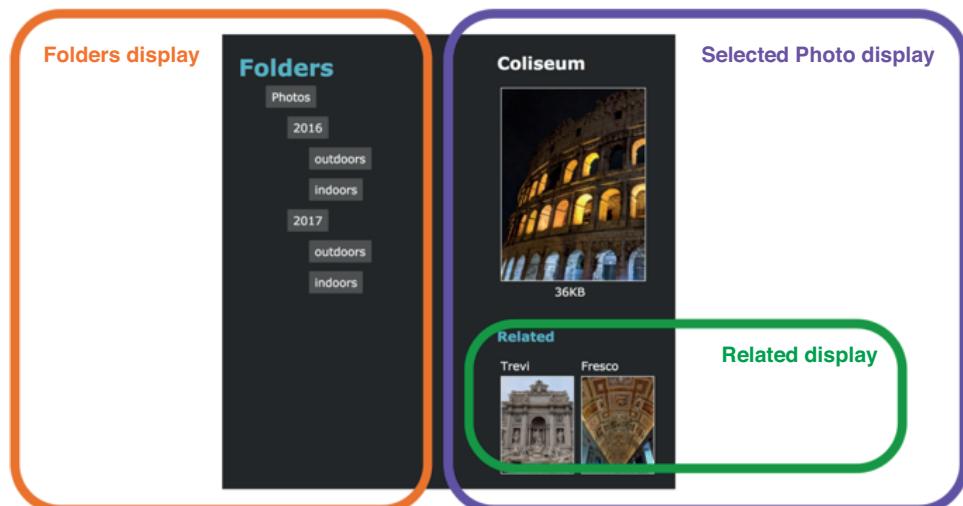


Figure 7.1 The Photo Folders page we’ll be building in this chapter

### 7.1.1 Setting up the page

It's normal to put the code for each page in an Elm application in its own .elm file. This means we'll be giving the PhotoGroove.elm file we've been working on in the previous chapters a sibling .elm file.

Our new file will have its own Model, view, update, and main. Like PhotoGroove.elm, the first thing it will do when the page loads is to fetch Model data from the server by using the `Http` module, similarly to the way we did it in chapter 4. The new file will be completely independent of PhotoGroove.elm—at least until we start linking the two pages together in chapter 8.

Over the last several chapters, we've built up PhotoGroove.elm gradually. First we used a record for our `Msg`, and then later a custom type. We also moved from `Browser.sandbox` to `Browser.element`.

This time, we can use the knowledge acquired over the previous chapters to cut right to the chase, by using `Browser.element` with a custom type for our `Msg` from the get-go. Let's create a file named `PhotoFolders.elm` in the `src/` directory, with the following contents.

**Listing 7.1 PhotoFolders.elm**

```
module PhotoFolders exposing (main)

import Http
import Json.Decode as Decode exposing (Decoder, int, list, string)
import Json.Decode.Pipeline exposing (required)

type alias Model =
    { selectedPhotoUrl : Maybe String }           ← "We'll define main later.

initialModel : Model
initialModel =
    { selectedPhotoUrl = Nothing }                ← "as Decode" lets us call (for example) Decode.succeed instead of Json.Decode.succeed.

init : () -> ( Model, Cmd Msg )
init =
    ( initialModel                         ← "Uses initialModel as the model when the page loads"
    , Http.get
        { url = "http://elm-in-action.com/folders/list"
        , expect = Http.expectJson GotInitialModel modelDecoder }           ← Begins an HTTP request to load data from the server when the page loads
    )                                         ←

modelDecoder : Decoder Model
modelDecoder =
    Decode.succeed initialModel             ← For now, ignore the server's response and succeed with initialModel.
```

```

type Msg
    = ClickedPhoto String
    | GotInitialModel (Result Http.Error Model)

```

We'll use this when the user clicks a photo to select it.

```

update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
    case msg of
        ClickedPhoto url ->
            ( { model | selectedPhotoUrl = Just url }, Cmd.none )

        GotInitialModel (Ok newModel) ->
            ( newModel, Cmd.none )

```

The `SelectPhotoUrl` message sets `selectedPhotoUrl` in the model.

```

        GotInitialModel (Err _) ->
            ( model, Cmd.none )

```

Accepts the new model we received from the server

We'll ignore page load errors for now.

This gets our new page's Model started with a single field: `selectedPhotoUrl`, a `Maybe String` that is initially `Nothing`—indicating the user has not selected a photo yet—and that will be set to a particular photo's URL string if the user selects that photo.

We've also defined two `Msg` values:

- The `ClickedPhoto` message sets the `selectedPhotoUrl` field in the model to be the URL contained in the message. We'll use this later, in the page's `view` function, when the user clicks a photo.
- The `GotInitialModel` message contains data coming back from the server. Just as in chapter 4, our `update` function will receive that data after the HTTP request we specified in `init` either fails or successfully completes. If it completes, `update` will replace our `Model` with the contents of this message.

We can use what we have here to describe a page that loads photos from the server and then lets users click them to select them. To complete this, we'll need to define a `view` function to render it all, as well as a `main` function to tie everything together.

### RENDERING THE NEW PAGE

We'll begin by adding a few imports to support our `view`. These go at the top of our imports:

```

import Browser
import Html exposing (...)
import Html.Attributes exposing (class, src)
import Html.Events exposing (onClick)

```

Next, let's add these `view` and `main` definitions to the end of `PhotoFolders.elm`:

```

view : Model -> Html Msg
view model =
    h1 [] [ text "The Grooviest Folders the world has ever seen" ]

main : Program () Model Msg
main =
    Browser.element

```

```
{ init = init
, view = view
, update = update
, subscriptions = \_ -> Sub.none
}
```

This won't display any actual photos yet, but it will at least get us to a point where we can bring up the page in a browser. We'll make this `view` function more featureful later.

### VIEWING THE PAGE

Let's compile this new file by using a command similar to the one we've been running in the previous chapters, but this time with `PhotoFolders.elm` instead of `PhotoGroove.elm`:

```
elm make --output=app.js src/PhotoFolders.elm
```

Now we can bring up the page in our browser to see how it looks so far. Before we can do this, we'll need to make one small tweak so that our new `PhotoFolders` code gets used instead of the `PhotoGroove` code as before. To do that, we'll need to replace the final `<script>` tag in `index.html` (the one that starts off `var app = ...`) with this much smaller one:

```
<script>
  var app = Elm.PhotoFolders.init({node: document.getElementById("app")});
</script>
```

**NOTE** Not only does the word `PhotoGroove` in this `var app =` declaration change to `PhotoFolders`, but we also stop passing `Pasta.version` and delete all the code in the `<script>` related to ports.

Great! Save it and open the page in your browser. You should see something like figure 7.2.

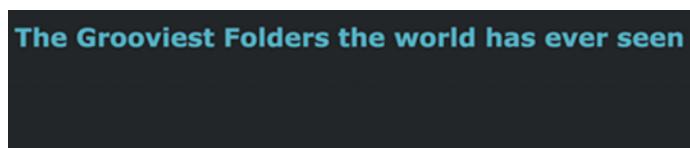


Figure 7.2 Viewing the majestic new Photo Folders page

Now that we have a basic page up and running, we're ready to start making it useful.

#### 7.1.2 **Storing photos by URL in a dictionary**

As impressive as this page already is, it'll be even better when it does something! When the user selects a photo, we want to show a large version of it, along with some smaller thumbnails of its related photos. Figure 7.3 shows how we want it to look.

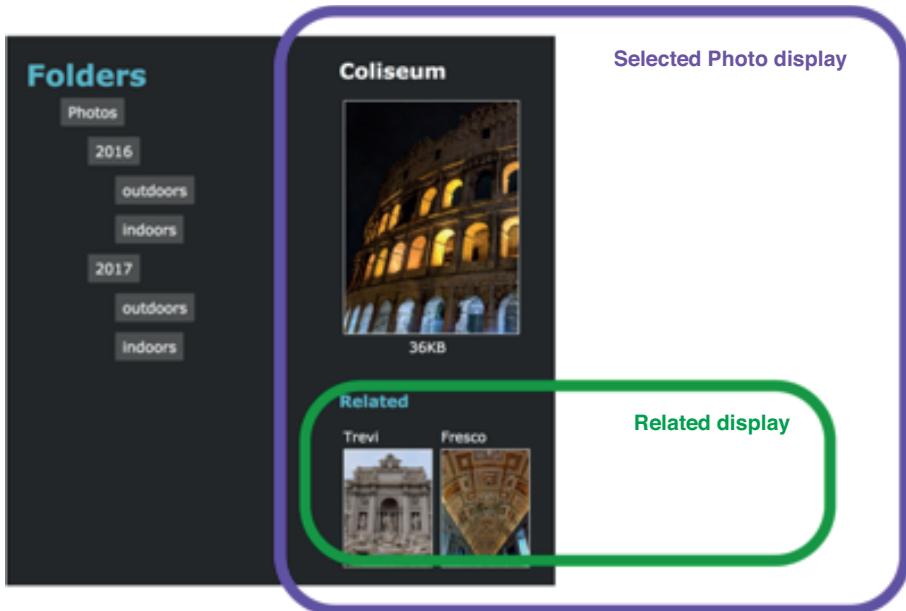


Figure 7.3 The Selected Photo and Related displays we'll be rendering

To implement this, we'll begin by creating two new functions, `viewSelectedPhoto` and `viewRelatedPhoto`, which we'll call from `view` to render the selected photo and its related thumbnails. Let's add the contents of the following listing to the end of `PhotoFolders.elm`.

#### Listing 7.2 PhotoFolders.elm

```

type alias Photo =
    { title : String
    , size : Int
    , relatedUrls : List String
    , url : String
    }

viewSelectedPhoto : Photo -> Html Msg
viewSelectedPhoto photo =
    div
        [ class "selected-photo" ]
        [ h2 [] [ text photo.title ]
        , img [src (urlPrefix ++ "photos/" ++ photo.url ++ "/full")] []
        , span [] [ text (String.fromInt photo.size ++ "KB") ]
        , h3 [] [ text "Related" ]
        , div [ class "related-photos" ]
            [ List.map viewRelatedPhoto photo.relatedUrls
            ]
    ]
```

**Calls**

**on each URL in**

**photo.relatedUrls**

We didn't have this field in `PhotoGroove.elm`.

Calling this function will require getting a Photo from our Model somehow.

```

viewRelatedPhoto : String -> Html Msg
viewRelatedPhoto url =
    img
        [ class "related-photo"
        , onClick (ClickedPhoto url)
        , src (urlPrefix ++ "photos/" ++ url ++ "/thumb")
        ]
    []
[]

urlPrefix : String
urlPrefix =
    "http://elm-in-action.com/"

```

↳ Uses the ClickedPhoto message we defined earlier

We started by defining a type alias `Photo` much like the one we used in `PhotoGroove.elm`, except the one we defined before didn't have a `relatedUrls` field. (After all, the Related Photos feature didn't exist back then!) We then used `Photo` to annotate `viewSelectedPhoto`.

### STORING AND RETRIEVING PHOTOS

Our new `viewSelectedPhoto` function takes a `Photo` as an argument, but our `Model` currently holds only a `Maybe String`. We'll need to begin storing some full-blown `Photo` records in our `Model` if we want to call that function.

Fortunately, our server will provide our `Model` with every `Photo` value we need when the page loads. This begs the question: once we obtain these `Photo` records from the server, how should we store them?

### USING A LIST OF PHOTOS

One way to store the photos would be to add a `photos : List Photo` field to our `Model`. Is a `List` the best choice we could make for this use case? Let's think through how `view` would use that `List Photo` to call `viewSelectedPhoto : Photo -> Html Msg`.

To call `viewSelectedPhoto`, we'd take the selected URL from `model.selectedPhotoUrl` (assuming it's a `Just` rather than a `Nothing`) and look through every single record in our `List` in search of a `Photo` whose `url` field matches that selected URL. If we found a matching `Photo` record, we'd pass it to `viewSelectedPhoto`. Otherwise, we'd have nothing to render and would do nothing.

Although this approach works, it has two issues:

- It's not terribly efficient for the task at hand. If the selected photo happens to be the final one in a list of a thousand photos, we have to examine every single one of those photos, one at a time, to find it. It would be more efficient to use a data structure that didn't have to look through every single `Photo` in that situation.
- In the event that multiple `Photo` records happen to have the given URL, it's not immediately clear how we will handle that.

### USING A DICTIONARY OF PHOTOS

We can avoid both of these problems by storing the photos, not in a list, but in a *dictionary*.

**DEFINITION** A *dictionary* is a collection in which each *value* is associated with a unique *key*.

Back in chapter 1, we talked about how *lists* in Elm must have elements of the same type: we can have [ 1, 2 ], or [ "a", "b" ], but not [ "a", 1 ]. This is because lists can be iterated over—using functions like `List.map`—and reliable iteration depends on elements having consistent types. We also covered how *records* in Elm can store content with mixed types, which comes at the cost of making it impossible to iterate over their fields or values.

*Dictionaries* have some of the characteristics of lists and some of the characteristics of records. As with lists, we can iterate over them. As with records, the values in a dictionary have no notion of a position—but we can efficiently look up any value by providing the associated key. Each key is guaranteed to be unique within the dictionary, so it is impossible to encounter multiple matches. This makes a dictionary a great choice for our use case. Table 7.1 summarizes these trade-offs among the three data structures.

**Table 7.1 Comparing records, lists, and dictionaries**

Structure	Iteration	Mixed type elements	Lookup by position	Lookup by key
Record	Unsupported	Supported	Unsupported	Efficient
List	Supported	Unsupported	Supported	Inefficient
Dictionary	Supported	Unsupported	Unsupported	Efficient

Let's get a better feel for dictionaries by playing around in `elm repl`. The following listing shows how to create a dictionary and retrieve values from it by using `Dict.fromList` and `Dict.get`.

### Listing 7.3 Creating dictionaries and accessing their values

```
> import Dict
> dict = Dict.fromList [ ( "pi, give or take", 3.14 ), ( "answer", 42 ) ]
Dict.fromList [ ... ] : Dict String Float
←
> Dict.get "a key we never added!" dict | Dict.get returns Nothing if the key is not found.
Nothing : Maybe Float
| Dict String Float means "strings for keys, floats for values."
|
> Dict.get "pi, give or take" dict | Dict.get returns Just and the value if found.
Just 3.14 : Maybe Float
|
> Dict.get "answer" dict | Dict.get on a Dict String Float always returns a Maybe Float.
Just 42 : Maybe Float
```

The `Dict.fromList` function takes a list of tuples and returns a `Dict`. Each tuple represents a key-value pair that will be stored in the dictionary.

If we call `Dict.get` on the resulting dictionary, passing a particular key, it will return the associated value—but only if it finds one. Remember that in chapter 3 we

saw that `Array.get` returns a `Maybe` value to represent the possibility that the requested element was not found? `Dict.get` does the same thing here: it returns `Nothing` if the given key was not present in the dictionary, and if the key was present, it returns the corresponding value wrapped in a `Just`.

**TIP** It's common for functions that look up values within Elm data structures to return a `Maybe` if the desired element might not be found. This approach is used in `Array.get`, `Dict.get`, `List.head`, and more.

### Dict's type parameters

You may recall that `List` and `Array` are parameterized on one type—for example, `List String` or `Array Int`. In contrast, `Dict` has two type parameters: one for the key, and one for the value—for example, `Dict Char Int` or `Dict String Photo`. In listing 7.2, we had a `Dict String Float` because we passed a `List (String, Float)` to `Dict.fromList`, which meant this dictionary would have a `String` for each of its keys, and a `Float` for each of its values.

### Constrained type variables: comparable, number, appendable

The type annotation for `Dict.get` is `(comparable -> Dict comparable value -> Maybe value)`. That `comparable` is no ordinary type variable! In chapter 3, we noted that type variables can have *almost* any name you like. The exceptions responsible for that “almost” are the type variable names reserved for Elm’s *constrained* type variables, which behave differently from other type variables:

- `number`, which can resolve to `Int` or `Float`
- `appendable`, which can resolve to `String` or `List`
- `comparable`, which can resolve to `Int`, `Float`, `Char`, `String`, `List` or a tuple of these

As an example of what these do, let’s look at the multiplication operator, `(*)`. If the type of `(*)` were `a -> a -> a`, you could use it to multiply anything—numbers, strings, you name it. However, its actual type is `number -> number -> number`. Because `number` is one of Elm’s constrained type variables, `number -> number -> number` can resolve to only one of the following:

```
Int -> Int -> Int
Float -> Float -> Float
```

The `number -> number -> number` function will resolve to one of these after it gets passed either an `Int` or a `Float` as one of its arguments. This means that multiplying two `Int` values will return an `Int`, multiplying two `Float` values will return a `Float`, and attempting to multiply an `Int` by a `Float` will result in a type mismatch. (The most common way to resolve this type mismatch is by calling `toFloat` on the `Int`.)

If you need to annotate a function that takes two independent number types, you can add more characters after the word `number` to create distinct type variable names that are still constrained by `number`. For example, `number`, `numberB`, `number2`, and `numberOfCats` all have different names but the same `number` constraint.

**(continued)**

The number constraint typically appears in core functions having to do with mathematics. `appendable` is used by the `(++)` operator. `comparable` appears in the definitions of `Dict` and `Set`, as well as in `List.sort` and mathematical inequality operators like `(<)` and `(>=)`. Data structures like `Dict` and `Set` use the `comparable` constraint to store their contents efficiently, which involves sorting them—and only the `comparable` types have implicit sorting functions built in.

In the case of `Dict`, its keys must be `comparable`, but its values can be any type. We can have a `Dict String Photo` because `Photo` is the value type, which can be anything, and `String` is `comparable`, making it an acceptable key type. We could not have a `Dict Photo String`, though, because `Photo` is a type alias for a record, and neither records nor custom types are `comparable`.

To create a dictionary-like collection with non-comparable keys, you can use a third-party package like `pzp1997/assoc-list`. Its API differs from `Dict` only in that its keys do not have the `comparable` restriction, and as a consequence, its runtime performance is worse than `Dict`'s.

### ADDING A DICTIONARY TO MODEL

Let's introduce a dictionary of photos to our model. First we'll import the `Dict` module:

```
import Dict exposing (Dict)
```

Then we'll update `Model` to include a `Dict String Photo` field—with the `String` being the photo URL we'll use as the key, and the `Photo` being the corresponding value:

```
type alias Model =
    { selectedPhotoUrl : Maybe String
    , photos : Dict String Photo
    }
```

If we recompile, we'll get an error. `initialModel` now needs to include a `photos` field. We'll have it initialize that field to an empty dictionary by using `Dict.empty` like so:

```
initialModel : Model
initialModel =
    { selectedPhotoUrl = Nothing
    , photos = Dict.empty
    }
```

Later in the chapter, we'll override this empty dictionary with some `Photo` records loaded from the server, but for now, having it start off empty will be enough to get our code compiling again.

### CALLING VIEWSELECTEDPHOTO FROM VIEW

Now we have a `viewSelectedPhoto` that does what we want, but only if `view` passes it a single `Photo` argument. How can `view` do that? The only argument `view` receives is `Model`, which has a `Dict String Photo` field and a `Maybe String` field, but no other sources of `Photo` values. How can we get a single `Photo` from this combination of values?

In situations like this, it's useful to take stock of the types we have to work with and the type we want to get to. It often turns out only a few functions or language features do anything useful with those types.

Here's a summary of where we are:

- We *want* a `Photo` for the selected photo, so `view` can pass it to `viewSelectedPhoto`.
- We *have* a `Maybe String` indicating which photo is selected, if any.
- We *have* a `Dict String Photo` of all the photos.

How can we use what we *have* to get what we *want*?

### USING DICT.GET WITH A MAYBE STRING

To get from a `Maybe String` of our selected photo's URL (assuming we actually have one) to a `Photo` record for that selected photo, we'll need to do three things:

- 1 Handle the possibility that `selectedPhotoUrl` is `Nothing`.
- 2 If it isn't `Nothing`, pass the selected photo URL to `Dict.get` on `model.photos`.
- 3 Handle the possibility that `Dict.get` returns `Nothing`.

We can do this with `Dict.get` and a nested case-expression, as shown in the following listing.

#### Listing 7.4 Implementing view as a nested case-expression

```
selectedPhoto : Html Msg
selectedPhoto =
    case model.selectedPhotoUrl of
        Just url ->
            case Dict.get url model.photos of
                Just photo ->
                    viewSelectedPhoto photo
                Nothing ->
                    text ""
        Nothing ->
            text ""

| Confirms selectedPhotoUrl
| is not nothing
| Confirms that url is present
| in the dictionary
| Empty text nodes
| render invisibly.
```

### REFACTORING TO USE MAYBE.ANDTHEN

We can express this same logic more concisely using the `Maybe.andThen` function:

```
Maybe.andThen : (original -> Maybe final) -> Maybe original -> Maybe final
```

Whenever we have two nested case-expressions like this, with both of them handling `Nothing` the same way, `Maybe.andThen` does exactly the same thing as the code we had before.

We'll use `Maybe.andThen` when we define `selectedPhoto` in our actual `view` function. Let's replace our existing `view` function with the following definition.

### Listing 7.5 Implementing view using `Maybe.andThen`

```
view : Model -> Html Msg
view model =
    let
        photoByUrl : String -> Maybe Photo
        photoByUrl url =
            Dict.get url model.photos

        selectedPhoto : Html Msg
        selectedPhoto =
            case Maybe.andThen photoByUrl model.selectedPhotoUrl of
                Just photo ->
                    viewSelectedPhoto photo
                Nothing ->
                    text ""

    in
    div [ class "content" ]
        [ div [ class "selected-photo" ] [ selectedPhoto ] ]
```

**Returns the photo with the given URL in `model.photos`**

**photo is the selected photo, if found in `model.photos`.**

**Finishes view by wrapping `selectedPhoto` in the structure the page needs**

### Comparing `andThen` and `map`

In chapter 6, you learned about `Result.map`, and compared it to `Json.Decode.map` and `List.map` in section 6.1.3. There is also a `Result.andThen` function, which works a bit like the `map` function we discussed in chapter 6. Here's how their types compare:

```
Result.andThen : (a -> Result x b) -> Result x a -> Result x b
Result.map     : (a ->           b) -> Result x a -> Result x b
```

Both functions accept a callback and a `Result`; both return the given value unchanged when given an `Err` variant; and when given an `Ok`, both pass the value inside that `Ok` to their callbacks.

They differ in that if `Result.map` receives an `Ok` variant, it always returns an `Ok` variant. The content of that `Ok` variant might be different, but it will definitely be an `Ok` and not an `Err`. In contrast, `Result.andThen` returns whatever its callback returns—which means it can potentially receive an `Ok` and turn it into an `Err`.

The `Maybe.map` function has a very similar relationship to `Maybe.andThen`:

```
Maybe.andThen : (a -> Maybe b) -> Maybe a -> Maybe b
Maybe.map     : (a ->           b) -> Maybe a -> Maybe b
```

Similarly to the behavior of `Result.map`, if `Maybe.map` receives a `Just`, it always returns a `Just`. If it receives `Nothing`, it returns `Nothing`.

Similarly to the behavior of `Result.andThen`, `Maybe.andThen` returns whatever its callback returns—meaning it can potentially receive a `Just` and turn it into a `Nothing`. As we will see later in the chapter, a similar `Json.Decode.andThen` function can likewise turn successes into failures.

This additional capability makes `andThen` strictly more powerful than `map`. Anything we can implement with `map`, we could implement with `andThen` instead. However, `map` is often preferred in practice because it's more concise, and more often than not, the extra power of `andThen` is not needed.

### RENDERING THE SELECTED PHOTO

Now everything compiles, but we can't see if it's working properly because we initialize our photo dictionary to `Dict.empty` and never change it. If we pretend we're already able to decode some useful `Photo` data from the server, we'll be able to try out our new page.

Let's change `modelDecoder` to this:

```
modelDecoder : Decoder Model
modelDecoder =
    Decode.succeed
        { selectedPhotoUrl = Just "trevi"
        , photos = Dict.fromList
            [ ( "trevi"
                , { title = "Trevi"
                    , relatedUrls = [ "coli", "fresco" ]
                    , size = 34
                    , url = "trevi"
                    }
                )
            , ( "fresco"
                , { title = "Fresco"
                    , relatedUrls = [ "trevi" ]
                    , size = 46
                    , url = "fresco"
                    }
                )
            , ( "coli"
                , { title = "Coliseum"
                    , relatedUrls = [ "trevi", "fresco" ]
                    , size = 36
                    , url = "coli"
                    }
                )
            ]
        }
```

If we rerun `elm make --output=app.js PhotoFolders.elm` and open the result in the browser, we can now see a lovely large photo with some related photos below it, as shown in figure 7.4.

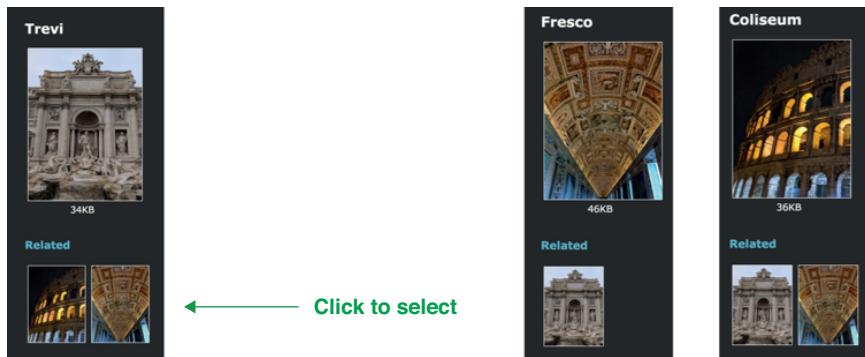


Figure 7.4 Viewing the selected photo with related photos below it

Fantastic! Not only does this page display the related photos below the selected one, but we can click them to change which one is selected. Next, we'll introduce the pholders—er, *folders*!

## 7.2 Modeling trees by using recursive custom types

Because another of our coworkers is taking care of the page where users can edit their folders, we are free to focus on the page that lets users browse through them. Later in the chapter, we'll load the folders and their contents from the server, but we'll start by hardcoding them just as we did with the Related Photos feature. This way, we can get the interaction working to our satisfaction before we have to deal with whatever data format the server happens to give us.

Each folder could contain one or more photos, as well as one or more subfolders—each of which can also contain more photos and more subfolders, and so on. This relationship forms a *tree*, which is a data structure we never used in the previous chapters.

### 7.2.1 Defining trees by using custom types

Let's say we tried to represent our folder tree structure with a type alias, like so:

```
type alias Folder = { name : String, subfolders : List Folder }
```

This won't work! If we try to compile it, we'll get an error. What's the problem with it?

The purpose of `type alias` is to name a type annotation. When the compiler encounters this name, it substitutes in the type annotation we associated with that name and proceeds as normal.

Now let's suppose the compiler encounters a `Folder` annotation and begins to expand it into the complete type. What happens? The expansion would go something like this:

```
{ name: String, photoUrls : List String, subfolders : List
  { name : String, photoUrls : List String, subfolders : List
    { name : String, photoUrls : List String, subfolders : List ...
```

Uh-oh. Trying to expand that type annotation would never end! This is why defining a `type alias` in terms of itself doesn't work, and why we'll need to use something else to define this `Folder` type.

### RECURSIVE CUSTOM TYPES

Fortunately, whereas type aliases give a name to an existing type, custom types actually define a brand-new type—and they can refer to themselves in their own definitions. Custom types that do this are known as a *recursive* custom types.

One of the many data structures we can define using a recursive custom type is a linked list—such as the `List` type we all know and love. Under the hood, an Elm `List` is structured like this custom type:

```
type MyList elem
  = Empty
  | Prepend elem (MyList elem)
```

**NOTE** When we write `[ 1, 2, 3 ]`, it's essentially syntax sugar for `Prepend 1 (Prepend 2 (Prepend 3 Empty))`. No other language support is necessary; every `List` function we've been using in this book—`map`, `head`, and so on—can be built using nothing more than case-expressions on this custom type.

### DEFINING FOLDER AS A RECURSIVE CUSTOM TYPE

We can use a similar approach to define `Folder` as a recursive custom type:

```
type Folder =
  Folder
  { name : String
  , photoUrls : List String
  , subfolders : List Folder
  }
```

Let's add this `type Folder` declaration right above our `type alias Model` declaration in `PhotoFolders.elm`.

Notice that whereas other custom types we've seen have had multiple variants—for example, `type Msg = ClickedPhoto String | ClickedSize ThumbnailSize`—this custom type has only one variant. It holds plenty of information, though, because that one variant contains a record: `type Folder = Folder { name : String, ... }`.

This is a common technique in Elm: when a `type alias` is the wrong fit, you can upgrade it to a custom type with a single variant. It's typical when doing this to give the

single variant the same name as the type itself—in this case, `type Folder = Folder { ... }`—but we just as easily could have called it something like `type Folder = SingleFolder { ... }` instead.

**TIP** This upgrade has no runtime cost when you run `elm make` with the `--optimize` flag. When Elm’s compiler sees a custom type with a single variant, it “unboxes” it, such that `type Foo = Foo String` compiles down to a plain `String` at runtime.

### ADDING HARDCODED DATA TO MODEL AND INIT

Now that we’ve defined `Folder`, let’s make these changes to `Model` and `init`:

- 1 Add a `root : Folder` field to the end of our type alias `Model` declaration. This will represent our root folder, which will contain all the subfolders inside it.
- 2 Add `root = Folder { name = "Loading...", photoUrls = [], subfolders = [] }` to the end of the `initialModel` record. This defines a placeholder root folder that says “Loading...” while we wait for the server to respond with the actual folders.

**NOTE** It would be nicer to represent this by using something like a `Maybe Folder` to model that the data has not loaded yet. In chapter 8, we’ll switch to an approach more like that.

Let’s also give ourselves some example folders to work with, by adding a hardcoded root folder to our `modelDecoder` like so:

```
modelDecoder : Decoder Model
modelDecoder =
    Decode.succeed
        { selectedPhotoUrl = ...
        , photos = ...
        , root =
            Folder
                { name = "Photos", photoUrls = []
                , subfolders =
                    [ Folder
                        { name = "2016", photoUrls = [ "trevi", "coli" ]
                        , subfolders =
                            [ Folder
                                { name = "outdoors"
                                , photoUrls = [], subfolders = []
                                }
                            , Folder
                                { name = "indoors"
                                , photoUrls = [ "fresco" ], subfolders = []
                                }
                            ]
                        }
                    , Folder
                        { name = "2017", photoUrls = []
                        , subfolders =
                            ...
                        }
                    ]
                }
        }
```

```

[ Folder
  { name = "outdoors"
    , photoUrls = [], subfolders = []
  }
, Folder
  { name = "indoors"
    , photoUrls = [], subfolders = []
  }
]
}
]
}
}

```

Now we can access `model.root` from our `view` function, and use it to render some folders.

### RENDERING FOLDERS

To render the folders, we'll start by writing a `viewFolder` function that renders a single folder. Let's add the contents of the following listing right after `viewRelatedPhoto`.

#### Listing 7.6 `viewFolder`

```

viewFolder : Folder -> Html Msg
viewFolder (Folder folder) =
  let
    subfolders =
      List.map viewFolder folder.subfolders
  in
    div [ class "folder" ]
      [ label [] [ text folder.name ]
      , div [ class "subfolders" ] subfolders
      ]

```

The code is annotated with two callouts:

- A callout pointing to the pattern match on `Folder folder` is labeled "Inline pattern match".
- A callout pointing to the recursive call `List.map viewFolder folder.subfolders` is labeled "viewFolder calls itself.".

This `viewFolder` implementation demonstrates a couple of new tricks.

### DESTRUCTURING SINGLE-VARIANT CUSTOM TYPES

First up is that `viewFolder (Folder folder)` syntax. This is a syntax shorthand that makes our code more concise. Our `Folder` type is a custom type that holds a single variant, and inside that variant is a record we want to access (with `{ name : String }` and so on).

One way to access that record is to use a case-expression to destructure our custom type's one and only variant (the variant named `Folder`, just like the type itself), the way we did in chapter 3:

```

viewFolder : Folder -> Html Msg
viewFolder wrappedFolder =
  case wrappedFolder of
    Folder folder ->
      ..."folder" now refers to the record we want...

```

Inside that one branch of the case-expression, `folder` would refer to the record we want, and we could then use it however we pleased. There's nothing wrong with this code, except that it could be shorter without losing any clarity.

Because the `Folder` custom type has exactly one variant, Elm lets us avoid writing a full case-expression by using the shorthand `viewFolder (Folder folder) = to` to destructure it inline instead. That shorter version is equivalent to the preceding longer case-expression version.

### RECURSIVE FUNCTIONS

Next, we have this expression: `List.map viewFolder folder.subfolders`. Notice that `viewFolder` is calling itself, making it a *recursive* function.

**DEFINITION** A function that calls itself is known as a *recursive* function.

### INCORPORATING VIEWFOLDER INTO VIEW

Let's use our hardcoded Model data to try out this `viewFolder` function. Add `div [ class "folders" ]` right before `div [ class "selected-photo" ]`, with the following inside it:

```
div [ class "content" ]
    [ div [ class "folders" ]
        [ h1 [] [ text "Folders" ]
        , viewFolder model.root
        ]
    , div [ class "selected-photo" ] [ selectedPhoto ]
    ]
```

Let's recompile and check out the results of our efforts in the browser; see figure 7.5.

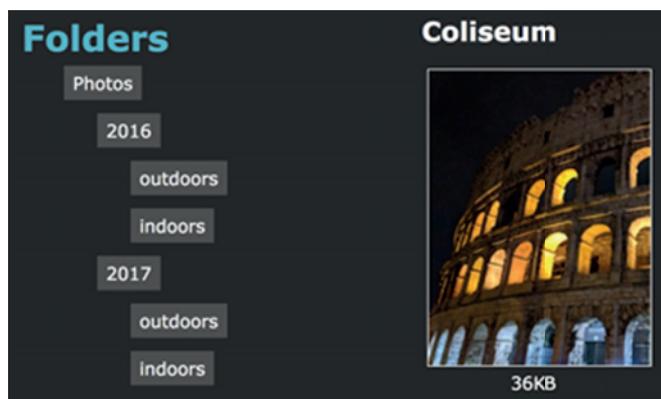


Figure 7.5 Viewing folders

Looking good! We can see our hardcoded folders rendered to the screen, but clicking them still does nothing at this point. Next, we'll introduce the ability to expand and collapse them.

## 7.2.2 Recursive messages

Whenever the user clicks a folder, we want it to toggle between being expanded and collapsed. This means we'll need to introduce a new piece of state to our `Folder`: a `Bool` indicating whether the folder is expanded. Let's start by making these changes:

- 1 Add an expanded : Bool field to the end of the record in our type Folder definition.
  - 2 Add expanded = True to each of the Folder records in our hardcoded modelDecoder. (A quick way to do this is to find/replace all instances of photoUrls = with expanded = True, photoUrls = in our PhotoFolders.elm file.)

## DESCRIBING DESCENT

To implement this feature, we'll need to add an `onClick` handler to each folder, to toggle its expanded state. Here's how we'll do this:

- 1 Pass onClick a new Msg that tells update which folder the user clicked.
  - 2 When update receives one of these messages, descend from the root folder into the folder tree and toggle the appropriate folder's expanded field in the Model.

The following listing shows the code we'll add to the end of PhotoFolders.elm to accomplish this.

#### **Listing 7.7** toggleExpanded andFolderPath

```

type FolderPath
  = End
  | Subfolder Int FolderPath

toggleExpanded : FolderPath -> Folder -> Folder
toggleExpanded path (Folder folder) =
  case path of
    End ->
      Folder { folder | expanded = not folder.expanded }

    "not" swaps
    True for False,
    and vice versa. └─▶ Folder { folder | expanded = not folder.expanded }

    Subfolder targetIndex remainingPath ->
      let
        subfolders : List Folder
        subfolders =
          List.indexedMap transform folder.subfolders

        transform : Int -> Folder -> Folder
        transform currentIndex currentSubfolder =
          if currentIndex == targetIndex then
            toggleExpanded remainingPath currentSubfolder
          else
            currentSubfolder

      in
        Folder { folder | subfolders = subfolders }
  
```

A path from a folder to a particular subfolder

Like Folder, FolderPath is also a recursive custom type.

Destructuring the Folder custom type inline

targetIndex is an Int. remainingPath is a FolderPath.

toggleExpanded is recursive; it calls itself.

`toggleExpanded` takes a `FolderPath` and a `Folder`, and does one of the following:

- If `FolderPath` is `End`, there are no subfolders to traverse into, so toggle the expanded value on the given folder.
- If `FolderPath` is `Subfolder targetIndex`, look through the given root's subfolders until we find the one at position `targetIndex`. Then call `toggleExpanded` again, this time passing that subfolder as the new root folder, and passing the remaining `FolderPath` after discarding the `Subfolder` value we just handled.

Technically, the function always toggles only the “root folder,” but its notion of which folder is the root changes as it processes `Subfolder` values.

Once it has resolved all the subfolders, the final call to `toggleExpanded` will receive the originally desired subfolder as its “root” argument, along with `Root` as its `FolderPath`, meaning it will toggle the expanded value as we want. Figure 7.6 shows how `FolderPath` can model a path to whichever folder the user clicks, and how `toggleExpanded` recurses along that path.

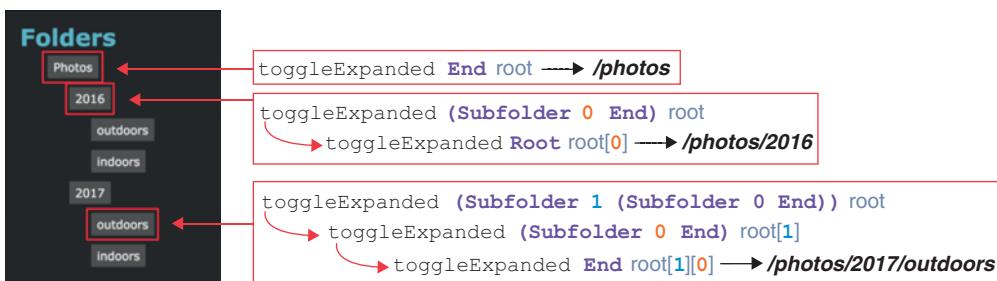


Figure 7.6 Using `toggleExpanded` to represent user interaction with folders

### LIST.INDEXEDMAP

To update only the subfolder at the desired index, `toggleExpanded` uses `List.indexedMap`, a function we haven't used before. It works similarly to `List.map`, but with one difference. Here are their types side by side:

```
List.map      : (oldVal -> newVal) -> List oldVal -> List newVal
List.indexedMap : (Int -> oldVal -> newVal) -> List oldVal -> List newVal
```

The only thing `List.indexedMap` does differently from `List.map` is that it passes an additional value to the transformation function: an `Int` representing the element's index within the list.

If you call `List.indexedMap` on the list `[ "foo", "bar", "baz" ]`, the transformation function will receive 0 and `"foo"`, then 1 and `"bar"`, and finally 2 and `"baz"`.

### TRANSFORMING SUBFOLDERS BASED ON INDEX

Here's how `toggleExpanded` uses `List.indexedMap` to alter subfolders:

```
subfolders : List Folder
subfolders =
    List.indexedMap transform root.subfolders
```

When `transform` gets called by `indexedMap`, it receives not only the particular subfolder it's about to transform, but also that subfolder's index within the `subfolders` list. It makes use of that index like so:

```
transform : Int -> Folder -> Folder
transform currentIndex currentSubfolder =
    if currentIndex == targetIndex then
        toggleExpanded remainingPath currentSubfolder
    else
        currentSubfolder
```

Because the `else` branch returns the original subfolder unchanged, this `transform` function actually transforms `subfolder` only if `currentIndex == targetIndex`. It transforms the subfolder at the requested `targetIndex` and leaves the others alone.

### INCORPORATING FOLDERPATH INTO MSG

Next, we'll connect `toggleExpand` to `update` by expanding our `Msg` type, introducing a `ClickedFolder` variant to go with our existing `ClickedPhoto` and `GotInitialModel` variants. This new variant will fire whenever the user clicks a folder, and it will use a `FolderPath` to describe where in the folder hierarchy the user clicked. The following listing shows the changes we'll make to `Msg` and `update`.

#### Listing 7.8 Adding ClickedFolder to Msg and update

```
type Msg
    = ClickedPhoto String
    | GotInitialModel (Result Http.Error Model)
    | ClickedFolder FolderPath
```

We'll make this fire when a user clicks a folder.

```
update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
    case msg of
        ClickedFolder path ->
            ( { model | root = toggleExpanded path model.root }, Cmd.none )
```

Adds a branch to cover our new Msg variant

Next, we'll make things interactive by connecting this `update` logic to view.

### 7.2.3 Event handlers with recursive messages

Now that update supports a Msg called ClickedFolder that toggles the expanded state of a particular folder, we can modify our viewFolder function to make the folders toggle between being expanded and collapsed on the user's click. While we're at it, we can also start rendering the folders differently depending on whether they are expanded. The following listing shows how we'll make both of these changes.

#### Listing 7.9 viewFolder with toggling expanded

```
viewFolder : FolderPath -> Folder -> Html Msg
viewFolder path (Folder folder) =
    let
        viewSubfolder : Int -> Folder -> Html Msg
        viewSubfolder index subfolder =
            viewFolder (appendIndex index path) subfolder
    in
    Click the folder's name to toggle expanded. | folderLabel =
        label [ onClick (ClickedFolder path) ] [ text folder.name ]
    in
    if folder.expanded then
        let
            contents =
                List.indexedMap viewSubfolder folder.subfolders
        in
        div [ class "folder expanded" ]
            [ folderLabel
            , div [ class "contents" ] contents
            ]
    else
        div [ class "folder collapsed" ] [ folderLabel ] <-- Don't render contents of collapsed folders.
    in
    appendIndex : Int -> FolderPath -> FolderPath
    appendIndex index path =
        case path of
            End ->
                Subfolder index End <-- Replaces the original End with (Subfolder index End)
            Subfolder subfolderIndex remainingPath ->
                Subfolder subfolderIndex (appendIndex index remainingPath)
    in
    Recurses until we reach the End <-->
```

Annotations for Listing 7.9:

- A callout points to the line `viewSubfolder index subfolder =` with the text: "Each subfolder's FolderPath is nested one deeper."
- A callout points to the line `contents = List.indexedMap viewSubfolder folder.subfolders` with the text: "Renders each subfolder by using its index"
- A callout points to the line `div [ class "contents" ] contents` with the text: "Renders the folder's label before its contents"
- A callout points to the line `div [ class "collapsed" ] [ folderLabel ]` with the text: "Don't render contents of collapsed folders."
- A callout points to the line `Subfolder index End` with the text: "Replaces the original End with (Subfolder index End)"
- A callout points to the line `Recurses until we reach the End` with the text: "Recurses until we reach the End"

#### APPENDINDEX

The appendIndex function is another recursive function. (As it turns out, they come up a lot when working with tree structures.) This one adds a new subfolder index onto the end of a FolderPath, so that viewFolder can build up a FolderPath as it works its way from the root folder through the subfolders.

**NOTE** If we wrote `(Subfolder index path)` instead of `(appendIndex index path)` inside viewFolder, the folder paths would get reversed. This wouldn't make a noticeable difference for the root folder and its first subdirectories, but it would result in some funky behavior when toggling other subfolders.

## MODIFYING VIEW

We'll also need to modify our top-level view function to change how it renders the root folder:

```
viewFolder End model.root
```

Thanks to our new `view` function, a `ClickedFolder` message will be sent to update whenever the user clicks a folder. Figure 7.7 shows the exact `Msg` that will be sent to update when each folder is clicked.

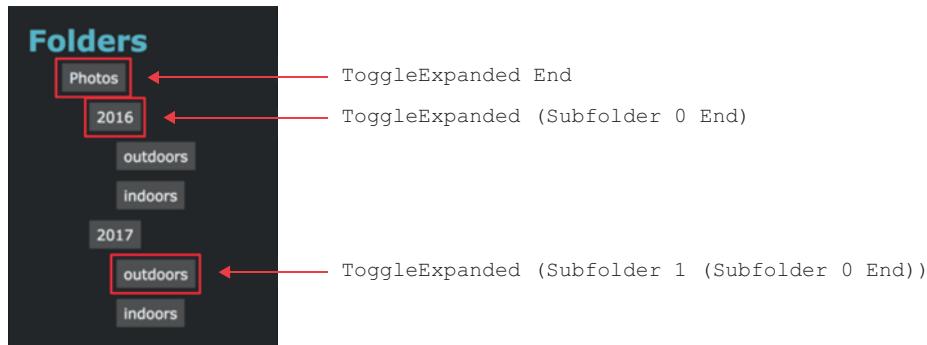


Figure 7.7 User clicks a subfolder, and `ClickedFolder` gets sent to update

Great! We have only one step remaining: make it so when the user clicks a photo, it becomes the selected one.

## SELECTING A PHOTO ON CLICK

First we'll introduce a `viewPhoto` function above `viewSelectedPhoto`, which will render an individual photo within a folder. We'll have this function reuse our existing `ClickedPhoto` message from section 7.1.1 like so:

```
viewPhoto : String -> Html Msg
viewPhoto url =
    div [ class "photo" , onClick (ClickedPhoto url) ]
        [ text url ]
```

Next, we'll use `viewPhoto` to render the photos right below where we're rendering the subfolders. Let's change the definition of `contents` in the let-expression at the end of `viewFolder` to look like this:

```
let
    contents =
        List.append
            (List.indexedMap viewSubfolder folder.subfolders)
            (List.map viewPhoto folder.photoUrls)
in
```

**NOTE** If you want an extra challenge, at the end of this chapter try introducing a feature whereby clicking the Related Photo causes the tree to expand to that photo.

Now the user can click a photo either within its folder or in the Related display, and have it become the selected photo. We've made things nicely interactive!

## 7.3 Decoding graphs and trees

We've now built an interface that renders a tree of folders, each of which can contain photos and subfolders, as well as a Selected Photo display that includes related photos. We defined hardcoded data for these displays so that we could try them out, but now it's time to load that data on the fly—by decoding JSON from our server.

### 7.3.1 Decoding dictionaries

The Model we defined in section 7.1 stores its photos in a field called `photos : Dict String Photo`. We'll start by defining a Decoder (`Dict String Photo`) that can decode one of those dictionaries from JSON.

#### SAMPLE JSON

Here's an example of the JSON format our server will send us to represent the photos:

```
{
    "2turtles": {
        "title": "Two Turtles",
        "related_photos": ["beach"],
        "size": 27
    },
    "beach": {
        "title": "At Chang's Beach!",
        "related_photos": ["wake", "2turtles"],
        "size": 36
    },
    "wake": {
        "title": "Boat wake",
        "related_photos": ["beach"],
        "size": 21
    }
}
```

In this structure, each photo's URL is a field in a JSON object, and the value associated with that URL holds the rest of the information about that photo. Translating this JSON into a `Photo` record will require decoding techniques that go beyond the basics we learned in chapter 4.

#### COMPARING PHOTO REPRESENTATIONS

First, let's compare how a `Photo` will be represented in our Elm code with the corresponding JSON representation coming from the server; see table 7.2.

**Table 7.2 Comparing type alias Photo and the JSON object we get from the server**

Elm record	JSON object
<pre>type alias Photo =     { title : String     , size : Int     , relatedUrls : List String     , url : String     }</pre>	<pre>{     "title": "Chang's Beach",     "size": 24,     "related_photos": ["maui.jpg"] }</pre>

**INTERMEDIATE REPRESENTATIONS**

The JSON object has three fields: `title`, `size`, and `related_photos`. That's not enough data for us to build a complete `Photo` record, but we can at least write a decoder that handles three of the four fields. We can figure out how to obtain the `url` field afterward. Let's begin by adding the code in the following listing to the end of `PhotoFolders.elm`.

**Listing 7.10 Creating a jsonPhotoDecoder**

```
type alias JsonPhoto =
    { title : String
    , size : Int
    , relatedUrls : List String
    }

jsonPhotoDecoder : Decoder JsonPhoto
jsonPhotoDecoder =
    Decode.succeed JsonPhoto
        |> required "title" string
        |> required "size" int
        |> required "related_photos" (list string)
```

The `JsonPhoto` type we've introduced here is an *intermediate representation*—a value we'll use only to help us translate from one value to another. In particular, a `JsonPhoto` value will help us get from JSON to a `Photo` record.

**DECODING URL STRINGS FROM ENCLOSING OBJECTS**

We can now decode a `JsonPhoto` record, which holds all the information necessary to make a `Photo` record except a URL string. If we can find some way to decode a URL string, we could combine that with our `JsonPhoto` to end up with the `Decoder Photo` we want.

With that in mind, let's take another look at our sample JSON:

```
{ "2turtles.jpg": { ... }, "beachday.jpg": { ... }, "day1maui.jpg": { ... } }
```

Hey, there are the URLs we need, right in the object's keys!

### DECODE.KEYVALUEPAIRS

We can decode those keys by using the `Decode.keyValuePairs` function. It has this type:

```
keyValuePairs : Decoder val -> Decoder (List ( String, val ))
```

This gives us a decoder that translates JSON objects into key-value tuples. The key's type is always `String`, because JSON object keys are strings by definition. The value's type depends on the `Decoder` we pass to the `keyValuePairs` function.

As an example, suppose we called `keyValuePairs jsonPhotoDecoder` and ran the resulting decoder on our JSON sample from earlier:

```
{ "turtles.jpg": { ... }, "beach.jpg": { ... }, "maui.jpg": { ... } }
```

The output would be a list of `( String, JsonPhoto )` tuples like so:

```
output : List ( String, JsonPhoto )
output =
  [ ( "2turtles.jpg", { title = "Turtles & sandals", ... } )
  , ( "beachday.jpg", { title = "At Chang's Beach!", ... } )
  , ( "day1maui.jpg", { title = "First day on Maui", ... } )
  ]
```

### TRANSLATING THE LIST OF TUPLES INTO A DICTIONARY

Now we can decode a list of `( String, JsonPhoto )` tuples, where the `String` is a photo's URL and `JsonPhoto` is everything else but the URL. We're getting closer!

Let's write a function that translates that list into the dictionary we want, by converting each `( String, JsonPhoto )` tuple into a `( String, Photo )` tuple and then passing a list of those to `Dict.fromList`. Here's the code we'll add to the end of `PhotoFolders.elm` to do this:

```
finishPhoto : ( String, JsonPhoto ) -> ( String, Photo )
finishPhoto ( url, json ) =
  ( url
  , { url = url
    , size = json.size
    , title = json.title
    , relatedUrls = json.relatedUrls
    }
  )

fromPairs : List ( String, JsonPhoto ) -> Dict String Photo
fromPairs pairs =
  pairs
  |> List.map finishPhoto
  |> Dict.fromList
```

Just as we did back in section 7.1.2 with `viewSelectedPhoto`, let's once again take stock of the values we *have*, and see if we can combine them to get the value we *want*:

- We *want* a `Decoder (Dict String Photo)` for which each key is the `Photo`'s `url`.

- We *have* a Decoder (List ( String, JsonPhoto )) for which each String is the URL that goes with that JsonPhoto.

How can we use what we *have* to get what we *want*?

#### COMBINING THE INGREDIENTS WITH DECODE.MAP

Just as before, often only a few functions or language features do anything useful with these types. In this case, we can reach our goal by using the Decode.map function, whose type may look familiar to fans of related artists List.map, Maybe.map, and Result.map:

```
Decode.map : (original -> goal) -> Decoder original -> Decoder goal
```

Here, our original type is List ( String, JsonPhoto ), and our goal type is Dict String Photo. Do we have a function that takes the one and returns the other?

We sure do! The fromPairs function we just wrote does exactly that. (What are the odds?) Let's add this to the end of PhotoFolders.elm, so that modelDecoder can use it later:

```
photosDecoder : Decoder (Dict String Photo)
photosDecoder =
    Decode.keyValuePairs jsonPhotoDecoder
        |> Decode.map fromPairs
```

**TIP** This “How can we use what we have to get what we want?” technique works out quite often. It’s a useful approach beyond just the two examples in this chapter, with views and with JSON decoding.

Our quest for a Decoder (Dict String Photo) is at an end. Huzzah!

### 7.3.2 Decoding recursive JSON

Now that we’ve added a JSON decoder for our Photo record, all we need is to do the same for Folder, and we should be able to load a complete Model from our server. Let’s see what JSON the server gives us for folders.

#### RECURSIVE JSON

Figure 7.8 shows a sample of the JSON we’ll receive from the server to describe our folders.

```
{
    "name": "All Photos",
    "photos": {"2turtles": {title: "Turtles & sandals", ... }},
    "subfolders": [
        {"name": "2016", "photos": {...}, "subfolders": [...]},
        {"name": "2017", "photos": {...}, "subfolders": [...]}
    ]
}
```

our Decoder (Dict String Photo) decodes this

Each subfolder has the same structure as this outer Folder

Figure 7.8 Sample of the JSON we will get back from the server to describe a Folder

Let's focus on the outermost JSON object, which has this structure:

```
{ "name": <folder name>, "photos": <photos>, "subfolders": <subfolders> }
```

Each of the `<subfolders>` also has this structure, and so do the subfolders' subfolders, and so on all the way down. It's a *recursive* JSON structure! Thankfully, our `Folder` type is already recursive, so it'll be able to store the data this JSON describes.

There's a catch: this is the one and only JSON structure the server will ever give us. That means we'll need to assemble our entire `Model` by using only JSON in this format.

### DECODING THE COMPLETE MODEL

Can this possibly be enough data to decode a complete `Model`? For that, we need values for the `Model`'s `root : Folder` field as well as its `photos : Dict String Photo` field. Also, the `Dict String Photo` needs to be a single source of truth for all photos across all subfolders; otherwise, we won't be able to click any photo in any folder to select it.

But where is our single source of truth in this JSON? Sure, each subfolder has its own `photos` field containing some `Photo` values, but that's not a single source of truth. Technically, this JSON contains all the information we need, but it's not organized in our ideal format; the photo data is intermixed with the folder data, whereas we want them to be neatly separated.

### GATHERING NESTED PHOTOS

We ask the team members who maintain this server endpoint if they'd be willing to make changes to their code to provide the JSON in our preferred format. But they're swamped lately—something about a “primary key overflow,” whatever that means—and can't accommodate us.

Instead of contorting the lovely data model we've built up over the course of the chapter to fit this JSON we happened to get from the server, we'll write a decoder that translates it into the format we want. After all, the whole point of decoders is to decouple our application's data model from whatever curveball external data formats the world decides to throw at us. In a different situation, we could be accessing a third-party service that gives us no say whatsoever in how the data gets formatted.

### DECODING A FOLDER

Let's write a decoder for our root `Folder` first. Here's the sample JSON we'll be working with:

```
{ "name": "pics from 2016", "photos": { ... }, "subfolders": [ ... ] }
```

We want to translate this into a `Folder` value:

- The folder's name is "pics from 2016".
- The folder's `photoUrls` value corresponds to the keys in that "photos" object.
- Each of the folder's subfolders is represented the same way this one is.

To do this, we'll add the contents of the following listing to the end of PhotoFolders.elm.

### Listing 7.11 Decoding both folders and photos in a single decoder

```

We defined photosDecoder in section 7.3.I.   folderDecoder : Decoder Folder
    folderDecoder =
        Decode.succeed folderFromJson
            |> required "name" string
            |> required "photos" photosDecoder
            |> required "subfolders" (list folderDecoder)

    folderFromJson : String -> Dict String Photo -> List Folder -> Folder
    folderFromJson name photos subfolders =
        Folder
            { name = name
            , expanded = True
            , subfolders = subfolders
            , photoUrls = Dict.keys photos
            }

```

Annotations for Listing 7.11:

- On success, passes decoded name, photos, and subfolders to folderFromJson**: Points to the call to `Decode.succeed`.
- Yikes! This decoder is defined in terms of itself!**: Points to the recursive call to `list folderDecoder`.
- We'll expand each folder by default.**: Points to the `Folder` record type definition.
- These argument types match the preceding "require" calls.**: Points to the arguments of `dict` and `list`.
- photos is a Dict String Photo; its keys are photo URLs.**: Points to the `photoUrls` field in the `Folder` record.

Let's compare the way we built our `Decoder Photo` to the way we've built a `Decoder Folder` here.

Here are the steps we used to create our `Photo` decoder:

- 1 We used type alias `JsonPhoto` as an intermediate representation, which gave us a `JsonPhoto : String -> Int -> List String -> JsonPhoto` function.
- 2 We called `Decode.succeed JsonPhoto`, meaning this `JsonPhoto` function would be called if all the decoding steps succeed.
- 3 We used `required` several times, to build up a `Decoder JsonPhoto` by specifying the fields and types we wanted to decode and then pass to the `JsonPhoto` function, which then returns a decoded `JsonPhoto` value.
- 4 We used `Decode.map` to translate a `Decoder JsonPhoto` into the `Decoder Photo` we ultimately wanted.

Here we're using a different approach to get a similar outcome:

- 1 Instead of using an intermediate representation like `JsonPhoto`, we handcraft a `folderFromJson : String -> Dict String Photo -> List Folder -> Folder` function.
- 2 We call `Decode.succeed folderFromJson`, meaning this `folderFromJson` function will be called if all the decoding steps succeed.
- 3 We use `required` several times, to build up a `Decoder Folder` by specifying the fields and types we want to decode and then pass to the `folderFromJson` function, which returns a decoded `Folder` value.

**NOTE** With this approach, we do not use an intermediate representation like `JsonPhoto`, so we do not need to use `Decode.map` to translate between that representation and the final decoder type we want.

This decoder ends up doing a bit more “postprocessing” than other decoders we’ve written—namely, calling `Dict.keys` on `photos` to get a `List String` of its keys, and adding `expanded = True`—but not much!

### IDENTIFYING A CYCLIC DEFINITION

Our `folderDecoder` implementation from listing 7.5 almost works . . . but not quite! If we try to compile it, we’ll get a cyclic-definition error.

The trouble is that we’ve defined a value in terms of itself. Imagine if we’d written this:

```
myString : String
myString =
    List.reverse myString
```

This has a problem similar to the one we saw in section 7.2.1, when we tried to make a type alias `Folder` that referenced `Folder` in one of its fields. Because a type alias is shorthand for a type we could have written by hand, when the compiler went to expand that alias out to the full type, it discovered that the resulting type would never end.

Just as a `type alias` declaration names a *type*, this `myString =` declaration names an *expression*. Anytime the compiler encounters `myString`, it will substitute the expression after the equals sign. This is where things go wrong.

Let’s look at how the compiler would expand `myString`:

```
List.reverse (List.reverse (List.reverse (List.reverse ...
```

The expansion never ends, because the compiler substitutes in `List.reverse str` as soon as it sees `myString`, then sees a `myString` in that `List.reverse myString` expression, and therefore substitutes `List.reverse myString` into *that* expression . . . and so on forever.

### THE CYCLIC DEFINITION IN FOLDERDECODER

Our current `folderDecoder` definition has this same problem. Here it is again:

```
folderDecoder : Decoder Folder
folderDecoder =
    Decode.succeed folderFromJson
        |> required "name" string
        |> required "photos" photosDecoder
        |> required "subfolders" folderDecoder
```

Just as in the case of `str = List.reverse str`, we’re trying to define a value in terms of a value we haven’t finished defining yet. This definition will also expand forever.

### FIXING THE CYCLIC DEFINITION BY USING DECODE.LAZY

We can solve this problem by using `Decode.lazy`. It has this type:

```
Decode.lazy : ((() -> Decoder val) -> Decoder val)
```

**NOTE** We first saw the `()` type in chapter 3. It's called *unit*, and it holds no information.

We can use `Decode.lazy` to remove the cyclic definition from `folderDecoder` like so:

```
folderDecoder =
    Decode.succeed folderFromJson
    |> required "name" string
    |> required "photos" photosDecoder
    |> required "subfolders" (Decode.lazy (\_ -> list folderDecoder))
```

**NOTE** The `list` here can go on either side of `Decode.lazy`; we could also have written this as `(list (Decode.lazy (\_ -> folderDecoder)))`. Although that way also works, it adds more visual separation between `list` and `folderDecoder`, making it harder to see which decoder we'll use for `"subfolders"`.

Here we no longer have the never-ending expansion problem, because after the compiler reaches `(\_ -> list folderDecoder)`, it stops expanding. That expression is already a fully formed anonymous function, which needs no further expansion.

Sure, later on, when this decoder actually gets run on some real JSON, `Decode.lazy` will call this anonymous function to obtain `folderDecoder`—but that will work just fine. By that time, `folderDecoder` will already have been successfully defined. This is the situation `Decode.lazy` was created to solve, and it will do the trick nicely here.

**TIP** If you see this cyclic-definition error on a decoder, it's likely that `Decode.lazy` can resolve it.

Now that we have a working decoder for `root : Folder`, we'll turn to the last decoder our model requires: a decoder for its `photos : Dict String Photo` field, the single source of truth for our detailed photo data.

### 7.3.3 Accumulating while decoding

We already have a `Decoder Folder` that works on this JSON structure, but it's perfectly reasonable for us to create a second decoder that also works on the same JSON. We'll do that when we create the final `Photo` dictionary we'll use in our Model. Add this to the end of your `PhotoFolders.elm` file:

```
modelPhotosDecoder : Decoder (Dict String Photo)
modelPhotosDecoder =
    Decode.succeed modelPhotosFromJson
    |> required "photos" photosDecoder
    |> required "subfolders" (Decode.lazy (\_ -> list
        modelPhotosDecoder))

modelPhotosFromJson :
    Dict String Photo
    -> List (Dict String Photo)
```

```

-> Dict String Photo
modelPhotosFromJson folderPhotos subfolderPhotos =
  List.foldl Dict.union folderPhotos subfolderPhotos

```

**NOTE** `modelPhotosDecoder` doesn't bother to decode the "name" field because it never uses the folders' names, only their photos.

This new `modelPhotosDecoder` will traverse the same JSON structure as `folderDecoder`, which is why they have so many similarities:

- Both use required "photos" `photosDecoder`.
- Both use `Decode.lazy` with `list` to recursively decode the "subfolders" field.
- Both give `Decode.succeed` a handwritten function instead of a record variant.

We see some new functions in `photosFromJson`; namely, `Dict.union` and `List.foldl`. What do they do?

### Dict.union

Let's start with `Dict.union`. Here is its type:

```
union : Dict comparable val -> Dict comparable val -> Dict comparable val
```

It iterates over the first dictionary and calls `Dict.insert` on each of its keys and values, inserting them into the second dictionary. The returned dictionary has the combined contents of both dictionaries.

**NOTE** Because the calls to `Dict.insert` use keys and values from the first dictionary, anytime the second dictionary already happens to have an entry for a particular key, it will get overridden.

We can use this to combine our various `Photo` dictionaries into the single dictionary that `Model` needs. However, because `Dict.union` combines only two individual dictionaries—and we need to combine many dictionaries—`Dict.union` will need some help. That's where `List.foldl` comes in.

### List.foldl and List.foldr

The `List` module offers two *fold* functions: `List.foldl` and `List.foldr`.

**NOTE** `foldl` is short for “fold from the left,” and `foldr` is short for “fold from the right.” JavaScript calls these functions `reduce` and `reduceRight` because they can *reduce* collections down to a single value. Any naming similarity between the `foldr` function and our `Folder` type is purely coincidental.

We can compare what `foldl` and `foldr` do by calling both functions in `elm repl`, passing the same arguments in each case:

```

> List.foldl
  (\letter str -> str ++ "-" ++ String.fromChar letter)
  "start"
  [ 'a', 'b', 'c', 'd' ]
"start-a-b-c-d" : String
> List.foldr

```

```
(\letter str -> str ++ "-" ++ String.fromCharCode letter)
"start"
[ 'a', 'b', 'c', 'd' ]
"start-d-c-b-a" : String
```

Let's walk through what's happening here.

### NAMING THE INGREDIENTS

First, note that both `List.foldl` and `List.foldr` have the same type:

```
(element -> state -> state) -> state -> List element -> state
```

We'll give those arguments some names:

- `(element -> state -> state)` is our update function.
- `state` is our initial state.
- `List element` is our list.

We've named the first argument the *update function* because it works similarly to The Elm Architecture's update function, specifically the version we used in chapter 2:

Elm Architecture update:	Msg -> Model -> Model
Fold function update:	element -> state -> state

Whenever the Elm Runtime calls `update`, it passes a `Msg` and the current `Model`, and gets back the updated `Model` it will use the next time it calls `update`. Similarly, each time a fold calls its update function, it passes an `element` and the previous `state`, and gets back the updated `state` to use the next time it calls the update function.

The first time the fold function calls its update function, it passes the *initial state* as the `state` argument and the first element in the *list* as the other argument. After repeating this process with the remaining elements in the list, it returns the final `state` value. (If the list is empty, it returns the initial state immediately.)

### DIFFERENCES BETWEEN FOLDL AND FOLDR

Although `foldl` and `foldr` both call their update functions on each element in the list, they differ in the order in which they pass those elements to their update functions. Table 7.3 compares the calls `foldl` and `foldr` make for the same arguments.

**Table 7.3 Calling foldl and foldr on the same arguments**

<code>List.foldl update [ 'a', 'b', 'c', 'd' ] "start"</code>	<code>List.foldr update [ 'a', 'b', 'c', 'd' ] "start"</code>
<pre>"start"  &gt; update 'a'  &gt; update 'b'  &gt; update 'c'  &gt; update 'd'</pre>	<pre>"start"  &gt; update 'd'  &gt; update 'c'  &gt; update 'b'  &gt; update 'a'</pre>

Both `foldl` and `foldr` begin with the initial state and then call the update function on it four times. But whereas `foldl` passes each element in its list to the update function in the same order as they appear in that list, `foldr` passes them in the reverse order.

### USING LIST.FOLDL WITH DICT.UNION

Now that we know how `foldl` works, let's break down the types involved in the expression where we've called it; see table 7.4.

**Table 7.4 Types involved in `(List.foldl Dict.union)` plus two more arguments from Decoder outputs**

Value	Type
<code>List.foldl</code>	<code>(element -&gt; state -&gt; state) -&gt; state -&gt; List element -&gt; state</code>
<code>Dict.union</code>	<code>Dict comparable val -&gt; Dict comparable val -&gt; Dict comparable val</code>
<code>folderPhotos</code>	<code>Dict String Photo</code>
<code>subfolderPhotos</code>	<code>List (Dict String Photo)</code>

In this expression, `folderPhotos` is our start value, so `List.foldl` will perform these steps:

- 1 Pass `Dict.union` the first dictionary in the `subfolderPhotos` list, with `folderPhotos` as the second argument. The result is our first state value.
- 2 Call `Dict.union`, passing the next dictionary in the `subfolderPhotos` list, with the previous outcome as the second argument. The result is our new state value.
- 3 Repeat the previous steps until we've iterated through the entire `subfolderPhotos` list. `List.foldl` returns the final state value.

In this way, we end up with a `Dict String Photo` value that combines all the photo information from the current folder as well as its subfolders.

**NOTE** The only time `List.foldl Dict.union` and `List.foldr Dict.union` will produce different values is when duplicate keys exist in the dictionaries involved. If that happens, the choice of `foldl` or `foldr` will change which values get overridden. We don't expect any duplicate keys (and even if we did, we wouldn't care how they got overridden), so we're choosing `foldl` only because it runs faster than `foldr`.

### JOINING TWO DECODERS

Finally, it's time for our `folderDecoder` and `modelPhotosDecoder` to team up and form a working `modelDecoder`. Let's replace the definition of `modelDecoder` with this:

```
modelDecoder : Decoder Model
modelDecoder =
    Decode.map2
```

```
(\photos root ->
  { photos = photos, root = root, selectedPhotoUrl = Nothing }
)
modelPhotosDecoder
folderDecoder
```

Like its smaller cousin `map`, the `Decode.map2` function transforms the *contents* of a value—in this case, a `Decoder` value—rather than the entire value. The difference is that `map2` takes an extra argument. Here are their types side by side:

<code>map : (val      -&gt; final) -&gt;</code>	<code>Decoder val -&gt; Decoder final</code>
<code>map2 : (one -&gt; two -&gt; final) -&gt;</code>	<code>Decoder one -&gt; Decoder two -&gt; Decoder final</code>

We used `map2` instead of `map` because building our Model requires the outputs of both decoders. We also could have used `Decode.andThen` for this purpose, which works similarly to the `Maybe.andThen` function we saw in section 7.1.2, but it's generally better to use the simpler function (in this case, `map2`) when either of two functions would do the job. (In practice, `Decode.andThen` tends to be used to perform validation on freshly decoded values.)

**TIP** Many other modules, like `Result` and `Random`, offer similar `map2` and `andThen` functions.

With these two decoders' powers combined, our `modelDecoder` is now fully operational!

**NOTE** If you're looking for extra challenges, you can try combining `modelPhotosDecoder` and `folderDecoder` into a single `Decoder` (`Folder`, `Dict String Photo`) that decodes both the folders and the photos in one pass. That version would use `Decode.map` instead of `Decode.map2` here.

### VIEWING THE FINISHED PAGE

After we recompile, the page should now load both photos and folders from the server. The result should be more folders and more photos than we previously had hardcoded. The final page should look something like figure 7.9, depending on which photo you select.

Now the Photo Folders page is loading its model data from the server. It gathers all the photos it finds in the folder JSON into a single `Dict String Photo`, which the rest of our page uses to make the folders and photos interactive. We did it!

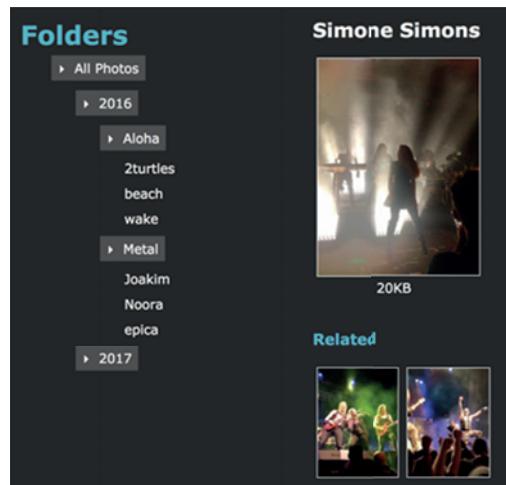


Figure 7.9 The final Photo Folders page

## Summary

In this chapter, we built a whole new page from scratch! The Photo Folders feature is sure to be a hit, thanks to our efforts. Along the way, you learned several new techniques:

- Using `Dict String Photo` to store photos by their URL.
- Using a recursive custom type of `type Folder = Folder { subfolders : List Folder, ... }` to represent a tree of folders with subfolders nested inside.
- Using a recursive `Msg` variant to implement expanding and collapsing on that tree.
- Using `Decode.keyValuePairs` to decode an object into key-value pairs for further processing with functions like `Decode.map`.
- Creating intermediate representations like `Decoder JsonPhoto` to decode what we can from a particular JSON object, then using `Decode.map` to use additional information to translate from `Decoder JsonPhoto` into a `Decoder Photo`. We used this technique to decode a photo's URL from its key in the enclosing JSON object.
- Using recursive decoders to decode tree structures, and seeing how `Decode.lazy` can fix cyclic-definition errors in recursive decoders.
- Using `Dict.union` to combine the contents of two dictionaries into one.
- Using `List.foldl` to reduce a list of values down to one value.
- Using the `map2` function to combine and transform two values—in this case, JSON decoders—into one value.

Here is the final `PhotoFolders.elm` file.

### Listing 7.12 PhotoFolders.elm

```
module PhotoFolders exposing (main)

import Dict exposing (Dict)
import Html exposing (...)
import Html.Attributes exposing (class, src)
import Html.Events exposing (onClick)
import Http
import Json.Decode as Decode exposing (Decoder, int, list, string)
import Json.Decode.Pipeline exposing (required)
```

```
type Folder
    = Folder
        { name : String
        , photoUrls : List String
        , subfolders : List Folder
        , expanded : Bool
        }
```

**Folder** is a custom type with a single variant, which is also named **Folder**.

```

type alias Model =
    { selectedPhotoUrl : Maybe String
    , photos : Dict String Photo
    , root : Folder
    }

initialModel : Model
initialModel =
    { selectedPhotoUrl = Nothing
    , photos = Dict.empty
    , root =
        Folder
            { name = "Loading..."
            , expanded = True
            , photoUrls = []
            , subfolders = []
            }
    }

init : () -> ( Model, Cmd Msg )
init =
    ( initialModel
    , Http.get
        { url = "http://elm-in-action.com/folders/list"
        , expect = Http.expectJson GotInitialModel modelDecoder
        }
    )

modelDecoder : Decoder Model
modelDecoder =
    Decode.map2
        (\photos root ->
            { photos = photos, root = root, selectedPhotoUrl = Nothing })
        modelPhotosDecoder
        folderDecoder

If both decoders succeed, run the callback to get the final value.

type Msg
    = ClickedPhoto String
    | GotInitialModel (Result Http.Error Model)
    | ClickedFolder FolderPath

update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
    case msg of
        ClickedFolder path ->
            ( { model | root = toggleExpanded path model.root }, Cmd.none )

        ClickedPhoto url ->
            ( { model | selectedPhotoUrl = Just url }, Cmd.none )

```

```

GotInitialModel (Ok newModel) ->
    ( newModel, Cmd.none )

GotInitialModel (Err _) ->
    ( model, Cmd.none )

view : Model -> Html Msg
view model =
    let
        photoByUrl : String -> Maybe Photo
        photoByUrl url =
            Dict.get url model.photos

        selectedPhoto : Html Msg
        selectedPhoto =
            case Maybe.andThen photoByUrl model.selectedPhotoUrl of
                Just photo ->
                    viewSelectedPhoto photo
                Nothing ->
                    text ""

    in
        div [ class "content" ]
            [ div [ class "folders" ]
                [ h1 [] [ text "Folders" ]
                , viewFolder End model.root
                ]
            , div [ class "selected-photo" ] [ selectedPhoto ]
            ]

main : Program () Model Msg
main =
    Browser.element
        { init = init
        , view = view
        , update = update
        , subscriptions = \_ -> Sub.none
        }

type alias Photo =
    { title : String
    , size : Int
    , relatedUrls : List String
    , url : String
    }

viewPhoto : String -> Html Msg
viewPhoto url =
    div [ class "photo", onClick (ClickedPhoto url) ]
        [ text url ]

```

**Maybe.andThen** is like **Maybe.map**, except it can change the outcome to **Nothing**.

```

viewSelectedPhoto : Photo -> Html Msg
viewSelectedPhoto photo =
    div
        [ class "selected-photo" ]
        [ h2 [] [ text photo.title ]
        , img [ src (urlPrefix ++ "photos/" ++ photo.url ++ "/full") ] []
        , span [] [ text (String.fromInt photo.size ++ "KB") ]
        , h3 [] [ text "Related" ]
        , div [ class "related-photos" ]
            (List.map viewRelatedPhoto photo.relatedUrls)
    ]

```

```

viewRelatedPhoto : String -> Html Msg
viewRelatedPhoto url =
    img
        [ class "related-photo"
        , onClick (ClickedPhoto url)
        , src (urlPrefix ++ "photos/" ++ url ++ "/thumb")
        ]
    []

```

```

viewFolder : FolderPath -> Folder -> Html Msg
viewFolder path (Folder folder) =
    let
        viewSubfolder : Int -> Folder -> Html Msg
        viewSubfolder index subfolder =
            viewFolder (appendIndex index path) subfolder ←
                viewFolder is a recursive function; it calls itself.

        folderLabel =
            label [ onClick (ClickedFolder path) ] [ text folder.name ]
        in
        if folder.expanded then
            let
                contents =
                    List.append
                        (List.indexedMap viewSubfolder folder.subfolders) ←
                            (List.map viewPhoto folder.photoUrls)
            in
            div [ class "folder expanded" ]
                [ folderLabel
                , div [ class "contents" ] contents
                ]
                indexedMap is like map, but the callback also receives the current index as an argument.

        else
            div [ class "folder collapsed" ] [ folderLabel ]

```

```

appendIndex : Int -> FolderPath -> FolderPath
appendIndex index path =
    case path of
        End ->
            Subfolder index End

```

```

Subfolder subfolderIndex remainingPath ->
    Subfolder subfolderIndex (appendIndex index remainingPath)

urlPrefix : String
urlPrefix =
    "http://elm-in-action.com/"

type FolderPath
    = End
    | Subfolder Int FolderPath

```

**FolderPath** is a recursive custom type; it potentially contains other **FolderPath**s.

```

toggleExpanded : FolderPath -> Folder -> Folder
toggleExpanded path (Folder root) =
    case path of
        End ->
            Folder { root | expanded = not root.expanded }

        Subfolder targetIndex remainingPath ->
            let
                subfolders : List Folder
                subfolders =
                    List.indexedMap transform root.subfolders

                transform : Int -> Folder -> Folder
                transform currentIndex currentSubfolder =
                    if currentIndex == targetIndex then
                        toggleExpanded remainingPath currentSubfolder

                    else
                        currentSubfolder
            in
            Folder { root | subfolders = subfolders }

type alias JsonPhoto =
    { title : String
    , size : Int
    , relatedUrls : List String
    }

jsonPhotoDecoder : Decoder JsonPhoto
jsonPhotoDecoder =
    Decode.succeed JsonPhoto
        |> required "title" string
        |> required "size" int
        |> required "related_photos" (list string)

finishPhoto : ( String, JsonPhoto ) -> ( String, Photo )
finishPhoto ( url, json ) =
    ( url

```

```

        , url = url
        , size = json.size
        , title = json.title
        , relatedUrls = json.relatedUrls
    }
)

fromPairs : List ( String, JsonPhoto ) -> Dict String Photo
fromPairs pairs =
    pairs
        |> List.map finishPhoto
        |> Dict.fromList

```

```

photosDecoder : Decoder (Dict String Photo)
photosDecoder =
    Decode.keyValuePairs jsonPhotoDecoder
        |> Decode.map fromPairs

```

**First decode the photos into key-value pairs; then finish turning them into a Dict of Photo records.**

```

folderDecoder : Decoder Folder
folderDecoder =
    Decode.succeed folderFromJson
        |> required "name" string
        |> required "photos" photosDecoder
        |> required "subfolders" (Decode.lazy (\_ -> list folderDecoder)) ◀

```

**Decode.lazy prevents cyclic-definition error.**

```

folderFromJson : String -> Dict String Photo -> List Folder -> Folder
folderFromJson name photos subfolders =
    Folder
        { name = name
        , expanded = True
        , subfolders = subfolders
        , photoUrls = Dict.keys photos
        }

```

```

modelPhotosDecoder : Decoder (Dict String Photo)
modelPhotosDecoder =
    Decode.succeed modelPhotosFromJson
        |> required "photos" photosDecoder
        |> required "subfolders" (Decode.lazy (\_ -> list
modelPhotosDecoder))

```

```

modelPhotosFromJson :
    Dict String Photo
    -> List (Dict String Photo)
    -> Dict String Photo
modelPhotosFromJson folderPhotos subfolderPhotos =
    List.foldl Dict.union folderPhotos subfolderPhotos ◀

```

**foldl starts with the folderPhotos dictionary, then traverses subfolderPhotos and unions each of those dictionaries with it.**

# *Single-page applications*



## **This chapter covers**

- Working with multiple modules
- Optimizing performance with `Html.Lazy`
- Routing
- Parsing URLs

Our manager adores the two pages we've built for Photo Groove, and has a visionary idea for where to go next: "Now that we have all these pages, we need a header across the top with links so users can get between them quickly. Oh! And make sure it doesn't do that unsightly flash of blank page when switching between them. That drives me bananas."

Indeed, two pages is a lot more than one; a header to switch between them sounds like just what the doctor ordered.

In this chapter, we'll build a navigation header that is shared between the two pages we've built in the previous chapters. We'll build the combined page by using a single-page application (SPA) architecture, so users can transition between the two pages without the browser performing a fresh page load.

The “single page” in “single-page application” refers to a *single page load*—the browser loads the page only once. From the user’s perspective, all the usual features of multiple pages still appear to work as normal: the URL in the address bar changes when clicking links, the browser’s Back button still returns to the previous URL, and so on. Let’s build ourselves a single-page application!

## 8.1 **Framing the page**

The first step in our plan for building this single-page application is to create a fresh Elm program that renders our header. We’ve also been informed by Legal that we’ll need a footer as well, although they still need to consult with Marketing on exactly what will go in it. Once we’ve finished the basic header and footer, we’ll get our application to respond to URL changes. Finally, we’ll render the appropriate page content between the header and footer.

### 8.1.1 **Creating Main.elm**

We’ll kick things off with a new file, Main.elm, which will go in the src/directory next to PhotoGroove.elm and PhotoFolders.elm. The following listing shows what we’ll put in it.

#### **Listing 8.1 Main.elm**

```
module Main exposing (main)

import Browser exposing (Document)
import Html exposing (Html, a, footer, h1, li, nav, text, ul)
import Html.Attributes exposing (classList, href)

type alias Model =
    {}  

    | We'll add some fields to Model later.

view : Model -> Document Msg  

view model =  

    { title = "Photo Groove, SPA Style"  

    , body = [ text "This isn't even my final form!" ] }  

    | This view function returns Document, letting it specify a title.  

    | The title of the page in the browser  

    | Notice that body is a List.

type Msg  

    = NothingYet  

    | We'll add some real variants to Msg later.

update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
    ( model, Cmd.none )
```

```

subscriptions : Model -> Sub Msg
subscriptions model =
    Sub.none

main : Program () Model Msg
main =
    Browser.document
        { init = _ -> ( {}, Cmd.none )
        , subscriptions = subscriptions
        , update = update
        , view = view
        }

```

← **Browser.document supports view returning a Document.**

A few things in this file are different from the way we've done things in previous chapters. Let's first look at `main`, which is now calling `Browser.document` instead of the trusty `Browser.element` we've been using up to this point.

The difference between the two is that in `Browser.element`, our view function must return `Html Msg`, whereas in `Browser.document`, our view function instead returns `Document Msg`. This gives our Elm application control over the entire page, whereas with `Browser.element` we were confined to a single DOM element on the page.

### RETURNING DOCUMENT INSTEAD OF HTML

Let's turn our attention to this new view function:

```

view : Model -> Document Msg
view model =
    { title = "Photo Groove, SPA Style"
    , body = [ text "This isn't even my final form!" ]
    }

```

This `Document Msg` value we're returning is a record with two fields:

- `title` is a string that sets the page's title in the browser. Because we control the whole page now, we can do that.
- `body` is a `List (Html Msg)` that specifies the children of the page's `<body>` element. It's a `List` rather than a single `Html Msg` node because we're controlling `<body>`'s entire list of children—whereas with `Browser.element`, we controlled a single element on the page.

The rest of `Main.elm` is similar to what we've done before. We don't have interesting `Model` or `Msg` types yet, but we'll expand them as we progress through the chapter. For now, let's move on to trying out what we've built!

### REVISING INDEX.HTML

To view our `Main.elm`, we'll need to tweak `index.html` once more. Similar to the change we made to it in chapter 7, we'll replace the final `<script>` tag in `index.html` (the one that starts off `var app = ...`) with this:

```

<script>
    var app = Elm.Main.init({node: document.getElementById("app")});
</script>

```

## VIEWING THE PAGE

With that in place, we can build our app.js file by using elm make like so:

```
elm make --output=app.js src/Main.elm
```

Open index.html in the browser, as shown in figure 8.1, and behold!

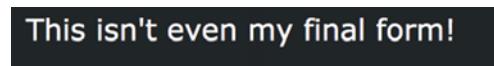


Figure 8.1 First confirmed sighting of the compiled Main.elm in the wild

Stunning! Glorious! A triumph!

Of note, check the title on the page. Even though index.html does not specify a <title>, the browser should now display “Photo Groove, SPA Style” as the page’s title. A fine start!

### 8.1.2 Rendering the header and footer

Now that we have a basic page up and running, we’re ready to dive headfirst into the header and footer. Our designers have mocked up a basic design, shown in figure 8.2.



Figure 8.2 The design mockup for the header

We’ll implement the design according to these rules:

- The words “Photo Groove” will go in an <h1> element.
- Folders and Gallery will be links.
- If the user is viewing the Folders page, the Folders link will be displayed as *active*, meaning it is underlined. Likewise with the Gallery page and the Gallery link. If the user is viewing neither of those pages, then neither link should be shown as active.

As for the footer, Legal and Marketing haven’t yet agreed about exactly what should go in there, so for now we’ll use a Douglas Adams quote as a placeholder. We assure ourselves that there’s no chance we’ll end up launching the final product before getting around to changing it.

## ADDING PAGE STATE TO THE MODEL

We could render the static content by changing only view, but that third header requirement—displaying some links as active depending on the current page—requires a change to Model. We won’t wire this up to the real URL until later in the

chapter, but for now we can at least define a `Page` type to represent the different states we care about, and add it to `Model`.

### Listing 8.2 Adding Page to Model

```
type alias Model =
    { page : Page }

type Page
    = Gallery
    | Folders
    | NotFound

view : Model -> Document Msg
view model =
    let
        content =
            text "This isn't even my final form!"
    in
        { title = "Photo Groove, SPA Style"
        , body =
            [ viewHeader model.page
            , content
            , viewFooter ] }
    }

viewFooter : Html msg
viewFooter =
    footer [] [ text "One is never alone with a rubber duck. -Douglas Adams" ]
```

The code in Listing 8.2 is annotated with several callout boxes:

- A box points to `viewHeader` with the text: "We'll define the `viewHeader` function in a moment."
- A box points to the list item `[ content ]` with the text: "Later, we'll replace this with different content depending on your page."
- A box points to the note "viewHeader is a function, but viewFooter is not; it takes no arguments." which is located between the two annotations.
- A box points to the type annotation `viewFooter : Html msg` with the text: "This type can be `Html msg` instead of `Html Msg` because `viewFooter` has no event handlers."

Here's what we've done:

- 1 Introduced a `Page` type that represents the three page states we care about: the user is viewing the `Gallery` page, the user is viewing the `Folders` page, and the user is viewing a URL we don't recognize—meaning we'll show a `NotFound` page.
- 2 Stored the current `Page` value in the `Model` so that `view` can render things differently depending on the current page state.
- 3 Reorganized `view` to render three distinct sections: the header (`viewHeader model.page`), the main page content (`content`), and the footer (`viewFooter`). We've already implemented `viewFooter`, we'll implement `viewHeader` next, and later in the chapter we'll take care of `content`.

Now that `Model` has a `page` field, we'll also need to change `init` to give it an initial value:

```
init = \_ -> ( { page = Gallery }, Cmd.none )
```

Lovely! Now let's turn to `viewHeader`.

### IMPLEMENTING VIEWHEADER

For `viewHeader`, we'll use a mixture of techniques we've seen throughout the book, but combined in new and exciting ways! Let's start by sketching a basic outline:

```
viewHeader : Page -> Html Msg
viewHeader page =
  let
    logo =
      h1 [] [ text "Photo Groove" ]

    links =
      ul [] []
  in
  nav [] [ logo, links ]
```

The function accepts only the current `Page` as its argument, because our design specification tells us the only way `viewHeader` renders things differently is when the current page changes—at which point it might render a different link as active.

From scanning through the rest of the function, we can tell a few things:

- It's returning a `<nav>`, the semantically appropriate element for a navigation bar.
- The only two elements inside the `<nav>` are the logo and the links.
- The logo is a static `<h1>` that never changes.

Not a bad start! The `links` are pretty boring—empty `<ul>` elements—at the moment, though. Let's make them more interesting.

### CREATING LINKS WITH NavLink

To implement the links, we'll define a helper function right below `links` in our `let`-expression, and then have `links` call it:

```
links =
  ul []
  [ NavLink Folders { url = "/", caption = "Folders" }
  , NavLink Gallery { url = "/gallery", caption = "Gallery" }
  ]

NavLink : Page -> { url : String, caption : String } -> Html msg
NavLink targetPage { url, caption } =
  li [ classList [ ( "active", page == targetPage ) ] ]
  [ a [ href url ] [ text caption ] ]
```

**TIP** As you can see with `NavLink` here, you can add type annotations to declarations inside `let`-expressions.

### DEFINING FUNCTIONS INSIDE LET-EXPRESSIONS

We've made helper functions before, but they haven't looked like this. Why is `NavLink` defined inside a `let`-expression instead of at the top level like the rest of our functions? And why is it taking a record for its second argument?

The reason `navLink` is defined in the let-expression is so that it can use `page` in the expression `page == targetPage`. Because `page` is an argument to the `viewHeader` function, if `navLink` were defined at the top level, it would need to accept `page : Page` as an additional argument, and that `page` value would have to be passed in every time.

**NOTE** It is a completely reasonable design decision to go the other way—to make `navLink` a top-level function with an extra argument. This design decision could have gone either way, which made it a convenient chance to show the technique—but don’t feel obliged to make the same choice in your own code. After all, top-level functions are by default nicer to maintain because their dependencies are more explicit.

### PREVENTING ARGUMENT MIX-UPS

So why does `navLink` take a `{ url : String, caption : String }` record for its second argument? Well, let’s suppose we didn’t use a record here. Consider what `navLink`’s type would be:

```
navLink : Page -> String -> String -> Html msg
```

What happens if we accidentally mix up the order of the two `String` arguments? The types will still line up, so the compiler won’t be able to help us . . . so how will we be able to look at a call site and tell if it’s passing them in the right order? We’d pretty much have to go look up the implementation for `navLink` to find out.

### PASSING “NAMED ARGUMENTS”

Anytime you have multiple arguments of the same type, and you’re concerned about accidentally passing them in the wrong order, putting them into a record is a quick way to achieve “named arguments.” I can tell at a glance that `{ url = "/", caption = "Folders" }` looks right, whereas something looks off about `{ url = "Folders", caption = "/" }`. The string `"Folders"` clearly isn’t a URL, so why is `url` being set to that?

When using this pattern, it’s common practice to destructure the arguments in the definition of the function:

```
navLink targetPage { url, caption } =
```

This way, they work and feel like normal arguments, but they are passed in with names instead of by position.

**TIP** If you want to destructure these fields, but also want to be able to access the original record in its entirety, you can use the `as` keyword to name the original record. For example, this would give the name `config` to the record while destructuring its fields: `navLink targetPage ({ url, caption } as config) =`.

### USING CLASSLIST

Notice that we're also using `classList` again, just as we did for `viewThumbnail` back in `PhotoGroove.elm`:

```
li [ classList [ ( "active", page == targetPage ) ] ]
    [ a [ href url ] [ text caption ] ]
```

This time, we're using it to add the `active` CSS class to our header link, but only when the page the link points to is the same as the page we're currently on. This will take care of the design requirement that the `Folders` link should be active when we're on the `Folders` page, and the same for the `Gallery` link.

### TRYING IT OUT

To test that this all works, try running `elm make` and refreshing the browser. Then, to make sure it responds to different page values in the model, change `page` from `Gallery` to `Folders` inside `init`, like so:

```
init = \_ -> ( { page = Folders }, Cmd.none )
```

After running `elm make` again and refreshing the browser, the active header link should have changed from `Gallery` to `Folders`. Great success!

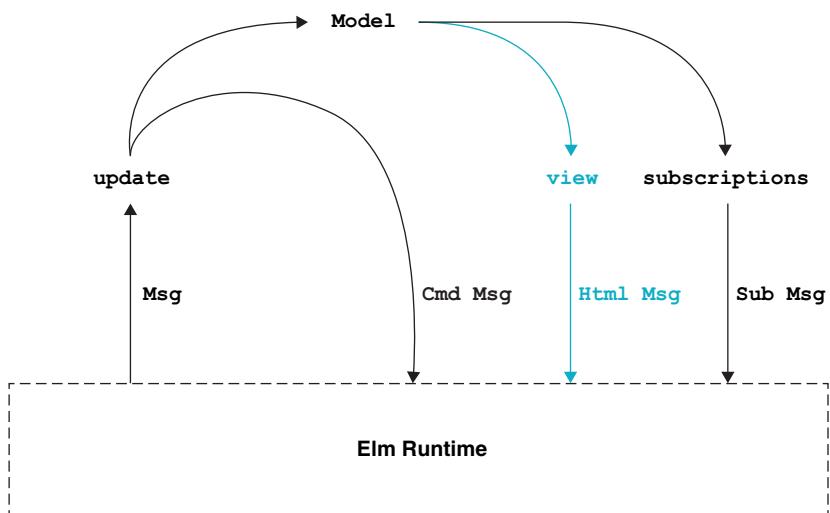
#### 8.1.3 *Skiping unnecessary renders with `Html.Lazy`*

At this point, nothing is stopping us from moving ahead with our implementation of the header. However, one performance optimization technique is so cheap—we will ultimately be adding five *characters* to our view function's implementation—that it's commonly used on headers before there is any noticeable performance problem. Most important, the technique we'll use will be very useful in the future. Among all Elm performance problems that appear in the wild, this is by far the most common way they are solved.

**NOTE** A notorious pitfall in software development is *premature optimization*—that is, spending time addressing performance problems that exist only in our minds. It's always worth asking the question: are we about to optimize prematurely? In this case, *we totally are*. But at least we're doing it for learning!

### BUILDING AN HTML MSG VALUE

Back in chapter 2, I introduced The Elm Architecture, which is how every Elm program describes a user interface. By the end of chapter 5, we had a complete diagram of it. Here it is again in figure 8.3, with the `view` part highlighted.



**Figure 8.3 The Elm Architecture**

Whenever the Elm Runtime calls our `view` function, it will return an `Html Msg` describing how we want the page to look. Building up this `Html Msg` representation usually doesn't take much of the computer's time, but if a `view` function gets large enough—and especially if it's running on an underpowered device like an old smartphone—it's possible (although rare) that assembling the `Html Msg` value itself can be the source of performance problems.

When this happens, the usual fix is to *avoid doing work*, by identifying sections of the `Html Msg` value that rarely change and avoiding having to rebuild them each time `view` is run.

#### PREMATURELY OPTIMIZING THE HEADER

We haven't observed any problems in Photo Groove, but we already know of one section of the page that will rarely change: the header. Nearly every time `viewHeader` is called, it will return the exact same `Html Msg` value as the previous time it was called. The only time it might possibly change is when `model.page` changes—because we navigated to a different page—in which case, it might return an `Html Msg` value with a different active link.

Happily, there's a quick way to tell the Elm Runtime to cache the previous return value of `viewHeader`, so `viewHeader` will get rerun only when `model.page` changes. If `model.page` is unchanged, that cached `Html Msg` value will be used, and `viewHeader` won't rebuild it at all. We'll do this by using the `Html.Lazy` module.

#### CALLING LAZY ON VIEWHEADER

Let's import the `Html.Lazy` module, exposing its `lazy` function:

```
import Html.Lazy exposing (lazy)
```

Next, we'll introduce that `lazy` function right before our call to `viewHeader`:

```
{ title = "Photo Groove, SPA Style"
, body =
  [ lazy viewHeader model.page
```

Now instead of calling `viewHeader`, passing `model.page`, we're calling `lazy`, passing `viewHeader` and `model.page`. This compiles because `lazy` has this type:

```
lazy : (arg -> Html msg) -> arg -> Html msg
```

In other words, `lazy` expects a function that does the following:

- Takes a single argument (we'll refer to this argument's type as `arg`)
- Returns some `Html`

Our `viewHeader : Page -> Html Msg` function fits this description exactly! (Here, the `arg` type refers to `Page`.)

Besides this function that takes an `arg`, the other argument that `lazy` expects is a value of type `arg`. It has to be an `arg` too because `lazy` plans to pass it to the function.

**TIP** If you want to use `lazy` with a function that takes multiple arguments, check out `lazy2` and `lazy3`.

### TRYING THE FIRST RUN

The first time `lazy viewHeader model.page` gets run, `lazy` will not improve our performance. In fact, it'll be almost as if we hadn't added `lazy` at all; `lazy` will call `viewHeader`, passing `model.page`, and return whatever `viewHeader` returned. (How boring!) However, as it does this, `lazy` also quietly does something else: it stores the value of `model.page` as well as the value `viewHeader` returned.

The next time our program executes this line of code, `lazy` will first take a quick look at the `model.page` value we pass it. If it's the same `model.page` value that we passed last time, `lazy` won't bother calling `viewHeader` at all; instead, it will immediately return the result it stored previously.

**NOTE** The `lazy` function is an interface to a particular feature of the Elm Runtime; there is no way we could have written it by using Elm code alone.

For details on how `lazy` decides whether a value has changed from one run to the next, see appendix C.

### GUARANTEES THAT MAKE SKIPPING SAFE

It's safe for `lazy` to skip calling `viewHeader` like this, thanks to two important guarantees:

- As you learned in chapter 3, when you call an Elm function passing the same arguments, it's guaranteed to return the same value.
- As you learned in chapter 4, Elm functions are guaranteed not to have side effects.

Putting these together, if we already know what a function returned the last time we called it, then there's never any need to call that function again with those same arguments. Running the function again is guaranteed to do nothing more than return the value we already know.

### Using `lazy` isn't free

It might seem that this ought to be the default behavior. Why not `lazy` everything? The answer is that `lazy` is not without its costs.

Remember, `lazy` relies on storing extra information about every function that gets passed to it. Each time we call `lazy`, our program takes up more memory and does a bit more work to store the value and compare the result. If we used `lazy` everywhere, we'd run the risk of ballooning our program's memory usage and doing a bunch of unnecessary comparisons. We might make our overall performance considerably worse by doing this.

This is why `lazy` is opt-in, and why it's best to use it only as needed.

### VERIFYING THAT SKIPPING HAPPENED

At this point, we've added the call to `lazy`. Great!

Now how do we know it's doing anything? There's no visual indication that `lazy` did or did not choose to skip `viewHeader`—after all, `lazy` is designed to be a behind-the-scenes optimization rather than an in-your-face one—so how can we tell if it did anything differently? An easy way to tell is by using a function that's helpful in more ways than one: `Debug.log`.

### UNDERSTANDING `DEBUG.LOG`

The `Debug.log` function is unusual among Elm functions in that it actually performs a side effect every time we call it. Specifically, whenever we call `Debug.log`, the Elm Runtime immediately sends a `String` to the browser's console—completely bypassing the typical Elm Architecture way of handling effects through returning `Cmd` values from `update`. It's harmless to do this, because all `Debug.log` does is write to the browser console for development purposes, and no other part of an Elm program can depend on that console.

Here is the type of this peculiar function:

```
Debug.log : String -> a -> a
```

We pass it a `String` to display in the console, as well as a value (of any type) to be displayed right after that `String`, and it returns the exact same value we gave it. The typical way we'd use this is by starting with something like this:

```
case msg of
```

... and then introducing a `Debug.log` like so:

```
case Debug.log "Processing this msg" msg of
```

If `msg` had the value `SlidHue 5`, this would log "Processing this msg: SlidHue 5" to the console, right when the `Debug.log` function was executed.

Because `Debug.log` returns its second argument—in this case, `msg`—adding `Debug.log` like this has no effect on the code's behavior. This case will still operate on `msg` just as before.

**TIP** If you ever find yourself wanting to use `Debug.log` on your `msg` or `model`, you might instead try running `elm make` with the `--debug` flag. This will add an interactive time-traveling debugger to your compiled program, which makes it much easier to see how your `msg` and `model` are changing over time. Try it out!

### USING DEBUG.LOG TO TELL WHEN A FUNCTION HAS BEEN RUN

The most common use for `Debug.log` is to engage in the age-old programming tradition of printing values to a console to see what they are at runtime. However, in our case, we can use it for a different purpose: as a way to tell when `viewHeader` has actually executed, and when `lazy` caused it to be skipped.

We'll modify the `navLink` function inside `viewHeader` to have its `page` value wrapped in a call to `Debug.log`, like so:

```
navLink route { url, caption } =
    li [ classList [ ( "active", isActive { link = route,
        page = Debug.log "Rendering nav link with" page
    } ) ] ] [ a [ href url ] [ text caption ] ]
```

**NOTE** We don't need to import the `Debug` module because it's one of the modules Elm imports by default. Appendix B provides a complete list of Elm's default imports.

### TRIGGERING RE-RENDERS

The Elm Runtime calls `view` only after a `Msg` gets sent to `update`, so to test this out, we'll need to introduce some sort of event handler. Our `Msg` type currently has one variant—called `NothingYet`—but for our purposes, that's enough. Let's add an `onMouseOver` to the last line of our `viewHeader` function like so:

```
nav [ onMouseOver NothingYet ] [ logo, links ]
```

We'll need to import `Html.Events` to access `onMouseOver`:

```
import Html.Events exposing (onMouseOver)
```

Now rerun `elm make` and refresh the page.

### DETECTING RENDERS

Open the developer console in your browser and try moving the mouse around. Whenever one of our "Running `viewHeader` with..." messages gets logged to the console, that means `lazy` must have decided to run `viewHeader`. Notice that because `model.page` isn't changing, `lazy` isn't rerunning it.

Now try removing the call to `lazy` in our `view` function, run `elm make` again, and refresh the page. This time, watch how much more gets logged to the console when you move the mouse. It's a dramatic difference! `lazy` is often at its most helpful in Elm programs that respond to frequently firing events like `mousemove`.

#### CLEANING UP THE DEBUGGING CODE

Having now verified that `lazy` is working as intended, let's remove all of these from `Main.elm`:

- The call to `Debug.log` in `navLink`
- The call to `onMouseOver` at the end of `viewHeader`
- The `Html.Events` import

They were all helpful at the time, but we won't be needing them for the rest of the chapter. Now that we've optimized this into a Blazing Fast Header, complete with simulated awareness of URL changes, we're ready to start handling some *real* URL changes!

## 8.2 Routing

When the user visits a particular URL in the browser, our application will be notified about the URL they visited. Then it will inspect the URL and use its contents to decide which page to run. This process of determining which logic to run, based on the URL the user has visited, is called *routing*, and it's what we'll implement next for our single-page application.

### 8.2.1 Handling the initial URL

Before we start writing any Elm code, we'll need to make a small tweak to the way we're loading our compiled Elm code in the browser.

So far, we've been opening `index.html` directly in the browser, resulting in an address bar that always begins with `file://` and ends in `index.html`. If we want to start basing our application logic on different URLs in that address bar, we'll need a different setup—one that doesn't rely on always having the same fixed `file://` URL in our address bar.

#### INSTALLING HTTP-SERVER-SPA

The `http-server-spa` package on `npm` will have us up and running in no time. (If you don't already have `npm` installed, head over to appendix A to get it.) Here's how to set it up:

- 1 Run `npm install -g http-server-spa`.
- 2 From the same directory as `index.html`, run `http-server-spa .` (Note the period at the end. It's important, and there must be a space before it.)
- 3 Leave this app running in the background for as long as you want to use it. (It's harmless to restart it, so you can stop it anytime and start it back up again later.)

The `http-server-spa` program is a static file server, which lets us visit `http://localhost:8080` in the browser to view `index.html`. It will serve `index.html` whenever we visit

any localhost:8080 URL—including localhost:8080/gallery and the like. Now our Elm code will always get run, no matter what localhost:8080 URL we visit.

### LOADING /APP.JS INSTEAD OF APP.JS

Before we can successfully view our application in the browser, we'll need to tweak index.html one final time. It's a subtle change. We're going to add a single slash character just inside the string "app.js" in the `<script>` that imports it:

```
<script src="/app.js"></script>
```

Without that slash, the browser will try to load the app.js file from a location relative to whatever URL is currently in the address bar. This means if we visit localhost:8080/gallery, the browser will try to load localhost:8080/gallery/app.js—but the file won't be there. It's actually hosted at localhost:8080/app.js (without the gallery/ part).

Fortunately, by loading the script from "/app.js" instead of "app.js", the browser will fetch the file from the same (correct) location no matter what URL we're visiting. Try it out! You should now be able to visit localhost:8080 (or localhost:8080/gallery, for that matter) and see the same thing you do when opening index.html directly.

### HANDLING DIFFERENT URL SCENARIOS

Onward to the URL handling! Our manager told us about three scenarios we'll need to support:

- When the user navigates to the base URL, with nothing after it—for instance, example.com rather than example.com/something—the application should display the Photo Folders page we built in chapter 7.
- When the user navigates to the base URL with /gallery after it—that is, example.com/gallery instead of example.com—we should show the Photo Groove page we built in the chapters leading up to chapter 7. Our manager says we're going to start calling this the “Gallery page,” so we'll rename the module accordingly a bit later.
- When the user navigates to /photos/2turtles, things get trickier: the application should display the Photo Folders page once again, but this time the turtles.jpg photo should be selected. The idea is that users should be able to share links to specific photos, so this feature is supposed to work for any photo displayed in Photo Groove, not just turtles.jpg.

Currently, our application displays the same page no matter what URL the user has entered, so the first thing we'll need to do is to examine the URL and do something different depending on which one we find.

### RECEIVING THE URL WITH BROWSER.APPLICATION

To examine the initial page URL, we'll need to upgrade `Browser.document` to `Browser.application`. As it turned out, that wasn't even our final form!

Let's replace our call to `Browser.document` with the following:

```
Browser.application
  { init = _ --> ( { page = Folders }, Cmd.none )
  , onUrlRequest = _ --> Debug.todo "handle URL requests"
  , onUrlChange = _ --> Debug.todo "handle URL changes"
  , subscriptions = _ --> Sub.none
  , update = update
  , view = view
  }
```

The changes that stand out the most here involve the two new fields: `onUrlChange` and `onUrlRequest`. They're both calling something called `Debug.todo`. What's that all about?

### USING DEBUG.TODO

The `Debug.todo` function tells Elm's compiler, “I'm not ready to work on this part of my code base yet, so for now just pretend I put some valid code here, and I'll get back to it later.” No matter where you put it, a call to `Debug.todo` will type-check, because this is its type:

```
Debug.todo : String -> a
```

**TIP** One of the handiest uses for `Debug.todo` is to let you play around with the way certain types fit together. Try defining a few custom types and functions, and implement all the function bodies by using `Debug.todo`. Now you can use `elm repl` to see if calling those functions in the ways you'd like to compiles—based only on their types. Once you're happy with how the types fit together, you can go back and implement for real.

Now at this point, you might be wondering: it's fun to pretend and all, but what happens if that call to `Debug.todo` actually gets run? Elm will throw a runtime exception. That's right, a *runtime exception!* Remember those?

For this reason, although `Debug.todo` is a helpful tool for trying things out before everything is completely ready, it's also something we never want to leave around before deploying to production. Elm is designed to produce reliable applications, not ones that crash because we forgot to clean up some temporary code.

Thankfully, the compiler won't let us forget. When running `elm make` with the `--optimize` flag—a best practice for production builds, because it produces smaller compiled `.js` files—we'll see an error if any usages of the `Debug` module (like `Debug.todo` or `Debug.log`) are still hanging around our code base.

**NOTE** `Debug.todo` is only one way to get Elm to throw a runtime exception. Another way is to run out of memory. Calling `modBy 0` on any number, using `==` on two values that contain functions, or trying to pass a malformed value into a port, all currently throw (self-explaining) runtime exceptions by design—although these behaviors could change in future Elm releases. It's also always possible that there is a bug in Elm's compiler or core libraries,

whose symptoms could be a crash. Programming languages are not immune to bugs, after all!

For now, `Debug.todo` will help us out by letting us wait until later to implement `onUrlChange` and `onUrlRequest`. We want to focus on handling the *initial URL* first.

### EXTRACTING INIT

You may have noticed a subtle change between `Browser.document` and `Browser.application`: the `init` function receives three arguments instead of one. As it happens, this expanded argument set includes the page's initial URL.

Let's define a top-level named function for `init` and have `Browser.application` use it:

```
init : () -> Url -> Nav.Key -> ( Model, Cmd Msg )
init flags url key =
    ( { page = Folders }, Cmd.none )

main : Program () Model Msg
main =
    Browser.application
        { init = init
        ...
        }
```

This `init` annotation includes two new types you haven't seen before: `Url` and `Nav.Key`. We'll need to add a couple of imports before those will compile:

```
import Browser.Navigation as Nav
import Url exposing (Url)
```

We'll use the `Nav.Key` value later, when we circle back to `onUrlChange` and `onUrlRequest`. For now, let's focus on that `Url` argument.

### INSTALLING THE ELM/URL PACKAGE

A `Url` is a record representing different attributes about the URL such as its protocol (for example, "http" or "https"), host (for example, "elm-lang.org" or "elm-in-action.com"), and path (for example, "/gallery" or "/photos/2turtles"). When our application starts up, `init` will be passed a `Url` value representing the current URL in the user's address bar when the page loaded.

This `Url` type comes from the `elm/url` package, which includes lots of helpful functions for working with URLs. Let's install it by running this at the command line:

```
elm install elm/url
```

**NOTE** Answer "Yes" when prompted to move `elm/url` from your *indirect* dependencies to your *direct* dependencies. For more on direct and indirect dependencies, see appendix B.

Besides the `Url` type, we'll be using some other goodies from the `elm/url` package shortly.

**TIP** It's often helpful to have the documentation for a package open while working with it, for quick reference. Try searching for the `elm/url` package on the `package.elm-lang.org` website, so you can quickly reference the types and descriptions of these functions as I introduce them. Make sure you're looking at the documentation for the same version of the `elm/url` package as the one in your `elm.json` file.

### INTERPRETING THE URL

Our `Model` already has a concept of which `Page` the user is viewing, so our goal at this point is to have `init` set that `model.page` value based on the `Url` it received. Let's have our initial translation from `Url` to `Page` work like this:

- If the URL is `localhost:8080/gallery`, we'll set `model.page` to be `Gallery`.
- If the URL is `localhost:8080`, we'll set it to `Folders`.
- If the URL is anything else, we'll default to `NotFound`.

Here's how we'll implement this:

```
init : () -> Url -> Nav.Key -> ( Model, Cmd Msg )
init flags url key =
  case url.path of
    "/gallery" ->
      ( { page = Gallery }, Cmd.none )
    "/" ->
      ( { page = Folders }, Cmd.none )
    _ ->
      ( { page = NotFound }, Cmd.none )
```

This revised `init` should mean we now see different active header links based on the URL of the page. Try it out! Open the browser and visit these URLs to see the different pages:

- `http://localhost:8080`
- `http://localhost:8080/gallery`
- `http://localhost:8080/djent`

Figure 8.4 shows the results—but beware! The `Debug.todo` we used earlier for `onUrlRequest` means that if you click either of the links, you'll get a runtime exception. We'll fix that later.

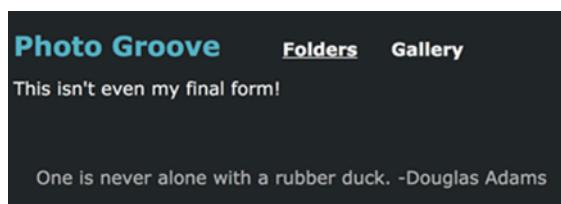


Figure 8.4 Viewing three different URLs

This is a great start! However, we still have yet to implement the final URL scenario our manager mentioned: handling URLs like `/photos/sand`. To implement that feature, we'll use a tool a bit more powerful than our current approach.

### 8.2.2 Parsing URL paths

Before we can parse a URL into a `Page` that stores the selected photo filename, we'll need to give `Page` the ability to store it. Let's add a new variant to the beginning of our type `Photo` declaration:

```
type Page
    = SelectedPhoto String
    | Gallery
    | Folders
    | NotFound
```

Now that we support this new `Page` type, we're all set up to parse some URLs into it.

#### UNDERSTANDING URL STRUCTURE

Single-page applications can get a lot of information out of a URL. Besides the path, there's the fragment, the query string, and more beyond that. Figure 8.5 diagrams some of the pieces of a URL that we might use in our SPA.

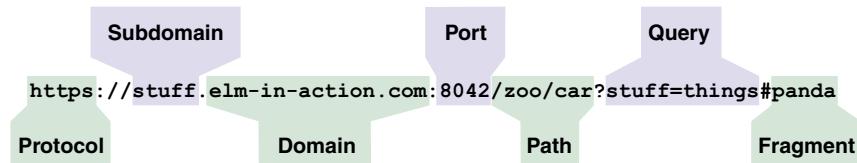


Figure 8.5 Anatomy of a URL

The `elm/url` package gives us three modules for working with the various pieces of a URL:

- `Url.Builder` helps us assemble URLs from these separate ingredients. We'll use it later in the chapter.
- `Url.Parser` and `Url.Parser.Query` help us translate the *path* and *query* portions of a URL into more helpful values. We'll be using `Url.Parser ...` soon. Really soon!

As foreshadowed in the previous bullet point, next we'll use `Url.Parser` to parse URLs like `/photos/surf` into information stored in our model.

#### DEFINING A PARSER

To use `Url.Parser`, we'll add this import to the top of `Main.elm`:

```
import Url.Parser as Parser exposing ((</>), Parser, s, string)
```

This will let us define the following `Parser` below our `init` declaration:

```
parser : Parser (Page -> a) a
parser =
    Parser.map SelectedPhoto (s "photos" </> Parser.string)
```

Similarly to the way a JSON Decoder value describes how to translate a JSON string into a different type, this `Parser` value describes how to translate a URL into a `Page`. Many of the concepts you've learned about JSON decoding in chapters 4 and 7 will apply here, but there are a few differences between `Decoder` and `Parser`.

**NOTE** One difference you might be wondering about is that type annotation. If we were decoding JSON into a `Page`, we would build a `Decoder Page`. However, our URL parser is not a `Parser Page`, but rather a `Parser (Page -> a) a`. The reason behind this has to do with the way parsers get built up internally, and is too long a detour for this chapter. To successfully build a single-page application, all we need to know is that `Parser (Route -> a) -> a` is the type of a `Parser` that translates a URL into a `Route`.

Let's break down the implementation of this parser:

```
Parser.map SelectedPhoto (s "photos" </> Parser.string)
```

The `(s "photos" </> Parser.string)` part says two things:

- This parser will succeed only if it is run on a URL whose path begins with the string `/photos` followed by a slash and then another string with a length of at least 1. (So the URL path `/photos/` would not match, but `/photos/a` would.)
- If it succeeds, the `Parser`'s final output will be the `String` following the `"photos/"` part of the URL path. (So it would succeed with `"puppy"` when parsing a path of `/photos/puppy`.)

**TIP** The `</>` operator expects a `Parser` value on each side, and the `Parser.s` function turns a hardcoded string into a parser for that string. For example, the parser `(s "photos" </> Parser.string </> s "other" </> s "things")` would match URLs like `/photos/foo/other/things`.

The `Parser.map SelectedPhoto` part works similarly to the `List.map`, `Result.map`, `Maybe.map`, and `Decode.map` functions we've seen so far: it transforms the value produced by the `Parser`. Without this call to `Parser.map`, our `Parser` would output a plain old `String` whenever it succeeds. Thanks to `Parser.map`, that `String` will instead be passed along to `SelectedPhoto`, so the resulting parser will output a `Page` we can store in our model.

### RUNNING A PARSER

Just as we pass `Decoder` values to functions like `Json.Decode.decodeString` in order to run them on a JSON string, we pass `Parser` values to `Parser.parse` in order to run them on a particular URL. Calling `Parser.parse` with our `Page` parser

will give us a `Maybe Page` value—`Nothing` if the parser did not match, and `Just page` if it did.

We could use this to sneak our parser into the default branch of `init`'s case-expression:

```
init : () -> Url -> Nav.Key -> ( Model, Cmd Msg )
init flags url key =
    case url.path of
        ...
        ...
        - ->
            if String.startsWith "/photos/" url.path then
                case Parser.parse parser url of
                    Just page ->
                        ( { page = page }, Cmd.none )

                    Nothing ->
                        ( { page = NotFound }, Cmd.none )

            else
                ( { page = NotFound }, Cmd.none )
```

Unfortunately, doing this would introduce code duplication in two places:

- We call `String.startsWith "/photos/" url.path` and then, immediately after, we run a `Parser` that verifies that the path begins with `/photos/`.
- This `Nothing` branch handles our “page not found” case, and then the `else` branch beneath it handles it again.

We can do better!

### COMPOSING PARSERS WITH PARSE.ONEOF

Thankfully, just as with JSON decoders, we can compose `Parser` values together in a variety of ways. Let's replace our `parser` implementation with this slightly more capable one:

```
parser : Parser (Page -> a) a
parser =
    Parser.oneOf
        [ Parser.map Folders Parser.top
        , Parser.map Gallery (s "gallery")
        , Parser.map SelectedPhoto (s "photos" </> Parser.string)
        ]
```

Here we can see three new things:

- `Parser.top`, which matches the root path. `Parser.map Folders Parser.top` returns a `Parser` that succeeds on a path of `/` and outputs a `Folders` value.
- `Parser.map Gallery (s "gallery")`, which matches `/gallery` and outputs a `Gallery` value. Note that although we called the `Parser.s` function again, this time we did not need to use the `</>` operator.

- `Parser.oneOf`, which takes a `List` of parsers and tries them one at a time until it either finds a match or runs out.

**TIP** There's also a `Json.Decode.oneOf` that works similarly. It's useful for decoding JSON fields that situationally hold different types.

Believe it or not, this new `Parser` can replace every conditional branch in our `init` function except the `NotFound` one. Let's revise `init` like so:

```
init : () -> Url -> Nav.Key -> ( Model, Cmd Msg )
init flags url key =
    ( { page = urlToPage url }, Cmd.none )

urlToPage : Url -> Page
urlToPage url =
    Parser.parse parser url
        |> Maybe.withDefault NotFound
```

We've now isolated our logic for translating a `Url` into a `Page` into the `urlToPage` function.

Here's how that function works: Our `Parser` uses `Parser.oneOf` to try each of three `Parsers`—first, one that matches "/" and outputs `Folders`; then, one that matches "/gallery" and maps to `Gallery`; and finally, one that matches "/photos/something" and maps to `SelectedPhoto` with the string after "/photos" wrapped up inside it.

If this parser succeeds, then great! We have our `Page` and store it in the model. If it fails, then the path was unrecognized, and we return the `NotFound` page by default.

### REVISING HEADER LINKS

We're almost done! The only missing puzzle piece is that our header logic doesn't account for our new `SelectedPhoto` variant. We'd like it to render the `Folders` link as active when the user is on any of the `/photos/something` URLs—after all, once we're finished implementing everything, the user will most definitely be looking at the `Folders` page.

We'll start by replacing our `page == targetPage` comparison with a call to a function called `isActive`, which we'll define next:

```
li [ classList [ ( "active", page == targetPage ) ] ]
li [ classList [ ( "active", isActive { link = targetPage, page = page } ) ]
]
```

We'll introduce `isActive` right below `viewHeader`, and implement it like so:

```
isActive : { link : Page, page : Page } -> Bool
isActive { link, page } =
    case ( link, page ) of
        -----
        ( Gallery,      Gallery      ) -> True
        ( Gallery,      _             ) -> False
```

```
( Folders,           Folders      ) -> True
( Folders,           SelectedPhoto _ ) -> True
( Folders,           _             ) -> False
( SelectedPhoto _,   _             ) -> False
( NotFound,          _             ) -> False
```

Don't panic! This is a totally normal case-expression if you squint at it—we're using `case` on a tuple of `( link, page )` and then pattern matching on various combinations of tuples that it might match—but it's been laid out like a table for demonstration purposes. (You can feel free to format it normally in your code, and leave out the long `-----` comment.)

### USING THE TRUTH TABLE PATTERN

You can think of this case-expression as using tuples and pattern matching to describe a *truth table* of how we should handle these various combinations of links and current pages. The first “row” in the table—`( Gallery, Gallery ) -> True`—says that if the link is to `Gallery`, and the current page is also `Gallery`, then `isActive` should be `True`. The next “row”—`( Gallery, _ ) -> False`—says that if the link is to `Gallery` and the current page is *anything else*, then `isActive` should be `False`.

This covers all the possible combinations of `Gallery` links, so we can move on to the more interesting `Folders` case. The `Folders` patterns look similar to the `Gallery` ones; we have `( Folders, Folders ) -> True` and `( Folders, _ ) -> False`. The crucial difference is that between the two we have `( Folders, SelectedPhoto _ ) -> True`, meaning that if the current page is any `SelectedPhoto` variant, `isActive` will be `True`. That's exactly what we were missing!

The remaining `( SelectedPhoto _, _ )` and `( NotFound, _ )` patterns won't come up, because we don't have header links that point to those pages. We're including them instead of adding a default `_ ->` pattern only to benefit our future selves: so we can get those helpful missing-patterns errors if we introduce another new variant to `Page` and forget to consider its implications on `isActive`.

### VIEWING THE SELECTED PHOTO PAGE

With all that in place, we should be able to view our “selected photo” route successfully. Try it out by visiting `localhost:8080/photos/something` (replacing “something” with various different words) and verify that the `Folders` link is indeed active.

Fantastic! Now that the initial URL is being handled gracefully, we're ready to circle back to those `Debug.todo` calls we made earlier, and make the links in the header work properly.

### 8.2.3 Handling URL changes

A common design goal of single-page applications is to maintain the URL bar's normal functionality. Ideally, it seems to the person using it as if they're using a multipage website, where links and the Back button work normally. The only noticeable difference is that things seem pleasantly snappier, because the SPA isn't doing a full page load for each new page.

### ONURLREQUEST AND ONURLCHANGE

The `onUrlRequest` and `onUrlChange` functions in `Browser.application` give us the power to pull off this magic trick. Let's wire them up, replacing our placeholder `Msg` type with one that has two variants:

```
type Msg
  = ClickedLink Browser.UrlRequest
  | ChangedUrl Url
```

Now let's replace the `Debug.todo` calls we made in `Browser.application` with these variants:

```
Browser.application
{ init = init
, onUrlRequest = ClickedLink
, onUrlChange = ChangedUrl
...}
```

We'll walk through these one at a time.

### OVERRIDING DEFAULT LINK BEHAVIOR

First we have `onUrlRequest = ClickedLink`. This says that whenever the user requests a new URL (by clicking a link), Elm's runtime will send a `ClickedLink` message to our `update` function. It's like a page-wide event handler, except that it goes a step further by overriding the default behavior of all links on the page.

With `Browser.application`, clicking links only sends this `ClickedLink` message—it doesn't automatically load a new page as the browser normally would. This gives us total control over what we want the application to do when the user clicks a link.

**NOTE** `Browser.application` does not override the “open link in new tab” functionality. You can still right-click a link and select Open in New Tab, or use one of the various shortcuts for this such as middle-clicking, Command-clicking, or Ctrl-clicking, depending on your system. It also doesn't override the behavior of links with the `download` attribute set, because they're supposed to download things instead of navigating.

The `onUrlChange = ChangedUrl` setting also sends a message to `update`, except it triggers under different circumstances. We'll talk about those circumstances shortly.

### HANDLING CLICKEDLINK

Next, let's incorporate the `ClickedLink` message into `update` like so:

```
update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
  case msg of
    ClickedLink urlRequest ->
      case urlRequest of
        Browser.External href ->
          ( model, Nav.load href )
```

```
Browser.Internal url ->
  ( model, Nav.pushUrl model.key (Url.toString url) )
```

**NOTE** We don't have a `model.key` field yet, but have no fear! We'll add it after we finish with update.

### INTERNAL AND EXTERNAL URL REQUESTS

The `Browser.UrlRequest` value inside `ClickedLink` has two variants. It looks like this:

```
type UrlRequest
  = External String
  | Internal Url
```

Our `ClickedLink` message will contain an `External` request if the user clicked a link to a different domain. For example, if they're viewing any URL whose domain is `elm-in-action.com` and the user clicks a link to anywhere on `manning.com`, that would be an `External` request containing the exact string of the `href` attribute of the link they clicked.

As you may have guessed, `ClickedLink` will contain an `Internal` request if the user clicked a link to the same domain. So if they're viewing an `elm-in-action.com` URL and they click a link to `/foo`, or to `elm-in-action.com/foo`, that will be an `Internal` request containing a `Url` record like the one `init` receives.

### NAV.LOAD

Let's take a closer look at what we're doing in the `Browser.External` branch:

```
Browser.External href ->
  ( model, Nav.load href )
```

This `Nav.load` performs a full page load, just as a traditional multipage app would do. This call essentially says, "If we get a request to a third-party page, load it as normal." We don't have to do it this way, though.

For example, if our manager later asks us to add a disclaimer like, "You are about to leave the comfort and safety of Photo Groove for the harsh wilderness of The Internet, an unfathomably complex series of tubes," we could implement that logic here instead of unconditionally calling `Nav.load` right away.

### NAV.PUSHURL

The `Internal` variant is similar to the `External` one, but slightly more involved:

```
Browser.Internal url ->
  ( model, Nav.pushUrl model.key (Url.toString url) )
```

The `Url.toString` call converts the `Url` to a `String`, because `Nav.pushUrl` wants the URL in `String` form rather than in record form. We'll get to `model.key` soon, but first let's go over what `Nav.pushUrl` does differently from the `Nav.load` we used in the `External` case.

Whereas `Nav.load` does a full page load of an entirely new page, all `pushUrl` does is to push the given URL onto the browser's history stack. This has a few implications:

- The URL shown in the browser's address bar will become this one.
- `Browser.application` will send a `ChangedUrl` event to update, with this URL stored inside it. That's because we specified `ChangedUrl` for our `onUrlChanged` handler when we set up our `Browser.application`.
- When the user clicks the Back button in the browser, this URL will now be one of the ones it goes back to. Also, when the user does that, `Browser.application` will send a `ChangedUrl` event to update.

This `Nav.pushUrl` function is how we give users the appearance of the address bar working as normal, without causing full page loads. Because it *only* manipulates the address bar, and does not directly request any page loads, we are free to display what *appears* to be a new page—without actually doing a real page load.

Because both `pushUrl` and the browser's Back button result in `UrlChanged` events being sent to `update`, we don't need separate handling code for the case where the user arrived at a given URL from `pushUrl` compared to using the browser's Back button. Once we implement handling code for the `ChangedUrl` message, we'll have covered both cases.

#### MODEL.KEY

Okay, so we have `Nav.load` to do full page loads, and `Nav.pushUrl` to push URLs onto the browser history and trigger a `ChangedUrl` message. What's the deal with that `model.key` argument to `Nav.pushUrl`? To understand what's happening there, let's go back to `init` and make a small addition to its implementation—setting `key = key` in the `Model` it returns:

```
init : () -> Url -> Nav.Key -> ( Model, Cmd Msg )
init flags url key =
    ( { page = urlToPage url, key = key }, Cmd.none )
```

Because the `key` argument to `init` has the type `Nav.Key`, we can infer that the type of `model.key` must also be `Nav.Key`, so let's add that to our `Model` type alias before moving on:

```
type alias Model =
    { page : Page, key : Nav.Key }
```

Let's recap what we know about `model.key`:

- It has the type `Nav.Key`, whatever that is.
- Our `init` function receives one from the Elm Runtime, and stores it in `Model`.
- Later, in `update`, we access the stored key via `model.key` and pass it to `Nav.pushUrl`.

This is precisely how `Nav.Key` is typically used: write it down in `init`, and then retrieve it later when `Nav.pushUrl` asks for it. Never change it!

## The design of Nav.Key

The reason `Nav.Key` exists is to restrict `Nav.pushUrl` to being used only by Elm programs started up by using `Browser.application`. Because the only way to obtain a `Nav.Key` is by having `init` provide one, and because only `Browser.application` has an `init` function that provides one, it is impossible to call `Nav.pushUrl` unless you originally started up by using `Browser.application`. Clever, eh?

This restriction exists because Elm's navigation APIs are designed with the assumption that they have total control over the page. That's what makes it safe for them to do things like overriding the default behavior for all links on the page. If that assumption is violated—say, because we were using `Browser.element` to embed a small Elm application inside an existing single-page application written in JavaScript—then using `pushUrl` could result in some nasty bugs.

The sole purpose of the `Nav.Key` restriction on `pushUrl` is to make these bugs impossible. As such, the inner value of `Nav.Key` doesn't matter one bit. (In fact, if you look at the source code for `Browser.Navigation`, you'll see that it is literally defined as `type Key = Key`.) All that matters is that it's a token proving that the Elm Runtime has been started up by using `Browser.application`, and thus you can be confident it has full control over the page.

Now that we have the `ClickedLink` message fully handled in `update`, it's time to circle back to the `ChangedUrl` message. Here's the code we'll add to `update`. Ready? Drumroll, please. . . .

```
ChangedUrl url ->
    ( { model | page = urlToPage url }, Cmd.none )
```

That's it! Granted, we're choosing to do about the least interesting thing possible here: whenever the URL changes because of a history change (such as a call to `Nav.pushUrl`, or the user using the Back button to go back to one of those changes), we translate that URL into a `Page` and store it in our `Model`.

We could do a lot more, though. For example, if we wanted to animate transitions between pages—using a fade, a slide, or even a cinematic wipe—this would be the place to do it.

## THE FULLY URL-ENABLED PAGE

If you recompile and bring up the page, you should see that URLs now fully work as expected:

- If you visit a URL, it renders the appropriate header links as active.
- Clicking either of the links in the header takes you to the appropriate URL, which results in the active link changing as appropriate.
- These behaviors continue to work as expected when using the browser's Back and Forward buttons.

Now that our URL handling is in place, we’re ready to tie it all together—by rendering the real pages between the header and footer, instead of the placeholder text we’ve been using so far.

## 8.3 Delegating pages

At this point, we have all the ingredients necessary to make our single-page application work:

- A working Photo Folders page from chapter 7
- A working Photo Gallery page from the earlier chapters
- A working Main module that handles URLs and maintains a conceptual Page

Our next task will be to unite the three into a single application. To do this, we’ll first change the `PhotoFolders` and `PhotoGroove` modules to expose their `init`, `view`, `update`, and `subscriptions` functions instead of having their own `Program` values. Then we’ll configure `Main` to call those functions depending on which page the user is viewing. Let’s get to it!

### 8.3.1 Revising module structure

Let’s start by incorporating our `PhotoFolders` module. Ultimately, we’d like `Main.elm` to render the Photo Folders page between our header and footer. To do that, we’ll need to call `PhotoFolders.view`. However, at the moment, our `Main` module can’t possibly call `PhotoFolders.view`, because the `PhotoFolders` module does not publicly expose `view`. Until it’s exposed, no other module can access that function.

#### EXPOSING VALUES IN THE PHOTOFOLDERS MODULE

Let’s address this by editing the first line of `PhotoFolders.elm` to say the following:

```
module PhotoFolders exposing (Model, Msg, init, update, view)
```

This declaration is now saying these things:

- This module’s name is `PhotoFolders`. (Big surprise!)
- It’s exposing the `Model` type alias, so other modules can import that type alias.
- It’s exposing the `Msg` type, but not its variants. (To expose its variants too, we would have written `Msg(..)` in the exposing list.)
- It’s exposing the `init`, `update`, and `view` functions.

**TIP** In general, it’s best to have modules expose values only when absolutely necessary. This principle extends to custom types’ variants as well; variants should be exposed only when absolutely necessary.

#### RENAMING PHOTOGROOVE.ELM

We’ll give `PhotoGroove.elm` the same treatment—and while we’re at it, we’ll add `init` to its `exposing` list and rename it `PhotoGallery.elm`, since that’s what our manager has started calling that page these days. We’ll change the first line of the renamed `PhotoGallery.elm` to this:

```
port module PhotoGallery exposing (init, Model, Msg, init, update, view)
```

Now that we've exposed these values, let's import these modules into our `Main` module:

```
import PhotoFolders as Folders
import PhotoGallery as Gallery
```

Now `Main` can call the `view` functions inside the `PhotoFolders` and `PhotoGallery` modules, by referring to them as `Folders.view`, and `Gallery.view`, respectively. Great!

**NOTE** If you want to run the tests again, you'll need to find/replace `PhotoGroove` with `PhotoGallery` in `PhotoGrooveTests.elm` too.

### STORING PHOTOFOLDERS.MODEL

Let's open up the `PhotoFolders` module and take a look at the type of `view`:

```
view : Model -> Html Msg
```

Hmm. How are we going to call that from `Main`? It says it wants a `Model`, but we're inside the `PhotoFolders` module—meaning it wants a `Folders.Model`, not a `Main.Model`. If we're calling this function from `Main`, how will we be able to provide this function with the `Folders.Model` it requires?

The answer is that we'll store a `Folders.Model` inside our `Main.Model`. Because we'll be calling `Folders.view` only when we're on the Photo Folders page—and, similarly, calling `Gallery.view` only when we're on the Gallery page—we can add these two models to our `Page` custom type instead of cramming both of them into the `Model` record.

Let's revise `Page` to look like this:

```
type Page
    = Gallery Gallery.Model
    | Folders Folders.Model
    | SelectedPhoto String Folders.Model
    | NotFound
```

Splendid! Now if our `Model` contains a `Page` that happens to be one of the two `PhotoFolders` variants—that is, `Folders` or `SelectedPhoto`—we'll have access to a `PhotoFolders.Model` value, which we can pass to `PhotoFolders.view` to render the page.

### MAIN.INIT AND PHOTOFOLDERS.INIT

Because we've changed the shape of our `Page` custom type, our code won't compile again until we populate those `Folders.Model` values in our `init` function. How can we obtain a `Folders.Model` value? By calling `Folders.init`.

Happily, `Folders.init` takes an argument we can easily provide. Here is its type:

```
Folders.init : () -> ( Folders.Model, Cmd Msg )
```

This means that by calling `Tuple.first (Folders.init ())`, we'll end up with the `Folders.Model` value we seek. No sweat, right?

## PROBLEMS WITH PAGE

Unfortunately, this approach creates a bit of a problem for our URL parser. It's supposed to parse a `String` into a `Page`. If we wanted that to keep working, we'd have to modify it like so:

```
Parser.oneOf
  [ Parser.map (Folders (Folders.init ())) Parser.top
  , Parser.map (Gallery (Gallery.init ())) (s "gallery")
  , Parser.map (SelectedPhoto (Folders.init ()))
    (s "photos" </> Parser.string)
  ]
```

Yikes—now we're calling `init` functions *three times* just to define a URL parser? Something feels off. There's a similar situation in `viewHeader`, too. We can no longer pass `navLink` a standalone `Folders` value, because instantiating a `Folders` value now requires a `Folders.Model`. Instead, we'll have to do something like this:

```
ul []
  [ navCtrl (Folders (Folders.init ()))
    { url = "/", caption = "Folders" }
  , navCtrl (Gallery (Gallery.init ()))
    { url = "/gallery", caption = "Gallery" }
  ]
```

This is getting out of hand! What's the problem here? Why isn't `Page` working well everywhere it used to, now that we've expanded it to hold onto more information?

## SIMILAR BUT NOT THE SAME

What we have here is a classic case of needing to revisit a data structure based on changing circumstances. We now have two needs that are similar but not quite the same:

- Storing either `Folders.Model` or `Gallery.Model`, depending on which page is being viewed. Here, our main goal is for the data structure to store different models.
- Representing a parsed route, such as `Folders` or `SelectedPhoto` `String`, as we were doing before. In this use case, we want the data structure to store no models, because we don't want `parser` or `navLink` to have to call `init` to do their jobs.

On closer inspection, these two goals are at odds. We need two different data structures!

Thankfully, there is no law against having two data structures that are *similar but not the same*. In fact, it is considered good practice in Elm to keep an eye out for situations like this. As we saw here, sometimes it's not obvious that a particular use case has outgrown a single data structure; we have to remember to revisit our assumptions as our program grows.

## PAGE AND ROUTE

Table 8.1 shows the two new data structures we'll be using for our different use cases.

**Table 8.1** Two data structures for use cases that are similar but not the same

Storing different models	Representing a parsed route
<pre>type Page   = GalleryPage Gallery.Model     FoldersPage Folders.Model     NotFound</pre>	<pre>type Route   = Gallery     Folders     SelectedPhoto String</pre>

After we separate these, a few more differences emerge:

- It doesn't actually make sense to have a Not Found route. After all, Not Found means our parser failed, and we couldn't recognize a route from the given URL.
- There is, however, a Not Found page; we want to store that in our Model so that we know to render a Not Found page to the viewer.
- For Page's purposes, there's no longer any need to have separate variants for Folders and SelectedPhoto. The information of which photo is selected (if any) will be stored in the Folders.Model value we already have in the FoldersPage variant.

Now that we've built out our data model, we're ready to put these two new types to use as we initialize our different page states.

### 8.3.2 Initializing page states

First, let's alter `navLink` to use our new `Route` type:

```
NavLink : Route -> { url : String, caption : String } -> Html msg
NavLink route { url, caption } =
  li [ classList [ ( "active", isActive { link = route, page = page } ) ] ]
    [ a [ href url ] [ text caption ] ]
```

We don't need to change how `navLink` is being called, because we used the same names for the `Route` variants (`Folders` and `Gallery`) as what they were called before. For the same reason, we don't need to change the implementation of `parser`, although we will need to change `Page` to `Route` in its type annotation:

```
parser : Parser (Route -> a) a
```

We'll need to revise `isActive` too, although its new truth table is shorter and easier to read:

```
isActive : { link : Route, page : Page } -> Bool
isActive { link, page } =
  case ( link,           page           ) of
  -----
  ( Gallery,          GalleryPage _ ) -> True
  ( Gallery,          _                  ) -> False
  ( Folders,          FoldersPage _  ) -> True
  ( Folders,          _                  ) -> False
  ( SelectedPhoto _, _                 ) -> False
```

This is a common benefit of separating one overloaded data structure into two: related code often ends up becoming clearer and more concise.

This new `Route` type has now resolved our previous problems with `init`. We still have `page : Page` in our `Model`, it still stores `Folders.Model` and `Gallery.Model` under the appropriate circumstances, and we no longer need to call `init` a bunch of times in `parser` or in `viewHeader`. Wonderful!

### REVISING URLTOPAGE

Next up: the `urlToPage` function. This is where we actually do want to call `Folders.init` and `Gallery.init`: when converting a `Url` to a `Page`. Here's a first draft that type-checks but doesn't quite do what we want yet:

```
urlToPage : Url -> Page
urlToPage url =
  case Parser.parse parser url of
    Just Gallery ->
      GalleryPage (Tuple.first (Gallery.init 1))

    Just Folders ->
      FoldersPage (Tuple.first (Folders.init ()))

    Just (SelectedPhoto filename) ->
      FoldersPage (Tuple.first (Folders.init ()))

    Nothing ->
      NotFound
```

This implementation has a lot going for it. It faithfully translates all the URL scenarios into a `Page` value, it never calls `init` functions unnecessarily, and it gives us `Model.Folders` and `Model.Gallery` values exactly in the places where we need them.

However, two problems stand out:

- `Gallery.init` takes a `Float` because, way back in chapter 5 (Remember chapter 5? We've come a long way since then!) we passed in the `Pasta.js` version number from `index.html` as a flag. Our current `Main` module isn't configured to accept any flags, so for now we're passing `Gallery.init` a hardcoded 1. We'll fix that soon.
- After going to all the trouble of parsing out the photo's filename from the `/photos/thing` URL in the `SelectedPhoto` branch, we then completely ignore that filename and call `Folders.init ()` just as we did in the `Folders` branch. In our defense, that's because at the moment `Folders.init` accepts only `()`. We haven't set it up to accept a filename yet, but we'll fix that too.

### REVISING FOLDERS.INIT

The `Folders.init` fix is quick, so let's knock that one out. What we'd like to do is to pass `Folders.init` the filename when we have it, and nothing when we don't—and then let `Folders.init` decide what to do with that information.

Sounds like a good use case for `Maybe`. Over in `PhotoFolders.elm`, we'll revise the `init` function to accept a `Maybe String` for the selected filename, and then record it directly in its model:

```
init : Maybe String -> ( Model, Cmd Msg )
init selectedFilename =
    ( { initialModel | selectedPhotoUrl = selectedFilename }
    , Http.get ...
    )
```

Piece of cake! This will mean `main` inside `PhotoFolders.elm` no longer type-checks, but we're done with it anyhow. It's safe to go ahead and delete it.

Now we can hop back to `Main.elm` and revise the `Folders` and `SelectedPhoto` branches in our `urlToPage` function to pass `Folders.init` the appropriate values depending on the route:

```
Just Folders ->
    FoldersPage (Tuple.first (Folders.init Nothing))

Just SelectedPhoto filename ->
    FoldersPage (Tuple.first (Folders.init (Just filename)))
```

The `Tuple.first` here extracts the `Model` portion of `Folders.init`'s return value, which has the type `( Folders.Model, Cmd.Msg )`—and `FoldersPage` wants the `Model` on its own.

### REVISING URLTOPAGE

The last thing to address is that hardcoded `Gallery.init 0`. To fix that, we'll need to make `urlToPage` accept the `Pasta.js` version number as an argument:

```
urlToPage : Float -> Url -> Page
urlToPage version url =
    case Parser.parse parser url of
        Just Gallery ->
            GalleryPage (Tuple.first (Gallery.init version))
```

Easy enough! Now that it accepts and uses a version number, we'll need to obtain the actual version number to pass it.

### REVISING INDEX.HTML

To obtain the version number from JavaScript, we'll need to edit `index.html`. Specifically, we'll adjust it to start passing in `Pasta.version` once again, as we first did back in chapter 5:

```
var app = Elm.Main.init({
    flags: Pasta.version,
    node: document.getElementById("app")
});
```

## REVISING MAIN.INIT

With that in place, we can switch back to Main.elm and revise our declarations for main and init to reflect the flags they'll now be receiving. main will now have this type annotation:

```
main : Program Float Model Msg
```

The change to Main.init is a bit less obvious. We're going to not only receive the Float and pass it along to urlToPage, but also start storing it in our top-level Model record—for reasons that will become apparent momentarily:

```
init : Float -> Url -> Nav.Key -> ( Model, Cmd Msg )
init version url key =
  ( { page = urlToPage version url, key = key, version = version }
  , Cmd.none
  )
```

Why bother storing this in the Model? We already passed it to urlToPage, which is the only function that needs it.

That's very true, but we also call urlToPage at the end of update. If we want that code to continue working, we'll need to have it pass version to urlToPage, and the only way we can access version from within update is if init stores that value in the model while it still can. Here's the change we'll make to the last line of update to make this work:

```
ChangedUrl url ->
  ( { model | page = urlToPage model.version url }, Cmd.none )
```

### Why not store the version in GalleryPage instead?

You may be wondering why we stored version in the top-level Model record instead of the Page variant for Gallery, because the Gallery page is the only one that uses the version number.

The reason is that when we switch Page values from GalleryPage Gallery.Model to FoldersPage Folders.Model, we have discarded all data that was held in the GalleryPage variant. This means that if the user goes from the Gallery page to the Folders page and back again, we will be on the FoldersPage variant and no longer have access to any information we stored in the GalleryPage variant before we switched pages.

Because the version is something we need to pass to Gallery.init, the only way we can be sure we'll have access to it every time we call Gallery.init is to store it in the top-level Model; that data is always available no matter which pages we transition between.

Finally, because we added a `version` field to `Model`, we'll need to update its type alias to match:

```
type alias Model =
    { page : Page, key : Nav.Key, version : Float }
```

Success! Our pages are now fully initialized, and we're ready for the final step: calling their `view` and `update` functions to render them between our header and footer.

### 8.3.3 Delegating page logic

As mentioned earlier, in order to call `Folders.view`, we need a `Folders.Model` to pass it. Fortunately, we now have one of those stored in our `Model`. Not only that, we also have a `Gallery.Model` to pass to `Gallery.view`.

Let's have the content declaration inside our `Main.view` function call these functions, depending on which page we currently have stored in the model:

```
content =
    case model.page of
        FoldersPage folders ->
            Folders.view folders

        GalleryPage gallery ->
            Gallery.view gallery

        NotFound ->
            text "Not Found"
```

Now we can rerun `elm make` and... huh? It didn't compile!

We have a subtle type mismatch here. `Main.view` wants to return an `Html Msg` value, but `Folders.view` returns an `Html Folders.Msg` value, and `Gallery.view` returns an `Html Gallery.Msg` value.

#### USING HTML.MAP

Just as a function that wants to return a `List Foo` can't return a `List Bar` instead, a function that wants to return an `Html Msg` can't return an `Html Gallery.Msg`. Fortunately, just as we could use `List.map` to convert a `List Foo` value into a `List Bar` value, we can use `Html.map` to convert an `Html Gallery.Msg` value into an `Html Msg` value.

Here's the type of `Html.map`. Spoiler alert: it's a lot like `List.map`, `Maybe.map`, and `Decode.map`:

```
Html.map : (before -> after) -> Html before -> Html after
```

This tells us that to convert `Html Gallery.Msg` into `Html Msg`, we need a `(Gallery.Msg -> Msg)` function. (Similarly, we'll also need a `(Folders.Msg -> Msg)`

function to convert the value returned by `Folders.view`.) We can get both of those by adding two new variants to our `Msg` type:

```
type Msg
    = ClickedLink Browser.UrlRequest
    | ChangedUrl Url
    | GotFoldersMsg Folders.Msg
    | GotGalleryMsg Gallery.Msg
```

### DELEGATING VIEW

Conveniently, the type of `GotFoldersMsg` is `(Folders.Msg -> Msg)`, and the type of `GotGalleryMsg` is `(Gallery.Msg -> Msg)`—exactly what we needed to pass to `Html.map`. That means we can do this:

```
FoldersPage folders ->
    Folders.view folders
        |> Html.map GotFoldersMsg

GalleryPage gallery ->
    Gallery.view gallery
        |> Html.map GotGalleryMsg
```

Conceptually, what `Html.map` is doing for us here is wrapping a `Folders.Msg` or `Gallery.Msg` in a `Main.Msg`, because `Main.update` knows how to deal with only `Main.Msg` values. Those wrapped messages will prove useful later when we handle these new messages inside `update`.

### DELEGATING SUBSCRIPTIONS

You may recall from chapter 5 that the Gallery page also has some relevant subscriptions that we'll need to incorporate by using a similar trick. The only difference is that we'll use `Sub.map` instead of `Html.map`, to translate a `Sub Gallery.Msg` into a `Sub Msg`:

```
subscriptions : Model -> Sub Msg
subscriptions model =
    case model.page of
        GalleryPage gallery ->
            Gallery.subscriptions gallery
                |> Sub.map GotGalleryMsg

    - ->
        Sub.none
```

No need to add any new variants to `Msg` this time. `GotGalleryMsg` has us covered already. However, we're currently referencing a `subscriptions` function from the `Gallery` module . . . but that module exposes no such function.

The last thing we need to do is to expose it. Add `subscriptions` to the list of exposed values in module `PhotoGallery` exposing at the top of `PhotoGallery.elm`, and we're all set.

## DELEGATING UPDATE

Now we have `view` delegating to `Folders.view` and `Gallery.view`, and subscriptions delegating to `Gallery.subscriptions`. All those functions compile just fine, but we'll get a missing-patterns error if we try to compile `Main.elm`, because our case-expression inside `update` doesn't account for the two new variants we just added to `Msg`. Let's handle those new `Msg` variants one at a time, starting with `GotFoldersMsg`.

### Listing 8.3 Delegating update

```
update msg model =
    case msg of
        ...
        GotFoldersMsg foldersMsg ->
            case model.page of
                FoldersPage folders ->
                    toFolders model (Folders.update foldersMsg folders)
                    <-- Delegates to Folders.update,
                           then converts its output
                           to ( Model, Cmd Msg )
                _ -> ( model, Cmd.none )   | If we aren't on the Folders page,
                                              ignore Folders messages.
        toFolders : Model -> ( Folders.Model, Cmd Folders.Msg ) -> ( Model, Cmd Msg )
        toFolders model ( folders, cmd ) =
            ( { model | page = FoldersPage folders } , <-- Stores the Folders.Model
              Cmd.map GotFoldersMsg cmd ) <-- in FoldersPage
            )
```

**Destructures the tuple inline**

**Cmd.map works just like Html.map and Sub.map.**

This requires a few more steps than those we did with `view` and `subscriptions`, but fundamentally we're doing the same delegation as we did there. Let's walk through the steps this is taking:

- 1 When `update` receives a `GetFoldersMsg`, first it checks `model.page` to see if we're actually on the `Folders` page. (We might not be! For example, the user might do something on the `Folders` page that sends an HTTP request, and then switch to a different page before the server responds. That response would arrive as a `Folders.Msg`, but `model.page` would no longer be `FoldersPage`.)
- 2 If we're not on `FoldersPage`, ignore the message. We could do some error logging here if we wanted to, but in this case, we'll assume the user no longer cares about the message (because they transitioned away from that page) and ignore the message.
- 3 Now that we have in scope `foldersMsg : Folders.Msg` (the value held in our `GotFoldersMsg`) as well as `folders : Folders.Model` (the value held in `FoldersPage`, our current `model.page` value), we can pass them both to

`Folders.update`. It will return a (`Folders.Model`, `Cmd Folders.Msg`) tuple.

- 4 We call `toFolders` to convert this (`Folders.Model`, `Cmd Folders.Msg`) tuple into the (`Model`, `Cmd Msg`) tuple that `update` wants to return. We do this by using `Cmd.map`, which works just like `Html.map` and `Sub.map`.

The code for the `GotGalleryMsg` branch and its corresponding `toGallery` function will follow the same recipe, except everywhere this code says `Folders`, that code will say `Gallery` instead. Try implementing it on your own. (If you get stuck, you can sneak a peek at the final code listing at the end of the chapter.)

#### TRYING THE PAGE

Everything compiles! Wonderful! Figure 8.6 shows how it looks.

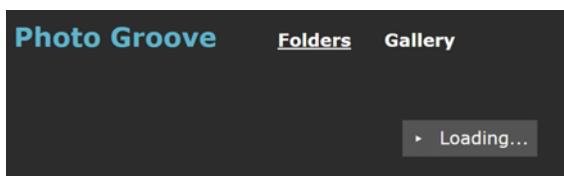


Figure 8.6 First confirmed sighting of the compiled `Main.elm` in the wild

Hmm, that doesn't quite look right. Upon closer inspection, the problem is that we only partially delegated `init`. We have it calling `Tuple.first` on the result of the `init` functions it calls. This compiles, but it means we're keeping the `Model` portion of the tuple and chucking the `Cmd` down a garbage chute.

#### KEEPING BOTH MODEL AND CMD FOR INIT

Without having their `init` commands run, our pages' initial HTTP requests aren't being sent to the server to load the pages' initial data. Whoops!

We'll fix that by deleting `urlToPage` (including from the module's exposing list) and replacing it with a more helpful `updateUrl` function like so:

```
init version url key =
    updateUrl url { page = NotFound, key = key, version = version }

updateUrl : Url -> Model -> ( Model, Cmd Msg )
updateUrl url model =
    case Parser.parse parser url of
        Just Gallery ->
            Gallery.init model.version
            |> toGallery model

        Just Folders ->
            Folders.init Nothing
            |> toFolders model
```

```

Just (SelectedPhoto filename) ->
  Folders.init (Just filename)
    |> toFolders model

Nothing ->
  ( { model | page = NotFound }, Cmd.none )

```

Because the `ChangedUrl` branch inside `update` also relied on `urlToPage`, we'll want to change it to use our shiny new `updateUrl` function instead:

```
ChangedUrl url ->
  updateUrl url model
```

Lovely! Let's try it out; see figure 8.7.

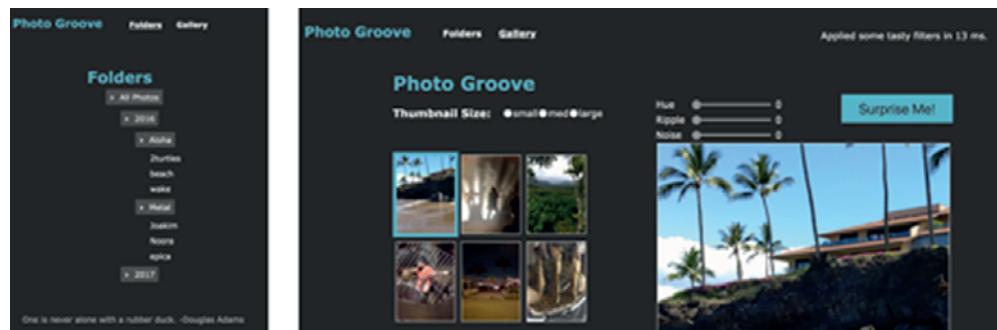


Figure 8.7 The final pages

### REMOVING DUPLICATION

Nice! We do have a bit of header duplication going on, though. `Main.viewHeader` puts `<h1>` in the upper left, and then each of the pages also puts its own competing `<h1>` in there below it—but that's easy enough to fix:

- In `PhotoGallery.elm`, delete the call to `h1` at the top of `viewLoaded`.
- In `PhotoFolders.elm`, delete the call to `h1` near the end of `view`.

With that cosmetic fix in the bank, we're ready for the final feature of the book. Thankfully, this one is extremely quick: we're going to change a grand total of *three* lines of code.

### LINKING TO /PHOTOS/FILENAME

We're going to turn the file buttons on the Folders page into links, so when the user clicks them, the URL bar will update to `/photos/filename`—meaning the user will be able to share it, bookmark it, and use the browser's Back button to return to it.

To make this work, we're going to replace our `<div class="photo">` buttons with `<a>` links that will change the URL to `/photos/whatever`. When the user clicks

one of those links, it will trigger a `UrlChange` in `Main.elm`, which in turn will cause it to invoke `Folders.init`, passing the newly selected value.

We will need to make one change before this will work, specifically to `PhotoFolders.update`. It currently resets the selected photo every time it receives a new list of them from the server (which will now happen every time we click a photo link, thanks to `Folders.init` being run again).

Instead, we'll make it preserve the currently selected photo by making this change:

```
update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
    ...
    GotInitialModel (Ok newModel) ->
        ( { newModel | selectedPhotoUrl = model.selectedPhotoUrl }, Cmd.none
    )
```

With that adjustment in place, all that remains is to introduce the link.

### MAKING THE FINAL CHANGE

This is it! This is the final touch before Photo Groove is complete. Are you excited? You deserve to be—you've come so far and learned so much!

Here's the change: inside `PhotoFolders.elm`, replace the `<div>` in `viewPhoto` with an `<a>` whose `href` is set to the appropriate `/photos/` URL:

```
viewPhoto : String -> Html Msg
viewPhoto url =
    a [ href ("/photos/" ++ url), class "photo", ... ]
```

The third and final change will be exposing `href`, because `PhotoFolders` wasn't using it before:

```
import Html.Attributes exposing (class, href, src)
```

That's it! Now when you click the different photos, the URL changes, and you can use the browser's Back button to reselect the previous photo. And with that, Photo Groove is complete, as shown in figure 8.8.

*You did it!* You built an entire Elm single-page application from start to finish! Give yourself a round of applause; you have 100% earned it. Congratulations, and seriously, well done!

### WHAT IF I WANT TO KEEP THIS PHOTO GROOVE GOING?

If you'd like to keep tinkering with Photo Groove, here are some ideas for things to try:

- Change the page's title depending on which page the user is viewing.
- There's a bit of code duplication between the `PhotoFolders` and `PhotoGallery` modules: they both have identical `urlPrefix` constants. Try replacing those two with a single `urlPrefix` constant that they both import and reference. (Spoiler: Moving it into `Main` and having them both import it won't work.)

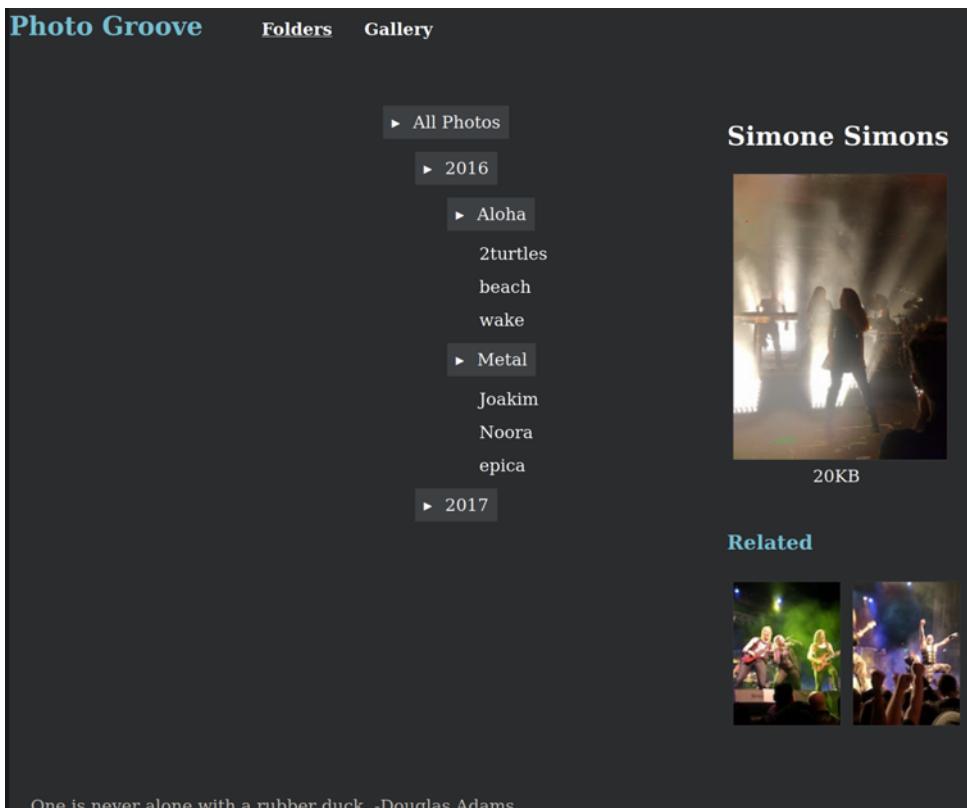


Figure 8.8 The final pages

- Theoretically, we shouldn't need the `SelectedPhotoUrl` variant in `PhotoFolders.Msg` because we switched to linking directly to the photo URLs. However, it's still in use in one place. See if you can think of a good change that would make it obsolete, and then drop it.
- Here's a more involved one, if you really want to roll up your sleeves. If you click quickly between photos on the Folders page, you briefly see a Loading message. This is because the URL is now changing, causing `Folders.init` to be rerun, which in turn triggers a new HTTP request. See if you can figure out a way to avoid doing this HTTP request when clicking between photos to change which one is selected, without causing any regressions anywhere else.

These are some ideas for ways to polish Photo Groove, but you can learn even more from exploring on your own. Think up a new feature to add and try adding it. You might be surprised at what you can do!

## Summary

Here are some of the new concepts you used in the course of building your single-page application:

- Coordinating between multiple modules in a single Elm project
- Rendering pages with custom titles by using `Browser.Document` and having `view` return a `Document` record
- Giving the Elm Runtime control of the entire page by using `Browser.application`
- Using `Debug.todo` as a temporary placeholder that always type-checks, but crashes at runtime if you actually reach the code that calls it
- Using the `onUrlRequest` and `onUrlChanged` events to respond to users clicking links and interacting with the browser's address bar
- Stashing `Nav.Key` in `Model` during `init`, for later use with `Nav.pushUrl` in `update`
- Parsing URLs in `Browser.application`'s `init` function by using `Url.Parser`
- Identifying when two data structures are similar but not the same, and splitting them up as we did with `Page` and `Route`
- Delegating to other pages's `init`, `view`, `subscriptions`, and `update` functions by using `Html.map`, `Sub.map`, and `Cmd.map`

Here is the final `Main.elm` file.

### Listing 8.4 Final Main.elm

```
module Main exposing (main)

import Browser exposing (Document)
import Browser.Navigation as Nav
import Html exposing (Html, a, footer, h1, li, nav, text, ul)
import Html.Attributes exposing (classList, href)
import Html.Lazy exposing (lazy)
import PhotoFolders as Folders
import PhotoGroove as Gallery
import Url exposing (Url)
import Url.Parser as Parser exposing ((</>), Parser, s, string)

type alias Model =
    { page : Page
    , key : Nav.Key
    , version : Float
    }

type Page
    = FoldersPage Folders.Model
    | GalleryPage Gallery.Model
```

**Stores the Folders model only when we're on the Folders page, and the same for Gallery**

```

| NotFound

type Route
= Gallery
| Folders
| SelectedPhoto String

```

These correspond to URL routes like `/gallery` and `/photos/foo`.

```

view : Model -> Document Msg
view model =
let
    content =
        case model.page of
            FoldersPage folders ->
                Folders.view folders
                |> Html.map GotFoldersMsg
            GalleryPage gallery ->
                Gallery.view gallery
                |> Html.map GotGalleryMsg
            NotFound ->
                text "Not Found"
in
{ title = "Photo Groove, SPA Style"
, body =
    [ lazy viewHeader model.page
    , content
    , viewFooter
    ]
}

```

Delegates view based on which page we're viewing

```

viewHeader : Page -> Html Msg
viewHeader page =
let
    logo =
        h1 [] [ text "Photo Groove" ]

    links =
        ul []
        [ NavLink Folders { url = "/", caption = "Folders" }
        , NavLink Gallery { url = "/gallery", caption = "Gallery" }
        ]

```

lazy means `viewHeader` reruns only when `model.page` changes.

```

NavLink : Route -> { url : String, caption : String } -> Html msg
NavLink route { url, caption } =
    li
        [ classList
        [ ( "active"
        , isActive { link = route, page = page }
        )
        ]
    ]

```

```

        [ a [ href url ] [ text caption ] ]
in
nav [] [ logo, links ]

parser : Parser (Route -> a) a
parser =
  Parser.oneOf
    [ Parser.map Folders.Parser.top
    , Parser.map Gallery (s "gallery")
    , Parser.map SelectedPhoto (s "photos" </> Parser.string)
    ]

isActive : { link : Route, page : Page } -> Bool
isActive { link, page } =
  case ( link, page ) of
    ( Gallery      , GalleryPage _ ) -> True
    ( Gallery      , _             ) -> False
    ( Folders      , FoldersPage _ ) -> True
    ( Folders      , _             ) -> False
    ( SelectedPhoto _, _           ) -> False

```

**Parses a Route based on whichever of these parsers passes first**

**Destructures “named arguments” immediately**

**A “truth table” determining whether a link should be shown as “active”**

```

viewFooter : Html msg
viewFooter =
  footer []
    [ text "One is never alone with a rubber duck. -Douglas Adams" ]

```

```

type Msg
  = ClickedLink Browser.UrlRequest
  | ChangedUrl Url
  | GotFoldersMsg Folders.Msg
  | GotGalleryMsg Gallery.Msg

```

**Wrapper messages for the Folders and Gallery pages**

```

update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
  case msg of
    ClickedLink urlRequest ->
      case urlRequest of
        Browser.External href ->
          ( model, Nav.load href )
        Handles requests to external domains by doing a full page load
        Browser.Internal url ->
          ( model, Nav.pushUrl model.key (Url.toString url) )

```

**Handles requests to our same domain by doing a pushUrl—which will trigger a ChangedUrl message**

```

ChangedUrl url ->
  updateUrl url model

```

**Delegates wrapped messages for the Folders page to Folders.update**

```

GotFoldersMsg foldersMsg ->
  case model.page of
    FoldersPage folders ->
      toFolders model (Folders.update foldersMsg folders)

```

```

    - ->                                | If we're on the Folders page,
    ( model, Cmd.none )                  | ignore non-Folders messages.

    GotGalleryMsg galleryMsg ->           case model.page of
        GalleryPage gallery ->             toGallery model (Gallery.update galleryMsg gallery)

    - ->                                |
    ( model, Cmd.none )

toFolders : Model -> ( Folders.Model, Cmd Folders.Msg ) -> ( Model, Cmd Msg )
toFolders model ( folders, cmd ) =
    ( { model | page = FoldersPage folders }
    , Cmd.map GotFoldersMsg cmd
    )

    | Converts a ( Model, Cmd
      | Msg ) from the Folders page
      | to Main's equivalent

toGallery : Model -> ( Gallery.Model, Cmd Gallery.Msg ) -> ( Model, Cmd Msg )
toGallery model ( gallery, cmd ) =
    ( { model | page = GalleryPage gallery }
    , Cmd.map GotGalleryMsg cmd
    )

main : Program Float Model Msg
main =
    Browser.application
        { init = init
        , onUrlChange = ChangedUrl
        , onUrlRequest = ClickedLink
        , subscriptions = subscriptions
        , update = update
        , view = view
        }

init : Float -> Url -> Nav.Key -> ( Model, Cmd Msg )
init version url key =
    updateUrl url { page = NotFound, key = key, version = version }

subscriptions : Model -> Sub Msg
subscriptions model =
    case model.page of
        GalleryPage gallery ->
            Gallery.subscriptions gallery
            |> Sub.map GotGalleryMsg

    - ->
        Sub.none

updateUrl : Url -> Model -> ( Model, Cmd Msg )
updateUrl url model =

```

```
case Parser.parse parser url of
    Just Gallery ->
        toGallery model (Gallery.init model.version)
    Just Folders ->
        toFolders model (Folders.init Nothing)
    Just (SelectedPhoto filename) ->
        toFolders model (Folders.init (Just filename))
    Nothing ->
        ( { model | page = NotFound }, Cmd.none )
```

When the URL changes,  
parse it into a Route  
and init a new Model  
and Cmd Msg.

# *appendix A*

## *Getting set up*

---

### **This appendix covers installing the following**

- Node.js (10.0.0 or higher) and NPM (6.0.0 or higher)
- Required command-line tools
- The *Elm in Action* repository
- Recommended optional tools

### **A.1    *Installing Node.js and NPM***

In addition to having the Elm Platform installed, the examples in this book require having Node.js 10.0.0 or higher and NPM 6.0.0 or higher installed as well. If you haven't already, visit <https://nodejs.org> and follow the instructions to download and install them.

**NOTE** The Node.js installer at <https://nodejs.org> also installs NPM for you, so if you install Node that way, you will not need to install NPM separately.

To confirm that you have Node.js 10.0.0 or higher and NPM 6.0.0 or higher installed, you should be able to run these commands in your terminal and see similar output:

```
$ node --version  
v10.0.0
```

```
$ npm --version  
6.0.0
```

If you have Node installed but not NPM, then your installation of Node is probably not the one from <https://nodejs.org>. Please make sure you have NPM installed before continuing.

## A.2 *Installing command-line tools*

Now that you have NPM installed, you can use it to get the Elm Platform along with the `elm-test` and `http-server-spa` command-line tools. (You'll need `elm-test` in chapter 6 and `http-server-spa` in chapter 8.) Here's the command:

```
npm install -g elm elm-test http-server-spa@1.3.0
```

**TIP** If `npm` gives you a lengthy error involving the word EACCES, visit <https://docs.npmjs.com/getting-started/fixing-npm-permissions> for how to resolve it. If you are unable to resolve this error, you can fall back on installing the Elm Platform directly from <http://elm-lang.org/install>, but this will get you through only chapters 1 through 5. Starting in chapter 6, being able to run `npm install -g` will be required to run the examples.

Let's verify that the Elm platform was installed properly:

```
elm --version  
0.19.1
```

If you see a version higher than `0.19.1`, then as of this writing, you are living in the future! Hello from the past, where `0.19.1` is the latest release.

**NOTE** Any version that starts with `0.19` should work fine with this book, but according to semantic versioning, a version number beginning with `0.20` or higher indicates breaking changes. In such a case, there's a good chance your examples will not compile. Try `npm install -g elm@latest-0.19.1` to get a compatible version.

## A.3 *Obtaining the Elm in Action repository*

This book does not require using Git or any Git knowledge. If you are not a Git user, you can download and extract a zip archive of the repository at <https://github.com/rfeldman/elm-in-action/archive/master.zip> and proceed directly to the next section.

Git users can download the repository by running this:

```
git clone https://github.com/rfeldman/elm-in-action.git
```

The repository has been tagged with various checkpoints. Suppose you are about to read chapter 2, section 2.2.1. You can visit this URL to obtain all the code necessary to work through the examples in section 2.2.1:

```
https://github.com/rtfeldman/elm-in-action/tree/2.2.1
```

You can replace the 2.2.1 in that URL with a different section number to view the code at the start of that section. For example, if you want to peek ahead and see where things stand at the end of section 2.2.1, you can bring up the 2.2.2 tag by visiting <https://github.com/rtfeldman/elm-in-action/tree/2.2.2> in a browser. Alternatively, you can run `git checkout 2.2.2` from a terminal if you ran `git clone` on the repository earlier.

## A.4 *Installing recommended optional tools*

To get syntax highlighting and other niceties, visit <http://elm-lang.org/install#syntax-highlighting> and select your editor of choice to find an appropriate Elm plugin. Make sure your editor is configured to convert tabs to spaces, as tab characters are syntax errors in Elm.

I also strongly recommend installing `elm-format`: <https://github.com/avh4/elm-format>. I absolutely love `elm-format`. It automatically formats Elm code according to a nice, consistent standard.

I use it for personal projects, my whole team at work uses it, and I have my editor configured to run it whenever I save. (Several editors enable this by default, but if not, there are easy instructions in the preceding link for how to enable format-on-save.) All of the examples in this book are formatted with `elm-format`, so using it will make life easier as you work through them.

## *appendix B*

# *Installing Elm packages*

**This appendix elaborates on these concepts first introduced in chapter 3**

- Direct and indirect dependencies
  - Default imports
  - Elm's semantic versioning
  - Installation of Elm packages

Whenever we run `elm install` to add a new dependency, it modifies our `elm.json` file. Here is the `elm.json` file we'll have at the beginning of the book's final chapter, chapter 8.

### **Listing B.1 Photo Groove's elm.json**

```
{  
  "type": "application",  
  "source-directories": [  
    "src"  
  ],  
}
```

We'd replace "application" with "package" if we were building a package.

Elm will look in our src/ directory only for source code.

```

"elm-version": "0.19.1",
"dependencies": {
    "direct": {
        "NoRedInk/elm-json-decode-pipeline": "1.0.0",
        "elm/browser": "1.0.1",
        "elm/core": "1.0.2",
        "elm/html": "1.0.0",
        "elm/http": "2.0.0",
        "elm/json": "1.1.2",
        "elm/random": "1.0.0"
    },
    "indirect": {
        "elm/bytes": "1.0.7",
        "elm/file": "1.0.1",
        "elm/time": "1.0.0",
        "elm/virtual-dom": "1.0.2"
    }
},
"test-dependencies": {
    "direct": {
        "elm-explorations/test": "1.2.0"
    },
    "indirect": {}
}
}

```

The code snippet shows annotations with callouts:

- A callout points to the "direct" dependency block with the text: "We can import modules from direct dependencies."
- A callout points to the "elm/time" entry in the "indirect" block with the text: "New releases mean you may see different version numbers in your elm.json."
- A callout points to the "test-dependencies" block with the text: "We cannot import modules from indirect dependencies."
- A callout points to the "elm-explorations/test" entry in the "test-dependencies/direct" block with the text: "test-dependencies are available only when running elm-test."

## B.1 Direct and indirect dependencies

As mentioned in chapter 3, section 3.3.1, an Elm package is a collection of modules, and packages can depend on other packages. These break down into direct and indirect dependencies:

- *Direct dependencies*—Packages we've installed using the `elm install` command. Our application code can reference anything these packages expose.
- *Indirect dependencies*—Packages our direct dependencies depend on. Our application code cannot directly reference anything in these packages. (If we want to use something they expose, we can always move them from *indirect* to *direct*.)

**NOTE** The reason indirect dependencies are listed explicitly, along with their version numbers, is so that teams working on the same Elm application can be confident everyone is using the exact same versions of all dependencies.

The reason `elm/core`, `elm/browser`, and `elm/html` were all installed by the `elm init` command we ran in chapter 2 is that they are the minimum requirements for building an Elm user interface in the browser:

- `elm/html` houses `Html` and related modules.
- `elm/browser` gives us the `Program` type that we use for `main`.

- `elm/core` has foundational modules like `List`, `String`, and `Cmd`. It also contains a module called `Basics`, which provides bread-and-butter stuff like arithmetic operations and the `not` function.

### Default imports

Certain frequently used `core` modules are imported by default. For example, there is an implicit `import List` at the top of each file, even if you don't manually write one. That's why you can write `List.reverse` even if you haven't explicitly imported the `List` module. Here are the default imports for every Elm file:

```
Basics, List, Maybe, Result, String, Tuple, Debug, Platform,  
Platform.Cmd as Cmd, Platform.Sub as Sub
```

In addition to these modules, many of the types and type constructors in `core` are exposed by default. For example, the `Maybe` type as well as its `Just` and `Nothing` variants are all exposed by default. This means you can always write `Nothing` instead of `Maybe.Nothing`. Check out the README for the `elm/core` package for an up-to-date list.

## B.2 Semantic versioning in packages

Packages have *version numbers* that are specified in a three-digit format, like so:

```
"elm/core": "1.0.1",  
"elm/http": "2.0.0"
```

All packages are initially released at version 1.0.0. Each of these three numbers has a specific meaning, according to certain *semantic versioning* rules, which in Elm are defined as follows:

- *Major version number* (the 3 in 3.2.1)—This number increments whenever a package makes a change to any public-facing values. For example, changing the type of a function that is publicly accessible, or removing the function altogether, would demand a major version number increase.
- *Minor version number* (the 2 in 3.2.1)—This increments whenever a package introduces a new public-facing value. You'd see a minor version number bump in a release that introduced new publicly accessible values without altering or removing any existing ones.
- *Patch version number* (the 1 in 3.2.1)—This increments whenever a release neither introduces nor alters any publicly accessible values. It might modify documentation or internal implementations, though; for example, to fix a bug discovered in a previous release.

When any of these numbers increments, the numbers after it become zero. As such, releasing a package updated from version 3.2.1 would change the version number as shown in table B.1.

**Table B.1 Incrementing a package version from 3.2.1**

Current version	Type of change	Next version
3.2.1	<i>Major change</i>	4.0.0
3.2.1	<i>Minor change</i>	3.3.0
3.2.1	<i>Patch change</i>	3.2.2

**B.2.1 Semantic versioning enforced**

All packages in Elm’s ecosystem are guaranteed to respect these semantic versioning rules. If a package author makes a breaking change to a publicly accessible value, and attempts to publish the package while increasing only the minor or patch version numbers, the package repository will detect this and refuse to publish. The author will see an error message explaining that this breaking change requires a major version number bump.

**B.2.2 Browsing package documentation**

Published packages are also required to document their publicly exposed values and to provide a link to their source code. You can view documentation and links to source code for any package in the Elm ecosystem by visiting <http://package.elm-lang.org>. This site lists the modules in each package and the values they expose.

**B.3 Example: Installing elm/url**

Let’s say we were to run `elm install elm/url`. After it completes, this command will have done the following:

- 1 Edited `elm.json` to include the latest version of `elm/url` as a direct dependency
- 2 Downloaded the code for the `elm/url` package to a directory called `.elm` inside our home directory
- 3 Downloaded any code necessary for `elm/url`’s dependencies into that same `.elm` directory, and listed them as indirect dependencies in our `elm.json` file

**TIP** `elm make` looks in that `.elm` directory for all downloaded packages, which means after `elm install` has downloaded a package, it will never bother downloading it again unless your `.elm` directory gets deleted. This also means you can use `elm init` and `elm install` when you’re offline; as long as the versions of all the packages you want to use have already been downloaded, you’ll be all set!

Ahh, the internet. Shout-out to any programmers who remember what sharing code was like before the internet. Personally, I liked to wrap a printout around the ankle of my pterodactyl.

# *appendix C*

## *Html.Lazy's change check*

---

**This appendix adds details about the `Html.Lazy` function first used in chapter 8**

- How `lazy` works with strings and numbers
- How it works for other values
- How it works when memory locations change

In chapter 8, we used the `Html.Lazy.lazy` function to skip running view code if certain values did not change on repeated calls. How does `lazy` decide whether a value has changed? The answer to this question involves two important design goals:

- `lazy` must never skip calling the function if there is any chance the function could return a different value. At worst, `lazy` should be an ineffective performance optimization; it should never cause bugs under any circumstances.
- Because it's a tool for making things run faster, `lazy` should perform the "Is it safe to skip?" check as quickly as possible.

To balance these goals, `lazy` does the fastest check it can to determine whether the argument it receives is *possibly different* from the last time it was called. This check

compiles down to using JavaScript's `====` operator, which often gives different results from Elm's `==` operator. Let's zoom in on some of those differences.

### C.1 **lazy's check for strings and numbers**

When it comes to strings and numbers, `lazy`'s check works the same way as plain old `==` checks do in Elm. If two strings or two numbers are equal according to Elm's `==` operator, then `lazy` considers them the same.

### C.2 **lazy's check for everything else**

For every other type in Elm, `lazy` checks whether the value has the same location in memory as it did before. Values other than strings and numbers get assigned a unique location in memory when they are initially defined, and they retain this memory location when they get passed around or returned from functions. For example, here are two values with the same content but different locations in memory:

```
jess =
  [ "dev", "dot", "to" ]

ben =
  [ "dev", "dot", "to" ]
```

Here, `jess == ben` evaluates to `True`, but `jess` and `ben` have different memory locations because they were initially defined separately. Table C.1 summarizes this relationship.

**Table C.1 Equality relationships between jess and ben**

First value	Second value	<code>==</code>	Memory locations
jess	jess	True	Same
ben	ben	True	Same
jess	ben	True	Different
ben	jess	True	Different

**TIP** In Elm, memory location is a detail that matters only for performance optimization, not application logic. The only consequence of changes that affect memory locations is that things might run faster or slower.

### C.3 **When memory locations stay the same**

Custom type variants that don't hold data—for example, the values `True`, `False`, and `Nothing`—always have the same memory location. They work the same way with `lazy`.

as strings and numbers do. (In contrast, values created with `Just` might not have the same memory locations, because `Just` holds data.)

Other values keep the same memory location when they are passed around. Table C.2 shows some ways to get a value with the same memory location as another value.

**Table C.2 Ways to get a value with the same memory location as another value**

Operation yielding same memory location	Examples
Assigning it to another constant	<code>sameMemory = oldValue</code>
Reading it from a record field	<code>sameMemory = record.oldValue</code>
Reading it by destructuring	<code>{ sameMemory } = record</code> <code>( sameMemory, _ ) = tuple</code>
	In a case-expression: <code>SomeVariant sameMemory -&gt;</code>
Passing it to a function	<code>myFunction sameMemory =</code>
Returning it from a function	<code>sameMemory = Tuple.first ( oldVal, [] )</code>

### C.3.1 Memory locations for collections

When creating a new collection based on an old collection, it's common to end up with the *content* of the new collection having the same memory location as before, but the *collection itself* having a different memory location. Table C.3 shows some ways to create such collections.

**Table C.3 Collections with different memory locations whose contents are the same**

Operation yielding different memory location	Examples
Updating a record	<code>newMemory = { oldRec   x = oldRec.x }</code>
Rewrapping a record or tuple	<code>newMemory =</code> <code>( Tuple.first oldTuple</code> <code>, Tuple.second oldTuple</code> <code>)</code>
Rewrapping a custom type variant	<code>newMemory =</code> <code>case someResult of</code> <code>Ok oldValue -&gt;</code> <code>Ok oldValue</code>  <code>Err oldValue -&gt;</code> <code>Err oldValue</code>
Mapping over a collection	<code>newMemory = List.map identity oldList</code>

### C.3.2 Memory locations across updates

In practice, model values are most often either records or custom types. According to the preceding rules, the only way for such a model to keep the same memory location after an update is if update returns unchanged the same model it receives as an argument. Consider this code:

```
update : Msg -> Model -> ( Model, Cmd Msg )
update msg model =
    case msg of
        Search ->
            ( model, runSearch model.query )

        SetQuery query ->
            ( { model | query = query }, Cmd.none )

view : Model -> Html Msg
view model =
    lazy viewEverything model
```

When update receives a `Search` message, it returns `model` unchanged. This means `model` will have the same memory location as before, and the `lazy` call inside `view` will skip running `viewEverything`.

However, when update receives a `SetQuery` message, it returns a record update of `model`, which will have a different memory location. This means the `lazy` call inside `view` will rerun `viewEverything`, passing the updated `model`.

**TIP** To get the most out of `lazy`, use it on functions that take only the subset of the `Model` they need.

### C.3.3 Memory locations for functions

Functions are first-class values in Elm, and their memory locations are relevant to `lazy`. This is true for any function passed to `lazy`, including the `viewSidebar` function we want to skip. `lazy` will skip calling `viewSidebar` only if the `viewSidebar` function we pass has the same memory location as the previous one we passed.

For this reason, it's never useful to pass `lazy` a function that was defined inside another function; there's no chance its memory location will be the same from one call to the next, so `lazy` can't possibly improve performance.

```
Possibly beneficial:   lazy      viewSidebar      model.user
No possible benefit: lazy (\arg -> viewSidebar arg) model.user
```

This is true not only of anonymous functions inside `view`, but also of named functions defined in a `let-expression` inside `view`.

### C.3.4 Named top-level functions always keep the same memory location

Conveniently, named functions defined at a module's top level always keep the same memory location. The following listing shows a `viewSidebar` function that will always work the way we want it to with `lazy`, and a `badViewSidebar` function that will never work right with `lazy` because it's defined inside another function.

#### Listing C.1 Defining functions in a lazy-friendly way

```
module MyModule exposing (view)

viewSidebar : User -> Html Msg
viewSidebar = ...
```

| **Named functions defined at the  
top level always work with lazy.**

```
view : Model -> Html Msg
view =
    let
        badViewSidebar : User -> Html Msg
        badViewSidebar =
            ...
    in
        lazy viewSidebar model.user
```

| **Functions defined inside other  
functions never work with lazy.**

← If we passed `badViewSidebar`  
instead, it would never get skipped.

As long as we always pass only named top-level functions to `lazy`, we'll be all set!

# *index*

---

## Symbols

---

\_ placeholder 106  
- operator 20  
: character 24  
:: operator 198  
:: pattern 98  
! prefix, JavaScript 11  
.title shorthand 179  
( ) value (unit) 83  
/ (division operator) 149  
+ operator 8  
++ operator 8, 20  
= character 24  
== operator, Elm 20, 299  
==== operator, JavaScript 299  
|> operator 99

## A

---

accumulating while decoding 235–245  
joining decoders 238–239  
    naming 237  
active class 253  
activity field 152  
activityChanges function 154–155, 158  
addActivityListener function 153  
addNums function 171  
ambiguous names 130  
amountFromModel argument 188  
andThen function 217  
anonymous functions 19–20, 46–48

app.js 259  
appendIndex 226  
applyFilters function 145, 149, 184  
arguments  
    initialization arguments 156–166  
    preventing mix-ups 252  
arithmetic operators 8, 21  
Array module 60  
Array.fromList 58  
Array.get function 71–73, 103  
as Encode alias 181  
as keyword 105–106, 130  
associativity of operators 22  
at function 135  
Attr.max property 132  
attributes 132

## B

---

BadBody error 118  
badViewSidebar function 302  
Basics module 130, 178, 296  
Basics.toFloat function 149  
"blink" element 31  
<body> tag 38  
Boolean values 68  
Booleans 11–13  
branches 66  
Browser.application 259–261, 268, 271  
Browser.document 248, 259  
Browser.element 79, 186, 207, 248, 271  
    passing subscriptions to 154–155  
    upgrading main to use 82–83

Browser.External 269  
 Browser.Navigation 271  
 Browser.sandbox function 50–51, 79, 82, 207  
 bugs 139, 178  
 buildPhoto function 115–117  
 button element 31, 128  
 buttons 67–76

---

**C**

<canvas> element 141, 146–147, 151  
 case-expressions 65–76  
   refactoring if-expression into 66–67  
 ChangedUrl event 270  
 Char argument 63  
 Char.isdigit function 20  
 characters 8, 17–18  
   Char argument 63  
 <choose-size> element 70  
 chosenSize function 67–68, 74, 140  
 class attribute 44  
 class function 31  
 classList 253  
 click events 197–198  
 ClickedFolder 225  
 ClickedLink 268  
 ClickedPhoto 50, 75–76, 144–145, 184–185, 196, 208  
 ClickedSize function 75–76  
 ClickedSurpriseMe function 75–76, 80–81, 97  
 Cmd for init 282–283  
 Cmd function 100–101  
 Cmd module 96, 296  
 Cmd.none 81  
 collections 22–28  
   fuzzing 194  
   in JSON 112–117  
   lists 23–24  
   memory locations for 300  
   records 24–26  
   tuples 26–28  
 command-line tools 292  
 commands  
   creating 142  
   creating by using ports 141–146  
     calling setFilters when selecting photos 144–145  
   port commands never send messages 143–144  
   port modules 142

port to define function 142  
 sharing code between update branches 145–146  
 generating random values with 77–88  
 in response to user input 80  
 introducing to Elm architecture 78–80  
 returning from updates 79  
 running on init 108  
 comments 9  
 compiler 55–88  
   case-expressions 65–76  
     buttons 67  
     refactoring if-expression into 66–67  
   custom types 65–76  
     enumerating possibilities with 67–71  
     holding data in 71–73  
     representing flexible messages with 74–76  
 documenting guarantees with type  
   annotations 56–65  
   adding optional type annotations 56–58  
   annotating functions with type variables 58–60  
   annotating longer functions 62–65  
   reusing annotations with type aliases 61–62  
 generating random values with commands 77–88  
   describing random values with Random.Generator 77–78  
   generating random values with Random.generate 80–88  
   introducing commands to Elm architecture 78–80  
 compiling to JavaScript 38  
 concrete types 59  
 conditionals 11–13  
 connectedCallback method 131–133  
 consistent type 26  
 const keyword 9  
 core modules 296  
 CubeDraft module 39  
 curried functions 46–47, 63  
 currying 48, 65  
 custom elements 126–141  
   handling custom events 133–137  
     adding event handling to viewFilter 136–137  
   decoding msg 135  
   decoding slide event 134  
   Html.Events.on 134  
   Json.Decode.at 135

- listening for custom events 133–134
  - refactoring to use pipelines 136
  - updating imports 135–136
  - using `Json.Decode.map` 135
  - importing 127–133
    - adding "range-slider" to page 128–129
    - ambiguous names 130
    - rendering sliders 130–131
    - replacing "input" with custom slider 131–133
      - resolving ambiguous names 130
      - viewing sliders 129
  - registering 127–128
  - rendering process 131
    - responding to slider changes 137–141
      - choosing approach 139
      - choosing reliability 140–141
      - considering future changes 139–140
      - considering potential bugs 139
  - Custom Elements Wrapper technique 127
  - custom events 133–137
    - adding event handling to `viewFilter` 136–137
    - decoding msg 135
    - decoding slide event 134
    - `Html.Events.on` 134
    - `Json.Decode.at` 135
    - listening for 133–134
    - refactoring to use pipelines 136
    - updating imports 135–136
    - using `Json.Decode.map` 135
  - custom types 65–76
    - defining trees with 218–222
    - adding hardcoded data to init 220–221
    - adding hardcoded data to model 220–221
    - defining folders as recursive custom type 219–220
    - incorporating `viewFolder` into view 222
    - recursive custom types 219
    - recursive functions 222
    - rendering folders 221
    - destructuring 73
    - destructuring single-variant custom types 221–222
    - enumerating possibilities with 67–71
    - rendering radio buttons 70
    - rendering thumbnail size radio buttons 69
    - rendering thumbnail sizes 70–71
    - holding data in 71–73
      - Just function 72–73
  - Maybe vs. `undefined` 71–72
  - Maybe, type variable of 72
  - implementing `Msg` as 74–75
  - representing flexible messages with 74–76
  - cyclic definition
    - error 234–235
    - fixing with `Decode.lazy` 234–235
    - identifying 234
    - in `folderDecoder` 234
- 
- D**
- dash function 19
  - data
    - fetching from servers 100–110
    - describing HTTP requests 100–103
    - sending HTTP requests 104–110
    - holding in custom types 71–73
    - destructuring custom types 73
    - Just function 72–73
    - Maybe type variable 72
    - Maybe vs. `undefined` 71–72
    - initialization data, sending to programs 156–157
    - modeling 205–245
      - decoding graphs 228–245
      - decoding trees 228–245
      - loaded data 92–93
      - modeling trees with recursive custom types 218–228
      - storing values by keys in dictionaries 206–218
    - receiving from Elm 146–150
      - adding Pasta library 146
      - converting amount value to percentage 149
    - receiving from JavaScript 152–166
    - receiving from `setFilters` port 146–147
    - sending
      - from JavaScript to Elm 152–153
      - to JavaScript 141–151
    - server-loaded 92–100
  - data field 57
  - data structures 274–275
  - `-debug` flag 257
  - Debug module 17
  - `Debug.log` 256–257
  - `Debug.todo` function 260–261, 267
  - debugging code 258
  - `Decode.andThen` function 239
  - `Decode.keyValuePairs` 230

Decode.lazy 234–236  
 Decode.map 231  
 Decode.map function 231  
 Decode.map2 function 239  
 Decode.succeed buildPhoto 116  
 Decode.succeed folderFromJson function 233  
 Decode.succeed function 236  
 Decoder Page 264  
 decoderTest function 173, 179  
 decodeString function 111, 173  
 decodeString photoDecoder 181  
 decoding  
     accumulating while 235–245  
         Dict.union 236  
         foldl vs. foldr 237–238  
         joining decoders 238–239  
         List.foldl with Dict.union 238  
         List.foldr 236–237  
         naming 237  
 decoders 238–239  
 dictionaries 228–231  
     comparing photo representations 228  
 Decode.keyValuePairs 230  
 Decode.map 231  
 intermediate representations 229  
 sample JSON 228  
 translating list of tuples into  
     dictionary 230–231  
 fields 114  
 folders 232–234  
 graphs 228–245  
 hardcoded  
     adding to init 220–221  
     adding to models 220–221  
 JSON 111–124  
 JSON arrays into lists 113  
 JSON collections 112–117  
 JSON HTTP responses 117–124  
     BadBody error 118  
     expectJSON in initialCmd 118  
     Http.expectJson 117  
     rendering metadata 119–124  
 JSON strings into results 111  
 models 232  
 msg 135  
 objects 113  
 pipelines 114–117  
 primitives 112  
 recursive JSON 231–235  
     cyclic definition in folderDecoder 234  
     fixing cyclic definition with  
         Decode.lazy 234–235  
     gathering nested photos 232  
     identifying cyclic definition 234  
 slide events 134  
 trees 228–245  
 URL strings from enclosing objects 229  
 delegating  
     page logic 279–290  
         Cmd for init 282–283  
         Html.map 279–280  
         linking to /photos/filename 283–284  
         model for init 282–283  
         removing duplications 283  
     pages 272–290  
         initializing page states 275–279  
         revising module structures 272–275  
     subscriptions 280  
     update 281–282  
     view 280  
 dependencies  
     direct 295  
     indirect 295  
     installing package dependencies 77–78  
     resolving data dependencies 95–100  
 descent 223–224  
 describe, grouping tests with 187  
 description field 57  
 destructuring custom types 73  
 detailUserSlidTo function 136  
 dictionaries  
     adding to models 214  
     decoding 228–231  
         Decode.keyValuePairs 230  
         Decode.map 231  
         decoding URL strings from enclosing  
             objects 229  
         intermediate representations 229  
         sample JSON 228  
 Dict 213  
 Dict Char Int 213  
 Dict module 214  
 Dict String Float 213  
 Dict String Photo 213, 239  
 Dict.empty 217  
 Dict.fromList function 212, 230  
 Dict.get 212, 215  
 Dict.union 236, 238  
     of photos 211–213  
     storing photos by URL in 209–218

Dict type parameters 213  
Dict.get with Maybe String 215  
lists of photos 211  
refactoring for Maybe.andThen 215–216  
rendering photos 217–218  
retrieving photos 211  
storing photos 211  
storing values by keys in 206–218  
translating list of tuples into 230–231  
direct dependencies 295  
div function 34, 36, 43, 65, 95  
division operator (/) 149  
<!doctype> tag 38  
Document Msg 248  
DOM (Document Object Model) 30, 40, 51, 132  
DOM nodes 34, 40, 191  
DOM structure, testing 189–193  
    building query.single 190  
    converting from Html to query 191  
    converting from query to expectation 191–192  
    partially applying Expect.equal 192  
    querying Html 190–191  
DOM updates  
    optimizing 151  
    timing 150–151  
        applying filters after loading photos 150  
        synchronizing with Elm runtime 151  
        timing ports 150–151  
        timing rendering 150–151  
double quotes 8  
Dreamwriter 4  
duplications, removing 283

## E

---

EACCES error 292  
effects  
    managing 100–101  
    side effects 100–101  
elem argument 97  
elements 30  
elementType variable 59  
Elm Architecture, The  
    introducing commands to 78–80  
    returning commands from updates 79  
    running commands in response to user input 80  
    user input with 40–54  
        handling events with messages 48–54

handling events with updates 48–54  
representing application states with models 40–48  
Elm in Action repository 292–293  
elm init command 32, 38, 295, 297  
elm install command 78, 168, 294–295, 297  
elm install elm/url command 297  
elm make command 38, 45, 67, 84, 253, 257, 297  
elm repl 7, 9, 15, 32, 57, 113, 260  
elm-explorations 168  
elm-explorations/test package 169  
elm-test command 168–169, 171, 174, 179, 185, 292–293  
elm-test init 169  
Elm-to-JavaScript ratio 5  
elm.json file 294  
Elm.PhotoGroove.init() method 39, 147, 158  
elm/browser package 111, 153, 295  
elm/core package 296  
elm/html package 153, 295  
elm/http package 100  
elm/json package 111  
elm/random package 295  
elm/url 261, 263, 297  
else branch 12  
else if 12–13, 65  
enclosing objects 229  
enumerating possibilities with custom types 67–71  
    rendering radio buttons 70  
    rendering thumbnail size radio buttons 69  
    rendering thumbnail sizes 70–71  
Err BadBody 117  
Err values 178  
Errored state 92, 94, 100  
errValue variable 103, 111  
event handling  
    adding to viewFilter 136–137  
    appendIndex 226  
    modifying views 227  
    selecting photos on click 227–228  
    with messages 48–54  
        adding OnClick to viewThumbnail 50  
        model-view-update loops 50–54  
    with recursive messages 226–228  
    with updates 48–54  
        adding OnClick to viewThumbnail 50  
        model-view-update loops 50–54  
Event.expect (ClickedPhoto url) 199

Event.simulate Event.click 199  
 Event.simulate function 199  
 expanding models 43–45  
 Expect.all 195–196  
 Expect.equal 171, 175  
 expectations 170  
     combining with Expect.all 195–196  
     converting from query to 191–192  
 expectJSON 118  
 exposing  
     importing unqualified values with 35–36  
     variants 185–186  
 exposing (...) 36  
 expressions 7–13  
     assigning names to 10  
     Booleans 11–13  
     characters 8  
     comments 9  
     conditionals 11–13  
     elm repl 7  
     strings 8  
 external URL requests 269

---

**F**

failing tests 173  
 failure output 174–175  
 False value 24, 299  
 fields, decoding 114  
 filenames, reading 104–105  
 files, renaming 169  
 filter() method 17, 24  
 filtering characters 17–18  
 FilterOptions function 142, 146  
 filters 125, 150  
 findAll function 192  
 firstPhoto element 98  
 firstUrl 105  
 fixed fields 26  
 flags  
     receiving initialization arguments via 156–166  
     sending to Elm 158–166  
 flags function 83  
 flexible messages  
     implementing Msg as custom type 74–75  
     missing-patterns error 75–76  
     representing with custom types 74–76  
 floats 16  
 Folder annotation 219–220  
 folderDecoder 234, 236, 238–239

folderFromJson function 233  
 FolderPath 224–226  
 folders  
     decoding 232–234  
     defining as recursive custom type 219–220  
     rendering 221  
 Folders.init 276–277, 285  
 Folders.Model 273–274  
 FoldersPage 281  
 FoldersPage Folders.Model 278  
 foldl 237–238  
 foldl vs. foldr 237–238  
     List.foldl 237  
     List.foldl with Dict.union 238  
     List.foldr 236  
 foldr 236–238  
 foo function 27  
 footers, rendering 249–253  
 fromList function 59, 61  
 fromPairs function 231  
 functions 13–22  
     annotating 57, 62–65  
     annotating viewThumbnail 65  
     with type variables 58–60  
 anonymous 19–20, 46–48  
 creating multiple tests with 186–188  
 creating scope with let-expressions 18–19  
 custom 187–188  
 defining 14–15  
     inside let-expressions 251–252  
     using a port to define 142  
 from string modules 16–17  
 importing 15, 17–18  
 memory locations for 301  
 named functions 302  
 operators 20–22  
     operator associativity 22  
     operator precedence 21  
     operator precedence and normal function calls 22  
 partially applied 63–65  
 recursive 222  
 view functions 41–42  
 fuzz tests 180–188  
     converting unit tests to 180–183  
         building JSON with Json.Encode 180–181  
         fuzz2 182–183  
         Json.Decode.decodeValue 181–182  
         Json.Encode.Value 181  
         randomly generated values 183

creating multiple tests with one function 186–188  
 grouping tests with `describe` 187  
 returning tests from custom function 187–188  
 testing update functions 184–186  
 exposing variants 185–186  
 testing `ClickedPhoto` 184–185  
`Fuzz.int` 183  
`Fuzz.intRange` function 194  
`Fuzz.list` function 194  
`Fuzz.map` 197  
`Fuzz.string` function 183, 194  
`fuzz2` 182–183  
 fuzzing  
 collections 194  
 view tests 193–196  
 combining expectations with `Expect.all` 195–196  
 customizing list sizes 194–195  
 rendering thumbnails, verification of 193

**G**

`Gallery.init` function 276  
`Gallery.Model` 274  
`Gallery.subscriptions` function 281  
`GalleryPage` `Gallery.Model` 278  
 GET request 100  
`GetFoldersMsg` 281  
`getPhotoUrl` function 73, 97  
`getUltimateAnswer` 83  
 git checkout command 293  
 git clone command 293  
`GotActivity` message 152  
`GotGalleryMsg` branch 280, 282  
`GotInitialModel` message 208, 225  
`GotPhotos` branch 108, 118, 150  
`GotRandomPhoto` 98, 145  
`GotSelectedIndex` 81–82, 98  
 graphs, decoding 228–245  
 accumulating while 235–245  
`Dict.union` 236  
`foldl` vs. `foldr` 237–238  
 joining decoders 238–239  
`List.foldl` 236–237  
`List.foldl` with `Dict.union` 238  
`List.foldr` 236–237  
 naming ingredients 237  
 viewing pages 239–245

decoding dictionaries 228–231  
 combining ingredients with `Decode.map` 231  
 comparing photo representations 228  
`Decode.keyValuePairs` 230  
 decoding URL strings from enclosing objects 229  
 intermediate representations 229  
 sample JSON 228  
 translating list of tuples into dictionary 230–231  
 decoding recursive JSON 231–235  
 cyclic definition in `folderDecoder` 234  
 decoding folders 232–234  
 decoding models 232  
 fixing cyclic definition with `Decode.lazy` 234–235  
 gathering nested photos 232  
 identifying cyclic definition 234  
 recursive JSON 231–232  
 guarantees, documenting with type annotations 56–65  
 adding optional type annotations 56–58  
 annotating functions 57  
 annotating lists 57–58  
 annotating records 57  
 annotating functions with type variables 58–60  
`ArrayList` 58  
 arrays 58  
 choosing names for type variables 59–60  
 creating arrays of photos 60  
 lists 58  
 type variables 59  
 annotating longer functions 62–65  
 annotating partially applied functions 63–65  
 annotating `viewThumbnail` 65  
 reusing annotations with type aliases 61–62  
 annotating `initialModel` with type alias 61  
`Html`, type variable of 62

**H**


---

`h1` function 34, 36  
`<h1>` element 249  
 hardcoded data  
 adding to `init` 220–221  
 adding to models 220–221  
`<head>` tag 38, 67

header links 266–267  
 headers  
   optimizing prematurely 254  
   rendering 249–253  
 helper function 41  
 higher-order functions 18, 43, 82  
 Html module 295  
   converting to query 191  
   querying 190–191  
   returning document instead of 248  
   to describe pages 31–36  
     declaring PhotoGroove modules 32–35  
     exposing (...) 36  
     importing unqualified values with  
       exposing 35–36  
     rendering pages 32  
   type variable of 62  
 Html Msg values 253–254  
 Html node 50  
<html> tag 38  
 Html.Attributes module 36, 69, 130, 134  
 Html.Attributes.property 129, 134  
 Html.Attributes.style attribute 37  
 Html.classList function 44  
 Html.div function 35  
 Html.Events module 50  
 Html.Events.on 134  
 Html.Events.onClick 153  
 Html.h1 function 35  
 Html.img function 35  
 Html.Lazy function 298–302  
   checking numbers 299  
   checking strings 299  
   memory locations 299–302  
     across updates 301  
     for collections 300  
     for functions 301  
     for named functions 302  
   skipping renders with 253–258  
     building Html Msg values 253–254  
     calling lazy on viewHeader 254–255  
     Debug.log 256–257  
     debugging code 258  
     detecting renders 257–258  
     prematurely optimizing header 254  
     skipping safely 255–256  
     triggering re-renders 257  
     verifying skipping 256  
 Html.map 279–280  
 Html.node function 128, 134  
 Html.Test.Event 199  
 Html.text function 35  
 HTTP GET request 100  
 HTTP requests  
   describing 100–103  
   Http.expectString 102–103  
   Http.get 101–103  
   managed effects vs. side effects 100–101  
   Maybe 103  
   Result 103  
   sending 104–110  
     as keyword 105–106  
     List.head 105  
     pattern matching 107–108  
     reading photo filenames with  
       String.split 104–105  
     running command on init 108  
     simplifying initialCmd 109–110  
     type aliases to create records 106–107  
 HTTP responses, decoding 117–124  
   BadBody error 118  
   expectJSON in initialCmd 118  
   Http.expectJson 117  
     rendering metadata 119–124  
 http-server-spa 258–259, 292  
 Http.Error type 103–104, 118  
 Http.expectJson 117  
 Http.expectString 102–103, 108–109, 117  
 Http.get 101–103  
 Http.jsonBody function 119  
 Http.post function 119  
 Http.send function 142

---

|

<i> tag 31  
 id function 31  
 identity function 178  
 if-expression 10, 66–67  
 if-statement 10  
 img function 31, 34, 36, 42, 45  
 immutable records 25  
 immutable value 22  
 imported types 60  
 importing  
   custom elements 127–133  
     adding "range-slider" to page 128–129  
     ambiguous names 130  
     custom element rendering process 131  
     Html.Attributes.property 129

registering custom elements 127–128  
rendering sliders 130–131  
replacing "input" with custom slider 131–133  
resolving ambiguous names 130  
viewing sliders 129  
functions 15–18  
filtering characters with `String.filter` 17–18  
from string modules 16–17  
unqualified values with exposing 35–36  
imports, updating 135–136  
`in` keyword 19  
incremental initialization, modeling 92–95  
fixing view 93–94  
modeling loaded data 92–93  
propagating changes 93  
rendering loaded photos 94  
using `<|` operator 94–95  
`index` function 73  
`index.html` 248, 277  
indexes 225  
indirect dependencies 295  
inequality operators 214  
infix-style calling 20–22  
`init`  
adding hardcoded data to 220–221  
`Cmd` for 282–283  
extracting 261  
model for 282–283  
running commands on 108  
`init` function 157, 261–262  
`initialCmd`  
  `expectJSON` in 118  
  simplifying 109–110  
initialization  
  arguments, receiving via flags 156–166  
  data, sending to programs 156–157  
  incremental, modeling 92–95  
    fixing view 93–94  
    modeling loaded data 92–93  
    propagating changes 93  
    rendering loaded photos 94  
    using `<|` operator 94–95  
  of page states 275–279  
    revising `Folders.init` 276–277  
    revising `index.html` 277  
    revising `Main.init` 278–279  
    revising `urlToPage` 276–277  
`initialModel` 60–61, 92, 138, 190, 214  
`initialModel.photos` 96

"input" 131–133  
`input` element 128  
Int argument 63  
integers 16  
intermediate representations 206, 229  
internal URL requests 269  
`isActive` function 266–267, 275  
`isEmpty` annotation 57  
`isKeepable` function 18–19  
`isPositive` function 14

---

**J**

JavaScript arrays 58  
  in JSON 113  
  of photos 60  
JavaScript language 125–166  
  break statement 66  
  class keyword 127  
  compiling to 38  
  receiving data from 152–166  
  sending data from 152–153  
  sending data to 141–151  
    creating commands by using ports 141–146  
    receiving data from Elm 146–150  
    timing DOM updates 150–151  
  using custom elements 126–141  
    handling custom events 133–137  
    importing custom elements 127–133  
    responding to slider changes 137–141  
JSON (JavaScript Object Notation) 228  
  arrays 113  
  building with `Json.Encode` 180–181  
  collections 112–117  
  decoder 172–176  
  decoding 111–124  
  HTTP responses 117–124  
  recursive JSON 231–235  
  strings 111–112  
`Json.Decode` module 112, 180  
`Json.Decode.at` 135  
`Json.Decode.bool` 113  
`Json.Decode.Decoder` 134  
`Json.Decode.decodeString` function 111, 158, 264  
`Json.Decode.decodeValue` 158–159, 181–182  
`Json.Decode.field` function 134  
`Json.Decode.int` function 134  
`Json.Decode.list` 113  
`Json.Decode.map` 135, 177, 197

Json.Decode.Pipeline module 114  
 Json.Encode 119, 129, 180–181  
 Json.Encode.int function 129  
 Json.Encode.Value 181  
 JsonPhoto function 233  
 JSR (JS Range) 131  
 Just function 72–73  
 Just type 296, 300

**K**


---

keys in dictionaries, storing values by 206–218  
 setting up pages 207–209  
 rendering pages 208–209  
 viewing pages 209  
 storing photos by URL in dictionaries 209–218  
 adding dictionaries to models 214  
 Dict type parameters 213  
 Dict.get with Maybe String 215  
 dictionaries of photos 211–213  
 lists of photos 211  
 refactoring for Maybe.andThen 215–216  
 rendering photos 217–218  
 retrieving photos 211  
 storing photos 211  
 keyValuePairs function 230

**L**


---

label element 128  
 lazy 254–256, 258  
 lazy viewHeader model.page 255  
 left-associative operator 22  
 let keyword 9, 19  
 let-expressions  
   creating scope with 18–19  
   defining functions inside 251–252  
 links  
   creating with navCtrl 251  
   overriding default behavior of 268  
 links function 251  
 List Bool annotation 57  
 List function 219  
 List module 296  
 List Photo value 99  
 list zipper data structure 92  
 List.filter function 23  
 List.foldl 236–238

List.foldr 236–237  
 List.head 105  
 List.head someList 105  
 List.indexedMap 224  
 List.map 42–43, 70, 177–178, 196–197, 212  
 List.partition foo bar 37  
 List.range function 195  
 List.reverse function 37  
 lists 23–24, 58  
   annotating 57–58  
   customizing sizes of 194–195  
   decoding JSON arrays into 113  
   non-empty 198  
   of photos 211  
   of tuples 230–231  
 loaded data 92–93  
 loaded photos 94  
 Loaded state 93, 98, 100  
 Loading state 92, 94, 100, 150

**M**


---

magnitude value 129  
 main  
   annotating 83  
   upgrading to use Browser.element 82–83  
 main value 32, 39, 49  
 Main.elm 247–249  
   returning document instead of Html 248  
   revising index.html 248  
   viewing pages 249  
 Main.init 273, 278–279  
 Main.view function 279  
 Main.viewHeader function 283  
 major version number 296  
 map functions 177, 197  
 Math.random() method 77–78, 100  
 max function 130, 132  
 Maybe 103  
   type variable of 72  
   undefined vs. 71–72  
 Maybe String 215  
 Maybe.andThen 215–217, 239  
 Maybe.map function 216  
 mdgriffith/elm-ui package 37  
 memory locations 299–302  
   across updates 301  
   for collections 300  
   for functions 301  
   for named functions 302

messages  
flexible  
    implementing `Msg` as custom type 74–75  
    missing-patterns error 75–76  
    representing with custom types 74–76  
handling events with 48–54  
    adding `OnClick` to `viewThumbnail` 50  
model-view-update loops 50–54  
recursive 223–225  
    describing descent 223–224  
    event handlers with 226–228  
incorporating `FolderPath` into `Msg` 225  
`List.indexedMap` 224  
transforming subfolders based on  
    index 225  
metadata 119–124  
minor version number 296  
missing-patterns error 75–76, 98, 267  
model for `init` 282–283  
Model type 43, 50, 79, 107, 184, 301  
model-view-update loops 50–54  
model.chosenSize argument 140  
model.key 270–271  
model.page value 253–255, 257, 262  
model.root function 221  
model.selectedUrl 95  
model.status 93  
modelDecoder 217, 220, 223  
modeling  
    data 205–245  
        decoding graphs 228–245  
        decoding trees 228–245  
        loaded data 92–93  
        storing values by keys in dictionaries  
            206–218  
    incremental initialization 92–95  
        fixing view 93–94  
        propagating changes 93  
    rendering loaded photos 94  
    using `<|` operator 94–95  
trees with recursive custom types 218–228  
    defining trees with custom types 218–222  
    event handlers with recursive  
        messages 226–228  
        recursive messages 223–225  
modelPhotosDecoder 236, 238–239  
models  
    adding dictionaries to 214  
    adding hardcoded data to 220–221  
    adding page state to 249–251  
    declaring 41  
    decoding 232  
    expanding 43–45  
    representing application states with 40–48  
    `List.map` 43  
    replacing anonymous functions with partial  
        applications 46–48  
    writing view functions 41–42  
module structures, revising 272–275  
    data structures 274–275  
    exposing values in `PhotoFolders` modules 272  
    `Main.init` 273  
    `PhotoFolders.init` 273  
    problems with pages 274  
    renaming 272–273  
    storing `PhotoFolders.model` 273  
modules, defined 15  
`Msg` 76, 80, 82, 101, 159, 184  
    as custom type 74–75  
    incorporating `FolderPath` into 225  
`msg`, decoding 135  
`msg.description` 66  
`msgDecoder` function 136  
multiline comments 9

---

**N**

named functions 302  
names  
    ambiguous 130  
    assigning to expressions 10  
    assigning to values 9–10  
        for type variables 59–60  
    naming 237  
`<nav>` tag 251  
`Nav.Key` value 261  
`Nav.load` 269  
`Nav.pushUrl` 269–270  
`NavLink` 251–252, 258  
negate function 130  
nested photos 232  
node function 31, 35, 132  
`Node.js` 291–292  
non-empty lists 198  
nonassociative operator 22  
`NonEmptyList` type 97  
`noPhotosNoThumbnails` 192, 194  
`NoRedInk/elm-json-decode-pipeline`  
    package 114  
not function 11, 130, 296

NotFound function 266, 275  
 Nothing type 72, 208, 215, 265, 296, 300  
 NPM 291–292  
 npm install -g command 292  
 numbers 299

**O**

objects, decoding 113  
 okValue variable 103  
 on function 134–136  
 OnClick attribute 50  
 onClick attribute 50, 62, 74, 76, 79, 153, 223  
 onMouseOver 257–258  
 onSlide function 136  
 onUrlChange 268  
 onUrlChanged handler 260–261, 270  
 onUrlRequest 260–261, 268  
 <| operator 94–95, 176, 179  
 operators 20–22  
   operator associativity 22  
   operator precedence 21–22  
 –optimize flag 220, 260  
 optimizing  
   DOM updates 151  
   headers prematurely 254  
 –output app.js 38

**P**

<p> tag 31  
 package dependencies 77–78  
 packages  
   installing 294–297  
     direct dependencies 295  
     indirect dependencies 295  
     installing elm/url 297  
     semantic versioning in packages 296–297  
   semantic versioning in 296–297  
     package documentation 297  
     semantic versioning 297  
 padLeft function 62–64  
 page logic, delegating 279–290  
   Cmd for init 282–283  
   delegating subscriptions 280  
   delegating update 281–282  
   delegating view 280  
   Html.map 279–280  
   linking to /photos/filename 283–284  
   model for init 282–283

removing duplications 283  
 page states  
   adding to models 249–251  
   initializing 275–279  
     revising Folders.init 276–277  
     revising index.html 277  
     revising Main.init 278–279  
     revising urlToPage 276–277  
 Page type 250, 273  
 pages 247–258  
   adding "range-slider" to 128–129  
   creating Main.elm 247–249  
     returning document instead of Html 248  
     revising index.html 248  
   delegating 272–275  
   Html module to describe 31–36  
     declaring PhotoGroove modules 32–35  
     exposing (...) 36  
     importing unqualified values with  
       exposing 35–36  
   problems with 274  
   rendering 30, 37–39, 208–209  
   rendering footers 249–253  
   rendering headers 249–253  
   setting up 207–209  
   skipping renders with Html.Lazy 253–258  
     building Html Msg values 253–254  
     calling lazy on viewHeader 254–255  
     Debug.log 256–257  
     debugging code 258  
     detecting renders 257–258  
     prematurely optimizing header 254  
     skipping safely 255–256  
     triggering re-renders 257  
     verifying skipping 256  
   URL-enabled 271–272  
   viewing 209, 239–245, 249  
 parentheses 176  
 Parser Page 264  
 Parser.map Gallery 265  
 Parser.oneOf 265–266  
 Parser.s function 265  
 Parser.top 265  
 parsers  
   composing with Parser.oneOf 265–266  
   defining 263–264  
   running 264–265  
 parsing URL paths 263–267  
   composing parsers with Parser.oneOf  
     265–266

defining parsers 263–264  
revising header links 266–267  
running parsers 264–265  
URL structure 263  
using truth table patterns 267  
viewing selected photo pages 267  
partial applications 46–48  
    replacing anonymous functions with partial applications 46–48  
partially applied functions 46–47, 63–65  
partition function 37  
Pasta library 146  
patch version number 296  
[ ] pattern 98–99  
patterns  
    matching 107–108, 118  
    missing 98  
photo argument 46, 215  
photo indexes 77  
Photo type alias 61, 114  
photoArray 61, 71, 73–74, 77, 93, 96–97  
photoDecoder 115, 117, 172  
PhotoFolders modules 209, 272, 284  
PhotoFolders.init 273  
PhotoFolders.model 273  
PhotoFolders.Msg 285  
PhotoFolders.update function 284  
photoFromUrl function 195  
PhotoGallery module 284  
PhotoGroove modules 4, 29, 32, 34–35, 39, 125, 173, 185, 272  
PhotoGroove.elm file 32, 34, 128  
PhotoGroove.SlidHue 185  
PhotoGroove.view function 191  
PhotoGrooveTests module 169, 174  
photos  
    arrays of 60  
    calling setFilters when selecting 144–145  
    choosing 198  
    comparing representations of 228  
    dictionaries of 211–213  
    filenames of 104–105  
    lists of 211  
    loaded 94  
    loading 150  
    nested 232  
    random, choosing 97  
    rendering 217–218  
    retrieving 211  
    selecting on click 227–228  
    storing 211  
    storing by URL in dictionaries 209–218  
    adding dictionaries to models 214  
    calling viewSelectedPhoto from view 215  
    Dict type parameters 213  
    Dict.get with Maybe String 215  
    refactoring for Maybe.andThen 215–216  
photoUrls value 232  
pipeline operators 99  
pipelines  
    decoding 114–117  
    refactoring to use 136  
pluralize function 15  
port keyword 142  
ports  
    app.ports.activityChanges.send 155–156  
    app.ports.setFilters.subscribe 147, 155  
    creating commands by using 141–146  
    calling setFilters when selecting photos 144–145  
    port commands never send messages 143–144  
    port modules 142  
    port to define functions 142  
    sharing code between update branches 145–146  
    port commands 143–144  
    port keyword 142  
    port module keyword 142  
    port modules 142  
    receiving real-time data from JavaScript via 152–156  
    calling app.ports.activityChanges.send 155–156  
    passing subscriptions to browser.element 154–155  
    sending data from JavaScript to Elm 152–153  
    subscriptions 153  
    subscription ports 154  
    timing 150–151  
    to define functions 142  
precedence of operators 21–22  
prefix-style calling 20–21  
premature optimization 253  
primitives, decoding 112  
projects 37–39  
    compiling to JavaScript 38  
    Elm runtime 39  
    main value 39

propagating changes 93  
properties 132

**Q**

qualified style 35  
queries  
  converting from Html to 191  
  converting to expectation 191–192  
Query module 189–190  
Query.children function 191  
Query.count function 191–193  
Query.find function 199  
Query.findAll function 191, 194, 199  
Query.findHtml function 190  
Query.fromHtml function 191  
Query.Multiple function 190  
query.single 190  
Query.Single function 190, 193–195  
querying Html 190–191

**R**

radio buttons  
  rendering 70  
  thumbnail size 69  
Random module 78  
random photo indexes 77  
random values 183  
  describing with Random.Generator 77–78  
  generating random photo indexes 77  
  installing package dependencies 77–78  
generating with commands 77–88  
generating with Random.generate 80–88  
  annotating main 83  
  calling Random.generate 81–82  
  upgrading main to use  
    Browser.element 82–83  
Random.bool 77  
Random.generate  
  calling 81–82  
  generating random values with 80–88  
  annotating main 83  
  upgrading main to use  
    Browser.element 82–83  
Random.Generator 77, 80–81  
  generating random photo indexes 77  
  installing package dependencies 77–78  
Random.Generator Bool 77  
Random.Generator Int 77, 79, 97  
Random.Generator Photo value 98  
Random.int function 77  
Random.uniform firstPhoto otherPhotos  
  function 99  
Random.uniform function 98  
randomPhotoPicker 77, 80–82, 97  
"range-slider" 126, 128–129, 131, 133  
<range-slider> 127–128  
RangeSlider class 131  
rangeSlider function 129–130  
re-renders 257  
React 4, 51, 127  
records 24–26  
  annotating 57  
  creating with type aliases 106–107  
  updating 25–26  
recursive custom types 219  
  defining folders as 219–220  
  modeling trees with 218–228  
  defining trees with custom types 218–222  
  event handlers with recursive  
    messages 226–228  
  recursive messages 223–225  
recursive functions 222  
recursive JSON, decoding 231–235  
  cyclic definition in folderDecoder 234  
  decoding folders 232–234  
  decoding models 232  
  fixing cyclic definition with Decode.lazy  
    234–235  
  gathering nested photos 232  
  identifying cyclic definition 234  
recursive messages 223–225  
  describing descent 223–224  
  event handlers with 226–228  
    appendIndex 226  
    modifying views 227  
    selecting photos on click 227–228  
incorporating FolderPath into Msg 225  
List.indexedMap 224  
transforming subfolders based on index 225  
reduce function 236  
reduceRight function 236  
refactoring  
  for Maybe.andThen 215–216  
  to use pipelines 136  
refactors 100  
registering custom elements 127–128  
reliability 140–141  
renaming files 169, 272–273

- rendering  
  custom elements 131  
  detecting 257–258  
  folders 221  
  footers 249–253  
  headers 249–253  
  loaded photos 94  
  metadata 119–124  
  pages 30–39, 208–209  
    building projects 37–39  
    describing using `Html` module 31–36  
  photos 217–218  
  radio buttons 70  
  skipping with `Html.Lazy` 253–258  
    building `Html Msg` values 253–254  
    calling lazy on `viewHeader` 254–255  
    `Debug.log` 256–257  
    debugging code 258  
    detecting renders 257–258  
    prematurely optimizing header 254  
    skipping safely 255–256  
    triggering re-renders 257  
    verifying skipping 256  
  sliders 130–131  
  thumbnail size radio buttons 69  
  thumbnail sizes 70–71  
  thumbnails 193  
  timing 150–151
- REPL (read-eval-print loop) 7
- representations  
  intermediate 229  
  of photos 228
- `requestAnimationFrame` function 151
- required function 116
- Result 103
- Result `Http.Error String` 103
- Result.`andThen` function 216
- Result.`map` 177–178, 197, 216
- Result.`mapError` 178
- results, decoding JSON strings into 111–112  
  `decodeString` function 111  
  decoding primitives 112
- return keyword 14–15
- reverse function 36
- right-associative operator 22
- Route type 275–276
- routing 258–272  
  handling initial URL 258–263  
  `Debug.todo` 260–261  
  extracting init 261
- handling URL scenarios 259
- installing elm/URL package 261
- installing http-server-spa 258–259
- interpreting URL 262–263
- loading `/app.js` instead of `app.js` 259
- receiving URL with  
  `Browser.application` 259–260
- handling URL changes 267–272  
  external URL requests 269  
  handling `ClickedLink` 268  
  internal URL requests 269  
  `model.key` 270–271  
  `Nav.load` 269  
  `Nav.pushUrl` 269–270  
  `onUrlChange` 268  
  `onUrlRequest` 268  
  overriding default link behavior 268  
  URL-enabled pages 271–272
- parsing URL paths 263–267  
  composing parsers with `Parser.oneOf` 265–266  
  defining parsers 263–264  
  revising header links 266–267  
  running parsers 264–265  
  URL structure 263  
  using truth table patterns 267  
  viewing selected photo pages 267
- rtfeldman/elm-css package 37
- rule function 33
- runtime 39, 151
- 
- S**
- scope 18–19
- `<script>` tag 146
- Search message 301
- `selectedPhotoUrl` field 208, 215, 285
- `selectedUrl` value 44–45, 48, 71, 77, 96, 105
- `selectPhoto` annotation 57
- `selectUrl` function 95–96
- semantic versioning 296–297
- server-loaded data 92–100  
  modeling incremental initialization 92–95  
  modeling loaded data 92–93  
  propagating changes 93  
  rendering loaded photos 94  
  using `<|` operator 94–95
- resolving data dependencies 95–100  
  `[ ]` pattern 98–99  
  choosing random photos 97

- server-loaded data (*continued*)
  - completed refactors 100
  - fixing updates 95–96
  - `GotRandomPhoto` 98
  - missing patterns 98
  - replacing `photoArray` 96–97
  - using pipeline operators 99
- servers 91–124
  - data from 100–110
    - describing HTTP requests 100–103
    - sending HTTP requests 104–110
  - decoding JSON 111–124
    - decoding JSON collections 112–117
    - decoding JSON HTTP responses 117–124
    - decoding JSON strings into results 111–112
  - preparing for server-loaded data 92–100
    - modeling incremental initialization 92–95
    - resolving data dependencies 95–100
- `Set` module 16
- `setFilters` 142–143, 149
  - calling when selecting photos 144–145
    - port, receiving data from 146–147
- `setQuery` message 301
- side effects 100–101, 141
- single page load 247
- single quotes 8
- single-line comments 9
- single-page applications. *See* SPAs
- single-variant custom types, destructuring 221–222
- `sizeToClass` function 70
- `sizeToString` function 70
- skipping
  - renders with `Html.Lazy` 253–258
    - building `Html Msg` values 253–254
    - calling lazy on `viewHeader` 254–255
    - `Debug.log` 256–257
    - debugging code 258
    - detecting renders 257–258
    - prematurely optimizing header 254
    - triggering re-renders 257
  - safely 255–256
  - verifying 256
- slide events, decoding 134
- sliders
  - rendering 130–131
  - replacing "input" with 131–133
  - responding to changes 137–141
    - choosing approach 139
- choosing reliability 140–141
- considering future changes 139–140
- considering potential bugs 139
- viewing 129
- `SlidHue` 184–185
- `slidHueSetsHue` test 187
- `SlidNoise` 186, 188
- `SlidRipple` 186, 188
- SPAs (single-page applications) 246–290
  - delegating pages 272–290
    - delegating page logic 279–290
    - initializing page states 275–279
    - revising module structures 272–275
  - framing pages 247–258
    - creating `Main.elm` 247–249
    - rendering footers 249–253
    - rendering headers 249–253
    - skipping renders with `Html.Lazy` 253–258
  - routing 258–272
    - handling initial URL 258–263
    - handling URL changes 267–272
    - parsing URL paths 263–267
- state
  - of applications, representing with models 40–48
    - declaring models 41
    - expanding models 43–45
    - `List.map` 43
    - replacing anonymous functions with partial applications 46–48
    - writing view functions 41–42
  - of pages, initializing 275–279
    - revising `Folders.init` 276–277
    - revising `index.html` 277
    - revising `Main.init` 278–279
    - revising `urlToPage` 276–277
- `string` 41, 44
- `String.filter` 17–18, 20, 23–24, 35
- `String.filter isKeepable` str 19
- `String.fromFloat` function 16, 157
- `String.toInt` function 16, 157
- `String.padLeft` function 63–64
- `String.reverse` function 37
- `String.split` 104–105
- `String.toUpperCase` function 16
- strings 8
  - checking with lazy 299
  - in JSON 111–112
  - triple-quoted strings 174
  - URL strings 229

Sub Gallery.Msg 280  
Sub Msg subscription 154  
subfolderPhotos 238  
subfolders 225  
subscription port 154  
subscriptions 153  
  delegating 280  
  passing to browser.element 154–155  
succeed function 116

## T

---

tagName 30  
targetIndex 224  
ternary expressions 10  
test dependencies 169  
test function 170–171  
Test.describe function 187  
Test.Html.Query 189  
Test.only function 192  
Test.skip function 192  
testing 167–202  
  ClickedPhoto 184–185  
  DOM structure 189–193  
    building Query.Single 190  
    converting from Html to Query 191  
    converting from Query to  
      Expectation 191–192  
    partially applying Expect.equal 192  
    querying Html 190–191  
  titles 176–177  
  update functions 184–186  
  user interactions 196–202  
    choosing photos 198  
    Fuzz.map 197  
    generating non-empty lists 198  
    Html.Test.Event 199  
    querying Html 198  
    simulating click events 197–198  
  views 188–202  
tests 168–172  
  creating multiple with one function 186–188  
  expectations 170  
  failing tests 173  
  grouping with describe 187  
  narrowing scope of 176–179  
    .title shorthand 179  
  Result.map 177  
    testing only titles 176–177  
  renaming files 169

returning from custom function 187–188  
running 174  
running unit tests 170  
unit tests 169–172  
testSlider function 187–188  
text function 31, 35–36  
text nodes 30  
textContent property 30  
this keyword 25  
this.appendChild method 131  
thumbnail size radio buttons 69  
thumbnailRendered 195–196  
thumbnails  
  rendering 193  
  rendering sizes 70–71  
ThumbnailSize type 68–69, 74  
thumbnailsWork 197  
timing  
  DOM updates 150–151  
    applying filters after loading photos 150  
    optimizing 151  
    synchronizing with Elm runtime 151  
  ports 150–151  
  rendering 150–151  
<title> tag 38  
titles, testing 176–177  
toFloat function 149  
toGallery function 282  
toggleExpanded 224–225  
toLowerCase function 16  
toMsg argument 188  
toMsg function 102, 136  
tools, installing 292–293  
toString method 16  
toUpperCase function 16  
transform function 225  
trees  
  decoding 228–245  
    accumulating while decoding 235–245  
    decoding dictionaries 228–231  
    decoding recursive JSON 231–235  
  defining with custom types 218–222  
    adding hardcoded data to init 220–221  
    adding hardcoded data to model 220–221  
    defining folder as recursive custom  
      type 219–220  
  destructuring single-variant custom  
    types 221–222  
  incorporating viewFolder into view 222  
  recursive custom types 219

- trees (*continued*)
  - recursive functions 222
  - rendering folders 221
  - modeling with recursive custom types 218–228
  - event handlers with recursive messages 226–228
  - recursive messages 223–225
- triple-quoted strings 174
- True value 24, 299
- truth table patterns 267
- tuple destructuring 26
- `Tuple.first` function 26
- `Tuple.pair` function 99
- `Tuple.second` function 26
- tuples 26–28, 46, 230–231
- type aliases
  - annotating `initialModel` with 61
  - creating records with 106–107
  - reusing annotations with 61–62
- type annotations
  - documenting guarantees with 56–65
  - annotating functions with type variables 58–60
  - annotating longer functions 62–65
  - reusing annotations with type aliases 61–62
  - functions 57, 62–65
    - partially applied 63–65
    - with type variables 58–60
  - `initialModel` with type alias 61
  - lists 57–58
  - main 83
  - optional, adding 56–58
    - annotating functions 57
    - annotating lists 57–58
    - annotating records 57
  - records 57
  - `viewThumbnail` 65
  - with type aliases 61–62
- type `Msg` declaration 74
- type variables 59
  - annotating functions with 58–60
    - `Array.fromList` 58
    - arrays 58
    - creating arrays of photos 60
    - lists 58
    - type variables 59
  - choosing names for 59–60
  - of `Html` 62
  - of `Maybe` 72
- type\_ attribute 69
- TypeScript 4–6
- 
- ## U
- undefined vs. `Maybe` 71–72
- uniform distribution 97
- unit tests
  - converting to fuzz tests 180–183
  - building JSON with `Json.Encode` 180–181
  - `fuzz2` 182–183
  - `Json.Decode.decodeValue` 181–182
  - `Json.Encode.Value` 181
  - randomly generated values 183
  - expectations 170
  - narrowing test scope 176–179
    - .title shorthand 179
    - `Result.map` 177
    - testing only titles 176–177
  - of JSON decoder 172–176
    - fixing failing tests 175–176
    - inspecting failure output 174–175
    - replacing parentheses with `<|` operator 176
  - running tests 174
  - triple-quoted strings 174
  - writing failing tests 173
- renaming files 169
- running 170
  - running unit tests 170
- unqualified style 35, 37
- unqualified values 35–36
- update
  - delegating 281–282
- update branches 145–146
- update functions, testing 184–186
  - exposing variants 185–186
  - testing `ClickedPhoto` 184–185
- updateForProgram function 186
- updates
  - handling events with 48–54
    - adding `OnClick` to `viewThumbnail` 50
    - model-view-update loops 50–54
    - memory locations across 301
    - returning commands from 79
  - `updateUrl` function 282
  - updating
    - imports 135–136
    - records 25–26
  - upgrading main to use `Browser.element` 82–83

## URL

- external requests 269
- handling changes 267–272
- handling ClickedLink 268
- model.key 270–271
- Nav.load 269
- Nav.pushUrl 269–270
- onUrlChange 268
- onUrlRequest 268
- overriding default link behavior 268
- in dictionaries, storing photos by 209–218
  - adding dictionaries to models 214
  - calling viewSelectedPhoto from view 215
  - Dict type parameters 213
  - Dict.get with Maybe String 215
- dictionaries of photos 211–213
- lists of photos 211
- refactoring for Maybe.andThen 215–216
- rendering photos 217–218
- retrieving photos 211
- storing photos 211
- initial, handling 258–263
  - Debug.todo 260–261
  - extracting init 261
  - installing elm/URL package 261
  - installing http-server-spa 258–259
    - loading /app.js instead of app.js 259
- internal requests 269
- interpreting 262–263
- paths, parsing 263–267
  - composing parsers with Parser.oneOf 265–266
  - defining parsers 263–264
  - revising header links 266–267
  - running parsers 264–265
- URL structure 263
  - using truth table patterns 267
  - viewing selected photo pages 267
- receiving with Browser.application 259–260
- scenarios, handling 259
- strings 229
- structure 263
- URL-enabled pages 271–272
- url field 229
- Url.Builder 263
- Url.Parser 263
- Url.Parser.Query 263
- Url.toString function 269
- UrlChange 284
- urlCount 195

## urlFuzzer 198

- urlPrefix assignment 56–57
- urlToPage 266, 276–278, 283
- user input
  - running commands in response to 80
  - with Elm architecture 40–54
    - handling events with messages 48–54
    - handling events with updates 48–54
    - representing application states with models 40–48

user interactions, testing 196–202

- choosing photos 198
- Fuzz.map 197
- generating non-empty lists 198
- Html.Test.Event 199
- simulating click events 197–198
- URL-enabled pages 198

userSlidTo 134

UTF-8 characters 8

## V

---

val property 129

value property 132

values

- assigning names to 9–10
- converting to percentage 149
- exposing in PhotoFolders modules 272
- storing by keys in dictionaries 206–218
  - setting up pages 207–209
  - storing photos by URL in dictionaries 209–218

var keyword 9

variants, exposing 185–186

varied types 26

view

- calling viewSelectedPhoto from 215

- delegating 280

- fixing 93–94

view functions 41–42

viewFilter 136–137

viewFilter function 130

viewFolder 221, 226

viewfolder 222

viewFooter 250

viewHeader 257, 266

- calling lazy on 254–255

- implementing 251

viewing pages 239–245

viewLoaded function 94, 130, 140

viewPhoto function 227  
viewRelatedPhoto function 210, 221  
views  
  incorporating viewFolder into 222  
  modifying 227  
  states, representing with models  
    writing view functions 41–42  
  testing 188–202  
    fuzzing view tests 193–196  
    testing DOM structure 189–193  
    testing user interactions 196–202  
viewSelectedPhoto 210–211, 215, 227, 230

viewSidebar function 301–302  
viewSizeChooser function 70, 74, 76  
viewThumbnail function 41–42, 44, 46, 48, 69,  
  119, 193  
  adding OnClick to 50  
  annotating 65  
virtual DOM 51  
virtual DOM node 31

## W

---

withoutDashes function 18–19

# Elm IN ACTION

Richard Feldman

**S**imply put, the Elm programming language transforms the way you think about frontend web development. Elm's legendary compiler is an incredible assistant, giving you the precise and user-friendly support you need to work efficiently. Elm applications have small bundle sizes that run faster than JavaScript frameworks and are famously easy to maintain as they grow. The catch? Elm isn't JavaScript, so you'll have some new skills to learn.

**Elm in Action** teaches you the Elm language along with a new approach to coding frontend applications. Chapter by chapter, you'll create a full-featured photo-browsing app, learning as you go about Elm's modular architecture, Elm testing, and how to work seamlessly with your favorite JavaScript libraries. You'll especially appreciate author and Elm core team member Richard Feldman's unique insights, based on his thousands of hours writing production code in Elm. When you're done, you'll have a toolbox of new development skills and a stunning web app for your portfolio.

## What's Inside

- Scalable design for production web applications
- Single-page applications in Elm
- Data modeling in Elm
- Accessing JavaScript from Elm

For web developers with no prior experience in Elm or functional programming.

**Richard Feldman** is a software engineer at NoRedInk and a well-known member of the Elm community.

To download their free eBook in PDF, ePUB, and Kindle formats, owners of this book should visit [manning.com/books/elm-in-action](http://manning.com/books/elm-in-action)



“This is the definitive book to learn Elm!”

—Ubaldo Pescatore, Generali

“A solid, evenly paced introduction to the Elm language as well as the fundamentals of functional programming.”

—Daniel Carl, Oatey

“If you are looking to learn Elm, this book is a must-have. Richard is a master instructor and the best ambassador for the Elm ecosystem.”

—Tahir Awan, Saudi Aramco

“A practical introduction to Elm grounded in a thorough and well-developed elaboration of the Elm Architecture.”

—Jake Romer, Bike Index



MANNING

\$49.99 / Can \$65.99 [INCLUDING eBOOK]

ISBN: 978-1-61729-404-4

9 781617 294044

54999