LEARN THE SCALA LANGUAGE IN A PRACTICAL, PROJECT-BASED WAY

HANDS-ON SCALA PROGRAMMING

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Free Chapters

Second Edition, published January 31 2026

ISBN 978-981-94-5226-2

Written and Published by Li Haoyi, brought up to date for the 2nd Edition with the help of Jamie Thompson (jamie-thompson-dev.github.io)

Book Website: https://www.handsonscala.com/

Chapter Discussion: https://www.handsonscala.com/discuss

Online materials: https://github.com/handsonscala/handsonscala

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Reviewers

Thanks to all the reviewers who helped review portions of this book and provide the feedback that helped refine this book and make it what it is today.

In alphabetical order:

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Earlier Editions

Hands-on Scala Programming 1st Edition ISBN 978-981-14-5693-0 was published June 1 2020.

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Foreword

Scala as a language delegates much to libraries. Instead of many primitive concepts and types it offers a few powerful abstractions that let libraries define flexible interfaces that are natural to use.

Haoyi's Scala libraries are a beautiful example of what can be built on top of these foundations. There's a whole universe he covers in this book: libraries for interacting with the operating system, testing, serialization, parsing, web-services to a full-featured REPL and build tool. A common thread of all these libraries is that they are simple and user-friendly.

Hands-On Scala is a great resource for learning how to use Scala. It covers a lot of ground with over a hundred mini-applications using Haoyi's Scala libraries in a straightforward way. Its code-first philosophy gets to the point quickly with minimal fuss, with code that is simple and easy to understand.

Making things simple is not easy. It requires restraint, thought, and expertise. Haoyi has laid out his approach in an illuminating blog post titled *Strategic Scala Style: The Principle of Least Power*, arguing that less power means more predictable code, faster understanding and easier maintenance for developers. I see *Hands-On Scala* as the *Principle of Least Power* in action: it shows that one can build powerful applications without needing complex frameworks.

The *Principle of Least Power* is what makes Haoyi's Scala code so easy to understand and his libraries so easy to use. *Hands-On Scala* is the best way to learn about writing Scala in this simple and straightforward manner, and a great resource for getting things done using the Scala ecosystem.

- **Martin Odersky, creator of the Scala Language**

Author's Note

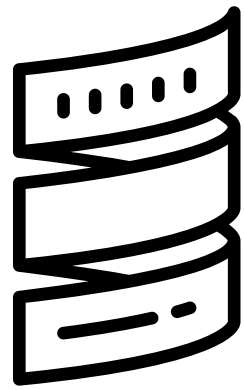
I first used Scala in 2012. Back then, the language was young and it was a rough experience: weak tooling, confusing libraries, and a community focused more on fun experiments rather than serious workloads. But something caught my interest. Here was a programming language that had the convenience of scripting, the performance and scalability of a compiled language, and a strong focus on safety and correctness. Normally convenience, performance, and safety were things you had to trade off against each other, but with Scala for the first time it seemed I could have them all.

Since then, I've worked in a wide range of languages: websites in PHP and Javascript, software in Java or C# or F#, and massive codebases in Python and Coffeescript. Problems around convenience, performance, and safety were ever-present, no matter which language I was working in. It was clear to me that Scala has already solved many of these eternal problems without compromise, but it was difficult to reap these benefits unless the ecosystem of tools, libraries and community could catch up.

Today, the Scala ecosystem has caught up. Tooling has matured, simpler libraries have emerged, and the community is increasingly using Scala in serious production deployments. I myself have played a part in this, building tools and libraries to help push Scala into the mainstream. The Scala experience today is better in every way than my experience in 2012.

This book aims to introduce the Scala programming experience of today. You will learn how to use Scala in real-world applications like building websites, concurrent data pipelines, or programming language interpreters. Through these projects, you will see how Scala is the easiest way to tackle complex and difficult problems in an elegant and straightforward manner.

- **Li Haoyi, author of *Hands-on Scala Programming***



Part I: Introduction to Scala

The first part of this book is a self-contained introduction to the Scala language. We assume that you have some background programming before, and aim to help translate your existing knowledge and apply it to Scala. You will come out of this familiar with the Scala language itself, ready to begin using it in a wide variety of interesting use cases.

1

Hands-on Scala


```scala
package app

object MinimalApplication extends cask.MainRoutes:
    @cask.get("/")
    def hello() = "Hello World!"

    initialize()
```
1.1.scala

Snippet 1.1: a tiny Scala web app, one of many example programs we will encounter in this book

Hands-on Scala teaches you how to use the Scala programming language in a practical, project-based fashion. Rather than trying to develop expertise in the deep details of the Scala language itself, *Hands-on Scala* aims to develop expertise using Scala in a broad range of practical applications. This book takes you from "hello world" to building interactive websites, parallel web crawlers, and distributed applications in Scala.

The book covers the concrete skills necessary for anyone using Scala professionally: handling files, data serializing, querying databases, concurrency, and so on. *Hands-on Scala* will guide you through completing several non-trivial projects which reflect the applications you may end up building as part of a software engineering job. This will let you quickly hit the ground running using Scala professionally.

1.1 Why Scala and Why This Book?

Scala combines object-oriented and functional programming in one concise, high-level language. Scala's static types help avoid bugs in complex applications, and its JVM (Java Virtual Machine) runtime gives you excellent performance and easy access to a huge ecosystem of tools and libraries. If you have ever felt limited by Python's poor performance, or inconvenienced by Java's verbosity, Scala could be a great programming language to try.

Hands-on Scala assumes you are a software developer who already has experience working in another programming language, and want to quickly become productive working with Scala. Note that this book is not targeted at complete newcomers to programming. We expect you to be familiar with basic programming concepts: variables, integers, conditionals, loops, functions, classes, and so on. We will touch on any cases where these concepts behave differently in Scala, but you should already have a basic understanding of how they work.

1.1.1 Why Scala

Scala is a general-purpose programming language, and has been applied to a wide variety of problems and domains: the Twitter social network has most of its backend systems written in Scala, the Apache Spark big data engine is implemented in Scala, the Chisel hardware design language is built on top of Scala. While Scala has never been as mainstream as languages like Python, Java, or C++, it remains heavily used in a wide range of companies and open source projects.

1.1.1.1 A Compiled Language that feels Dynamic

Scala is a language that scales well from one-line snippets to million-line production codebases, with the convenience of a scripting language and the performance and scalability of a compiled language. Scala's conciseness makes rapid prototyping a joy, while its optimizing compiler and fast JVM runtime provide great performance to support your heaviest production workloads. Rather than being forced to learn a different language for each use case, Scala lets you re-use your existing skills so you can focus your attention on the actual task at hand.

1.1.1.2 Easy Safety and Correctness

Scala's functional programming style and type-checking compiler helps rule out entire classes of bugs and defects, saving you time and effort you can instead spend developing features for your users. Rather than fighting `TypeError`s and `NullPointerException`s in production, Scala surfaces mistakes and issues early on during compilation so you can resolve them before they impact your bottom line. Deploy your code with the confidence that you won't get woken up by outages caused by silly bugs or trivial mistakes.

1.1.1.3 A Broad and Deep Ecosystem

As a language running on the Java Virtual Machine, Scala has access to the large Java ecosystem of standard libraries and tools that you will inevitably need to build production applications. Whether you are looking for a Protobuf parser, a machine learning toolkit, a database access library, a profiler to find bottlenecks, or monitoring tools for your production deployment, Scala has everything you need to bring your code to production.

1.1.2 Why This Book?

The goal of *Hands-on Scala* is to make a software engineer productive using the Scala programming language as quickly as possible.

1.1.2.1 Beyond the Scala Language

Most existing Scala books focus on teaching you the language. However, knowing the minutiae of language details is neither necessary nor sufficient when the time comes to set up a website, integrate with a third-party API, or structure non-trivial applications. *Hands-on Scala* aims to bridge that gap.

This book goes beyond the Scala language itself, to also cover the various tools and libraries you need to use Scala for typical real-world work. *Hands-on Scala* will ensure you have the supporting skills necessary to use the Scala language to the fullest.

1.1.2.2 Focused on Real Projects

The chapters in *Hands-on Scala* are project-based: every chapter builds up to a small project in Scala to accomplish something immediately useful in real-world workplaces. These are followed up with exercises (*1.4.3*) to consolidate your knowledge and test your intuition for the topic at hand.

In the course of *Hands-on Scala*, you will work through projects such as:

- An incremental static website generator
- A project migration tool using the Github API
- A parallel web crawler
- An interactive database-backed chat website
- A real-time networked file synchronizer
- A programming language interpreter

These projects serve dual purposes: to motivate the tools and techniques you will learn about in each chapter, and also to build up your engineering toolbox. The API clients, web scrapers, file synchronizers, static site generators, web apps, and other projects you will build are all based on real-world projects implemented in Scala. By the end of this book, you will have concrete experience in the specific tasks common when doing professional work using Scala.

1.1.2.3 Code First

Hands-on Scala starts and ends with working code. The concepts you learn in this book are backed up by over 140 executable code examples that demonstrate the concepts in action, and every chapter ends with a set of exercises with complete executable solutions. More than just a source of knowledge, *Hands-on Scala* can also serve as a cookbook you can use to kickstart any project you work on in future.

Hands-on Scala acknowledges that as a reader, your time is valuable. Every chapter, section and paragraph has been carefully crafted to teach the important concepts needed and get you to a working application. You can then take your working code and evolve it into your next project, tool, or product.

1.2 How This Book Is Organized

This book is organized into four parts:

Part I Introduction to Scala is a self-contained introduction to the Scala language. We assume that you have some background programming before, and aim to help translate your existing knowledge and apply it to Scala. You will get a basic Scala developer environment set up and get familiar with the Scala language itself, ready to begin applying it in a wide variety of interesting use cases.

Part II Local Development explores the core tools and techniques necessary for writing Scala applications that run on a single computer. We will cover algorithms, files and subprocess management, data serialization, scripts and build pipelines. This chapter builds towards a capstone project where we write an efficient incremental static site generator using the Scala language.

Part III Web Services covers using Scala in a world of servers and clients, systems and services. We will explore using Scala both as a client and as a server, exchanging HTML and JSON over HTTP or Websockets. This part builds towards two capstone projects: a parallel web crawler and an interactive database-backed chat website, each representing common use cases you are likely to encounter using Scala in a networked, distributed environment.

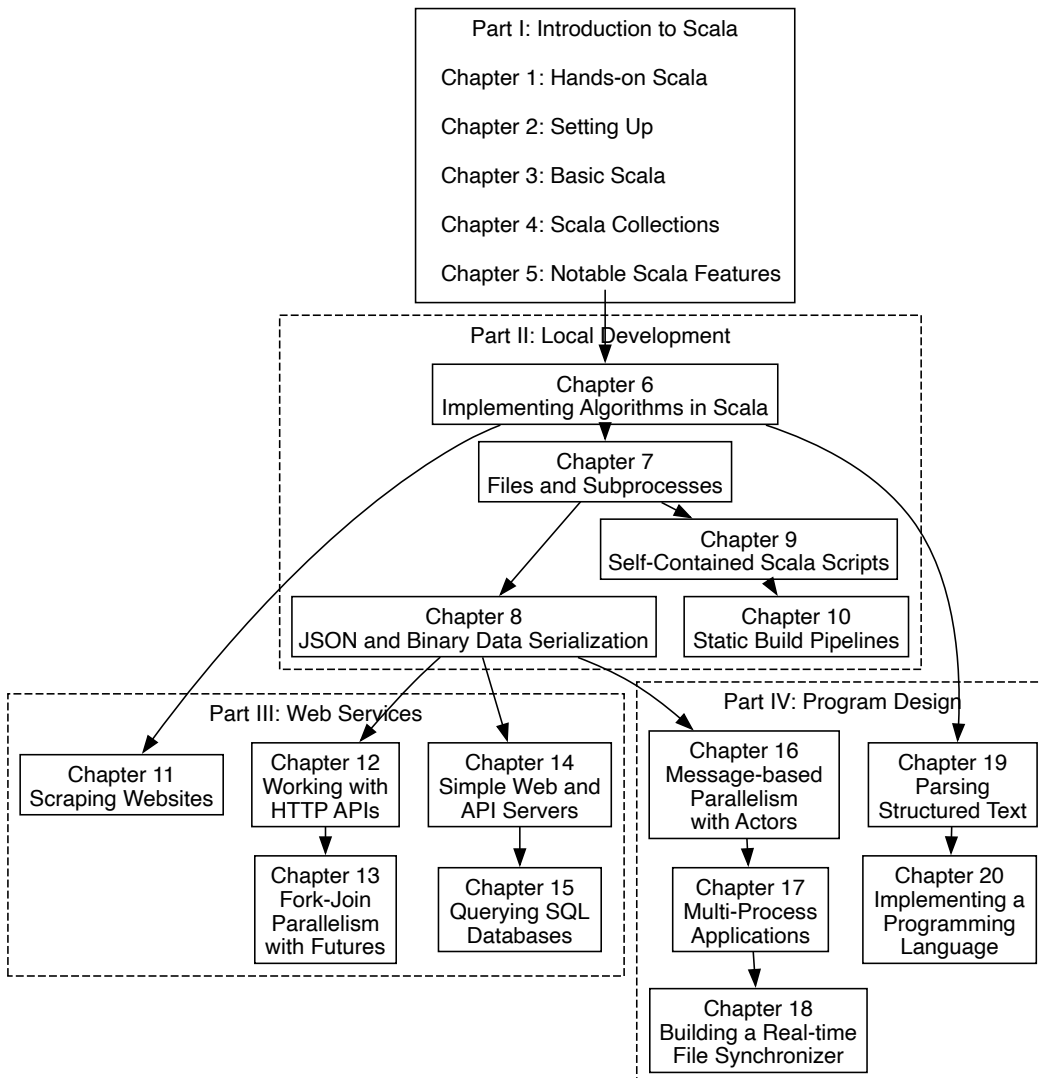
Part IV Program Design explores different ways of structuring your Scala application to tackle real-world problems. This chapter builds towards another two capstone projects: building a real-time file synchronizer and building a programming-language interpreter. These projects will give you a glimpse of the very different ways the Scala language can be used to implement challenging applications in an elegant and intuitive manner.

Each part is broken down into five chapters, each of which has its own small projects and exercises. Each chapter contains both small code snippets as well as entire programs, which can be accessed via links (*1.4*) for copy-pasting into your editor or command-line.

The libraries and tools used in this book have their own comprehensive online documentation. *Hands-on Scala* does not aim to be a comprehensive reference to every possible topic, but instead will link you to the online documentation if you wish to learn more. Each chapter will also make note of alternate sets of libraries or tools that you may encounter using Scala in the wild.

1.2.1 Chapter Dependency Graph

While *Hands-on Scala* is intended to be read cover-to-cover, you can also pick and choose which specific topics you want to read about. The following diagram shows the dependencies between chapters, so you can chart your own path through the book focusing on the things you are most interested in learning.



1.3 Code Snippet and Examples

In this book, we will be going through a lot of code. As a reader, we expect you to follow along with the code throughout the chapter: that means working with your terminal and your editor open, entering and executing the code examples given. Make sure you execute the code and see it working, to give yourself a feel for how the code behaves. This section will walk through what you can expect from the code snippets and examples.

1.3.1 Command-Line Snippets

Our command-line code snippets will assume you are using `bash` or a compatible shell like `sh` or `zsh`. On Windows, the shell can be accessed through Windows Subsystem for Linux. All these shells behave similarly, and we will be using code snippets prefixed by a `$` to indicate commands being entered into the Unix shell:

```
$ ls
build.mill
foo
mill

$ find . -type f
.
./build.mill
./foo/src/Example.scala
./mill
```

1.2.bash

In each case, the command entered is on the line prefixed by `$`, followed by the expected output of the command, and separated from the next command by an empty line.

1.3.2 Scala REPL Snippets

Within Scala, the simplest way to write code is in the Scala REPL (Read-Eval-Print-Loop). This is an interactive command-line that lets you enter lines of Scala code to run and immediately see their output. Code snippets to be entered into the REPL are prefixed by `scala>`, shortened to `>` for the purposes of this book:

```
scala> 1 + 1
res0: Int = 2

> println("Hello World")
Hello World
```

1.3.scala

In each case, the command entered is on the line prefixed by `scala>`, with the following lines being the expected output of the command. The value of the entered expression may be implicitly printed to the terminal, as is the case for the `1 + 1` snippet above, or it may be explicitly printed via `println`.

The Scala REPL also supports multi-line input, by enclosing the lines in a curly brace `{}` block:

```
> {
  println("Hello" + (" " * 5) + "World")
  println("Hello" + (" " * 10) + "World")
  println("Hello" + (" " * 15) + "World")
  }
Hello     World
Hello          World
Hello               World
```
1.4.scala

This is useful when we want to ensure the code is run as a single unit, rather than in multiple steps with a delay between them while the user is typing. Installation of Scala will be covered in ***Chapter 2: Setting Up***.

1.3.3 Source Files

Many examples in this book require source files on disk: these may be run as scripts, or compiled and run as part of a larger project. All such snippets contain the name of the file in the top-right corner:

build.mill
```
import mill.*, scalalib.*

object foo extends ScalaModule:
    def scalaVersion = "3.8.2"
```
1.5.scala

foo/src/Example.scala
```
package foo

def main() =
    println("Hello World")
```
1.6.scala

1.3.4 Diffs

We will illustrate changes to a file via *diffs*. A diff is a snippet of code with `+` and `-` indicating the lines that were added and removed:

```
     def hello() =
-        "Hello World!"
+        doctype("html")(
+            html(
+                head(),
+                body(
+                    h1("Hello!"),
+                    p("World")
+                )
+            )
+        )
```
1.7.scala

1.4 Online Materials

The following Github repository acts as an online hub for all *Hands-on Scala* notes, errata, discussion, materials, and code examples:

- https://github.com/handsonscala/handsonscala

1.4.1 Code Snippets

Every code snippet in this book is available in the `snippets/` folder of the *Hands-on Scala* online repository:

- https://github.com/handsonscala/handsonscala/blob/v2/snippets

For example the code snippet with the tag `1.1.scala` is available at the following URL:

- https://github.com/handsonscala/handsonscala/blob/v2/snippets/1.1.scala

This lets you copy-paste code where convenient, rather than tediously typing out the code snippets by hand. Note that these snippets may include diffs and fragments that are not executable on their own. For executable examples, this book also provides complete Executable Code Examples (*1.4.2*).

1.4.2 Executable Code Examples

The code presented in this book is executable, and by following the instructions and code snippets in each chapter you should be able to run and reproduce all examples shown. *Hands-on Scala* also provides a set of complete executable examples online at:

- https://github.com/handsonscala/handsonscala/blob/v2/examples

Each of the examples in the `handsonscala/handsonscala` repository contains a `readme.md` file containing the command necessary to run that example. Throughout the book, we will refer to the online examples via callouts such as:

> **See example 6.1 - MergeSort**

As we progress through each chapter, we will often start from an initial piece of code and modify it via Diffs (*1.3.4*) or Code Snippets (*1.4.1*) to produce the final program. The intermediate programs would be too verbose to show in full at every step in the process, but these executable code examples give you a chance to see the complete working code at each stage of modification.

Each example is fully self-contained: following the setup in ***Chapter 2: Setting Up***, you can run the command in each folder's `readme.md` and see the code execute in a self-contained fashion. You can use the working code as a basis for experimentation, or build upon it to create your own programs and applications. All code snippets and examples in this book are MIT licensed.

1.4.3 Exercises

Starting from chapter 5, every chapter come with some exercises at the end:

> **Exercise:** Tries can come in both mutable and immutable variants. Define an `ImmutableTrie` class that has the same methods as the `Trie` class we discussed in this chapter, but instead of a `def add` method it should take a sequence of strings during construction and construct the data structure without any use of `var`s or `mutable` collections.
>
> **See example 6.7 - ImmutableTrie**

The goal of these exercises is to synthesize what you learned in the chapter into useful skills. Some exercises ask you to write new code, others ask you to modify the code presented in the chapter, while others ask you to combine techniques from multiple chapters to achieve some outcome. These will help you consolidate what you learned and build a solid foundation that you can apply to future tasks and challenges.

The solutions to these exercises are also available online as executable code examples.

1.4.4 Resources

The last set of files in the `handsonscala/handsonscala` Github repository are the *resources*: sample data files that are used to exercise the code in a chapter. These are available at:

- https://github.com/handsonscala/handsonscala/blob/v2/resources

For the chapters that make use of these resource files, you can download them by going to the linked file on Github, clicking the `Raw` button to view the raw contents of the file in the browser, and then `Cmd-S`/`Ctrl-S` to save the file to your disk for your code to access.

1.4.5 Online Discussion

For further help or discussion about this book, feel free to visit the chapter-specific discussion threads, which will be linked to at the end of each chapter. You can use these threads to discuss topics specific to each chapter, without it getting mixed up in other discussion:

- http://www.handsonscala.com/discuss (listing of all chapter discussions)
- http://www.handsonscala.com/discuss/2 (chapter 2 discussion)

1.5 Conclusion

This first chapter should have given you an idea of what this book is about, and what you can expect working your way through it. Now that we have covered how this book works, we will proceed to set up your Scala development environment that you will be using for the rest of this book.

> **Discuss Chapter 1 online at https://www.handsonscala.com/discuss/1**

2

Setting Up


```
$ ./mill repl
Welcome to Scala
Type in expressions for evaluation. Or try :help.

> 1 + 1
res0: Int = 2

> println("hello world" + "!" * 10)
hello world!!!!!!!!!!
```
2.1.scala

Snippet 2.1: getting started with the Scala REPL

In this chapter, we will set up a simple Scala programming environment, giving you the ability to write, run, and test your Scala code. We will use this setup throughout the rest of the book. It will be a simple setup, but enough so you can get productive immediately with the Scala language.

Setting up your development environment is a crucial step in learning a new programming language. Make sure you get the setup in this chapter working. If you have issues, come to the online discussions at https://github.com/handsonscala/handsonscala/issues/2 to get help resolving them so you can proceed with the rest of the book in peace without tooling-related distractions.

2.1 Installing Mill

For the purposes of this book, we will be using the Mill build tool (mill-build.org) to build, run, and test our Scala code. Mill is the only command-line tool you need to work with Scala, typically combined with an IDE or editor like IntelliJ (*2.3.1*) or VSCode (*2.3.2*).

Mill can be installed locally in any folder by running:

Mac/Linux

```
> export REPO=https://repo1.maven.org/maven2/com/lihaoyi/mill-dist
> curl -L $REPO/1.1.3/mill-dist-1.1.3-mill.sh -o mill
> chmod +x mill
> ./mill version
1.1.3                                                    2.2.bash
```

Mill handles the downloading and caching of all necessary tools on your behalf: the JVM runtime, the Scala compiler and standard library, and any necessary third-party libraries. The `./mill` bootstrap script also ensures that once Mill is set up within your codebase it is available anywhere the codebase happens to be checked out: your laptop, your colleague's cloud devbox, or the machines running your CI cluster. Overall this saves us all the hassle of installing all components manually in every environment your code needs to run in.

2.1.1 Installing Java

While most of the examples in this book involve building and running your code within Mill, a few of them involve packaging your code in Mill but running it later outside. For that you need to install `java` on your machine, version 21 to be consistent with Mill's defaults. You can download the appropriate installer from any one of the following pages:

- https://adoptium.net/en-GB/temurin/releases?version=21
- https://downloads.corretto.aws/#/downloads?version=21&type=jdk

While other versions of Java may work, you should stick with version 21 to ensure compatibility with all the examples in this book, since different versions may cause subtle changes in behavior that would result in confusion and make it more difficult to follow along.

2.1.2 Windows Setup

If you are on Windows, the easiest way to follow along this book is to use the *Windows Subsystem for Linux 2* (WSL2) to provide a unix-like environment to run your code in. This can be done by following the documentation on the Microsoft website:

- https://docs.microsoft.com/en-us/windows/wsl/wsl2-install

WSL2 allows you to choose which Linux environment to host on your Windows computer. For this book, we will be using Ubuntu 18.04 LTS. Completing the setup, you should have a Ubuntu terminal open with a standard linux filesystem and your Windows filesystem available under the `/mnt/c/` folder:

```
$ cd /mnt/c

$ ls
'Documents and Settings'    PerfLogs        'Program Files (x86)'   Recovery
'Program Files'             ProgramData     Recovery.txt            Users
...
```
2.3.bash

The files in `/mnt/c/` are shared between your Windows environment and your Linux environment:

- You can edit your code on Windows, and run it through the terminal on Linux.
- You can generate files on disk on Linux, and view them in the Windows Explorer

From there, you should be able to run the *Mac/Linux* `curl` command above within WSL2 to set up your `./mill` script.

Many of the chapters in this book assume you are running your code in WSL2's Ubuntu/Linux environment, while graphical editors like IntelliJ or VSCode will need to be running on your Windows environment, and WSL2 allows you to swap between Linux and Windows seamlessly. While the Scala language can also be developed directly on Windows, using WSL2 will allow you to avoid compatibility issues and other distractions as you work through this book.

If you wish to install the `./mill` script directly on your Window environment, you may use the command below, which should work in a PowerShell terminal in Windows 10/11. This should work for the most Scala code examples, but the shell snippets such as `ls` or `find` that we make use of may have a different syntax on Windows, making it more difficult to follow along with the chapters that use them.

Windows

```
> $REPO = "https://repo1.maven.org/maven2/com/lihaoyi/mill-dist"
> curl.exe -L "$REPO/1.1.3/mill-dist-1.1.3-mill.bat" -o mill.bat
> ./mill version
1.1.3
```
2.4.bash

2.1.3 The Scala REPL

The Scala REPL is an interactive Scala command-line in which you can enter code expressions and have their result printed. It can be started via `./mill repl`

```
$ ./mill repl
Welcome to Scala
Type in expressions for evaluation. Or try :help.
> 1 + 1
res0: Int = 2

> "i am cow".substring(2, 4)
res1: String = "am"
```
2.5.scala

Invalid code prints an error:

```
> "i am cow".substing(2, 3)
-- [E008] Not Found Error: ----------------------------------------------------
1 |"i am cow".substing(2, 3)
  |^^^^^^^^^^^^^^^^^^
  |value substing is not a member of String -
  |did you mean ("i am cow" : String).substring?
```
2.6.scala

2.1.3.1 REPL Tab-Completion

You can use tab-completion after a `.` to display the available methods on a particular object, a partial method name to filter that listing, or a complete method name to display the method signatures:

```
> "i am cow".<tab>
exists                reduceLeftOption      toVector
filter                reduceOption          transform
filterNot             reduceRight           translateEscapes
find                  reduceRightOption     transpose
...

> "i am cow".sub<tab>
subSequence   substring

> "i am cow".substring<tab>
def substring(x$0: Int, x$1: Int): String
def substring(x$0: Int): String
```
2.7.scala

2.1.3.2 Interrupting REPL Code

If a REPL command is taking too long to run, you can kill it via `Ctrl-C`:

```
> while true do { Thread.sleep(1000); println(1 + 1) } // loop forever
2
2
2
^C
Attempting to interrupt...
java.lang.InterruptedException: sleep interrupted
  at java.base/java.lang.Thread.sleep0(Native Method)
  at java.base/java.lang.Thread.sleep(Thread.java:509)
  ... 30 elided

>
```
2.8.scala

2.1.4 Scala Scripts

In addition to providing a REPL, Mill can run Scala Script files. A Scala Script is any file containing Scala code, ending in `.scala`. Scala Scripts are a lightweight way of running Scala code that is more convenient, though less configurable, than using a fully-featured build tool like Mill.

For now, you can create the following file `myScript.scala`, using any text editor of your choice (Vim, Sublime Text, VSCode, Notepad, etc.). We will explore setting up a more feature-rich IDE later in IDE Support (*2.3*).

myScript.scala

```
def main() =
    println(1 + 1) // 2

    println("hello" + " " + "world") // hello world

    println(List("I", "am", "cow")) // List(I, am, cow)
```

2.9.scala

Note that in scripts, you need to `println` each expression since scripts do not echo out their values. After that, you can then run the script via `./mill myScript.scala`:

```
$ ./mill myScript.scala
2
hello world
List(I, am, cow)
```

2.10.bash

The first time you run the script file, it will take a moment to compile the script to an executable. Subsequent runs will be faster since the script is already compiled.

2.1.4.1 Watching Scripts

If you are working on a single script, you can use the `./mill -w` or `./mill --watch` command to watch a script and re-run it when things change:

```
$ ./mill -w myScript.scala
2
hello world
List(I, am, cow)
Watching for changes... (Enter to re-run, Ctrl+C to exit)
```

2.11.bash

Now whenever you make changes to the script file, it will automatically get re-compiled and re-run. This is much faster than running it over and over manually, and is convenient when you are actively working on a single script to try and get it right.

You can edit your Scala scripts with whatever editor you feel comfortable with: IntelliJ (*2.3.1*), VSCode (*2.3.2*), or any other text editor.

2.1.4.2 Script Main Methods

Scripts that are run directly need to start in a MainArgs `def main()` method, which can optionally take parameters that the user passes from the command line:

```
def main(myArg: String, myOtherArg: Int) =
    println("hello" + " " + myOtherArg)

    println(myOtherArg + myOtherArg)
```
myScript.scala

2.12.scala

```
$ ./mill myScript.scala
Missing arguments: --my-arg <str> --my-other-arg <int>
Expected Signature: main
  --my-arg <str>
  --my-other-arg <int>

$ ./mill myScript.scala --my-arg "mooo" --my-other-arg 7
hello mooo
14
```
2.13.bash

2.1.5 Using Scripts from the REPL

You can open up a REPL with access to the functions in a Scala file by running the `:repl` command on the specific script file. For example, given the following definition:

```
def hello(n: Int) =
    "hello world" + "!" * n
```
hello.scala

2.14.scala

You can then open a REPL with access to it as follows:

```
$ ./mill hello.scala:repl
> hello(12)
res0: String = "hello world!!!!!!!!!!!!"
```
2.15.bash

Things to note:

- If you make changes to the script file, you need to exit the REPL using `Ctrl-D` and re-open it to make use of the modified script.

You can also combine `:repl` with `--watch`/`-w`:

```
$ ./mill -w hello.scala:repl
```

In which case when you exit with `Ctrl-D` it will automatically restart the REPL if the script file has changed.

2.1.6 Mill Projects

Apart from supporting a REPL and small scripts, Mill can also be used for larger projects. The easiest way to get started with Mill is to download an example project:

```
$ export REPO=https://repo1.maven.org/maven2/com/lihaoyi/mill-dist/1.1.3

$ export FILENAME=mill-dist-1.1.3-example-scalalib-basic-6-programmable

$ curl -L "$REPO/$FILENAME.zip" -o "$FILENAME.zip"

$ unzip "$FILENAME.zip" && rm "$FILENAME.zip"

$ mv $FILENAME/* . && rm -r $FILENAME

$ find . -type f
./build.mill
./mill
./foo/src/Foo.scala
./foo/test/src/FooTests.scala
./mill.bat
```

2.16.bash

You can see that the example project has 8 files (5 that we will focus on now). A `build.mill` file that contains the project definition, defining a module `foo` with a test module `test` inside:

build.mill

```
package build
import mill.*, scalalib.*

object foo extends ScalaModule {
    def scalaVersion = "3.7.1"
    def mvnDeps = Seq(
        mvn"com.lihaoyi::scalatags:0.13.1",
        mvn"com.lihaoyi::mainargs:0.7.8"
    )

    object test extends ScalaTests {
        def mvnDeps = Seq(mvn"com.lihaoyi::utest:0.9.4")
        def testFramework = "utest.runner.Framework"
    }
}
```

2.17.scala

The `test` module definition above comes with a dependency on one third party library: `mvn"com.lihaoyi::utest:0.9.4"`. We will see other libraries as we progress through the book and how to use them in our Mill projects.

The Scala code for the `foo` module lives inside the `foo/src/` folder:

foo/src/Foo.scala

```
package foo
import scalatags.Text.all.*
import mainargs.{main, Parser}

object Foo {
    def generateHtml(text: String) = {
        h1(text).toString
    }

    def main(text: String) = {
        println(generateHtml(text))
    }

    def main(args: Array[String]): Unit = Parser(this).runOrExit(args)
}
```

2.18.scala

While the Scala code for the `foo.test` test module lives inside the `foo/test/src/` folder:

foo/test/src/FooTests.scala

```
package foo

import utest.*

object FooTests extends TestSuite {
    def tests = Tests {
        test("simple") {
            val result = Foo.generateHtml("hello")
            assert(result == "<h1>hello</h1>")
            result
        }
        test("escaping") {
            val result = Foo.generateHtml("<hello>")
            assert(result == "<h1>&lt;hello&gt;</h1>")
            result
        }
    }
}
```

2.19.scala

Lastly, the example project contains a `mill` executable file (`mill.bat` for Windows). You can use this file as a launcher to compile and run the project, via `./mill ...`:

```
$ ./mill foo.compile
compiling 3 Scala sources to out/mill-build/compile.dest/classes ...

$ ./mill foo.run --text hello
<h1>hello</h1>
```
2.20.bash

While above we run both `./mill foo.compile` and `./mill foo.run`, if you want to run your code you can always just run `./mill foo.run`. Mill will automatically re-compile your code if necessary before running it.

To use Mill in any other project, or to start a brand-new project using Mill, it is enough to copy over the `mill` script file to that project's root directory, or to download it again using the `curl` command we used earlier.

2.1.7 Running Unit Tests

To get started with testing in Mill, you can run `./mill foo.test`:

```
$ ./mill foo.test
120] foo.test.compile compiling 1 Scala source to out/foo/test/compile.dest/classes ...
120] done compiling
127] foo.test.testForked Running Test Class foo.FooTests
127] ------------------------------ Running Tests ------------------------------
127] + foo.FooTests.simple 20ms  <h1>hello</h1>
127] + foo.FooTests.escaping 0ms  <h1>&lt;hello&gt;</h1>
127] Tests: 2, Passed: 2, Failed: 0
127/127] ============================== foo.test ============================== 1s
```
2.21.bash

This shows the successful result of the one test that comes built in to the example repository.

2.1.8 Creating a Stand-Alone Executable

So far, we have only been running code within the Mill build tool. But what if we want to prepare our code to run without Mill, e.g. to deploy it to production systems? To do so, you can run `./mill foo.assembly` to to create an `out.jar` file that can be distributed, deployed and run without the Mill build tool in place. By default, Mill creates the output for the `foo.assembly` task in `out/foo/assembly.dest`, but you can use `./mill show` to print out the full path:

```
$ ./mill show foo.assembly
".../out/foo/assembly.dest/out.jar"
```
2.22.scala

You can run the executable assembly to verify that it does what you expect. Note that this requires to run the `foo.assembly` task first.

```
$ out/foo/assembly.dest/out.jar --text hello
<h1>hello</h1>
```
2.23.bash

In general, running Scala code in a Mill project requires a bit more setup than running it interactively in the Scala REPL or Scala Scripts, but the ability to easily test and package your code is crucial for any production software.

2.2 (Optional) Scala-CLI

An alternative to using `./mill` for the Scala REPL and scripts is Scala-CLI, which can be installed from the following URL:

- http://scala-cli.virtuslab.org/

Scala-CLI can be used to run the REPL via the `scala` command:

```
$ scala
Welcome to Scala 3.8.1

scala> 1 + 1
val res0: Int = 2
```
2.24.scala

Or run scripts from the command line:

```
$ cat foo.scala
def main(args: Array[String]): Unit = {
    println("Hello World")
}

$ scala foo.scala
Hello World
```
2.25.scala

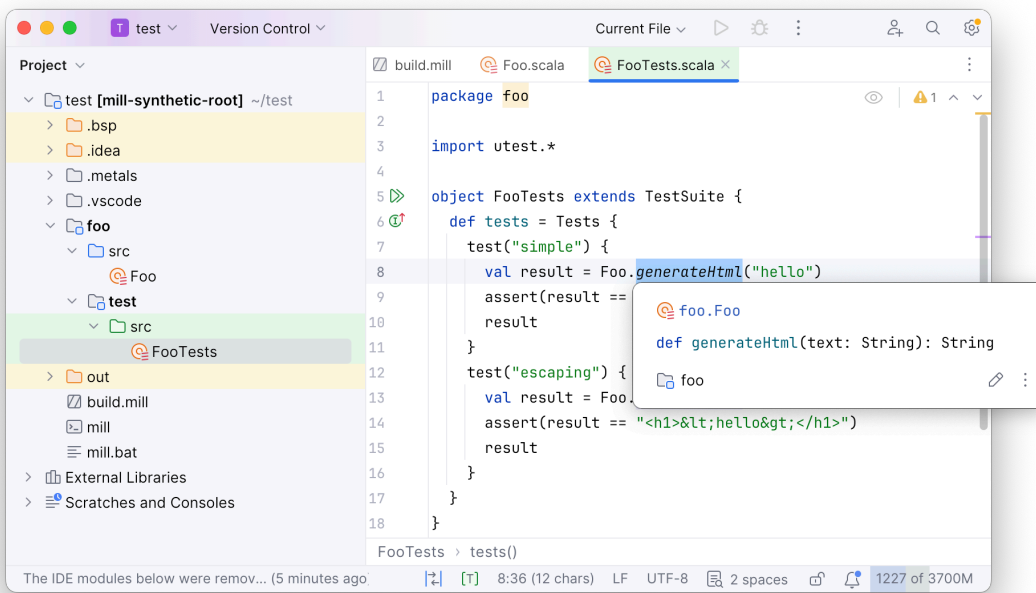
Note that Scala-CLI's scripts and REPL have a slightly different set of default libraries than Mill's scripts and REPL, so you may need to include libraries manually via the `--dependency` flag in the REPL or `//> using dep` clauses in scripts.

2.3 IDE Support

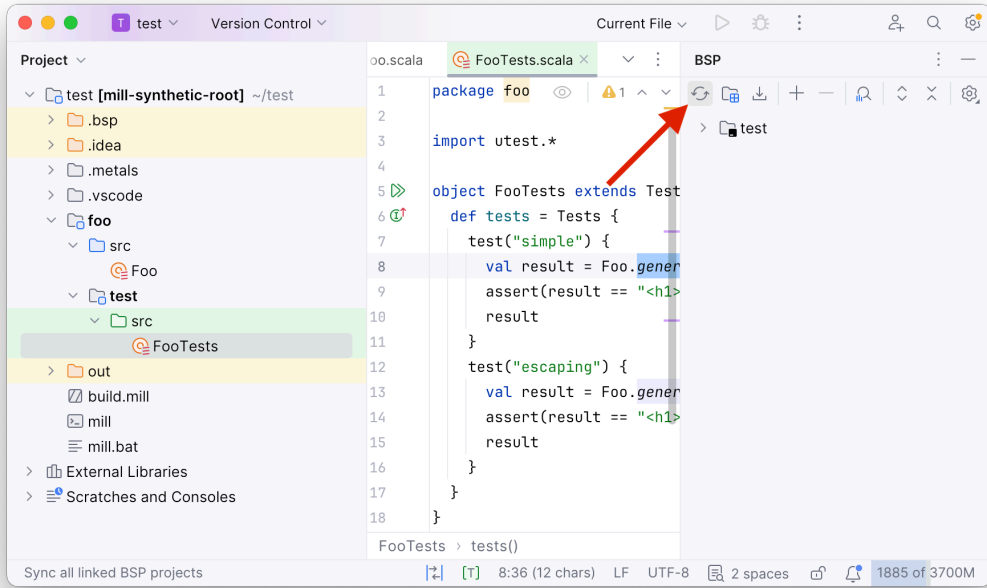
2.3.1 Installing IntelliJ for Scala

To use Mill with IntelliJ, first ensure you have the free IntelliJ Scala Plugin installed. This is necessary as Mill build files are written in Scala, even if you are using it to build a Java or Kotlin project.

Once you have the plugin installed, you can use IntelliJ to open any project containing a Mill `build.mill` file, and IntelliJ will automatically load the Mill build. This will provide support both for your application code, as well as the code in the `build.mill`. You can try this on the example Mill project you downloaded earlier in the section Mill Projects (*2.1.6*):



If you make changes to your Mill `build.mill`, you can ask Intellij to load those updates by opening the "BSP" tab and clicking the "Refresh" button

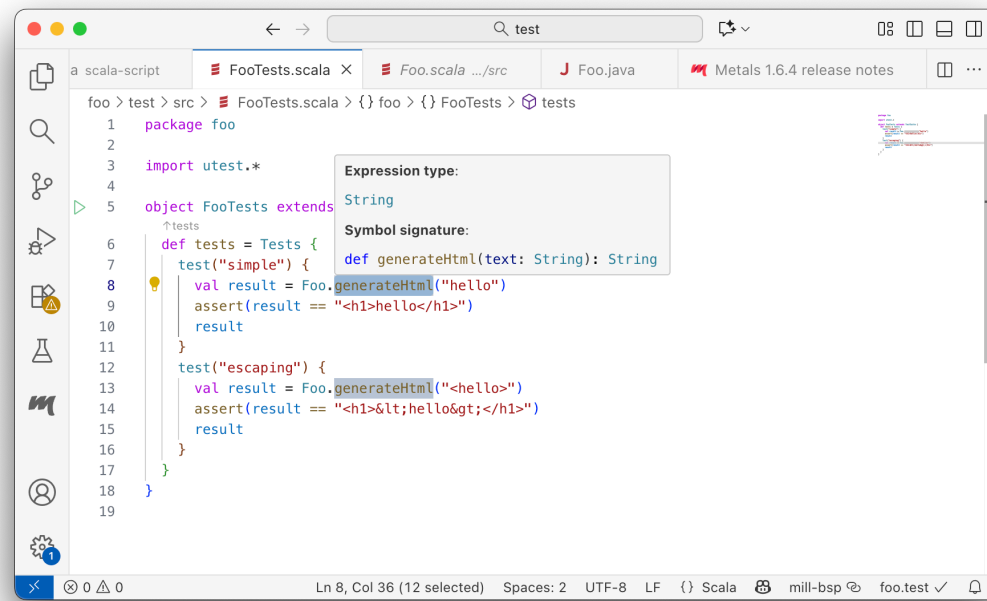


In general, you may need to refresh IntelliJ any time you make changes to the build configuration of the project: adding or removing dependencies to `build.mill`, creating new Scala Scripts (*2.1.4*) or changing the dependencies of those scripts.

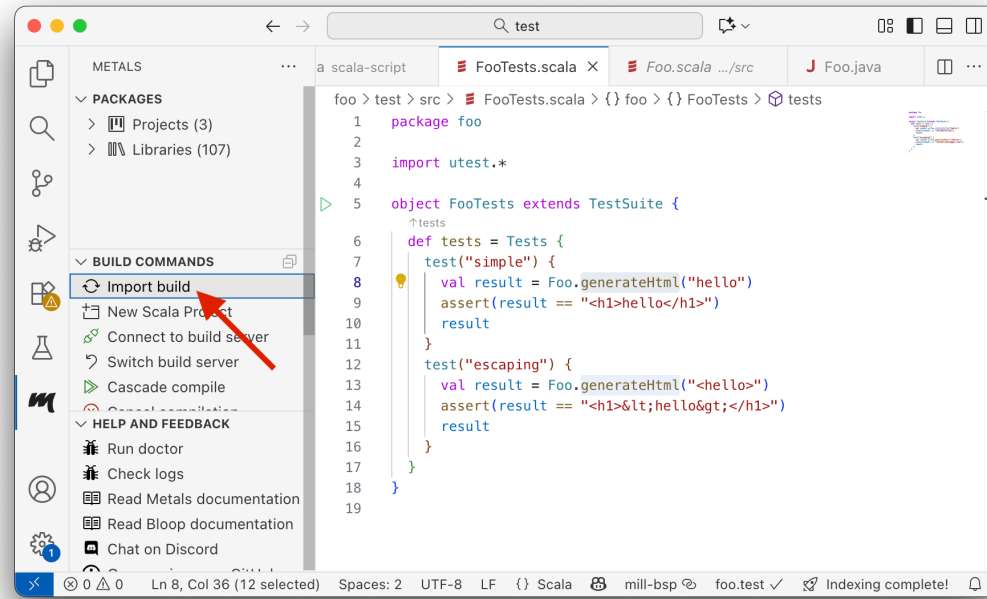
2.3.2 Visual Studio Code Support

To use Mill with VSCode, first ensure you have the free Metals VSCode Scala language server installed. This is necessary as Mill build files are written in Scala, even if you are using it to build a Java project.

Once you have the language server installed, you can ask VSCode to open any folder containing a Mill `build.mill` file, and VSCode will ask you to import your Mill build. This will provide support both for your application code, as well as the code in the `build.mill`:



If you make changes to your Mill `build.mill`, you can ask VSCode to load those updates by opening the "Metals" tab and clicking the "Import build" button.



Like IntelliJ, you need to re-import the build into VSCode any time you make changes to build configuration: changing dependencies, new modules, creating new scripts

Metals also supports other editors such as Vim, Sublime Text, Atom, and others. For more details, refer to their documentation for how to install the relevant editor plugin:

- https://scalameta.org/metals/docs/editors/overview.html

2.4 Conclusion

By now, you should have three main things set up:

- Your `./mill` or `./mill.bat` bootstrap script, to run `./mill repl`, or `./mill myScript.scala`
- A Mill example project, which you can run via `./mill foo.run` or test via `./mill foo.test`
- Either IntelliJ or VSCode support for your Mill example projects

We will be using Mill as the primary build tool throughout this book. Before you move on to the following chapters, take some time to experiment with these tools: write some code in the Scala REPL, create some more scripts, add code and tests to the Mill example projects and run them. These are the main tools that we will use throughout this book.

Discuss Chapter 2 online at https://www.handsonscala.com/discuss/2

3

Basic Scala


```
for i <- Range.inclusive(1, 100) do
    println(
        if i % 3 == 0 && i % 5 == 0
        then "FizzBuzz"
        else if i % 3 == 0 then "Fizz"
        else if i % 5 == 0 then "Buzz"
        else i
    )
```
3.1.scala

Snippet 3.1: the popular "FizzBuzz" programming challenge, implemented in Scala

This chapter is a quick tour of the Scala language. For now we will focus on the basics of Scala that are similar to what you might find in any mainstream programming language.

The goal of this chapter is to get you familiar enough that you can take the same sort of code you are used to writing in some other language and write it in Scala without difficulty. This chapter will not cover more Scala-specific programming styles or language features: those will be left for ***Chapter 5: Notable Scala Features***.

For this chapter, we will write our code in the Scala REPL:

```
$ ./mill repl
Welcome to Scala
Type in expressions for evaluation. Or try :help.

scala>
```
3.2.bash

3.1 Values

3.1.1 Primitives

Scala has the following sets of primitive types:

Type	Values
`Byte`	`-128` to `127`
`Short`	`-32,768` to `32,767`
`Int`	`-2,147,483,648` to `2,147,483,647`
`Long`	`-9,223,372,036,854,775,808` to `9,223,372,036,854,775,807`

Type	Values
`Boolean`	`true`, `false`
`Char`	`'a'`, `'0'`, `'Z'`, `'包'`, ...
`Float`	32-bit Floating point
`Double`	64-bit Floating point

These types are identical to the primitive types in Java, and would be similar to those in C#, C++, or any other statically typed programming language. Each type supports the typical operations, e.g. booleans support boolean logic `||` `&&`, numbers support arithmetic `+` `-` `*` `/` and bitwise operations `|` `&`, and so on. All values support `==` to check for equality and `!=` to check for inequality.

Numbers default to 32-bit `Int`s. Precedence for arithmetic operations follows other programming languages: `*` and `/` have higher precedence than `+` or `-`, and parentheses can be used for grouping.

```
> 1 + 2 * 3
res0: Int = 7
```
3.3.scala

```
> (1 + 2) * 3
res1: Int = 9
```
3.4.scala

`Int`s are signed and wrap-around on overflow, while 64-bit `Long`s suffixed with `L` have a bigger range and do not overflow as easily:

```
> 2147483647
res2: Int = 2147483647

> 2147483647 + 1
res3: Int = -2147483648 // negative
```
3.5.scala

```
> 2147483647L
res4: Long = 2147483647L

> 2147483647L + 1L
res5: Long = 2147483648L // positive
```
3.6.scala

Apart from the basic operators, there are a lot of useful methods on `java.lang.Integer` and `java.lang.Long`:

```
> java.lang.Integer.<tab>
BYTES                   decode                  numberOfTrailingZeros
signum                  MAX_VALUE               divideUnsigned
getInteger              parseUnsignedInt        toBinaryString
...

> java.lang.Integer.toBinaryString(123)
res6: String = "1111011"

> java.lang.Integer.numberOfTrailingZeros(24)
res7: Int = 3
```
3.7.scala

64-bit `Double`s are specified using the `1.0` syntax, and have a similar set of arithmetic operations. You can also use the `1.0F` syntax to ask for 32-bit `Float`s:

```
> 1.0 / 3.0
res8: Double = 0.3333333333333333
```
3.8.scala

```
> 1.0F / 3.0F
res9: Float = 0.33333334F
```
3.9.scala

32-bit `Float`s take up half as much memory as 64-bit `Double`s, but are more prone to rounding errors during arithmetic operations. `java.lang.Float` and `java.lang.Double` have a similar set of useful operations you can perform on `Float`s and `Double`s.

3.1.2 Strings

`String`s in Scala are arrays of 16-bit `Char`s:

```
> "hello world"
res10: String = "hello world"
```
3.10.scala

`String`s can be sliced with `.substring`, constructed via concatenation using `+`, or via string interpolation by prefixing the literal with `s"..."` and interpolating the values with `$` or `${...}`:

```
> "hello world".substring(0, 5)
res11: String = "hello"

> "hello world".substring(5, 10)
res12: String = " worl"
```
3.11.scala

```
> "hello" + 1 + " " + "world" + 2
res13: String = "hello1 world2"

> val x = 1; val y = 2

> s"Hello $x World $y"
res15: String = "Hello 1 World 2"

> s"Hello ${x + y} World ${x - y}"
res16: String = "Hello 3 World -1"
```
3.12.scala

3.1.3 Local Values and Variables

You can name local values with the `val` keyword:

```
> val x = 1

> x + 2
res18: Int = 3
```
3.13.scala

Note that `val`s are immutable: you cannot re-assign the `val x` to a different value after the fact. If you want a local variable that can be re-assigned, you must use the `var` keyword.

```
> x = 3
-- [E052] Type Error: ------------------
1 |x = 3
  |^^^^^
  |Reassignment to val x
```
3.14.scala

```
> var y = 1

> y + 2
res20: Int = 3

> y = 3

> y + 2
res22: Int = 5
```
3.15.scala

In general, you should try to use `val` where possible: most named values in your program likely do not need to be re-assigned, and using `val` helps prevent mistakes where you re-assign something accidentally. Use `var` only if you are sure you will need to re-assign something later.

Both `val`s and `var`s can be annotated with explicit types. These can serve as documentation for people reading your code, as well as a way to catch errors if you accidentally assign the wrong type of value to a variable

```
> val x: Int = 1

> var s: String = "Hello"

> s = "World" // OK
```
3.16.scala

```
> val z: Int = "Hello" // Not OK
-- [E007] Type Mismatch Error: ---------
1 |val z: Int = "Hello"
  |             ^^^^^^^
  |        Found:    ("Hello" : String)
  |        Required: Int
```
3.17.scala

3.1.4 Tuples

Tuples are fixed-length collections of values, which may be of different types:

```
> val t = (1, true, "hello")
t: (Int, Boolean, String) = (1, true, "hello")
```

3.18.scala

```
> t(0)
res27: Int = 1

> t(1)
res28: Boolean = true

> t(2)
res29: String = "hello"
```

3.19.scala

Above, we are storing a tuple into the local value `t` using the `(a, b, c)` syntax, and then accessing the fields by their index to extract the values out of it, using the syntax `t(0)`, `t(1)` and `t(2)`. The fields in a tuple are immutable.

The type of the local value `t` can be annotated as a tuple type:

```
> val t: (Int, Boolean, String) = (1, true, "hello")
```

You can also use the `val (a, b, c) = t` syntax to extract all the values at once, and assign them to meaningful names:

```
> val (a, b, c) = t
a: Int = 1
b: Boolean = true
c: String = "hello"
```

3.20.scala

```
> a
res31: Int = 1

> b
res32: Boolean = true

> c
res33: String = "hello"
```

3.21.scala

Tuples can be any size, up to the maximum 32-bit signed integer:

```
> val t = (1, true, "hello", 'c', 0.2, 0.5f)
t: (Int, Boolean, String, Char, Double, Float) = (1, true, "hello", 'c', 0.2, 0.5F)
```

3.22.scala

Most tuples should be relatively small. Large tuples can easily get confusing: while working with `t(0)` `t(1)` and `t(2)` is probably fine, when you end up working with `t(10)` `t(12)` it becomes easy to mix up the different fields. If you find yourself working with large tuples, consider defining a Class (3.4) or Case Class that we will see in ***Chapter 5: Notable Scala Features***.

3.1.5 Arrays

Arrays are fixed-length collections of values, which are all of the same type, and are instantiated using the `Array[T](a, b, c)` syntax. Entries within each array are retrieved using `a(n)`:

```
> val a = Array[Int](1, 2, 3, 4)

> a(0) // first entry, array indices start from 0
res36: Int = 1

> a(3) // last entry
res37: Int = 4

> val a2 = Array[String]("one", "two", "three", "four")

> a2(1) // second entry
res39: String = "two"
```

3.23.scala

The type parameter inside the square brackets `[Int]` or `[String]` determines the type of the array, while the parameters inside the parenthesis `(1, 2, 3, 4)` determine its initial contents. Note that looking up an Array by index is done via parentheses `a(3)` rather than square brackets `a[3]` as is common in many other programming languages.

You can omit the explicit type parameter and let the compiler infer the Array's type, or create an array of a specified length and type using `new Array[T](length)`, and assign values to each index later:

```
> val a = Array(1, 2, 3, 4)
a: Array[Int] = Array(1, 2, 3, 4)

> val a2 = Array(
      "one", "two",
      "three", "four"
  )
a2: Array[String] = Array(
    "one", "two",
    "three", "four"
)
```

3.24.scala

```
> val a = new Array[Int](4)
a: Array[Int] = Array(0, 0, 0, 0)

> a(0) = 1

> a(2) = 100

> a
res45: Array[Int] = Array(1, 0, 100, 0)
```

3.25.scala

For `Array`s created using `new Array`, all entries start off with default values (`0` for numeric arrays, `false` for `Boolean` arrays, and `null` for `String`s and other types). `Array`s are mutable and fixed-length: you can change the value of each entry but cannot change the number of entries by adding or removing values. We will see how to create variable-length collections later in ***Chapter 4: Scala Collections***.

3.1.5.1 Multi-Dimensional Arrays

Multi-dimensional arrays are typically modeled as arrays-of-arrays:

```
> val multi = Array(Array(1, 2), Array(3, 4))
multi: Array[Array[Int]] = Array(Array(1, 2), Array(3, 4))

> multi(0)(0)
res47: Int = 1

> multi(0)(1)
res48: Int = 2

> multi(1)(0)
res49: Int = 3

> multi(1)(1)
res50: Int = 4
```

3.26.scala

Multi-dimensional arrays can be useful to represent grids, matrices, and similar values.

3.1.5.2 Array and Collection Operations

Arrays and other collections support a lot of methods that are useful for working with them: transforming, filtering, aggregating, etc. A few of these are shown below:

```
> val arr = Array(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)

> arr.filter(_ % 2 == 0)
res1: Array[Int] = Array(2, 4, 6, 8, 10)

> arr.filter(_ % 2 == 0).map(_ * 10)
res2: Array[Int] = Array(20, 40, 60, 80, 100)

> arr.filter(_ % 2 == 0).map(_ * 10).mkString(" ")
res3: String = "20 40 60 80 100"

> arr.filter(_ % 2 == 0).map(_ * 10).sum
res4: Int = 300

> arr.filter(_ % 2 == 0).map(_ * 10).reduce(_ * _)
res5: Int = 384000000
```

3.27.scala

In general, when working with arrays and collections, it is preferable to use these collection operations rather than constructing them from scratch via loops and assignment. We discuss these in more detail in ***Chapter 4: Scala Collections***.

3.1.6 Options

Scala's `Option[T]` type allows you to represent a value that may or may not exist. An `Option[T]` can either be `Some(v: T)` indicating that a value is present, or `None` indicating that it is absent:

```
> def hello(title: String, firstName: String, lastNameOpt: Option[String]) =
      lastNameOpt match
          case Some(lastName) => println(s"Hello $title. $lastName")
          case None => println(s"Hello $firstName")

> hello("Mr", "Haoyi", None)
Hello Haoyi

> hello("Mr", "Haoyi", Some("Li"))
Hello Mr. Li
```
3.28.scala

The above example shows you how to construct `Option`s using `Some` and `None`, as well as `match`ing on them in the same way. Many APIs in Scala rely on `Option`s rather than `null`s for values that may or may not exist. In general, `Option`s force you to handle both cases of present/absent, whereas when using `null`s it is easy to forget whether or not a value is null-able, resulting in confusing `NullPointerException`s at runtime. We will go deeper into pattern matching in ***Chapter 5: Notable Scala Features***.

`Option`s contain some helper methods that make it easy to work with the optional value, such as `getOrElse`, which substitutes an alternate value if the `Option` is `None`:

```
> Some("Li").getOrElse("<unknown>")
res54: String = "Li"
```
3.29.scala

```
> None.getOrElse("<unknown>")
res55: String = "<unknown>"
```
3.30.scala

`Option`s are very similar to a collection whose size is `0` or `1`. You can loop over them like normal collections, or transform them with standard collection operations like `.map`. We will learn more about collection operations in ***Chapter 4: Scala Collections***.

```
> def hi(name: Option[String]) =
      for s <- name do println(s"Hi $s")

> hi(None) // does nothing

> hi(Some("Haoyi"))
Hi Haoyi
```
3.31.scala

```
> def count(name: Option[String]) =
      name.map(_.length).getOrElse(-1)

> count(Some("Haoyi"))
res60: Int = 5

> count(None)
res61: Int = -1
```
3.32.scala

See example 3.1 - Values

3.2 Loops, Conditionals, Comprehensions

3.2.1 For-Loops

For-loops in Scala are similar to "foreach" loops in other languages: they directly loop over the elements in a collection, without needing to explicitly maintain and increment an index. If you want to loop over a range of indices, you can loop over a `Range` such as `Range(0, 4)`:

```
> var total = 0

> val nums = Array(1, 10, 100, 1000)

> for num <- nums do total += num

> total
res65: Int = 1111
```

3.33.scala

```
> var total = 0

> for i <- Range(0, 4) do
      println("Looping " + i)
      total = total + i
Looping 0
Looping 1
Looping 2
Looping 3

> total
res68: Int = 6
```

3.34.scala

The default `Range` is left-inclusive right-exclusive, and so does not loop over the value `4` in the example above. If you want to loop over a right-inclusive range, you can use `Range.inclusive`:

```
> for i <- Range.inclusive(0, 4) do println(i) // Range.inclusive(0, 4) includes 4
...
4
```

3.35.scala

You can loop over nested `Array`s or nested `Range`s by placing multiple `<-`s in the header of the loop, either on the same line or multiple lines, and add `if` guards to run the loop on only a subset of the elements:

```
> val multi = Array(Array(1, 2, 3), Array(4, 5, 6))
```

```
> for arr <- multi; i <- arr
  do println(i)
1
2
3
4
5
6
```

3.36.scala

```
> for
      arr <- multi
      i <- arr
      if i % 2 == 0
  do println(i)
2
4
6
```

3.37.scala

3.2.2 If-Else

`if-else` conditionals are similar to those in any other programming language. One thing to note is that in Scala `if-else` can also be used as an expression, similar to the `a ? b : c` ternary expressions in other languages. Scala does not have a separate ternary expression syntax, and so the `if-else` can be directly used as the right-hand-side of the `total +=` below.

```
> var total = 0

> for i <- Range(0, 10) do
      if i % 2 == 0 then total += i
      else total += 2

> total
res74: Int = 30
```
3.38.scala

```
> var total = 0

> for i <- Range(0, 10) do
      total += (if i % 2 == 0 then i else 2)

> total
res77: Int = 30
```
3.39.scala

3.2.3 Fizzbuzz

Now that we know the basics of Scala syntax, let's consider the common "Fizzbuzz" programming challenge:

> *Write a short program that prints each number from 1 to 100 on a new line.*
>
> *For each multiple of 3, print "Fizz", for each multiple of 5, print "Buzz".*
>
> *For numbers which are multiples of both 3 and 5, print "FizzBuzz" instead of the number.*

We can accomplish this as follows:

```
> for i <- Range.inclusive(1, 100) do
      if i % 3 == 0 && i % 5 == 0 then println("FizzBuzz")
      else if i % 3 == 0 then println("Fizz")
      else if i % 5 == 0 then println("Buzz")
      else println(i)
```
3.40.scala

Since `if-else` is an expression, we can also write it inside the `println`, or assign it to a local `val` within the loop which you then pass to `println`:

```
for i <- Range.inclusive(1, 100) do
    println(
        if i % 3 == 0 && i % 5 == 0
        then "FizzBuzz"
        else if i % 3 == 0 then "Fizz"
        else if i % 5 == 0 then "Buzz"
        else i
    )
```
3.41.scala

```
for i <- Range.inclusive(1, 100) do
    val message =
        if i % 3 == 0 && i % 5 == 0
        then "FizzBuzz"
        else if i % 3 == 0 then "Fizz"
        else if i % 5 == 0 then "Buzz"
        else i

    println(message)
```
3.42.scala

3.2.4 Comprehensions

Apart from using `for` to define loops that perform some action, you can also use `for` together with `yield` to transform a collection into a new collection:

```
> val a = Array(1, 2, 3, 4)

> val a3 = for i <- a yield "hello " + i
a3: Array[String] = Array("hello 1", "hello 2", "hello 3", "hello 4")
```
3.43.scala

Similar to loops, you can filter which items end up in the final collection using an `if` guard:

```
> val a4 = for i <- a if i % 2 == 0 yield "hello " + i
a4: Array[String] = Array("hello 2", "hello 4")
```
3.44.scala

Like loops, comprehensions are useful for combining multiple input arrays into a final flat array. you can either put each `a <- b` generator on the same line, separated by `;`, or spread over multiple lines for easier reading. Note that the order of `<-`s within the nested comprehension matters, just like how the order of nested loops affects the order in which the loop actions will take place:

```
val flattened = for
    i <- Array(1, 2)
    s <- Array("hello", "world")
    if s + i != "world2"
yield s + i
```
3.45.scala

```
flattened: Array[String] = Array(
    "hello1",
    "world1",
    "hello2"
)
```
3.46.output-scala

```
val flattened2 = for
    s <- Array("hello", "world")
    i <- Array(1, 2)
    if s + i != "world2"
yield s + i
```
3.47.scala

```
flattened2: Array[String] = Array(
    "hello1",
    "hello2",
    "world1"
)
```
3.48.output-scala

We can use comprehensions to write a version of FizzBuzz that doesn't print its results immediately to the console, but returns them as a `Seq` (short for "sequence"):

```
val fizzbuzz =
    for i <- Range.inclusive(1, 100) yield
        if i % 3 == 0 && i % 5 == 0
        then "FizzBuzz"
        else if i % 3 == 0 then "Fizz"
        else if i % 5 == 0 then "Buzz"
        else i.toString
```
3.49.scala

```
fizzbuzz: IndexedSeq[String] = Vector(
    "1",
    "2",
    "Fizz",
    "4",
    "Buzz"...
```
3.50.output-scala

See example 3.2 - LoopsConditionals

3.3 Methods and Functions

3.3.1 Methods

You can define methods using the `def` keyword:

```
> def printHello(times: Int) =
      println("hello " + times)
```
3.51.scala

```
> printHello(1)
hello 1

> printHello(times = 2) // explicit param name
hello 2
```
3.52.scala

Passing in the wrong type of argument, or missing required arguments, is a compiler error:

```
> printHello("1")
-- [E007] Type Mismatch Error: ---------
1 |printHello("1")
  |           ^^^
  |           Found:    ("1" : String)
  |           Required: Int
```
3.53.scala

```
> printHello()
-- [E171] Type Error: ----------------------
1 |printHello()
  |^^^^^^^^^^^^
  |missing argument for parameter times of
  |method printHello: (times: Int): Unit
```
3.54.scala

However, if the argument has a default value, then passing it is optional.

```
> def printHello2(times: Int = 0) =
      println("hello " + times)
```
3.55.scala

```
> printHello2(1)
hello 1

> printHello2()
hello 0
```
3.56.scala

3.3.1.1 Returning Values from Methods

Apart from performing actions like printing, methods can also return values. The last expression within an indented block is treated as the return value of a Scala method. There is also a `return` keyword, but is typically not used except for special circumstances:

```
> def hello(i: Int = 0): String =
      val word = "hello"
      val space = " "
      // last expression is returned
      word + space + i
```
3.57.scala

```
> def hello(i: Int = 0): String =
      val word = "hello"
      val space = " "
      // explicit return
      return word + space + i
```
3.58.scala

You can call the method and print out or perform other computation on the returned value:

```
> hello(1)
res96: String = "hello 1"

> println(hello())
hello 0
```
3.59.scala

```
> val twoHellos = hello(123) + " " + hello(456)
twoHellos: String = "hello 123 hello 456"

> twoHellos.reverse
res99: String = "654 olleh 321 olleh"
```
3.60.scala

3.3.2 Function Values

You can define function values using the `=>` syntax. Functions values are similar to methods, in that you call them with arguments and they can perform some action or return some value. Unlike methods, functions themselves are values: you can pass them around, store them in variables, and call them later.

```
> var g: Int => Int = i => i + 1

> g(10)
res101: Int = 11
```
3.61.scala

```
> g = i => i * 2 // re-assigning `g`

> g(10)
res103: Int = 20
```
3.62.scala

Note that unlike methods, function values cannot have optional arguments (i.e. with default values). When a method is converted into a function value (by assigning a method to a `val`), any optional arguments must be explicitly included, and any type parameters must be fixed to concrete types. Function values are also anonymous, which makes stack traces involving them less convenient to read than those using methods.

In general, you should prefer using methods unless you really need the flexibility to pass as parameters or store them in variables. But if you need that flexibility, function values are a great tool to have.

3.3.2.1 Methods taking Functions

One common use case of function values is to pass them into methods that take function parameters. Such methods are often called "higher order methods". Below, we have a class `Box` with a method `printMsg` that prints its contents (an `Int`), and a separate method `update` that takes a function of type `Int => Int` that can be used to update `x`. You can then pass a function literal into `update` in order to change the value of `x`:

```
> class Box(var x: Int):
      def update(f: Int => Int) =
          x = f(x)
      def printMsg(msg: String) =
          println(msg + x)
```
3.63.scala

```
> val b = Box(1)

> b.printMsg("Hello")
Hello1

> b.update(i => i + 5)

> b.printMsg("Hello")
Hello6
```
3.64.scala

Simple functions literals like `i => i + 5` can also be written via the shorthand `_ + 5`, with the underscore `_` standing in for the function parameter.

```
> b.update(_ + 5)

> b.printMsg("Hello")
Hello11
```
3.65.scala

This placeholder syntax for function literals also works for multi-argument functions, e.g. `(x, y) => x + y` can be written as `_ + _`.

Any method that takes a function as an argument can also be given a method reference, as long as the method's signature matches that of the function type, here `Int => Int`:

```
> def increment(i: Int) = i + 1

> val b = Box(123)

> b.update(increment) // Providing a method reference

> b.update(x => increment(x)) // Explicitly writing out the function literal

> b.update: x => // can pass a lambda without parens or braces
      increment(x)

> b.update(increment(_)) // You can also use the `_` placeholder syntax

> b.printMsg("result: ")
result: 127
```
3.66.scala

3.3.3 Multiple Parameter Lists

Methods can be defined to take multiple parameter lists. This is useful for writing higher-order methods that can be used like control structures, such as the `loop` method below:

```
> def loop(start: Int, end: Int)(callback: Int => Unit) =
      for i <- Range(start, end) do callback(i)

> loop(start = 5, end = 8): i =>
      println(s"i has value ${i}")
i has value 5
i has value 6
i has value 7
```
3.67.scala

The ability to pass function literals to methods is used to great effect in the standard library, to concisely perform transformations on collections. We will see more of that in ***Chapter 4: Scala Collections***.

3.3.4 Generic Methods

Methods can be defined to be *generic* meaning that they can work on multiple types. These are have type parameters defined with `[...]` syntax before the value parameters defined with `(...)` syntax. For example, below is a method that returns the first and last elements of an array:

```
> def firstAndLastElements[T](arr: Array[T]): (T, T) = (arr(0), arr(arr.length - 1))

> firstAndLastElements(Array(1, 2, 3, 4, 5))
res1: (Int, Int) = (1, 5)

> firstAndLastElements(Array("i", "am", "cow"))
res2: (String, String) = ("i", "cow")
```
3.68.scala

Above we can see the method takes an `Array[T]` and returns a tuple `(T, T)` containing two `T`s, but the method doesn't actually care what `T` is. Thus when passed an `Array[Int]` it returns a tuple of `(Int, Int)`, and when passed an `Array[String]` it returns a tuple of `(String, String)`.

The `[T]` parameter of `firstAndLastElements` can often be inferred, and above we do not need to provide it. But you can also specify the type parameter explicitly when calling the method:

```
> firstAndLastElements[Int](Array(1, 2, 3, 4, 5))
res3: (Int, Int) = (1, 5)

> firstAndLastElements[String](Array("i", "am", "cow"))
res4: (String, String) = ("i", "cow")
```
3.69.scala

This can be useful in more non-trivial code where it's not obvious what type is being inferred, or if the type being inferred is not what you expect.

See example 3.3 - MethodsFunctions

3.4 Classes

You can define classes using the `class` keyword, and instantiate them using `new`. By default, all arguments passed into the class constructor are available in all of the class' methods: the `(x: Int)` above defines both the private fields as well as the class' constructor. `x` is thus accessible in the `printMsg` function, but cannot be accessed outside the class:

```
> class Foo(x: Int):
      def printMsg(msg: String) =
          println(msg + x)
```

3.70.scala

```
> val f = new Foo(1)

> f.printMsg("hello") // `printMsg` uses `x`
hello1

> f.x // Code outside of `Foo` cannot use `x`
-- [E173] Reference Error: -------------
1 |f.x
  |^^^
  |x can only be accessed from Foo.
```

3.71.scala

You can also omit the `new` keyword instantiate classes via just `Foo(1)`:

```
> val f = Foo(1)
```

To make `x` publicly accessible you can make it a `val`, and to make it mutable you can make it a `var`:

```
> class Bar(val x: Int):
      def printMsg(msg: String) =
          println(msg + x)
```

3.72.scala

```
> val b = Bar(1)

> b.x // `x` can now be used outside of `Bar`
res122: Int = 1
```

3.73.scala

```
> class Qux(var x: Int):
      def printMsg(msg: String) =
          // `x` is a `var` so we can modify it
          x += 1
          println(msg + x)
```

3.74.scala

```
> val q = Qux(1)

> q.printMsg("hello")
hello2

> q.printMsg("hello")
hello3
```

3.75.scala

You can also use `val`s or `var`s in the body of a class to store data. These get computed once when the class is instantiated:

```
> class Baz(x: Int):
      val bangs = "!" * x
      def printMsg(msg: String) =
          println(msg + bangs)
```
3.76.scala

```
> val z = Baz(3)

> z.printMsg("hello")
hello!!!
```
3.77.scala

3.4.1 Object Oriented Programming

Scala `class`es support most standard object-oriented programming features

3.4.1.1 extends, override, and super

```
> class FooPrintsTwice(x: Int) extends Foo(x * 2):
      override def printMsg(msg: String) =
          super.printMsg(msg)
          super.printMsg(msg * 2)

> new FooPrintsTwice(123).printMsg("hello")
hello246
hello246hello246
```
3.78.scala

Note in this example that when we call `extends`, we also get a chance to forward constructor parameters to the parent constructor, modifying them along the way if necessary. When we `override def printMsg` we also get a chance to call `super.printMsg` however we like (in this case, twice) and forward whatever arguments we like (in this case, repeat the parameter forwarded to the second `super` call).

3.4.1.2 final

Methods marked as `final` cannot be overridden:

```
> class FinalFoo(x: Int):
      final def printMsg(msg: String) = println(msg + x)

> class FinalFooOverride(x: Int) extends FinalFoo(x):
      override def printMsg(msg: String) = println(msg + x * 2)
-- [E164] Declaration Error: ----------------------------------------------------
  |error overriding method printMsg in class FinalFoo of type (msg: String): Unit;
  |  method printMsg of type (msg: String): Unit cannot override final member method
```
3.79.scala

3.4.1.3 Abstract Classes and Methods

Classes marked as `abstract` can have abstract methods, which are method `def`s that do not have an implementation. These must be implemented by any non-abstract sub-classes.

```
> abstract class AbstractFoo(x: Int):
      def printMsg(msg: String): Unit

> class ConcreteFoo1(x: Int) extends AbstractFoo(x) // Missing abstract method
-- Error: ----------------------------------------------------------------------
  |class ConcreteFoo1 needs to be abstract, since def printMsg(msg: String): Unit
  |in class AbstractFoo is not defined

> class ConcreteFoo1(x: Int) extends AbstractFoo(x): // OK
      def printMsg(msg: String) = println(msg + x)
```
3.80.scala

3.5 Traits

`trait`s are similar to `interface`s in traditional object-oriented languages: a set of methods that multiple classes can inherit. Instances of these classes can then be used interchangeably. Unlike inheriting from a `class`, inheriting from multiple `trait`s is allowed, and `trait` methods are allowed to be `abstract` by default:

```
> trait Point:
      def magnitude: Double

> trait Jsonable:
      def toJson: String

> class Point2D(x: Double, y: Double) extends Point, Jsonable:
      def magnitude = math.sqrt(x * x + y * y)
      def toJson = s"[$x, $y]"

> class Point3D(x: Double, y: Double, z: Double) extends Point, Jsonable:
      def magnitude = math.sqrt(x * x + y * y + z * z)
      def toJson = s"[$x, $y, $z]"

> val points = Array(Point2D(1, 2), Point3D(4, 5, 6))

> for p <- points do println(p.magnitude)
2.23606797749979
8.774964387392123

> for p <- points do println(p.toJson)
[1.0, 2.0]
[4.0, 5.0, 6.0]
```
3.81.scala

Above, we have defined a `Point` and `Jsonable` traits with methods `def magnitude: Double` and `def toJson: String` respectively. The subclasses `Point2D` and `Point3D` both have different sets of parameters, but they both implement `def magnitude` and `def toJson`. Thus we can put both `Point2D`s and `Point3D`s into our `points` array and treat them all uniformly as objects with a `def magnitude` and `def toJson` methods, regardless of what their actual class is.

3.5.1 Trait Implementations

In addition to abstract `def`s that purely define an interface, Scala `trait`s can also contain implementations to let you re-use common logic between the different sub-classes. The `Point2D`/`Point3D` example we saw earlier can be re-organized as follows, with the `def magnitude` and `def toJson` logic centralized within `trait Point` and `trait Jsonable`:

```
trait Point:
    def coordinates: Seq[Double]
    def magnitude: Double = math.sqrt(coordinates.map(v => v * v).sum)

trait Jsonable:
    def coordinates: Seq[Double]
    def toJson: String = "[" + coordinates.mkString(", ") + "]"

class Point2D(x: Double, y: Double) extends Point, Jsonable:
    def coordinates = Seq(x, y)

class Point3D(x: Double, y: Double, z: Double) extends Point, Jsonable:
    def coordinates = Seq(x, y, z)
```

3.82.scala

In this way the sub-classes `Point2D` and `Point3D` only need to implement a single `def coordinates: Seq[Double]` method, and they automatically inherit the implementations of `magnitude` and `toJson` from the `trait`s that they inherit. This can reduce boilerplate and ensure the different sub-classes have a consistent implementation of the logic within each `trait`.

Like `class`es, `trait`s support standard object-oriented programming features like `override` and `super`:

```
> trait PrettyJsonable extends Jsonable:
      override def toJson = "***" + super.toJson + "***"

> class PrettyPoint3D(x: Double, y: Double, z: Double) extends Point3D(x,y,z), PrettyJsonable

> PrettyPoint3D(1, 2, 3).toJson
res0: String = "***[1.0, 2.0, 3.0]***"
```

3.83.scala

See example 3.4 - ClassesTraits

3.6 Singleton Objects

Singleton objects in Scala can be defined with the `object` keyword. These have a variety of use cases that we will discuss below:

3.6.1 Namespaces and Static Methods

Singleton objects are useful to put `def`s and `var`s and other definitions into namespaces. This is similar to `static` methods in languages like Java or C#, or packages in languages like Python. When a complicated part of your program starts getting messy with many variables and methods, grouping related definitions into named `object`s can help keep things neat:

```
> object Thing:
      var x = 1
      def hello = "world " + x
```

3.84.scala

```
> Thing.hello
res0: String = "world 1"

> Thing.x = 5

> Thing.hello
res1: String = "world 5"
```

3.85.scala

3.6.2 Singleton Object Inheritance

Unlike static methods in other languages, methods in singleton objects can be inherited from `class`es and `trait`s:

```
> class Box(var x: Int):
      def update(f: Int => Int) =
          x = f(x)
      def printMsg(msg: String) =
          println(msg + x)

> object SingletonBox extends Box(10)
```

3.86.scala

```
> SingletonBox.update(x => x + 5)

> SingletonBox.printMsg("hello")
hello15
```

3.87.scala

This has two uses:

- If you have methods in a `class` or `trait` that you want your singleton object to also have, you can just `extends` it in your singleton object and inherit those definitions
- If you have a `class` or `trait` that has some special values, e.g. a "default" value or a "null" value, making it a singleton object is a convenient way to do so. For example:

```
object EmptyInputStream extends java.io.InputStream:
    // return -1 to immediately signal end of stream without returning any data
    def read(): Int = -1
```

3.88.scala

3.6.3 Companion Objects

An `object` with the same name as a `class` that it is defined next to is called a *companion object*. Companion objects serve a similar purpose to static methods in other languages, and are often used to group together methods, variables, factory methods, and other functionality that is related to a `trait` or `class` but does not belong to any specific instance.

```
class Foo():
    // instance methods and variables specific to each instance of Foo

object Foo:
    // methods and variables related to Foo but not any specific instance
```
3.89.scala

For example, the `List` class has an `object List` singleton object that contains things like:

- Factory methods: `List.apply`, `Array.fill`
- Copy-constructors: `List.from`
- Special values: `List.empty`
- Builders: `List.newBuilder`, `List.iterableFactory`
- `private` methods and fields used in the internal implementation of `List` that are shared and not specific to any particular instance

`object List` inherits much of this functionality from a super-class shared with the other Scala collection types, which also allows it to be used as a value in methods that expect that super-class such as `Array.to`:

```
> Array(1, 2, 3).to(List)
res0: List[Int] = List(1, 2, 3)
```
3.90.scala

We will explore more of the operations available on `Array` and `List`, and how to use them, later in ***Chapter 4: Scala Collections***.

See example 3.5 - SingletonObjects

3.7 Optional Braces and Indentation

Scala can use braces to delimit blocks, but they are optional, and in their absence the language uses indentation to determine where blocks of code start and end. Semicolons are similarly optional and generally not used. For example, the two snippets below show the same Scala code with the braces present (left) and without braces instead using indentation to delimit blocks of code (right):

```
class Box(var x: Int) {
  def update(f: Int => Int) = {
    x = f(x)
  }

  def printMsg(msg: String) = {
    val finalMsg = msg + x
    println(finalMsg)
  }
}

val myBox = new Box(10)

myBox.update { previous =>
  println(s"Incrementing $previous!")
  previous + 1
}

myBox.printMsg("hello") // hello11
```

3.91.scala

```
class Box(var x: Int):
    def update(f: Int => Int) =
        x = f(x)

    def printMsg(msg: String) =
        val finalMsg = msg + x
        println(finalMsg)

val myBox = new Box(10)

myBox.update: previous =>
    println(s"Incrementing $previous!")
    previous + 1

myBox.printMsg("hello") // hello11
```

3.92.scala

In this book we recommend using 4-space indents when using an indent-delimited style, rather than the 2-space indents that were common for brace-delimited Scala, as in the absence of braces the extra indentation helps ensure things remain readable. In general, relying on indentation is preferred: braces remain available, but are typically only used in the following scenarios:

- Backwards compatibility with older versions of Scala (2.x) that do not support indentation syntax.
- Squeeze things onto a single line. This isn't something you do often, but sometimes can be useful:

```
myBox.update { previous => println(s"Incrementing $previous!"); previous + 1 }
```

3.8 Conclusion

In this chapter, we have gone through a lightning tour of the core Scala language. While the exact syntax may be new to you, the concepts should be mostly familiar: primitives, arrays, loops, conditionals, methods, and classes are part of almost every programming language.

Next we will look at the core of the Scala standard library: the Scala Collections.

Exercise: Write a recursive method `printMsgs` that can receive an array of `Msg` class instances, each with an optional `parent` ID, and use it to print it in a threaded fashion. That means that child messages are printed out indented underneath their parents, and the nesting can be arbitrarily deep.

PrintMessages.scala

```
class Msg(val id: Int, val parent: Option[Int], val txt: String)
def printMsgs(messages: Array[Msg]): Unit = ...
```

3.93.scala

TestPrintMessages.scala

```
//| moduleDeps: [PrintMessages.scala]
def main() =
    printMsgs(Array(
        Msg(0, None, "Hello"),
        Msg(1, Some(0), "World"),
        Msg(2, None, "I am Cow"),
        Msg(3, Some(2), "Hear me moo"),
        Msg(4, Some(2), "I am Cow"),
        Msg(5, Some(4), "Hear me moo, moo")
    ))
```

3.94.scala

expected.txt

```
#0 Hello
    #1 World
#2 I am Cow
    #3 Hear me moo
    #4 I am Cow
        #5 Hear me moo, moo
```

3.95.output

See example 3.6 - PrintMessages

Exercise: Define a pair of methods `withFileWriter` and `withFileReader` that can be called as shown below. Each method should take the name of a file, and a function value that is called with a `java.io.BufferedReader` or `java.io.BufferedWriter` that it can use to read or write data. Opening and closing of the reader/writer should be automatic, such that a caller cannot forget to close the file. This is similar to Python "context managers" or Java "try-with-resource" syntax.

TestContextManagers.scala

```
//| moduleDeps: [ContextManagers.scala]
def main() =
    withFileWriter("File.txt"): writer =>
        writer.write("Hello\n")
        writer.write("World!")

    val result = withFileReader("File.txt"): reader =>
        reader.readLine() + "\n" + reader.readLine()

    assert(result == "Hello\nWorld!")
```

3.96.scala

For now you can use the Java standard library APIs `java.nio.file.Files.newBufferedWriter` and `newBufferedReader` for working with file readers and writers. We will get more familiar with working with files and the filesystem in ***Chapter 7: Files and Subprocesses***.

See example 3.7 - ContextManagers

Exercise: Define a `def flexibleFizzBuzz` method that takes a `String => Unit` callback function as its argument, and allows the caller to decide what they want to do with the output. The caller can choose to ignore the output, `println` the output directly, or store the output in a previously-allocated array they already have handy.

```
> flexibleFizzBuzz: s => {/* ignore */}

> flexibleFizzBuzz(println)
1
2
Fizz
4
Buzz
...
```

3.97.scala

```
> var i = 0

> val output = new Array[String](100)

> flexibleFizzBuzz: s =>
    output(i) = s
    i += 1

> output
res125: Array[String] = Array(
  "1",
  "2",
  "Fizz",
  "4",
  "Buzz",
...
```

3.98.scala

See example 3.8 - FlexibleFizzBuzz

Discuss Chapter 3 online at https://www.handsonscala.com/discuss/3

4

Scala Collections


```
> def stdDev(a: Array[Double]): Double =
      val mean = a.sum / a.length
      val squareErrors = a.map(x => x - mean).map(x => x * x)
      math.sqrt(squareErrors.sum / a.length)


> stdDev(Array(1, 2, 3))
res0: Double = 0.816496580927726
```

4.1.scala

Snippet 4.1: calculating the standard deviation of an array using Scala Collection operations

The core of the Scala standard library is its *collections*: a common set of containers and data structures that are shared by all Scala programs. Scala's collections make it easy for you to manipulate arrays, linked lists, sets, maps and other data structures in convenient ways, providing built-in many of the data structures needed for implementing a typical application.

This chapter will walk through the common operations that apply to all collection types, before discussing the individual data structures and when you might use each of them in practice.

4.1 Operations

Scala collections provide many common operations for constructing them, querying them, or transforming them. These operations are present on the `Array`s we saw in ***Chapter 3: Basic Scala***, but they also apply to all the collections we will cover in this chapter: Vectors (*4.2.1*), Sets (*4.2.3*), Maps (*4.2.4*), etc.

4.1.1 Builders

```
> val b = Array.newBuilder[Int]
b: mutable.ArrayBuilder[Int] = ArrayBuilder.ofInt

> b += 1

> b += 2

> b.result()
res2: Array[Int] = Array(1, 2)
```
4.2.scala

Builders let you efficiently construct a collection of unknown length, "freezing" it into the collection you want at the end. This is most useful for constructing `Array`s or immutable collections where you cannot add or remove elements once the collection has been constructed.

4.1.2 Factory Methods

```
> Array.fill(5)("hello") // Array with "hello" repeated 5 times
res3: Array[String] = Array("hello", "hello", "hello", "hello", "hello")

> Array.tabulate(5)(n => s"hello $n") // each value computed from the index
res4: Array[String] = Array("hello 0", "hello 1", "hello 2", "hello 3", "hello 4")

> Array(1, 2, 3) ++ Array(4, 5, 6) // Concat two Arrays into a larger one
res5: Array[Int] = Array(1, 2, 3, 4, 5, 6)
```
4.3.scala

Factory methods provide another way to instantiate collections: with every element the same, with each element constructed depending on the index, or from multiple smaller collections. This can be more convenient than using Builders (*4.1.1*) in many common use cases.

See example 4.1 - BuildersFactories

4.1.3 Transforms

```
> Array(1, 2, 3, 4, 5).map(i => i * 2) // Multiply each element by 2
res5: Array[Int] = Array(2, 4, 6, 8, 10)

> Array(1, 2, 3, 4, 5).filter(i => i % 2 == 1) // only odd elements
res6: Array[Int] = Array(1, 3, 5)

> Array(1, 2, 3, 4, 5).take(2) // Keep first two elements
res7: Array[Int] = Array(1, 2)

> Array(1, 2, 3, 4, 5).drop(2) // Discard first two elements
res8: Array[Int] = Array(3, 4, 5)

> Array(1, 2, 3, 4, 5).slice(1, 4) // Keep elements from index 1-4
res9: Array[Int] = Array(2, 3, 4)

> Array(1, 2, 3, 4, 5, 4, 3, 2, 1, 2, 3, 4, 5).distinct // no duplicates
res10: Array[Int] = Array(1, 2, 3, 4, 5)
```
4.4.scala

Transforms take an existing collection and create a new collection modified in some way. Note that these transformations create copies of the collection, and leave the original unchanged. That means if you are still using the original array, its contents will not be modified by the transform:

```
> val a = Array(1, 2, 3, 4, 5)
a: Array[Int] = Array(1, 2, 3, 4, 5)

> val a2 = a.map(x => x + 10)
a2: Array[Int] = Array(11, 12, 13, 14, 15)

> a(0) // Note that `a` is unchanged!
res11: Int = 1

> a2(0) // Only `a2` contains the new value, since it was the one that was modified
res12: Int = 11
```
4.5.scala

The copying involved in these collection transformations does have some overhead, but in most cases that should not cause issues. If a piece of code does turn out to be a bottleneck that is slowing down your program, you can always convert your `.map`/`.filter`/etc. transformation code into mutating operations over raw `Array`s or In-Place Operations (*4.3.4*) over Mutable Collections (*4.3*) to optimize for performance.

See example 4.2 - Transforms

4.1.4 Queries

```
> Array(1, 2, 3, 4, 5, 6, 7).find(i => i % 2 == 0 && i > 4)
res13: Option[Int] = Some(6)

> Array(1, 2, 3, 4, 5, 6, 7).find(i => i % 2 == 0 && i > 10)
res14: Option[Int] = None

> Array(1, 2, 3, 4, 5, 6, 7).exists(x => x > 1) // any elements more than 1?
res15: Boolean = true

> Array(1, 2, 3, 4, 5, 6, 7).exists(_ < 0) // same as a.exists(x => x < 0)
res16: Boolean = false
```
4.6.scala

Queries let you search for elements within your collection, returning either a `Boolean` indicating if a matching element exists, or an `Option` containing the element that was found. This can make it convenient to find things inside your collections without the verbosity of writing for-loops to inspect the elements one by one.

4.1.5 Aggregations

4.1.5.1 mkString

Stringifies the elements in a collection and combines them into one long string, with the given separator. Optionally can take a start and end delimiter:

```
> Array(1, 2, 3, 4, 5, 6, 7).mkString(",")
res17: String = "1,2,3,4,5,6,7"

> Array(1, 2, 3, 4, 5, 6, 7).mkString("[", ",", "]")
res18: String = "[1,2,3,4,5,6,7]"
```
4.7.scala

4.1.5.2 foldLeft

Takes a starting value and a function that it uses to combine each element of your collection with the starting value, to produce a final result:

```
> Array(1, 2, 3, 4, 5, 6, 7).foldLeft(0)((x, y) => x + y) // overall sum
res19: Int = 28

> Array(1, 2, 3, 4, 5, 6, 7).foldLeft(1)((x, y) => x * y) // overall product
res20: Int = 5040

> Array(1, 2, 3, 4, 5, 6, 7).foldLeft(1)(_ * _) // same, but shorthand
res21: Int = 5040
```
4.8.scala

In general, `foldLeft` is similar to a `for`-loop and accumulator `var`, and the above sum-of-all-elements `foldLeft` call can equivalently be written as:

```
> {
  var total = 0
  for i <- Array(1, 2, 3, 4, 5, 6, 7) do total += i
  }
total: Int = 28
```
4.9.scala

4.1.5.3 groupBy

Groups your collection into a `Map` of smaller collections depending on a key:

```
> val grouped = Array(1, 2, 3, 4, 5, 6, 7).groupBy(_ % 2)
grouped: Map[Int, Array[Int]] = Map(0 -> Array(2, 4, 6), 1 -> Array(1, 3, 5, 7))

> grouped(0)
res24: Array[Int] = Array(2, 4, 6)

> grouped(1)
res25: Array[Int] = Array(1, 3, 5, 7)
```
4.10.scala

See example 4.3 - QueriesAggregations

4.1.6 Combining Operations

It is common to chain more than one operation together to achieve what you want. For example, here is a function that computes the standard deviation of an array of numbers:

```
> def stdDev(a: Array[Double]): Double =
      val mean = a.foldLeft(0.0)(_ + _) / a.length
      val squareErrors = a.map(_ - mean).map(x => x * x)
      math.sqrt(squareErrors.foldLeft(0.0)(_ + _) / a.length)

> stdDev(Array(1, 2, 3, 4, 5))
res26: Double = 1.4142135623730951

> stdDev(Array(3, 3, 3))
res27: Double = 0.0
```
4.11.scala

Scala collections provide a convenient helper method `.sum` that is equivalent to `.foldLeft(0.0)(_ + _)`, so the above code can be simplified to:

```
> def stdDev(a: Array[Double]): Double =
      val mean = a.sum / a.length
      val squareErrors = a.map(_ - mean).map(x => x * x)
      math.sqrt(squareErrors.sum / a.length)
```
4.12.scala

As another example, here is a function that uses `.exists`, `.map` and `.distinct` to check if an incoming grid of numbers is a valid Sudoku grid:

```
> def isValidSudoku(grid: Array[Array[Int]]): Boolean =
      !Range(0, 9).exists: i =>
          val row = Range(0, 9).map(grid(i)(_))
          val col = Range(0, 9).map(grid(_)(i))
          val square = Range(0, 9).map(j => grid((i % 3) * 3 + j % 3)((i / 3) * 3 + j / 3))
          row.distinct.length != row.length ||
          col.distinct.length != col.length ||
          square.distinct.length != square.length
```
4.13.scala

This implementation receives a Sudoku grid, represented as a 2-dimensional `Array[Array[Int]]`. For each `i` from `0` to `9`, we pick out a single row, column, and 3x3 square. It then checks that each such row/column/square has 9 unique numbers by calling `.distinct` to remove any duplicates, and then checking if the `.length` has changed as a result of that removal.

We can test this on some example grids to verify that it works:

```
isValidSudoku(Array(
    Array(5,3,4,  6,7,8,  9,1,2),
    Array(6,7,2,  1,9,5,  3,4,8),
    Array(1,9,8,  3,4,2,  5,6,7),

    Array(8,5,9,  7,6,1,  4,2,3),
    Array(4,2,6,  8,5,3,  7,9,1),
    Array(7,1,3,  9,2,4,  8,5,6),

    Array(9,6,1,  5,3,7,  2,8,4),
    Array(2,8,7,  4,1,9,  6,3,5),
    Array(3,4,5,  2,8,6,  1,7,9)
)) //true
```
4.14.scala

```
isValidSudoku(Array(
    Array(5,3,4,  6,7,8,  9,1,2),
    Array(6,7,2,  1,9,5,  3,4,8),
    Array(1,9,8,  3,4,2,  5,6,7),

    Array(8,5,9,  7,6,1,  4,2,3),
    Array(4,2,6,  8,5,3,  7,9,1),
    Array(7,1,3,  9,2,4,  8,5,6),

    Array(9,6,1,  5,3,7,  2,8,4),
    Array(2,8,7,  4,1,9,  6,3,5),
    Array(3,4,5,  2,8,6,  1,7,8)
)) // false,    should be 9 ^
```
4.15.scala

Chaining collection transformations in this manner will always have some overhead, but for most use cases the overhead is worth the convenience and simplicity that these transforms give you. If collection transforms do become a bottleneck, you can optimize the code using Views (*4.1.7*), In-Place Operations (*4.3.4*), or finally by looping over the raw `Array`s yourself.

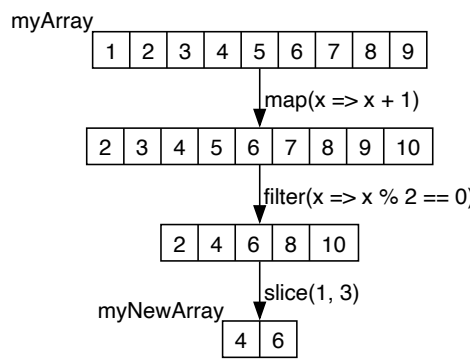
See example 4.4 - Combining

4.1.7 Views

When you chain multiple transformations on a collection, we are creating many intermediate collections that are immediately thrown away. For example, in the following snippet:

```
> val myArray = Array(1, 2, 3, 4, 5, 6, 7, 8, 9)
myArray: Array[Int] = Array(1, 2, 3, 4, 5, 6, 7, 8, 9)

> val myNewArray = myArray.map(x => x + 1).filter(x => x % 2 == 0).slice(1, 3)
myNewArray: Array[Int] = Array(4, 6)
```
4.16.scala

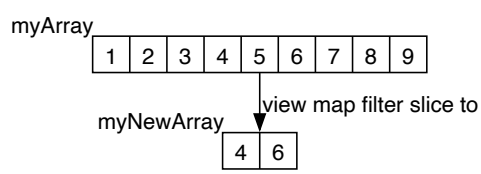
The chain of `.map` `.filter` `.slice` operations ends up traversing the collection three times, creating three new collections, but only the last collection ends up being stored in `myNewArray` and the others are discarded.



This creation and traversal of intermediate collections is wasteful. In cases where you have long chains of collection transformations that are becoming a performance bottleneck, you can use the `.view` method together with `.to` to "fuse" the operations together:

```
> val myNewArray = myArray.view.map(_ + 1).filter(_ % 2 == 0).slice(1, 3).to(Array)
myNewArray: Array[Int] = Array(4, 6)
```
4.17.scala

Using `.view` before the `map`/`filter`/`slice` transformation operations defers the actual traversal and creation of a new collection until later, when we call `.to` to convert it back into a concrete collection type:



This allows us to perform this chain of `map`/`filter`/`slice` transformations with only a single traversal, and only creating a single output collection. This reduces the amount of unnecessary processing and memory allocations.

4.2 Immutable Collections

While `Array`s are the low-level primitive, most Scala applications are built upon its mutable and immutable collections: `Vector`s, `List`s, `Set`s, and `Map`s. Of these, immutable collections are by far the most common.

Immutable collections rule out an entire class of bugs due to unexpected modifications, and are especially useful in multi-threaded scenarios where you can safely pass immutable collections between threads without worrying about thread-safety issues. Most immutable collections use Structural Sharing (*4.2.6*) to make creating updated copies cheap, allowing you to use them in all but the most performance critical code.

4.2.1 Immutable Vectors

`Vector`s are fixed-size, immutable linear sequences. They are a good general-purpose sequence data structure, and provide efficient *O(log n)* performance for most operations.

```
> val v = Vector(1, 2, 3, 4)
v: Vector[Int] = Vector(1, 2, 3, 4)

> v(0)
res33: Int = 1

> val v2 = v.updated(2, 10)
v2: Vector[Int] = Vector(1, 2, 10, 4)

> println(v) // `v` is unchanged!
Vector(1, 2, 3, 4)
```

4.18.scala

```
> val v = Vector[Int]()
v: Vector[Int] = Vector()

> val v1 = v :+ 1
v1: Vector[Int] = Vector(1)

> val v2 = 4 +: v1
v2: Vector[Int] = Vector(4, 1)

> val v3 = v2.tail
v3: Vector[Int] = Vector(1)
```

4.19.scala

Unlike `Array`s where `a(...) = ...` mutates it in place, a `Vector`'s `.updated` method returns a new `Vector` with the modification while leaving the old `Vector` unchanged. Due to Structural Sharing (*4.2.6*), this is a reasonably-efficient *O(log n)* operation. Similarly, using `:+` and `+:` to create a new `Vector` with additional elements on either side, or using `.tail` to create a new `Vector` with one element removed, are all *O(log n)* as well:

`Vector`s support the same set of Operations (*4.1*) that `Array`s and other collections do: builders (*4.1.1*), factory methods (*4.1.2*), transforms (*4.1.3*), etc.

In general, using `Vector`s is handy when you have a sequence you know will not change, but need flexibility in how you work with it. Their tree structure makes most operations reasonably efficient, although they will never be quite as fast as `Array`s for in-place updates or Immutable Lists (*4.2.2*) for adding and removing elements at the front.

See example 4.6 - ImmutableVectors

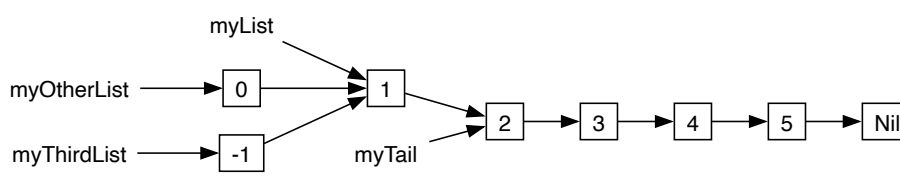
4.2.2 Immutable Lists

```
> val myList = List(1, 2, 3, 4, 5)
myList: List[Int] = List(1, 2, 3, 4, 5)

> myList.head
res48: Int = 1

> val myTail = myList.tail
myTail: List[Int] = List(2, 3, 4, 5)

> val myOtherList = 0 :: myList
myOtherList: List[Int] = List(0, 1, 2, 3, 4, 5)

> val myThirdList = -1 :: myList
myThirdList: List[Int] = List(-1, 1, 2, 3, 4, 5)
```

4.20.scala

Scala's immutable `List`s are a singly-linked list data structure. Each node in the list has a value and pointer to the next node, terminating in a `Nil` node. `List`s have a fast *O(1)* `.head` method to look up the first item in the list, a fast *O(1)* `.tail` method to create a list without the first element, and a fast *O(1)* `::` operator to create a new `List` with one more element in front.

`.tail` and `::` are efficient because they can share much of the existing `List`: `.tail` returns a reference to the next node in the singly linked structure, while `::` adds a new node in front. The fact that multiple lists can share nodes means that in the above example, `myList`, `myTail`, `myOtherList` and `myThirdList` are actually mostly the same data structure:



This can result in significant memory savings if you have a large number of collections that have identical elements on one side, e.g. paths on a filesystem which all share the same prefix. Rather than creating an updated copy of an `Array` in *O(n)* time, or an updated copy of a `Vector` in *O(log n)* time, pre-pending an item to a `List` is a fast *O(1)* operation.

The downside of `List`s is that indexed lookup via `myList(i)` is a slow *O(n)* operation, since you need to traverse the list starting from the left to find the element you want. Appending/removing elements on the right hand side of the list is also a slow *O(n)*, since it needs to make a copy of the entire list. For use cases where you want fast indexed lookup or fast appends/removes on the right, you should consider using Vectors (*4.2.1*) or mutable ArrayDeques (*4.3.1*) instead.

See example 4.9 - ImmutableLists

4.2.3 Immutable Sets

Scala's immutable `Set`s are unordered collections of elements without duplicates, and provide an efficient *O(log n)* `.contains` method. `Set`s can be constructed via `+` and elements removed by `-`, or combined via `++`. Note that duplicates elements are discarded:

```
> val s = Set(1, 2, 3)
s: Set[Int] = Set(1, 2, 3)

> s.contains(2)
res37: Boolean = true

> s.contains(4)
res38: Boolean = false
```
4.21.scala

```
> Set(1, 2, 3) + 4 + 5
res39: Set[Int] = HashSet(5, 1, 2, 3, 4)

> Set(1, 2, 3) - 2
res40: Set[Int] = Set(1, 3)

> Set(1, 2, 3) ++ Set(2, 3, 4)
res41: Set[Int] = Set(1, 2, 3, 4)
```
4.22.scala

The uniqueness of items within a `Set` is also sometimes useful when you want to ensure that a collection does not contain any duplicates.

You can iterate over `Set`s using for-loops, but the order of items is undefined and should not be relied upon (small sets may preserve insertion order but this isn't guaranteed):

```
> for i <- Set(1, 2, 3, 4, 5) do println(i)
5
1
2
3
4
```
4.23.scala

Most immutable `Set` operations take time *O(log n)* in the size of the `Set`. This is fast enough for most purposes, but in cases where it isn't you can always fall back to Mutable Sets (*4.3.2*) for better performance. `Set`s also support the standard set of operations common to all collections.

See example 4.7 - ImmutableSets

4.2.4 Immutable Maps

Immutable maps are unordered collections of keys and values, allowing efficient lookup by key:

```
> val m = Map("one" -> 1, "two" -> 2, "three" -> 3)
m: Map[String, Int] = Map("one" -> 1, "two" -> 2, "three" -> 3)

> m.contains("two")
res42: Boolean = true

> m("two")
res43: Int = 2
```

4.24.scala

You can also use `.get` if you're not sure whether a map contains a key or not. This returns `Some(v)` if the key is present, `None` if not:

```
> m.get("one")
res44: Option[Int] = Some(1)

> m.get("four")
res45: Option[Int] = None
```

4.25.scala

While `Map`s support the same set of operations as other collections, they are treated as collections of tuples representing each key-value pair. Conversions via `.to` requires a collection of tuples to convert from, `+` adds tuples to the `Map` as key-value pairs, and `for` loops iterate over tuples:

```
> Vector(("one", 1), ("two", 2), ("three", 3)).to(Map)
res46: Map[String, Int] = Map("one" -> 1, "two" -> 2, "three" -> 3)

> Map[String, Int]() + ("one" -> 1) + ("three" -> 3)
res47: Map[String, Int] = Map("one" -> 1, "three" -> 3)

> for (k, v) <- m do println(k + " " + v)
one 1
two 2
three 3
```

4.26.scala

Like `Set`s, the order of items when iterating over a `Map` is undefined and should not be relied upon, (small maps may preserve insertion order but this isn't guaranteed), and most immutable `Map` operations take time *O(log n)* in the size of the `Map`.

See example 4.8 - ImmutableMaps

4.2.5 Converters

You can convert among `Array`s and other collections like Vector (*4.2.1*)s and Set (*4.2.3*) using the `.to` method:

```
> Array(1, 2, 3).to(Vector)
res30: Vector[Int] = Vector(1, 2, 3)

> Array(1, 1, 2, 2, 3, 4).to(Set)
res31: Set[Int] = Set(1, 2, 3, 4)

> Vector(1, 2, 3).to(mutable.ArrayDeque)
res32: mutable.ArrayDeque[Int] = ArrayDeque(1, 2, 3)

> Map(1 -> "one", 2 -> "two").to(mutable.Buffer)
res33: mutable.Buffer[(Int, String)] = ArrayBuffer((1, "one"), (2, "two"))
```

4.27.scala

See example 4.5 - ConvertersViews

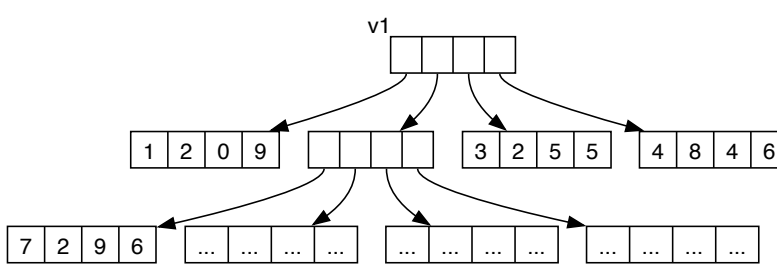
4.2.6 Structural Sharing

`Vector`s and other immutable collections implement their *O(log n)* copy-and-update operations by re-using portions of their tree structure. This avoids copying the whole tree, resulting in a "new" `Vector` that shares much of the old tree structure with only minor modifications.

Consider a large `Vector`, `v1`:

```
> val v1 = Vector(1,2,0,9,   7,2,9,6,  ...,  3,2,5,5,   4,8,4,6)
```

This is represented in-memory as a tree structure, whose breadth and depth depend on the size of the `Vector`:

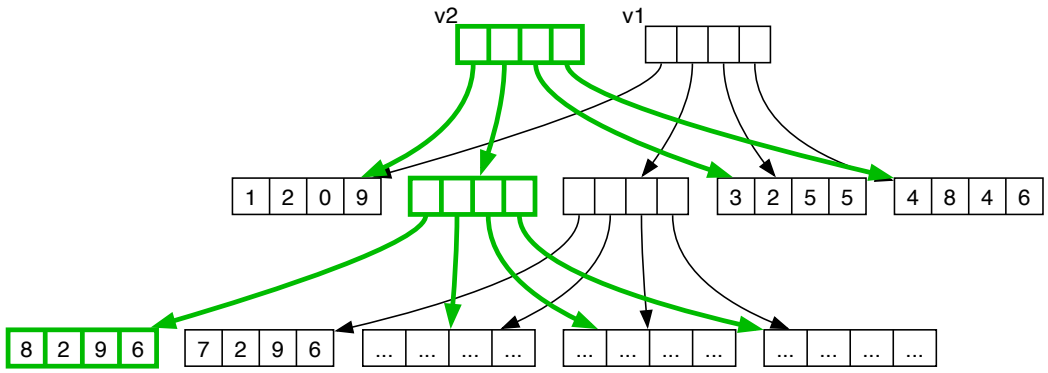


This example is somewhat simplified - a `Vector` in Scala has 32 elements per tree node rather than the 4 shown above - but it will serve us well enough to illustrate how the `Vector` data structure works.

Let us consider what happens if we want to perform an update, e.g. replacing the fifth value `7` in the above `Vector` with the value `8`:

```
> val v2 = v1.updated(4, 8)
v2 = Vector(1,2,0,9,   8,2,9,6,  ...,  3,2,5,5,   4,8,4,6)
```
4.28.scala

This is done by making updated copies of the nodes in the tree that are in the direct path down to the value we wish to update, but re-using all other nodes unchanged:



In this example `Vector` with 9 nodes, only 3 of the nodes end up needing to be copied. In a large `Vector`, the number of nodes that need to be copied is proportional to the height of the tree, while other nodes can be re-used: this structural sharing is what allows updated copies of the `Vector` to be created in only $O(log\ n)$ time. This is much less than the $O(n)$ time it takes to make a full copy of a mutable `Array` or other data structure.

Nevertheless, updating a `Vector` does always involve a certain amount of copying, and will never be as fast as updating mutable data structures in-place. In some cases where performance is important and you are updating a collection very frequently, you might consider using a mutable ArrayDeque (*4.3.1*) which has faster $O(1)$ update/append/prepend operations, or raw `Array`s if you know the size of your collection in advance.

A similar tree-shaped data structure is also used to implement Immutable Sets (*4.2.3*) and Immutable Maps (*4.2.4*).

4.3 Mutable Collections

Mutable collections are in general faster than their immutable counterparts when used for in-place operations. However, mutability comes at a cost: you need to be much more careful sharing them between different parts of your program. It is easy to create bugs where a shared mutable collection is updated unexpectedly, forcing you to hunt down which line in a large codebase is performing the unwanted update.

A common approach is to use mutable collections locally within a function or private to a class where there is a performance bottleneck, but to use immutable collections elsewhere where speed is less of a concern. That gives you the high performance of mutable collections where it matters most, while not sacrificing the safety that immutable collections give you throughout the bulk of your application logic.

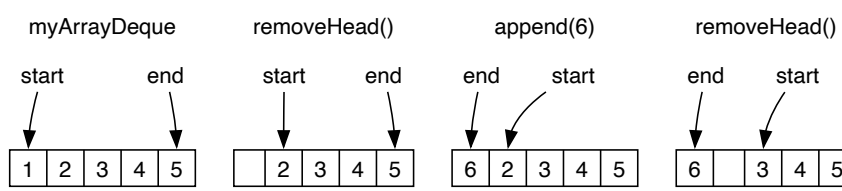
4.3.1 Mutable ArrayDeques

`ArrayDeque`s are general-purpose mutable, linear collections that provide efficient *O(1)* indexed lookups, *O(1)* indexed updates, and *O(1)* insertion and removal at both left and right ends:

```
> import scala.collection.mutable

> val myArrayDeque = mutable.ArrayDeque(1, 2, 3, 4, 5)

> myArrayDeque.removeHead()
res49: Int = 1

> myArrayDeque.append(6)
res50: mutable.ArrayDeque[Int] = ArrayDeque(2, 3, 4, 5, 6)

> myArrayDeque.removeHead()
res51: Int = 2

> println(myArrayDeque)
ArrayDeque(3, 4, 5, 6)
```

4.29.scala

`ArrayDeque`s implement the abstract `collection.mutable.Buffer` interface, and are implemented as a circular buffer, with pointers to the logical start and end of the collection within the buffer. The operations above can be visualized as follows, from left to right:



An `ArrayDeque` tries to re-use the same underlying `Array` as much as possible, only moving the `start` and `end` pointers around as elements get added or removed from either end. Only if the total number of elements grows beyond the current capacity does the underlying `Array` get re-allocated, and the size is increased by a fix multiple to keep the amortized cost of this re-allocation small.

As a result, operations on an `ArrayDeque` are much faster than the equivalent operations on an immutable `Vector`, which has to allocate *O(log n)* new tree nodes for every operation you perform.

`ArrayDeque`s have the standard suite of Operations (*4.1*). They can serve many roles:

- An `Array` that can grow: an `Array.newBuilder` does not allow indexed lookup or modification while the array is being built, and an `Array` does not allow adding more elements. An `ArrayDeque` allows both

- A faster, mutable alternative to immutable `Vector`s, if you find adding/removing items from either end using `:+`/`+:` or `.tail`/`.init` is a bottleneck in your code. Appending and prepending to `ArrayDeque`s is much faster than the equivalent `Vector` operations
- A first-in-first-out Queue, by inserting items to the right via `.append`, and removing items via `.removeHead`
- A first-in-last-out Stack, by inserting items to the right via `.append`, and removing items via `.removeLast`

If you want to "freeze" a mutable `ArrayDeque` into an immutable `Vector`, you can use `.to(Vector)`:

```
> myArrayDeque.to(Vector)
res52: Vector[Int] = Vector(3, 4, 5, 6)
```
4.30.scala

Note that this makes a copy of the entire collection.

See example 4.10 - MutableArrayDeques

4.3.2 Mutable Sets

The Scala standard library provides mutable `Set`s as a counterpart to the immutable `Set`s we saw earlier. Mutable sets also provide efficient `.contains` checks (*O(1)*), but instead of constructing new copies of the `Set` via `+` and `-`, you instead add and remove elements from the Set via `.add` and `.remove`:

```
> import scala.collection.mutable

> val s = mutable.Set(1, 2, 3)
s: mutable.Set[Int] = HashSet(1, 2, 3)

> s.contains(2)
res53: Boolean = true

> s.contains(4)
res54: Boolean = false
```
4.31.scala

```
> s.add(4)
res55: Boolean = true

> s.remove(1)
res56: Boolean = true

> println(s)
HashSet(2, 3, 4)
```
4.32.scala

You can "freeze" a mutable `Set` into an immutable `Set` by using `.to(Set)`, which makes a copy you cannot mutate using `.add` or `.remove`, and convert it back to a mutable `Set` the same way. Note that each such conversion makes a copy of the entire set.

See example 4.11 - MutableSets

4.3.3 Mutable Maps

Mutable `Map`s are again just like immutable `Map`s, but allow you to mutate the `Map` by adding or removing key-value pairs:

```
> import scala.collection.mutable
> val m = mutable.Map("one" -> 1, "two" -> 2, "three" -> 3)
m: mutable.Map[String, Int] = HashMap("two" -> 2, "three" -> 3, "one" -> 1)

> m.remove("two")
res57: Option[Int] = Some(2)

> m("five") = 5

> m
res58: mutable.Map[String, Int] = HashMap("five" -> 5, "three" -> 3, "one" -> 1)
```

4.33.scala

Mutable `Map`s have a convenient `getOrElseUpdate` function, that allows you to look up a value by key, and compute/store the value if there isn't one already present:

```
> val m = mutable.Map("one" -> 1, "two" -> 2, "three" -> 3)

> m.getOrElseUpdate("three", -1) // already present, returns existing value
res59: Int = 3

> m // `m` is unchanged
res60: mutable.Map[String, Int] = HashMap(
    "two" -> 2,
    "three" -> 3,
    "one" -> 1
)

> m.getOrElseUpdate("four", -1) // not present, put and returns new value
res63: Int = -1

> m // `m` now contains "four" -> -1
res61: mutable.Map[String, Int] = HashMap(
    "two" -> 2,
    "three" -> 3,
    "four" -> -1,
    "one" -> 1
)
```

4.34.scala

`.getOrElseUpdate` makes it convenient to use a mutable `Map` as a cache: the second parameter to `.getOrElseUpdate` is a lazy "by-name" parameter, and is only evaluated when the key is not found in the `Map`. This provides the common "check if key present, if so return value, otherwise insert new value and return that" workflow built in. We will go into more detail how by-name parameters work in ***Chapter 5: Notable Scala Features***.

Mutable `Map`s are implemented as hash-tables, with `m(...)` lookups and `m(...) = ...` updates being efficient $O(1)$ operations.

See example 4.12 - MutableMaps

4.3.4 In-Place Operations

All mutable collections, including `Array`s, have in-place versions of many common collection operations. These allow you to perform the operation on the mutable collection without having to make a transformed copy:

```
> val a = mutable.ArrayDeque(1, 2, 3, 4)
a: mutable.ArrayDeque[Int] = ArrayDeque(1, 2, 3, 4)

> a.mapInPlace(_ + 1)
res62: mutable.ArrayDeque[Int] = ArrayDeque(2, 3, 4, 5)

> a.filterInPlace(_ % 2 == 0)
res63: mutable.ArrayDeque[Int] = ArrayDeque(2, 4)

> a // `a` was modified in place
res64: mutable.ArrayDeque[Int] = ArrayDeque(2, 4)
```

4.35.scala

Apart from those shown above, there is also `dropInPlace`, `sliceInPlace`, `sortInPlace`, etc. Using in-place operations rather than normal transformations avoids the cost of allocating new transformed collections, and can help in performance-critical scenarios.

See example 4.13 - InPlaceOperations

4.4 Common Interfaces

In many cases, a piece of code does not care exactly what collection it is working on. For example, code that just needs something that can be iterated over in order can take a `Seq[T]`:

```
> def iterateOverSomething[T](items: Seq[T]) =
      for i <- items do println(i)

> iterateOverSomething(Vector(1, 2, 3))
1
2
3

> iterateOverSomething(List(("one", 1), ("two", 2), ("three", 3)))
(one,1)
(two,2)
(three,3)
```

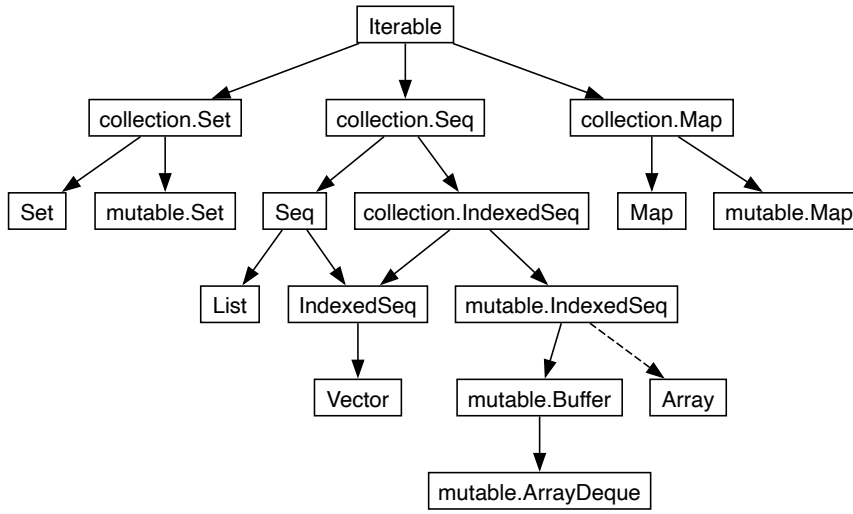
4.36.scala

Code that needs something which provides efficient indexed lookup doesn't care if it's an `Array` or `Vector`, but cannot work with a `List`. In that case, your code can take a `collection.IndexedSeq[T]` (the common interface of both immutable and mutable sequences):

```
> def getMiddleItem[T](items: collection.IndexedSeq[T]) = items(items.length / 2)

> getMiddleItem(Vector(1, 2, 3, 4, 5))
res65: Int = 3

> getMiddleItem(Array(2, 4, 6))
res66: Int = 4
```

4.37.scala

The hierarchy of data types we have seen so far is as follows:



Depending on what you want your code to be able to accept, you can pick the relevant type in the hierarchy: `Iterable`, `IndexedSeq`, `Seq`, `collection.Seq`, etc. In general, most code defaults to using immutable `Seq`s, `Set`s and `Map`s. Mutable collections under the `collection.mutable` package are only used where necessary, and it is best to keep them local within a function or private to a class. `collection.{Seq,Set,Map}` serve as common interfaces to both mutable and immutable collections.

See example 4.14 - CommonInterfaces

4.5 Conclusion

In this chapter, we have gone through the basic collections that underlie the Scala standard library: `Array`, immutable `Vector`/`Set`/`Map`/`List`, and mutable `ArrayDeque`/`Set`/`Map`. We have seen how to construct collections, query them, convert one to another, and write functions that work with multiple possible collection types.

This chapter should have given you a foundation for competently working with Scala's collections library, which is widely used throughout every Scala program. We will now go through some of the more unique features of the Scala language, to round off your introduction to Scala.

Exercise: Modify the `def isValidSudoku` method we defined in this chapter to allow testing the validity of partially-filled Sudoku grids, with un-filled cells marked by the value `0`.

```
isValidSudoku(Array(
    Array(3,1,6, 5,7,8, 4,9,2),
    Array(5,2,9, 1,3,4, 7,6,8),
    Array(4,8,7, 6,2,9, 5,3,1),
    Array(2,6,3, 0,1,0, 0,8,0),
    Array(9,7,4, 8,6,3, 0,0,5),
    Array(8,5,1, 0,9,0, 6,0,0),
    Array(1,3,0, 0,0,0, 2,5,0),
    Array(0,0,0, 0,0,0, 0,7,4),
    Array(0,0,5, 2,0,6, 3,0,0)
)) // true
```

4.38.scala

```
isValidSudoku(Array(
    Array(3,1,6, 5,7,8, 4,9,3),
    Array(5,2,9, 1,3,4, 7,6,8),
    Array(4,8,7, 6,2,9, 5,3,1),
    Array(2,6,3, 0,1,0, 0,8,0),
    Array(9,7,4, 8,6,3, 0,0,5),
    Array(8,5,1, 0,9,0, 6,0,0),
    Array(1,3,0, 0,0,0, 2,5,0),
    Array(0,0,0, 0,0,0, 0,7,4),
    Array(0,0,5, 2,0,6, 3,0,0)
)) // false, top row has two 3s
```

4.39.scala

See example 4.15 - PartialValidSudoku

Exercise: Write a `def renderSudoku` method that can be used to pretty-print a Sudoku grid as shown below: with the zeroes representing unfilled cells left out, and each 3x3 square surrounded by horizontal and vertical lines.

```
> println(renderSudoku(Array(
      Array(3,1,6, 5,7,8, 4,9,2),
      Array(5,2,9, 1,3,4, 7,6,8),
      Array(4,8,7, 6,2,9, 5,3,1),
      Array(2,6,3, 0,1,0, 0,8,0),
      Array(9,7,4, 8,6,3, 0,0,5),
      Array(8,5,1, 0,9,0, 6,0,0),
      Array(1,3,0, 0,0,0, 2,5,0),
      Array(0,0,0, 0,0,0, 0,7,4),
      Array(0,0,5, 2,0,6, 3,0,0)
  )))
```

4.40.scala

```
+-------+-------+-------+
| 3 1 6 | 5 7 8 | 4 9 2 |
| 5 2 9 | 1 3 4 | 7 6 8 |
| 4 8 7 | 6 2 9 | 5 3 1 |
+-------+-------+-------+
| 2 6 3 |   1   |   8   |
| 9 7 4 | 8 6 3 |     5 |
| 8 5 1 |   9   | 6     |
+-------+-------+-------+
| 1 3   |       | 2 5   |
|       |       |   7 4 |
|     5 | 2   6 | 3     |
+-------+-------+-------+
```

4.41.output-scala

You might find the `Array.grouped` operator useful for this, though you can also do without it.

See example 4.16 - RenderSudoku

Discuss Chapter 4 online at https://www.handsonscala.com/discuss/4

5

Notable Scala Features


```
> def getDayMonthYear(s: String) = s match
      case s"$day-$month-$year" =>
          println(s"found day: $day, month: $month, year: $year")
      case _ => println("not a date")

> getDayMonthYear("9-8-1965")
found day: 9, month: 8, year: 1965

> getDayMonthYear("9-8")
not a date
```

5.1.scala

Snippet 5.1: using Scala's pattern matching feature to parse simple string patterns

This chapter will cover some of the more interesting and unusual features of Scala. For each such feature, we will cover both what the feature does as well as some common use cases to give you an intuition for what it is useful for.

Not every feature in this chapter will be something you use day-to-day. Nevertheless, even these less-commonly-used features are used often enough that it is valuable to have a high-level understanding for when you eventually encounter them in the wild.

5.1 Case Classes, Sealed Traits, and Enums

5.1.1 Case Classes

`case class`es are like normal `class`es, but meant to represent `class`es which are "just data": where all the data is immutable and public, without any mutable state or encapsulation. Their use case is similar to "structs" in C/C++, "POJOs" in Java or "Data Classes" in Python or Kotlin. Their name comes from the fact that they support pattern matching (*5.2*) via the `case` keyword.

Case classes are defined with the `case` keyword. All of their constructor parameters are public fields by default. Like normal classes, you can define instance methods or properties in the body of the `case class`.

```
> case class Point(x: Int, y: Int):
      def z = x + y

> val p = Point(1, 2)
p: Point = Point(x = 1, y = 2)
```

5.2.scala

```
> p.x
res0: Int = 1

> p.y
res1: Int = 2

> p.z
res2: Int = 3
```

5.3.scala

`case class`s give you a few things for free:

- A `.toString` implemented to show you the constructor parameter values
- A `==` implemented to check if the constructor parameter values are equal
- A `.copy` method to conveniently create modified copies of the case class instance

```
> p.toString
res2: String = "Point(1,2)"

> val p2 = Point(1, 2)
p2: Point = Point(x = 1, y = 2)

> p == p2
res3: Boolean = true
```

5.4.scala

```
> val p = Point(1, 2)
p: Point = Point(x = 1, y = 2)

> val p3 = p.copy(y = 10)
p3: Point = Point(x = 1, y = 10)

> val p4 = p3.copy(x = 20)
p4: Point = Point(x = 20, y = 10)
```

5.5.scala

`case class`es are a good replacement for large tuples, since instead of extracting their values via indices e.g. `p(0)` `p(1)` `p(6)` you can extract the values via their names like `.x` and `.y`. That is much easier than trying to remember exactly what field `p(6)` in a large tuple represents!

See example 5.1 - CaseClass

5.1.2 Sealed Traits

`trait`s can also be defined `sealed`, and only extended by a fixed set of `case class`es. In the following example, we define a `sealed trait Point` extended by two `case class`es: `Point2D` and `Point3D`:

```
> {
  sealed trait Point
  case class Point2D(x: Double, y: Double) extends Point
  case class Point3D(x: Double, y: Double, z: Double) extends Point
  }

> def magnitude(p: Point) = p match
      case Point2D(x, y) => math.sqrt(x * x + y * y)
      case Point3D(x, y, z) => math.sqrt(x * x + y * y + z * z)

> val points: Array[Point] = Array(Point2D(1, 2), Point3D(4, 5, 6))
points: Array[Point] = Array(
    Point2D(x = 1.0, y = 2.0),
    Point3D(x = 4.0, y = 5.0, z = 6.0)
)

> for p <- points do println(magnitude(p))
2.23606797749979
8.774964387392123
```

5.6.scala

The core difference between normal `trait`s and `sealed trait`s can be summarized as follows:

- Normal `trait`s are *open*, so any number of classes can inherit from the trait as long as they provide all the required methods, and instances of those classes can be used interchangeably via the `trait`'s required methods.

- `sealed trait`s are *closed*: they only allow a fixed set of classes to inherit from them, and all inheriting classes must be defined together with the trait itself in the same file or REPL command (hence the curlies `{}` surrounding the `Point`/`Point2D`/`Point3D` definitions above).

Because there are only a fixed number of classes inheriting from `sealed trait Point`, we can use pattern matching in the `def magnitude` function above to define how each kind of `Point` should be handled.

See example 5.2 - SealedTrait

5.1.3 Enums

Scala `enum`s are a convenient way of defining a `sealed trait` with all its `case`s nested within it. The simplest `enum` is just a fixed set of constants:

```
> enum Color:
      case Red, Green, Blue

> val myColors = Seq(Color.Red, Color.Green, Color.Blue, Color.Red, Color.Green)

> myColors.count(_ != Color.Red)
res1: Int = 3
```
5.7.scala

`enum`s can also be parametrized such that each element has some data associated with it:

```
> enum Color(val rgb: Int, val chineseName: String):
      case Red   extends Color(0xFF0000, "红")
      case Green extends Color(0x00FF00, "绿")
      case Blue  extends Color(0x0000FF, "蓝")

> val myColors = Seq(Color.Red, Color.Green, Color.Blue, Color.Red, Color.Green)

> myColors.map(_.rgb.toHexString).mkString(" ")
res3: String = "ff0000 ff00 ff ff0000 ff00"

> myColors.map(_.chineseName).mkString(" ")
res2: String = "红 绿 蓝 红 绿"
```
5.8.scala

5.1.3.1 Non-Trivial Enums

One common use case for enums is to model data types such as JSON. A `Json` data structure can be defined as:

```
> enum Json:
      case Null()
      case Bool(value: Boolean)
      case Str(value: String)
      case Num(value: Double)
      case Arr(value: Seq[Json])
      case Dict(value: Map[String, Json])

> val myJsonDict = Json.Dict(Map("hello" -> Json.Str("world"), "number" -> Json.Num(1)))
myJsonDict: Json = Dict(Map("hello" -> Str("world"), "number" -> Num(1.0)))
```
5.9.scala

The typical way you work with enums is via pattern matching. Below, we define a `stringify` method that recursively pattern matches on an input `value0: Json` and converts it to a string:

```
> def stringify(value0: Json): String = value0 match
      case Json.Null() => "null"
      case Json.Bool(value) => value.toString
      case Json.Str(value) => "\"" + value.replace("\"", "\\\"") + "\""
      case Json.Num(value) => value.toString
      case Json.Arr(value) => "[" + value.map(stringify).mkString(", ") + "]"
      case Json.Dict(value) =>
          value
              .map((k, v) => stringify(Json.Str(k)) + ": " + stringify(v))
              .mkString("{", ", ", "}")

> stringify(myJsonDict)
"{\"hello\": \"world\", \"number\": 1.0}"
```

5.10.scala

Note how the `case`s of `Json` are nested within it, so you need to reference them qualified via `Json.Null`, `Json.Bool`, etc. While the above example is shown in the REPL, in larger codebases it is common to put relevant static methods like `def stringify` on the `enum`'s companion object, in this case `object Json`, such that it is called via `Json.stringify`:

```
object Json:
    def stringify(value0: Json): String = ...

println(Json.stringify(Json.Str("hello"))) // "hello"
```

5.11.scala

Enums can also have instance methods defined in the `enum` body. Within an instance method the `Json.` qualifier can be dropped, because the cases will be in lexical scope. For example, rather than making `def stringify` a static method, you can make it an instance method as shown below:

```
enum Json:
    case ...

    def stringify: String = this match
        case Null() => "null"
        case Bool(value) => value.toString
        case Str(value) => "\"" + value.replace("\"", "\\\"") + "\""
        case Num(value) => value.toString
        case Arr(value) => "[" + value.map(_.stringify).mkString(", ") + "]"
        case Dict(value) =>
            value.map{ (k, v) => Str(k).stringify + ": " + v.stringify }.mkString("{", ", ",
"}")

println(Json.Str("hello").stringify) // "hello"
```

5.12.scala

Note that unlike `sealed trait`/`case class` hierarchies, `enum`s cannot have method `def`s attached to the individual `case`s. All instance methods or fields must be defined for the `enum` as a whole, and `case`-specific logic implemented using pattern matching on `this` as shown above.

See example 5.3 - Enums

5.1.4 Choosing between Normal Traits and Classes v.s. Sealed Traits or Enums

Both normal `trait`s and `sealed trait`s are common in Scala applications: normal `trait`s for interfaces which may have any number of subclasses, and `sealed trait`s where the number of subclasses is fixed.

Normal `trait`s and `sealed trait`s make different things easy:

- A normal `class` or `trait` hierarchy makes it easy to add additional sub-classes: just define your class and implement the necessary methods. However, it makes it difficult to add new methods: a new method needs to be added to all existing subclasses, of which there may be many.

- A `sealed trait` or `enum` hierarchy is the opposite: it is easy to add new methods, since a new method can simply pattern match on each sub-class and decide what it wants to do for each. However, adding new sub-classes is difficult, as you need to go to all existing pattern matches and add the `case` to handle your new sub-class

In general, `sealed trait` or `enum`s are good for modeling hierarchies where you expect the number of sub-classes to change very little or not-at-all. Using the example from earlier, JSON is ideal to model with an `enum`:

```
enum Json:
    case Null()
    case Bool(value: Boolean)
    case Str(value: String)
    case Num(value: Double)
    case Arr(value: Seq[Json])
    case Dict(value: Map[String, Json])
```
5.13.scala

- A JSON value can only be JSON null, boolean, number, string, array, or dictionary.

- JSON has not changed in 20 years, so it is unlikely that anyone will need to extend our JSON `enum` with additional subclasses.

- While the set of sub-classes is fixed, the range of operations we may want to do on a JSON blob is unbounded: parse it, serialize it, pretty-print it, minify it, sanitize it, etc.

Thus it makes sense to model a JSON data structure as a closed `sealed trait` or `enum` hierarchy rather than a normal open `trait` or `class` hierarchy.

5.2 Pattern Matching

5.2.1 Match

Scala allows pattern matching on values using the `match` keyword. This is similar to the `switch` statement found in other programming languages, but more flexible: apart from `match`ing on primitive integers and strings, you can also use `match` to extract values from ("destructure") composite data types like tuples and `case class`es. Note that in many examples below, there is a `case _ =>` clause which defines the default case if none of the earlier cases matched.

5.2.1.1 Matching on `Int`s

```
> def dayOfWeek(x: Int) = x match
      case 1 => "Mon"; case 2 => "Tue"
      case 3 => "Wed"; case 4 => "Thu"
      case 5 => "Fri"; case 6 => "Sat"
      case 7 => "Sun"; case _ => "Other"

> dayOfWeek(5)
res5: String = "Fri"

> dayOfWeek(-1)
res6: String = "Other"
```

5.14.scala

5.2.1.2 Matching on `String`s

```
> def dayIndex(d: String) = d match
      case "Mon" => 1; case "Tue" => 2
      case "Wed" => 3; case "Thu" => 4
      case "Fri" => 5; case "Sat" => 6
      case "Sun" => 7; case _ => -1

> dayIndex("Fri")
res7: Int = 5

> dayIndex("Other")
res8: Int = -1
```

5.15.scala

5.2.1.3 Matching on tuple `(Int, Int)`

```
> for i <- Range.inclusive(1, 100) do
      val s = (i % 3, i % 5) match
          case (0, 0) => "FizzBuzz"
          case (0, _) => "Fizz"
          case (_, 0) => "Buzz"
          case _ => i
      println(s)
1
2
Fizz
4
Buzz
...
```

5.16.scala

5.2.1.4 Matching on tuple `(Boolean, Boolean)`

```
> for i <- Range.inclusive(1, 100) do
      val s = (i % 3 == 0, i % 5 == 0) match
          case (true, true) => "FizzBuzz"
          case (true, false) => "Fizz"
          case (false, true) => "Buzz"
          case (false, false) => i
      println(s)
1
2
Fizz
4
Buzz
...
```

5.17.scala

5.2.1.5 Matching on Case Classes:

```
> case class Point(x: Int, y: Int)

> def direction(p: Point) = p match
      case Point(0, 0) => "origin"
      case Point(_, 0) => "horizontal"
      case Point(0, _) => "vertical"
      case _ => "diagonal"

> direction(Point(0, 0))
res9: String = "origin"

> direction(Point(1, 1))
res10: String = "diagonal"

> direction(Point(10, 0))
res11: String = "horizontal"
```

5.18.scala

5.2.1.6 Matching on String Patterns:

```
> def splitDate(s: String) = s match
      case s"$day-$month-$year" =>
          s"$day / $month / $year"
      case _ => "not a date"

> splitDate("9-8-1965")
res12: String = "9 / 8 / 1965"

> splitDate("9-8")
res13: String = "not a date"
```

5.19.scala

(Note that pattern matching on string patterns only supports simple glob-like patterns, and doesn't support richer patterns like Regular Expressions. For those, you can use the functionality of the `scala.util.matching.Regex` class)

5.2.2 Nested Matches

Patterns can also be nested, e.g. this example matches a string pattern within a `case class` pattern:

```
> case class Person(name: String, title: String)

> def greet(p: Person) = p match
      case Person(s"$first $last", title) =>
          println(s"Hello $title $last")

      case Person(name, title) =>
          println(s"Hello $title $name")

> greet(Person("Haoyi Li", "Mr"))
Hello Mr Li

> greet(Person("Who?", "Dr"))
Hello Dr Who?
```

5.20.scala

Patterns can be nested arbitrarily deeply. The following example matches string patterns, inside a `case class`, inside a tuple:

```
> def greet2(husband: Person, wife: Person) = (husband, wife) match
      case (Person(s"$first1 $last1", _), Person(s"$first2 $last2", _))
          if last1 == last2 =>
          println(s"Hello Mr and Ms $last1")

      case (Person(name1, _), Person(name2, _)) =>
          println(s"Hello $name1 and $name2")

> greet2(Person("James Bond", "Mr"), Person("Jane Bond", "Ms"))
Hello Mr and Ms Bond

> greet2(Person("James Bond", "Mr"), Person("Jane", "Ms"))
Hello James Bond and Jane
```
5.21.scala

5.2.3 Loops and Vals

The last two places you can use pattern matching are inside `for`-loops and `val` definitions. Pattern matching in `for`-loops is useful when you need to iterate over collections of tuples:

```
> val a = Array[(Int, String)]((1, "one"), (2, "two"), (3, "three"))

> for (i, s) <- a do println(s + i)
one1
two2
three3
```
5.22.scala

Pattern matching in `val` statements is useful when you are sure the value will match the given pattern, and all you want to do is extract the parts you want. If the value doesn't match, this fails with an exception:

```
> case class Point(x: Int, y: Int)

> val p = Point(123, 456)

> val Point(x, y) = p
x: Int = 123
y: Int = 456
```
5.23.scala

```
> val s"$first $second" =
      "Hello World".runtimeChecked

first: String = "Hello"
second: String = "World"

> val flipped = s"$second $first"
flipped: String = "World Hello"

> val s"$first $second" =
      "Hello".runtimeChecked

scala.MatchError: Hello
```
5.24.scala

5.2.4 Pattern Matching on Sealed Traits, Enums, and Case Classes

Pattern matching lets you elegantly work with structured data comprising `case class`es, `sealed trait`s, or `enum`s. For example, let's consider a simple `sealed trait` that represents arithmetic expressions:

```
> {
  sealed trait Expr
  case class BinOp(left: Expr, op: String, right: Expr) extends Expr
  case class Literal(value: Int) extends Expr
  case class Variable(name: String) extends Expr
  }
```
5.25.scala

Where `BinOp` stands for "Binary Operation". This can represent the arithmetic expressions, such as the following

`x + 1`	`BinOp(Variable("x"), "+", Literal(1))`

`x * (y - 1)`	`BinOp(`
	`  Variable("x"),`
	`  "*",`
	`  BinOp(Variable("y"), "-", Literal(1))`
	`)`
	5.26.scala

`(x + 1) * (y - 1)`	`BinOp(`
	`  BinOp(Variable("x"), "+", Literal(1)),`
	`  "*",`
	`  BinOp(Variable("y"), "-", Literal(1))`
	`)`
	5.27.scala

For now, we will ignore the parsing process that turns the string on the left into the structured `case class` structure on the right: we will cover that in ***Chapter 19: Parsing Structured Text***. Let us instead consider two things you may want to do once you have parsed such an arithmetic expression to the `case class`es we see above: we may want to print it to a human-friendly string, or we may want to evaluate it given some variable values.

5.2.4.1 Stringifying Our Expressions

Converting the expressions to a string can be done using the following approach:

- If an `Expr` is a `Literal`, the string is the value of the literal
- If an `Expr` is a `Variable`, the string is the name of the variable
- If an `Expr` is a `BinOp`, the string is the stringified left expression, followed by the operation, followed by the stringified right expression

Converted to pattern matching code, this can be written as follows:

```
> def stringify(expr: Expr): String = expr match
      case BinOp(left, op, right) => s"(${stringify(left)} $op ${stringify(right)})"
      case Literal(value) => value.toString
      case Variable(name) => name                                    5.28.scala
```

We can construct some `Expr`s and feed them into our `stringify` function to see the output:

```
> val smallExpr = BinOp(
      Variable("x"),
      "+",
      Literal(1)
  )

> stringify(smallExpr)
res52: String = "(x + 1)"                                            5.29.scala
```

```
> val largeExpr = BinOp(
      BinOp(Variable("x"), "+", Literal(1)),
      "*",
      BinOp(Variable("y"), "-", Literal(1))
  )

> stringify(largeExpr)
res54: String = "((x + 1) * (y - 1))"                                5.30.scala
```

5.2.4.2 Evaluating Our Expressions

Evaluation is a bit more complex than stringifying the expressions, but only slightly. We need to pass in a `values` map that holds the numeric value of every variable, and we need to treat `+`, `-`, and `*` operations differently:

```
> def eval(expr: Expr, values: Map[String, Int]): Int =
      expr.runtimeChecked match
          case BinOp(left, "+", right) => eval(left, values) + eval(right, values)
          case BinOp(left, "-", right) => eval(left, values) - eval(right, values)
          case BinOp(left, "*", right) => eval(left, values) * eval(right, values)
          case Literal(value) => value
          case Variable(name) => values(name)

> eval(largeExpr, Map("x" -> 10, "y" -> 20))
res17: Int = 209                                                     5.31.scala
```

Overall, this looks relatively similar to the `stringify` function we wrote earlier: a recursive function that pattern matches on the `expr: Expr` parameter to handle each `case class` that implements `Expr`. The cases handling child-free `Literal` and `Variable` are trivial, while in the `BinOp` case we recurse on both left and right children before combining the result. This is a common way of working with recursive data structures in any language, and Scala's `sealed trait`s, `enum`s, `case class`es and pattern matching make it concise and easy.

This `Expr` structure and the printer and evaluator we have written are intentionally simplistic, just to give us a chance to see how pattern matching can be used to easily work with structured data modeled as `case class`es, `sealed trait`s, and `enum`s. We will be exploring these techniques much more deeply in ***Chapter 20: Implementing a Programming Language***.

See example 5.4 - PatternMatching

5.3 By-Name Parameters

```
> def func(arg: => String) = ...
```

Scala "by-name" method parameters are parameters whose type is defined as `: => T` syntax, which are evaluated each time they are referenced in the method body. This has three primary use cases:

1. Avoiding evaluation if the argument does not end up being used
2. Wrapping evaluation to run setup and teardown code before and after the argument evaluates
3. Repeating evaluation of the argument more than once

5.3.1 Avoiding Evaluation

The following `log` method uses a by-name parameter to avoid evaluating the `msg: => String` unless it is actually going to get printed. This can help avoid spending CPU time constructing log messages (here via `"Hello " + 123 + " World"`) even when logging is disabled:

```
> var logLevel = 1

> def log(l: Int, msg: => String) =
      if l > logLevel
      then println(msg)
```

5.32.scala

```
> log(2, "Hello " + 123 + " World")
Hello 123 World

> logLevel = 3
logLevel: Int = 3

> log(2, "Hello " + 123 + " World")
<no output>
```

5.33.scala

Often a method does not end up using all of its arguments all the time. In the above example, by not computing log messages when they are not needed, we can save a significant amount of CPU time and object allocations which may make a difference in performance-sensitive applications.

The `getOrElse` and `getOrElseUpdate` methods we saw in ***Chapter 4: Scala Collections*** are similar: these methods do not use the argument representing the default value if the value we are looking for is already present. By making the default value a by-name parameter, we do not have to evaluate it in the case where it does not get used.

5.3.2 Wrapping Evaluation

Using by-name parameters to "wrap" the evaluation of your method in some setup/teardown code is another common pattern. The following `measureTime` function defers evaluation of `f: => Unit`, allowing us to run `System.nanoTime()` before and after the argument is evaluated and thus print out the time taken:

```
> def measureTime(f: => Unit) =
      val start = System.nanoTime()
      f
      val end = System.nanoTime()
      val ms = (end - start) / 1000000
      println("Evaluation took " + ms + " milliseconds")

> measureTime(new Array[String](100 * 1000 * 1000).hashCode())
Evaluation took 29 milliseconds

> measureTime: // block syntax for calling a method
      new Array[String](100 * 1000 * 1000).hashCode()

Evaluation took 32 milliseconds

> measureTime { // curly brace syntax
      new Array[String](100 * 1000 * 1000).hashCode()
  }

Evaluation took 27 milliseconds                                    5.34.scala
```

There are many other use cases for such wrapping:

- Setting some thread-local context while the argument is being evaluated
- Evaluating the argument inside a `try-catch` block so we can handle exceptions
- Evaluating the argument in a `Future` so the logic runs asynchronously on another thread

These are all cases where using by-name parameter can help.

5.3.3 Repeating Evaluation

The last use case we will cover for by-name parameters is repeating evaluation of the method argument. The following snippet defines a generic `retry` method: this method takes in an argument, evaluates it within a `try-catch` block, and re-executes it on failure with a maximum number of attempts. We test this by using it to wrap a call which may fail, and seeing the `retry` messages get printed to the console.

```
> def retry[T](max: Int)(f: => T): T =
      var tries = 0
      var result: Option[T] = None
      while result == None do
          try
              result = Some(f)
          catch case e: Throwable =>
              tries += 1
              if tries > max then throw e
              else
                  println(s"retry #$tries")
      result.get
```

5.35.scala

```
> val baseUrl = "https://httpbin.org/status"

> retry(max = 5):
      // Only succeeds with 200
      // status 1/3 of the time
      requests.get(s"$baseUrl/200,400,500")
retry #1
retry #2
res16: requests.Response = Response(
    ".../httpbin.org/status/200,400,500",
    statusCode = 200,
    ...
)
```

5.36.scala

Above we define `retry` as a generic function taking a type parameter `[T]`, taking a by-name parameter that computes a value of type `T`, and returning a `T` once the code block is successful. We can then use `retry` to wrap a code block of any type, and it will retry that block and return the first `T` it successfully computes.

Making `retry` take a by-name parameter is what allows it to repeat evaluation of the `requests.get` block where necessary. Other use cases for repetition include running performance benchmarks or performing load tests. In general, by-name parameters aren't something you use very often, but when necessary they let you write code that manipulates the evaluation of a method argument in a variety of useful ways: instrumenting it, retrying it, eliding it, etc.

We will learn more about the `requests` library that we used in the above snippet in ***Chapter 12: Working with HTTP APIs***.

See example 5.5 - ByName

5.4 Apply Methods

Scala allows you to define an `apply` method on an object that lets you call that object like a function via the `foo(...)` syntax. In the example below, because `class Add` has a `def apply` method, we can write `add1(10)` or `addMore(10)` on instances of `Add` without needing to spell out `add1.apply(10)` or `addMore.apply(10)`:

```
> class Add(x: Int):
      def apply(y: Int) = x + y

> val add1 = Add(1)

> val addMore = Add(5)
```

5.37.scala

```
> add1(10)
res0: Int = 11

> addMore(10)
res1: Int = 15
```

5.38.scala

This can be useful when the class or object has one "primary" way it is used. One common use for this is factory methods in the companion object of a class. In the example below, we define `class Foo` that takes an `Int` in its constructor, but also a factory method `def apply` on the companion `object Foo` that takes a `String` and converts it to an `Int` to pass it to the constructor:

```
class Foo(x: Int):
    def printMsg(msg: String) =
        println(msg + x)

object Foo:
    def apply(s: String): Foo =
        new Foo(s.toInt)
```

5.39.scala

```
> val x = new Foo(123) // call constructor

> val y = Foo("123") // call factory method
```

5.40.scala

This gives us a natural place to put factory methods related to `Foo` in a way that downstream users can easily discover and make use of.

Note that when an `apply` method is present on the companion object, you need to explicitly write `new Foo(...)` if you want to call the class constructor, since `Foo(...)` would refer to the factory method on the companion object:

```
> Foo(123)
-- [E007] Type Mismatch Error: ------------------------------------------------
1 |Foo(123)
  |    ^^^
  |    Found:    (123 : Int)
  |    Required: String

> new Foo(123).printMsg("hello")
hello123
```

5.41.scala

5.4.1 Universal Apply Methods

If a class does not have a companion object that explicitly declares an `apply` method, then the compiler will automatically generate an `apply` factory method in the companion, which directly forwards any parameters to the constructor. This "universal" `apply` method allows you to construct values from most classes without `new`.

```
> class Bar(x: Int) // no `apply` declared

> val x = new Bar(23) // call constructor
```
5.42.scala

```
> val y = Bar(23) // calls generated apply

> val z = Bar.apply(23) // or explicitly
```
5.43.scala

5.5 Context Parameters

A *context parameter* (also known as an *implicit parameter*) is a parameter that is automatically filled in for you when calling a function. Context parameters are introduced by a `using` clause. For example, consider the following class `Foo` and the function `bar` that declares a `(using foo: Foo)` parameter:

```
> class Foo(val value: Int)

> def bar(using foo: Foo) = foo.value + 10
```
5.44.scala

5.5.1 Given Instances

If you try to call `bar` without a `given Foo` value in scope, (known as a *given instance*), you get a compilation error. To call `bar`, you need to define a given instance of the type `Foo`, so the call to `bar` can resolve it from the enclosing scope:

```
> bar
-- [E172] Type Error: ------------------
1 |bar
  |   ^
  |   No given instance of type Foo was
  |   found for parameter foo of method
  |   bar
```
5.45.scala

```
> given foo: Foo = Foo(1)

> bar // `foo` resolved implicitly
res17: Int = 11

> bar(using foo) // `foo` passed explicitly
res18: Int = 11
```
5.46.scala

Context parameters are similarly to the *default values* we saw in ***Chapter 3: Basic Scala***. Both of them allow you to pass in a value explicitly or fall back to some default. The main difference is that while default values are "hard coded" at the definition site of the method, context parameters take their default value from whatever `given` instance is in scope at the call-site. We'll now look into a more concrete example before digging into a more advanced use cases in Typeclass Inference (*5.6*).

5.5.2 Passing ExecutionContext to Futures

As an example, code using `scala.concurrent.Future` from the standard library needs an `ExecutionContext` to work. As a result, we end up passing this `ExecutionContext` everywhere, which is tedious and verbose:

```
def getEmployee(ec: ExecutionContext, id: Int): Future[Employee] = ...
def getRole(ec: ExecutionContext, employee: Employee): Future[Role] = ...

val executionContext: ExecutionContext = ...

val bigEmployee: Future[EmployeeWithRole] =
    getEmployee(executionContext, 100).flatMap(
        e => getRole(executionContext, e).map(executionContext, r => EmployeeWithRole(e, r))
    )
```

5.47.scala

`getEmployee` and `getRole` perform asynchronous actions, which we then `map` and `flatMap` to do further work. Exactly how the `Future`s work is beyond the scope of this section: for now, what is notable is how every operation needs to be passed the `executionContext` to do their work.

Without context parameters, we have the following options:

- Passing `executionContext` explicitly is verbose and can make your code harder to read: the logic we care about is drowned in a sea of boilerplate `executionContext` passing
- Making `executionContext` global would be concise, but would lose the flexibility of passing different values in different parts of your program
- Putting `executionContext` into a thread-local variable would maintain flexibility and conciseness, but it is error-prone and easy to forget to set the thread-local before running code that needs it

All of these options have tradeoffs, forcing us to either sacrifice conciseness, flexibility, or safety. Scala's context parameters provide a fourth option: passing `executionContext` implicitly, which gives us the conciseness, flexibility, and safety that the above options are unable to give us.

5.5.3 Dependency Injection via Using Clauses

To resolve these issues, we can make all these functions take the `executionContext` as a context parameter. This is already the case for standard library operations like `flatMap` and `map` on `Future`s, and we can modify our `getEmployee` and `getRole` functions to follow suit by adding `using` clauses. After that, we can redefine `executionContext` as a `given` instance, and it will automatically get picked up by all the method calls below.

```
def getEmployee(id: Int)(using ec: ExecutionContext): Future[Employee] = ...
def getRole(employee: Employee)(using ExecutionContext): Future[Role] = ...

given executionContext: ExecutionContext = ...

val bigEmployee: Future[EmployeeWithRole] =
    getEmployee(100).flatMap(e => getRole(e).map(r => EmployeeWithRole(e, r)))
```

5.48.scala

Anonymous context parameters: Using clauses can also declare anonymous context parameters, where only the type is specified. e.g. the `(using ExecutionContext)` syntax in the `getRole` method.

Context parameters can help clean up code where we pass the same shared context or configuration object throughout your entire application:

- By making the "uninteresting" parameter passing implicit, it can focus the reader's attention on the core logic of your application. And if a context parameter only exists to be passed along implicitly, making it anonymous helps to avoid unnecessary attention.
- Since context parameters can be passed explicitly, they preserve the flexibility for the developer in case they want to manually specify or override the context parameter being passed.
- The fact that missing given instances are a compile time error makes their usage less error-prone than thread-locals. A missing given instance will be caught early, before code is compiled and deployed.

See example 5.7 - ImplicitParameters

5.6 Typeclass Inference

A second way that context parameters are useful is by using them to associate values to types. This is often called a *typeclass*, the term originating from the Haskell programming language, although it has nothing to do with types and `class`es in Scala. While typeclasses are a technique built on the same `given` instances and `using` clauses described earlier, they are an interesting and important enough technique to deserve their own section in this chapter.

5.6.1 Problem Statement: Parsing Command Line Arguments

Let us consider the task of parsing command-line arguments, given as `String`s, into Scala values of various types: `Int`s, `Boolean`s, `Double`s, etc. This is a common task that almost every program has to deal with, either directly or by using a library.

A first sketch may be writing a generic method to parse the values. The signature might look something like:

```
def parseFromString[T](s: String): T = ...

val args = Seq("123", "true", "7.5")
val myInt = parseFromString[Int](args(0))
val myBoolean = parseFromString[Boolean](args(1))
val myDouble = parseFromString[Double](args(2))
```
5.49.scala

On the surface this seems impossible to implement:

- How does the `parseCliArgument` know how to convert the given `String` into an arbitrary `T`?
- How does it know what types `T` a command-line argument can be parsed into, and which it cannot? For example, we should be able to parse a `String` into an `Int`, but should not be able to parse a `String` into a `java.net.ServerSocket`

5.6.2 Separate Parser Objects

A second sketch at a solution may be to define separate parser objects, one for each type we need to be able to parse. For example:

```
trait StrParser[T]:
    def parse(s: String): T

object ParseInt extends StrParser[Int]:
    def parse(s: String) = s.toInt

object ParseBoolean extends StrParser[Boolean]:
    def parse(s: String) = s.toBoolean

object ParseDouble extends StrParser[Double]:
    def parse(s: String) = s.toDouble
```
5.50.scala

We can then call these as follows:

```
val args = Seq("123", "true", "7.5")
val myInt = ParseInt.parse(args(0))
val myBoolean = ParseBoolean.parse(args(1))
val myDouble = ParseDouble.parse(args(2))
```
5.51.scala

This works. However, it then leads to another problem: if we wanted to write a method that didn't parse a `String` directly, but parsed a value from the console, how would we do that? We have two options.

5.6.2.1 Re-Using Our StrParsers

The first option is writing a whole new set of `object`s dedicated to parsing from the console:

```
trait ConsoleParser[T]:
    def parse(): T

object ConsoleParseInt extends ConsoleParser[Int]:
    def parse() = scala.Console.in.readLine().toInt

object ConsoleParseBoolean extends ConsoleParser[Boolean]:
    def parse() = scala.Console.in.readLine().toBoolean

object ConsoleParseDouble extends ConsoleParser[Double]:
    def parse() = scala.Console.in.readLine().toDouble

val myInt = ConsoleParseInt.parse()
val myBoolean = ConsoleParseBoolean.parse()
val myDouble = ConsoleParseDouble.parse()
```
5.52.scala

The second option is defining a helper method that receives a `StrParser[T]` as an argument, which we would need to pass in to tell it how to parse the type `T`

```
def parseFromConsole[T](parser: StrParser[T]) = parser.parse(scala.Console.in.readLine())

val myInt = parseFromConsole[Int](ParseInt)
val myBoolean = parseFromConsole[Boolean](ParseBoolean)
val myDouble = parseFromConsole[Double](ParseDouble)
```
5.53.scala

Both of these solutions are clunky:

1. The first because we need to duplicate all the `Int`/`Boolean`/`Double`/etc. parsers. What if we need to parse input from the network? From files? We would need to duplicate every parser for each case.

2. The second because we need to pass these `ParseFoo` objects everywhere. Often there is only a single `StrParser[Int]` we can pass to `parseFromConsole[Int]`. Why can't the compiler infer it for us?

5.6.3 Solution: given StrParser

The solution to the problems above is to make the instances of `StrParser` `given`:

```
trait StrParser[T]:
    def parse(s: String): T

object StrParser:
    given ParseInt: StrParser[Int]:
        def parse(s: String) = s.toInt

    given ParseBoolean: StrParser[Boolean]:
        def parse(s: String) = s.toBoolean

    given ParseDouble: StrParser[Double]:
        def parse(s: String) = s.toDouble
```

5.54.scala

We put the `given ParseInt`, `ParseBoolean`, etc. in a companion `object StrParser` with the same name as the `trait StrParser` next to it. Given instances in the *companion object* are also treated specially, and do not need to be imported into scope in order to be used as a context parameter.

Note that if you are entering this into the Scala REPL, you need to surround both declarations with an extra pair of curly brackets `{...}` so that both the `trait` and `object` are defined in the same REPL command.

Now, while we can still explicitly call `ParseInt.parse(args(0))` to parse literal strings as before, we can now write a generic function that automatically uses the correct instance of `StrParser` depending on what type we asked it to parse:

```
def parseFromString[T](s: String)(using parser: StrParser[T]) = parser.parse(s)

val args = Seq("123", "true", "7.5")
val myInt = parseFromString[Int](args(0))
val myBoolean = parseFromString[Boolean](args(1))
val myDouble = parseFromString[Double](args(2))
```

5.55.scala

This looks similar to our initial sketch, except by taking a `(using parser: StrParser[T])` parameter the function can now automatically infer the correct `StrParser` for each type it is trying to parse.

5.6.3.1 Re-Using Our given StrParsers

Making our `StrParser[T]`s given instances means we can re-use them without duplicating our parsers or passing them around manually. For example, we can write a function that parses strings from the console:

```
def parseFromConsole[T](using parser: StrParser[T]) =
    parser.parse(scala.Console.in.readLine())

val myInt = parseFromConsole[Int]
```

5.56.scala

The call to `parseFromConsole[Int]` automatically infers the `StrParser.ParseInt` given instance from the `StrParser` companion object, without needing to duplicate it or tediously pass it around. That makes it very easy to write code that works with a generic type `T` as long as `T` has a suitable `StrParser`.

5.6.3.2 Context-Bound Syntax

This technique of taking a context parameter with a generic type is common enough that the Scala language provides dedicated syntax for it. The following method signature:

```
def parseFromString[T](s: String)(using parser: StrParser[T]) = ...
```

Can be written more concisely as:

```
def parseFromString[T: StrParser](s: String) = ...
```

This syntax is referred to as a *context bound*, and it is semantically equivalent to the `(using parser: StrParser[T])` syntax above. When using the context bound syntax, the context parameter is anonymous, i.e. isn't given a name, and so we cannot call `parser.parse` like we did earlier. Instead, we can resolve the given instances via the `summon` function, e.g. `summon[StrParser[T]].parse`.

5.6.3.3 Compile-Time Safety with Given Instances

As Typeclass Inference uses the same `given` language feature we saw earlier, mistakes such as attempting to call `parseFromConsole` with an invalid type produce a compile error:

```
> val myDatagramSocket = parseFromConsole[java.net.DatagramSocket]
-- [E172] Type Error: ----------------------------------------------------
1 |val myDatagramSocket = parseFromConsole[java.net.DatagramSocket]
  |                                                    ^
  |No given instance of type StrParser[java.net.DatagramSocket] was found
  |for parameter parser of method parseFromConsole                  5.57.scala
```

Similarly, if you try to call a method taking a `(using parser: StrParser[T])` from another method that does not have such an implicit available, the compiler will also raise an error:

```
> def genericMethodWithoutImplicit[T](s: String) = parseFromString[T](s)
-- [E172] Type Error: ----------------------------------------------------
1 |def genericMethodWithoutImplicit[T](s: String) = parseFromString[T](s)
  |                                                                  ^
  |No given instance of type StrParser[T] was found for parameter parser of
  |method parseFromString                                           5.58.scala
```

Most of the things we have done with Typeclass Inference could also be achieved using runtime reflection. However, relying on runtime reflection is fragile, and it is very easy for mistakes, bugs, or mis-configurations to make it to production before failing catastrophically. In contrast, Scala's `given` instances and `using` clauses let you achieve the same outcome but in a safe fashion: mistakes are caught early at compile-time, and you can fix them at your leisure rather than under the pressure of a ongoing production outage.

5.6.4 Recursive Typeclass Inference

We have already seen how we can use the typeclass technique to automatically pick which `StrParser` to use based on the type we want to parse to. This can also work for more complex types, where we tell the compiler we want a `Seq[Int]`, `(Int, Boolean)`, or even nested types like `Seq[(Int, Boolean)]`, and the compiler will automatically assemble the logic necessary to parse the type we want.

5.6.4.1 Parsing Sequences

For example, the following `ParseSeq` given instance definition provides a `StrParser[Seq[T]]` for any type `T` which itself has an implicit `StrParser[T]` in scope:

```
given ParseSeq: [T] => (p: StrParser[T]) => StrParser[Seq[T]]:
    def parse(s: String) = s.split(',').toSeq.map(p.parse)
```
5.59.scala

Note that unlike the `given`s we defined earlier which are singletons, here we have a `given` with type and term parameters. Depending on the type `T`, we would need a different `StrParser[T]`, and thus need a different `StrParser[Seq[T]]`. `given ParseSeq` would thus return a different `StrParser` each time it is called with a different type `T`.

Note also that in given declarations such as `ParseSeq` above, the `(p: StrParser[T]) =>` syntax actually declares a context parameter, rather than an ordinary term parameter, so to explicitly pass in an argument at the call-site requires `(using ...)` syntax.

From this one definition, we can now parse `Seq[Boolean]`s, `Seq[Int]`s, etc.

```
> parseFromString[Seq[Boolean]]("true,false,true")
res19: Seq[Boolean] = ArraySeq(true, false, true)

> parseFromString[Seq[Int]]("1,2,3,4")
res20: Seq[Int] = ArraySeq(1, 2, 3, 4)
```
5.60.scala

What we are effectively doing is teaching the compiler how to produce a `StrParser[Seq[T]]` for any type `T` as long as it has a given `StrParser[T]` available. Since we already have `StrParser[Int]`, `StrParser[Boolean]`, and `StrParser[Double]` available, the `ParseSeq` given instance provides any of `StrParser[Seq[Int]]`, `StrParser[Seq[Boolean]]`, and `StrParser[Seq[Double]]` for free.

The `StrParser[Seq[T]]` we are instantiating has a parse method that receives a parameter `s: String` and returns a `Seq[T]`. We just needed to implement the logic necessary to do that transformation, which we have done in the code snippet above.

5.6.4.2 Parsing Tuples

Similar to how we defined a `given` to parse `Seq[T]`s, we could do the same to parse tuples. We do so below by assuming that tuples are represented by `key=value` pairs in the input string:

```
given ParseTuple: [T, V] => (p1: StrParser[T], p2: StrParser[V]) => StrParser[(T, V)]:
    def parse(s: String) =
        val Array(left, right) = s.split('=').runtimeChecked
        (p1.parse(left), p2.parse(right))
```
5.61.scala

This definition produces a `StrParser[(T, V)]`, but only for a type `T` and type `V` for which there are `StrParser`s available. Now we can parse tuples, as `=`-separated pairs:

```
> parseFromString[(Int, Boolean)]("123=true")
res21: (Int, Boolean) = (123, true)

> parseFromString[(Boolean, Double)]("true=1.5")
res22: (Boolean, Double) = (true, 1.5)
```
5.62.scala

5.6.4.3 Parsing Nested Structures

The two definitions above, `given ParseSeq` and `given ParseTuple`, are enough to let us also parse sequences of tuples, or tuples of sequences:

```
> parseFromString[Seq[(Int, Boolean)]]("1=true,2=false,3=true")
res23: Seq[(Int, Boolean)] = ArraySeq((1, true), (2, false), (3, true))

> parseFromString[(Seq[Int], Seq[Boolean])]("1,2,3=true,false,true")
res24: (Seq[Int], Seq[Boolean]) = (ArraySeq(1, 2, 3), ArraySeq(true, false, true))
```
5.63.scala

Note that in this case we cannot handle nested `Seq[Seq[T]]`s or nested tuples due to how we're naively splitting the input string. A more structured parser handles such cases without issues, allowing us to specify an arbitrarily complex output type and automatically inferring the necessary parser. We will use a serialization library that uses this technique in ***Chapter 8: JSON and Binary Data Serialization***.

Most statically typed programming languages can infer types to some degree: even if not every expression is annotated with an explicit type, the compiler can still figure out the types based on the program structure. Typeclass derivation is effectively the reverse: by providing an explicit type, the compiler can infer the program structure necessary to provide a value of the type we are looking for.

In the example above, we just need to define how to handle the basic types - how to produce a `StrParser[Boolean]`, `StrParser[Int]`, `StrParser[Seq[T]]`, `StrParser[(T, V)]` - and the compiler is able to figure out how to produce a `StrParser[Seq[(Int, Boolean)]]` when we need it.

See example 5.8 - TypeclassInference

5.7 Conclusion

In this chapter, we have explored some of the more unique features of Scala. Case Classes or Pattern Matching you will use on a daily basis, while By-Name Parameters, Context Parameters, Given Instances, or Typeclass Inference are more advanced tools that you might only use when dictated by a framework or library. Nevertheless, these are the features that make the Scala language what it is, providing a way to tackle difficult problems more elegantly than most mainstream languages allow.

We have walked through the basic motivation and use cases for these features in this chapter. You will get familiar with more use cases as we see the features in action throughout the rest of this book.

This chapter will be the last in which we discuss the Scala programming language in isolation: subsequent chapters will introduce you to much more complex topics like working with your operating system, remote services, and third-party libraries. The Scala language fundamentals you have learned so far will serve you well as you broaden your horizons, from learning about the Scala language itself to using the Scala language to solve real-world problems.

Exercise: Define a function that uses pattern matching on the `Expr`s we saw earlier to perform simple algebraic simplifications:

`(1 + 1)`	`2`
`((1 + 1) * x)`	`(2 * x)`
`((2 - 1) * x)`	`x`
`(((1 + 1) * y) + ((1 - 1) * x))`	`(2 * y)`

See example 5.9 - Simplify

Exercise: Modify the `def retry` function earlier that takes a by-name parameter and make it perform an exponential backoff, sleeping between retries, with a configurable initial `delay` in milliseconds:

```
retry(max = 50, delay = 100 /*milliseconds*/):
    requests.get(s"$httpbin/status/200,400,500")
```
5.64.scala

See example 5.10 - Backoff

Exercise: Modify the typeclass-based `parseFromString` method we saw earlier to take a JSON-like format, where lists are demarcated by square brackets with comma-separated elements. This should allow it to parse and construct arbitrarily deep nested data structures automatically via typeclass inference:

```
> parseFromString[Seq[Boolean]](
      // 1 layer of nesting
      "[true,false,true]"
  )
res1: Seq[Boolean] = List(true, false, true)

> parseFromString[Seq[(Seq[Int], Seq[Boolean])]](
      // 3 layers of nesting
      "[[[1],[true]],[[2,3],[false,true]],[[4,5,6],[false,true,false]]]"
  )
res2: Seq[(Seq[Int], Seq[Boolean])] = List(
    (List(1), List(true)),
    (List(2, 3), List(false, true)),
    (List(4, 5, 6), List(false, true, false))
)

> parseFromString[Seq[(Seq[Int], Seq[(Boolean, Double)])]](
      // 4 layers of nesting
      "[[[1],[[true,0.5]]],[[2,3],[[false,1.5],[true,2.5]]]]"
  )
res3: Seq[(Seq[Int], Seq[(Boolean, Double)])] = List(
    (List(1), List((true, 0.5))),
    (List(2, 3), List((false, 1.5), (true, 2.5)))
)
```

5.65.scala

A production-ready version of this `parseFromString` method exists in `upickle.read`, which we will see in ***Chapter 8: JSON and Binary Data Serialization***.

See example 5.11 - Deserialize

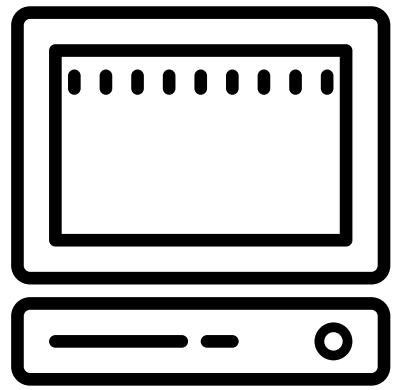
Exercise: How about using typeclasses to generate JSON, rather than parse it? Write a `writeToString` method that uses a `StrWriter` typeclass to take nested values parsed by `parseFromString`, and serialize them to the same strings they were parsed from.

```
> writeToString[Seq[Boolean]](Seq(true, false, true))
res1: String = "[true,false,true]"

> writeToString(Seq(true, false, true)) // type can be inferred
res2: String = "[true,false,true]"

> writeToString[Seq[(Seq[Int], Seq[Boolean])]](
      Seq(
          (Seq(1), Seq(true)),
          (Seq(2, 3), Seq(false, true)),
          (Seq(4, 5, 6), Seq(false, true, false))
      )
  )
res3: String = "[[[1],[true]],[[2,3],[false,true]],[[4,5,6],[false,true,false]]]"

> writeToString(
      Seq(
          (Seq(1), Seq((true, 0.5))),
          (Seq(2, 3), Seq((false, 1.5), (true, 2.5)))
      )
  )
res4: String = "[[[1],[[true,0.5]]],[[2,3],[[false,1.5],[true,2.5]]]]"
```

5.66.scala

See example 5.12 - Serialize

Discuss Chapter 5 online at https://www.handsonscala.com/discuss/5



Part II: Local Development

The second part of this book explores the core tools and techniques necessary for writing Scala applications that run on a single computer. We will cover algorithms, files and subprocess management, data serialization, scripts and build pipelines. This chapter builds towards a capstone project where we write an efficient incremental static site generator using the Scala language.

6

Implementing Algorithms in Scala


```scala
def breadthFirstSearch[T](start: T, graph: Map[T, Seq[T]]): Set[T] =
    val seen = collection.mutable.Set(start)
    val queue = collection.mutable.ArrayDeque(start)

    while queue.nonEmpty do
        val current = queue.removeHead()
        for next <- graph(current) if !seen.contains(next) do
            seen.add(next)
            queue.append(next)

    seen.toSet
```

6.1.scala

Snippet 6.1: a simple breadth-first-search algorithm we will implement using Scala in this chapter

In this chapter, we will walk you through the implementation of a number of common algorithms using the Scala programming language. These algorithms are commonly taught in schools and tested at professional job interviews, so you have likely seen them before.

By implementing them in Scala, we aim to get you more familiar with using the Scala programming language to solve small problems in isolation. We will also see how some of the unique language features we saw in ***Chapter 5: Notable Scala Features*** can be applied to simplify the implementation of these well-known algorithms. This will prepare us for subsequent chapters which will expand in scope to include many different kinds of systems, APIs, tools and techniques.

7

Files and Subprocesses


```
> os.walk(os.pwd).filter(os.isFile).map(p => (os.size(p), p)).sortBy(-_(0)).take(5)
res0: IndexedSeq[(Long, os.Path)] = ArraySeq(
    (6340270L, /Users/lihaoyi/test/post/Reimagining/GithubHistory.gif),
    (6008395L, /Users/lihaoyi/test/post/SmartNation/routes.json),
    (5499949L, /Users/lihaoyi/test/post/slides/Why-You-Might-Like-Scala.js.pdf),
    (5461595L, /Users/lihaoyi/test/post/slides/Cross-Platform-Development-in-...),
    (4576936L, /Users/lihaoyi/test/post/Reimagining/FluentSearch.gif)
)
```
7.1.scala

Snippet 7.1: a short Scala code snippet to find the five largest files in a directory tree

Working with files and subprocesses is one of the most common things you do in programming: from the Bash shell, to Python or Ruby scripts, to large applications written in a compiled language. At some point everyone will have to write to a file or talk to a subprocess. This chapter will walk you through how to perform basic file and subprocess operations in Scala.

This chapter finishes with two small projects: building a simple file synchronizer, and building a streaming subprocess pipeline. These projects will form the basis for ***Chapter 17: Multi-Process Applications*** and ***Chapter 18: Building a Real-time File Synchronizer***

8

JSON and Binary Data Serialization


```
> val output = ujson.Arr(
      ujson.Obj("hello" -> "world", "answer" -> 42),
      true
  )

> output(0)("hello") = "goodbye"

> output(0)("tags") = ujson.Arr("cool", "yay", "nice")

> println(output)
[{"hello":"goodbye","answer":42,"tags":["cool","yay","nice"]},true]
```

8.1.scala

Snippet 8.1: manipulating a JSON tree structure in the Scala REPL

Data serialization is an important tool in any programmer's toolbox. While variables and classes are enough to store data within a process, most data tends to outlive a single program process: whether saved to disk, exchanged between processes, or sent over the network. This chapter will cover how to serialize your Scala data structures to two common data formats - textual JSON and binary MessagePack - and how you can interact with the structured data in a variety of useful ways.

The JSON workflows we learn in this chapter will be used later in ***Chapter 12: Working with HTTP APIs*** and ***Chapter 14: Simple Web and API Servers***, while the binary serialization techniques we learn here will be used later in ***Chapter 17: Multi-Process Applications***.

9

Self-Contained Scala Scripts


```
os.write(
    os.pwd / "_blog/index.html",
    doctype("html")(
        html(
            body(
                h1("Blog"),
                for (_, suffix, _) <- postInfo
                yield h2(a(href := ("post/" + mdNameToHtml(suffix)))(suffix))
            )
        )
    )
)
```

9.1.scala

Snippet 9.1: rendering a HTML page using the third-party Scalatags HTML library

Scala Scripts are a great way to write small programs. Each script is self-contained and can download its own dependencies when necessary, and make use of both Java and Scala libraries. This lets you write and distribute scripts without spending time fiddling with build configuration or library installation.

In this chapter, we will write a static site generator script that uses third-party libraries to process Markdown input files and generate a set of HTML output files, ready for deployment on any static file hosting service. This will form the foundation for ***Chapter 10: Static Build Pipelines***, where we will turn the static site generator into an efficient incremental build pipeline by using the Mill build tool.

10

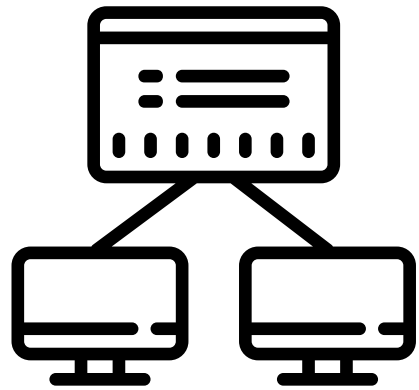
Static Build Pipelines


```
import mill.*

def srcs = Task.Source("src")

def concat = Task:
    os.write(Task.dest / "concat.txt",  os.list(srcs().path).map(os.read(_)))
    PathRef(Task.dest / "concat.txt")
```
10.1.scala

Snippet 10.1: the definition of a simple Mill build pipeline

Build pipelines are a common pattern, where you have files and assets you want to process but want to do so efficiently, incrementally, and in parallel. This usually means only re-processing files when they change, and re-using the already processed assets as much as possible. Whether you are compiling Scala, minifying Javascript, or compressing tarballs, many of these file-processing workflows can be slow. Parallelizing these workflows and avoiding unnecessary work can greatly speed up your development cycle.

This chapter will walk through how to use the Mill build tool to set up these build pipelines, and demonstrate the advantages of a build pipeline over a naive build script. We will take the simple static site generator we wrote in ***Chapter 9: Self-Contained Scala Scripts*** and convert it into an efficient build pipeline that can incrementally update the static site as you make changes to the sources. We will be using the Mill build tool in several of the projects later in the book, starting with ***Chapter 14: Simple Web and API Servers***.



Part III: Web Services

The third part of this book covers using Scala in a world of servers and clients, systems and services. We will explore using Scala both as a client and as a server, exchanging HTML and JSON over HTTP or Websockets. This part builds towards two capstone projects: a parallel web crawler and an interactive chat website, each representing common use cases you are likely to encounter using Scala in a networked, distributed environment.

11

Scraping Websites


```
> val doc = Jsoup.connect("http://en.wikipedia.org/").get()

> doc.title()
res0: String = "Wikipedia, the free encyclopedia"

> val headlines = doc.select("#mp-itn b a")
headlines: org.jsoup.select.Elements =
<a href="/wiki/Michel_Devoret" title="Michel Devoret">Michel Devoret</a>
<a href="/wiki/Mary_E._Brunkow" title="Mary E. Brunkow">Mary E. Brunkow</a>
<a href="/wiki/Shimon_Sakaguchi" title="Shimon Sakaguchi">Shimon Sakaguchi</a>
...
```
11.1.scala

Snippet 11.1: scraping Wikipedia's front-page links using the Jsoup third-party library in the Scala REPL

The user-facing interface of most networked systems is a website. In fact, often that is the *only* interface! This chapter will walk you through using the Jsoup library from Scala to scrape human-readable HTML pages, unlocking the ability to extract data from websites that do not provide access via an API.

Apart from third-party scraping websites, Jsoup is also a useful tool for testing the HTML user interfaces that we will encounter in ***Chapter 14: Simple Web and API Servers***. This chapter is also a chance to get more familiar with using Java libraries from Scala, a necessary skill to take advantage of the broad and deep Java ecosystem. Lastly, it is an exercise in doing non-trivial interactive development in the Scala REPL, which is a great place to prototype and try out pieces of code that are not ready to be saved in a script or project.

12

Working with HTTP APIs


```
> requests.post(
      "https://api.github.com/repos/lihaoyi/test/issues",
      data = ujson.Obj("title" -> "hello"),
      headers = Map("Authorization" -> s"token $token")
  )
res2: requests.Response = Response(
    url = "https://api.github.com/repos/lihaoyi/test/issues",
    statusCode = 201,
    statusMessage = "Created",
...
```

12.1.scala

Snippet 12.1: interacting with Github's HTTP API from the Scala REPL

HTTP APIs have become the standard for any organization that wants to let external developers integrate with their systems. This chapter will walk you through how to access HTTP APIs in Scala, building up to a simple use case: migrating Github issues from one repository to another using Github's public API.

We will build upon techniques learned in this chapter in ***Chapter 13: Fork-Join Parallelism with Futures***, where we will be writing a parallel web crawler using the Wikipedia JSON API to walk the graph of articles and the links between them.

13

Fork-Join Parallelism with Futures


```scala
def fetchAllLinksParallel(startTitle: String, depth: Int): Set[String] =
    var seen = Set(startTitle)
    var current = Set(startTitle)

    for i <- Range(0, depth) do
        val futures = for title <- current yield Future{ fetchLinks(title) }
        val nextTitleLists = futures.map(Await.result(_, Inf))
        current = nextTitleLists.flatten.filter(!seen.contains(_))
        seen = seen ++ current

    seen
```

13.1.scala

Snippet 13.1: a simple parallel web-crawler implemented using Scala Futures

The Scala programming language comes with a Futures API. Futures make parallel and asynchronous programming much easier to handle than working with traditional techniques of threads, locks, and callbacks.

This chapter dives into Scala's Futures: how to use them, how they work, and how you can use them to parallelize data processing workflows. It culminates in using Futures together with the techniques we learned in ***Chapter 12: Working with HTTP APIs*** to write a high-performance concurrent web crawler in a straightforward and intuitive way.

14

Simple Web and API Servers


```scala
package app
object MinimalApplication extends cask.MainRoutes:
    @cask.get("/")
    def hello() =
        "Hello World!"

    @cask.post("/do-thing")
    def doThing(request: cask.Request) =
        request.text().reverse

    initialize()
```

14.1.scala

Snippet 14.1: a minimal Scala web application, using the Cask web framework

Web and API servers are the backbone of internet systems. While in the last few chapters we learned to access these systems from a *client's* perspective, this chapter will teach you how to provide such APIs and Websites from the *server's* perspective. We will walk through a complete example of building a simple real-time chat website serving both HTML web pages and JSON API endpoints. We will re-visit this website in ***Chapter 15: Querying SQL Databases***, where we will convert its simple in-memory datastore into a proper SQL database.

15

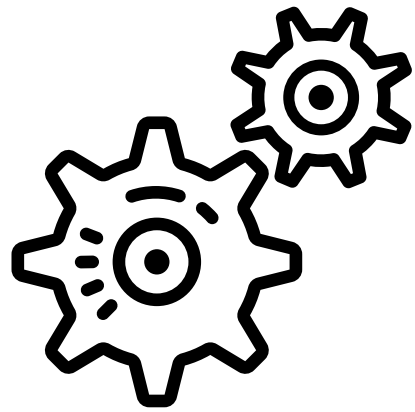
Querying SQL Databases


```
> db.run(
      City.select
          .filter(c => c.population > 5000000 && c.countryCode === "CHN")
          .map(c => (c.name, c.countryCode, c.district, c.population))
  )
query: SELECT city0.name AS res_0, city0.countrycode AS res_1, ...
res35: Seq[(String, String, String, Int)] = Vector(
    ("Shanghai", "CHN", "Shanghai", 9696300),
    ("Peking", "CHN", "Peking", 7472000),
    ("Chongqing", "CHN", "Chongqing", 6351600),
    ("Tianjin", "CHN", "Tianjin", 5286800)
)
```

15.1.scala

Snippet 15.1: using the ScalaSql database query library from the Scala REPL

Most modern systems are backed by relational databases. This chapter will walk you through the basics of using a relational database from Scala, using the ScalaSql query library. We will work through small self-contained examples of how to store and query data within a Postgres database, and then convert the interactive chat website we implemented in ***Chapter 14: Simple Web and API Servers*** to use a Postgres database for data storage.



Part IV: Program Design

The fourth and last part of this book explores different ways of structuring your Scala application to tackle real-world problems. This chapter builds towards another two capstone projects: building a real-time file synchronizer and building a programming-language interpreter. These projects will give you a glimpse of the very different ways the Scala language can be used to implement challenging applications in an elegant and intuitive manner.

16

Message-based Parallelism with Actors


```
class SimpleUploadActor()(using cc: castor.Context)
extends castor.SimpleActor[String]:
    def run(msg: String) =
        val res = requests.post("https://httpbin.org/post", data = msg)
        println("response " + res.statusCode)
```
16.1.scala

Snippet 16.1: a simple actor implemented in Scala using the Castor library

Message-based parallelism is a technique that involves splitting your application logic into multiple "actors", each of which can run concurrently, and only interacts with other actors by exchanging asynchronous messages. This style of programming was popularized by the Erlang programming language and the Akka Scala actor library, but the approach is broadly useful and not limited to any particular language or library.

This chapter will introduce the fundamental concepts of message-based parallelism with actors, and how to use them to achieve parallelism in scenarios where the techniques we covered in ***Chapter 13: Fork-Join Parallelism with Futures*** cannot be applied. We will first discuss the basic actor APIs, see how they can be used in a standalone use case, and then see how they can be used in more involved multi-actor pipelines. The techniques in this chapter will come in useful later in ***Chapter 18: Building a Real-time File Synchronizer***.

17

Multi-Process Applications


```
def send[T: upickle.Writer](out: DataOutputStream, msg: T): Unit =
    val bytes = upickle.writeBinary(msg)
    out.writeInt(bytes.length)
    out.write(bytes)
    out.flush()

def receive[T: upickle.Reader](in: DataInputStream) =
    val buf = new Array[Byte](in.readInt())
    in.readFully(buf)
    upickle.readBinary[T](buf)                                    17.1.scala
```

Snippet 17.1: RPC send and receive methods for sending data over an operating system pipe or network

While all our programs so far have run within a single process, in real world scenarios you will be working as part of a larger system, and the application itself may need to be split into multiple processes. This chapter will walk you through how to do so: configuring your build tool to support multiple Scala processes, sharing code and exchanging serialized messages. These are the building blocks that form the foundation of any distributed system.

As this chapter's project, we will be building a simple multi-process file synchronizer that can work over a network. This chapter builds upon the simple single-process file synchronizer in ***Chapter 7: Files and Subprocesses***, and will form the basis for ***Chapter 18: Building a Real-time File Synchronizer***.

18

Building a Real-time File Synchronizer


```
object SyncActor extends castor.SimpleActor[Msg]:
    def run(msg: Msg): Unit = msg match
        case ChangedPath(value) => Shared.send(agent.stdin.data, Rpc.StatPath(value))
        case AgentResponse(Rpc.StatInfo(p, remoteHash)) =>
            val localHash = Shared.hashPath(src / p)
            if localHash != remoteHash && localHash.isDefined then
                Shared.send(agent.stdin.data, Rpc.WriteOver(os.read.bytes(src / p), p)) 18.1.scala
```

Snippet 18.1: an actor used as part of our real-time file synchronizer

In this chapter, we will write a file synchronizer that can keep the destination folder up to date even as the source folder changes over time. This chapter serves as a capstone project, tying together concepts from ***Chapter 17: Multi-Process Applications*** and ***Chapter 16: Message-based Parallelism with Actors***.

The techniques in this chapter form the basis for "event driven" architectures, which are common in many distributed systems. Real-time file synchronization is a difficult problem, and we will see how we can use the Scala language and libraries to approach it in an elegant and understandable way.

19

Parsing Structured Text


```
> def parser[T: P] = P(
      ("hello" | "goodbye").! ~ " ".rep(1) ~ ("world" | "seattle").! ~ End
  )

> fastparse.parse("hello seattle", parser(using _))
res0: fastparse.Parsed[(String, String)] = Success(
    value = ("hello", "seattle"),
    index = 13
)

> fastparse.parse("hello     world", parser(using _))
res1: fastparse.Parsed[(String, String)] = Success(
    value = ("hello", "world"),
    index = 15
)
```

19.1.scala

Snippet 19.1: parsing simple text formats using the FastParse library

One common programming task is parsing structured text. This chapter will introduce how to parse text in Scala using the FastParse library, before diving into an example where we write a simple arithmetic parser in Scala. This will allow you to work competently with unusual data formats, query languages, or source code for which you do not already have an existing parser at hand.

We will build upon the parsing techniques learned in this chapter as part of ***Chapter 20: Implementing a Programming Language***.

20

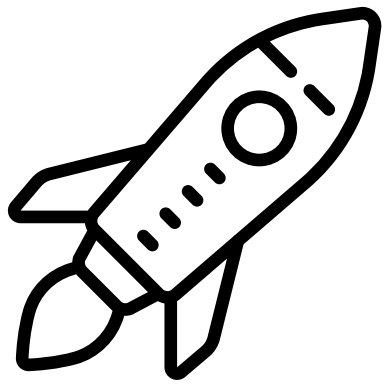
Implementing a Programming Language


```scala
def evaluate(expr: Expr, scope: Map[String, Value]): Value = expr match
    case Expr.Str(s) => Value.Str(s)
    case Expr.Dict(kvs) => Value.Dict(kvs.map((k, v) => (k, evaluate(v, scope))))
    case Expr.Plus(left, right) =>
        val Value.Str(leftStr) = evaluate(left, scope).runtimeChecked
        val Value.Str(rightStr) = evaluate(right, scope).runtimeChecked
        Value.Str(leftStr + rightStr)
```
20.1.scala

Snippet 20.1: evaluating a syntax tree using pattern matching

This chapter builds upon the simple parsers we learned in ***Chapter 19: Parsing Structured Text***, and walks you through the process of implementing a simple programming language in Scala.

Working with programming language source code is a strength of Scala: parsing, analyzing, compiling, or interpreting it. This chapter will show you how easy it is to write a simple interpreter to parse and evaluate program source code in Scala. Even if your goal is not to implement an entirely new programming language, these techniques are still useful: for writing linters, program analyzers, query engines, and other such tools.



Conclusion

This is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.

Winston Churchill

If you have made it this far through *Hands-on Scala*, you should by now be comfortable using the Scala programming language in a wide range of scenarios. You've implemented algorithms, API clients, web servers, file synchronizers, and programming languages. You've dealt with concurrency and parallelism. You've worked with the filesystem, databases, data serialization, and many other cross-cutting concerns that you would find in any real-world software system.

This book only walks you through a narrow slice of the Scala ecosystem: there is a wealth of libraries and frameworks that people use writing Scala in production, and it is impossible to cover them all in one book. Nevertheless, the core concepts you learned here apply regardless of which specific toolset you end up using. Breadth-first search is breadth-first search, and a HTTP request is a HTTP request, regardless of how the exact method calls are spelled.

Scala is a flexible, broadly useful programming language. By now you have seen how Scala can be used to tackle even difficult, complex problems in an elegant and straightforward manner. While this book is not the final word in learning Scala, it should be enough for you to take off on your own, and get started solving real problems and delivering real value using the Scala language.