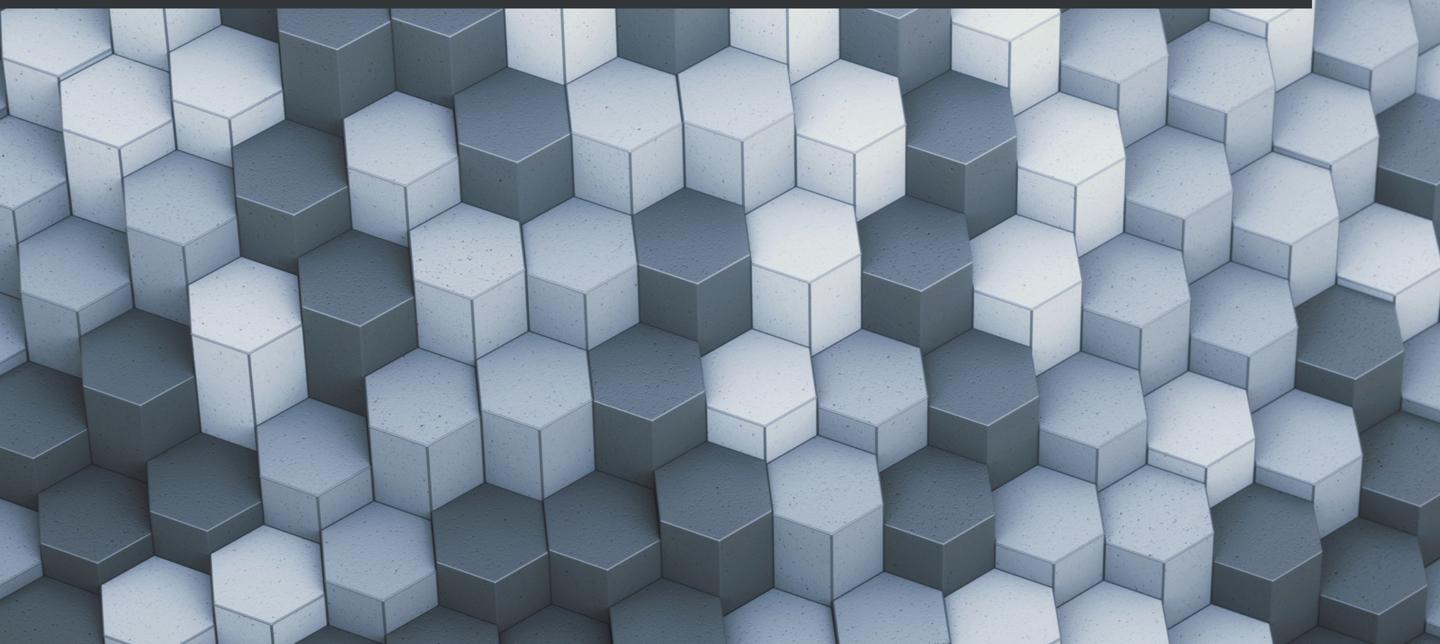
Designing Hexagonal Architecture with Java

An architect's guide to building maintainable and change-tolerant applications with Java and Quarkus



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To the memory of my mother, Rosimar Pinheiro, who instilled in me the desire to learn. To my father, Davi, for teaching me the value of persistence. To my brother, Bruno Pinheiro, for his influence on my character and career. To my wife, Eloise, for being my loving partner throughout our joint life journey.

– Davi Vieira

Contributors

About the author

Davi Vieira is a software craftsman with a vested interest in the challenges faced by large enterprises in software design, development, and architecture. He has more than 10 years of experience constructing and maintaining complex, long-lasting, and mission-critical systems using object-oriented languages. He values the good lessons and the software development tradition left by others who came before him. Inspired by this software tradition, he develops and evolves his ideas.

I want to thank Fagner Silva for introducing me to hexagonal architecture. I'm also grateful to Paulo Lagranha, who gave me precious life lessons and believed in my ideas. A special thanks to Alok Dhuri, Rohit Singh, Rosal Colaco, Deeksha Thakkar, and all the Packt team. I cannot express in words how grateful I am for their patience, guidance, and support through the whole book development process. Finally, I'd like to thank the technical reviewer, Antonino Rau, who profoundly and positively influenced my ideas in the book.

About the reviewer

Antonino Rau has a background in the philosophy of language and computer science, with over 20 years of experience as a technical leader specialized in architecting distributed systems, mainly using Domain Driven Design strategic and tactical patterns to tackle complex projects.

He has worked for several Italian and American companies (including Expert.ai, Condé Nast, and recently Compass), mainly operating in the area of content management, workflow, and recommendation systems, developing expertise in applied machine learning, distributed systems, and multiple architectural styles.

Antonino moved from Rome, Italy, to New York 10 years ago, where he now lives with his beautiful wife, three children, and two cute cats.

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Preface

Since I started to work in software development, I have always felt overwhelmed by the recurring challenge of untangling and learning complex code. For me, part of that complexity derived from tight schedules, speed for speed's sake, feature quantity over code quality, and management pressure to deliver working software no matter the consequences. Under such circumstances, I always find it hard to find enough time for refactoring and other software quality concerns. And I also considered it unfair to blame people who had to write poorly structured code because they had no other choice.

For those interested in economics, there is an axiom that says we're always in a state of scarcity. Nothing is unlimited in this world. Certain people may experience abundance, but the harsh reality is that all resources are scarce: water, food, electricity, money. They all are served in a limited amount. Wise, and very often richer, are those who know how to use their resources intelligently to produce good results. This scarcity condition cascades to all human activities. Software development is one of them.

Every software project is given a limited number of resources to be carried out. We call successful the software project that knows how to use its resources intelligently. Working software is the most important output of a successful project. Unfortunately, this is not the only success criteria. If we deliver working software that is hard to maintain and expect to change that software in the future, then we're not using our resources intelligently. So, in my view, a successful software project delivers working and maintainable software.

But how can we create working and maintainable software with scarce resources? I think this question has existed and has remained partially answered since the first line of code was written. I say partially answered because the circumstances of every software project may be so peculiar that it's hard to find an answer that encompasses all possibilities. Software architecture is one of the efforts to organize ideas supporting the creation of well-structured and maintainable software.

One notable software architecture effort came from a guy called Alistair Cockburn. He was aware that a software system might contain code that exists only to solve business problems. On the other hand, he noted that there is also code that exists only to allow the software system to integrate with external systems and technologies. He then conceived an approach to organize the code and avoid the problems that arise when we mix code that solves business problems with code that integrates technologies. He gave that approach the name hexagonal architecture.

It's the goal of this book to explore and extend hexagonal architecture ideas. More than that, we aim to frame hexagonal architecture in the context of a recent trend in the technology industry: cloud-native development. We live in the cloud era. It's hard to talk about any software development topic and ignore how it relates to the cloud's contemporary software practices. To help us in such an undertaking, we chose Quarkus as the cloud-native framework to guide us in this fascinating cloud-native development world.

You can expect a hybrid approach where theory and practice are blended to improve the learning experience. We'll spend some time discussing concepts, but we'll also have fun by dirtying our hands while putting these concepts into practice.

You may have reached a dead-end in your software project where things are so hard that new features are too complex to add and existent ones are equally difficult to maintain. Maybe you're an enthusiast searching for new ideas to improve your code base. No matter your reasons, I invite you to be my guest on this enlightening learning journey.

Who this book is for

This book is for software architects and Java developers who want to improve code maintainability and enhance productivity with an architecture that allows changes in technology without compromising business logic, which is precisely what hexagonal architecture does. Intermediate knowledge of the Java programming language and familiarity with Jakarta EE will help you to get the most out of this book.

What this book covers

Chapter 1, *Why Hexagonal Architecture?*, starts by saying that software that is not well organized and lacks sound architecture principles may work fine but will present a high risk of developing technical debt. As new features are added, the software tends to become more complex to maintain because there is no common ground to guide the addition or change of features. Based on this problem, this chapter explains why hexagonal architecture helps tackle technical debt by establishing an approach where business code is decoupled from technology code, allowing the former to evolve without dependency on the latter.

Chapter 2, *Wrapping Business Rules inside Domain Hexagon*, follows a domain-driven approach and describes what Domain Entities are, what role they play within hexagonal architecture, and how they wrap business rules and data in simple Java POJOs. It explains why Domain Entities are the most important part of code and why they should not depend on anything other than other Domain Entities. Finally, it explains how business rules inside a domain entity can be implemented using the Specification design pattern.

Chapter 3, *Handling Behavior with Ports and Uses Cases*, covers what use cases are, explaining that they are used to define software intent with interfaces describing things the software can do. Then, it explains what input ports are, classes that implement use case interfaces, and specifies in concrete ways how the software intent should be accomplished. It talks about output ports and their role in abstractly defining the behavior of operations that need to get data from outside the software. And finally, this chapter explains how use cases and ports are grouped together in what's called the Application hexagon.

Chapter 4, *Creating Adapters to Interact with the Outside World*, shows how adapters allow the software to integrate with different technologies. It explains that the same port can have multiple adapters: input adapters, bound to input ports, enable the application to expose its functionalities through different communication protocols, such as REST, gRPC, or WebSocket. Output adapters, bound to output ports, allow the application to communicate with varying data sources, whether it be databases or even brokers or other applications. Finally, it shows how all adapters are grouped together in the Framework hexagon.

Chapter 5, *Exploring the Nature of Driving and Driven Operations*, explains that driver operations drive the software behavior by starting one of its exposed functions. It details the Driver operations life cycle showing how a request is captured on Framework hexagon through an input adapter, then handed down to an input port on the application framework until it reaches Domain Entities on the Domain hexagon. It shows that a use case starts driven operations from the Application hexagon when the software needs to get data from outside, going from an output port to an output adapter to fulfill the use case needs.

Chapter 6, *Building the Domain Hexagon*, shows how to start developing a telco's network and topology inventory application by first creating the Domain hexagon as a Java module. Then, this chapter shows how business rules and data are mapped to Domain Entities' classes and methods. The business rules are arranged in different algorithms with the aim of the Specification design pattern. Finally, it shows how to unit test the Domain hexagon.

Chapter 7, *Building the Application Hexagon*, starts by adding the Application hexagon as the second Java module on the application. It then explains how to create the use case interface that describes the software's operations to manage the network and topology inventory. It shows how to implement the use case with an input port, giving a detailed description of how the code should be arranged. It details the creation of an output port interface and its role in obtaining data from external sources. Finally, it explains how to test the Application hexagon.

Chapter 8, *Building the Framework Hexagon*, starts by adding the Framework hexagon as the third Java module on the application. Then it teaches how to create an input adapter and how it will carry its operation through an input port. After that, an output adapter will be created through the implementation of an output port. The output adapter will show how data can be fetched from external sources and converted to be dealt with in Domain terms. Finally, it explains how to test the Framework hexagon.

Chapter 9, *Applying Dependency Inversion with Java Modules*, talks a little bit about Java modules, explaining why they are important to enforce the hexagonal architecture principles related to dependency inversion. It explains that Java modules don't allow cyclic dependencies and because of that there is no way to make two modules depend on each other at the same time. You will learn how to configure the module descriptor in this hexagonal application.

Chapter 10, *Adding Quarkus to a Modularized Hexagonal Application*, briefly explains the Quarkus framework and its main features, then it advances to show how to add Quarkus to the hexagonal application that has been developed in the previous chapters. It introduces the creation of a fourth module, called `bootstrap`, that serves to get the application started and is used to group together the Domain, Application, and Framework modules.

Chapter 11, *Leveraging CDI Beans to Manage Ports and Use Cases*, explains how to transform the already developed ports and use cases into CDI Beans, leveraging Enterprise Java's power in the hexagonal architecture. It starts by explaining what CDI Beans are, then shows how to implement them on input ports and output ports. Finally, it describes how to adjust the Application framework tests to use Quarkus CDI bean test features.

Chapter 12, *Using RESTEasy Reactive to Implement Input Adapters*, starts by comparing reactive and imperative approaches for REST endpoints, detailing why the reactive approach performs better. It explains how to implement input adapters with Quarkus RESTEasy Reactive capabilities by explaining how to add the correct annotations and inject the proper dependencies to call input ports. In order to expose the hexagonal application APIs, this chapter explains how to add OpenAPI and SwaggerUI. Finally, it shows how to test the reactive input port with Quarkus test tools.

Chapter 13, *Persisting Data with Output Adapters and Hibernate Reactive*, talks about Hibernate Reactive and how it helps Quarkus to provide reactive capabilities for data persistence. It explains how to create a reactive output adapter to persist data on a MySQL database. Finally, it shows how to test the reactive output adapter with Quarkus test tools.

Chapter 14, *Setting Up Dockerfile and Kubernetes Objects for Cloud Deployment*, explains how to create a Dockerfile for the hexagonal application based on Quarkus. It explains in detail how to package all the modules and dependencies in one single Docker image. It then shows how to create Kubernetes objects such as `Deployment` and `Service` for the hexagonal application and test them in a minikube local Kubernetes cluster.

Chapter 15, *Good Design Practices for Your Hexagonal Application*, talks about some good practices you can adopt while creating each hexagon for your application. Starting with the Domain hexagon, we focus on Domain Driven Design aspects to clarify the business problems the application is supposed to solve. Then we move on to a discussion about the alternative ways to set up use cases and ports in the Application hexagon. And finally, we discuss the consequences of having to maintain multiple adapters.

Assessments contains all the answers to the questions from all the chapters in this book.

To get the most out of this book

Software/hardware covered in the book	**Operating system requirements**
Maven 3.6	Windows, macOS, or Linux
Java SE Development Kit	Windows, macOS, or Linux

If you are using the digital version of this book, we advise you to type the code yourself or access the code from the book's GitHub repository (a link is available in the next section). Doing so will help you avoid any potential errors related to the copying and pasting of code.

Download the example code files

You can download the example code files for this book from GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java`. If there's an update to the code, it will be updated in the GitHub repository.

We have other code bundles from our rich catalog of books and videos available at `https://github.com/PacktPublishing/`. Check them out!

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We also provide a PDF file that has color images of the screenshots and diagrams used in this book. You can download it here: `https://static.packt-cdn.com/downloads/9781801816489_ColorImages.pdf`.

Conventions used

There are a number of text conventions used throughout this book.

`Code in text`: Indicates code words in text, database table names, folder names, filenames, file extensions, pathnames, dummy URLs, user input, and Twitter handles. Here is an example: "This Maven command creates the basic directory structure for the `bootstrap` module."

A block of code is set as follows:

```
<dependency>
    <groupId>io.quarkus</groupId>
    <artifactId>quarkus-hibernate-validator</artifactId>
</dependency>
```

When we wish to draw your attention to a particular part of a code block, the relevant lines or items are set in bold:

```
mvn archetype:generate \
-DarchetypeGroupId=org.codehaus.mojo.archetypes \
-DarchetypeArtifactId=pom-root \
-DarchetypeVersion=RELEASE \
-DgroupId=dev.davivieira \
-DartifactId=topology-inventory \
-Dversion=1.0-SNAPSHOT \
-DinteractiveMode=false
```

Any command-line input or output is written as follows:

```
java -jar bootstrap/target/bootstrap-1.0-SNAPSHOT-runner.jar
```

Bold: Indicates a new term, an important word, or words that you see onscreen. For instance, words in menus or dialog boxes appear in **bold**. Here is an example: "Here, we have a representation showing how straightforward the AOT compilation process is to transform Java byte code into **Machine Code**."

> **Tips or Important Notes**
> Appear like this.

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Section 1: Architecture Fundamentals

In this section, you will gain a solid understanding of hexagonal architecture elements: domain entities, use cases, ports, and adapters. Starting with a discussion about why we would apply hexagonal architecture principles to our project, we progressively advance our exploration by learning how to organize problem domain code with **Domain Driven Design** techniques.

Then, we examine the important role use cases and ports play in expressing system behaviors. Moving ahead, we explore how adapters allow the hexagonal system to be compatible with different protocols and technologies. Finally, we close the section by discussing how driving and driven operations influence the behaviors of a hexagonal system.

This section comprises the following chapters:

- *Chapter 1*, *Why Hexagonal Architecture?*
- *Chapter 2*, *Wrapping Business Rules inside Domain Hexagon*
- *Chapter 3*, *Handling Behavior with Ports and Use Cases*
- *Chapter 4*, *Creating Adapters to Interact with the Outside World*
- *Chapter 5*, *Exploring the Nature of Driving and Driven Operations*

1 Why Hexagonal Architecture?

Software that's not well organized and lacks sound software architecture principles may work just fine but develop technical debt over time. As new features are added, the software may become more complex to maintain because there is no common ground to guide code changes. Based on that problem, this chapter will explain how the hexagonal architecture helps tackle technical debt by establishing an approach where business logic is decoupled from technology code, allowing the former to evolve without dependency on the latter.

In this chapter, we will cover the following topics:

- Reviewing software architecture
- Understanding the hexagonal architecture

By the end of this chapter, you will have learned about the hexagonal architecture's main concepts: entities, use cases, ports, and adapters. You'll also know about some basic techniques so that you can start applying hexagonal principles to your projects.

Technical requirements

To compile and run the code examples presented in this chapter, you need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. They are both available for Linux, Mac, and Windows operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter01`.

Reviewing software architecture

The word *architecture* is old. Its origin in history goes back to times when man used to build things with rudimentary tools, often with his own hands. Yet, each generation repeatedly overcame the limitations of its era and constructed magnificent buildings that stand to this day: take a look at the Florence Cathedral and its dome design, which was conceived by Filippo Brunelleschi – what an excellent architecture example!

Architects are more than just ordinary builders who build things without much thinking. It's quite the opposite – they are the ones who care the most about the aesthetics, underlying structures, and design principles. Sometimes, they play a fundamental role by pushing the limits of what is possible to do with the resources at hand. The Florence Cathedral, as has already been said, proves that point.

I'll not take this analogy too far because software is not like a physical building. And, although there should be some similarities between building and software architects, the latter differs considerably because of the living and evolving nature of their software craft. But we can agree that both share the same ideal: to build things right.

This ideal helps us understand what software architecture is. If we're aiming to build not just working software, but an easily maintainable and well-structured one, the software can even be considered, to a certain degree, a piece of art because of the care and attention to details we employed to build it. Then, we can take that as a noble definition for software architecture.

It's also important to state that a software architect's role should not only be constrained to decide how things should be made. As in the Florence Cathedral example, where Filippo Brunelleschi himself laid bricks in the building to prove his ideas were sound; a software architect should get his hands dirty to prove his architecture is good.

Software architecture should not be the fruit of one person's mind. Although there are a few who urge others to pursue a path of technical excellence by providing guidance and establishing the foundations, for architecture to evolve and mature, it's necessary to have the collaboration and experience of everyone involved in the effort to improve software quality.

What follows is a discussion around the technical and organizational challenges we may encounter in our journey to create and evolve a software architecture. This will help us tackle the threat of chaos and indomitable complexity.

The invisible things

Software development is not a trivial activity. It demands considerable effort to become competent in any programming language and an even greater effort to use that skill to build software that generates profit. Surprisingly, sometimes, it may not be just enough to make profitable software.

When we talk about profitable software, we're talking about software that solves real-world problems. In the context of large enterprises, it's software that meets business needs. Also, everyone who has worked in large enterprises understands that the client generally doesn't want to know how the software is built. They are interested in what they can see: a working software meeting business expectations. After all, that's what pays bills at the end of the day.

But the things that clients cannot see also have some importance. Such things are known as non-functional requirements. They are things related to security, maintainability, operability, and other capabilities. If adequate care is not taken, those things, which are unseen from the clients' perspective, can compromise the software's purpose. That compromise can occur subtly and gradually, giving origin to several problems, including technical debt.

I've mentioned previously that software architecture is about doing things right. So, it means that among its concerns, we should include both unseen and seen things. For things that are seen by the client, it's essential to deeply understand the problem domain. That's where techniques such as **Domain Driven Design** (**DDD**) can help us approach the problem. This allows us to structure the software in a form that makes sense not just for programmers but also for everyone involved in the problem domain. DDD also plays a key role in shaping the unseen part by defining cohesively the underlying structures that will allow us to solve client needs, which it does in a well-structured and maintainable manner.

Technical debt

Coined by Ward Cunningham, **technical debt** is a term used to describe how much unnecessary complexity exists in software code. Such unnecessary complexity may also be referred to as *cruft* – that's the difference between the current code and how it would ideally be. We'll learn how technical debt can appear in a software project shortly.

To develop software that just works is one thing. You assemble code in a way you think is adequate to meet business needs, and then package and throw it into production. In production, your software meets the client's expectations, so everything is fine, and life goes on. Sometime later, another developer comes in to add new features to that same software you started. Like you, this developer assembles code in a way he thinks is adequate to meet business needs, but there are things in your code this developer doesn't clearly understand. Hence, he adds elements to the software in a slightly different manner than you would. The software makes its way into production, and the customer is satisfied. So, the cycle repeats.

Software working as expected is what we can see from the previous scenario. But what we cannot see so clearly is that the lack of common ground, in terms of defining how features should be added or modified to the software, leaves a gap that every developer will try to fill whenever he does not know how to handle such changes. This gap leaves space for the growth of things such as technical debt.

Reality very often pushes us to situations where we just cannot avoid technical debt. Tight schedules, poor planning, unskilled people, and, of course, the lack of software architecture are some of the factors that can contribute to the creation of technical debt. Needless to say, we should not believe that the enforcement of software architecture will magically solve all our technical debt problems. Far from that – here, we're just tackling one facet of the problem. All other technical debt factors will remain and can undermine our efforts to establish a sound software architecture.

Vicious cycle

Financial debts tend to continue to grow if you do pay them. Also, the bank and authorities can come after you and your assets if you don't pay those debts in time. Contrary to its financial counterpart, technical debts don't necessarily grow if you don't pay them. What determines their growth, though, is the rate and nature of software changes. Based on that, we can assume that frequent and complex changes have a higher potential to increase technical debt.

You always have the prerogative not to pay technical debts – sometimes, that's the best choice, depending on the circumstances – but you diminish your capacity to change the software as you do so. With higher technical debt rates, the code becomes more and more unmanageable, causing developers to either avoid touching the code at all or finding awkward workarounds to solve the issues.

I believe most of us at least once had the unpleasant experience of maintaining brittle, insanely complex systems. In such scenarios, instead of spending time working with valuable things for the software, we spend more time fighting technical debts to open space to introduce new features. If we don't keep the technical debts controlled, one day, it will not be worth adding new features to the overloaded technical debt system. That's when people decide to abandon applications, start a new one, and repeat the cycle. So, the effort in tackling technical debt should be motivated to break that cycle.

It's not for everyone

This zest for quality and correctness that emerges from any serious architectural undertaking is not always present. As pointed out by *big ball of mud*, there are scenarios where the most profit-driven software in a company is an absolute big ball of mud. This is software that has grown without any sense of order and is complicated to understand and maintain. Developers who dare to tackle the complexity posed by this kind of system are like warriors fighting a hydra. The refactoring effort required to impose any order in such complexity is sometimes not worth it.

This big ball of mud is not the only problem. There are also cultural and organizational factors that can undermine any software architecture effort. Very often, I've stumbled upon teammates who simply didn't care about architecture principles. The least-effort path to deliver code to production is the norm to be followed in their minds. It's not hard to find this kind of person in projects with a high turnaround of developers. Because there is no sense of ownership, there is no incentive to produce high-quality code.

Pushing the discipline to follow a software architecture is hard. Both the technical team and management should be aligned on the advantages and implications of following such a discipline. It's important to understand that spending more time upfront on dealing with technical aspects that don't add much value, in terms of customer features, may play a crucial role in the long term. All the effort is paid back with more maintainable software, relieving developers who no longer need to fight hydras, and managers who are now better positioned to meet business deadlines.

Before trying to promote, let alone enforce, any software architecture principle, it is advisable to assess the current environment to make sure there are neither cultural nor organizational factors playing against the attitude of a few trying to raise the bar to better-developed systems.

Monolithic or distributed

There is a recurring discussion in the software community about the organization of a system's components and responsibilities. In the past, when expensive computing resources and network bandwidth were the problems that influenced the software architecture, developers tended to group plenty of responsibilities into a single software unit to optimize resource usage and prevent the network overhead that would occur in a distributed environment. But there is a tenuous line separating a maintainable and cohesive monolithic system from an entangled and hard-to-maintain one.

The crossing of such a line is a red flag, showing the system has accumulated so many responsibilities and has become so complex to maintain that any change poses a severe risk of breaking the entire software. I'm not saying that every monolithic that grows becomes a mess. I'm trying to convey that the accumulation of responsibilities can cause serious problems to a monolithic system when such responsibility aggregation is not done with care. Apart from this responsibility issue, it's also equally important to make sure the software is easy to develop, test, and deploy. If the software is too large, developers may have difficulty trying to run and test it locally. It can also have a serious impact on continuous integration pipelines, impacting the compiling, testing, and deployment stages of such pipelines, ultimately compromising the feedback loop that is so crucial in a DevOps context.

On the other hand, if we know when a system accumulates sufficient responsibilities, we can rethink the overall software architecture and break down the large monolithic into smaller and more manageable – sometimes autonomous – software components that are often isolated in runtime environments. This approach had strong adoption with **Service Oriented Architecture** (**SOA**) and then with what can be called its evolution: the **microservice architecture**.

Both SOA and microservices can be considered different flavors of distributed systems. Microservice architecture, in particular, is made possible mainly because computing and network resources are not as expensive as they used to be, bringing lots of benefits related to strong decoupling and faster software delivery. However, this does not come without costs, because if we had to deal with complexity in just one place, now the challenge is to deal with complexity scattered around the network.

The hexagonal architecture proposed in this book can be applied to both monolithic and distributed systems. With monolithic, the application may be consumed by a frontend and, at the same time, consume data from a database or other data sources. The hexagonal approach can help us develop a more change-tolerant monolithic system that can even be tested without the **Frontend** and the **Database**. The following diagram illustrates a common **Monolithic** system:

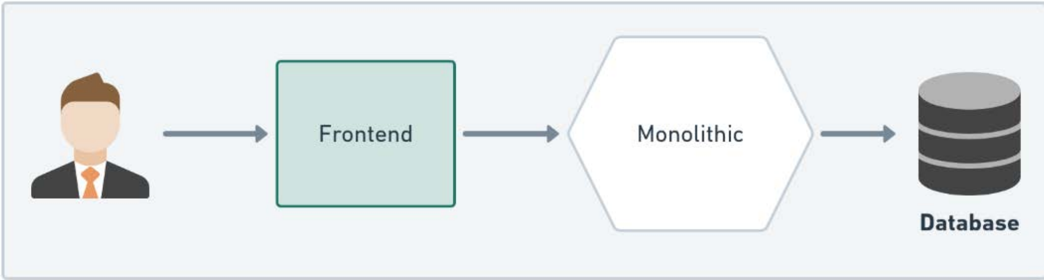

Figure 1.1 – The hexagonal architecture with a monolithic system

For distributed systems, we may be dealing with lots of different technologies. The hexagonal architecture shines in these scenarios because the nature of its ports and adapters allows the software to deal with constant technology changes. The following diagram shows a typical microservice architecture where we could apply hexagonal principles:

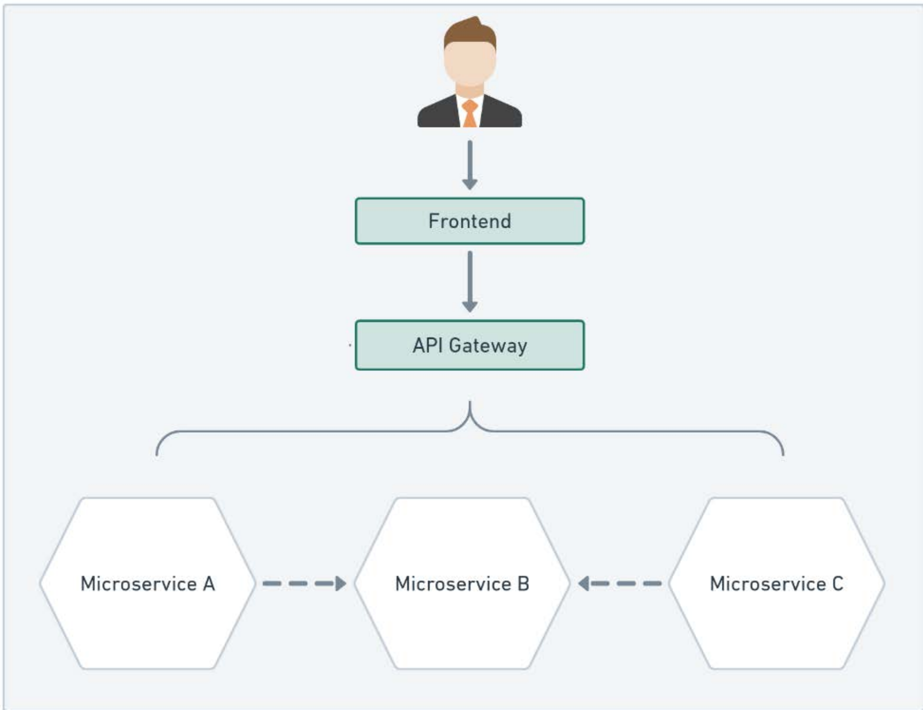

Figure 1.2 – The hexagonal architecture with a microservices system

One of the great advantages of microservice architecture is that you can use different technologies and programming languages to compose the system. We can develop a frontend application using JavaScript, some APIs with Java, and a data processing application with Python. The hexagonal architecture can help us in this kind of heterogeneous technological scenario.

Making decisions

All this discussion around software architecture concerns is relevant because we may undermine our capability to maintain and evolve software in the long run if we ignore those concerns. Of course, there are situations where we're not so ambitious about how sophisticated, maintainable, and feature-rich our software will be.

It may not be worth all the time and effort to build things in the right way for such situations because what's needed is working software to be delivered as fast as possible. In the end, it's a matter of priorities. But we should be cautious not to fall into the trap that we can fix things later. Sometimes, we can have the money to do so but sometimes, we may not. Wrong decisions at the beginning of a project can cost us a high price in the long term.

The decisions we take regarding code structure and software architecture lead us to what calls internal quality. The degree to which software code is well organized and maintainable corresponds to its internal quality. On the other hand, the value perception about how valuable and good a piece of software can be from a user's perspective corresponds to its external quality. Internal and external quality are not directly connected. It's not difficult to find useful software with a messy code base.

The effort spent on internal quality should be seen as an investment where the return is not immediate and visible to the user. The investment return comes as the software evolves. The value is perceived by constantly adding changes to the software without increasing the time and money required to add such changes, as the following pseudo-graph shows:

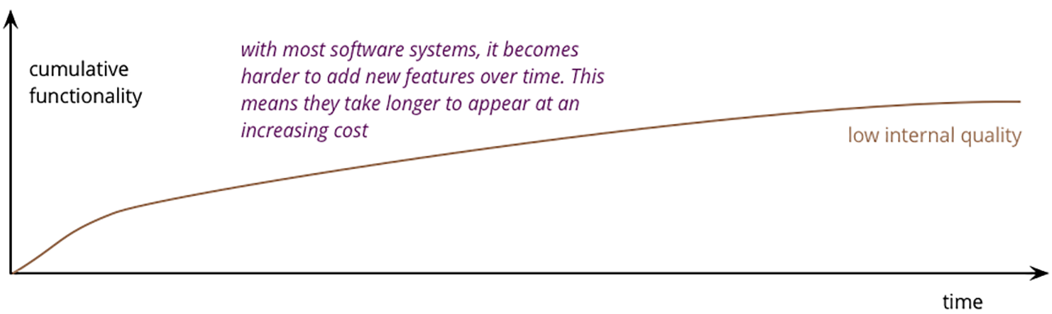

Figure 1.3 – Pseudo-graph showing the impact of changes

But how can we make the right decisions? That's a trick question because we often don't have enough information to assist in the decision-making process that will lead us to a software architecture that best meets business needs. Most of the time, even the client doesn't know their needs. That information generally comes as the project evolves. Instead of making upfront decisions, a more sensible approach is to wait until enough information is received, allowing us to be more assertive. This approach naturally leads us to a software architecture that reflects these concerns, which are related to a lack of information and the necessity to accommodate changes as they occur.

That necessity and also the capacity to change systems is a crucial point in software design. If we spend too much effort thinking on designing upfront, we may end up overengineering and possibly overpriced solutions. The other way around is dangerous because we risk increasing the cost of change by being careless about design. As pointed out in *Extreme Programming Explained: Embrace Change*, the resources spent on design should match a system's need to process changes at an acceptable pace without increasing the cost to process such changes.

This book is concerned with a software architecture that allows us to postpone decisions by making change-tolerant applications able to cope with changes when decisions are finally made. But reality can be harsh sometimes, forcing us to make hurried decisions with scarce information. These precipitated actions can result in unpleasant consequences such as technical debt.

Now that we're aware of some of the problems related to software architecture, we're in a better position to explore possible solutions to mitigate those issues. To help us in that effort, let's start by looking into the fundamentals of hexagonal architecture.

Understanding the hexagonal architecture

> *"Create your application to work without either a UI or a database so that you can run automated regression tests against the application, work when the database becomes unavailable, and link applications together without any user involvement."*
> *- Alistair Cockburn.*

This quote lays the groundwork for understanding hexagonal architecture. We can go even further with Cockburn's thoughts and make our application work without any technology, not just the technology related to UI or databases.

One of the main ideas of the hexagonal architecture is to separate business code from technology code. Still, not just that, we must also make sure the technology side depends on the business one so that the latter can evolve without any concerns regarding which technology is used to fulfill business goals. And we must also be able to change technology code by causing no harm to its business counterpart. To achieve these goals, we must determine a place where the business code will exist, isolated and protected from any technology concerns. It'll give rise to the creation of our first hexagon: the **Domain hexagon**.

In the Domain hexagon, we assemble the elements responsible for describing the core problems we want our software to solve. Entities and value objects are the main elements that are utilized in the Domain hexagon. Entities represent things we can assign an identity to, and value objects are immutable components that we can use to compose our entities. The terms used in this book refer to both the entities and value objects that come from DDD principles.

We also need ways to use, process, and orchestrate the business rules coming from the Domain hexagon. That's what the **Application hexagon** does. It sits between the business and technology sides, serving as a middleman to interact with both parties. The Application hexagon utilizes ports and use cases to perform its functions. We will explore those things in more detail in the next section.

The **Framework hexagon** provides the outside world interface. That's the place where we have the opportunity to determine how to expose application features – this is where we define REST or gRPC endpoints, for example. And to consume things from external sources, we use the Framework hexagon to specify the mechanisms to fetch data from databases, message brokers, or any other system. In the hexagonal architecture, we materialize technology decisions through adapters. The following diagram provides a high-level view of the architecture:

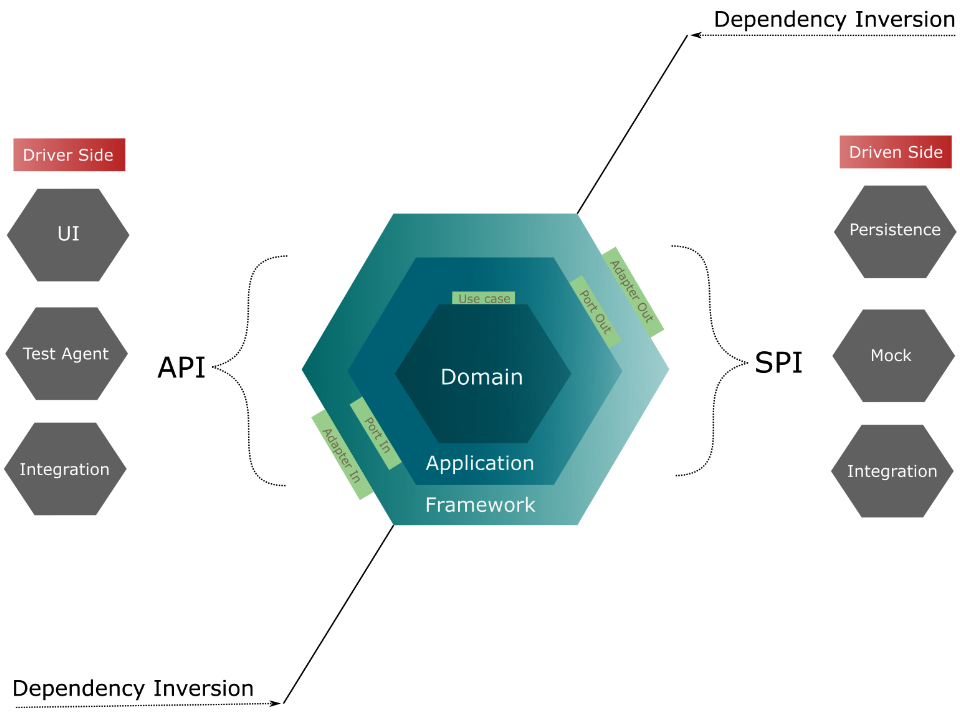

Figure 1.4 – The hexagonal architecture

Next, we'll go deeper into the components, roles, and structures of each hexagon.

Domain hexagon

The **Domain hexagon** represents an effort to understand and model a real-world problem. Suppose you're in a project that needs to create a network and topology inventory for a telecom company. This inventory's main purpose is to provide a comprehensive view of all the resources that comprise the network. Among those resources, we have routers, switches, racks, shelves, and other equipment types. Our goal here is to use the Domain hexagon to model the knowledge required to identify, categorize, and correlate those network and topology elements into code, as well as provide a lucid and organized view of the desired inventory. That knowledge should be, as much as possible, represented in a technology-agnostic form.

This quest is not a trivial one. Developers involved in such an undertaking may not know telecom businesses and set aside this inventory thing. As recommended by *Domain-Driven Design: Tackling Complexity in the Heart of Software*, it's necessary to consult domain experts or other developers who already know the domain problem. If none of them are available, you should try to fill the knowledge gap by looking at books or any other material that teaches about the problem domain.

Inside the Domain hexagon, we have entities corresponding to critical business data and rules. They are critical because they represent a model of the real problem. That model takes some time to evolve and consistently reflect the problem we're trying to model. That's the case with new software projects where neither developers nor domain experts have a clear vision of the system's purpose in its early stages. In such scenarios, which are particularly recurrent in startup environments, it's normal and predictable to have an initial awkward domain model that evolves only as business ideas evolve and are validated by users and domain experts. It's a curious situation where the domain model is unknown, even to the so-called domain experts.

On the other hand, in scenarios where the problem domain exists and is clear in the minds of domain experts, if we fail to grasp that problem domain and how it translates into entities and other Domain objects, such as value objects, we will build our software based on weak or wrong assumptions.

This can be considered one reason why any software starts simple and, as its code base grows, accumulates technical debt and becomes harder to maintain. These weak assumptions may lead to a fragile and unexpressive code that can initially solve business problems but is not ready to accommodate changes in a cohesive way. Bear in mind that the Domain hexagon is composed of whatever kind of object categories you feel are good for representing the problem domain. Here is a representation based just on **Entities** and **Value Objects**:

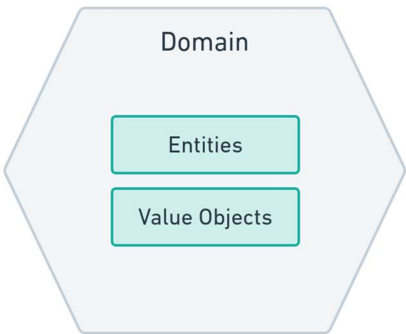

Figure 1.5 – Domain hexagon

Now, let's talk about the components that comprise this hexagon.

Entities

Entities help us build more expressive code. What characterizes an entity is its sense of continuity and identity, as described by *Domain-Driven Design: Tackling Complexity in the Heart of Software*. That continuity is related to the life cycle and mutable characteristics of the object. For example, in our network and topology inventory scenario, we mentioned the existence of routers. For a router, we can define whether its state is enabled or disabled.

Also, we can assign some properties describing the relationship that a router has with different routers and other network equipment. All those properties may change over time, so we can see that the router is not a static thing and that its characteristics inside the problem domain can change. Because of that, we can state that the router has a life cycle. Apart from that, every router should be unique in an inventory, so it must have an identity. So, this sense of continuity and identity are the elements that determine an entity.

The following code shows a `Router` entity class composed of the `RouterType` and `RouterId` value objects:

```
public class Router {

    private final RouterType;
    private final RouterId;

    public Router(RouterType, RouterId routerId){
        this.routerType = routerType;
        this.routerId = routerId;
    }

    public static Predicate<Router>
      filterRouterByType(RouterType routerType){
        return routerType.equals(RouterType.CORE)
                ? isCore() :
                isEdge();
    }

    private static Predicate<Router> isCore(){
        return p -> p.getRouterType() == RouterType.CORE;
    }

```

```
    private static Predicate<Router> isEdge(){
        return p -> p.getRouterType() == RouterType.EDGE;
    }

    public static List<Router> filterRouter(List<Router>
      routers, Predicate<Router> predicate){
        return routers.stream()
                .filter(predicate)
                .collect(Collectors.<Router>toList());
    }

    public RouterType getRouterType() {
        return routerType;
    }
}
```

Now, let's move on and look at value objects.

Value objects

Value objects help us complement our code's expressiveness when there is no need to identify something uniquely, as well as when we are more concerned about the object's attributes than its identity. We can use value objects to compose an entity object, so we must make value objects immutable to avoid unforeseen inconsistencies throughout the Domain. In the router example presented previously, we can represent the `Type` router as a value object attribute from the `Router` entity:

```
public enum Type {
    EDGE,
    CORE;
}
```

Next, we'll learn about the Application hexagon.

Application hexagon

So far, we've been discussing how the Domain hexagon encapsulates business rules with entities and value objects. But there are situations where the software does not need to operate directly at the Domain level. *Clean Architecture: A Craftsman's Guide to Software Structure and Design* states that some operations exist solely to allow the automation provided by the software. These operations – although they support business rules – would not exist outside the context of the software. We're talking about application-specific operations.

The **Application hexagon** is where we abstractly deal with application-specific tasks. I mean abstract because we're not directly dealing with technology concerns yet. This hexagon expresses the software's user intent and features based on the Domain hexagon's business rules.

Based on the same topology and inventory network scenario described previously, suppose you need a way to query routers of the same type. It would require some data handling to produce such results. Your software would need to capture some user input to query for router types. You may want to use a particular business rule to validate user input and another business rule to verify the data that's fetched from external sources. If no constraints are violated, your software provides some data showing a list of routers of the same type. We can group all those different tasks in a use case. The following diagram depicts the **Application** hexagon's high-level structure based on **Use Cases**, **Input Ports**, and **Output Ports**:

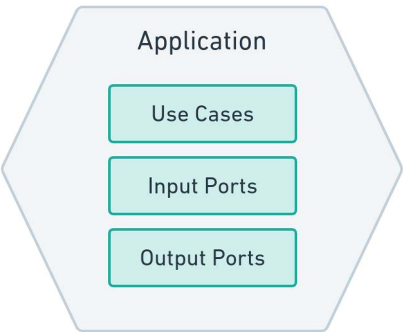

Figure 1.6 – The Application hexagon

The following sections will discuss the components of this hexagon.

Use cases

Use cases represent the system's behavior through application-specific operations, which exist within the software realm to support the domain's constraints. Use cases may interact directly with entities and other use cases, making them flexible components. In Java, we represent use cases as abstractions defined by interfaces expressing what the software can do. The following code shows a use case that provides an operation to get a filtered list of routers:

```
public interface RouterViewUseCase {
    List<Router> getRouters(Predicate<Router> filter);
}
```

Note the `Predicate` filter. We're going to use it to filter the router list when implementing that use case with an input port.

Input ports

If use cases are just interfaces describing what the software does, we still need to implement the use case interface. That's the role of the **input port**. By being a component that's directly attached to use cases, at the Application level, input ports allow us to implement software intent on domain terms. Here is an input port providing an implementation that fulfills the software intent stated in the use case:

```
public class RouterViewInputPort implements RouterViewUseCase {

    private RouterViewOutputPort routerListOutputPort;

    public RouterViewInputPort(RouterViewOutputPort
      routerViewOutputPort) {
        this.routerListOutputPort = routerViewOutputPort;
    }

    @Override
    public List<Router> getRouters(Predicate<Router>
      filter) {
        var routers =
          routerListOutputPort.fetchRouters();
        return Router.retrieveRouter(routers, filter);
    }
}
```

This example shows us how we could use a domain constraint to make sure we're filtering the routers we want to retrieve. From the input port's implementation, we can also get things from outside the application. We can do that using output ports.

Output ports

There are situations in which a use case needs to fetch data from external resources to achieve its goals. That's the role of **output ports**, which are represented as interfaces describing, in a technology-agnostic way, which kind of data a use case or input port would need to get from outside to perform its operations. I say agnostic because output ports don't care if the data comes from a particular relational database technology or a filesystem, for example. We assign this responsibility to output adapters, which we'll look at shortly:

```
public interface RouterViewOutputPort {
      List<Router> fetchRouters();
}
```

Now, let's discuss the last type of hexagon.

Framework hexagon

Things seem well organized with our critical business rules constrained to the Domain hexagon, followed by the Application hexagon dealing with some application-specific operations through the means of use cases, input ports, and output ports. Now comes the moment when we need to decide which technologies should be allowed to communicate with our software. That communication can occur in two forms, one known as driving and another known as driven. For the driver side, we use **Input Adapters**, and for the driven side, we use **Output Adapters**, as shown in the following diagram:

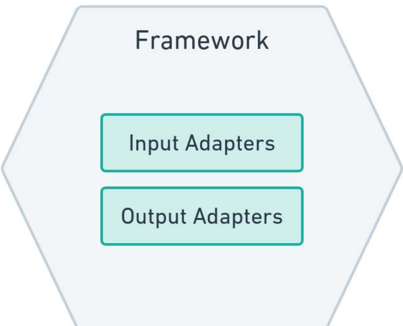

Figure 1.7 – The Framework hexagon

Let's look at this in more detail.

Driving operations and input adapters

Driving operations are the ones that request actions to the software. It can be a user with a command-line client or a frontend application on behalf of the user, for example. There may be some testing suites checking the correctness of things exposed by your software. Or it can be just other applications in a large ecosystem needing to interact with some exposed software features. This communication occurs through an **Application Programming Interface** (**API**) built on top of the input adapters.

This API defines how external entities will interact with your system and then translate their request to your domain's application. The term *driving* is used because those external entities are driving the behavior of the system. **Input Adapters** can define the application's supported communication protocols, as shown here:

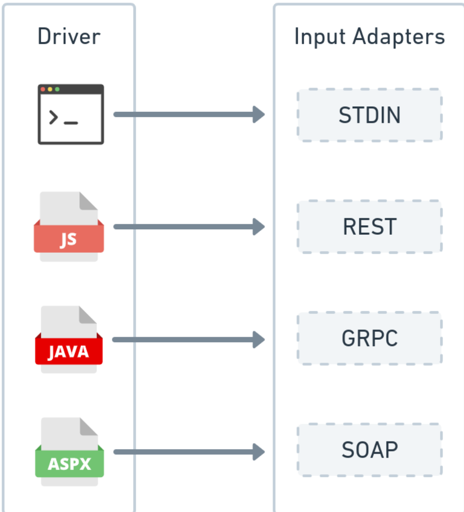

Figure 1.8 – Driver operations and input adapters

Suppose you need to expose some software features to legacy applications that work just with **SOAP** over HTTP/1.1 and, at the same time, you need to make those same features available to new clients who could leverage the advantages of using **GRPC** over HTTP/2. With the hexagonal architecture, you could create an input adapter for both scenarios, with each adapter attached to the same input port that would, in turn, translate the request downstream to work in terms of the domain. Here is an input adapter using a use case reference to call one of the input port operations:

```
public class RouterViewCLIAdapter {

    RouterViewUseCase;

```

```
    public RouterViewCLIAdapter(){
        setAdapters();
    }

    public List<Router> obtainRelatedRouters(String type) {
        return routerViewUseCase.getRouters(
              Router.filterRouterByType(RouterType.valueOf(
                type)));
    }

    private void setAdapters(){
     this.routerViewUseCase = new RouterViewInputPort
      (RouterViewFileAdapter.getInstance());
    }
}
```

This example illustrates the creation of an input adapter that gets data from the STDIN. Note the use of the input port through its use case interface. Here, we passed the command that encapsulates input data that's used on the Application hexagon to deal with the Domain hexagon's constraints. If we want to enable other communication forms in our system, such as REST, we just have to create a new REST adapter containing the dependencies to expose a REST communication's endpoint. We will do this in the following chapters as we add more features to our hexagonal application.

Driven operations and output adapters

On the other side of the coin, we have **driven operations**. These operations are triggered from your application and go into the outside world to get data to fulfill the software's needs. A driven operation generally occurs in response to some driving one. As you may imagine, the way we define the driven side is through **output adapters**. These adapters must conform to our output ports by implementing them.

Remember, an output port tells us which kind of data it needs to perform some application-specific tasks. It's up to the output adapter to describe how it will get the data. Here is a diagram of **Output Adapters** and **Driven** operations:

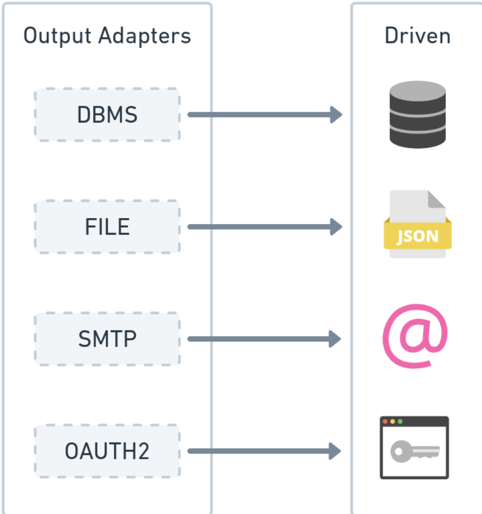

Figure 1.9 – Driven operations and output adapters

Suppose your application started working with Oracle relational databases and, after a while, you decided to change technologies and move on to a NoSQL approach, embracing MongoDB instead as your data source. In the beginning, you'd have just one output adapter to allow persistence with Oracle databases. To enable communication with MongoDB, you'd have to create an output adapter on the Framework hexagon, leaving the Application and, most importantly, Domain hexagons untouched. Because both the input and output adapters are pointing inside the hexagon, we're making them depend on both the Application and Domain hexagons, hence inverting the dependency.

The term *driven* is used because those operations are driven and controlled by the hexagonal application itself, triggering actions in other external systems. Note in the following example how the output adapter implements the output port interface to specify how the application is going to obtain external data:

```
public class RouterViewFileAdapter implements
RouterViewOutputPort {

    @Override
    public List<Router> fetchRouters() {
        return readFileAsString();
```

```
    }

    private static List<Router> readFileAsString() {
        List<Router> routers = new ArrayList<>();
        try (Stream<String> stream = new BufferedReader(
                new InputStreamReader(RouterViewFileAdapter
                  .class.getClassLoader().
                    getResourceAsStream("routers.txt")))
                      .lines()){
            stream.forEach(line ->{
               String[] routerEntry = line.split(";");
               var id = routerEntry[0];
               var type = routerEntry[1];
               Router = new Router
                (RouterType.valueOf(type),RouterId.of(id));
                routers.add(router);
            });
        } catch (Exception e){
           e.printStackTrace();
        }
        return routers;
    }
}
```

The output port states what data the application needs from outside. The output adapter in the previous example provides a specific way to get that data through a local file.

Having discussed the various hexagons in this architecture, we will now look at the advantages that this approach brings.

Advantages of the hexagonal approach

If you're looking for a pattern to help you standardize the way software is developed at your company or even in personal projects, the hexagonal architecture can be used as the basis to create such standardization by influencing how classes, packages, and the code structure as a whole are organized.

In my experience of working on large projects with multiple vendors and bringing lots of new developers to contribute to the same code base, the hexagonal architecture helps organizations establish the foundational principles on which the software is structured. Whenever a developer switched projects, he had a shallow learning curve to understand how the software was structured because he was already acquainted with hexagonal principles he'd learned about in previous projects. This factor, in particular, is directly related to the long-term benefits of software with a minor degree of technical debt.

Applications with a high degree of maintainability that are easy to change and test are always welcomed. Now, let's learn how the hexagonal architecture can help us obtain such advantages.

Change-tolerant

Technology changes are happening at a swift pace. New programming languages and a myriad of sophisticated tools are emerging every day. To beat the competition, very often, it's not enough to just stick with well-established and time-tested technologies. The use of cutting-edge technology becomes no longer a choice but a necessity, and if the software is not prepared to accommodate such changes, the company risks losing money and time in big refactoring because the software architecture is not change-tolerant.

So, the ports and adapters nature of the hexagonal architecture gives us a strong advantage by providing the architectural principles to create applications that are ready to incorporate technological changes with less friction.

Maintainability

If it's necessary to change some business rule, you know that the only thing that should be changed is the Domain hexagon. On the other hand, if we need to allow an existing feature to be triggered by a client that uses a particular technology or protocol that is not supported by the application yet, we just need to create a new adapter, which we can only do in the Framework hexagon.

This separation of concerns seems simple, but when enforced as an architectural principle, it grants a degree of predictability that's enough to decrease the mental overload of grasping the basic software structures before deep diving into its complexities. Time has always been a scarce resource, and if there's a chance to save it through an architecture approach that removes some mental barriers, I think we should at least try it.

Testability

One of the hexagonal architecture's ultimate goals is to allow developers to test the application when its external dependencies are not present, such as its UI and databases, as Alistair Cockburn stated. This does not mean, however, that this architecture ignores integration tests. Far from that – instead, it allows a more continuous integration approach by giving us the required flexibility to test the most critical part of the code, even in the absence of technology dependencies.

By assessing each of the elements comprising the hexagonal architecture and being aware of the advantages such an architecture can bring to our projects, we're now furnished with the fundamentals to develop hexagonal applications.

Summary

In this chapter, we learned how important software architecture is in establishing the foundations to develop robust and high-quality applications. We looked at the pernicious nature of technical debt and how we can tackle it with sound software architecture. Finally, we overviewed the hexagonal architecture's core components and how they enable us to develop more change-tolerant, maintainable, and testable software.

With that knowledge, we're now able to apply these hexagonal principles to build applications based on the proposed Domain, Application, and Framework hexagons, which help us establish the boundaries between business code from technology code. This lays the groundwork for developing complete hexagonal systems.

In the next chapter, we're going to explore how to start developing a hexagonal application by looking at its most important part: the Domain hexagon.

Questions

1. What are the three hexagons that comprise the hexagonal architecture?
2. What's the role of the Domain hexagon?
3. When should we utilize use cases?
4. The input and output adapters are present in which hexagon?
5. What's the difference between driving and driven operations?

Further reading

- *Get Your Hands Dirty on Clean Architecture: A hands-on guide to creating clean web applications with code examples in Java*, by Tom Hombergs, published by Packt Publishing Ltd. (September 2019).

2
Wrapping Business Rules inside Domain Hexagon

In the previous chapter, we learned about the Domain as the first hexagon in hexagonal architecture. By being the innermost hexagon, the Domain does not depend on anything above it. Also, we make all the other hexagons depend on the Domain to conduct their operations. This kind of arrangement confers the Domain hexagon a degree of responsibility and relevance far higher than other hexagons. We employ such an arrangement because it is on a domain where we group all the business rules and data that most represent the problem we are trying to solve.

Among the techniques to model a problem domain, **Domain Driven Design** (**DDD**) is widely adopted in projects that emphasize software code as a medium to convey knowledge about a business. An always-present concern to separate what constitutes the core problem domain and what is secondary to it makes DDD a suitable approach to support the hexagonal architecture goal to separate technology code from business code.

The principles and techniques we are about to see in this chapter will serve as the basis to build the Domain hexagon.

In this chapter, we will cover the following topics:

- Modeling a problem domain with entities
- Enhancing descriptiveness with value objects
- Assuring consistency with aggregates
- Working with domain services
- Using Policy and Specification patterns to deal with business rules
- Defining business rules as **Plain Old Java Objects** (**POJOs**)

By the end of this chapter, you will have learned the building blocks of DDD and will be able to apply the presented concepts in the development of hexagonal applications.

Technical requirements

To compile and run the code examples presented in this chapter, you need the latest **Java Standard Edition** (**SE**) **Development Kit** and **Maven 3.6** installed on your computer. They are all available for the Linux, Mac, and Windows operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter02`.

Modeling a problem domain with entities

In DDD, before any code is written, there must be lots of discussions between developers and domain experts—the people who have a deep understanding of the business. Those discussions provide valuable information acquired through a process called knowledge crunching, which is based on brainstorming between those developers and domain experts. That knowledge is then incorporated into the **Ubiquitous Language**. This language works as the *lingua franca* among everyone involved in the project and is present in documentation, day-to-day conversations, and—of course—in the code.

When we're dealing with entities, we must always pay attention to how much we can learn about the business by just reading the code, because the real deal happens when we employ the knowledge-crunching technique in order to continually evolve the Ubiquitous Language and make the code speak that language. That's the basis for rich entities that really capture relevant behaviors and are more than mere data objects.

For an entity to be considered as an entity, it must have an identity; so, we'll see how to assign identity in a way that is aligned with the hexagonal architecture goal to separate concerns between business and technology code.

The purity of domain entities

When we're modeling a problem domain, the main focus is to capture, as precisely as possible, a real-life scenario into code. That scenario is often composed of several processes working together to support the organization's goals to meet customer expectations. This ability to fulfill customer needs will ultimately determine the organization's capacity to generate profit. So, the problem-domain modeling effort is crucial for determining the overall success of any organization that relies on its software to make money. A failure to understand and translate business requirements into code will obviously result in the loss of money.

Central to that problem-domain modeling effort is the creation of entities. Due to the proximity entities have with business requirements, we should strive to shield these entities from technical requirements. We do that to prevent the blurring of business-related code with technology-related code. By technology, I mean those things that exist and make sense only in the context of software.

Those same technology concerns would not make sense if we were only considering the business requirements without the software. We also have to recognize that a problem domain may not always refer to pure business requirements. A problem domain may be purely technological, such as creating a new development framework. I don't think hexagonal architecture is the best approach in those scenarios because its emphasis is on projects trying to solve conventional business problems.

Domain entities should be pure in the sense that they deal only with business concerns. For technology-specific things, we have the prerogative to utilize ports, use cases, and adapters, as we'll see in the following chapters.

Relevant entities

The presence of two elements characterizes a relevant entity: business rules and business data. It is not unusual to see entity classes modeled almost like database entity objects that express only the data part and forget the rules. These rules may end up in parts of code other than the domain.

This kind of leak is harmful because it makes it difficult to guess what the entity does by just looking at it. That phenomenon is prevalent in what is called an **anemic domain model**. The entity objects coming from anemic domain models generally have data but lack behavior. By not coupling data with behavior, the anemic domain model goes against the very essence of **Object Oriented Programming** (**OOP**). When behavior is not present on domain objects, we have to go somewhere else to fully grasp what the entity is supposed to do, thus generating a mental overload that can quickly become an onerous burden as the code base grows.

On the other side of the coin, we should not overload entity classes with logic that is not intrinsic to the entity we're trying to model. That's not a trivial thing to do, because at first, we may think an operation is a part of the entity to discover later on that it's not.

For things considered not intrinsic to entity behavior, we have the prerogative to use a domain service. With services, we can accommodate those operations that don't fit quite nicely into an entity class.

In the previous chapter, we created a `retrieveRouter` method to filter and list routers in the `Router` class, as illustrated in the following code snippet:

```
public static List<Router> retrieveRouter(List<Router> routers,
Predicate<Router> predicate){
      return routers.stream()
          .filter(predicate)
          .collect(Collectors.<Router>toList());
}
```

Could we consider this list router's behavior an intrinsic characteristic of routers in the real world? If our problem domain says the opposite, then we should remove this behavior from the entity class. *And what about the constraints that we use to check the router type before we add a router to the list?* If we consider this verification a router-intrinsic behavior, we have the following options:

- Embed this constraint directly in the entity class.
- Create a specification to assert the constraint.

Specifications are a subject we're going to see later in this chapter, but for now, you can see specifications as predicate mechanisms to assure we're working with the correct objects. The following code snippet provides an example of a `Router` entity class with the router type-check constraints embedded directly on it:

```
public class Router {
/** Code omitted **/
     public static Predicate<Router> filterRouterByType
       (RouterType routerType){
          return routerType.equals(RouterType.CORE)
                ? Router.isCore() :
                Router.isEdge();
     }

     private static Predicate<Router> isCore(){
          return p -> p.getRouterType() == RouterType.CORE;
     }

     private static Predicate<Router> isEdge(){
          return p -> p.getRouterType() == RouterType.EDGE;
     }
/** Code omitted **/
}
```

To accommodate the domain service method, we need first to create a domain service class called `RouterSearch` and move to it the `retrieveRouter` method from the `Router` class, as follows:

```
public class RouterSearch {

    public static List<Router> retrieveRouter(List<Router>
      routers, Predicate<Router> predicate){
          return routers.stream()
                .filter(predicate)
                .collect(Collectors.<Router>toList());
    }
}
```

The `isCore`, `isEdge`, and `filterRouterByType` constraint methods continue to exist in the `Router` entity class. We only moved the `retrieveRouter` method from `Router` to `RouterSearch`. That `retrieveRouter` method can now be consumed as a service by other objects on the Domain and in other hexagons. Later in this chapter, in the *Working with domain services* section, we will take a closer look into domain services.

Using UUIDs to define identity

You may be familiar with **identifier** (**ID**)-generation techniques that rely on database sequence mechanisms to generate and avoid duplication of IDs. Although it's convenient to delegate this responsibility to a database, by doing so, we're coupling a crucial aspect of our software to an external system.

Suppose we're aiming to develop a hexagonal application that lets us evolve the business code with as few technology dependencies as possible. In that case, we need to find a way to turn this identity generation into an independent process.

A common approach to establish an identity that does not rely on a central authority is with a **universally unique identifier**, or simply **UUID**. This is a 128-bit number widely used to assure universal uniqueness in computer systems. There are four different methods to generate UUIDs: time-based, **Distributed Computer Environment** (**DCE**) security, name-based, and randomly generated. The following code snippet shows how you can create name-based and randomly generated UUIDs:

```
// Name-based UUID
var bytes = new byte[20];
new Random().nextBytes(bytes);
var nameBasedUUID = UUID.nameUUIDFromBytes(bytes);

// Randomly generated UUID
var randomUUID = UUID.randomUUID();
```

Beware of UUIDs. You can have performance issues if your data source is a relational database. Because UUIDs are strings, they consume more memory than the integers created by autogenerated IDs provided by relational databases. The use of UUIDs can cause a considerable impact on the size and index management of databases. There is no free lunch. Computer resources are the price to be paid for such an agnostic ID-generation solution. It's up to you to decide if the benefits of this approach outweigh the disadvantages.

Once defined, the entity ID should not change, so it becomes an immutable attribute. This immutable characteristic makes the entity ID attribute a suitable candidate to be modeled as a value object. Based on that topology and network inventory example we were dealing with in the previous chapter, the following code snippet shows us a simple approach to create a value object class to represent the ID of our `Router` entity:

```
public class RouterId {

     private final UUID id;

     private RouterId(UUID id){
          this.id = id;
     }

     public static RouterId withId(String id){
          return new RouterId(UUID.fromString(id));
     }

     public static RouterId withoutId(){
          return new RouterId(UUID.randomUUID());
     }
}
```

The `withId` factory method allows the reconstitution of `Router` entities when we have the ID. The `withoutID` factory method enables the generation of new IDs if we're dealing with a new `Router` entity.

Entities are first-class citizens in a hexagonal architecture. They are the foundational elements from which other software components will derive. But they alone aren't enough to create rich domain models, because not everything in a domain possesses an identity. We need something to express objects that don't need to be uniquely identified. We fill this gap with value objects, a type of object intended to help us increase the descriptiveness of a problem domain.

Enhancing descriptiveness with value objects

Implementing Domain-Driven Design pointed out quite well that we should use value objects to measure, quantify, or describe things from our problem domain. For example, you can describe an ID attribute with a value object instead of a long or integer value. You can wrap a double or big decimal attribute into a specific value object to express quantification more clearly.

We're not fully satisfied with just using the built-in language types to model a problem domain. To make the system more explicit about its nature and purposes, we wrap those built-in language data types—and even our own created types—into well-defined value objects.

This effort to convey meaning is based on the following two fundamental characteristics about value objects:

- They are immutable.
- They don't have an identity.

Suppose you have painted a picture. Imagine how strange would it be if, for some reason, after you've finished your work, parts of your picture mysteriously change colors. Colors in this example are like value objects that we use to create a picture, and each color can be a value object. So, to ensure our paint will persist, the colors, once used, must not change and must be immutable once used. I base my argument for value objects on this idea that some characteristics must never change because they are the raw material we use to describe a problem domain.

Raw material alone neither expresses much meaning nor has much value. The real value comes when we combine and work in that raw stuff to form relevant and discernable things. Because value objects alone are like raw material, we don't bother to replace them or throw them away. *And if they are not so important, why should we assign them an identity and take the same care we have with entities?*

The bottom line is that value objects should be discardable and easily replaceable objects that we use to compose an entity or other type of object.

When modeling an entity class, for example, we have two options: to use or not use value objects on entity attributes. Here is an example of the second approach:

```
public class Event implements Comparable<Event> {
      private EventId id;
      private OffsetDateTime timestamp;
      private String protocol;
```

```
    private String activity;
    ...
}
```

Consider the following log excerpt as data entries we want to parse into the `Event` objects:

```
00:44:06.906367 100430035020260940012015 IPV6 casanova.58183 >
menuvivofibra.br.domain: 64865+ PTR? 1.0.0.224.in-addr.arpa.
(40)
00:44:06.912775 100430035020260940012016 IPV4 menuvivofibra.
br.domain > casanova.58183: 64865 1/0/0 PTR all-systems.mcast.
net. (75)
```

After being properly parsed, we would have `Event` objects with network traffic activity string fields, as shown here:

```
casanova.58183 > menuvivofibra.br.domain
```

Before the greater-than sign, we have the source host and, after, the destination host. For the sake of this example, let's see it as an activity representing the source and destination of a packet. By being a string, it leaves a burden for clients that want to retrieve the source or destination host from the string, as illustrated here:

```
var srcHost = event.getActivity().split(">")[0]
//casanova.58183
```

Let's try with an `Activity` value object, as follows:

```
public class Activity {
    private String description;
    private String srcHost;
    private String dstHost;

    public Activity (String description, String srcHost,
      String dstHost){

        this.description = description;
        this.srcHost = description.split(">")[0];
        this.srcHost = description.split(">")[1];
    }

```

```
    public String retrieveSrcHost(){
        return this.srcHost;
    }
}
```

Then, we update the `Event` entity class, as follows:

```
public class Event implements Comparable<Event> {
    private EventId id;
    private OffsetDateTime timestamp;
    private String protocol;
    private Activity activity;
    ...
}
```

The client code becomes clearer and more expressive, as we can see in the following snippet. Also, clients don't need to handle the data themselves to retrieve the source and destination hosts:

```
var srcHost = event.getActivity().retrieveSrcHost()
//casanova.58183
```

With value objects, we have more flexibility and control over our data, letting us express the domain model in a more cohesive way.

Assuring consistency with aggregates

We've so far seen how valuable entities are to represent things in a problem domain. Also, we saw how value objects are essential to enhance the descriptiveness of the model we are modeling. *But how to proceed when we have a group of related entities and value objects that express a whole concept when put together?* For such a scenario, we should employ the use of **aggregates**. The idea is that objects inside an aggregate operate in a consistent and isolated manner. To achieve such consistency, we must ensure that any change on any aggregate object is conditioned to the variants imposed by such an aggregate.

Aggregates are like an orchestrator that orchestrates data and behavior on the objects it controls. For this approach to work, we need to define an entry point to interact with the aggregate realm. This entry point is also known as the aggregate root, which keeps references to the entities and value objects that are part of the aggregate. With the boundary provided by aggregates, we're in a better position to assure consistency in the operations conducted by the objects within that boundary. By formally establishing conceptual boundaries to ensure consistency in the activities based on our problem domain, it will be easier for us to incorporate techniques such as optimistic or pessimistic locking, and technologies such as the **Java Transaction API** (**JTA**) to support consistent transactional operations. With well-structured aggregates, we have better conditions to apply whichever approach we think is good for enabling transactions on our system.

From a performance and scalability perspective, we should always strive to keep our aggregates as small as possible. The reason is simple: large aggregate objects consume more memory. Too many aggregate objects being instantiated at the same time can compromise the overall **Java Virtual Machine** (**JVM**) performance. This rule applies to anything in the OOP world, but we emphasize aggregates because of their ability to integrate objects.

A small aggregate generally contains just one entity that acts as the aggregate root and other value objects. The way to make two different aggregates interact with each other is through their aggregate root, which happens to be an entity root with its unique ID. The aggregate root is used for persistence purposes as well. So, you'll perform changes on aggregate child objects through the aggregate root, and when your changes are done, you'll use the same aggregate root to commit those changes to your persistence system.

On the other hand, if you don't see the non-functional requirements of performance and scalability as something critical, I think that aggregates can grow to have more than one entity with proper care.

To illustrate how we can model an aggregate, let's return to our network and topology inventory scenario. One of the business needs is to catalog the equipment and networks connected to a specific **Edge Router**. Below this **Edge Router**, we have a **Level 3 Switch** responsible for creating **Virtual Local-Area Networks** (**VLANs**) for different networks. The scheme would be something like the one shown here:

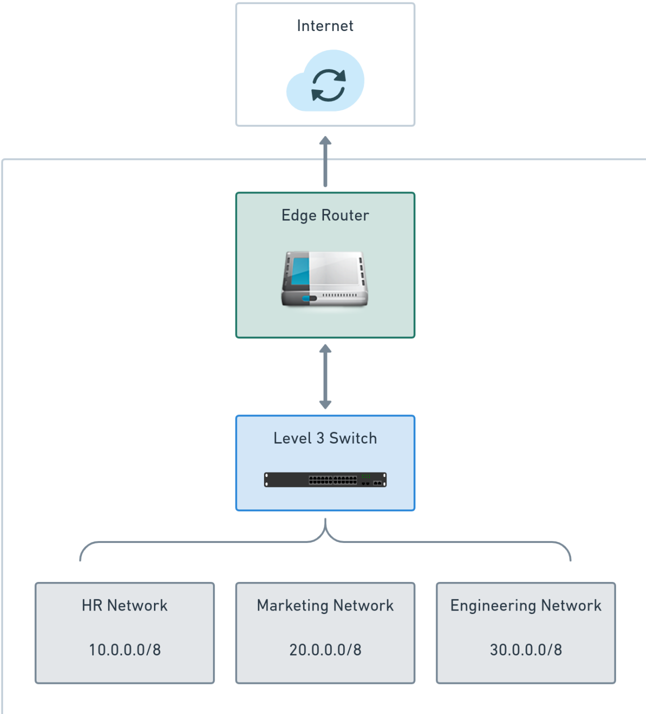

Figure 2.1 – Network components

The catalog of equipment, networks, and relationships is used for the infrastructure department to help them plan and implement changes on the overall network. A router or switch alone don't tell us too much about the network. The real value comes when we aggregate all the network components and their interconnections.

This kind of information will allow the infrastructure department to have more visibility and make well-based decisions. The epicenter of our aggregate is the edge router entity, which happens to be our aggregate root. The switch is also an entity. We model its VLAN networks as value objects. The context here is clear: a network composed of HR, marketing, and engineering VLAN networks connected to a switch that, in turn, is connected to the edge router. The internet and other networks can be considered in a different context. Here is a **Unified Modeling Language** (**UML**)-like representation of the aggregate root:

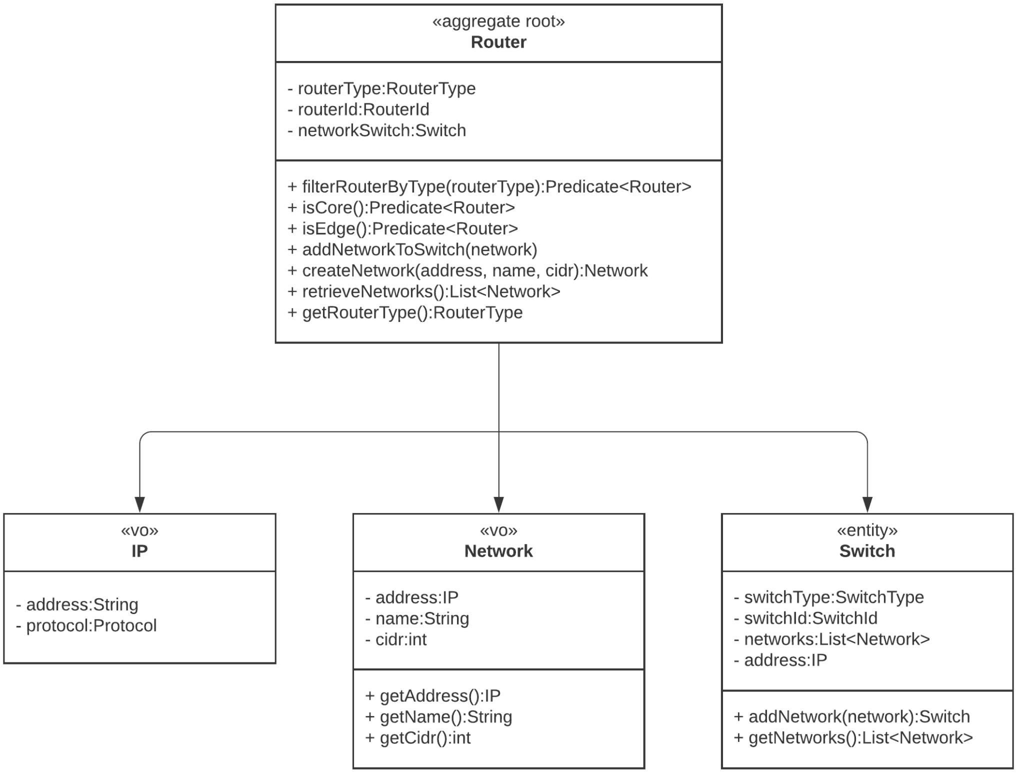

Figure 2.2 – Aggregate grouping together all network components

Starting from the bottom level, we have `Network` as a value object, as illustrated in the following code snippet:

```
public class Network {

     private final IP address;
     private finalString name;
     private final long cidr;

     public Network(IP address, String name, long cidr){
          if(cidr <1 || cidr>32){
               throw new
IllegalArgumentException("Invalid                     CIDR
value");
```

```
            }
            this.address = address;
            this.cidr = cidr;
      }
}
```

Note that the **Internet Protocol** (**IP**) address attribute is a value object as well, as shown in the following code snippet:

```
public class IP {

      private final String address;
      private final Protocol;

      private IP(String address){
            if(address == null)
            throw new IllegalArgumentException("Null IP
              address");

            if(address.length()<=15) {
                  this.protocol = Protocol.IPV4;
            } else {
                  this.protocol = Protocol.IPV6;
            }
            this.address = address;
      }
}
```

You may have noted some validation rules in the constructors of the `IP` and `Network` value objects' classes. Those validations work as guards to prevent the wrong construction of value objects. Putting those guards in instance creation is one way to free clients from the burden of validating value objects. That's exactly what is happening on the `Network` class where we are just validating the `cidr` attribute because `IP` will come already validated.

There's also a `Protocol enum` value object that we use to compose the `IP` value object, as illustrated in the following code snippet:

```
public enum Protocol {
     IPV4,
     IPV6;
}
```

After modeling the `IP`, `Network`, and `Protocol` value objects, we have now the necessary objects to model the `Switch` class, as follows:

```
public class Switch {
     private SwitchType type;
     private SwitchId switchId;
     private List<Network> networkList;
     private IP address;

    public Switch (SwitchType switchType, SwitchId
      switchId, List<Network> networks, IP address){
        this.switchType = switchType;
        this.switchId = switchId;
        this.networks = networks;
        this.address = address;
    }

    public Switch addNetwork(Network network){
        var networks = new
          ArrayList<>(Arrays.asList(network));
        networks.add(network);
        return new Switch(this.switchType, this.switchId,
          networks, this.address);
    }

    public List<Network> getNetworks() {
        return networks;
    }
}
```

Because networks are directly connected to a switch, we created an `addNetwork` method to support the capability to add more networks to a switch. Note that this method returns a new `Switch` object with an extended list of networks.

On top of all the value objects we have created so far, we need to formalize a boundary with an aggregate root. That's the role of our `Router` entity class, as illustrated in the following code snippet:

```
public class Router {
    private final RouterType routerType;
    private final RouterId routerid;
    private Switch networkSwitch;
    public Router(RouterType, RouterId
      routerid){
        this.routerType = routerType;
        this.routerid = routerid;     }
    public static Predicate<Router>
      filterRouterByType(RouterType routerType){
        return routerType.equals(RouterType.CORE)
                ? Router.isCore() :
                Router.isEdge();     }
    public static Predicate<Router> isCore(){
        return p -> p.getRouterType() == RouterType.CORE; }
    public static Predicate<Router> isEdge(){
        return p -> p.getRouterType() == RouterType.EDGE; }
    public void addNetworkToSwitch(Network network){
        this.networkSwitch =
          networkSwitch.addNetwork(network);  }
    public Network createNetwork(IP address, String name,
      int cidr){
        return new Network(address, name, cidr); }
```

```
    public List<Network> retrieveNetworks(){
        return networkSwitch.getNetworks();   }
    public RouterType getRouterType(){
        return routerType;   }
    @Override
    public String toString(){
        return "Router{" +
                "type=" + routerType +
                ", id=" + routerid +
          '}';
    }
}
```

We've added a value object to represent the list of IP addresses the router uses for both internal and external communication (for example, the internet). The `networkSwitch` entity represents the switch connected directly to this router. Then, we added two methods, one to create a new network and another to connect an existing network to the switch.

By putting these methods on the aggregate root, we delegate to it the responsibility to handle all the objects under its context, thus enhancing consistency when we are dealing with such aggregation of objects. Also, this is an effort to prevent the anemic domain model approach, whereby entities are just data objects without any kind of behavior.

Next, we're going to see how to use domain services to call those operations contained in the aggregate.

Working with domain services

When modeling a problem domain, we'll certainly face situations where the task at hand does not fit adequately into any of the object categories that we've seen so far in the domain hexagon: entities, value objects, and aggregates. Earlier in this chapter, we met a situation where we removed from the `Router` entity a method responsible for retrieving a list of routers. That method seemed to be in the wrong place because, in our topology and network inventory scenario, a router usually doesn't list other routers. To deal with this cumbersome situation, we've refactored the router list method in a separate object. Eric Evans calls such objects **domain services**.

I believe it's important to distinguish domain services from any other type of service. For example, in **Model-View-Controller** (**MVC**) architectures, services are often seen as bridges that connect the different facets of an application, handling data and orchestrating calls within and outside the system. Their usage is often associated with software development frameworks such as Spring that even have a service annotation. But independent of the context, I believe the main difference between distinguished service types lies not in the meaning but in the scope.

What makes something a service? It's the ability to perform some worthwhile effort. This characteristic is inherent to any service, both in the real world and with computers. However, in the latter case, we should care about **Separation of Concerns** (**SoC**), modularization, decoupling, and other relevant matter for good architecture. It's based on those concerns that we nail down domain services to the realm of the Domain hexagon. They perform worthwhile tasks—as any other services—but within the constrained scope of our problem domain. This means domain services should not call services or other objects that operate in application or framework hexagons. Instead, objects from those hexagons are clients who call domain services.

In the previous section, we created the following two methods in our `Router` entity class, which is also the aggregate root:

```
public void addNetworkToSwitch(Network network){
    this.networkSwitch = networkSwitch.addNetwork(network);
}

public Network createNetwork(IP address, String name, long
cidr){
    return new Network(address, name, cidr);
}
```

In the following code snippet, we have a service class operating over those two `Router` entity methods:

```
public class NetworkOperation {

     final private int MINIMUM_ALLOWED_CIDR = 8;
     public void createNewNetwork(Router router, IP
       address, String name, int cidr) {

     if(cidr < MINIMUM_ALLOWED_CIDR)
```

```
        throw new IllegalArgumentException("CIDR is
          below      "+MINIMUM_ALLOWED_CIDR);

        if(isNetworkAvailable(router, address))
        throw new IllegalArgumentException("Address already
          exist");

        Network =
          router.createNetwork(address,name,cidr);
        router.addNetworkToSwitch(network);
        }

        private boolean isNetworkAvailable(Router router, IP
          address){

             var availability = true;
             for (Network network : router.retrieveNetworks()) {
                  if(network.getAddress().equals(address) &&
                    network.getCidr() == cidr)
                       availability = false;
                       break;
             }
             return availability;
        }
 }
```

We have a method called `createNewNetwork` that is responsible for creating a new network object and adding it to the switch linked to our router. We should meet two constraints to be able to create a network. The first, simple one checks if the minimum **Classless Inter-Domain Routing** (**CIDR**) has not been violated. The second constraint is somewhat more elaborate. It verifies whether the network address is already being used anywhere on the whole network.

With this approach, we're delegating to the `NetworkOperation` domain service class the responsibility to deal with tasks that don't fit quite well into entities or value objects. That's also a valuable effort to prevent entity and value object classes from growing too large with far more features than necessary according to the problem domain.

Until now, we've been dealing with invariants directly on entities, value objects, or service classes. Next, we'll see an approach to accommodate those invariants in a more orderly and organized way.

Using policy and specification to deal with business rules

One of the most valuable things a system possesses is its codified business rules. Those rules represent a vital effort to understand a real-world problem and translate that understanding into working software. That's not a trivial task, for sure. In DDD, we learn how crucial it is to work closely with domain experts to model our problem domain correctly. If domain experts are not available, we should seek developers with knowledge in the business. If none of them is available, we have no choice but to embark on a knowledge-seeking journey through books and any other resources that can help us grasp our problem domain's inner workings.

Once the business knowledge is acquired and we have enough relevant information about the problem domain's steps and processes, we can then start the adventure to transform that knowledge into code. At a first glance, this process to understand business needs and transform them into software seems simple. Instead, it's been the fruit of very good debates that have given rise to various methodologies and even an important manifesto called the **Agile manifesto**. It's not my goal here to discuss the best approach to understand business needs. Instead, the idea here is to present some of the techniques we can use to transform that business knowledge into working software.

We always have the prerogative to do things in our way, sometimes ignoring the knowledge resulting from the experience of others who came before us. When dealing with business rules, this is by no means different. In the previous examples, we have been doing this very thing, scattering business rules around the code without any second thought. We now have an opportunity to fix that approach and tap into the knowledge of others who came before us.

Policy and Specification patterns are two patterns that can help us better organize our code's business rules.

A **policy**, also known as a strategy, is a pattern that encapsulates part of the problem domain in a block of code. For those familiar with the Strategy pattern (*Gang of Four*), the term algorithm can be used to describe that encapsulated block of code. The main characteristic of a policy is that it performs some action or processing on the data provided. Policies are intentionally kept separate from entities and value objects to avoid coupling. This decoupling provides the well-known benefit of evolving one part without direct impact or side-effects on the other.

On the other hand, **specifications** are like conditions or predicates used to ensure the properties of an object. However, what characterizes a specification is its care to encapsulate those predicates in a more expressive way than mere logical operators. Once encapsulated, those specifications can be reused and even combined to express the problem domain better.

When used together, policies and specifications are sound techniques to improve the robustness and consistency of our business rules across the code. A specification ensures that only suitable objects are handled to our policies. We have a catalog of different and easily changeable algorithms at our disposal with policies.

Let's first see how we can refactor our `NetworkOperation` service class to use specifications. We'll start by creating a `Specification` interface, as follows:

```
public interface Specification<T> {
          boolean isSatisfiedBy(T t);
     Specification<T> and(Specification<T> specification);
}
```

It's through the `isSatisfiedBy` implementation that we're going to define our predicates. Followed by this interface, we need to create an abstract class that implements the `and` method to allow us to combine specifications, as illustrated in the following code snippet:

```
public abstract class AbstractSpecification<T> implements
Specification<T> {

     public abstract boolean isSatisfiedBy(T t);
     public Specification<T> and(final Specification<T>
       specification){
          return new AndSpecification<T>(this,
```

```
            specification);
      }
}
```

There is just a method for the `AND` operator because we are not dealing with other operators such as `OR` and `NOT`, but it's common to implement methods for those operators. To conclude the creation of our base types, we implement the `AndSpecification` class, as follows:

```
public class AndSpecification<T> extends
AbstractSpecification<T> {

      private Specification<T> spec1;
      private Specification<T> spec2;

      public AndSpecification(final Specification<T> spec1,
        final Specification<T> spec2) {

           this.spec1 = spec1;
           this.spec2 = spec2;
      }

      public boolean isSatisfiedBy(final T t) {
           return spec1.isSatisfiedBy(t) &&
             spec2.isSatisfiedBy(t);
      }
}
```

We are now ready to create our own specifications. The first one is about the business rule that limits the minimum CIDR allowed for the creation of new networks. The code is illustrated in the following snippet:

```
if(cidr < MINIMUM_ALLOWED_CIDR)
      throw new IllegalArgumentException("CIDR is
        below "+MINIMUM_ALLOWED_CIDR);
```

The corresponding specification will look like this:

```
public class CIDRSpecification extends
AbstractSpecification<Integer> {

      final static public int MINIMUM_ALLOWED_CIDR = 8;

      @Override
      public boolean isSatisfiedBy(Integer cidr) {
            return cidr > MINIMUM_ALLOWED_CIDR;
      }
}
```

Next, we'll deal with the business rules that check if the network address is not already being used, as follows:

```
if(isNetworkAvailable(router, address))
throw new IllegalArgumentException("Address already exist");
...
private boolean isNetworkAvailable(Router router, IP address){
      var availability = true;
      for (Network network : router.retrieveNetworks()) {
            if(network.getAddress().equals(address) &&
              network.getCidr() == cidr)
                        availability = false;
                        break;
            }
            return availability;
      }
```

The refactoring of the previous code basically consists of moving the `isNetworkAvailable` method from the entity to the specification class, as shown in the following code snippet:

```
public class NetworkAvailabilitySpecification extends
AbstractSpecification<Router> {

      private IP address;
      private String name;
```

```
    private int cidr;

    public NetworkAvailabilitySpecification(IP address,
      String name, int cidr) {
        this.address = address;
        this.name = name;
        this.cidr = cidr;
    }

    @Override
    public boolean isSatisfiedBy(Router router) {
        return router!=null &&
          isNetworkAvailable(router);
    }

    private boolean isNetworkAvailable(Router router){
        var availability = true;

        for (Network network : router.retrieveNetworks()) {
            if(network.getAddress().equals(address) &&
               network.getName().equals(name)&&
                 network.getCidr() == cidr)
            availability = false;
            break;
        }
        return availability;
    }
}
```

To illustrate how to combine two specifications with the `and` method, we create two more specifications. The first one is to establish the maximum allowed networks and is shown in the following code snippet:

```
public class NetworkAmountSpecification extends
AbstractSpecification<Router> {

    final static public int MAXIMUM_ALLOWED_NETWORKS = 6;
```

```
    @Override
    public boolean isSatisfiedBy(Router router) {
        return router.retrieveNetworks().size()
          <=MAXIMUM_ALLOWED_NETWORKS;
    }
}
```

And the second specification is to ensure that we're dealing only with edge or core routers. This is shown in the following code snippet:

```
public class RouterTypeSpecification extends
AbstractSpecification<Router> {

    @Override
    public boolean isSatisfiedBy(Router router) {
        return
        router.getRouterType().equals(RouterType.EDGE) ||
          router.getRouterType().equals(RouterType.CORE);
    }
}
```

We're now ready to refactor our domain service responsible for creating new networks to use those specifications, as follows:

```
public class NetworkOperation {

    public void createNewNetwork(Router router, IP
      address, String name, int cidr) {

        var availabilitySpec = new
          NetworkAvailabilitySpecification(address, name,
            cidr);
        var cidrSpec = new CIDRSpecification();
        var routerTypeSpec = new
          RouterTypeSpecification();
        var amountSpec = new
          NetworkAmountSpecification();

```

```
            if(cidrSpec.isSatisfiedBy(cidr))
                 throw new IllegalArgumentException("CIDR is
                   below
                   "+CIDRSpecification.MINIMUM_ALLOWED_CIDR);

            if(availabilitySpec.isSatisfiedBy(router))
                 throw new IllegalArgumentException("Address
                   already exist");

            if(amountSpec.and(routerTypeSpec).isSatisfiedBy
              (router)) {
                 Network network =
                   router.createNetwork(address, name, cidr);
                 router.addNetworkToSwitch(network);
            }
       }
  }
```

To understand how policies work, we're going to create a service class to help us retrieve a list of network events based on a specific algorithm to parse raw event data. This parse algorithm can or cannot be considered part of the problem domain; usually, it's not, but for the sake of this example, let's assume it is.

We are about to create two policies: the first is to parse string log entries into `Event` objects using a pure **regular expression** (**regex**)-based algorithm where we explicitly inform the regex pattern, while the second one will accomplish the same thing but with a split-based algorithm that uses just a space delimiter. The choice between both policies can be based on performance and the ability to customize the parsing mechanisms, among other things.

First, we create an `EventParser` interface, as follows:

```
public interface EventParser {

     DateTimeFormatter formatter =
       DateTimeFormatter.ofPattern("yyyy-MM-dd
         HH:mm:ss.SSS").withZone(ZoneId.of("UTC"));

```

```
    Event parseEvent(String event);
}
```

We'll use the `formatter` attribute in both event-parser implementation classes.

Let's start implementing the regex parser policy, as follows:

```
public class RegexEventParser implements EventParser{

    @Override
    public Event parseEvent(String event) {
        final String regex = "(\\\"[^\\\"]+\\\")|\\S+";
        final Pattern pattern = Pattern.compile(regex,
          Pattern.MULTILINE);

        final Matcher matcher = pattern.matcher(event);
        var fields = new ArrayList<>();

        while (matcher.find()) {
            fields.add(matcher.group(0));
        }

        var timestamp =
          LocalDateTime.parse(matcher.group(0),
            formatter).atOffset(ZoneOffset.UTC);
        var id = EventId.of(matcher.group(1));
        var protocol =
          Protocol.valueOf(matcher.group(2));
        var activity = new Activity(matcher.group(3),
          matcher.group(5));
        return new Event(timestamp, id, protocol,
          activity);
    }
}
```

The split parser policy seems simpler, as we can see here:

```
public class SplitEventParser implements EventParser{
          @Override
     public Event parseEvent(String event) {
          var fields = Arrays.asList(event.split(" "));

          var timestamp =
            LocalDateTime.parse(fields.get(0),
              formatter).atOffset(ZoneOffset.UTC);
          var id = EventId.of(fields.get(1));
          var protocol = Protocol.valueOf(fields.get(2));
          var activity = new Activity(fields.get(3),
            fields.get(5));

          return new Event(timestamp,id, protocol,
            activity);
     }
}
```

Note that the `Event` constructor is being called with the parsed attributes. We need to update our `Event` entity class to enable it to work with our policies. We can do so with the following code:

```
public class Event implements Comparable<Event>{

     private OffsetDateTime timestamp;
     private EventId id;
     private Protocol protocol;
     private Activity activity;

     public Event(OffsetDateTime timestamp, EventId id,
       Protocol protocol, Activity activity){

          this.timestamp = timestamp;
          this.id = id;
          this.protocol = protocol;
```

```
            this.activity = activity;
       }

       public static Event parsedEvent(String
         unparsedEvent, ParsePolicyType policy){

            switch (policy){
                 case REGEX:
                      return new RegexEventParser()
                        .parseEvent(unparsedEvent);
                   case SPLIT:
                      return new SplitEventParser()
                        .parseEvent(unparsedEvent);
                 default: throw  new
                  IllegalArgumentException("Invalid policy");
            }
       }
 ...
 }
```

The switch that allows us to choose between policies relies on the following enum:

```
public enum ParsePolicyType {
    REGEX,
    SPLIT;
}
```

We're now ready to create an `EventSearch` service class with a method to retrieve network events. This domain service will allow us to choose which kind of parse algorithm to use when retrieving events. Here's the code we'll need for this:

```
public class EventSearch {

     public List<Event> retrieveEvents(List<String>
       unparsedEvents, ParsePolicyType policyType){

          var parsedEvents = new ArrayList<Event>();
          unparsedEvents.stream().forEach(event →{
```

```
                parsedEvents.add(Event.parsedEvent(event,
            policyType));
            });
            return parsedEvents;
        }
    }
```

Now that we are acquainted with Policy and Specification patterns, let's see the benefits of modeling our business rules as POJOs.

Defining business rules as POJOs

Back in the day, when enterprise development was strongly influenced by Java 2 Platform, **Enterprise Edition** (**J2EE**) (known today as Jakarta EE), there was a technology called **Enterprise JavaBeans** (**EJB**) responsible for lifting from developers all the heavy weight required to manage software development plumbing activities related to transaction management, security, and object life cycles. The EJB promise was that developers could focus their energy on developing business features, while the J2EE container would take care of all the infrastructure details. EJB fulfilled this promise, but not without a price. It was time-consuming and boring to create and maintain EJBs in their first versions. There were lots of things to do involving various **Extensible Markup Language** (**XML**) configurations and deployment descriptors, and, to make things worse, there was little space to reuse these EJB objects because they had so much boilerplate. They weren't like POJOs: simple and reusable.

This issue with the first EJB versions—version 2 especially—helped to motivate the creation of improved solutions that could leverage the simplicity of POJOs. Among those solutions, we can mention EJB 3 and the technologies derived from frameworks such as Spring and Quarkus. What all those technologies have in common, though, is the incentive and flexibility to work with POJOs.

POJOs are appealing because they are nothing more than regular Java objects. It is simple to understand a POJO because we're dealing only with Java standard **Application Programming Interfaces** (**APIs**) instead of custom libraries and frameworks. That's what makes POJOs a category of developer-friendly objects easier to understand and reuse across different parts of an application. If we're aiming for change-tolerant applications, then the use of POJOs is always recommended to diminish coupling with specific technologies, allowing the application to switch between different technologies or frameworks without much friction.

This flexibility offered by POJOs allows them to participate, simultaneously if needed, in different system departments. For example, nothing prevents someone from using the same POJO in transactional, persistence, and user-presentation contexts. We can also use POJOs to represent business rules: the entity, policy, and specification objects presented in this chapter are good examples of how we can embody business rules within POJOs.

By using POJOs to model business rules, we leverage all the benefits related to reusability and simplicity that a POJO can provide. They also go hand in hand with the important goal of keeping domain objects shielded from any technological details, which will ultimately contribute to the essential SoC efforts to support more supple and sober designs.

Summary

The DDD topics we covered in this chapter are paramount in our effort to develop hexagonal applications because it's through the use of DDD techniques that we'll be able to shape a decoupled, consistent, and business-oriented Domain hexagon that will be the foundation for the Application and Framework hexagons.

It's always essential to understand the basics. By looking closer into the main DDD concepts, we found the basic techniques to aid us in developing the Domain hexagon. We covered how to make pure and relevant entities and how to assign an identity to them. With value objects, we understood how important they are in conveying meaning and enhancing the descriptiveness of a problem domain. Aggregates showed us how to group related entities and value objects to describe whole operations from our problem domain. Also, we saw how aggregates are instrumental in assuring consistency with transactions.

Followed by aggregates, we learned that domain services let us express behaviors that don't fit well into entities or value objects, and to better organize the business rules, we learned about Policy and Specification patterns. Finally, we assessed the benefits of reusability and simplicity that POJOs provide when defining business rules. With the ideas and techniques explored in this chapter, we can build a Domain hexagon that captures and properly arranges into code the business rules that will influence the behavior of the entire application.

We're now ready to move one step higher up the ladder by entering the realm of the Application hexagon, where we'll see how to combine and orchestrate business rules to create software functionality through use cases and ports.

Questions

1. What is the main attribute of entities not found on value objects?
2. Can value objects be mutable?
3. Every aggregate must have an entry-point object to allow communication with other objects controlled by the aggregate. What is the name of this entry-point object?
4. Are domain services allowed to call objects on other hexagons?
5. What is the difference between a policy and a specification?
6. What is the benefit of defining business rules as a POJO?

Further reading

- *Implementing Domain-Driven Design* (Vernon, 2016)
- *Domain-Driven Design: Tackling Complexity in the Heart of Software* (Evans, 2003)
- *Extreme Programming Explained: Embrace Change* (Beck, 1999)

3
Handling Behavior with Ports and Use Cases

Once we have defined the business rules in the Domain hexagon, we can start thinking about ways to use those rules to create software features while considering how the system will handle the data coming from users and other applications. Ports and use cases address such concerns in the hexagonal architecture, where we need to orchestrate system data and business rules to provide useful software functionality.

In this chapter, we'll explore how to employ use cases to define the behaviors supported by the software. Integrated with use cases, we'll understand the role of input and output ports in establishing the communication flow within the hexagonal system.

We will cover the following topics:

- Expressing software behavior with use cases
- Implementing use cases with input ports
- Using output ports to deal with external data
- Automating behavior with the Application hexagon

By the end of this chapter, you'll be able to employ ports and use cases to coordinate all the things a hexagonal system must do to achieve software goals. Once you have grasped the fundamentals of ports and use cases, it will be possible to utilize them to combine elements from both the Domain and Application hexagons to construct powerful features.

Technical requirements

To compile and run the code examples presented in this chapter, you will need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. They are both available for Linux, Mac, and Windows operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter03`.

Expressing software behavior with use cases

A **software system** is nothing more than a set of behaviors working together to achieve the goals defined by users or even other software systems. A software behavior, in turn, is a worthy action that, alone or combined with other software actions, contributes to realizing a worthy software goal. Such goals are intimately connected to the desires expressed by interested users or systems.

We can classify those interested folks as stakeholders or actors from which we will ultimately derive the real-world needs that will be transmuted into goals. These will be fulfilled by what *Writing Effective Use Cases* calls the **System under Discussion** (**SuD**), or simply the software you are developing.

From the hexagonal architecture's standpoint, we can relate these actors to what we saw in *Chapter 1*, *Why Hexagonal Architecture?*, when discussing driver and driven operations. In the same vein, we can classify the SuD actors: the **driver actor** is a person or system that triggers one of the SuD behaviors, while the **driven actor** is an external system consumed by the SuD.

To express, both in functional and non-functional terms, what a system does, people such as Ivar Jacobson and Alistair Cockburn and the Agile community in general have contributed to developing useful techniques to transform business requirements into meaningful written descriptions of how a system should behave. Among those techniques, one that stands out is that of use cases.

Unlike the UML, which depicts a high-level view of the system through the relationship between diagrams, use cases perform a deeper dive by providing a detailed written description of SuD behaviors. **Use cases** are a valuable technique to set SuD goals, the means or behaviors to fulfill them, the possible failure scenarios, and what to do when they occur. When combined with DDD techniques, use cases are instrumental in bridging the gap of dealing with application-specific activities that mean more to the SuD – and the Application hexagon – than to the problem domain and its business rules in the Domain hexagon. By thinking in terms of use cases, we are making a significant step to improve the separation of concerns in the hexagonal architecture.

We can create use cases by simply writing a description about them, but it's also possible to express them through code. Next, we'll learn how to create use cases both in written and code form.

How to create a use case

There are elaborated approaches to creating written use cases where you may specify detailed and standardized information about the input data, possible behaviors, and use case results. Cockburn classifies those detailed use cases as fully dressed ones. Fully dressed use cases may be helpful in new teams, where people are not used to working together. The standards enforced by the fully dressed approach help provide a clear path about how a use case should be built. It helps prevent situations where a person may consider certain use case aspects that are not present in use cases written by another person. A fully dressed use case looks as follows:

- **Actor**: Infrastructure engineer
- **Goal**: To add a new network to an edge router
- **Scope**: Infrastructure department
- **Trigger**: A particular reason to segregate network access through a different network
- **Input data**: Router ID, network name, address, and CIDR
- **Actions**:

  I. Look up router ID.

  II. Validate that the network address doesn't already exist.

  III. Validate that the CIDR is not below the minimum allowed.

  IV. If the previous validations are okay, add the network to the informed router.

On the opposite side, we have the less formal, more casual types of use cases. The main characteristic of casual use cases is that they don't follow standards about how the information should be recorded. They try to convey as much meaning as possible in one or two paragraphs, as mentioned in the following example.

The infrastructure engineer sends a request to the application containing the router ID, network name, address, and CIDR. The application performs a lookup in the router ID, then validates if the network does not already exist, followed by another validation to confirm that the CIDR value is not below the minimum allowed. If all the validations are okay, then the system proceeds to add the network to the informed router.

Aside from the formal and casual written techniques, it's possible to express user intent directly in the code through automated tests. That approach relies on **Behavior Driven Design** (**BDD**) principles related to discovery, formulation, and automation. In such an approach, you start talking with the business' people trying to discover what they need. The output of this discovery process contains examples of situations and behaviors depicting the business need. Then, you move on to the formulation phase, where structured documentation is created based on those examples. Finally, the automation phase is where tests are created and executed to validate those behaviors from examples described and structured in previous phases.

When employing BDD earlier in software development, we have the opportunity to create use cases iteratively based on examples and tests created to validate business ideas.

With the aid of tools such as Cucumber, we can adopt the BDD approach in our hexagonal application. To convert the written use cases we built previously, we'd need to create a Cucumber feature file:

```
@addNetworkToRouter
Feature: Add network to a router
I want to be able to add a network to an existent router

Scenario: Adding a network to an existent router
Given I provide a router ID and the network details
When I found the router
And The network address is valid and doesn't already exist
And The CIDR is valid
Then Add the network to the router
```

Then, based on the steps provided by the `Given`, `When`, `And`, and `Then` terms from the feature files, we'd create a test class to automate the validation of our use case steps:

```
public class AddNetworkSteps {

RouterId routerId;
Router router;
RouterNetworkFileAdapter routerNetworkFileAdapter =
  RouterNetworkFileAdapter.getInstance();
Network network =
new Network(new IP("20.0.0.0"), "Marketing", 8);

/** Code omitted **/
}
```

First, we have to declare the types and initialize the objects we will use to perform our tests. In the preceding code, we declared the `RouterId` and `Router` types. Then, we initialized the `RouterNetworkFileAdapter` and `Network` instances.

After preparing the resources we need to test, we can start by implementing the first step on our test:

```
@Given("I provide a router ID and the network details")
public void obtain_routerId() {
this.routerId = RouterId.withId(
"ca23800e-9b5a-11eb-a8b3-0242ac130003");
}
```

The `@Given` annotation describes the retrieval of `RouterId`. We can use this ID to fetch a router:

```
@When("I found the router")
public void lookup_router() {
router = routerNetworkFileAdapter.fetchRouterById(routerId);
}
```

By using `RouterNetworkFileAdapter` and `RouterId`, we retrieve a `Router` object. Next, we can check if the `Network` object meets the desired requirements before adding it to the router:

```
@And(
"The network address is valid and doesn't already exist")
public void check_address_validity_and_existence() {
var availabilitySpec =
new NetworkAvailabilitySpecification(
network.getAddress(), network.getName(), network.getCidr());

if(!availabilitySpec.isSatisfiedBy(router))
throw new IllegalArgumentException("Address already exist");
}
```

To ensure the network is valid, we must apply the rules from `NetworkAvailabilitySpecification`. Next, we must check the network CIDR:

```
@Given("The CIDR is valid")
public void check_cidr() {
var cidrSpec = new CIDRSpecification();
if(cidrSpec.isSatisfiedBy(network.getCidr()))
throw new IllegalArgumentException(
"CIDR is below"+CIDRSpecification.MINIMUM_ALLOWED_CIDR);
}
```

As the last verification step, we must apply the rules from `CIDRSpecification`. If everything is fine, then we can add the network to the switch:

```
@Then("Add the network to the router")
public void add_network() {
router.addNetworkToSwitch(network);
}
```

By calling the `addNetworkToSwitch` method from `Router`, we have added the network to the router.

The following is a visual representation of the formal, casual, and BDD-based types of use cases:

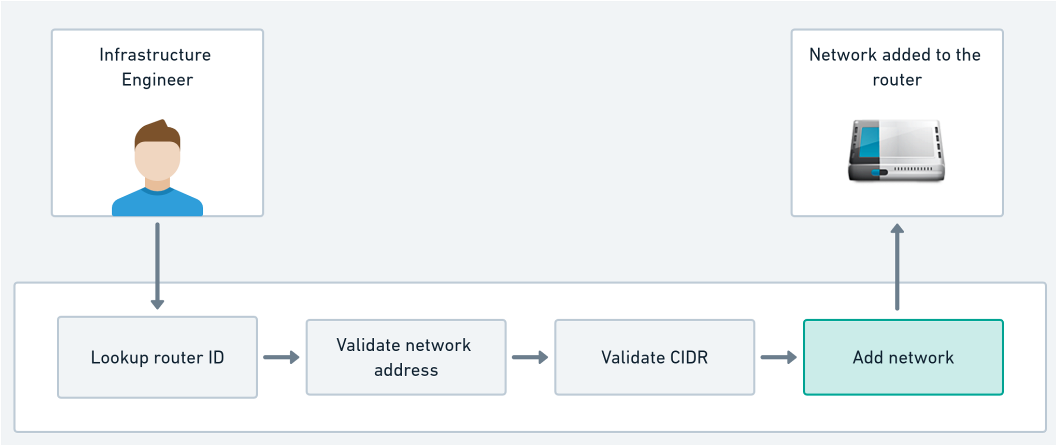

Figure 3.1 – A use case for the topology and inventory network system

Both fully dressed, casual, and BDD-based use cases express the same thing. The main difference lies not in the *what* but rather *how* the two techniques achieve the same objective to describe system behavior. As we may expect, the best choice is conditioned to money, time, and organization constraints.

We could bypass this use case creation/process and go straight on to code the use case. Although I don't consider that formal use case structuring part a required step, I certainly consider it a recommended one. By writing down and structuring the use case's expected behaviors, we're engaging in a valuable additional step to help us clarify and better organize our ideas regarding the use case's arrangement. Once the structuring effort is made, we only need to translate that into its code counterpart.

What I propose in developing hexagonal applications is to design use cases as abstractions rather than implementations. I use interfaces in these examples, but there is no problem using abstract classes. The following code shows a use case interface based on its written form:

```
public interface RouterNetworkUseCase {

    Router addNetworkToRouter(RouterId routerId, Network
network);
}
```

We define use cases as interfaces for two reasons:

- To provide different ways of fulfilling use cases goals
- To allow dependency on abstraction rather than implementation

The role of use cases in the hexagonal architecture is that they allow us to implement input ports. It's through input ports that we construct the logic that will, for example, call Domain hexagon services, other use cases, and external resources through output ports. The UML representation of the use case and its input port is as follows:

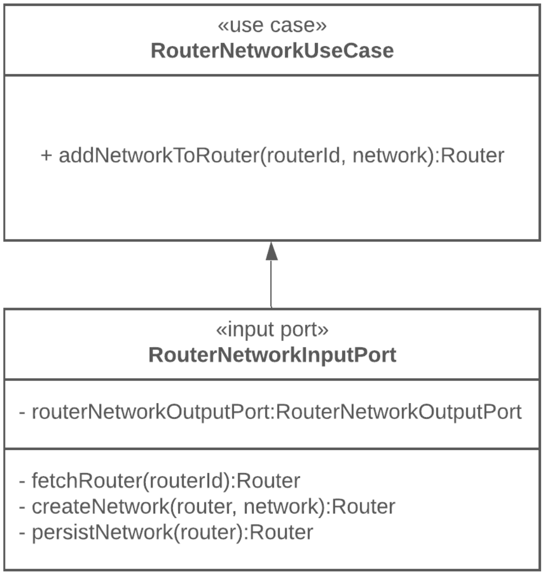

Figure 3.2 – A use case for the topology and inventory network system

Now that we know how to create use cases, both in written and code form, let's explore the ways to implement use cases with input ports.

Implementing use cases with input ports

In the hexagonal architecture, there is this idea about driving and driven operations. We've seen that such classification is also valid to determine which actors interact with the hexagon system. Driving actors are the ones who send requests to the application, while the driven actors representing the external components accessed by the application. We use **input ports** – also known as **primary ports** – to allow the communication flow between driving actors and the driving operations exposed by a hexagonal system.
Use cases tell us what behaviors the application will support, while input ports tell us how such behaviors will be performed.

Input ports play an integrating role because they are like pipes that allow the data to flow from driving actors when they hit the hexagonal system through one of its adapters on the Framework hexagon. In the same vein, input ports provide the pipes for communication with business rules from the Domain hexagon. Through input ports, we also orchestrate communication with external systems through output ports and adapters.

Input ports are in the crossroads of a hexagonal system, helping to translate what comes from the outside and goes in the direction of the Domain and Application hexagons. Input ports are also essential in orchestrating communication with external systems. In the following diagram, we can see how the **Application Hexagon** is the integration point between **Driving Actor** and **Driven Actor** and their respective input and output ports and adapters:

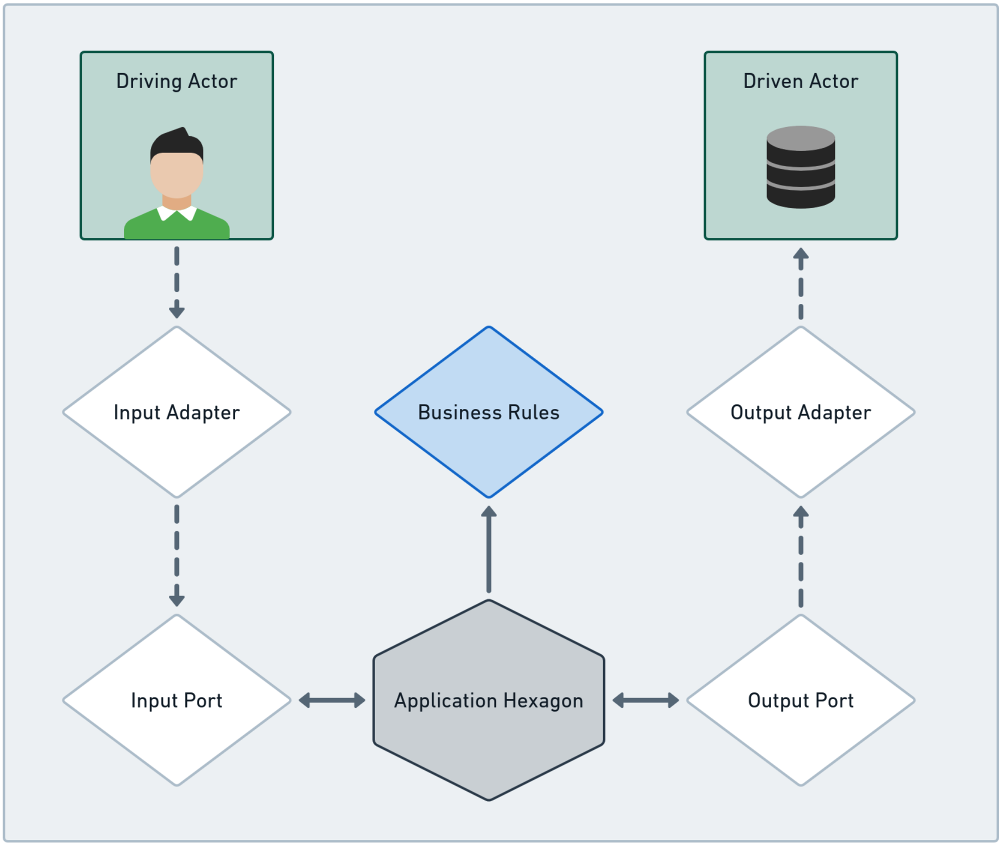

Figure 3.3 – Ports and the Application hexagon

In the previous section, we defined a use case interface describing an operation that allowed us to add a network to a router. Let's learn how to create an input port by implementing that use case:

```
public class RouterNetworkInputPortimplements
RouterNetworkUseCase {
privatefinal RouterNetworkOutputPort routerNetworkOutputPort;
    public RouterNetworkInputPort(RouterNetworkOutputPort
      routerNetworkOutputPort){
this.routerNetworkOutputPort = routerNetworkOutputPort;
}
@Override
public Router addNetworkToRouter(RouterId routerId, Network
 network) {
var router = fetchRouter(routerId);
return createNetwork(router, network);
}

private Router fetchRouter(RouterId routerId) {
return routerNetworkOutputPort.fetchRouterById(routerId);
}

private Router createNetwork(Router router, Network network) {
return persistNetwork(router) ?
NetworkOperation.createNewNetwork(router, network) :
router;
}

private boolean persistNetwork(Router router) {
return routerNetworkOutputPort.persistRouter(router);
}
}
```

With this input port implementation, we have a clear view of what actions the software must perform to fulfill the use case's goal of adding a network to the router. Before we look closer at the input port methods, let's consider the `RouterNetworkOutputPort` interface's declaration:

```
public interface RouterNetworkOutputPort {

     Router fetchRouterById(RouterId routerId);
     boolean persistRouter(Router router);
}
```

This output port states that the application intends to obtain and persist data on external sources. The hexagon system is not aware of whether the external source is a database, a flat file, or another system. Here, we only state the intention to get data from outside.

The `addNetworkToRouter` method, which is returning a `Router` object, is the only public method that's exposed by the input port. We make all other methods private because they are not supposed to be used outside the context of this input port. The input port starts its job by using `RouterId` to retrieve a `Router` object, then it creates a new `Network` object on that `Router` object. Remember, the `Network` object comprises the address, name, and CIDR attributes, as expressed in the use case's written form. The `fetchRouter` method will try to obtain a `Router` object by passing a `RouterID` to the output port's `fetchRouterById` method. That's when the input port will need to coordinate an external call that will be carried out by an output adapter that implements the output port.

If everything goes well, the input port will receive the desired `Router` object and will be able to create a network object and add it to the informed router. At this point, the input port is interacting with a Domain service called `createNewNetwork`. This service works under the constraints imposed by business rules from the Domain hexagon. Finally, the input port coordinates the persistence of the whole operation through the `persistRouter` method from the output port.

This input port does not contain anything specific to the problem domain. Its primary concern is to handle data by orchestrating internal calls with Domain services and external calls with output ports. The input port sets the operation's execution order and provides the Domain hexagon with data in a format it understands.

External calls are interactions that are performed by the hexagonal application to get from or persist data to external systems. This is the subject of the next section, where we'll learn how to use output ports to deal with things living outside the application.

Using output ports to deal with external data

Output ports, also known as **secondary ports**, represent the application's intent to deal with external data. It's through output ports that we prepare the system to communicate with the outside world. By allowing this communication, we can associate output ports with driven actors and operations. Remember, driven actors are external systems, while driven operations are used to communicate with such systems.

I say that we're preparing the hexagonal application to communicate with the outside world because, at the Application hexagon level, we don't know how that communication will occur yet. This approach is based on Uncle Bob's wise advice to postpone, as much as possible, any decisions concerned about which technologies will be used to fulfill the application's needs. By doing that, we're putting more emphasis on the problem domain than on technological details. I'm not saying that the persistence or messaging mechanisms, for example, are not relevant enough to influence the application's design. Instead, the idea is to not let external technologies dictate how the application is designed.

In the early stages of a software project, it's not uncommon to see people discussing whether to use Postgres or Oracle databases for persistence, Kafka or Redis for pub-sub activities, and so on. Those types of discussions exert a strong influence on how the software solves business problems where it's hard to imagine that software solving the same business problems but with different technologies. Sometimes, it's even inconceivable to consider such a thing because the whole application architecture is centered on specific technologies.

As people who work with technology, we're always eager to use the hottest development framework or a modern programming language. That is a good attitude, and I think we should continuously pursue better techniques and sophisticated ways to solve problems. But prudence is advised to properly balance our focus between the technology and problem domain aspects of a system.

It's not only about repositories

You may be used to using terms such as repository or **Data Access Objects** (**DAO**) to describe application behaviors related to persistence in a database. On hexagonal applications, we replace repositories with output ports.

Repositories are often associated with database operations, a fact that, by the way, is also enforced by some development frameworks that formalize this association through persistence features offered by the framework. A recurring example of this approach is similar to the following code:

```
public interface PasswordResetTokenRepository extends
JpaRepository<PasswordResetToken, Long> {

     PasswordResetToken findByToken(String token);
     PasswordResetToken findByUser(User user);
     Stream<PasswordResetToken>
       findAllByExpiryDateLessThan(Date now);
     void deleteByExpiryDateLessThan(Date now);

     @Modifying
     @Query("delete from PasswordResetToken t where
       t.expiryDate <= ?1")
     void deleteAllExpiredSince(Date now);
}
```

The usage of the `JpaRepository` interface and the `@Query` annotation from the Spring Framework reinforces the notion that the password data will come from a database.

The underlying idea about output ports is that we're not inferring that persistence or any kind of external communication will occur with a database system. Instead, the output port's scope is broader. Its concern is with communicating with any system, be it a database, a messaging system, or a local or network filesystem, for example.

A more hexagonal approach to the password reset interface shown previously would look something like the following code:

```
public interface PasswordResetTokenOutputPort {

     PasswordResetToken findByToken(String token);
     PasswordResetToken findByUser(User user);
     Stream<PasswordResetToken>
       findAllByExpiryDateLessThan(Date now);
     void deleteByExpiryDateLessThan(Date now);
     void deleteAllExpiredSince(Date now);
}
```

By not extending types from a specific framework and avoiding the usage of annotations such as `@Query`, we're turning the output port into a POJO. The usage of annotations per se is not a problem. The issue lies more in the purpose of their usage. If the aim is to use annotations to implement features that only exist in a particular framework, we are then coupling the software to that framework. Instead, if the purpose is to use annotations to implement features based on Java standard specifications, we are making a valuable effort to make the software more tolerant to change.

The data that's obtained from an output port today may come directly from a relational database. Tomorrow, this same data can be obtained from a REST API of some application. Those details are not necessary from the Application hexagon's perspective because the components in this hexagon are not concerned with how the data is obtained.

Their main concern is in expressing what kind of data they need to conduct their activities. And the way those Application hexagon components define what data they need is based on the entities and values objects from the Domain hexagon. With this arrangement, where an output port states what type of data it needs, we can plug multiple adapters into the same output port. So, these adapters carry out the necessary tasks to obtain the data, as expressed by the output port. This flow is shown in the following diagram:

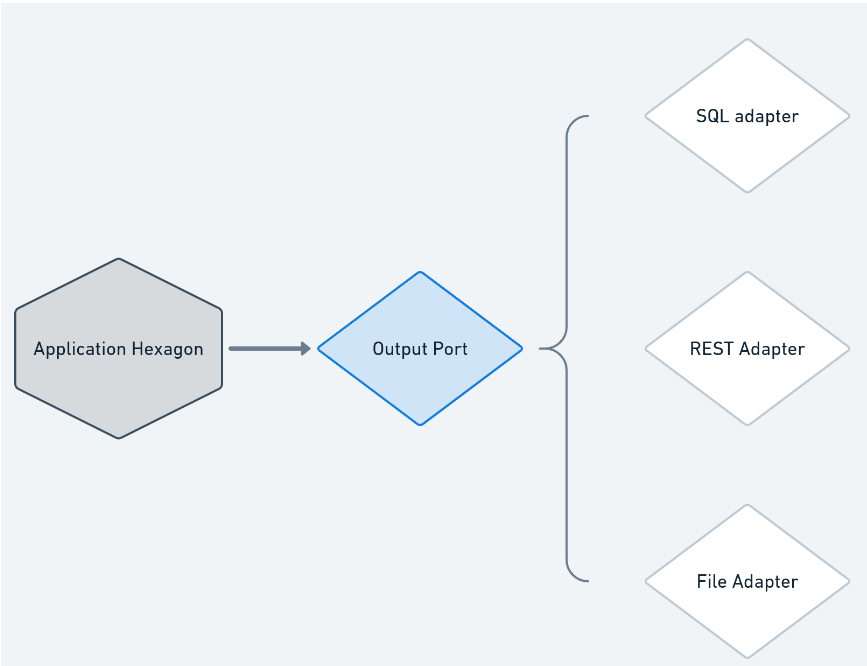

Figure 3.4 – The output port and its adapters

The output port's main goal is to state what kind of data it needs without specifying how it will get that data. That's the reason why we define them as interfaces and not implementations. The implementation part is reserved for output adapters, an essential hexagonal architecture component that we'll look at in the next chapter. To conclude our analysis on output ports, let's explore where they should be used.

Where to use output ports

At the beginning of this chapter, we learned how use cases establish the necessary actions to accomplish something useful in the application. Among these actions, there may be situations that require us to interact with external systems.

So, the reason to create and utilize output ports will be derived from the activities performed by use cases. In code, the reference for an output port will not appear in the use case's interface declaration. The usage of output ports is made explicit when we implement the use case with an input port. That's what we did when we implemented `RouterNetworkUseCase` and declared a `RouterNetworkOutputPort` attribute at the beginning of `RouterNetworkInputPort`:

```
public class RouterNetworkInputPort implements
RouterNetworkUseCase {

     private final RouterNetworkOutputPort
       routerNetworkOutputPort;

     public RouterNetworkInputPort(RouterNetworkOutputPort
       routerNetworkOutputPort){
          this.routerNetworkOutputPort =
            routerNetworkOutputPort;
     }

     private Router fetchRouter(RouterId routerId) {
          return routerNetworkOutputPort.fetchRouterById
            (routerId);
     }

     private boolean persistNetwork(Router router) {
```

```
            return routerNetworkOutputPort.persistRouter
              (router);
        }
    }
```

You may be wondering when and how the instance for an output port is created. The previous example shows one approach where the input port constructor receives a reference for an output port object. This object will be an implementation provided by an output adapter.

Among the operations defined by a use case and implemented by an input port, some operations are responsible for getting from or persisting data to external sources. That's where output ports come in to provide the data required to fulfill the use case's goal.

In the same way that a use goal is used to represent a software intent, without saying how this intent will be realized, output ports do the same thing by representing what kind of data the application needs, without needing to know how that data will be obtained. Output ports, along with input ports and use cases, are the hexagonal architecture components that support the automation effort that characterizes the Application hexagon, which we'll examine in the next section.

Automating behavior with the Application hexagon

Automation is one of the most valuable things software can do. The advent of computation brought radical changes to how people solve their problems. An interesting scenario is that of the credit card industry in its early years. When banks started to offer credit cards to their customers, most of the back-office activities were done manually. If you wanted to pay for something with a credit card, the person in the store would need to call their bank, who, in turn, would need to contact your card issuer to confirm you had credit. As the technology evolved, computer systems were able to automate this credit verification process.

If we decided to use the hexagonal architecture to build a credit card verification system, those required steps to confirm the cardholder's credit could be expressed using a use case. With an input port, we could handle business rules and all the data necessary to achieve the use case goal, consuming, if necessary, external systems through an output port. When we put all those activities together, the fundamental role of the Application hexagon in automating those activities to fulfill the system's intent becomes more apparent.

One advantage of implementing the Application hexagon is that we don't need to be specific about which technologies we should use to fulfill the automation needs of our system. Of course, it's possible to add a fancy development framework to make our lives easier when handling certain activities later on – such as object life cycle management, which is provided by **Contexts and Dependency Injection** (**CDI**) mechanisms – but it's that purist approach of not focusing on technological details that make hexagon systems easier to integrate with different technologies.

As we continue exploring the possibilities offered by the hexagonal architecture, we'll see that using a development framework is not a central point for software development. Instead, in hexagonal systems, frameworks are like ordinary utilitarian libraries that we use to strategically solve a specific problem.

Summary

In this chapter, we learned how to arrange the components that are responsible for organizing and building the features provided by the software. By looking into use cases, we grasped the fundamental principles to translate the behaviors that allow a system to meet users' goals into code. We discovered how input ports play a central role by implementing use cases and acting as middlemen, intermediating the communication flow between internal and external things. With output ports, we can express the need for data from external sources without coupling the hexagonal system with specific technologies. Finally, by using use cases and input and output ports together, we saw how the Application hexagon supports the software's automation effort.

By learning how to arrange things inside the Application hexagon, we can now combine business rules, entities, Domain services, use cases, and other components from both the Application and Domain hexagons to create fully-fledged features in the hexagon application, ready to be integrated with different technologies. Such integration can be accomplished with the so-called adapters in the Framework hexagon. That's what we will look at in the next chapter.

Questions

1. What is the purpose of use cases?
2. Input ports implement use cases. Why do we have to do that?
3. Where should output ports be used?
4. What is the advantage of implementing the Application hexagon?

Further reading

- *Writing Effective Use Cases*, (Alistair Cockburn, 2000)
- *Clean Architecture*, (Robert Cecil Martin, 2017)

4
Creating Adapters to Interact with the Outside World

There is a moment in software development when we need to decide which technologies will be supported by a system. We've been discussing in the previous chapters how technological choices should not be the primary driver for developing hexagonal applications. In fact, the applications based on such architecture present a high degree of changeability, enabling with as little friction as possible a system to be integrated with different technologies. This is due to how the **hexagonal architecture** helps to establish a clear frontier between which part of the code is related to business and which is related to technology.

In this chapter, we're going to explore the hexagonal approach to establish this frontier. We'll learn about the role adapters play when we need to set up technologies or protocols to enable a hexagonal application to communicate with the outside world.

We'll learn about the following topics in this chapter:

- Understanding adapters
- Using input adapters to allow driving operations
- Using output adapters to speak with different data sources

By the end of this chapter, you'll know how input adapters, in conjunction with input ports, can be used to expose the same software features to work with different technologies. In the same vein, you will learn how output adapters are powerful in making your application more versatile when it needs to talk with different data source technologies.

Technical requirements

To compile and run the code examples presented in this chapter, you need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. To interact with the adapters, we also recommend installing `curl` and `jq`. All those tools are available for **Linux**, **Mac**, and **Windows** operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter04`.

Understanding adapters

In hexagonal architecture, adapters have a different role than the adapters described in *Design Patterns: Elements of Reusable Object-Oriented Software* by Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides. In the **Gang of Four** (**GoF**) design patterns, we use adapters to make the interfaces of two diverging classes compatible with each other. In the hexagonal architecture, we use adapters to allow a system to be compatible with different technologies or protocols. Although the adapter's role in those two approaches may differ, it would be correct to state that both approaches share the same purpose, that is, to adapt something to fit correctly into another thing.

A practical analogy to understand the role adapters play in hexagonal architecture is about remote connections to a computer. Every modern operating system is compatible with remote connection protocols. In the past and even today, in certain situations, it was common to use **Telnet** to open a remote connection to a computer. Over time, other protocols emerged, such as **SSH** for console connections, **RDP**, and **Virtual Network Computing** (**VNC**) for a graphical alternative.

Those protocols only define how you're going to access the operating system, and once you're there, you can execute commands and have access to the features that an operating system provides. It's not uncommon for an operating system to offer more than one protocol to allow remote connection. That's good because it widens the communication possibilities. There may be situations where it's necessary to support both Telnet and SSH connections simultaneously, maybe because there is an unusual client that works only with Telnet.

By using the preceding analogy, we can replace the operating system with an application developed using **Java**, or any other programming language. And we can replace remote connection protocols such as SSH and Telnet with HTTP-based communication protocols, such as **REST** and **gRPC**. Assuming our Java application is a hexagonal one, the features offered by such applications are organized into use cases, ports, and business rules from the **Application** and **Domain** hexagons. If you want to make those features available for both REST and gRPC clients, you need to create REST and gRPC adapters. Adapters used to expose application features are called **input adapters**. And to connect those input adapters to the rest of our system, we associate input ports with input adapters, as illustrated in the following figure:

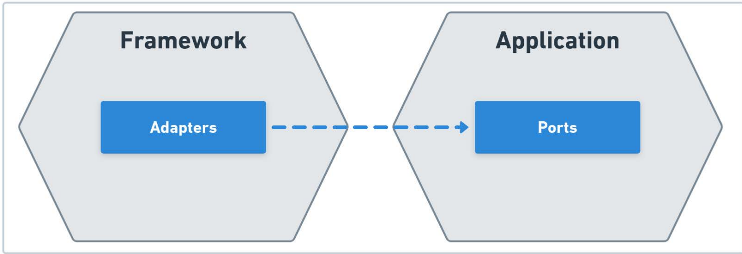

Figure 4.1 – The relationship between adapters and ports

We can define input adapters to allow users and other systems to interact with the application. In the same way, we can also define output adapters to translate data generated by the hexagonal application and communicate with external systems. Here we can see that both input and output adapters live in the extremities of the **Framework** hexagon:

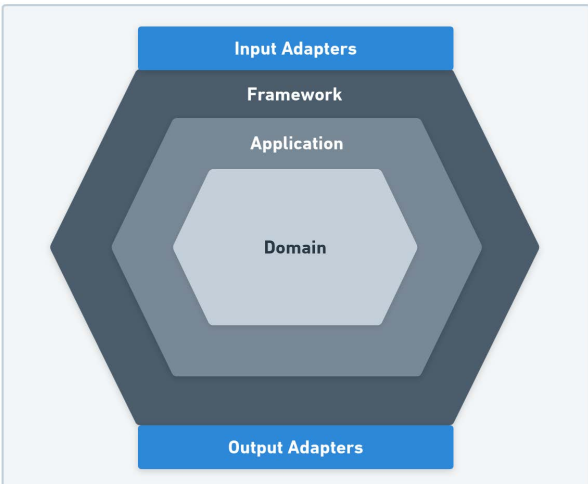

Figure 4.2 – The location of input and output adapters

Let's explore in the next section how we can work with input adapters.

Using input adapters to allow driving operations

You probably may have heard that if there's something we can always count on, it's that things will always change. And when we talk about technology changes, that statement is even stronger. We live in an era where computers are not so expensive as they used to be in the past. No matter whether we're dealing with desktops, mobile, or cloud computing, year by year, computer resources, in general, become cheaper and more accessible to everyone. This accessibility means that more people tend to be involved and can collaborate with software development initiatives.

That growing collaboration results in newer programming languages, tools, and development frameworks to support the creative effort to solve people's problems with better and modern solutions. In this innovative and technological heterogeneous context, a good amount of current software development is made. One of the concerns that arises when developing software in such a context is how a system will stay relevant and profitable in the face of constant technological changes. If a system is designed to intertwine business rules with technological details, it won't be easy to incorporate new technology without significant refactoring. In hexagonal architecture, input adapters are the elements that help us to make software compatible with different technologies.

Input adapters are like the remote communication protocols mentioned in the example presented in the previous section. That comparison is valid because input adapters work like protocols, defining which technologies are supported as a means to access the features provided by a hexagonal system. Input adapters mark a clear frontier between what is inside the hexagon and what is outside, and perform what we call driving operations.

From outside the hexagon, there may be users or other systems interacting with the hexagonal application. We have learned that these users and systems are also known as primary actors, playing a pivotal role in shaping application use cases. The interaction between primary actors and the hexagonal application occurs through input adapters. Such interaction is defined by driving operations. We call them driving because primary actors drive, in the sense that they initiate and influence the state and behavior of hexagonal systems.

Input adapters, when put together, form the hexagonal application's API. Because input adapters are in this boundary that exposes the hexagonal system to the outside world, they naturally become the interface for anyone interested in interacting with the system. As we progress in the book, we'll see how to leverage the input adapters' arrangement to structure and expose the application APIs, using tools like **Swagger**.

We have been emphasizing the adapters' characteristics to make a system compatible with different technologies or protocols. A more **Domain-Driven Design** (**DDD**) approach suggests other purposes for using an adapter.

A prevalent concern on DDD-based architectures is about integrating the elements of a legacy system into a new one. It occurs in scenarios where a legacy system with relevant knowledge crunched in its domain model solves some important problems but also shows inconsistencies in its design. You don't want to give up the legacy system, but you also don't want the new system design to be influenced by the legacy system's design. To tackle this situation, you can employ what *Implementing Domain-Driven Design* by Vaughn Vernon and *Domain-Driven Design: Tackling Complexity in the Heart of Software* by Eric Evans call an **anti-corruption layer**. This layer is based on the adapters used to integrate bounded contexts from both the legacy and the new systems. In such a scenario, the adapters are responsible for preventing the new system's design from being contaminated by the legacy system's design.

Although we're not applying this kind of usage for adapters in the hexagonal architecture, it's important to be aware that we can use this DDD-based adapter approach to a hexagonal system.

We learned that the connection between primary actors and the hexagonal application occurs through input adapters. Let's see now how to make input adapters connect to other hexagons in the system.

Creating input adapters

Input ports are the means through which we implement use cases, specifying how an input port performs the operations to achieve use case goals. The input port object needs to receive what Jacobson (1992) called a *stimulus* to perform its operations. This stimulus is nothing more than an object calling another. The input port object receives all the necessary data to conduct its operations through the stimulus sent by an input adapter. However, it's at this stage that eventual transformations may take place to convert input data into a format that's compatible with the Domain hexagon.

In the previous chapter, we created a use case to add networks to a router. To achieve the use case goals, we'll create two input adapters: an adapter for communication through HTTP REST and another for command-line execution. In the following UML diagram, we have **RouterNetworkAdapter** as an abstract parent class extended by **RouterNetworkRestAdapter** and **RouterNetworkCLIAdapter** classes:

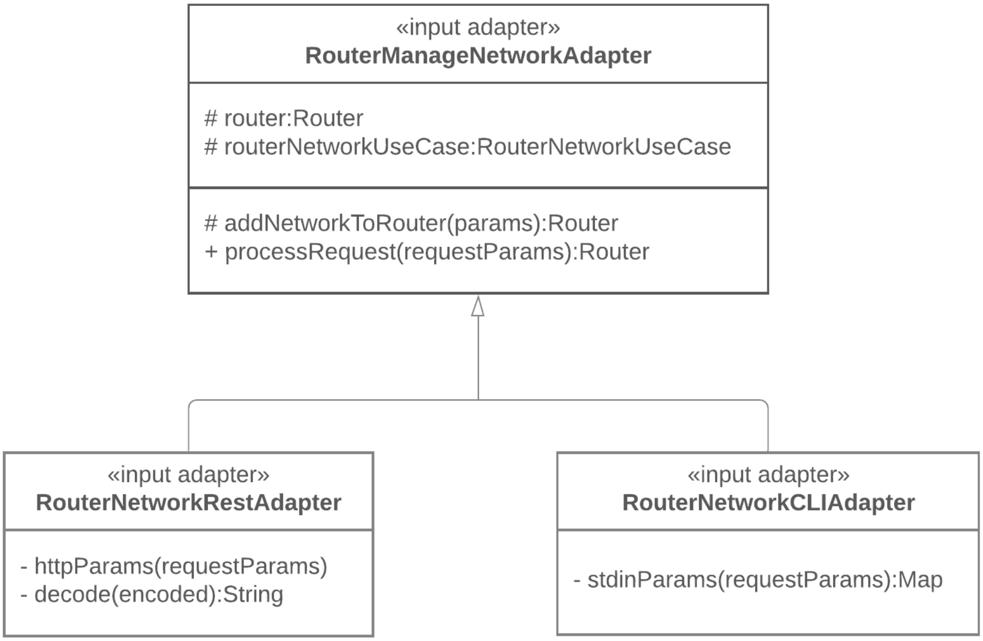

Figure 4.3 – UML representation of input adapters

We will define an adapter abstract base class, followed by two implementations, one for an adapter to receive data from HTTP REST connections and another for the console `STDIN` connection. To simulate access to these two adapters, we'll create a client class to bootstrap the application.

The base adapter

Let's start by defining the `RouterNetworkAdapter` abstract base class:

```
public abstract class RouterNetworkAdapter {

    protected Router router;
    protected RouterNetworkUseCase;

```

```
    protected Router addNetworkToRouter(
    Map<String, String> params){
        var routerId = RouterId.
               withId(params.get("routerId"));
        var network = new Network(IP.fromAddress(
               params.get("address")),
               params.get("name"),
               Integer.valueOf(params.get("cidr")));
        return routerNetworkUseCase.
               addNetworkToRouter(routerId, network);
    }

    public abstract Router processRequest(
                           Object requestParams);
}
```

The idea of this base adapter is to provide standard operations to communicate with the adapter's correspondent input port. In that case, we use the `addNetworkToRouter` adapter method to receive the parameters required to build the `RouterID` and `Network` objects, which are utilized to start the use case operation to add the network to a router. These parameters may come from different sources, either via an HTTP request or via the shell/console with `STDIN`, but they are treated the same way once they arrive at the `addNetworkToRouter` method.

We don't refer to input ports directly. Instead, we utilize a use case interface reference. This use case reference is passed and initialized by the input adapter's constructor.

The REST input adapter

Now that we have defined the base `RouterNetworkAdapter` abstract class, we can proceed to create the REST adapter. We start by defining the `RouterNetworkRestAdapter` constructor:

```
public RouterNetworkRestAdapter(RouterNetworkUseCase
routerNetworkUseCase){
    this.routerNetworkUseCase = routerNetworkUseCase;
}
```

We use the `RouterNetworkRestAdapter` constructor to receive and initialize the `RouterNetworkUseCase` use case reference.

The following code shows us how a client could call-initialize this `RouterNetworkRestAdapter` input adapter:

```
RouterNetworkOutputPort outputPort = RouterNetworkH2Adapter.
getInstance();
RouterNetworkUseCase usecase = new
RouterNetworkInputPort(outputPort);
RouterNetworkAdapter inputAdapter = new
RouterNetworkRestAdapter(usecase);
```

The intention here is to express that the REST input adapter requires an H2 in-memory database output adapter. Here, we're explicitly stating which output adapter object the input adapter needs to perform its activities. That can be considered a vanilla approach, where we don't use framework-based dependency injection techniques like **CDI beans**. Later on, all those adapter constructors can be removed to use dependency injection annotations from frameworks such as **Quarkus** or **Spring**.

After defining the `RouterNetworkAdapter` constructor, we then implement the `processRequest` method:

```
@Override
public Router processRequest(Object requestParams){
/** code omitted **/
    httpserver.createContext("/network/add", (exchange -> {
      if ("GET".equals(exchange.getRequestMethod())) {
       var query = exchange.getRequestURI().getRawQuery();
       httpParams(query, params);
       router = this.addNetworkToRouter(params);
       ObjectMapper mapper = new ObjectMapper();
       var routerJson = mapper.writeValueAsString(
       RouterJsonFileMapper.toJson(router));
       exchange.getResponseHeaders().
       set("Content-Type","application/json");
       exchange.sendResponseHeaders(
       200,routerJson.getBytes().length);
       OutputStream output = exchange.getResponseBody();
```

```
        output.write(routerJson.getBytes());
        output.flush();
       } else {
         exchange.sendResponseHeaders(405, -1);
       }
/** code omitted **/
}
```

This method receives an `httpServer` object, which is used to create the HTTP endpoint to receive `GET` requests at `/network/add`. The client code that calls `processRequest` is similar to the following excerpt:

```
var httpserver = HttpServer.create(new InetSocketAddress(8080),
0);
routerNetworkAdapter.processRequest(httpserver);
```

The REST adapter receives user data via an HTTP request, parses request parameters, and uses them to call `addNetworkToRouter` defined in the `RouterNetworkAdapter` parent class:

```
router = this.addNetworkToRouter(params);
```

Remember that the input adapter is responsible for converting user data into suitable parameters used to trigger an input port by using its use case reference:

```
routerNetworkUseCase.addNetworkToRouter(routerId, network);
```

At this moment, the data leaves the Framework hexagon and goes to the **Application hexagon**. Now, let's see how to connect another adapter to the same input port. The difference, though, is that this adapter is used for command-line execution. This time, the system will not receive data from an HTTP request but rather through a user typing on the keyboard (`STDIN`).

The CLI input adapter

To create the second input adapter, we again extend the base adapter class:

```
public class RouterNetworkCLIAdapter extends
RouterNetworkAdapter {
    public RouterNetworkCLIAdapter(
    RouterNetworkUseCase routerNetworkUseCase){
```

```
        this.routerNetworkUseCase = routerNetworkUseCase;
    }
/** code omitted **/
}
```

We define the `RouterNetworkCLIAdapter` constructor to receive and initialize the `RouterNetworkUseCase` use case that this input adapter needs.

For the CLI input adapter, we use a different output adapter. Instead of persisting an in-memory database, this output adapter uses the filesystem.

The following code shows us how a client could initialize the `RouterNetworkCLIAdapter` input adapter:

```
RouterNetworkOutputPort outputPort = RouterNetworkFileAdapter.
getInstance();
RouterNetworkUseCase usecase = new
RouterNetworkInputPort(outputPort);
RouterNetworkAdapter inputAdapter = new
RouterNetworkCLIAdapter(routerNetworkUseCase);
```

First, we get a `RouterNetworkOutputPort` output port reference. Then, with that reference, we retrieve a `RouterNetworkUseCase` use case. Finally, we get `RouterNetworkAdapter` using the use case defined previously.

The following is how we implement the `processRequest` method for the CLI adapter:

```
@Override
public Router processRequest(Object requestParams){
    var params = stdinParams(requestParams);
    router = this.addNetworkToRouter(params);
    ObjectMapper mapper = new ObjectMapper();
    try {
        var routerJson = mapper.writeValueAsString
                     (RouterJsonFileMapper.toJson(router));
        System.out.println(routerJson);
    } catch (JsonProcessingException e) {
        e.printStackTrace();
    }
    return router;
}
```

In the REST adapter, we have the `httpParams` method to retrieve data from an HTTP request. Now, in `processRequest` from the CLI adapter, we have a `stdinParams` method to retrieve data from the console.

The `processRequest` method from the REST and CLI adapters have differences in handling input data, but both have one thing in common. Once they capture input data into the `params` variable, they both call the `addNetworkToRouter` method inherited from the adapter base class:

```
router = this.addNetworkToRouter(params);
```

From this point on, the data follows the same flow as the one described in the REST adapter scenario, where the input adapter calls the input port through a use case interface reference.

Now that we've finished creating the REST and CLI input adapters, let's see how to call these adapters.

Calling the input adapters

Here is the client code to control which adapter to choose:

```
public class App {
/** code omitted **/
    void setAdapter(String adapter) {
        switch (adapter){
            case "rest":
                outputPort =
                RouterNetworkH2Adapter.getInstance();
                usecase =
                new RouterNetworkInputPort(outputPort);
                inputAdapter =
                new RouterNetworkRestAdapter(usecase);
                rest();
                break;
            default:
                outputPort =
                RouterNetworkFileAdapter.getInstance();
                usecase =
                new RouterNetworkInputPort(outputPort);
```

```
                inputAdapter =
                new RouterNetworkCLIAdapter(usecase);
                cli();
        }
    }
}
```

If we pass `rest` as a parameter when executing the program, the `switch-case` condition will create a REST adapter instance and call the `rest` method:

```
private void rest() {
    try {
        System.out.println("REST endpoint listening on
                           port 8080...");
        var httpserver = HttpServer.create(
        new netSocketAddress(8080), 0);
        routerNetworkAdapter.processRequest(httpserver);
    } catch (IOException e){
        e.printStackTrace();
    }
}
```

The `rest` method, in turn, calls the `processRequest` method from the REST input adapter.

Otherwise, if we pass the `cli` parameter when executing the program, `switch-case` will, by default, create a CLI adapter and call the `cli` method:

```
private void cli() {
    Scanner = new Scanner(System.in);
    routerNetworkAdapter.processRequest(scanner);
}
```

The `cli` method then calls the `processRequest` method from the CLI input adapter.

Here are the steps for calling the input adapters:

1. With the code sample from GitHub, within the `chapter4` directory, you can compile the application by running the following command:

   ```
   mvn clean package
   ```

2. To call the REST adapter, you run the `.jar` file with the `rest` parameter:

```
$ java -jar target/chapter4-1.0-SNAPSHOT-jar-with-
dependencies.jar rest
REST endpoint listening on port 8080…
```

3. Once the application is up, you can fire up an HTTP `GET` request to create and add a network:

```
curl -vv "http://localhost:8080/network/
add?routerId=ca23800e-9b5a-11eb-a8b3-0242ac130003&address
=40.0.0.0&name=Finance&cidr=8"
```

4. To call the CLI adapter, you run the `.jar` file with no parameters:

```
$ java -jar target/chapter4-1.0-SNAPSHOT-jar-with-
dependencies.jar cli
Please inform the Router ID:
ca23800e-9b5a-11eb-a8b3-0242ac130003
Please inform the IP address:
40.0.0.0
Please inform the Network Name:
Finance
Please inform the CIDR:
8
```

The application will ask you to inform the router ID and other network additional details to call the CLI adapter. Here, we gave the same data as those used to call the REST adapter.

In this section, we learned how to use input adapters to expose hexagonal application features. By defining first a base input adapter, we extended it to create a REST adapter for HTTP requests and a CLI adapter for console/`STDIN` requests. This arrangement helped us grasp the fundamental role input adapters play in exploring different ways to access the same functionality in a hexagonal system.

Input adapters are the front doors through which we access all the features a hexagonal application can provide. With input adapters, we can easily make the system accessible through different technologies without disturbing business logic. By the same token, we can make a hexagonal application speak with varying data sources. We accomplish that with output adapters, which we'll see in the next section.

Using output adapters to speak with different data sources

What characterizes an object-oriented system is its ability to treat data and behavior as closely related things. This proximity happens to mimic the way things are in the real world. Both animate and inanimate beings have attributes and can perform or be the target of some action. For people starting to learn object-oriented programming, we present examples such as a car, which has four wheels and can drive – wheels being the data and driving the behavior. Examples like that express the fundamental principle that data and behavior should not be treated as separated things but should be united inside what we call objects.

This object idea has laid the ground for the development of vast and complex systems over the last few decades. A good part of those systems is business applications running on enterprise environments. The object paradigm had conquered enterprise development because its high-level approach has allowed people to be more productive and precise when creating software to solve business problems. The procedural paradigm was cumbersome and too low-level for the demands of the enterprise.

In addition to object-oriented languages, enterprise software also relies on ways to obtain and persist data. It's hard to imagine a system that is not integrated with data sources such as databases, message queues, or file servers, for example. The need to store things has always been present in computation. The problem, though, has been how this need has influenced and dictated the whole software structure. With the advent of **RDBMS**, there comes the requirement as well to formalize data through **schemas**. These schemas, then, would serve as a reference to establish data relationships and how the application deals with such relationships. After some time, people started to look for alternatives to avoid the formalism and strict normalization principles imposed by RDBMS. The problem is not in the formalism per se but in using RDBMS where there's no need for that.

As an alternative to RDBMS, there came **NoSQL** databases, proposing a way to store data that didn't rely on tables, columns, and schemas as a means of data organization. The NoSQL approach offers different data storage techniques, based on documents, key-value stores, wide-column stores, and graphs. Not constrained with only the RDBMS approach, software developers then started using these NoSQL techniques to meet business requirements in a better way and avoid cumbersome solutions that relied on RDBMS because there were no alternatives.

Aside from databases, other data sources have been used to fulfill software needs to handle data. Filesystems, message brokers, directory-based storage (**LDAP**), and mainframe storage, to name a few, are some of the ways software can handle data. In the world of cloud computing, it's becoming more natural to integrate a system with different technologies to send or receive data. This integration presents some challenges in software development because the system now needs to understand and make itself understandable in a heterogeneous technological context. That situation is even more exacerbated with architectures such as microservices that promote such heterogeneity. To tackle this challenge, we need techniques to overcome the vicissitudes of technologically heterogeneous environments.

We saw in the previous section that we can plug multiple input adapters into the same input port. The same is true for output adapters and ports. Next, we'll see how to create output adapters and plug them into the hexagon system output ports.

Creating output adapters

Together with input adapters, output adapters are the second component that comprises the Framework hexagon. The output adapter's role in the hexagonal architecture is to deal with driven operations. Remember, driven operations are those initiated by the hexagonal application itself to interact with external systems to send or receive some data. These driven operations are described through use cases and are triggered by operations present in the use case's input port implementations. Whenever a use case states the need to deal with data that lives in external systems, it means the hexagonal application will require at least one output adapter and port to meet such requirements.

We learned that output ports present in the Application hexagon express the interaction with external systems in abstract ways. Output adapters, in turn, have the responsibility to describe, in concrete terms, how this interaction will occur. With output adapters, we make up our minds about which technologies the system will use to allow data persistence and other types of external integrations.

Until now, we have been talking about data based solely on the requirements expressed by the domain model we created in the Domain hexagon. After all, it's the domain model from the Domain hexagon that drives the shape of the whole hexagonal system. Technological concerns are just mere details that must adhere to the domain model and not the other way around.

By putting the output port as an interface in the Application hexagon, and the output adapter as the implementation of that interface in the Framework hexagon, we are structuring the hexagonal system to support different technologies. In this structure, we have the output adapter in the Framework hexagon that must conform to the output port interface in the Application hexagon that, in turn, must rely on the domain model from the Domain hexagon.

In the previous section, you may have noticed the usage of two different output adapters – the `RouterNetworkH2Adapter` adapter to deal with data from in-memory databases and the `RouterNetworkFileAdapter` adapter to read and persist files from a local filesystem. These two output adapters are implementations of the output ports we created in the Application hexagon:

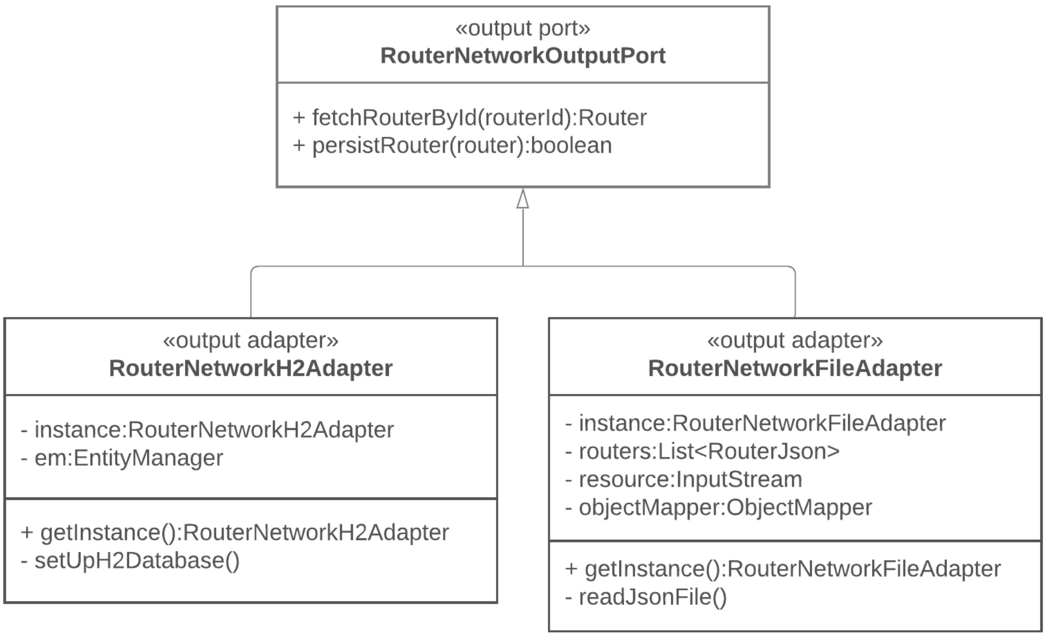

Figure 4.4 – UML representation of output adapters

We'll start by implementing `RouterNetworkH2Adapter`. It uses an H2 in-memory database to set up all the required tables and relationships. This adapter implementation shows us how to adapt the domain model data to a relational database. Then, we proceed to implement `RouterNetworkFilAdapter`, which uses a **JSON** file-backed data structure. Both H2 and JSON file implementations are based on the data provided by the topology and inventory sample system we've been working on. These two adapters will allow two ways to attach an additional network to an existent switch:

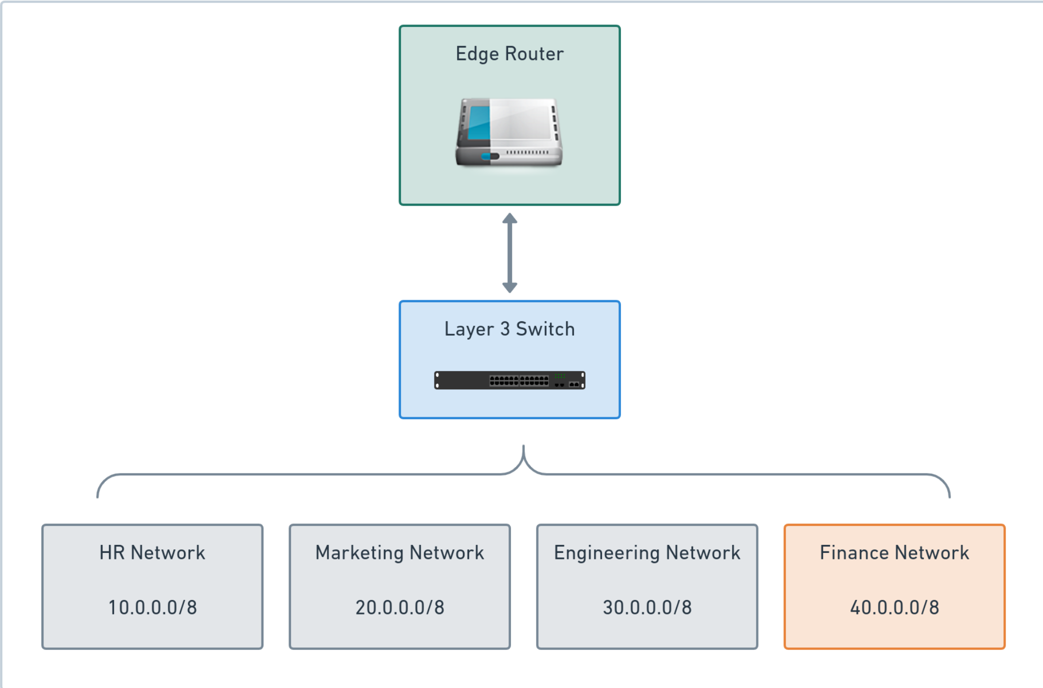

Figure 4.5 – Topology and inventory system with a finance network

Using the same input data from the previous section, we'll attach **Finance Network** to **Layer 3 Switch** from **Edge Router** through one of the available two output adapters.

The H2 output adapter

Before implementing the H2 output adapter, we first need to define the database structure of the topology and inventory system. To determine that structure, we create the `resources/inventory.sql` file with the following SQL statements:

```
CREATE TABLE routers(
    router_id UUID PRIMARY KEY NOT NULL,
    router_type VARCHAR(255)
);
CREATE TABLE switches (
    switch_id UUID PRIMARY KEY NOT NULL,
    router_id UUID,
    switch_type VARCHAR(255),
```

```
    switch_ip_protocol VARCHAR(255),
    switch_ip_address VARCHAR(255),
    PRIMARY KEY (switch_id),
    FOREIGN KEY (router_id) REFERENCES routers(router_id)
);
CREATE TABLE networks (
    network_id int NOT NULL PRIMARY KEY AUTO_INCREMENT,
    switch_id UUID,
    network_protocol VARCHAR(255),
    network_address VARCHAR(255),
    network_name VARCHAR(255),
    network_cidr VARCHAR(255),
    PRIMARY KEY (network_id),
    FOREIGN KEY (switch_id) REFERENCES switches(switch_id)
);
INSERT INTO routers(router_id, router_type) VALUES('ca23800e-
9b5a-11eb-a8b3-0242ac130003', 'EDGE');
INSERT INTO switches(switch_id, router_id, switch_type, switch_
ip_protocol, switch_ip_address)
VALUES('922dbcd5-d071-41bd-920b-00f83eb4bb46', 'ca23800e-9b5a-
11eb-a8b3-0242ac130003', 'LAYER3', 'IPV4', '9.0.0.9');
INSERT INTO networks(switch_id, network_protocol, network_
address, network_name, network_cidr)
VALUES('922dbcd5-d071-41bd-920b-00f83eb4bb46', 'IPV4',
'10.0.0.0', 'HR', '8');
INSERT INTO networks(switch_id, network_protocol, network_
address, network_name, network_cidr)
VALUES('922dbcd5-d071-41bd-920b-00f83eb4bb46', 'IPV4',
'20.0.0.0', 'Marketing', '8');
INSERT INTO networks(switch_id, network_protocol, network_
address, network_name, network_cidr)
VALUES('922dbcd5-d071-41bd-920b-00f83eb4bb46', 'IPV4',
'30.0.0.0', 'Engineering', '8');
```

Although `switches` and `networks` have primary keys, we treat `switches` as entities and `networks` as values objects that are part of the `Router` entity in the domain model. We are imposing our model over the technological arrangement and not the other way around.

We don't use these primary keys from `switches` and `networks` tables as references in the domain model. Instead, we use the `router_id` value to correlate the `Router` entity with its `Switch` and `Network` objects and their respective database tables. This correlation enables the formation of an aggregate where `Router` is the aggregate root, and `Switch` and `Network` are the objects used to compose the aggregate.

Now, we can proceed to implement `RouterNetworkOutputPort` to create the `RouterNetworkH2Adapter` class:

```
public class RouterNetworkH2Adapter implements
RouterNetworkOutputPort {
     private static RouterNetworkH2Adapter instance;

     @PersistenceContext
     private EntityManager em;
     private RouterNetworkH2Adapter(){
          setUpH2Database();
     }
     @Override
     public Router fetchRouterById(RouterId routerId) {
          var routerData = em.
              getReference(RouterData.class,
              routerId.getUUID());
          return RouterH2Mapper.toDomain(routerData);
     }
     @Override
     public boolean persistRouter(Router router) {
          var routerData = RouterH2Mapper.toH2(router);
          em.persist(routerData);
          return true;
     }
     private void setUpH2Database() {
          var entityManagerFactory = Persistence.
          createEntityManagerFactory("inventory");
          var em = entityManagerFactory.
          createEntityManager();
          this.em = em;
```

```
     }
/** code omitted **/
}
```

The first method we override is `fetchRouterById`, where we receive `routerId` to fetch a router from the H2 database using our entity manager reference. We cannot use the `Router` domain entity class to map directly to the database. Also, we cannot use the database entity as a domain entity. That's why we use the `toDomain` method on `fetchRouterById` to map data from the H2 database to the domain.

We do the same mapping procedure, using the `toH2` method on `persistRouter` to convert from the domain to the H2 database. The `setUpH2Database` method initiates the database when the application starts. To create only one instance of the H2 adapter, we define a singleton through the `getInstance` method:

```
public static RouterNetworkH2Adapter getInstance() {
    if (instance == null) {
        instance = new RouterNetworkH2Adapter();
    }
    return instance;
}
```

The `instance` field is used to provide a singleton object of the H2 output adapter. Note that the constructor calls the `setUpH2Database` method to create a database connection using `EntityManagerFactory`. To properly configure the entity manager, we create the `resources/META-INF/persistence.xml` file with a property to set up the H2 database:

```
<?xml version="1.0" encoding="UTF-8" ?>
<!-- code omitted -->
<property
     name="jakarta.persistence.jdbc.url"
          value="jdbc:h2:mem:inventory;
          MODE=MYSQL;
          DB_CLOSE_DELAY=-1;
          DB_CLOSE_ON_EXIT=FALSE;
          IGNORECASE=TRUE;
          INIT=CREATE SCHEMA IF NOT EXISTS inventory\;
          RUNSCRIPT FROM 'classpath:inventory.sql'" />
<!-- code omitted -->
```

Remember, our domain model comes first, so we don't want to couple the system with database technology. That's why we need to create a `RouterData` **ORM** class to map directly to the database types. Here, we are using **EclipseLink**, but you can use any **JPA-compliant** implementation:

```
@Getter
@AllArgsConstructor
@NoArgsConstructor
@Entity
@Table(name = "routers")
@SecondaryTable(name = "switches")
@MappedSuperclass
@Converter(name="uuidConverter", converterClass=
UUIDTypeConverter.class)
public class RouterData implements Serializable {

    @Id
    @Column(name="router_id",
            columnDefinition = "uuid",
            updatable = false )
    @Convert("uuidConverter")
    private UUID routerId;

    @Embedded
    @Enumerated(EnumType.STRING)
    @Column(name="router_type")
    private RouterTypeData routerType;


    @OneToOne(cascade = CascadeType.ALL)
    @JoinColumn(table = "switches",
            name = "router_id",
            referencedColumnName = "router_id")
    private SwitchData networkSwitch;
}
```

We use **Lombok** `@Getter`, `@NoArgsConstructor`, and `@AllArgsConstructor` annotations to diminish the verbosity of the class. We will use the getters and constructor later to convert the data class to a domain model class.

The usage of the `@Table` and `@SecondaryTable` annotations serves to represent the relationship between routers and switches tables. This relationship is mapped through the `@OntToOne` and `@JoinColumn` annotations, specifying that both tables must be linked through the `router_id` attribute.

To use `UUID` as an ID in EclipseLink, we need to create the following converter class:

```
public class UUIDTypeConverter implements Converter {
     @Override
     public UUID convertObjectValueToDataValue(Object
                    objectValue, Session session) {
          return (UUID) objectValue;
     }
     @Override
     public UUID convertDataValueToObjectValue(Object
                    dataValue, Session session) {
          return (UUID) dataValue;
     }
     @Override
     public boolean isMutable() {
          return true;
     }
     @Override
     public void initialize(
     DatabaseMapping mapping, Session session){
          DatabaseField field = mapping.getField();
          field.setSqlType(Types.OTHER);
          field.setTypeName("java.util.UUID");
          field.setColumnDefinition("UUID");
     }
}
```

This is the class we use inside the `@Converter` annotation at the top of the `RouterData` class. Without this converter, there will be an exception stating a problem in mapping the `routerId` attribute. Following the declaration of `routerId`, there is a `RouterTypeData` attribute called `routerType`. For every ORM attribute, we add the `Data` suffix to the class name. Aside from `RouterData`, we do that with `RouterTypeData` and `SwitchData`. Remember that in the domain model, the equivalent types are `Router`, `RouterType`, and `Switch`.

`RouterTypeData` is the `enum` where we store the router type:

```
@Embeddable
public enum RouterTypeData {
     EDGE,
     CORE;
}
```

The `@Embeddable` annotation allows the `enum` data to be mapped to the `router_type` field in the base through the `@Embedded` annotation:

```
@Embedded
@Enumerated(EnumType.STRING)
@Column(name="router_type")
private RouterTypeData routerType;
```

As the last `RouterData` field, we refer to `SwitchData` in the `networkSwitch` variable, which we use to create the relationship between a router and switch. Let's see how the `SwitchData` class is implemented:

```
@Getter
@AllArgsConstructor
@NoArgsConstructor
@Entity
@Table(name = "switches")
@SecondaryTable(name = "networks")
@MappedSuperclass
@Converter(name="uuidConverter", converterClass=
UUIDTypeConverter.class)
public class SwitchData implements Serializable {

```

```
    @Id
    @Column(name="switch_id",
            columnDefinition = "uuid",
            updatable = false )
    @Convert("uuidConverter")
    private UUID switchId;

    @Column(name="router_id")
    @Convert("uuidConverter")
    private UUID routerId;

    @Enumerated(EnumType.STRING)
    @Embedded
    @Column(name = "switch_type")
    private SwitchTypeData switchType;

    @OneToMany
    @JoinColumn(table = "networks",
            name = "switch_id",
            referencedColumnName = "switch_id")
    private List<NetworkData> networks;

    @Embedded
    @AttributeOverrides({
            @AttributeOverride(
                    name = "address",
                    column = @Column(
                            name = "switch_ip_address")),
            @AttributeOverride(
                    name = "protocol",
                    column = @Column(
                            name = "switch_ip_protocol")),
    })
    private IPData ip;
}
```

We apply the same techniques in SwitchData that we applied in RouterData. There is a subtle difference though, which is the relationship established between switches and networks tables. To create such a relationship, we use the @OneToMany and @JoinColumn annotations to create a link between the SwitchData and NetworkData types using the switch_id attribute. A reference to a list of NetworkData objects is required because of the @OneToMany annotation.

Similar to RouterDataType, we have SwitchDataType, which is an enum equivalent of SwitchType from the domain model:

```
@Embeddable
public enum SwitchTypeData {
     LAYER2,
     LAYER3;
}
```

In the topology and inventory system, we attach networks directly to a switch. To map the domain entity to the H2 database entity, we implement the NetworkData class:

```
@Getter
@AllArgsConstructor
@NoArgsConstructor
@Entity
@Table(name = "networks")
@MappedSuperclass
@Converter(name="uuidConverter", converterClass=
UUIDTypeConverter.class)
public class NetworkData implements Serializable {

    @Id
    @Column(name="network_id")
    private int id;

    @Column(name="switch_id")
    @Convert("uuidConverter")
    private UUID switchId;

    @Embedded
    @AttributeOverrides({
```

```
            @AttributeOverride(
                    name = "address",
                    column = @Column(
                            name = "network_address")),
            @AttributeOverride(
                    name = "protocol",
                    column = @Column(
                            name = "network_protocol")),
    })
    IPData ip;

    @Column(name="network_name")
    String name;

    @Column(name="network_cidr")
    Integer cidr;
/** code omitted **/
}
```

All attributes we have in `NetworkData` are the same ones present in its domain entity counterpart. The only difference is the annotations we add to turn it into a database entity.

Both `SwitchData` and `NetworkData` classes declare the `IPData` field. We encounter a similar behavior in the domain model, where `Switch` and `Network` objects have an `IP` attribute. Here is how we should implement the `IPData` class:

```
@Embeddable
@Getter
public class IPData {

    private String address;

    @Enumerated(EnumType.STRING)
    @Embedded
    private ProtocolData protocol;

    private IPData(String address){
        if(address == null)
```

```
            throw new IllegalArgumentException("Null IP
                          address");
        this.address = address;
        if(address.length()<=15) {
            this.protocol = ProtocolData.IPV4;
        } else {
            this.protocol = ProtocolData.IPV6;
        }
    }

    public IPData() {}

    public static IPData fromAddress(String address){
        return new IPData(address);
    }
}
```

`ProtocolData` follows the same pattern used by other `enum`-based types:

```
@Embeddable
public enum ProtocolData {
     IPV4,
     IPV6;
}
```

You could argue that there is some repetition in creating all those classes to integrate the system with a database. That's true. It's a trade-off where we give up reusability in favor of changeability, making the application capable of better integration with RDBMS and other data sources.

Now that we have created all the ORM classes to allow integration with the H2 database, we need to translate database objects to domain model objects and vice versa. We accomplish it by creating a mapper class with mapper methods. Let's start with the methods we use to convert database entities to domain entities:

```
public static Router toDomain(RouterData routerData){
/** code omitted **/
    return new Router(routerType, routerId, networkSwitch);
}
```

The `toDomain` method receives a `RouterData` type representing the database entity and returns a `Router` domain entity.

To convert a list of `NetworkData` database entity objects to a list of `Network` domain entity objects, we use the `getNetworksFromData` method:

```
private static List<Network>
getNetworksFromData(List<NetworkData> networkData){
    List<Network> networks = new ArrayList<>();
    networkData.forEach(data ->{
        var network = new Network(
                IP.fromAddress(data.getIp().getAddress()),
                data.getName(),data.getCidr());
        networks.add(network);});
    return networks;
}
```

It receives a list of `NetworkData` database entity objects and returns a list of `Network` domain entity objects. Then, to convert from a domain model entity to an H2 database entity, we create the `toH2` mapper method:

```
public static RouterData toH2(Router router){
/** code omitted **/
return new RouterData(routerId, routerTypeData, switchData);
}
```

The `toH2` method receives a `Router` domain entity object as a parameter, to do the proper mapping, and then it returns a `RouterData` object.

Finally, to convert a list of `Network` domain entity objects to a list of `NetworkData` database entity objects, we have the `getNetworksFromDomain` method:

```
private static List<NetworkData>
getNetworksFromDomain(List<Network> networks, UUID switchId){
    List<NetworkData> networkDataList = new ArrayList<>();
    networks.forEach(network -> { var networkData = new
                    NetworkData(switchId,
                IPData.fromAddress(
                network.getAddress().getIPAddress()),
                network.getName(),
                network.getCidr());
```

```
        networkDataList.add(networkData);});
        return networkDataList;
}
```

The `getNetworksFromDomain` method receives a list of `Network` domain entity objects and a `UUID`-type switch ID as parameters. With that data, this method is able to do the proper mapping, returning a list of `NetworkData` database entity objects.

The `toDomain` static method is used when we need to convert the H2 database object into the domain model:

```
@Override
public Router fetchRouterById(RouterId routerId) {
     var routerData = em.getReference(
     RouterData.class, routerId.getUUID());
     return RouterH2Mapper.toDomain(routerData);
}
```

When persisting the domain model entity to the H2 database, we use the `toH2` static method:

```
@Override
public boolean persistRouter(Router router) {
     var routerData = RouterH2Mapper.toH2(router);
     em.persist(routerData);
     return true;
}
```

The `fetchRouterById` and `persistRouter` methods are called from the `RouterNetworkInputPort` object, using a `RouterNetworkOutputPort` interface reference:

```
private Router fetchRouter(RouterId routerId) {
     return routerNetworkOutputPort.
     fetchRouterById(routerId);
}
/** code omitted **/
private boolean persistNetwork(Router router) {
     return routerNetworkOutputPort.
     persistRouter(router);
}
```

Remember that `RouterNetworkOutputPort` is resolved during runtime based on the parameter we pass to the `RouterNetworkInputPort` constructor. With this technique, we blind the hexagonal system regarding where it needs to go to get data. It can be a relational database or a `.json` file, as we'll see in the next section.

The file adapter

To create the file adapter, we can apply the same ideas used to create the H2 database adapter, with just some minor adjustments to accommodate the file-backed data source. This data source is a `.json` file containing the same data used to create the previous database. So, to start, you can create a `.json` file at `resources/inventory.json` with the following content:

```
[{
    "routerId": "ca23800e-9b5a-11eb-a8b3-0242ac130003",
    "routerType": "EDGE",
    "switch":{
      "switchId": "922dbcd5-d071-41bd-920b-00f83eb4bb46",
      "ip": {
        "protocol": "IPV4", "address": "9.0.0.9"
      },
      "switchType": "LAYER3",
      "networks":[
        {
          "ip": {
            "protocol": "IPV4", "address": "10.0.0.0"
          },
          "networkName": "HR", "networkCidr": "8"
        },
        {
          "ip": {
            "protocol": "IPV4", "address": "20.0.0.0"
          },
          "networkName": "Marketing", "networkCidr": "8"
        },
        {
          "ip": {
            "protocol": "IPV4", "address": "30.0.0.0"
```

```
            },
            "networkName": "Engineering", "networkCidr": "8"
          }
        ]
      }
}]
```

The purpose of adding a network to fulfill use case goals remains the same, so again we will implement the `RouterNetworkOutputPort` interface to create `RouterNetworkFileAdapter`:

```
public class RouterNetworkFileAdapter implements
RouterNetworkOutputPort {
/** code omitted **/
    @Override
    public Router fetchRouterById(RouterId routerId) {
        Router = new Router();
        for(RouterJson: routers){
              if(routerJson.getRouterId().
              equals(routerId.getUUID())){
                    router =  RouterJsonFileMapper.
                    toDomain(routerJson);
              break;
            }
        }
        return router;
    }

    @Override
    public boolean persistRouter(Router router) {
        var routerJson = RouterJsonFileMapper.
                            toJson(router);
        try {
            var localDir = Paths.get("").
                                 toAbsolutePath().toString();
            var file = new File(localDir+
                           "/inventory.json");
```

```
            file.delete();
            objectMapper.writeValue(file, routerJson);
        } catch (IOException e) {
            e.printStackTrace();
        }
        return true;
    }
/** code omitted **/
}
```

The `fetchRouterById` method returns a `Router` object by parsing a `.json` file using the `RouterId` parameter. The `persistRouter` method persists changes in the `inventory.json` file.

Instead of using an entity manager and EclipseLink, we use the `Jackson` libraries to serialize and deserialize the JSON data. To load the `inventory.json` file into memory, we use the adapter constructor to call the `readJsonFile` method to load the `inventory.json` file into a list of `RouterJson` objects:

```
private void readJsonFile(){
    try {
        this.routers = objectMapper.readValue(
             resource,
             new TypeReference<List<RouterJson>>(){});
        } catch (Exception e) {
           e.printStackTrace();
        }
}
private RouterNetworkFileAdapter() {
    this.objectMapper = new ObjectMapper();
    this.resource = getClass().getClassLoader().
    getResourceAsStream("inventory.json");
    readJsonFile();
}
```

As in the H2 case, with JSON, we also need to create special classes to map between JSON objects and domain model objects. The classes' structure is similar to the H2 ORM classes, with differences mainly in the annotations used to create the adequate mapping. Let's see how to implement the `RouterJson` class:

```
/** Code omitted **/
@JsonInclude(value = JsonInclude.Include.NON_NULL)
public class RouterJson {

     @JsonProperty("routerId")
     private UUID routerId;
     @JsonProperty("routerType")
     private RouterTypeJson routerType;
     @JsonProperty("switch")
     private SwitchJson networkSwitch;
}
```

We use the `@JsonInclude` and `@JsonProperty` annotations to map class attributes to JSON fields. These JSON mappings are much more straightforward than H2 mappings because we don't need to deal with database relationships. The `RouterTypeJson`, `SwitchJson`, and all other JSON map classes are similar in using the same annotations to convert JSON and domain model objects.

To convert `RouterJson` to `Router`, we use the `toDomain` method from the `RouterJsonFileMapper` mapper class:

```
RouterJsonFileMapper.toDomain(routerJson);
```

We use the `toJson` method to convert from `Router` to `RouterJson`:

```
RouterJsonFileMapper.toJson(router);
```

`RouterJsonFileMapper` is similar to its H2 counterpart but simpler, because we don't need to deal with **one-to-many** or **one-to-one** relationships. Let's start with the methods used to convert JSON objects to domain objects:

```
public static Router toDomain(RouterJson routerJson){
    /** code omitted **/
    return new Router(routerType, routerId, networkSwitch);
}
```

The `toDomain` method here receives a `RouterJson` object as a parameter, performs the proper mapping, and then returns a `Router` object. A similar procedure occurs when we need to convert a list of `NetworkJson` JSON objects to a list of `Network` domain objects:

```
private static List<Network>
getNetworksFromJson(List<NetworkJson> networkJson){
    List<Network> networks = new ArrayList<>();
    networkJson.forEach(json ->{
        var network = new Network(
                IP.fromAddress(json.getIp().
                getAddress()),
                json.getNetworkName(),
                Integer.valueOf(json.getCidr()));
        networks.add(network);
    });
    return networks;
}
```

The `getNetworksFromJson` method receives a list of `NetworkJson` objects as parameters and returns an adequately mapped list of `Network` objects.

Let's see the methods used to convert domain objects into JSON objects:

```
public static RouterJson toJson(Router router){
    /** code omitted **/
    return new RouterJson(
                routerId,
                routerTypeJson,
                switchJson);
}
```

The `toJson` method does the opposite of what `toDomain` does. Instead of a JSON object as a parameter, the `toJson` method here receives a `Router` domain object, performs the proper mapping, and returns a `RouterJson` object.

Finally, we have a situation where it's necessary to convert a list of `Network` domain objects into a list of `NetworkJson` JSON objects:

```
private static
List<NetworkJson>  getNetworksFromDomain(List<Network>
networks){
    List<NetworkJson> networkJsonList = new ArrayList<>();
    networks.forEach(network -> {
        var networkJson = new NetworkJson(
                IPJson.fromAddress(
                network.
                getAddress().
                getIPAddress()),
                network.getName(),
                String.valueOf(network.getCidr())
        );
        networkJsonList.add(networkJson);
    });
    return networkJsonList;
}
```

By receiving a list of `Network` objects as parameters, the `getNetworksFromDomain` method can proceed to map the needed attributes and return a list of `NetworkJson` objects.

Now that we have completed the file output adapter implementation, let's play around, calling both the file and H2 output adapters.

Calling the output adapters

Before calling the adapter, let's compile the application. Navigate to the `chapter4` directory and run the following command:

```
mvn clean package
```

To call the H2 output adapter, we need to use the REST input adapter. We can do that by providing the `rest` parameter when executing the `.jar` file:

```
$ java -jar target/chapter4-1.0-SNAPSHOT-jar-with-dependencies.
jar rest
$ curl -vv "http://localhost:8080/network/
add?routerId=ca23800e-9b5a-11eb-a8b3-0242ac130003&address=40.0.
0.0&name=Finance&cidr=8" | jq
```

The file output adapter is accessible through the CLI input adapter:

```
$ java -jar target/chapter4-1.0-SNAPSHOT-jar-with-dependencies.
jar
Please inform the Router ID:
ca23800e-9b5a-11eb-a8b3-0242ac130003
Please inform the IP address:
40.0.0.0
Please inform the Network Name:
Finance
Please inform the CIDR:
8
```

The result of calling both the H2 and file output adapters will be the same:

```
{
  "routerId": "ca23800e-9b5a-11eb-a8b3-0242ac130003",
  "routerType": "EDGE",
  "switch": {
    "switchId": "922dbcd5-d071-41bd-920b-00f83eb4bb46",
    "ip": {
      "address": "9.0.0.9", "protocol": "IPV4"
    },
    "switchType": "LAYER3",
    "networks": [
      {
        "ip": {
          "address": "10.0.0.0", "protocol": "IPV4"
        },
```

```
          "networkName": "HR",
          "networkCidr": "8"
        },
        {
          "ip": {
            "address": "20.0.0.0", "protocol": "IPV4"
          },
          "networkName": "Marketing",
          "networkCidr": "8"
        },
        {
          "ip": {
            "address": "30.0.0.0", "protocol": "IPV4"
          },
          "networkName": "Engineering",
          "networkCidr": "8"
        },
        {
          "ip": {
            "address": "40.0.0.0", "protocol": "IPV4"
          },
          "networkName": "Finance",
          "networkCidr": "8"
        }
      ]
    }
  }
```

Note the `Finance` network block at the end of the output, which confirms that the data was correctly persisted.

By creating these two output adapters, we enabled the hexagonal application to speak with different data sources. The best part was that we didn't need to change anything in the Domain or Application hexagons.

The only requirement to create an output adapter is implementing an output port interface from the Application hexagon. These output adapters' examples showed how the hexagonal approach protects the business logic from technological concerns. Of course, there is a trade-off when we decide to follow this path. But if we aim to make change-tolerant systems centered in the domain model, the hexagonal architecture provides the necessary techniques needed for that.

Summary

We learned in this chapter that adapters are used to define the technologies that are supported by a hexagonal application. We created two input adapters to allow driving operations, that is, a REST adapter to receive data from HTTP connections and a CLI adapter to receive data from `STDIN`. Both input adapters were attached to the same input port, allowing the hexagonal system to use the same logic to process requests coming in distinct formats.

Then, we created an H2 database output adapter and a JSON file output adapter to make the hexagonal application communicate with different data sources. These two output adapters were attached to the same output port, enabling the hexagonal system to persist and obtain data from external sources so that the data source technology did not influence the business logic.

By knowing the purpose of input and output adapters and understanding how to implement them, we can now create systems that can tolerate significant technological changes without substantial refactoring. This benefit is achieved because all the system components, including the adapters, are developed around the domain model.

To fully understand the dynamic between adapters and other hexagonal architecture elements, we're going to look into the life cycle of driving and driven operations in the next chapter.

Questions

1. When should we create an input adapter?
2. What is the benefit of connecting multiple input adapters to the same input port?
3. What interface must we implement to create output adapters?
4. Which hexagon do the input and output adapters belong to?

Further reading

- *Get Your Hands Dirty on Clean Architecture: A hands-on guide to creating clean web applications with code examples in Java*, Tom Hombergs, Packt Publishing Ltd. 2019
- *Object-Oriented Software Engineering: A Use Case Driven Approach*, Ivar Jacobson, Pearson Education, 1992
- *Domain-Driven Design: Tackling Complexity in the Heart of Software*, Eric Evans, Pearson Education, 2003
- *Implementing Domain-Driven Design*, Vaughn Vernon, Pearson Education, 2013
- *Hexagonal architecture* (`https://alistair.cockburn.us/hexagonal-architecture/`), Alistair Cockburn

5
Exploring the Nature of Driving and Driven Operations

We spent the previous chapters analyzing the elements comprising each hexagon in the **hexagonal architecture**. We learned about entities, value objects, and business rules, and how to arrange them in the Domain hexagon to create a meaningful domain model. Next, when dealing with the Application hexagon, we learned how to utilize use cases and ports to create fully-fledged software features on top of the domain model. Finally, we learned how to create adapters to integrate the hexagonal application features with different technologies.

To better comprehend a hexagonal system, we also need to be aware of its surroundings. That's why in this chapter, we explore the nature of driving and driven operations, as they represent the external elements interacting with the hexagonal application. On the driving side, we'll see how frontend applications act as primary actors, driving the behavior of a hexagonal system. On the driven side, we will learn what is necessary to enable a message-based system to be driven by a hexagonal system.

In this chapter, we will cover the following topics:

- Reaching the hexagonal application with driving operations
- Integrating web applications with the hexagonal system
- Running test agents and calling the hexagonal system from other applications
- Handling external resources with driven operations

By the end of this chapter, you will know the most common driving and driven operations. Once you understand these operations and how they influence the inner structure of a hexagonal system, you'll have learned all the building blocks of the hexagonal architecture, enabling you to develop complete hexagonal applications while leveraging all the techniques presented so far.

Technical requirements

To compile and run the code examples presented in this chapter, you need the **Java SE Development Kit** (**JDK**) (version 11 or higher) and **Maven 3.6** installed on your computer. They are all available for **Linux**, **Mac**, and **Windows** operating systems. You will also need to download these tools: **Postman**, **Newman** (from **NPM**), and **Kafka**. We recommend using Linux to run Kafka properly. If you're using a Windows system, you can use **Windows Subsystem for Linux** (**WSL**) to run Kafka.

You can download the latest version of Kafka from `https://kafka.apache.org/downloads.html`.

You can download the latest version of Postman from `https://www.postman.com/downloads`.

You can download the latest version of Newman from `https://www.npmjs.com/package/newman`.

You can find the code files for this chapter on GitHub:

`https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter05`

Reaching the hexagonal application with driving operations

We may consider it inconceivable that a system can be self-contained in the sense that no one interacts with it and that this system doesn't interact with other users or systems. Such an arrangement goes against the fundamentals of computer architecture (von Neumann, 1940), which presume the presence of input and output operations in any computer system. Indeed, it's difficult to imagine a useful software program that doesn't receive any data nor produce any result.

Through the lens of the hexagonal architecture, the input side of a system is controlled by driving operations. We call them *driving operations* because they actually initiate and drive the behavior of a hexagonal application.

In *Chapter 3*, *Handling Behavior with Ports and Use Cases*, we related driving operations to primary actors. These actors are in charge of triggering driving operations in the hexagonal system. The driving operations can assume different facets: they can be users interacting directly with the system through a command-line console, a web **user interface** (**UI**) application requesting data to present it in a browser, a testing agent wanting to validate a specific test case, or any other system interested in the features exposed by the hexagonal application.

All these different facets are grouped in the **Driving Side**, as shown in the following diagram:

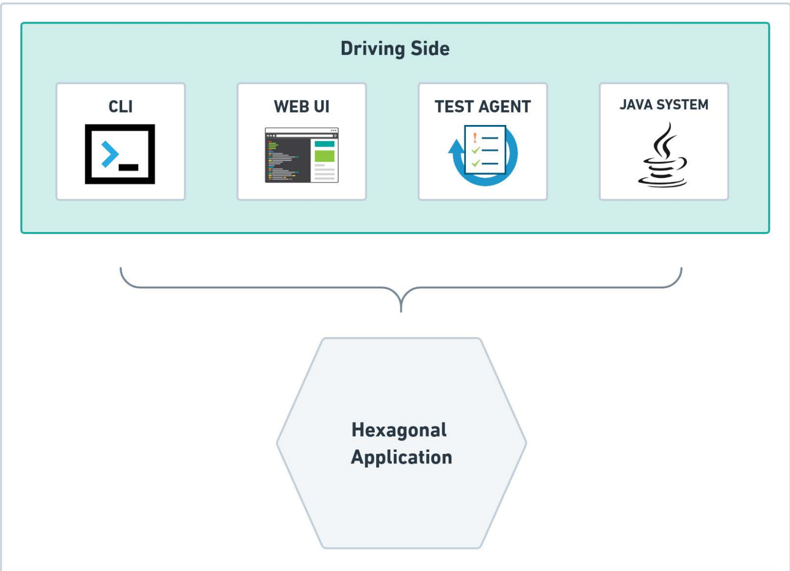

Figure 5.1 – The driving side and the hexagonal application

We saw in the previous chapter how to interact with a hexagonal application using a **Command-Line Interface** (**CLI**) and through **HTTP REST**. Now, we'll explore how to integrate other types of driving operations to communicate with the topology and inventory system we've been developing so far.

Once we have these integrations in place, we will analyze the path a request needs to make in order to traverse all the hexagons until it reaches domain one. This exercise will help us to understand the role played by each hexagon and its components in processing the request of a driving operation. So, let's start by integrating a web UI with the hexagonal system.

Integrating web applications with the hexagonal system

Nowadays, with the advent of **HTML 5**, modern **JavaScript**, and continuously improving web development techniques, it's possible to build highly sophisticated systems that run directly from the web browser. Faster internet connections, more computational resources, and better and well-established web standards have all contributed to the improvement of web applications. The old and cluttered **Flash** or **Java Applet**-based systems, for example, have been replaced by frontend applications based on fancy frameworks such as **Angular**, **React**, or **Vue**.

Not only has the technology evolved and changed, but the practices surrounding web development have evolved too. Encouraged by the **Model-View-Controller** (**MVC**) pattern, developers used to group presentation code with business logic in a single software unit. The MVC's purpose has been to establish clear boundaries between different categories of components – model, view, and controller – in an application. But because the presentation and business code were most often part of the same software project and assembled into the same `.ear` or `.war` package file, it isn't rare to see business logic leak into the presentation code.

Java EE (now **Jakarta EE**) and other frameworks, such as **Struts**, utilized technologies such as **Servlets**, **JSP**, and **JSF** to allow full integration between presentation and business code. After some time, people started to realize that this practice of putting frontend and backend code too close to each other could be a source of entropy for their software projects.

As a response to such practices, the industry turned to decoupled architectures where the frontend system is a separate, standalone application that interacts via the network with one or more backend systems.

So, we will create a simple standalone, frontend application that obtains its data from our topology and inventory system. Our application will be based only on HTML 5, CSS, and *vanilla* JavaScript. The application aims to allow users to add networks to a router and retrieve existing routers from the system database. We will also refactor part of the hexagonal application to enable better integration with our frontend application. The result will be a web browser application integrated with the hexagonal system, as shown in the following screenshot:

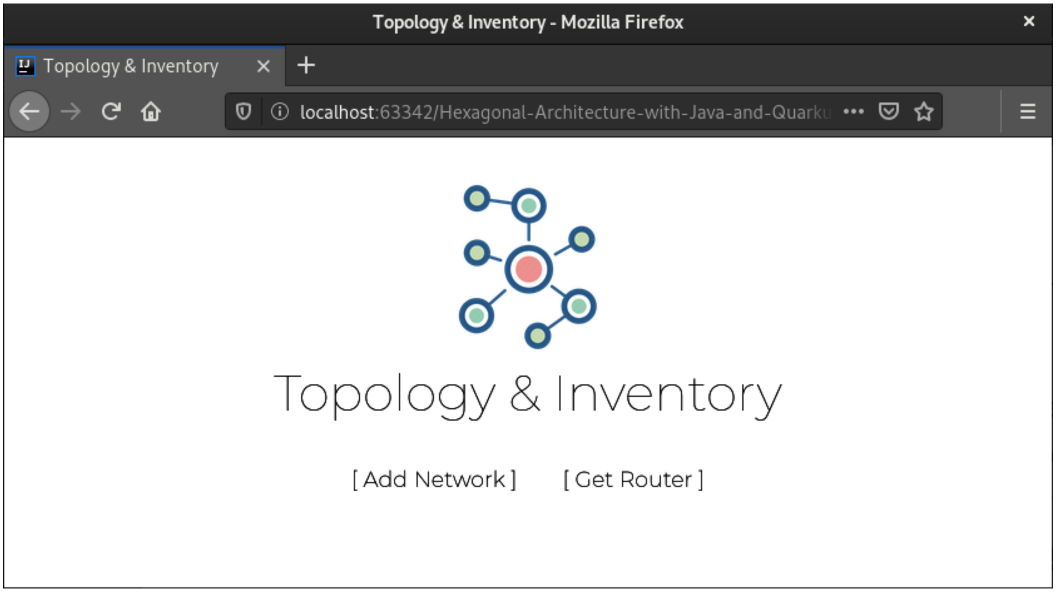

Figure 5.2 – The topology and inventory frontend application

The frontend application will allow users to add networks to an existing router and view a graphical representation of the router and its networks.

Let's start enhancing the hexagonal application by adding the `getRouter` method to the `RouterNetworkUseCase` interface:

```
public interface RouterNetworkUseCase {

    Router addNetworkToRouter(RouterId,
    Network network);

    Router getRouter(RouterId routerId);
}
```

The getRouter method signature is simple. It receives RouterId and returns a Router object. We need this behavior to allow the frontend application to display a router.

Next, we need to provide an implementation for the getRouter method. We do that by implementing the RouterNetworkUseCase interface with the RouterNetworkInputPort class:

```
public class RouterNetworkInputPort implements
RouterNetworkUseCase {
/** code omitted **/
    @Override
    public Router getRouter(RouterId routerId) {
        return fetchRouter(routerId);
    }

    private Router fetchRouter(RouterId routerId) {
        return routerNetworkOutputPort.
               fetchRouterById(routerId);
    }
/** code omitted **/
}
```

Notice that fetchRouter already existed in the input port implementation, but we didn't have an exposed operation that allowed us to retrieve the router. The fetchRouter method is then used not only by the addNetworkToRouter method but now also by getRouter.

It's necessary to propagate the input port change to the input adapter. We do that by creating a getRouter method on the base input adapter defined in the RouterNetworkAdapter abstract class:

```
public Router getRouter(Map<String, String> params) {
    var routerId = RouterId.
    withId(params.get("routerId"));
    return routerNetworkUseCase.getRouter(routerId);
}
```

Remember that RouterNetworkAdapter is the base input adapter for both RouterNetworkCLIAdapter and RouterNetworkRestAdapter.

To allow the frontend application to communicate with the hexagonal system, we'll use the REST adapter. So, there are some changes we need to make in `RouterNetworkRestAdapter` to allow this communication:

```
@Override
public Router processRequest(Object requestParams){
/** code omitted **/
    if (exchange.
      getRequestURI().getPath().equals("/network/add")) {
        try {
            router = this.addNetworkToRouter(params);
        } catch (Exception e) {
            exchange.sendResponseHeaders(
            400, e.getMessage().getBytes().length);
            OutputStream output = exchange.
            getResponseBody();
            output.write(e.getMessage().getBytes());
            output.flush();
        }
    }
    if (exchange.
      getRequestURI().getPath().contains("/network/get")) {
        router = this.getRouter(params);
    }
/** code omitted **/
}
```

The changes to the `processRequest` method were made so it can properly handle requests coming from the `/network/add` and `/network/get` paths.

We can move now to the development of the frontend part of our topology and inventory system. Our focus will be on the HTML and JavaScript elements. We'll create two pages: the first one is to allow users to add networks, and the second one is where users will be able to retrieve a graphical view of a router and its networks.

Creating the Add Network page

Let's start by creating the first HTML page, as shown in the following screenshot:

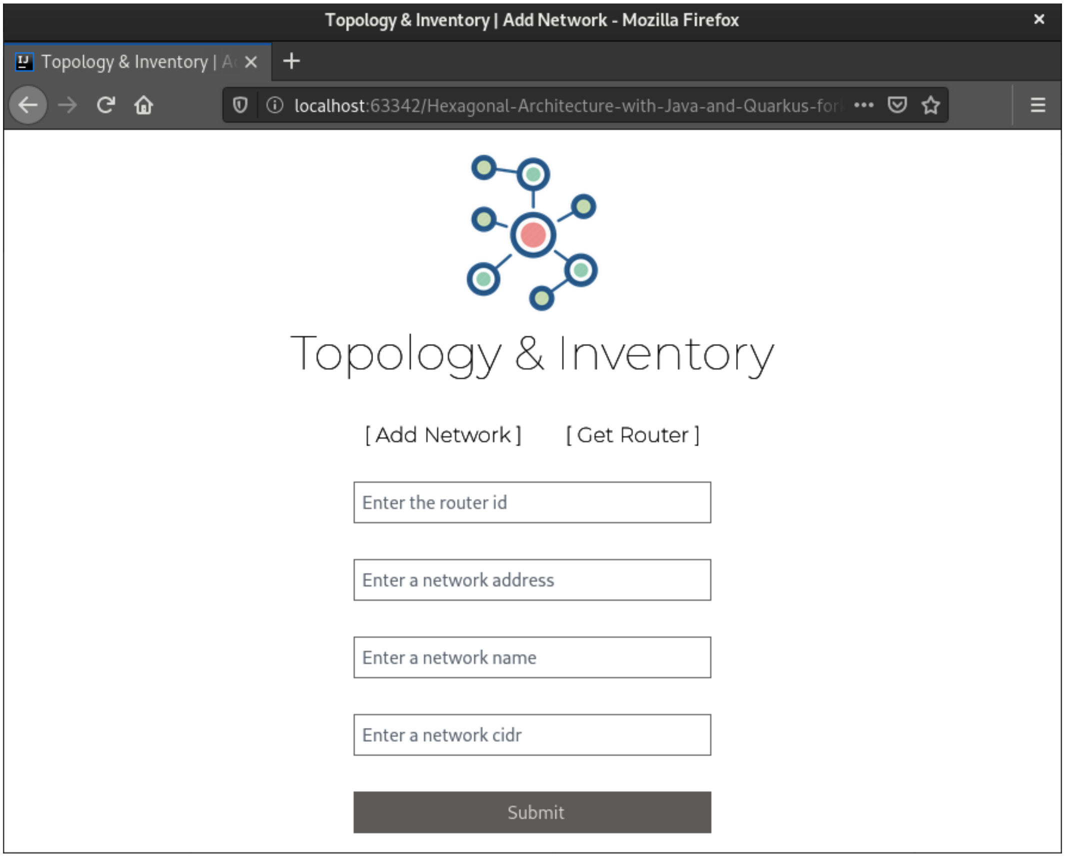

Figure 5.3 – The Add Network page of the topology and inventory frontend application

The **Add Network** page contains a form, where users are asked to type the necessary data to add a network to an existing router. Here is the code for the form:

```
<html>
  <head>
    <title>Topology & Inventory | Add Network</title>
    /** code omitted **/
  </head>
  <body>
      /** code omitted **/
```

```
        <form name="addNetwork" onsubmit="return
         false;">
        /** code omitted **/
        </form>
      <script src="js/networkTools.js"></script>
    </body>
  </html>
```

In order to process the preceding **Add Network** page form, we use a JavaScript function called `addNetworkToRouter` that is present in the `networkTools.js` file:

```
function addNetworkToRouter() {
    const routerId = document.
    getElementById("routerId").value;
    const address = document.
    getElementById("address").value;
    const name = document.getElementById("name").value;
    const cidr = document.getElementById("cidr").value;
    const xhttp = new XMLHttpRequest();
    xhttp.open("GET",
    "http://localhost:8080/network/add?
        routerId=" + routerId + "&" +
        "address=" + address + "&" +
        "name=" + name + "&" +
        "cidr=" + cidr, true);
    xhttp.onload = function(
        if (xhttp.status === 200) {
            document.
            getElementById("message").
            innerHTML = "Network added with success!"
        } else {
            document.
            getElementById("message").
            innerHTML = "An error occurred while
            trying to add the network."
        }
```

```
        };
        xhttp.send();
    }
```

We use the `XMLHttpRequest` object to process GET requests in the `/network/add` endpoint exposed by the REST adapter in the hexagonal application. It is a short JavaScript code that captures the values entered in the HTML form, processes them, and then shows a success message if everything goes okay or an error message if not, as we can see here:

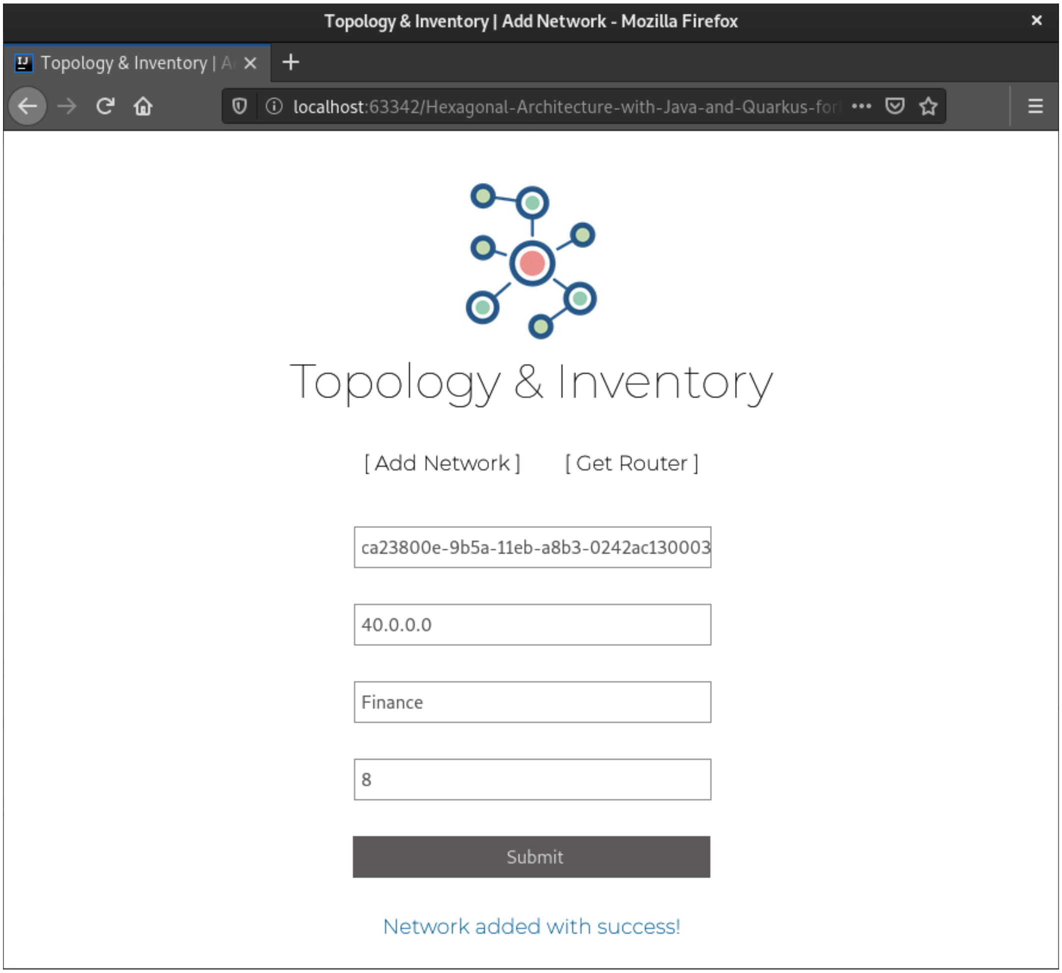

Figure 5.4 – Adding a new network in the topology and inventory application

Now, let's move on to the creation of the **Get Router** page.

Creating the Get Router page

The **Get Router** page contains an HTML form to process the user request, but it also provides a graphical view based on the JSON response obtained from the hexagonal application. Let's start by considering the HTML form:

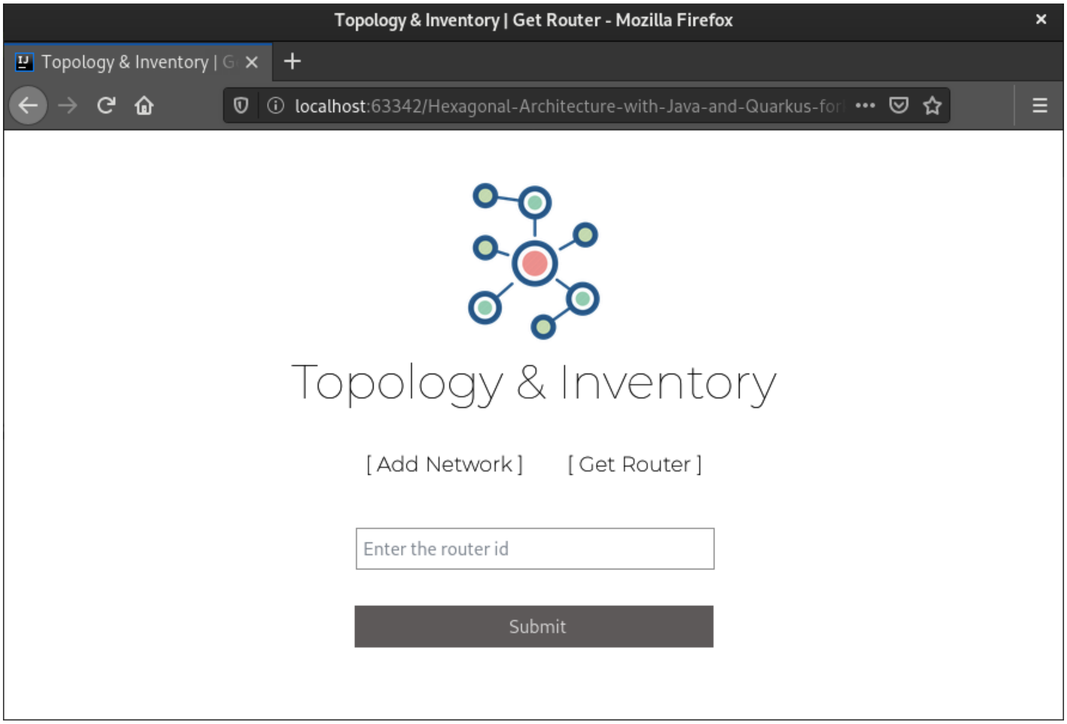

Figure 5.5 – The Get Network page of the topology and inventory frontend application

The **Get Router** HTML page follows the same structure as the one we used on the **Add Network** page, but this form uses only one parameter to query a router from the hexagonal application.

To create a JSON-based graphical view of the router and its networks, we'll use a JavaScript library called `D3` that consumes the JSON data and produces the graphical view. The JavaScript code processes the form, and then it uses the JSON response with the `D3` libraries:

```
function getRouter() {
    const routerId = document.
    getElementById("routerId").value;
    var xhttp = new XMLHttpRequest();
    xhttp.onreadystatechange = function() {
```

```
        console.log(this.responseText);
        if (this.readyState == 4 && this.status == 200) {
            const json = JSON.parse(this.responseText)
            createTree(json)
        }
    };
    xhttp.open(
    "GET",
    "http://localhost:8080/network/get?routerId="+routerId,
    true);
    xhttp.send();
}

function createTree(json) {
    const container = document.getElementById("container");
    const vt = new VTree(container);
    const reader = new Vtree.reader.Object();

    var data = reader.read(json);
    vt.data(data).update();
}
```

Here, we are passing the `/network/get` endpoint defined previously in the hexagonal application. The `getRouter` function processes the GET requests and uses the JSON response as the parameter for the `createTree` function that will construct the graphical view of the network.

If we fill the form with the router ID, `ca23800e-9b5a-11eb-a8b3-0242ac130003`, to retrieve a router, the result we get is like the one shown in the following screenshot:

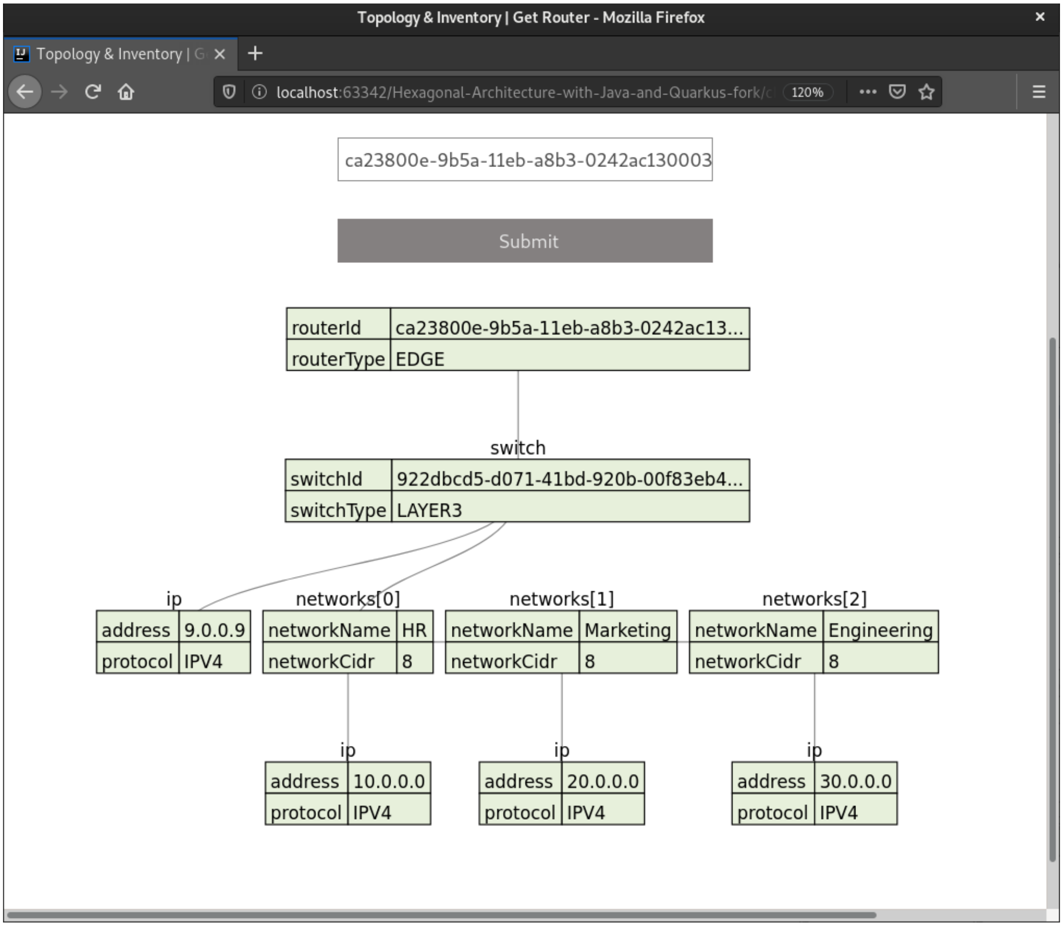

Figure 5.6 – The network graphical view provided by the Get Router page

Remember, the data presented in the preceding screenshot came ultimately from the H2 in-memory database that we attached directly to the REST input adapter used here by the frontend application.

Now, let's see how test agents can be integrated with the topology and inventory system.

Running test agents

Aside from frontend applications, another common type of driven operation comes from test and monitoring agents interacting with the hexagonal system to verify its features are working well. With tools like Postman, we can create comprehensive test cases to validate how the application behaves when faced with certain requests.

In addition, we can periodically issue requests to certain application endpoints to check if they are healthy. This practice has been popularized with tools such as **Spring Actuator**, which provides a specific endpoint in the application that allows you to check if it's healthy. Also, some techniques involve the use of probe mechanisms that periodically send a request to the application to see if it is alive. For example, if the application is not alive or is causing timeouts, then it can be automatically restarted. In cloud-native architecture based on **Kubernetes**, it's common to see systems using probe mechanisms.

This section will explore how to run a simple test case to confirm whether the application behaves according to our expectations. There will be no need to change the topology and inventory system we have been developing so far. Here, we will create a test case using a tool called Postman. In Postman, test cases are known as **testing collections**. Once these testing collections are made, we can execute them using **Newman**, which is a CLI tool used specifically to run Postman collections.

To get started, you have to follow these steps:

1. Download both Postman and Newman. The download links are available in the *Technical requirements* section. The collection used in this chapter is also present in the chapter's GitHub repository (`https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/blob/main/Chapter05/topology-inventory.postman_collection.json`).
2. Import the collection to Postman.
3. Once imported, the collection will present two requests. One request is for the `getRouter` endpoint and the other is for `addNetwork`. The following screenshot shows how the two requests should appear after importing the collections to Postman:

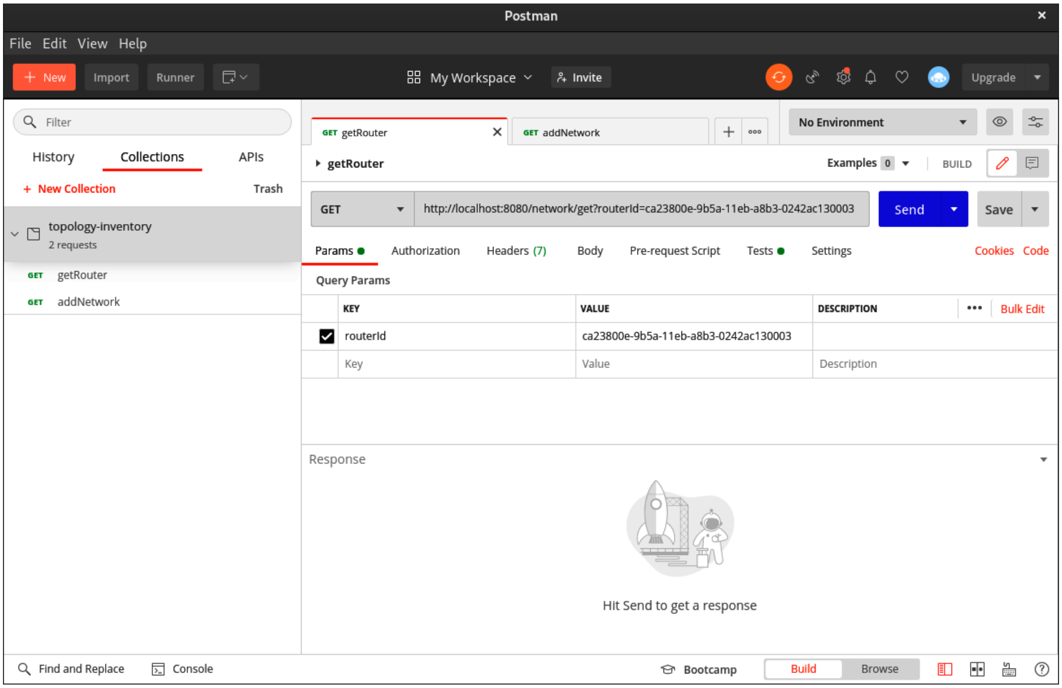

Figure 5.7 – The topology and inventory collection from Postman

4. Before running the test on Postman, be sure to bring up the topology and inventory application by running the following command from the project's `root` directory:

```
java -jar target/topology-inventory-1.0-SNAPSHOT-jar-
with-dependencies.jar rest
```

Our goal in testing the `getRouter` request is to confirm if the application returns an `HTTP 200` response code when we try to retrieve a router by passing a router ID.

5. Then, we want to validate if the returned value is what we are expecting. In this case, we expect to encounter only three networks in the system: `HR`, `Marketing`, and `Engineering`. In Postman, we create tests for each request. So, we will create tests for the two requests present in the collection we imported. Let's start by creating a test for the `getRouter` request:

```
pm.test("Status code is 200", () => {
  pm.expect(pm.response.code).to.eql(200);
});
```

```
pm.test("The response has all properties", () => {
  const responseJson = pm.response.json();
  pm.expect(
      responseJson.switch.networks).
      to.have.lengthOf(3);
  pm.expect(
      responseJson.switch.networks[0].networkName).
      to.eql('HR');
  pm.expect(
      responseJson.switch.networks[1].networkName).
      to.eql('Marketing');
  pm.expect(
      responseJson.switch.networks[2].networkName).
      to.eql('Engineering');
});
```

In the preceding code, we first check if the HTTP response code is `200`. Then, we proceed to parse and peek at the JSON response data to see if it matches what we expect. In this test, we expect a response containing a router with a switch comprising three networks.

6. The test from the `addNetwork` request is similar to the `getRouter` request's test. The difference, though, is that the response expected this time contains the additional `Finance` network, as we can see in the following test code:

```
pm.test("Status code is 200", () => {
  pm.expect(pm.response.code).to.eql(200);
});

pm.test("The response has all properties", () => {
  const responseJson = pm.response.json();
  pm.expect(
      responseJson.switch.networks).
      to.have.lengthOf(4);
  pm.expect(
      responseJson.switch.networks[3].networkName).
      to.eql('Finance');
});
```

The `addNetwork` request in that collection adds a network named `Finance`. That's why we are only checking to see if the `Finance` network was correctly added. Also, we expect the list of networks length to be `4` after adding the `Finance` network.

7. If you want to run these tests from outside Postman, you can do that by first exporting the collection to a `.json` file, then using Newman to execute the tests from that collection:

```
newman run topology-inventory.postman_collection.json
```

The result is something like the one presented in the following screenshot:

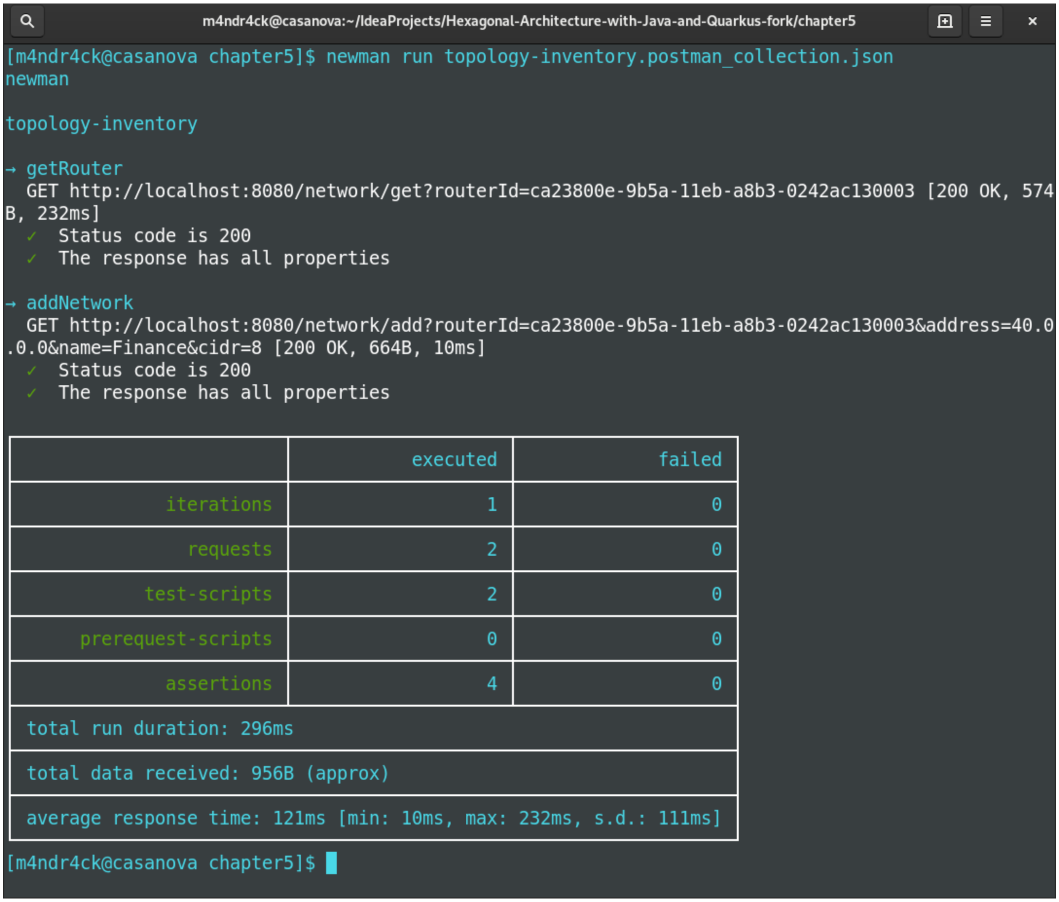

Figure 5.8 – Running topology and inventory application tests with Newman

This kind of test execution using Newman is ideal for integrating the hexagonal application into **Continuous Integration** (**CI**) pipelines. Developers use Postman to create collections and their respective tests, and these same collections are triggered and validated through CI tools (such as **Jenkins**) that can use Newman to execute the tests.

Now that we are acquainted with both frontend applications and test agents as means of driving operations, let's check out one more type of driving operation. This kind of driving operation is widespread in distributed or microservices architecture, where different applications from the same system communicate with each other through the network.

Calling the hexagonal system from other applications

There is a recurring debate whether to develop a monolith or a microservices system. In a monolith, we have data flowing directly between objects and method calls. All the software instructions are grouped in the same application, diminishing the communication overhead, and centralizing the logs generated by the system.

With both microservices and a distributed system, we have part of the data flowing through the network between standalone, self-contained applications that cooperate in providing the features of the whole system. This approach decouples the development, allowing more modularized components. It also improves compilation times because the packages are smaller, contributing to faster feedback loops in CI tools. Microservices, though, offer some challenges because the logs are not centralized anymore, and the network communication overhead can represent a limiting factor, depending on the system's purpose.

In a distributed approach, two or more hexagonal self-contained systems can comprise the whole hexagonal-based system. In such a scenario, the hexagonal **System A** that initiates the request acts as a primary actor and triggers a driving operation on the hexagonal **System B**, as shown in the following diagram:

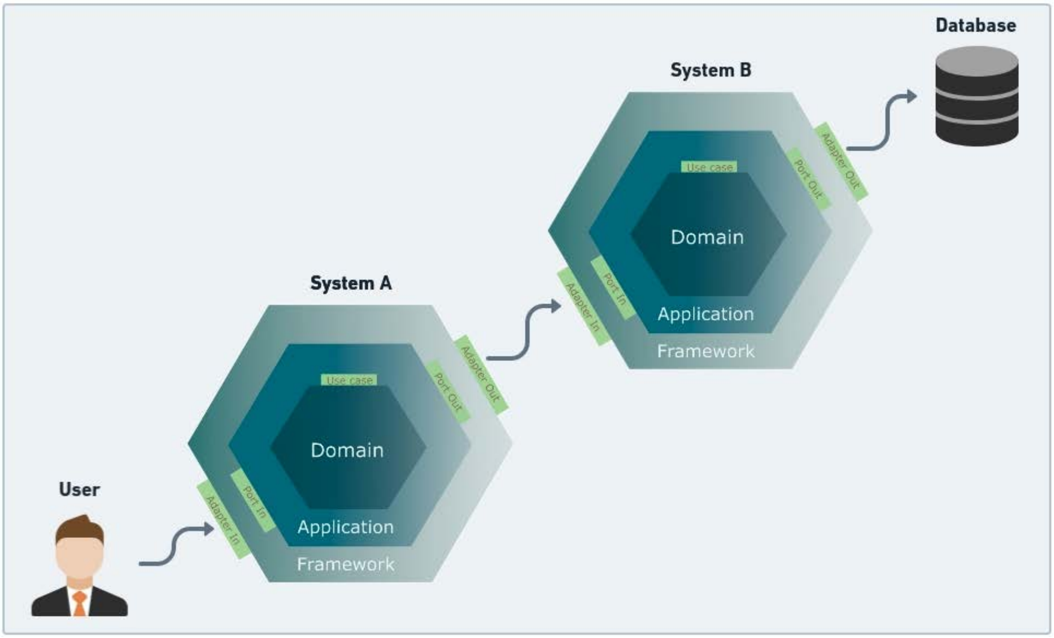

Figure 5.9 – Multiple hexagonal applications

Note that **System A** triggers a request through one of its output adapters. This request goes directly to one of the input adapters from **System B**. An exciting thing about distributed architecture is that you don't need to use the same programming language to develop all the system components.

In a distributed architecture scenario, we could write **System A** in Java and **System B** in Python. As long as they agree on a common medium of communication – JSON and HTTP, for example – they can cooperate in the same system. With the advent of container technologies such as Docker and Kubernetes, it's not a big deal to have a technology-hybrid system.

This section has looked at what driving operations are and how we can use them to interact with the hexagonal system. In the next section, we'll see the other side of the coin: driven operations.

Handling external resources with driven operations

A general characteristic of business applications is their need to send or request data from other systems. We've already seen that output ports and adapters are the hexagonal architecture components we use to allow the hexagonal system to interact with external resources without compromising the business logic. These external resources are also known as *secondary actors* and provide data or capabilities absent in the hexagonal application that requests them.

When the hexagonal application sends a request to a secondary actor – generally on behalf of a primary actor who first triggered a driving operation from one of the hexagon application's use cases – we call such a request a *driven* operation. It's driven because these operations are controlled and driven by the hexagonal system.

So, *driving* operations come from primary actor's requests that drive the behavior of a hexagonal system, whereas *driven* operations are the requests initiated by the hexagonal application itself toward secondary actors (such as databases or other systems). The following diagram shows the driven side with some driven operations:

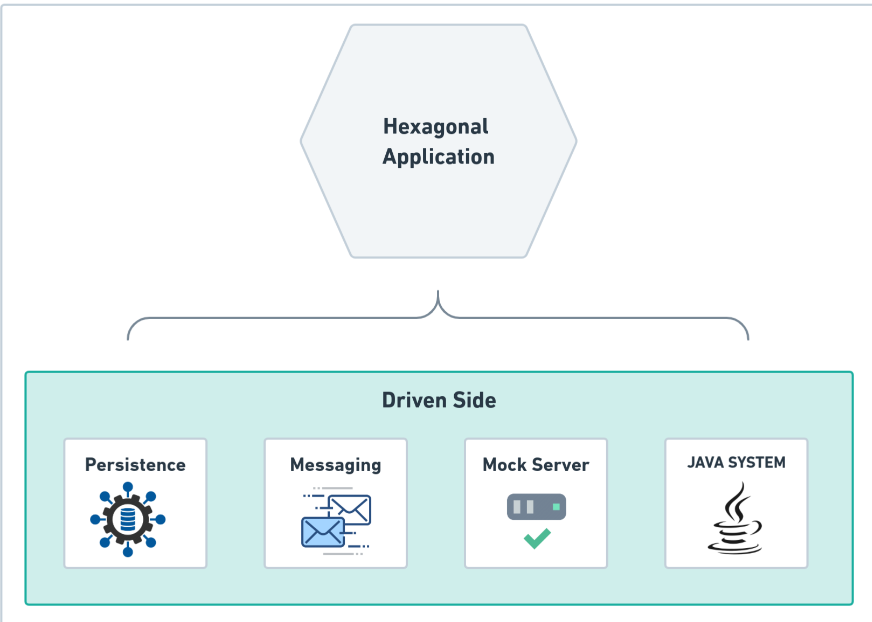

Figure 5.10 – The driven side and the hexagonal application

This section will explore some of the possible driven operations a hexagonal application can perform, as shown in the preceding diagram.

Data persistence

Driven operations based on data persistence are the most common. The H2 output adapter we created in *Chapter 4*, *Creating Adapters to Interact with the Outside World*, is one example of a driven operation that deals with data persistence by utilizing an in-memory database. This kind of driven operation often leverages **Object-Relational Mapping** (**ORM**) techniques to handle and translate objects between the hexagonal system and a database. In the Java world, **Hibernate** and **EclipseLink** provide robust **Java Persistence API** (**JPA**) implementations to provide ORM features.

Transaction mechanisms are also a part of persistence-based driven operations. When working with transactions, we can make the hexagonal system directly deal with transactional boundaries or delegate this responsibility to an application server.

Messaging and events

Not every system relies only on synchronous communication. Depending on the situation, you may want to trigger events about your *stuff* without interrupting the runtime flow of your application.

There are types of architecture strongly influenced by techniques where the communication between system components occurs asynchronously. These systems become more loosely coupled by employing such techniques because their components are no longer attached to the interfaces provided by other applications. Instead of relying solely on APIs blocking connections, we let messages and events drive the behavior of applications in a non-blocking way.

By *blocking*, we mean those connections that need to wait for a response to let the application flow to proceed. The non-block approach allows an application to send a request and move forward without the need for an immediate response. There are also situations where an application reacts to message or events to take some action.

Message-based systems are secondary actors driven by the hexagonal application. Unlike databases, where the communication will start from the hexagonal application, there are scenarios where the message-based system will start the communication with the hexagonal application. But to receive or send messages, the hexagonal system always needs to first establish a flow of communication with a message system. Such a scenario is widespread when dealing with technologies like Kafka, where the application can be both a consumer and producer of messages. To be integrated with a message system such as Kafka, the hexagonal application needs to express its intent by joining a **Kafka topic**.

To better understand how a message-based system integrates with a hexagonal application, we'll implement a feature in our topology and inventory system to allows us to see events produced by the application. The backend hexagonal part of the system will send events to Kafka, and the frontend will consume those events in real-time and display them in the web browser. We'll implement this feature by executing the following steps:

1. Let's start by bringing up Kafka and creating a topic for our application. The Kafka download URL is available in the *Technical requirements* section. Once you have downloaded the latest Kafka version, extract it:

```
$ curl "https://downloads.apache.org/kafka/2.8.0/
kafka_2.13-2.8.0.tgz" -o ./kafka_2.13-2.8.0.tgz
$ tar -xzf kafka_2.13-2.8.0.tgz
$ cd kafka_2.13-2.8.0
```

2. Before proceeding, be sure to have JDK version 11 or higher installed on your system. Once Java is properly installed and configured, you can start the `zookeeper` service:

```
$ bin/zookeeper-server-start.sh config/zookeeper.
properties
```

3. Be sure to open a separate shell session or tab, and start the Kafka `broker` service:

```
$ bin/kafka-server-start.sh config/server.properties
```

4. At this point, Kafka is up and running in your environment. Let's now create the topic for our application in a third shell session or tab:

```
bin/kafka-topics.sh --create --topic topoloy-inventory-
events --bootstrap-server localhost:9092
```

5. Now, we need to add proper ports and adapters to enable the hexagonal application to send and consume events from Kafka. Let's do that with the `NotifyEventOutputPort` output port:

```
public interface NotifyEventOutputPort {
    void sendEvent(String Event);
    String getEvent();
}}
```

6. Next, we implement the output port with the `NotifyEventKafkaAdapter` output adapter. We start the `NotifyEventKafkaAdapter` adapter implementation by first defining the Kafka connection properties:

```
public class NotifyEventKafkaAdapter implements
NotifyEventOutputPort {
    private static String KAFKA_BROKERS =
      "localhost:9092";
    private static String
      GROUP_ID_CONFIG="consumerGroup1";
    private static String CLIENT_ID="hexagonal-
      client";
    private static String TOPIC_NAME=
    "topology-inventory-events";
    private static String
      OFFSET_RESET_EARLIER="earliest";
    private static Integer
      MAX_NO_MESSAGE_FOUND_COUNT=100;
    /** code omitted **/
}
```

Note that the `KAFKA_BROKERS` variable value, set to `localhost:9092`, corresponds to the host and port used to bootstrap the Kafka topic. The `TOPIC_NAME` variable value, set to `topology-inventory-events`, represents the topic that we use to produce and consume messages.

7. Let's move on now to create the method to send messages to our Kafka topic:

```
private static Producer<Long, String> createProducer(){
    Properties props = new Properties();

    props.put(ProducerConfig.
    BOOTSTRAP_SERVERS_CONFIG, KAFKA_BROKERS);
    props.put(ProducerConfig.
    CLIENT_ID_CONFIG, CLIENT_ID);
    props.put(ProducerConfig.
    KEY_SERIALIZER_CLASS_CONFIG,
    LongSerializer.class.getName());
    props.put(ProducerConfig.
```

```
        VALUE_SERIALIZER_CLASS_CONFIG,
        StringSerializer.class.getName());
        return new KafkaProducer<>(props);
    }
```

The `createProducer` method configures the producer properties by setting the required attributes in the `ProducerConfig` class. Then, it returns a `KafkaProducer` instance that we use to produce messages in the Kafka topic.

8. On the other hand, we have the `consumer` method, which consumes the messages generated by the `Producer` method:

```
    public static Consumer<Long, String> createConsumer(){
        Properties props = new Properties();

        props.put(ConsumerConfig.
        BOOTSTRAP_SERVERS_CONFIG,KAFKA_BROKERS);
        props.put(ConsumerConfig.
        GROUP_ID_CONFIG, GROUP_ID_CONFIG);
        props.put(ConsumerConfig.
        KEY_DESERIALIZER_CLASS_CONFIG,
        LongDeserializer.class.getName());
        props.put(ConsumerConfig.
        VALUE_DESERIALIZER_CLASS_CONFIG,
        StringDeserializer.class.getName());
        props.put(ConsumerConfig.MAX_POLL_RECORDS_CONFIG,
                  1);
        props.put(ConsumerConfig.
        ENABLE_AUTO_COMMIT_CONFIG,"false");
        props.put(ConsumerConfig.
        AUTO_OFFSET_RESET_CONFIG, OFFSET_RESET_EARLIER);
        Consumer<Long, String> consumer =
        new KafkaConsumer<>(props);
        consumer.
        subscribe(Collections.singletonList(TOPIC_NAME));
        return consumer;
    }
```

With the `createConsumer` method, we use the `ConsumerConfig` class to set the required properties. This method returns a `KafkaConsumer` instance that we use to consume and read messages from the Kafka topic.

9. Moving ahead, we override the first method, `sendEvent`, declared in `NotifyEventOutputPort`. It's with this method that we'll be able to send messages to the Kafka `producer` instance:

```
@Override
public void sendEvent(String eventMessage){
    var record = new ProducerRecord<Long, String>(
            TOPIC_NAME, eventMessage);
    try {
        var metadata = producer.send(record).get();
        System.out.println("Event message " +
                "sent to the topic "+TOPIC_NAME+": "
                +eventMessage+".");
        getEvent();
    }catch (Exception e){
        e.printStackTrace();
    }
}
```

The first line of the `sendEvent` method creates a `ProducerRecord` instance which informs the constructor parameters about the topic name and the message we intend to send as an event. Near the end, we have a call to the `getEvent` method.

10. As we shall see next in more detail, we call this method to consume messages from Kafka and forward them to a `WebSocket` server:

```
@Override
public String getEvent(){
    int noMessageToFetch = 0;
    AtomicReference<String> event =
    new AtomicReference<>("");
    while (true) {
    /** code omitted **/
        consumerRecords.forEach(record -> {
            event.set(record.value());
        });
```

```
        }
        var eventMessage = event.toString();
        if(sendToWebsocket)
        sendMessage(eventMessage);
        return eventMessage;
    }
```

The `getEvent` method relies on the `KafkaConsumer` instance assigned to the `consumer` variable. With that instance, it retrieves messages from the Kafka topic.

11. After retrieving the message, the `getEvent` method calls the `sendMessage` method to forward that message to the `WebSocket` server:

```
    public void sendMessage(String message){
        try {
            var client = new WebSocketClientAdapter(
            new URI("ws://localhost:8887"));
            client.connectBlocking();
            client.send(message);
            client.closeBlocking();
        } catch (URISyntaxException |
                InterruptedException e) {
            e.printStackTrace();
        }
    }
```

The `sendMessage` method receives a parameter as a string, containing the consumed Kafka topic message. It then forwards that message to a `WebSocket` server running at the `8887` port.

Let's see briefly how that `WebSocket` server is implemented:

```
public class NotifyEventWebSocketAdapter extends
WebSocketServer {
/** code omitted **/
public static void startServer() throws IOException,
InterruptedException {
    var ws = new NotifyEventWebSocketAdapter(
    new InetSocketAddress("localhost", 8887));
    ws.setReuseAddr(true);
    ws.start();
```

```
    System.out.println("Topology & Inventory" +
    " webSocket started on port: " + ws.getPort());
    BufferedReader sysin =
    new BufferedReader(new InputStreamReader(System.in));
    while (true) {
        String in = sysin.readLine();
        ws.broadcast(in);
        if (in.equals("exit")) {
            ws.stop();
            break;
        }
    }
}
/** code omitted **/
}
```

The `startServer` method creates an instance of `NotifyEventWebSocketAdapter`, containing the host and port of the `WebSocket` server. When we are starting the hexagonal application, one of the first things that occur is the calling of the `startServer` method to bring up the `WebSocket` server on port `8887`:

```
void setAdapter(String adapter) throws IOException,
InterruptedException {
    switch (adapter){
        case "rest":
            routerOutputPort =
            RouterNetworkH2Adapter.getInstance();
            notifyOutputPort =
            NotifyEventKafkaAdapter.getInstance();
            usecase =
            new RouterNetworkInputPort(routerOutputPort,
            notifyOutputPort);
            inputAdapter =
            new RouterNetworkRestAdapter(usecase);
            rest();
            NotifyEventWebSocketAdapter.startServer();
            break;
        default:
```

```
            routerOutputPort =
            RouterNetworkFileAdapter.getInstance();
            usecase =
            new RouterNetworkInputPort(routerOutputPort);
            inputAdapter =
            new RouterNetworkCLIAdapter(usecase);
            cli();
    }
}
```

Along with a `WebSocket` server class, we also need to implement a `WebSocket` client class to process the events coming from Kafka:

```
public class WebSocketClientAdapter extends org.java_websocket.
client.WebSocketClient {

    public WebSocketClientAdapter(URI serverUri) {
        super(serverUri);
    }

    @Override
    public void onMessage(String message) {
        String channel = message;
    }

    @Override
    public void onOpen(ServerHandshake handshake) {
        System.out.println("opened connection");
    }

    @Override
    public void onClose(int code, String reason,
    boolean remote) {
        System.out.println("closed connection");
    }

```

```
    @Override
    public void onError(Exception ex) {
        ex.printStackTrace();
    }
}
```

When a message is consumed from the Kafka topic, the hexagonal application uses `WebSocketClientAdapter` to forward the message to the `WebSocket` server. The `onMessage`, `onOpen`, `onClose`, and `onError` methods represent the `WebSocket` protocol operations that the `WebSocketClientAdapter` class needs to support.

The last thing we need to do in the hexagonal application is to make the `addNetworkToRouter` and `getRouter` methods send events using the ports and adapters we have just created:

```
public class RouterNetworkInputPort implements
RouterNetworkUseCase {
    /** Code omitted **/
    @Override
    public Router addNetworkToRouter(
    RouterId routerId,  Network network) {
        var router = fetchRouter(routerId);
        notifyEventOutputPort.
        sendEvent("Adding "+network.getName()
        +" network to router "+router.getId().getUUID());
        return createNetwork(router, network);
    }

    @Override
    public Router getRouter(RouterId routerId) {
        notifyEventOutputPort.
        sendEvent(
        "Retrieving router ID"+routerId.getUUID());
        return fetchRouter(routerId);
    }
    /** Code omitted **/
}
```

Note that now we are calling `sendEvent` on both methods (`addNetworkToRouter` and `getRouter`), so whenever we add a network or retrieve a router, the hexagonal application will send an event informing us what has happened.

We can now add an events page to allow the frontend application to connect with the `WebSocket` server from the hexagonal application. The following screenshot shows us the **Events** page that we'll create:

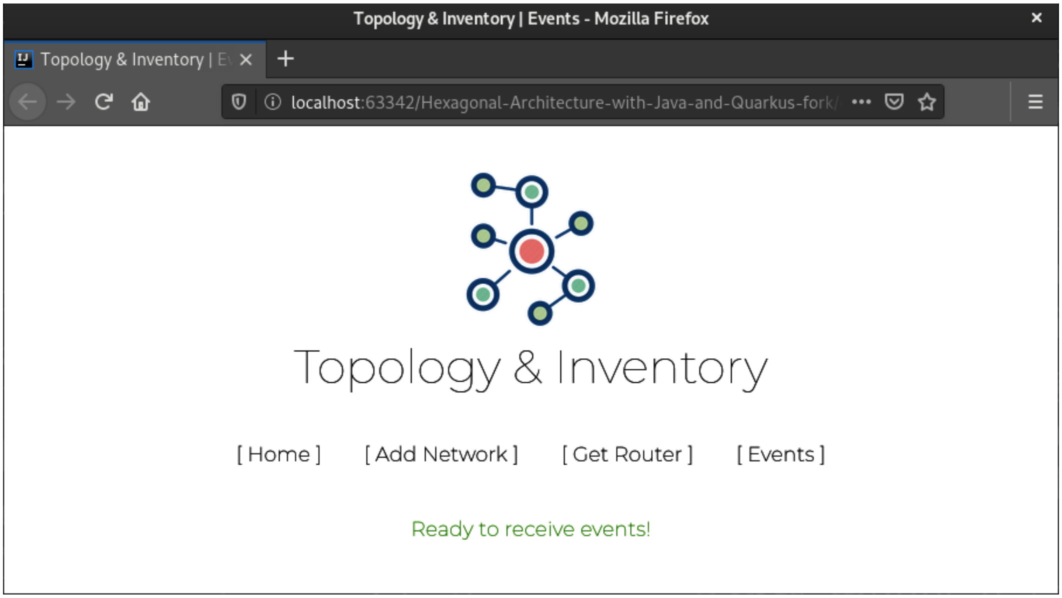

Figure 5.11 – The topology and inventory application Events page

The **Events** page follows the same structure we used in previous pages. The important part of this page is the JavaScript code utilized to connect users to the `WebSocket` server exposed by our hexagonal application:

```
var wsocket;

function connect() {
    wsocket = new WebSocket("ws://localhost:8887");
    wsocket.onopen = onopen;
    wsocket.onmessage = onmessage;
    wsocket.onclose = onclose;
}

```

```
    function onopen() {
    console.log("Connected!");
}

    function onmessage(event) {
    console.log("Data received: " + event.data);
    var tag = document.createElement("div");
    tag.id = "message";
    var text = document.createTextNode(">>"+event.data);
    tag.appendChild(text);
    var element = document.getElementById("events");
    element.appendChild(tag);
}

    function onclose(e) {
    console.log("Connection closed.");
}
window.addEventListener("load", connect, false);
```

The `onmessage` method creates and appends a new `div` HTML element for every new message received from the `WebSocket` connection. So, every event generated by the hexagonal application will be sent to Kafka and printed in real-time in the frontend application. The communication between the frontend, the hexagonal application with `WebSocket`, and the Kafka message system form the following flow:

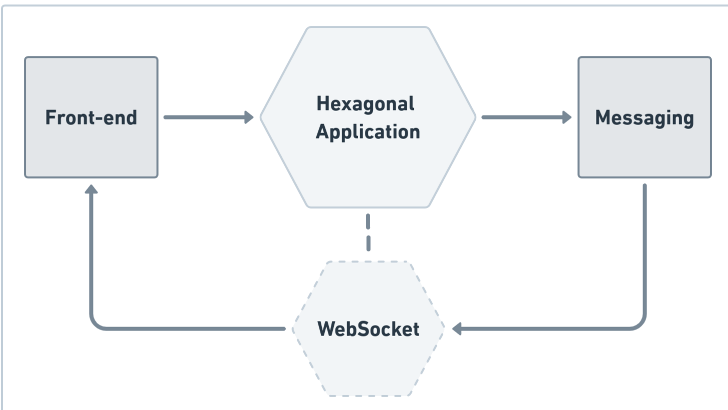

Figure 5.12 – The flow between the frontend, the hexagonal application with WebSocket, and the message system

To test this flow, make sure to have your local Kafka running, then, start the hexagonal application:

```
java -jar target/topology-inventory-1.0-SNAPSHOT-jar-with-dependencies.jar rest
REST endpoint listening on port 8080...
Topology & Inventory WebSocket started on port 8887...
```

To create a `WebSocket` connection between your browser and the application, you need to open the **Events** page from the frontend application. To see the data flowing to the **Events** page, try to add a network or retrieve a router using the `ca23800e-9b5a-11eb-a8b3-0242ac130003` ID. The event entries will appear as follows on the **Events** page:

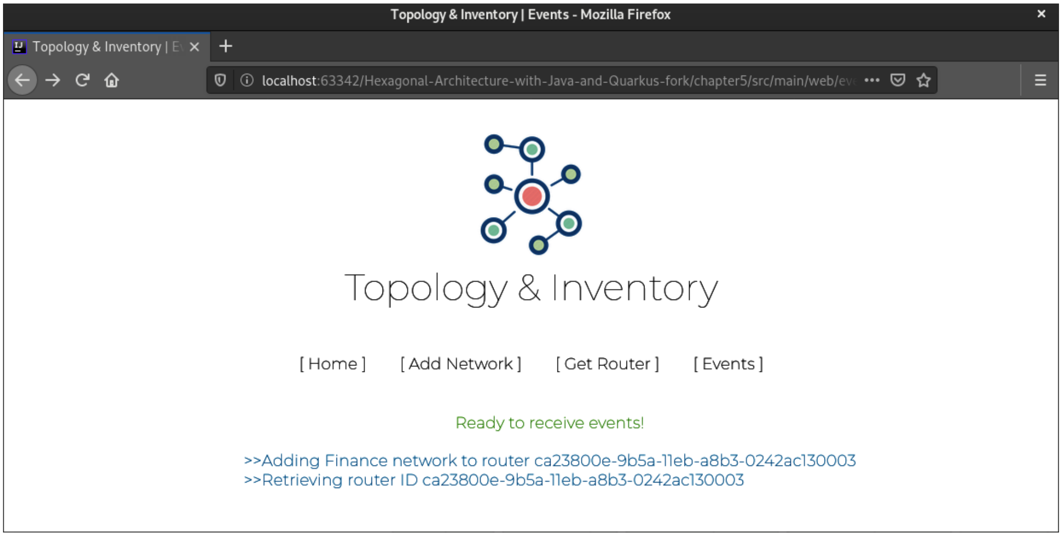

Figure 5.13 – The frontend application receiving events from Kafka through a WebSocket connection

This integration using Kafka and WebSockets has shown us how a hexagonal application deals with message-driven operations. We didn't need to touch the business logic to add these technologies. All we had to do was create more ports and adapters to augment the system capabilities.

Now, let's briefly see one more type of driven operation a hexagonal application can handle.

Mock servers

The typical approach for software development is to have multiple environments, such as development, QA, and production. The first working software releases start going to development environments, then progressively make their way to production. This journey to production is generally conducted by CI pipelines that constantly validate and assure the software is working well.

Among CI validations, unit and integration tests may happen during the pipeline execution. Integration tests, in particular, depend on external components such as other applications, systems, databases, and services – all of them provided in different environments.

The execution of integration tests in development environments poses low risks but can cause problems if there is, for example, concurrent usage of resources. This concurrency issue can generate inconsistency in test results. For QA, the situation is slightly more complicated because we must assure consistency when dealing with test data explicitly tailored to specific scenarios. If that test data changes inadvertently, we may find inconsistencies in test results again. But the cost to test failures in QA is even higher than in development environments.

In order to overcome testing obstacles, some tools simulate application endpoints and their responses. Those tools are known as **mock solutions**, and they come in various shapes and forms. You can manually mock the responses and endpoints of a service your application needs; however, this is not always trivial, and it may take considerable effort. Also, there are sophisticated tools that do the dirty work and let you focus just on the logic. That is the role of mocking servers.

Because mocking servers act as an external entity providing useful resources to the application, we also consider them secondary actors driven by a hexagonal system that wants to leverage mocking server capabilities instead of hitting actual systems.

By no means have we exhausted all the possible driven operations a hexagonal system can have. But in this section, we peeked into some of the relevant driven operations present in a hexagonal application.

Summary

In this chapter, we had the opportunity to dive deep into the nature of driving and driven operations. Although we had already dealt with them in previous chapters, we examined these operations in more depth.

Starting with *driving operations*, we learned that they drive the hexagonal application's behavior by calling its input adapters. To illustrate driving operations, we first created a frontend application to play the role of a primary actor requesting data through the input adapters provided by the topology and inventory hexagonal application. Then, to explore testing tools as driving operations, we created a Postman collection with tests based on API endpoints exposed by the hexagonal application.

On the *driven operations* side, we saw how to enable the hexagonal application to work with message-based systems like Kafka. To better understand the effects of message-based systems on the hexagonal application, we created ports and adapters that enabled the application to send and consume messages from Kafka. Also, we made a `WebSocket` server to let the frontend application retrieve the events generated by the hexagonal system in real-time.

By handling different kinds of driving and driven operations, we can now better comprehend the workings of a hexagonal system, its surroundings, and how these influence the hexagonal application.

The fundamentals acquired from this chapter and the previous ones provide all the building blocks to start developing robust, change-tolerant systems with the hexagonal architecture instruments.

In the next chapter, we'll apply the things we have learned to initiate the construction of a production-grade hexagonal system that will incorporate features from the Java module system and **Quarkus** framework.

Questions

1. What are driving operations?
2. Give one example of a driving operation.
3. What are driven operations?
4. Give one example of a driven operation.

Section 2: Using Hexagons to Create a Solid Foundation

By following a real-world example of software that manages a telco's network and topology inventory, in this section, you will learn how to implement the building blocks for this hexagonal application.

This is a hands-on section where we'll have the opportunity to get our hands dirty while applying the hexagonal architecture principles. We start by implementing the Domain hexagon, which contains the domain model of the topology and inventory system. Then, we implement the Application hexagon by using use cases and ports to express system behaviors. To enable and expose features provided by the hexagonal application, we use adapters to implement the Framework hexagon. Closing this section, we learn how to use Java modules to apply dependency inversion in our hexagonal application.

This section comprises the following chapters:

6 Building the Domain Hexagon

In previous chapters, we had the opportunity to employ **Domain Driven Design** (**DDD**) techniques such as entities and value objects to create a domain model. But until now, we haven't touched on organizing packages, classes, and modules to fit the hexagonal architecture purpose.

The **Domain hexagon** is the place to start developing a hexagonal application. Based on the domain, we derive all other hexagons. We can say that the Domain hexagon is the brain of hexagonal systems because the core fundamental business logic resides in such a hexagon.

So, in this chapter, we will start to explore how to structure from the very bottom of a hexagonal application project using a Java module approach. This will help us ensure better encapsulation and unit testing to validate our code as we develop the Domain hexagon components.

We will cover the following topics in this chapter:

- Bootstrapping the Domain hexagon
- Understanding the problem domain
- Defining value objects

- Defining entities and specifications
- Defining domain services
- Testing the Domain hexagon

By the end of this chapter, you will have acquired a hands-on perspective about the development of all the Domain hexagon components. This knowledge will enable you to take care of all the details regarding the structure and arrangement of classes and packages in the Domain hexagon.

Technical requirements

To compile and run the code examples presented in this chapter, you will need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. They are all available for Linux, Mac, and Windows operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter06`.

Bootstrapping the Domain hexagon

The hexagonal application project that we're going to start in this chapter is actually a continuation of the topology and inventory system that we've been developing in the previous chapters. However, the difference here is that we will augment some of the system's capabilities and use the **Java Platform Module System** (**JPMS**) to encapsulate the Domain hexagon in a Java module.

To get started with bootstrapping the Domain hexagon, let's create a multi-module Maven project, as follows:

1. We first create a parent project called `topology-inventory` by executing the following code:

```
mvn archetype:generate \
-DarchetypeGroupId=org.codehaus.mojo.archetypes \
-DarchetypeArtifactId=pom-root \
-DarchetypeVersion=RELEASE \
-DgroupId=dev.davivieira \
```

```
-DartifactId=topology-inventory \
-Dversion=1.0-SNAPSHOT \
-DinteractiveMode=false
```

We use the `archetype:generate` Maven goal to generate a Maven root project for the system. It creates a `pom.xml` file with the coordinates we pass in the command's parameters, such as `groupId` and `artifcatId`.

2. Then, we create a module for the Domain hexagon, like this:

```
cd topology-inventory
mvn archetype:generate \
  -DarchetypeGroupId=de.rieckpil.archetypes  \
  -DarchetypeArtifactId=testing-toolkit \
  -DarchetypeVersion=1.0.0 \
  -DgroupId=dev.davivieira \
  -DartifactId=domain \
  -Dversion=1.0-SNAPSHOT \
  -Dpackage=dev.davivieira.topologyinventory.domain \
  -DinteractiveMode=false
```

We recommend running the preceding command directly on the CMD instead of PowerShell if you are using Windows. If you need to use PowerShell, you'll need to wrap each command part in double quotes.

As shown in the preceding code snippet, we enter the `topology-inventory` Maven project root directory generated in the first step, and again we run the `archetype:generate` Maven goal. The result is a Maven module called `domain` that is part of the `topology-inventory` Maven project.

3. After executing the `mvn` commands to create a `topology-inventory` Maven root project, and then the `domain` module, you'll have a directory tree similar to the one shown here:

Figure 6.1 – Directory structure of the Domain hexagon

Since the release of **Java 9**, it is possible to create modules by putting the `module-info.java` module descriptor file into a Java project root directory. When you create a Java module using this file, you close the access to all public packages in that module. To make public packages accessible to other modules, you need to export the desired packages in the module descriptor file. There are other interesting things to say about Java modules, but we reserved them for *Chapter 9*, *Applying Dependency Inversion with Java Modules*.

To transform the Domain hexagon in a Java module, you need to create a module descriptor file at `topology-inventory/domain/src/java/module-info.java`, as follows:

```
module domain {
}
```

Because we're not yet allowing access to any public packages, nor depending on other modules, we leave the `module-info.java` file with no entries.

In order to make not just the domain but all other hexagons with less verbose classes, we'll add the `lombok` library on the `pom.xml` project root, as follows:

```
<dependencies>
  <dependency>
      <groupId>org.projectlombok</groupId>
      <artifactId>lombok</artifactId>
      <version>1.18.20</version>
      <scope>compile</scope>
  </dependency>
</dependencies>
```

It's also important to configure the annotation processing paths for `lombok` as otherwise, there will be compilation failures. You can do this by running the following code:

```
<plugins>
  <plugin>
      <groupId>org.apache.maven.plugins</groupId>
      <artifactId>maven-compiler-plugin</artifactId>
      <version>3.8.1</version>
      <configuration>
          <source>11</source>
          <target>11</target>
          <annotationProcessorPaths>
              <path>
                  <groupId>org.projectlombok</groupId>
                  <artifactId>lombok</artifactId>
                  <version>1.18.20</version>
              </path>
          </annotationProcessorPaths>
      </configuration>
  </plugin>
</plugins>
```

It's inside the `maven-compile-plugin` plugin block that we add the configuration for `annotationProcessorPaths`.

Because we are adding the Lombok dependency, we need to update the domain's `module-info.java` file, like this:

```
module domain {
    requires static lombok;
}
```

We are now ready to start developing the Domain hexagon on top of our fully modularized structure. Let's move on to understand the problem domain of our enhanced topology and inventory system.

Understanding the problem domain

We start modeling the problem domain by considering the fact that a core router can connect to both core and edge routers. Edge routers, in turn, connect to switches and their networks. The following diagram depicts this scenario:

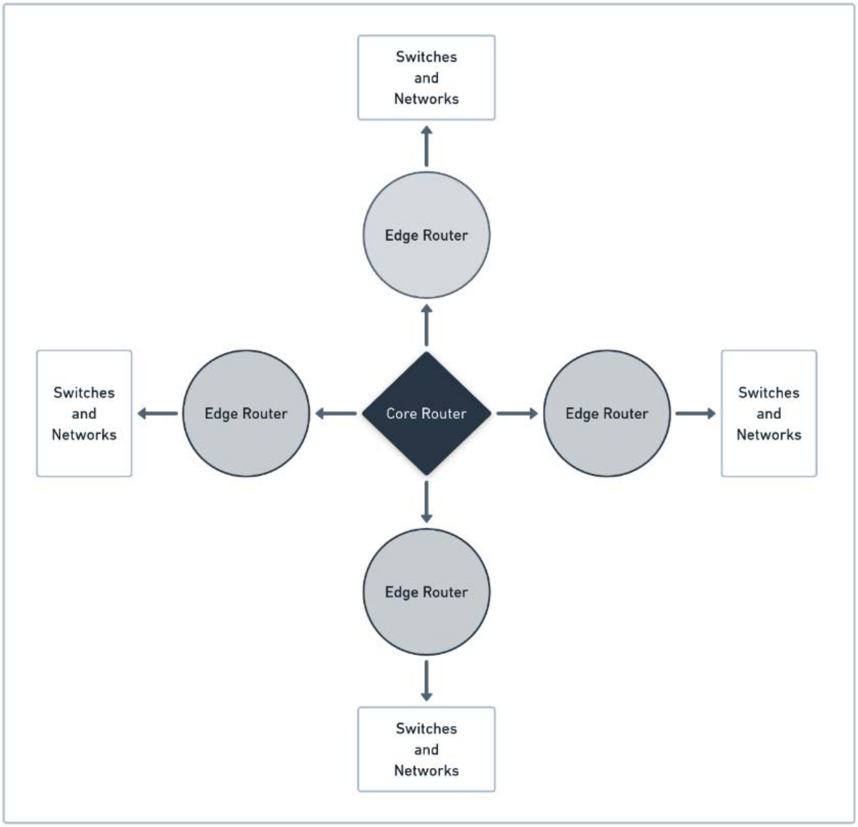

Figure 6.2 – A use case for the topology and inventory network system

Core routers are faster and deal with high traffic loads, and they don't deal directly with the traffic generated from a switch and its networks. On the other hand, edge routers deal directly with traffic generated by a switch and its networks. In our scenario, an edge router is not allowed to connect to other edge routers; it can only connect to core routers and switches. A switch can have multiple networks.

Bear in mind that's a particular arrangement established for our scenario. By no means does it represent a strict rule of how to organize network components. Here is a diagram showing the arrangement of our scenario:

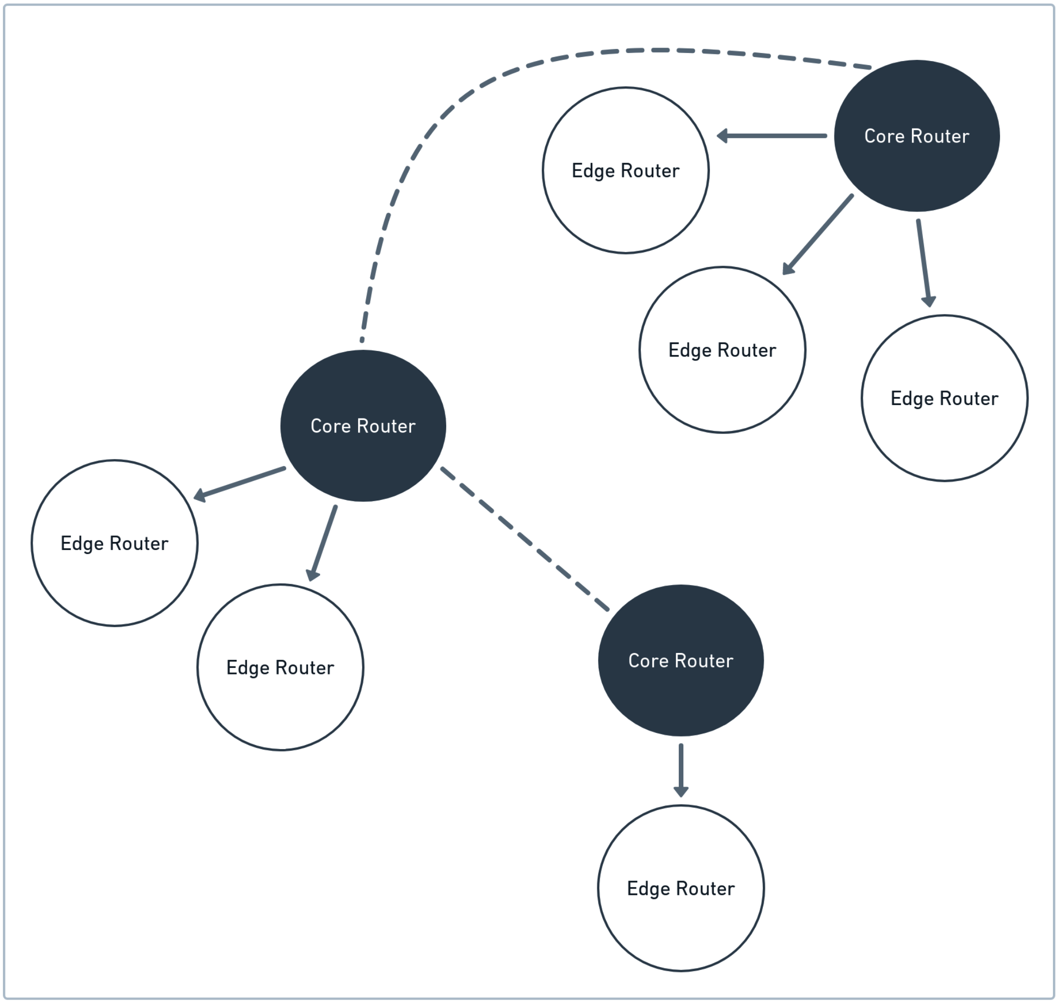

Figure 6.3 – A use case for the topology and inventory network system (continued)

The topology and inventory system's purpose is to allow users to view and manage network assets. By network assets, we mean routers, switches, and networks—routers and switches being physical assets, and networks being logical assets are provided by switches. Those assets are spread across different locations, and the system should show the interconnectivity between assets and their sites. A location is composed of the complete address, along with its latitude and longitude.

The management part is based on nothing more than **Create, Read, Update, Delete** (**CRUD**)-like operations, allowing users to exert control over the topology and inventory systems' data.

Our approach for building such a system is to first create a Domain hexagon using a domain model containing the operations and rules required to fulfill the system's purpose at its highest level. Our intention at the highest level is to validate business ideas straight on the Domain hexagon without the aid of things present on Application and Framework hexagons. As things move on to these hexagons, they tend to become more technology-specific, operating at a lower level, because technology-specific things are far away from the Domain hexagon. The degree to which we maintain the core system functionalities within the Domain hexagon heavily influences how loosely coupled the hexagonal system will be.

To validate the methods and classes of the Domain hexagon, we'll create unit tests to ensure domain operations are working as expected. This will give us an assurance degree to move forward and use these operations on the Application hexagon.

Next, we start building the hexagonal system foundation with value objects, the architecture component that lets us create a domain model that better expresses the problem domain.

Defining value objects

As we have already seen in *Chapter 2*, *Wrapping Business Rules inside the Domain Hexagon*, entities are the elements we use to classify system components that have an identity. On the other hand, the value objects don't have an identity. We use value objects to describe those system parts where there is no need to define an identity. Then, we have aggregates that serve to encapsulate the objects' related entities and values.

I recommend starting by creating value objects first because they are like the building blocks, the raw material we'll use to build more elaborated value objects, and—most importantly—the entities. Now, we'll add all the value object classes on the Domain hexagon module created in the previous section when we bootstrapped the Domain hexagon. We'll use the following steps to define value objects:

1. Let's start with the `Id` value object class, as follows:

```
package dev.davivieira.topologyinventory.domain.vo;

import lombok.EqualsAndHashCode;
import lombok.Getter;
import lombok.ToString;

import java.util.UUID;

@Getter
@ToString
@EqualsAndHashCode
public class Id {

    private final UUID id;

    private Id(UUID id){
        this.id = id;
    }

    public static Id withId(String id){
        return new Id(UUID.fromString(id));
    }

    public static Id withoutId(){
        return new Id(UUID.randomUUID());
    }
}
```

The preceding code is very straightforward, with just one `UUID` attribute that we use to store the `id` value. We use the `withId` static method to create `Id` instances with a given string. If we want to create something new, we should use the `withoutId` static method that randomly generates IDs.

2. The `Vendor enum` value object class, as we'll see in the *Defining entities and specifications* section, is used on both router and switch entity classes. You can see this class in the following code snippet:

```
package dev.davivieira.topologyinventory.domain.vo;

public enum Vendor {
    CISCO,
    NETGEAR,
    HP,
    TPLINK,
    DLINK,
    JUNIPER
}
```

We're modeling the `Vendor` class as an `enum` to let us easily illustrate the system features.

3. We do the same thing with the `Model enum`, as follows:

```
package dev.davivieira.topologyinventory.domain.vo;

public enum Model {
    XYZ0001,
    XYZ0002,
    XYZ0003,
    XYZ0004
}
```

4. For `Protocol`, we create an `enum` value object to represent both **Internet Protocol version 4** (**IPv4**) and **IP version 6** (**IPv6**) protocols, as follows:

```
package dev.davivieira.topologyinventory.domain.vo;

public enum Protocol {
```

```
    IPV4,
    IPV6;
}
```

5. To help us clearly define which kind of router we're dealing with, we'll create a `RouterType` `enum`, as follows:

```
package dev.davivieira.topologyinventory.domain.vo;

public enum RouterType {
    EDGE,
    CORE;
}
```

6. The same idea is also applied for available switch types, as we can see here:

```
package dev.davivieira.topologyinventory.domain.vo;

public enum SwitchType {
    LAYER2,
    LAYER3;
}
```

7. As every router and switch has a location, we have to create a `Location` value object class, as follows:

```
package dev.davivieira.topologyinventory.domain.vo;

import lombok.AllArgsConstructor;
import lombok.Builder;
import lombok.EqualsAndHashCode;
import lombok.Getter;
import lombok.ToString;

@Builder
@AllArgsConstructor
@Getter
@ToString
@EqualsAndHashCode
```

```
public class Location {

    private String address;
    private String city;
    private String state;
    private int zipCode;
    private String country;

    private float latitude;
    private float longitude;
}
```

We introduce the `Location` value object with attributes that allow us to identify an address uniquely. That's why we also have `latitude` and `longitude` as class attributes.

The value objects we just created are the most important ones because they are the basic building blocks for the other value objects and entities that comprise the entire system. Next, we can create more elaborated value objects based on those we just created, as follows:

1. Let's start with the `IP` value object, as illustrated in the following code snippet:

```
/** Code omitted **/
public class IP {
    private String ipAddress;
    private Protocol;
    public IP(String ipAddress){
      if(ipAddress == null)
          throw new IllegalArgumentException(
          "Null IP address");
         this.ipAddress = ipAddress;
      if(ipAddress.length()<=15) {
          this.protocol = Protocol.IPV4;
      } else {
        this.protocol = Protocol.IPV6;
      }

```

```
    }
/** Code omitted **/
}
```

With the `IP` value object class, we can create both **IPv4** and **IPv6** addresses. The constraint that checks which protocol to use is within the value object constructor. The logic we use to validate the IP address is a simple one, just for the sake of our example. For a more comprehensive validation, we could use the `InetAddressValidator` class from the `commons-validator` library.

2. Then, we create a value object to represent networks that will be added to a switch, as follows:

```
package dev.davivieira.topologyinventory.domain.vo;

import lombok.Builder;
import lombok.EqualsAndHashCode;
import lombok.Getter;
import lombok.ToString;

@Builder
@Getter
@ToString
@EqualsAndHashCode
public class Network {

    private IP networkAddress;
    private String networkName;
    private int networkCidr;

    public Network(IP networkAddress,
    String networkName, int networkCidr){
        if(networkCidr <1 || networkCidr>32){
            throw new IllegalArgumentException(
            "Invalid CIDR value");
        }
        this.networkAddress = networkAddress;
```

```
            this.networkName = networkName;
            this.networkCidr = networkCidr;
        }
    }
```

We model the `Network` value object to store the IP address, network name, and **Classless Inter-Domain Routing** (**CIDR**) attributes. CIDR is a network address notation composed of two numbers: the first number (for example, `10.0.0.0`) is the network base IP address. The second number (for example, `24`) is used to determine the network subnet mask and how many IP addresses will be available in this network. In the `Network` class, we are referring to the second CIDR number.

Inside the `Network` constructor, we put the constraint to validate whether the CIDR value is valid.

In the end, you'll have a package and class structure similar to the one shown in the following screenshot:

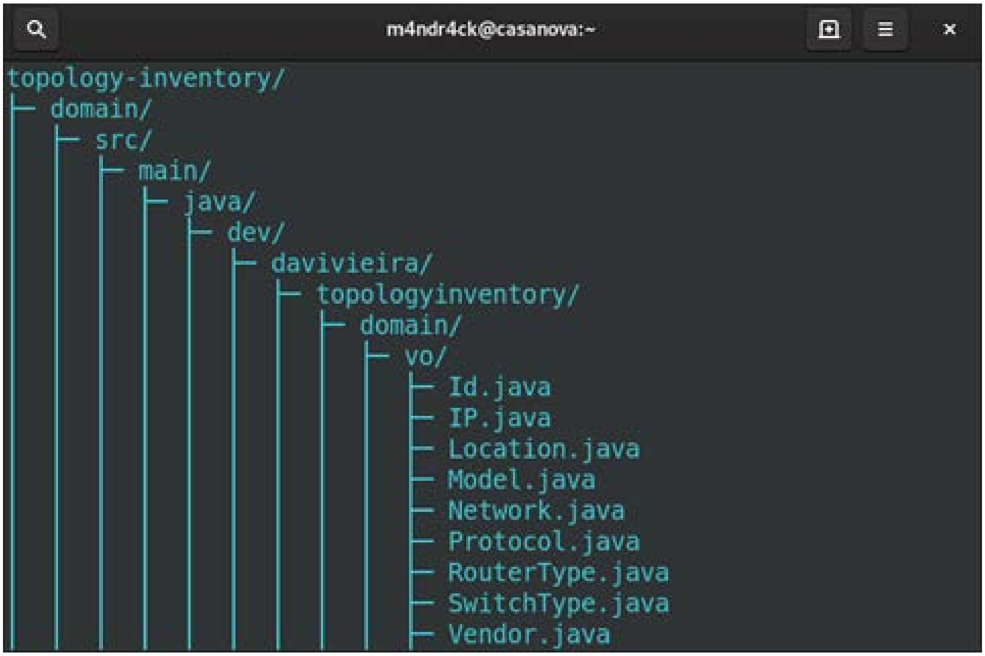

Figure 6.4 – The directory structure of value objects

On top of the value objects, which are our Domain hexagon's building blocks, we can move on to creating entities and their specifications.

Defining entities and specifications

Once we have created all the value objects, we can start to think about how to represent the elements in entities that have an identity. Also, we need to develop specifications to define business rules that govern constraints, which the entities should obey.

Remember that what characterizes an entity is its identity and the presence of business rules and data. In the topology and inventory system, we have as entities `Equipment`, `Router`, and `Switch`.

Inside the `domain` Java module we created previously, we'll add the entities classes within a package called `entity`.

The Equipment and Router abstract entities

Both router and switch are different types of network equipment, so we'll start by creating an `Equipment` abstract class, as follows:

```
package dev.davivieira.topologyinventory.domain.entity;

import dev.davivieira.topologyinventory.domain.vo.IP;
import dev.davivieira.topologyinventory.domain.vo.Id;
import dev.davivieira.topologyinventory.domain.vo.Location;
import dev.davivieira.topologyinventory.domain.vo.Model;
import dev.davivieira.topologyinventory.domain.vo.Vendor;
import lombok.AllArgsConstructor;
import lombok.Getter;

@Getter
@AllArgsConstructor
public abstract class Equipment {
    protected Id id;
    protected Vendor vendor;
    protected Model model;
    protected IP ip;
    protected Location location;

    public static Predicate<Equipment>
    getVendorPredicate(Vendor vendor){
```

```
        return r -> r.getVendor().equals(vendor);
    }
}
```

Most of the value objects created in the previous section are present here in the `Equipment` entity. We use the predicate provided by `getVendorTypePredicate` to apply the filters that only retrieve a specific vendor's equipment.

Deriving from `Equipment`, we create a `Router` abstract class, as follows:

```
package dev.davivieira.topologyinventory.domain.entity;

import dev.davivieira.topologyinventory.domain.vo.IP;
import dev.davivieira.topologyinventory.domain.vo.Id;
import dev.davivieira.topologyinventory.domain.vo.Location;
import dev.davivieira.topologyinventory.domain.vo.Model;
import dev.davivieira.topologyinventory.domain.vo.RouterType;
import dev.davivieira.topologyinventory.domain.vo.Vendor;

import lombok.Getter;
import java.util.function.Predicate;

@Getter
public abstract class Router extends Equipment {

    protected final RouterType routerType;

    public static Predicate<Router>
    getRouterTypePredicate(RouterType routerType){
        return r -> r.getRouterType().equals(routerType);
    }
    /** Code omitted **/
}
```

The `Router` abstract class defines predicates common to either core or edge routers. We use the predicate provided by `getRouterTypePredicate` to apply filters that retrieve only routers of a specific type.

Here, we have more two predicates from the `Router` abstract class:

```
public static Predicate<Equipment>
getModelPredicate(Model model){
    return r -> r.getModel().equals(model);
}

public static Predicate<Equipment>
getCountryPredicate(Location location){
    return p ->
     p.location.getCountry().equals(location.getCountry());
}
```

We use the `getModelPredicate` and `getCountryPredicate` predicates to retrieve routers of a specific model or a particular country.

The `Router` abstract class provides the common attributes shared by core and edge routers. It's in the `Router` class that we introduce the predicates to serve as filters when querying lists of routers.

Core router entity and its specifications

Moving ahead, let's implement the `CoreRouter` entity class, as follows:

```
/** Imports omitted **/
public class CoreRouter extends Router{
    /** Code omitted **/
    public Router addRouter(Router anyRouter){
        var sameCountryRouterSpec =
        new SameCountrySpec(this);
        var sameIpSpec =
        new SameIpSpec(this);

        sameCountryRouterSpec.check(anyRouter);
        sameIpSpec.check(anyRouter);

        return this.routers.put(anyRouter.id, anyRouter);
    }
/** Code omitted **/
}
```

Core routers can be connected to other core and edge routers. To allow such behavior in the `CoreRouter` class, we create an `addRouter` method receiving the `Router` abstract type as a parameter. We also use the `SameCountrySpec` specification to make sure edge routers are in the same country as the core router.

This rule doesn't apply when we try to connect a core router to another core router. Then, we have a specification to confirm the routers don't have the IP address. We make the business rules more explicit and the code easier to read and understand by using specifications. You could write this code without any specification, just throwing `if-else` conditions with the required variables, but the mental load required to understand the code for anyone not acquainted with it would probably be higher.

Here, we have the `removeRouter` method:

```
public Router removeRouter(Router anyRouter){
    var emptyRoutersSpec = new EmptyRouterSpec();
    var emptySwitchSpec = new EmptySwitchSpec();

    switch (anyRouter.routerType) {
        case CORE:
            var coreRouter = (CoreRouter)anyRouter;
            emptyRoutersSpec.check(coreRouter);
        case EDGE:
            var edgeRouter = (EdgeRouter)anyRouter;
            emptySwitchSpec.check(edgeRouter);
    }
    return this.routers.remove(anyRouter.id);
}
```

For the `removeRouter` method, we have the `EmptyRouterSpec` specification that prevents us from removing a router that has any other routers connected to it. The `EmptySwitchSpec` specification checks if a router has any switch connected to it.

Core routers deal only with other routers. That's why there is no reference to switches in the `CoreRouter` entity class.

Note that the two methods, `addRouter` and `removeRouter`, operate directly on a `Router` type parameter, using domain specifications to check that there are no constraint violations before making any changes. Let's closely examine the specifications used by the `CoreRouter` entity, starting with the `SameCountrySpec` specification. This specification makes sure that edge routers are always from the same country as their core routers.

The package specification is where we'll put all the specifications, so that's the package in which we'll put the SameCountrySpec specification, as follows:

```
/** Imports omitted **/
public class SameCountrySpec extends
AbstractSpecification<Equipment> {

    private Equipment equipment;

    public SameCountrySpec(Equipment equipment){
        this.equipment = equipment;
    }
/** Code omitted **/
}
```

The SameCountrySpec constructor receives an Equipment object that we use to initialize the equipment private field.

Continuing with the SameCountrySpec implementation, we override the isSatisfiedBy method, as follows:

```
@Override
public boolean isSatisfiedBy(Equipment anyEquipment) {
    if(anyEquipment instanceof CoreRouter) {
        return true;
    } else if (
    anyEquipment != null && this.equipment != null) {
        return this
        .equipment
        .getLocation()
        .getCountry()
        .equals(
           anyEquipment.getLocation().getCountry());
    } else{
        return false;
    }
}
```

The SameCountrySpec implementation does not apply for core routers. That's why we always return true when the object is a CoreRouter entity. Otherwise, we proceed with the validation to check if the equipment is not in a different country.

Next, we override the check method, as follows:

```
@Override
public void check(Equipment equipment) {
    if(!isSatisfiedBy(equipment))
        throw new GenericSpecificationException(
        "The equipments should be in the same country");
}
```

We use the check method to run the specification. Other classes can call this method to verify whether the specification is being met or not.

It's possible to connect two core routers from different countries. What's not possible, as stated previously, is to connect edge and core routers that are not present in the same country. Note that this specification is based on the Equipment type, allowing us to reuse this specification not just with routers but also on switches.

The following SameIpSpec specification ensures that no equipment has the same IP address:

```
/** Imports omitted **/
public class SameIpSpec extends
AbstractSpecification<Equipment>{

    private Equipment equipment;

    public SameIpSpec(Equipment equipment){
        this.equipment = equipment;
    }

    @Override
    public boolean isSatisfiedBy(Equipment anyEquipment) {
        return
       !equipment.getIp().equals(anyEquipment.getIp());
    }
    @Override
```

```
    public void check(Equipment equipment) {
        if(!isSatisfiedBy(equipment))
            throw new GenericSpecificationException("It's
              not possible to attach routers with the same
              IP");
    }
}
```

The `SameCountrySpec` and `SameIpSpec` specifications are used by the `addRouter` method to ensure that no constraints are violated before adding any router to a core router.

Moving ahead, we have the `EmptyRouterSpec` and `EmptySwitchSpec` specifications. Before a router is removed, we must make sure no other routers or switches are connected to such a router. These are very simple specifications. Let's start by seeing the `EmptyRouterSpec` specification, as follows:

```
/** Imports omitted **/
public class EmptyRouterSpec extends
AbstractSpecification<CoreRouter> {

    @Override
    public boolean isSatisfiedBy(CoreRouter coreRouter) {
        return coreRouter.getRouters()==null||
                coreRouter.getRouters().isEmpty();
    }

    @Override
    public void check(CoreRouter coreRouter) {
        if(!isSatisfiedBy(coreRouter))
            throw new GenericSpecificationException("It
              isn't allowed to remove a core router with
              other routers attached to it");
    }
}
```

This specification is based on the `CoreRouter` type because only core routers can be connected to other core and edge routers.

The EmptySwitchSpec class is given as follows:

```
/** Imports omitted **/
public class EmptySwitchSpec extends
AbstractSpecification<EdgeRouter> {

    @Override
    public boolean isSatisfiedBy(EdgeRouter edgeRouter) {
        return edgeRouter.getSwitches()==null ||
                edgeRouter.getSwitches().isEmpty();
    }

    @Override
    public void check(EdgeRouter edgeRouter) {
        if(!isSatisfiedBy(edgeRouter))
            throw new GenericSpecificationException("It
              isn't allowed to remove an edge router with a
              switch attached to it");
    }
}
```

The EmptySwitchSpec class is very similar to the EmptyRouterSpec class. The difference, though, is that only edge routers can have switches. That's why this specification is based on the EdgeRouter type.

Edge router entity and its specifications

Now that we're done with the CoreRouter entity and its specifications, we can move on to create an EdgeRouter entity class, as follows:

```
/** Imports omitted **/
public class EdgeRouter extends Router {

    /**Code omitted **/
    private Map<Id, Switch> switches;

```

```
    public void addSwitch(Switch anySwitch){
        var sameCountryRouterSpec =
        new SameCountrySpec(this);
        var sameIpSpec = new SameIpSpec(this);

        sameCountryRouterSpec.check(anySwitch);
        sameIpSpec.check(anySwitch);

        this.switches.put(anySwitch.id,anySwitch);
    }
    /** Code omitted **/
}
```

The `addSwitch` method's purpose is to connect switches to edge routers. Also, in the `EdgeRouter` class, we reuse the same `SameCountrySpec` and `SameIpSpec` specifications used when implementing the `CoreRouter` class.

Next, we have the `removeSwitch` method from the `EdgeRouter` class, as illustrated in the following code snippet:

```
public Switch removeSwitch(Switch anySwitch){
    var emptyNetworkSpec = new EmptyNetworkSpec();
    emptyNetworkSpec.check(anySwitch);

    return this.switches.remove(anySwitch.id);
}
```

For the `removeSwitch` method, we have the `EmptyNetworkSpec` specification to ensure that a switch has no networks connected to it.

As we saw in the `CoreRouter` class, here, we're also using the `SameCountrySpec` and `SameIpSpec` specifications again. But the context is different because we're adding a switch to a router. The only new specification used in the `EdgeRouter` class is the `EmptyNetworkSpec` specification, which is used to ensure all networks are removed from a switch before the switch can be removed from an edge router.

Switch entity and its specifications

What's left now is the implementation of the `Switch` entity class and its related specifications. The ideas we use here are similar to what we applied in core and edge router entities. Let's start by creating a `Switch` entity class, as follows:

```
/** Imports omitted **/
public class Switch extends Equipment {

    private SwitchType switchType;
    private List<Network> switchNetworks;
    /** Code omitted **/
    public static Predicate<Switch>getSwitchTypePredicate
      (SwitchType switchType){
        return s -> s.switchType.equals(switchType);
    }
    /** Code omitted **/
}
```

We start the `Switch` class implementation by creating a `getSwitchTypePredicate` method predicate that we used to filter switch collections by the switch type.

Next, we create a `addNetworkToSwitch` method, as follows:

```
public boolean addNetworkToSwitch(Network network) {
    var availabilitySpec =
    new NetworkAvailabilitySpec(network);
    var cidrSpec = new CIDRSpecification();
    var amountSpec = new NetworkAmountSpec();

    cidrSpec.check(network.getNetworkCidr());
    availabilitySpec.check(this);
    amountSpec.check(this);

    return this.switchNetworks.add(network);
}
```

The `addNetworkToSwitch` method receives a `Network` type parameter that we use to add a network to a switch. But before adding the network, we need to check some constraints expressed by the specifications. The first one is the `NetworkAvailabilitySpec` specification, which verifies whether the network already exists on the switch. Then, we use the `CIDRSpecification` specification to check whether the network CIDR is valid. Finally, we use the `NetworkAmountSpec` specification to validate whether we have surpassed the maximum networks allowed on the switch.

Next, we have the `removeNetworkFromSwitch` method, as illustrated in the following code snippet:

```
public boolean removeNetworkFromSwitch(
Network network){
    return this.switchNetworks.remove(network);
}
```

As there are no constraints for removing networks from a switch, this method does not use any specifications.

To summarize, right at the beginning of the `Switch` class, we declared a predicate to allow us to filter switch collections based on switch types (`LAYER2` and `LAYER3`). The `addNetworktoSwitch` method uses the `NetworkAvailabilitySpec`, `NetworkAmountSpec`, and `CIDRSpecification` specifications that we already defined in *Chapter 2*, *Wrapping Business Rules inside the Domain Hexagon*. If none of these specifications' constraints are violated, a `Network` object will be added to the switch.

Finally, we have the `removeNetworkFromSwitch` method that doesn't look at any specification to remove networks from a switch.

With the `Switch` entity implementation, we conclude the modeling of the entities and specifications required to fulfill the topology and inventory system's purpose.

For all the entities, you should have a package and class structure similar to this:

Figure 6.5 – The directory structure of entities

As we can see in the preceding screenshot, we put all entities inside the `entity` package.

And for all the specifications, the package and class structure should look like this:

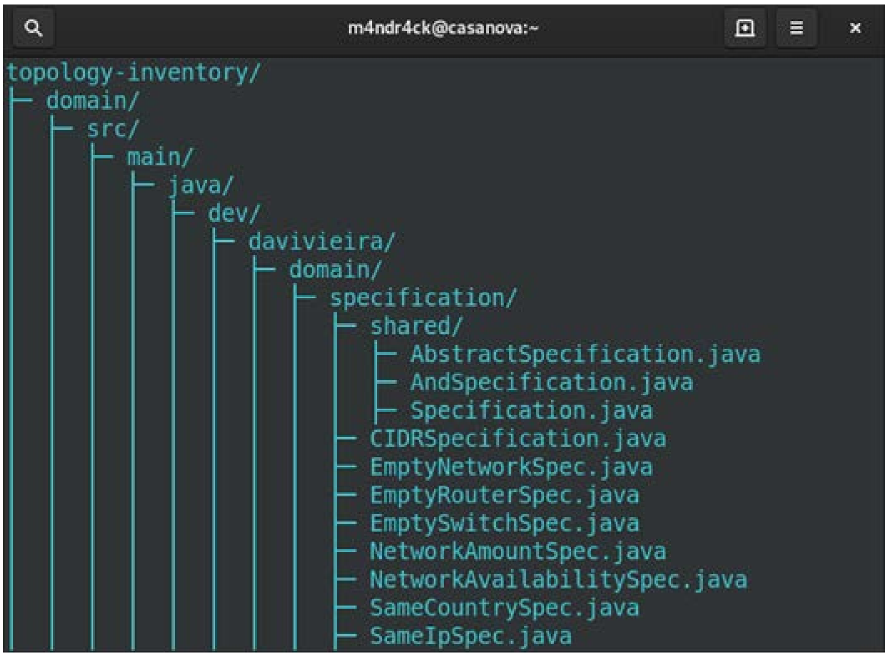

Figure 6.6 – The directory structure of specifications

Some of the specifications used by the topology and inventory system were already created in *Chapter 2*, *Wrapping Business Rules inside the Domain Hexagon*. The remaining specifications are the ones we created in this section.

Based on the entities we have just created, we can now think of tasks that are not directly related to such entities. That is the case of services that work as an alternative for providing capabilities outside domain entities. Let's see next how to implement services that let us find, filter, and retrieve data from the system.

Defining domain services

The topology and inventory system is about the visualization and management of network assets, so we need to enable the user to handle collections of such network assets. One way to do that is through services. With services, we can define behaviors to deal with system entities and value objects.

All the services that we'll create in this section reside in the `service` package.

Let's start by creating a service to deal with collections of routers.

Router service

In the previous section, when implementing the `Router`, `CoreRouter`, and `EdgeRouter` entities, we also created some methods to return predicates to aid us in filtering collections of routers. With a domain service, we can use these predicates to filter such collections, as follows:

```
package dev.davivieira.topologyinventory.domain.service;

import dev.davivieira.topologyinventory.domain.entity.
Equipment;
import dev.davivieira.topologyinventory.domain.entity.Router;
import dev.davivieira.topologyinventory.domain.vo.Id;
import java.util.List;
import java.util.Map;
import java.util.function.Predicate;
import java.util.stream.Collectors;

public class RouterService {

```

```
    public static List<Router>
    filterAndRetrieveRouter(List<Router> routers,
    Predicate<Equipment> routerPredicate){
        return routers
                .stream()
                .filter(routerPredicate)
                .collect(Collectors.<Router>toList());
    }

    public static Router findById(
    Map<Id,Router> routers, Id id){
        return routers.get(id);
    }
}
```

For the `filterAndRetrieveRouter` method, we pass a list of routers and a predicate, to filter that list, as parameters. Then, we define a `findById` method to retrieve a router using an `Id` type parameter.

Now, let's see the service operations we can use to handle switches.

Switch service

This service follows the same idea we applied to the router service. It's primarily based on the predicate provided by the `getSwitchTypePredicate` method to filter collections of switches based on their type. As new predicates arise, we can use them as new criteria to filter switch collections. Also, note that the `findById` method is used again to allow switch retrieval based on the `Id` type parameter. Here is the code:

```
package dev.davivieira.topologyinventory.domain.service;

import dev.davivieira.topologyinventory.domain.entity.Switch;
import dev.davivieira.topologyinventory.domain.vo.Id;
import java.util.List;
import java.util.Map;
import java.util.function.Predicate;
import java.util.stream.Collectors;

```

```
public class SwitchService {

    public static List<Switch> filterAndRetrieveSwitch
      (List<Switch>   switches, Predicate<Switch>
       switchPredicate){
      return switches
                 .stream()
                 .filter(switchPredicate)
                 .collect(Collectors.<Switch>toList());
    }

    public static Switch findById(Map<Id,Switch> switches,
      Id id){
      return switches.get(id);
    }
}
```

Although we don't model the network as entities in the domain model, there is no issue in creating service classes to handle collections of network value objects.

Let's create a last service class for the topology and inventory system.

Network service

This service is based primarily on a need to filter network collections based on the IP protocol. We can have collections of both IPv4 and IPv6 networks. This service provides the capacity to filter such collections based on the network IP protocol. The following code is used to create a `NetworkService` class:

```
package dev.davivieira.topologyinventory.domain.service;

import dev.davivieira.topologyinventory.domain.vo.Network;
import java.util.List;
import java.util.function.Predicate;
import java.util.stream.Collectors;

public class NetworkService {

```

```
    public static List<Network> filterAndRetrieveNetworks
      (List<Network> networks, Predicate<Network>
       networkPredicate){
        return networks
                .stream()
                .filter(networkPredicate)
                .collect(Collectors.<Network>toList());
    }
}
```

The `filterAndRetrieveNetworks` method receives a list of networks and a predicate as parameters to filter them. It returns a filtered list of networks.

With `NetworkService`, we conclude the creation of domain services.

After creating all these services, you'll have a package and class structure like the one shown here:

Figure 6.7 – The directory structure of domain services

To drive the development of value objects, entities, specifications, and services, you can assume a **Test-Driven Development** (**TDD**) approach, where you can start creating broken tests, and then implement the correct classes and methods to make those tests pass. We did the contrary here to provide a big picture of the components we needed to create in order to build the Domain hexagon for the topology and inventory system.

Before we move to the development of the Application hexagon, we need to ensure the operations we created in the Domain hexagon are working as expected; otherwise, the upstream hexagons will break when performing these operations. So, next, we'll see how to test the Domain hexagon.

In this section, we created services that operate under the Domain-hexagon level. Instead of putting more behaviors directly on entities, we created separate service classes to enable behaviors that we don't consider inherently part of the entities. These services allow us to handle collections of routers, switches, and networks.

Testing the Domain hexagon

To test the Domain hexagon appropriately, we should rely only on its components, ignoring anything coming from other hexagons. After all, these hexagons should depend on the domain and not the other way around. As we have already seen, the Domain hexagon concentrates on the core system logic. It is from that logic we derive the structure and behavior of the Application and Framework hexagons. By building a robust and well-tested Domain hexagon, we're building a solid foundation for the entire system.

Among the operations performed by the topology and inventory system, we can consider adding, removing, and searching network assets as the most important ones. We'll use the following steps to test these operations:

1. Let's start by seeing how we can test the addition of network equipment, as follows:

```
@Test
public void addNetworkToSwitch(){
    var location = createLocation("US");
    var newNetwork = createTestNetwork("30.0.0.1", 8);
    var networkSwitch =
    createSwitch("30.0.0.0", 8, location);

    assertTrue(
    networkSwitch.addNetworkToSwitch(newNetwork));
}
```

The `addNetworkToSwitch` method checks the successful path when the system can add a network to a switch. The following test checks the unhappy path for this:

```
@Test
public void
addNetworkToSwitch_failBecauseSameNetworkAddress(){
```

```
        var location = createLocation("US");
        var newNetwork = createTestNetwork("30.0.0.0", 8);
        var networkSwitch = createSwitch(
        "30.0.0.0", 8, location);

        assertThrows(GenericSpecificationException.class,
          () ->
          networkSwitch.addNetworkToSwitch(newNetwork));
    }
```

The `addNetworkToSwitch_failBecauseSameNetworkAddress` method checks the unsuccessful path when we try to add a network that already exists in the switch.

2. Next, we have test scenarios where we want to add a switch to an edge router, as illustrated in the following code snippet:

```
    @Test
    public void addSwitchToEdgeRouter(){
        edgeRouter.addSwitch(networkSwitch);

        assertEquals(1,edgeRouter.getSwitches().size());
    }
```

We added a switch to an edge router with no switches attached; such an edge router should contain exactly one switch attached to it. The following code snippet has the unhappy path for the `addSwitchToEdgeRouter` method:

```
    @Test
    public void addSwitchToEdgeRouter_
    failBecauseEquipmentOfDifferentCountries(){
        var locationUS = createLocation("US");
        var locationJP = createLocation("JP");
        var networkSwitch =
        createSwitch("30.0.0.0", 8, locationUS);
        var edgeRouter =
        createEdgeRouter(locationJP,"30.0.0.1");

```

```
    assertThrows(GenericSpecificationException.class,
    () -> edgeRouter.addSwitch(networkSwitch));
}
```

When we try to add a switch that is of a different country than the edge router, the `addSwitchToEdgeRouter` method checks the successful path while the `addSwitchToEdgeRouter_failBecauseEquipmentOfDifferentCountries` method checks the unsuccessful one.

3. Next, we have test scenarios where we want to add an edge router to a core router, as illustrated in the following code snippet:

```
@Test
public void addEdgeToCoreRouter(){
    coreRouter.addRouter(edgeRouter);

    assertEquals(1,coreRouter.getRouters().size());
}
```

The `addEdgeToCoreRouter` method checks the successful path when we try to add an edge router that is in the same country as the core router. The next code snippet has the unhappy path for the `addEdgeToCoreRouter` method:

```
@Test
public void addEdgeToCoreRouter_
failBecauseRoutersOfDifferentCountries(){
    var locationUS = createLocation("US");
    var locationJP = createLocation("JP");
    var edgeRouter =
    createEdgeRouter(locationUS,"30.0.0.1");
    var coreRouter =
    createCoreRouter(locationJP, "40.0.0.1");

    assertThrows(GenericSpecificationException.class,
    () -> coreRouter.addRouter(edgeRouter));
}
```

The `addEdgeToCoreRouter_failBecauseRoutersOfDifferentCountries` method checks the unsuccessful path when the edge and core routers are in different countries.

4. Next, we have test scenarios where we want to add a core router to another core router, as illustrated in the following code snippet:

```
@Test
public void addCoreToCoreRouter(){
     coreRouter.addRouter(newCoreRouter);
     assertEquals(2,coreRouter.getRouters().size());
}
```

   The `addCoreToCoreRouter` method checks the successful path when we can add a core router to another one. In the following code snippet, we have the unhappy path for this method:

```
@Test
public void addCoreToCoreRouter_
failBecauseRoutersOfSameIp(){
     var location = createLocation("US");
     var coreRouter = createCoreRouter(
     location, "30.0.0.1");
     var newCoreRouter = createCoreRouter(
     location, "30.0.0.1");

     assertThrows(GenericSpecificationException.class,
     () -> coreRouter.addRouter(newCoreRouter));
}
```

   The `addCoreToCoreRouter_failBecauseRoutersOfSameIp` method checks the unsuccessful path when we try to add core routers with the same IP address.

   With these tests, we can also check if the specifications are working as expected.

5. Then, there are other scenarios where it's necessary to remove any router from a core router, a switch from an edge router, and a network from a switch, as illustrated in the following code snippet:

```
@Test
public void removeRouter(){
     var location = createLocation("US");
     var coreRouter = createCoreRouter(
     location, "30.0.0.1");
     var edgeRouter = createEdgeRouter(
```

```
        location, "40.0.0.1");
    var expectedId = edgeRouter.getId();

    coreRouter.addRouter(edgeRouter);
    var actualId =
    coreRouter.removeRouter(edgeRouter).getId();

    assertEquals(expectedId, actualId);
}
```

The `removeRouter` test method checks whether we can remove an edge router from a core router. In the following code snippet, we test the removal with a switch:

```
@Test
public void removeSwitch(){
    var location = createLocation("US");
    var network = createTestNetwork("30.0.0.0", 8);
    var networkSwitch =
    createSwitch("30.0.0.0", 8, location);
    var edgeRouter = createEdgeRouter(
    location, "40.0.0.1");

    edgeRouter.addSwitch(networkSwitch);
    networkSwitch.removeNetworkFromSwitch(network);
    var expectedId =
    Id.withId(
    "f8c3de3d-1fea-4d7c-a8b0-29f63c4c3490");
    var actualId=
    edgeRouter.removeSwitch(networkSwitch).getId();

    assertEquals(expectedId, actualId);
}
```

The `removeSwitch` test method checks whether we can remove a switch from an edge router. In the following code snippet, we test removal with a network:

```
@Test
public void removeNetwork(){
    var location = createLocation("US");
```

```
        var network = createTestNetwork("30.0.0.0", 8);
        var networkSwitch =
        createSwitch("30.0.0.0", 8, location);

        assertEquals(
        1, networkSwitch.getSwitchNetworks().size());
        assertTrue(
        networkSwitch.removeNetworkFromSwitch(network));
        assertEquals(
        0, networkSwitch.getSwitchNetworks().size());
    }
```

The `removeNetwork` test method checks whether we can remove a network from a switch.

After the adding and removing operations, we have to test the filter and retrieve operations.

6. To filter routers by type, we implement the following test:

```
    @Test
    public void filterRouterByType(){
        List<Router> routers = new ArrayList<>();
        var location = createLocation("US");
        var coreRouter = createCoreRouter(
        location, "30.0.0.1");
        var edgeRouter = createEdgeRouter(
        location, "40.0.0.1");

        routers.add(coreRouter);
        routers.add(edgeRouter);

        var coreRouters =
        RouterService.filterAndRetrieveRouter(routers,
        Router.getRouterTypePredicate(RouterType.CORE));
        var actualCoreType =
        coreRouters.get(0).getRouterType();
```

```
        assertEquals(RouterType.CORE, actualCoreType);

        var edgeRouters =
        RouterService.filterAndRetrieveRouter(routers,
        Router.getRouterTypePredicate(RouterType.EDGE));
        var actualEdgeType =
        edgeRouters.get(0).getRouterType();
        assertEquals(RouterType.EDGE, actualEdgeType);
    }
```

The `filterRouterByType` method tests the operations available on the `RouterService` class. In the preceding case, we check if the `filterAndRetrieveRouter` method can really filter and retrieve `CORE` or `EDGE` routers from a list containing different types of routers.

7. To filter routers by vendor, we have the following test:

```
    @Test
    public void filterRouterByVendor(){
        List<Router> routers = new ArrayList<>();
        var location = createLocation("US");
        var coreRouter = createCoreRouter(
        location, "30.0.0.1");
        var edgeRouter = createEdgeRouter(
        location, "40.0.0.1");

        routers.add(coreRouter);
        routers.add(edgeRouter);

        var actualVendor =
        RouterService.filterAndRetrieveRouter(routers,
        Router.getVendorPredicate(
        Vendor.HP)).get(0).getVendor();
        assertEquals(Vendor.HP, actualVendor);

        actualVendor =
        RouterService.filterAndRetrieveRouter(routers,
        Router.getVendorPredicate(
```

```
        Vendor.CISCO)).get(0).getVendor();
        assertEquals(Vendor.CISCO, actualVendor);
    }
```

By using a predicate provided by the `getVendorPredicate` method, we call `filterAndRetrieveRouter` from the `RouterService` class. Then, we check if the retrieved router model is what we are looking for.

8. Next, we test the same `filterRouterByLocation` method but with a different predicate, as follows:

```
    @Test
    public void filterRouterByLocation(){
        List<Router> routers = new ArrayList<>();
        var location = createLocation("US");
        var coreRouter = createCoreRouter(
        location, "30.0.0.1");

        routers.add(coreRouter);

        var actualCountry =
        RouterService.filterAndRetrieveRouter(routers,
        Router.getCountryPredicate(
        location)).get(0).getLocation().getCountry();

        assertEquals(
        location.getCountry(), actualCountry);
    }
```

By calling the `getCountryPredicate` method, we receive the predicate to filter routers by country. The result of this method is stored in the `actualCountry` variable, which we use in the test assertion.

9. Next, we test the `filterRouterByModel` method, as follows:

```
    @Test
    public void filterRouterByModel(){
        List<Router> routers = new ArrayList<>();
        var location = createLocation("US");
        var coreRouter = createCoreRouter(
```

```
        location, "30.0.0.1");
        var newCoreRouter = createCoreRouter(
        location, "40.0.0.1");

        coreRouter.addRouter(newCoreRouter);
        routers.add(coreRouter);

        var actualModel=
        RouterService.filterAndRetrieveRouter(routers,
        Router.getModelPredicate(
        Model.XYZ0001)).get(0).getModel();

        assertEquals(Model.XYZ0001, actualModel);
    }
```

The goal here is to confirm whether the `filterAndRetrieveRouter` method is working as expected when we need to filter router lists based on the router model.

10. Here, we have a test for the `filterAndRetrieveSwitch` method from the `SwitchService` class:

```
    @Test
    public void filterSwitchByType(){
        List<Switch> switches = new ArrayList<>();
        var location = createLocation("US");
        var networkSwitch = createSwitch(
        "30.0.0.0", 8, location);

        switches.add(networkSwitch);

        var actualSwitchType =
        SwitchService.filterAndRetrieveSwitch(switches,
        Switch.getSwitchTypePredicate(
        SwitchType.LAYER3)).get(0).getSwitchType();

        assertEquals(
        SwitchType.LAYER3, actualSwitchType);
    }
```

The goal here is to check whether it is possible to filter switch lists using the predicate provided by the `getSwitchTypePredicate` method. This is the predicate we use to filter switch lists by type. The `assertEquals` method, in the end, checks whether the expected switch type matches what we are expecting.

11. Next, we test the operations to retrieve routers and switches by using their IDs, as follows:

```
@Test
public void findRouterById() {
    List<Router> routers = new ArrayList<>();
    Map<Id, Router> routersOfCoreRouter =
    new HashMap<>();
    var location = createLocation("US");
    var coreRouter = createCoreRouter(
    location, "30.0.0.1");
    var newCoreRouter = createCoreRouter(
    location, "40.0.0.1");

    coreRouter.addRouter(newCoreRouter);
    routersOfCoreRouter.put(
    newCoreRouter.getId(), newCoreRouter);

    var expectedId = newCoreRouter.getId();
    var actualId =
    RouterService.findById(
    routersOfCoreRouter, expectedId).getId();

    assertEquals(expectedId, actualId);
}
```

With `findRouterById`, we test the `findById` method from `RouterService`.

12. Finally, we implement the `findSwitchById` method, like this:

```
@Test
public void findSwitchById(){
    List<Switch> switches = new ArrayList<>();
    Map<Id, Switch> switchesOfEdgeRouter =
    new HashMap<>();
```

```
        var location = createLocation("US");
        var networkSwitch = createSwitch(
        "30.0.0.0", 8, location);

        switchesOfEdgeRouter.put(
        networkSwitch.getId(), networkSwitch);

        var expectedId =
        Id.withId("f8c3de3d-1fea-4d7c-a8b0-29f63c4c3490");
        var actualId =
        SwitchService.findById(
        switchesOfEdgeRouter, expectedId).getId();

        assertEquals(expectedId, actualId);
    }
```

With `findSwitchById`, we test the `findById` method from `SwitchService`.

After implementing and executing these tests, you should see the following output showing that `19` tests were executed successfully:

```
[INFO] -------------------------------------------------------
[INFO]  T E S T S
[INFO] -------------------------------------------------------
[INFO] Running dev.davivieira.topologyinventory.domain.
DomainTest
[INFO] Tests run: 19, Failures: 0, Errors: 0, Skipped: 0, Time
elapsed: 0.04 s - in dev.davivieira.topologyinventory.domain.
DomainTest
[INFO]
[INFO] Results:
[INFO]
[INFO] Tests run: 19, Failures: 0, Errors: 0, Skipped: 0
```

The successful execution of these tests ensures us that the most fundamental operations from the Domain hexagon are working as expected.

That's the green light we need to move ahead and start the development of the Application hexagon.

Summary

Based on the topology and inventory system we have been developing in previous chapters, this chapter provided a hands-on approach to the early steps of developing a hexagonal system. We started by first bootstrapping the Domain hexagon as a modularized Maven project and using the JPMS.

Then, we engaged in a brief analysis to understand the problem domain related to the management of network assets. Next, we translated the problem domain into a domain model based on value objects, entities, specifications, and services. Finally, we tested everything we've done to ensure things won't break when we start to develop the Application hexagon on top of the domain one.

By learning to develop a robust Domain hexagon, we're laying a solid foundation that the Application and Framework hexagons can rely on. In the next chapter, we will learn to build the Application hexagon by assembling the useful features and everything else we've created in the Domain hexagon.

Questions

1. Which technologies are used to bootstrap the Domain hexagon as a modularized application?
2. Why did we start developing the Domain hexagon by creating value objects first?
3. Once we understand the problem domain, what's the next step?
4. Why is it so important to develop a robust and well-tested Domain hexagon?

7
Building the Application Hexagon

Once we have a foundation provided by the Domain hexagon, we can build the remaining part of the system on top of this. It's time to think about how the system will coordinate the handling of different data and behaviors to fulfill the needs of different actors and we will explore this through a discussion of use case examples. To accomplish this, we need to create the Application hexagon on top of the foundation defined by the Domain hexagon.

To continue building the modular structure initiated in the previous chapter, where we configured the Domain hexagon as a **Java** module, we will continue to use the modular approach by defining the Application hexagon as the second Java module of our hexagonal system.

In order to provide a better view of the system's capabilities, one recommended approach is to use **Cucumber**, which is a well-known behavior-driven development technology that uses concepts such as features and scenarios to describe the system's behavior. So, for the Application hexagon, we'll use Cucumber to help us in shaping the hexagonal system's use cases.

Cucumber enables us to test the Application hexagon and express the structure of the use cases in a non-technical way.

In this chapter, we'll learn about the following topics:

- Bootstrapping the Application hexagon
- Defining use cases
- Implementing use cases with input ports
- Testing the Application hexagon

By the end of this chapter, you'll know how to utilize use cases as a blueprint to drive the development of the entire Application hexagon. By expressing the user intent through use cases and deriving objects from them to implement ports, you'll be able to develop the code to accomplish use case goals in a structured way.

Technical requirements

To compile and run the code examples presented in this chapter, you need the latest **Java SE Development Kit** (**JDK**) and **Maven 3.6** installed on your computer. They are all available for the **Linux**, **Mac**, and **Windows** operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter07`.

Bootstrapping the Application hexagon

The Application hexagon orchestrates internal requests through the Domain hexagon and external requests through the Framework hexagon. We construct the system's features based on the domain model provided by the Domain hexagon with ports and use cases. In the Application hexagon, we don't specify any constraint or business rule. Instead, our aim for the Application hexagon is to define and control the data flow in the hexagonal system.

To continue developing the topology and inventory system, we have to bootstrap the Application hexagon as a Maven and Java module. Let's start with the Maven configuration:

```
mvn archetype:generate \
  -DarchetypeGroupId=de.rieckpil.archetypes  \
  -DarchetypeArtifactId=testing-toolkit \
  -DarchetypeVersion=1.0.0 \
  -DgroupId=dev.davivieira \
```

```
    -DartifactId=application \
    -Dversion=1.0-SNAPSHOT \
    -Dpackage=dev.davivieira.topologyinventory.application \
    -DinteractiveMode=false
```

The preceding command creates the basic Maven project's structure for the Application hexagon. Here, we set the module's `groupId` coordinate to `dev.davivieira` and `version` to `1.0-SNAPSHOT`, the same ones used for the parent project. We set `artifactId` as `application` to uniquely identify this module in the Maven project.

You need to run the preceding `mvn` command in the Maven project root directory by using the following commands:

```
$ cd topology-inventory
$ mvn archetype:generate ...
```

This creates the skeleton project structure for the Application hexagon. The directory structure will be like the following screenshot:

Figure 7.1 – Directory structure of the Application hexagon

The root `pom.xml` file should contain the `application` and `domain` Maven modules:

```
<modules>
     <module>domain</module>
     <module>application</module>
</modules>
```

Following the Maven module project creation, we need to configure the Application hexagon as a Java module by creating the `module` descriptor file in `application/src/java/module-info.java`:

```
module application {
     requires domain;
     requires static lombok;
}
```

Note the first `requires` entry: it states that the `application` module depends on the `domain` module. We need to add the Domain hexagon dependency at `application/pom.xml`:

```
<dependency>
     groupId>dev.davivieira</groupId>
     <artifactId>domain</artifactId>
     <version>1.0-SNAPSHOT</version>
     <scope>compile</scope>
</dependency>
```

The Maven coordinates `groupId`, `artifactId`, and `version` are used to specify the correct parameters to fetch the Domain hexagon's Maven module.

Because we'll utilize Cucumber to provide a written description and also test our use cases, we need to add its dependencies to `application/pom.xml`:

```
<dependency>
     <groupId>io.cucumber</groupId>
     <artifactId>cucumber-java</artifactId>
     <version>6.10.4</version>
     <scope>test</scope>
</dependency>
```

```
<dependency>
    <groupId>io.cucumber</groupId>
    <artifactId>cucumber-junit</artifactId>
    <version>6.10.4</version>
    <scope>test</scope>
</dependency>
<dependency>
    <groupId>io.cucumber</groupId>
    <artifactId>cucumber-picocontainer</artifactId>
    <version>6.10.4</version>
    <scope>test</scope>
</dependency>
```

As stated in this chapter's introduction, we'll use Cucumber to structure and test use cases. The Maven dependencies declared in the previous code examples are required to enable Cucumber in the Application hexagon.

Once the Application hexagon's Maven module and Java module are properly configured for the topology and inventory system, we can move on and start defining use cases for the system.

Defining use cases

The topology and inventory system allows users to manage network resources such as routers, switches, and networks. To enable this management, we have created a domain model in the previous chapter that represents the relationship between those resources. What we have to do now is construct the system's features in terms of the domain model. These features represent user intent when interacting with the system.

To make it possible to express use cases in both written and code form, we use Cucumber, a valuable tool to enable non-technical people to grasp the use cases that exist in the code.

By relying on Cucumber concepts such as features and scenarios, we can create use case descriptions that are easy to follow. The use case descriptions that are shaped using Cucumber can serve as references for developing use case interfaces.

Before creating the use case interfaces for the topology and inventory system, we first need to structure the use cases in feature files consumed by Cucumber. Feature files are where we'll describe a sequence of written statements that define the use case. This same written description is then used while implementing the classes to test the use case.

Creating written descriptions for router management use cases

To get started, let's create the `RouterAdd.feature` file that describes the use case related to adding routers to the system:

```
@RouterAdd
Feature: Can I add an edge router to a core router?

  Scenario: Adding an edge router to a core router
    Given I have an edge router
    And I have a core router
    Then I add an edge router to a core router

  Scenario: Adding a core router to another core router
    Given I have a core router
    And I have another core router
    Then I add this core router to the core router
```

This feature file describes two scenarios: the first is when the user wants to add an edge router to a core router; the second is when the user wants to add a core router to another core router.

After that, we have the `RouterCreate.feature` file:

```
@RouterCreate
Feature: Can I create a new router?

  Scenario: Creating a new core router
    Given I provide all required data to create a core
          router
    Then A new core router is created

  Scenario: Creating a new edge router
    Given I provide all required data to create an edge router
    Then A new edge router is created
```

Here, we have two scenarios describing the creation of both core and edge routers.

Finally, there is the `RouterRemove.feature` file:

```
@RouterRemove
Feature: Can I remove routers?

  Scenario: Removing an edge router from a core router
    Given The core router has at least one edge
          router connected to it
    And The switch has no networks attached to it
    And The edge router has no switches attached to it
    Then I remove the edge router from the core router

  Scenario: Removing a core router from another core router
    Given The core router has at least one core router
          connected to it
    And The core router has no other routers connected to
        it
    Then I remove the core router from another core router
```

For each of the two scenarios described, we define a specific set of constraints to allow the router removal. Once we have Cucumber scenarios describing the supported behaviors regarding router management, we can define the use case interface that will allow the implementation of the operations. These operations will enable such behaviors.

Defining the use case interface for router management

A good use case interface for router management should contain operations that allow the system to fulfill the scenarios described by the `RouterAdd.feature`, `RouterCreate.feature`, and `RouterRemove.feature` files. The following use case interface is defined in reference to the scenarios we described in the Cucumber feature files:

```
package dev.davivieira.topologyinventory.application.usecases;

import dev.davivieira.topologyinventory.domain.entity.
CoreRouter;
import dev.davivieira.topologyinventory.domain.entity.Router;
import dev.davivieira.topologyinventory.domain.vo.IP;
import dev.davivieira.topologyinventory.domain.vo.Id;
```

```
import dev.davivieira.topologyinventory.domain.vo.Location;
import dev.davivieira.topologyinventory.domain.vo.Model;
import dev.davivieira.topologyinventory.domain.vo.RouterType;
import dev.davivieira.topologyinventory.domain.vo.Vendor;

public interface RouterManagementUseCase {
    Router createRouter(
            Vendor vendor,
            Model model,
            IP ip,
            Location location,
            RouterType routerType);
    CoreRouter addRouterToCoreRouter(
            Router router, CoreRouter coreRouter);
    Router removeRouterFromCoreRouter(
            Router router, CoreRouter coreRouter);

    Router retrieveRouter(Id id);
    Router persistRouter(Router router);
}
```

The `createRouter` method is based on the `RouterCreate.feature` Cucumber file. The `addRouterToCoreRouter` and `removeRouterFromCoreRouter` methods are for the `RouterAdd.feature` and `RouterRemove.feature` files, respectively. Now, let's move on to create the written descriptions for the switch management use cases.

Creating written descriptions for switch management use cases

We start by creating the `SwitchAdd.feature` file:

```
@SwitchAdd
Feature: Can I add a switch to an edge router?

  Scenario: Adding a switch to an edge router
    Given I provide a switch
    Then I add the switch to the edge router
```

This is a very straightforward use case scenario. Given that we provide a valid switch, we can add it to an edge router. There is no mention of the core routers because they are not supposed to receive switch connections.

Next, we create the `SwitchCreate.feature` file:

```
@SwitchCreate
Feature: Can I create new switches?

  Scenario: Creating a new switch
    Given I provide all required data to create a switch
    Then A new switch is created
```

This scenario is similar to the `RouterCreate.feature` file in the sense that if we provide all the required data, a new `switch` object is created.

And finally, we create the `SwitchRemove.feature` file:

```
@SwitchRemove
Feature: Can I remove a switch from an edge router?

  Scenario: Removing a switch from an edge router
    Given I know the switch I want to remove
    And The switch has no networks
    Then I remove the switch from the edge router
```

So, to remove a switch from an edge router, we have to make sure the switch has no networks connected to it. This is what the preceding scenario asserts.

Now, let's define the use case interface for switch management, based on the Cucumber scenarios we just created.

Defining the use case interface for switch management

As we did with routers, we will do the same for switches by creating a use case interface to define the switch management operations based on the written descriptions we made previously in our Cucumber feature files:

```
package dev.davivieira.topologyinventory.application.usecases;

import dev.davivieira.topologyinventory.domain.entity.
EdgeRouter;
```

```
import dev.davivieira.topologyinventory.domain.entity.Switch;
import dev.davivieira.topologyinventory.domain.vo.IP;
import dev.davivieira.topologyinventory.domain.vo.Location;
import dev.davivieira.topologyinventory.domain.vo.Model;
import dev.davivieira.topologyinventory.domain.vo.SwitchType;
import dev.davivieira.topologyinventory.domain.vo.Vendor;
public interface SwitchManagementUseCase {

    Switch createSwitch(
            Vendor vendor,
            Model model,
            IP ip,
            Location location,
            SwitchType switchType
            );

    EdgeRouter addSwitchToEdgeRouter(Switch networkSwitch,
    EdgeRouter edgeRouter);

    EdgeRouter removeSwitchFromEdgeRouter(Switch
    networkSwitch,
    EdgeRouter edgeRouter);
}
```

The `createSwitch`, `addSwitchToEdgeRouter`, and `removeSwitchFromEdgeRouter` methods correspond to the Cucumber `SwitchCreate.feature`, `SwitchAdd.feature`, and `SwitchRemove.feature` feature files, respectively. The `createSwitch` method receives all the required parameters to construct a `Switch` object. Both the `addSwitchToEdgeRouter` and `removeSwitchFromEdgeRouter` methods receive a switch and an edge router as parameters. And, both methods return `EdgeRouter`.

To finish the definition of use cases, we still need to create the Cucumber feature files and interfaces for networks. Let's do that!

Creating written descriptions for network management use cases

For networks, we continue following the same pattern of the add, create, and remove operations previously used on routers and switches. Let's start with the `NetworkAdd.feature` file:

```
@NetworkAdd
Feature: Can I add a network to a switch?

  Scenario: Adding a network to a switch
    Given I have a network
    And I have a switch to add a network
    Then I add the network to the switch
```

This is a simple scenario to ensure that we're capable of adding networks to a switch.

Following the addition of networks, we have the `NetworkCreate.feature` file:

```
@NetworkCreate
Feature: Can I create new networks?

  Scenario: Creating a new network
    Given I provide all required data to create a network
    Then A new network is created
```

For network creation, as we did with routers and switches, we also make sure that all required data is properly provided so a new network is created.

Finally, we have the `NetworkRemove.feature` file:

```
@NetworkRemove
Feature: Can I remove a network from a switch?

  Scenario: Removing a network from a switch
    Given I know the network I want to remove
    And I have a switch to remove a network
    Then I remove the network from the switch
```

It follows the same structure of the adding scenario but checks the system's capability to remove networks from a switch.

Now that we have Cucumber scenarios for network management, let's define a use case interface to perform such scenarios.

Defining the use case interface for network management

The `NetworkManagementUseCase` interface follows the same structure of previously defined interfaces where we declared methods for creation, addition, and removal operations:

```
package dev.davivieira.topologyinventory.application.usecases;

import dev.davivieira.topologyinventory.domain.entity.Switch;
import dev.davivieira.topologyinventory.domain.vo.IP;
import dev.davivieira.topologyinventory.domain.vo.Network;

public interface NetworkManagementUseCase {

    Network createNetwork(
            IP networkAddress,
            String networkName,
            int networkCidr);

    Switch addNetworkToSwitch(Network network,
    Switch networkSwitch);

    Switch removeNetworkFromSwitch(Network network,
    Switch networkSwitch);
}
```

Here again, we declare the `createNetwork`, `addNetworkToSwitch`, and `removeNetworkFromSwitch` methods based on the written descriptions from the Cucumber feature files. These three method declarations in the `NetworkManagementUseCase` interface represent the first step in implementing the capabilities that will allow the management of networks, as described in the scenarios we created using Cucumber.

In this section, we learned about an approach where we started the use case development by first describing the behaviors and scenarios expected from the system. Once the scenarios were well elaborated, we then utilized those same scenarios as a reference to define the use case interfaces that will allow the system to perform the behaviors described in such scenarios.

Now that we have all the use case interfaces to manage routers, switches, and networks, we can provide an input port implementation for each of these use case interfaces.

Implementing use cases with input ports

Input ports are a central element of the Application hexagon. They play a crucial integration role because it is through them that we bridge the gap between the Domain and Framework hexagons. We can get external data from an output port and forward that data to the Domain hexagon by using output ports. Once the Domain hexagon's business logic is applied to the data, the Application hexagon moves that data downstream until it reaches one of the output adapters in the Framework hexagon.

When creating the Application hexagon, you'll be able to define output port interfaces, but because there is no Framework hexagon yet to provide an output adapter as an implementation, you'll not be able to use these output ports.

You'll see output port declarations in the following code, but they are not being used yet. We're just preparing the Application hexagon to work when we have the Framework hexagon to provide the implementations.

The following steps will help us to implement use cases with input ports:

1. We start by creating a `RouterManagementOutputPort` field in the `RouterManagementInputPort` class:

```
package dev.davivieira.topologyinventory.application.
ports.input;

import dev.davivieira.topologyinventory.application.
ports.output.RouterManagementOutputPort;
import dev.davivieira.topologyinventory.application.
usecases.RouterManagementUseCase;
import dev.davivieira.topologyinventory.domain.entity.
CoreRouter;
import dev.davivieira.topologyinventory.domain.entity.
Router;
```

```
import dev.davivieira.topologyinventory.domain.entity.
factory.RouterFactory;
import dev.davivieira.topologyinventory.domain.vo.IP;
import dev.davivieira.topologyinventory.domain.vo.Id;
import dev.davivieira.topologyinventory.domain.
vo.Location;
import dev.davivieira.topologyinventory.domain.vo.Model;
import dev.davivieira.topologyinventory.domain.
vo.RouterType;
import dev.davivieira.topologyinventory.domain.vo.Vendor;
import lombok.NoArgsConstructor;

@NoArgsConstructor
public class RouterManagementInputPort implements
RouterManagementUseCase {

    RouterManagementOutputPort
    routerManagementOutputPort;
    /** Code omitted
}
```

We create this `RouterManagementOutputPort` interface field because we don't want to depend directly on its implementation. Remember, output adapters implement output ports.

2. Next, we implement the `createRouter` method:

```
@Override
public Router createRouter(Vendor vendor,
                           Model model,
                           IP ip,
                           Location location,
                           RouterType routerType) {
    return RouterFactory.getRouter(
           vendor,model,ip,location,routerType);
}
```

With the `createRouter` method, we'll receive all the required parameters to construct a `Router` object. The object creation is delegated to the `getRouter` method from the `RouterFactory` class.

3. Next, we implement the `retrieveRouter` method:

```
@Override
public Router retrieveRouter(Id id) {
    return
      routerManagementOutputPort.retrieveRouter(id);
}
```

It's a very straightforward method that uses `Id` to obtain the `Router` objects using the `retrieveRouter` method from the `RouterManagementOutputPort` output port.

4. Next, we implement the `persistRouter` method:

```
@Override
public Router persistRouter(Router router) {
    return
     routerManagementOutputPort.persistRouter(router);
}
```

To persist a router, we need to pass the `Router` object we want to persist. This method is generally used after any operation that creates new `Router` objects or causes changes in existing ones.

5. Next, we implement the `addRouterToCoreRouter` method:

```
@Override
public CoreRouter addRouterToCoreRouter(Router router,
CoreRouter coreRouter) {
    var addedRouter = coreRouter.addRouter(router);
    //persistRouter(addedRouter);
    return addedRouter;
}
```

To add `Router` to `CoreRouter`, we call the `addRouter` method from `CoreRouter`. We're not persisting `Router` because we don't have an adapter to allow us to do that. So, we just return the added `Router` object.

6. Finally, we implement `removeRouterFromCoreRouter`:

```
@Override
public Router removeRouterFromCoreRouter(Router router,
CoreRouter coreRouter) {
    var removedRouter =
    coreRouter.removeRouter(router);
    //persistRouter(removedRouter);
    return removedRouter;
}
```

   Again, we use one of the methods present in the `CoreRouter` class. Here, we call the `removeRouter` method to remove `Router` from `CoreRouter`. Then, we return `removedRouter`, instead of actually removing it from an external data source.

The first method we implemented, `createRouter`, can produce either core or edge routers. To accomplish this, we need to provide a factory method directly in the Domain hexagon in a class called `RouterFactory`. The following is how we implement this `getRouter` factory method:

```
public static Router getRouter(Vendor vendor,
                                   Model model,
                                   IP ip,
                                   Location location,
                                   RouterType routerType){

        switch (routerType){
            case CORE:
                return CoreRouter.builder().
                        id(Id.withoutId()).
                        vendor(vendor).
                        model(model).
                        ip(ip).
                        location(location).
                        routerType(routerType).
                        build();
/** Code omitted **/
```

The `RouterType` parameter, which we pass to the `getRouter` method, has only two possible values: `CORE` or `EDGE`. The switch looks into one of these two values to determine which builder method to use. If `RouterType` is `CORE`, then the builder method from `CoreRouter` is called. Otherwise, the builder method from `EdgeRouter` is used, as we can see here:

```
case EDGE:
    return EdgeRouter.builder().
                 id(Id.withoutId()).
                 vendor(vendor).
                 model(model).
                 ip(ip).
                 location(location).
                 routerType(routerType).
                 build();
default:
    throw new UnsupportedOperationException(
    "No valid router type informed");
```

If neither `CORE` nor `EDGE` is informed, the default behavior is to throw an exception saying that no valid router type was informed.

Let's implement the `SwitchManagementUseCase` interface with `SwitchManagementInputPort`:

1. We start by implementing the `createSwitch` method:

```
package dev.davivieira.topologyinventory.application.
ports.input;

import dev.davivieira.topologyinventory.application.
usecases.SwitchManagementUseCase;
import dev.davivieira.topologyinventory.domain.entity.
EdgeRouter;
import dev.davivieira.topologyinventory.domain.entity.
Switch;
import dev.davivieira.topologyinventory.domain.vo.IP;
import dev.davivieira.topologyinventory.domain.vo.Id;
import dev.davivieira.topologyinventory.domain.
vo.Location;
```

```
import dev.davivieira.topologyinventory.domain.vo.Model;
import dev.davivieira.topologyinventory.domain.
vo.SwitchType;
import dev.davivieira.topologyinventory.domain.vo.Vendor;

public class SwitchManagementInputPort implements
SwitchManagementUseCase {
    @Override
    public Switch createSwitch(
            Vendor vendor,
            Model model,
            IP ip,
            Location location,
            SwitchType switchType) {
        return Switch.builder()
                .id(Id.withoutId())
                .vendor(vendor)
                .model(model)
                .ip(ip)
                .location(location).switchType
                  (switchType).build();
    }
/** Code omitted **/
}
```

For the `createSwitch` method, we don't need a factory method to create objects because there are no switch object variations as compared to routers. Instead, we generate switch objects using the builder method directly from the `Switch` class.

2. Next, we implement the `addSwitchToEdgeRouter` method:

```
@Override
public EdgeRouter addSwitchToEdgeRouter(
Switch networkSwitch, EdgeRouter edgeRouter) {
    edgeRouter.addSwitch(networkSwitch);
    return edgeRouter;
}
```

Then, we have addSwitchToEdgeRouter, which receives Switch and EdgeRouter as parameters, to add switches to an edge router. There is no way to persist switches without persisting routers as well. That's why we did not put a persistence method here. By doing that, we are enforcing all switch persistence operations to occur only when we persist routers.

Remember that Router is an aggregate (a cluster of domain objects) that controls the life cycle of other entities and value objects, including Switch type objects.

3. Finally, we implement the removeSwitchFromEdgeRouter method:

```
@Override
public EdgeRouter removeSwitchFromEdgeRouter(
Switch networkSwitch,EdgeRouter edgeRouter) {
    edgeRouter.removeSwitch(networkSwitch);
    return edgeRouter;
}
```

The last method, removeSwitchFromEdgeRouter, receives the same parameters, Switch and EdgeRouter, and removes switches from edge routers using the removeSwitch method present in an EdgeRouter instance.

Now, let's see how we can implement the NetworkManagementUseCase interface with NetworkManagementInputPort:

1. We start by implementing the createNetwork method:

```
package dev.davivieira.topologyinventory.application.
ports.input;
import dev.davivieira.topologyinventory.application.
usecases.NetworkManagementUseCase;
import dev.davivieira.topologyinventory.domain.entity.
Switch;
import dev.davivieira.topologyinventory.domain.vo.IP;
import dev.davivieira.topologyinventory.domain.
vo.Network;
import lombok.NoArgsConstructor;
@NoArgsConstructor
public class NetworkManagementInputPort implements
NetworkManagementUseCase {
    @Override
    public Network createNetwork(
```

```
      IP networkAddress, String networkName,
      int networkCidr) {
          return  Network
                  .builder()
                  .networkAddress(networkAddress)
                  .networkName(networkName)
                  .networkCidr(networkCidr).build();
      }
  /** Code omitted **/
  }
```

To create a new network, we use all the received method parameters in conjunction with the builder method from the `Network` class.

2. Next, we implement `addNetworkToSwitch`:

```
@Override
public Switch addNetworkToSwitch(
Network network, Switch networkSwitch) {
    networkSwitch.addNetworkToSwitch(network);
    return networkSwitch;
}
```

Here, we receive `Network` and `Switch` objects. Then, we call the `addNetworkToSwitch` method on `Switch` by passing the `Network` object as a parameter. Then, we return a `Switch` object with the added `Network` object.

3. Finally, we implement the `removeNetworkFromSwitch` method:

```
@Override
public Switch removeNetworkFromSwitch(
Network network, Switch networkSwitch) {
    networkSwitch.removeNetworkFromSwitch(network);
    return networkSwitch;
}
```

We receive `Network` and `Switch` objects as parameters, like in the `addNetworkToSwitch` method. But to remove the network from a switch, we call `removeNetworkFromSwitch` from the `Switch` object.

This ends the input port implementation for the router, switch, and network management. To ensure everything is working as expected, let's create Cucumber tests based on the written use case descriptions and these input ports we have just created.

Testing the Application hexagon

An interesting and useful thing about Cucumber is that we can use the same written scenario description provided in the feature file to tailor the unit tests. In addition, these written scenarios provide an easy way to understand and implement the hexagonal system's use cases. We're also laying the groundwork for the development of unit tests in the Application hexagon.

So, the tests we're about to build in this section are a continuation of the written scenario descriptions we created for the router, switch, and network management operations. Our goal here is to test input port implementations to ensure these ports will work as expected when input adapters come to call them.

To get started, we need to create the `ApplicationTest` test class to enable Cucumber:

```
package dev.davivieira.topologyinventory.application;

import io.cucumber.junit.Cucumber;
import io.cucumber.junit.CucumberOptions;
import org.junit.runner.RunWith;

@RunWith(Cucumber.class)
@CucumberOptions(
        plugin = {"pretty", "html:target/cucumber-result"}
)
public class ApplicationTest {

}
```

The important part is the `@RunWith` annotation that triggers the initialization of the Cucumber engine.

Let's start by creating the tests to check whether the system is capable of adding routers.

In the same way we created a `RouterAdd.feature` file, we'll create its counterpart as a `RouterAdd.java` test class. The location for both files will resemble the following:

- `src/test/java/dev/davivieira/topologyinventory/application/RouterAdd.java`
- `src/test/resources/dev/davivieira/topologyinventory/application/routers/RouterAdd.feature`

The following scenario, adding an edge router to a core router, walks through the necessary steps to add an edge router to a core router:

1. The first step is to get an edge router:

   ```
   @Given("I have an edge router")
   public void assert_edge_router_exists(){
       edgeRouter = (EdgeRouter)
       this.routerManagementUseCase.createRouter(
               Vendor.HP,
               Model.XYZ0004,
               IP.fromAddress("20.0.0.1"),
               locationA,
               EDGE
       );
       assertNotNull(edgeRouter);
   }
   ```

   Here, we are using the `createRouter` method from `RouterManagementUseCase` to create edge router objects. We need to cast the returned object to a `EdgeRouter` type because the `createRouter` method returns `Router`. Then, to make sure that we received a proper router object, we call `assertNotNull` on `edgeRouter`.

2. Now that we have `EdgeRouter`, we need to create `CoreRouter` by using the `createRouter` method again:

   ```
   @And("I have a core router")
   public void assert_core_router_exists(){
       coreRouter = (CoreRouter)
       this.routerManagementUseCase.createRouter(
   ```

```
                Vendor.CISCO,
                Model.XYZ0001,
                IP.fromAddress("30.0.0.1"),
                locationA,
                CORE
        );
        assertNotNull(coreRouter);
    }
```

This code follows the exact same pattern as the first step. The only difference, though, is that we are passing `CORE` as `RouterType` to the `createRouter` method from `RouterManagementUseCase`.

3. With these two objects, `EdgeRouter` and `CoreRouter`, we can now test the addition of the former into the latter:

```
    @Then("I add an edge router to a core router")
    public void add_edge_to_core_router(){
        var actualEdgeId = edgeRouter.getId();
        var routerWithEdge =
        (CoreRouter)  this.routerManagementUseCase.
        addRouterToCoreRouter(edgeRouter, coreRouter);
        var expectedEdgeId =
        routerWithEdge.getRouters().get(actualEdgeId).
        getId();
        assertEquals(actualEdgeId, expectedEdgeId);
    }
```

The `addRouterToCoreRouter` method receives `EdgeRouter` and `CoreRouter` as parameters. At the end of the method, we compare the actual and expected edge router IDs to confirm whether the edge router has been added correctly into the core router.

To test the execution of the Cucumber scenario steps from `RouterAdd.feature`, we have to run the following Maven command:

```
mvn test
```

The output will be similar to the one shown as follows:

```
@RouterAdd
Scenario: Adding an edge router to a core router # dev/
davivieira/topologyinventory/application/routers/RouterAdd.
feature:4
Given I have an edge router # dev.davivieira.topologyinventory.
application.RouterAdd.assert_edge_router_exists()
And I have a core router # dev.davivieira.topologyinventory.
application.RouterAdd.assert_core_router_exists()
Then I add an edge router to a core router # dev.davivieira.
topologyinventory.application.RouterAdd.add_edge_to_core_
router()
```

The Cucumber test passes through the testing methods in the `RouterAdd.java` file in the same order as they were declared in the `RouterAdd.feature` file.

Now, let's see how we can implement the `RouterCreate.java` test class for the `RouterCreate.feature` file. Their file locations will resemble the following:

- `RouterCreate.java` file: `src/test/java/dev/davivieira/topologyinventory/application/RouterCreate.java`
- `RouterCreate.feature` file: `src/test/resources/dev/davivieira/topologyinventory/application/routers/RouterCreate.feature`

The first scenario, creating a new core router, walks through the required steps to create a new core router in the system:

1. The first step is to create a new core router:

```
@Given("I provide all required data to create a core
router")
public void create_core_router(){
    router =  this.routerManagementUseCase.
            createRouter(
            Vendor.CISCO,
            Model.XYZ0001,
            IP.fromAddress("20.0.0.1"),
            locationA,
            CORE
    );
}
```

We provide all the required data to the `createRouter` method from `RouterManagementUseCase` in order to create a new core router.

2. Then, we proceed to confirm whether the router created was indeed a core router:

```
@Then("A new core router is created")
public void a_new_core_router_is_created(){
   assertNotNull(router);
   assertEquals(CORE, router.getRouterType());
}
```

The first assertion checks whether we received a null pointer. The second assertion looks into the router's type to confirm that it's a core router.

The second scenario, creating a new edge router, checks whether we can simply create an edge router by using the `createRouter` method from `RouterManagementUseCase`:

1. First, we create an edge router:

```
@Given("I provide all required data to create an edge
router")
public void create_edge_router(){
    router =
      this.routerManagementUseCase.createRouter(
            Vendor.HP,
            Model.XYZ0004,
            IP.fromAddress("30.0.0.1"),
            locationA,
            EDGE
    );
}
```

We follow the same procedure for creating the core router objects, but now we are informing the `EDGE` parameter as `RouterType` for object creation.

2. In the last scenario step, we just execute the assertions:

```
@Then("A new edge router is created")
public void a_new_edge_router_is_created(){
    assertNotNull(router);
    assertEquals(EDGE, router.getRouterType());
}
```

The first assertion checks with the `assertNotNull` method whether the router reference is not `null`. Then, it proceeds by executing `assertEquals` to check whether the router created is an `EdgeRouter`.

To run the tests related to the creation of routers, we execute the following Maven command in the project root directory:

```
mvn test
```

The test result should contain the following output:

```
@RouterCreate
Scenario: Creating a new edge router # dev/davivieira/
topologyinventory/application/routers/RouterCreate.feature:8
Given I provide all required data to create an edge router #
dev.davivieira.topologyinventory.application.RouterCreate.
create_edge_router()
Then A new edge router is created # dev.davivieira.
topologyinventory.application.RouterCreate.a_new_edge_router_
is_created()
```

Now that we're done with the scenario to create routers, let's see how to implement the `RouterRemove.java` test class for the `RouterRemove.feature` file. The file locations are as follows:

- `src/test/java/dev/davivieira/topologyinventory/application/RouterRemove.java`
- `src/test/resources/dev/davivieira/topologyinventory/application/routers/RouterRemove.feature`

We have to create the methods to test a scenario where we want to remove an edge router from a core router.

1. To get started, we first need to know whether the core router we are working with has at least an edge router connected to it:

```
@Given("The core router has at least one edge router
connected to it")
public void the_core_router_has_at_least_one_edge_router_
connected_to_it(){
    var predicate =
      Router.getRouterTypePredicate(EDGE);
    edgeRouter = (EdgeRouter)
```

```
        this.coreRouter.getRouters().
              entrySet().
              stream().
              map(routerMap -> routerMap.getValue()).
              filter(predicate).
              findFirst().get();
      assertEquals(EDGE, edgeRouter.getRouterType());
  }
```

From a core router, we search for an edge router connected to it. Then, we store the returned edge router in the `edgeRouter` variable. Following that, we assert the type of router to confirm whether we have an edge router.

2. Next, we have to check that there are no networks attached to the switch connected to the edge router. We have to check this, otherwise, we will not be able to remove the switch from the edge router:

```
  @And("The switch has no networks attached to it")
  public void the_switch_has_no_networks_attached_to_it(){
      var networksSize =
      networkSwitch.getSwitchNetworks().size();
      assertEquals(1, networksSize);
      networkSwitch.removeNetworkFromSwitch(network);
      networksSize =
        networkSwitch.getSwitchNetworks().size();
      assertEquals(0, networksSize);
  }
```

To assert a switch has no networks connected to it, we first check the size of the networks on the switch. It should return `1`. Then, we remove the network and check the size again. It should return `0`.

We must ensure that the switch has no networks attached to it to make that switch eligible for removal.

3. Next, we can proceed to check that there are no switches connected to the edge router:

```
  @And("The edge router has no switches attached to it")
  public void the_edge_router_has_no_switches_attached_to_
  it(){
      var switchesSize =
        edgeRouter.getSwitches().size();
```

```
        assertEquals(1, switchesSize);
        edgeRouter.removeSwitch(networkSwitch);
        switchesSize = edgeRouter.getSwitches().size();
        assertEquals(0, switchesSize);
    }
```

Here, we remove the switch using the `removeSwitch` method, followed by an assertion to confirm that the edge router has no more switches connected.

4. Now, we can test the removal of the edge router from the core router:

```
    @Then("I remove the edge router from the core router")
    public void edge_router_is_removed_from_core_router(){
        var actualID = edgeRouter.getId();
        var expectedID = this.routerManagementUseCase.
               removeRouterFromCoreRouter(
               edgeRouter, coreRouter).
               getId();
        assertEquals(expectedID, actualID);
    }
```

To test the removal of an edge router from the core router, we first get the edge router ID of the router we intend to remove. We store this ID in the `actualID` variable. Then, we proceed to the actual removal. The `removeRouterFromCoreRouter` method returns the removed router. So, we can use the removed router ID, stored in the `expectedID` variable, to check with the `assertEquals` method whether the router was really removed.

To confirm the tests related to router removal are working, we execute the Maven test goal in the project root directory:

```
mvn test
```

The results you get after executing the tests should be similar to the following output:

```
@RouterRemove
Scenario: Removing an edge router from a core router # dev/davivieira/topologyinventory/application/routers/RouterRemove.feature:4
Given The core router has at least one edge router connected to it # dev.davivieira.topologyinventory.application.RouterRemove.the_core_router_has_at_least_one_edge_router_connected_to_it()
```

```
And The switch has no networks attached to it # dev.davivieira.
topologyinventory.application.RouterRemove.the_switch_has_no_
networks_attached_to_it()
And The edge router has no switches attached to it # dev.
davivieira.topologyinventory.application.RouterRemove.the_edge_
router_has_no_switches_attached_to_it()
Then I remove the edge router from the core router # dev.
davivieira.topologyinventory.application.RouterRemove.edge_
router_is_removed_from_core_router()
```

The preceding output provides the execution details of the four testing methods involved in removing the edge router from the core router.

We have completed the testing part for router management. For switch and network management, we follow the same ideas. In the book's GitHub repository, you can access the topology and inventory code with all its tests.

Summary

On top of the Domain hexagon, we built the Application hexagon with use cases and ports. For use cases, we heavily relied on the behavior-driven development tool called Cucumber. With Cucumber, we could express the use cases supported by the system not only in code terms but also in written words.

We started by creating Cucumber feature files containing the use case written descriptions and then used them as a reference to create use case interfaces. These interfaces were then implemented by input ports that provided a concrete way to achieve use case goals. Finally, we built use case tests, based again on the written description provided by Cucumber.

By implementing and testing the Application hexagon in this way, we leveraged the special capabilities of Cucumber to express the system's behavior in a declarative and straightforward form, and we used these same capabilities to implement and test the entire Application hexagon.

On top of the Application hexagon and the features it provides, we need to decide how such features will be exposed. Also, some of these features require access to external data sources. We'll address all these concerns by developing the Framework hexagon in the next chapter.

Questions

1. What do we call the files where we declare Cucumber scenarios?
2. On which other Java module does the Application hexagon depend?
3. Which hexagonal architecture component is used to implement use cases?

8
Building the Framework Hexagon

When building a hexagonal application, the last step consists of exposing application features by connecting input adapters to input ports. Also, if there is any need to get data from, or persist it inside, external systems, then we need to connect output adapters to output ports. The Framework hexagon is the place where we assemble all the adapters required to make the hexagonal system.

We first created the domain model using things including entities, value objects, and specifications in the Domain hexagon. Then, in the Application hexagon, we expressed the user's intent using use cases and ports. Now, in the Framework hexagon, we have to employ adapters to expose system features and define which technologies will be used to enable such features.

What is so compelling about the hexagonal architecture is that we can add and remove adapters without worrying about changing the core system logic wrapped in the Domain hexagon. Of course, there is a price to be paid in the form of data translation between Domain entities and external entities. But in exchange, we gain a more decoupled system with clear boundaries between its realms of responsibilities.

In this chapter, we will cover the following topics:

- Bootstrapping the Framework hexagon
- Implementing output adapters
- Implementing input adapters
- Testing the Framework hexagon

By the end of this chapter, you'll learn to create input adapters to make the hexagonal application features accessible to other users and systems. Also, you'll learn to implement output adapters to enable the hexagonal system to communicate with external data sources.

Technical requirements

To compile and run the code examples presented in this chapter, you'll need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. They are all available for the Linux, Mac, and Windows operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter08`.

Bootstrapping the Framework hexagon

When building a system using hexagonal architecture, you don't need to decide up front if the system API will be exposed using REST or gRPC, nor if the system's primary data source will be a MySQL database or MongoDB. Instead, what you need to do is start modeling your problem domain in the Domain hexagon, then designing and implementing use cases in the Application hexagon. Then, only after creating the previous two hexagons, you'll need to start thinking about which technologies will enable the hexagonal system's functionalities.

The hexagonal approach centered on **Domain Driven Design** allows us to postpone the decisions regarding the underlying technologies internal or external to the hexagonal system. Another prerogative of the hexagonal approach is the pluggable nature of the adapters. If you want to expose some system feature to be accessible through REST, you create and plug a REST input adapter into an input port. Later on, if you want to expose that same feature for clients using gRPC, you can create and plug a gRPC input adapter into the same input port.

When dealing with external data sources, we have the same pluggable prerogatives when using output adapters. You can plug different output adapters to the same output port, changing the underlying data source technology without incurring major refactoring on the whole hexagonal system.

To further explore input adapters, we'll have a more in-depth discussion in *Chapter 12*, *Using RESTEasy Reactive to Implement Input Adapters*. Also, we'll investigate more possibilities for output adapters in *Chapter 13*, *Persisting Data with Output Adapters and Hibernate Reactive*.

Let's stick to the basics and create a solid structure for input and output adapters. On top of such a structure, we'll be able to, later on, add the exciting features provided by the Quarkus framework.

Continuing the development of the topology and inventory system, we need to bootstrap the Framework hexagon as a Maven and Java module.

Inside the topology and inventory Maven root project, we have to run the following command:

```
mvn archetype:generate \
    -DarchetypeGroupId=de.rieckpil.archetypes  \
    -DarchetypeArtifactId=testing-toolkit \
    -DarchetypeVersion=1.0.0 \
    -DgroupId=dev.davivieira \
    -DartifactId=framework \
    -Dversion=1.0-SNAPSHOT \
    -Dpackage=dev.davivieira.topologyinventory.framework \
    -DinteractiveMode=false
```

We recommend running the preceding command directly on CMD instead of PowerShell if you are using Windows. If you need to use PowerShell, you'll need to wrap each part of the command in double-quotes.

The `mvn archetype:generate` goal creates a Maven module called `framework` inside `topology-inventory`. This module comes with a skeleton directory structure based on the `groupId` and `artificatId` we passed in to the `mvn` command. Also, it includes a child `pom.xml` file inside the `framework` directory.

After executing the `mvn` command to create the `framework` module, the root project's `pom.xml` file will be updated to contain the new module:

```
<modules>
  <module>domain</module>
```

```
    <module>application</module>
    <module>framework</module>
</modules>
```

The `framework` module is inserted in the end as the latest module we have just added.

Because the `framework` module depends on both `domain` and `application` modules, we need to add them as dependencies in the `framework` module's `pom.xml` file:

```
<dependencies>
    <dependency>
        <groupId>dev.davivieira</groupId>
        <artifactId>domain</artifactId>
        <version>1.0-SNAPSHOT</version>
    </dependency>
    <dependency>
        <groupId>dev.davivieira</groupId>
        <artifactId>application</artifactId>
        <version>1.0-SNAPSHOT</version>
    </dependency>
<dependencies>
```

After running the Maven command to create the `framework` module, you should see a directory tree similar to the one shown here:

Figure 8.1 – The directory structure of the Framework hexagon

There should be a child `pom.xml` file in the `framework` directory, and a parent `pom.xml` file in the `topology-inventory` directory.

Once we have completed the Maven configuration, we can create the descriptor file that turns the `framework` Maven module into a Java module. We do that by creating the following file, `topology-inventory/framework/src/java/module-info.java`:

```
module framework {
     requires domain;
     requires application;
}
```

Because we have added `domain` and `application` as Maven dependencies on framework's `pom.xml` file, we can also add them as Java module dependencies in the `module-info.java` descriptor file.

With both the Maven and Java modules properly configured for the Framework hexagon, we can move on to create first the output adapters for the topology and inventory system.

Implementing output adapters

We start implementing the output adapters to set up the integration between our topology and inventory system and the underlying data source technology that is an H2 in-memory database. It's also important to implement output adapters first because we refer to them when implementing the input adapters.

The topology and inventory system allows external data retrieval for routers' and switches' entities. So, in this section, we will review the output ports' interfaces that get external data related to these entities. Also, we'll provide an output adapter implementation for each output port interface.

Router management output adapter

The router output adapter we need to create should implement this `RouterManagementOutputPort` interface:

```
package dev.davivieira.topologyinventory.application.ports.
output;

import dev.davivieira.topologyinventory.domain.entity.Router;
import dev.davivieira.topologyinventory.domain.vo.Id;

```

```
public interface RouterManagementOutputPort {
    Router retrieveRouter(Id id);

    Router removeRouter(Id id);

    Router persistRouter(Router router);
}
```

Both `retrieveRouter` and `removeRouter` methods' signatures have `Id` as a parameter. We use that `Id` to identify the router on the underlying data source. Then, we have the `persistRouter` method signature receiving a `Router` parameter that can represent both core and edge routers. We use that `Router` parameter to persist the data in the data source.

For the topology and inventory system, for now, we have to implement only one output adapter to allow the system to use an `H2` in-memory database.

We start the implementation with the `RouterManagementH2Adapter` class:

```
package dev.davivieira.topologyinventory.framework.adapters.
output.h2;

import dev.davivieira.topologyinventory.application.ports.
output.RouterManagementOutputPort;
import dev.davivieira.topologyinventory.domain.entity.Router;
import dev.davivieira.topologyinventory.domain.vo.Id;
import dev.davivieira.topologyinventory.framework.adapters.
output.h2.data.RouterData;
import dev.davivieira.topologyinventory.framework.adapters.
output.h2.mappers.RouterH2Mapper;
import jakarta.persistence.EntityManager;
import jakarta.persistence.EntityManagerFactory;
import jakarta.persistence.Persistence;
import jakarta.persistence.PersistenceContext;

public class RouterManagementH2Adapter implements
RouterManagementOutputPort {

    private static RouterManagementH2Adapter instance;

```

```
    @PersistenceContext
    private EntityManager em;

    private RouterManagementH2Adapter(){
        setUpH2Database();
    }
    /** Code omitted **/
}
```

The H2 database connection is controlled by `EntityManager`. This connection is configured by the `setUpH2Database` method, which we execute when we call the class's empty constructor. We use the variable called `instance` to provide a singleton so other objects can trigger database operations.

Let's implement each method declared on the output port interface:

1. We start with the `retrieveRouter` method that receives `Id` as a parameter:

   ```
   @Override
   public Router retrieveRouter(Id id) {
       var routerData = em.getReference(
                        RouterData.class, id.getUuid());
       return RouterH2Mapper.routerDataToDomain(routerData);
   }
   ```

   The `getReference` method from `EntityManager` is called with `RouterData.class` and the UUID value is extracted from the `Id` object. `RouterData` is a database entity class that we use to map data coming from the database into the `Router` domain entity class. This mapping is accomplished by the `routerDataToDomain` method from the `RouterH2Mapper` class.

2. Then, we implement the `removeRouter` method that removes a router from the database:

   ```
   @Override
   public Router removeRouter(Id id) {
       var routerData = em.getReference(
                        RouterData.class, id.getUuid());
       em.remove(routerData);
       return null;
   }
   ```

To remove a router, we first have to retrieve it by calling the `getReference` method. Once we have a `RouterData` object representing the database entity, we can call the `remove` method from `EntityManager`, `which` can delete the router from the database.

3. Finally, we implement the `persistRouter` method:

```
@Override
public Router persistRouter(Router router) {
    var routerData = RouterH2Mapper.
                     routerDomainToData(router);
    em.persist(routerData);
    return router;
}
```

It receives a `Router` domain entity object that needs to be converted to a `RouterData` database entity object that can be persisted with the `persist` method from `EntityManager`.

By implementing the `retrieveRouter`, `removeRouter`, and `persistRouter` methods, we provide the basic database operations required by the topology and inventory system.

Let's move on to see how the switch output adapters' implementation.

Switch management output adapter

The output adapter we implement for the switch is simpler because we don't need to persist switches directly, nor remove them. The sole purpose of the switch's output adapter is to enable the retrieval of switches from the database. We allow persistence only through the router output adapter.

To get started, let's define the `SwitchManagementOutputPort` interface:

```
package dev.davivieira.topologyinventory.application.ports.
output;

import dev.davivieira.topologyinventory.domain.entity.Switch;
import dev.davivieira.topologyinventory.domain.vo.Id;

public interface SwitchManagementOutputPort {
    Switch retrieveSwitch(Id id);
}
```

We have just one method called `retrieveSwitch` that receives `Id` and returns `Switch`.

The `SwitchSwitchManagementH2Adapter` output adapter implementation is very straightforward and similar to its router counterpart. So, we'll just assess the implementation of the `retrieveSwitch` method:

```
/** Code omitted **/
public class SwitchManagementH2Adapter implements
SwitchManagementOutputPort {

    /** Code omitted **/
    @Override
    public Switch retrieveSwitch(Id id) {
        var switchData = em.getReference(
                         SwitchData.class, id.getUuid());
        return
        RouterH2Mapper.switchDataToDomain(switchData);
    }
    /** Code omitted **/
}
```

We call the `getReference` method from `EntityManager` with `SwitchData.class` and a UUID value as parameters in order to retrieve a `SwitchData` database entity object. Then, this object is converted to a `Switch` domain entity when we call the `switchDataToDomain` method from the `RouterH2Mapper` class.

Now that we have both `RouterManagementH2Adapter` and `SwitchManagementH2Adapter` properly implemented, we can proceed to implement the input adapters.

Implementing input adapters

When building the Application hexagon, we need to create use cases and input ports to express system capabilities. To make these capabilities available to users and other systems, we need to build input adapters and connect them to input ports.

For the topology and inventory system, we will implement a set of generic input adapters as Java POJO. These generic input adapters are the basis for the technologically specific implementation that takes place in *Chapter 12*, *Using RESTEasy Reactive to Implement Input Adapters*. In that chapter, we will reimplement the generic input adapters as RESTEasy-based input adapters using the Quarkus framework.

The input adapter's central role is to receive requests from outside the hexagonal system and fulfill these requests using an input port.

Continuing to develop the topology and inventory system, let's implement the input adapters that receive requests related to router management.

Router management input adapter

We start by creating the `RouterManagementGenericAdapter` class:

```
public class RouterManagementGenericAdapter {

    private RouterManagementUseCase
      routerManagementUseCase;

    public RouterManagementGenericAdapter(){
        setPorts();
    }
    /** Code omitted **/
}
```

We start the `RouterManagementGenericAdapter` implementation by declaring a class attribute for `RouterManagementUseCase`. Instead of using an input port class reference, we utilize the use case interface reference, `RouterManagementUseCase`, to connect to the input port.

On the constructor of `RouterManagementGenericAdapter`, we call the `setPorts` method that instantiates `RouterManagementInputPort` with a `RouterManagementH2Adapter` parameter as an output port for connection to an H2 in-memory database that the input port uses.

The following is how we should implement the `setPorts` method:

```
private void setPorts(){
    this.routerManagementUseCase =
            new RouterManagementInputPort(
            RouterManagementH2Adapter.getInstance()
    );
}
/** Code omitted **/
```

The `setPorts` method stores a `RouterManagementInputPort` object in the `RouterManagementUseCase` attribute we defined earlier.

After class initialization, we need to create the methods that expose the operations supported by the hexagonal system. The intent here is to receive the request in the input adapter and forward it to an input port by using its use case interface reference:

1. Here are the operations to retrieve and remove routers from the system:

```
/**
 * GET /router/retrieve/{id}
 * */
public Router retrieveRouter(Id id){
    return routerManagementUseCase.retrieveRouter(id);
}

/**
 * GET /router/remove/{id}
 * */
public Router removeRouter(Id id){
    return routerManagementUseCase.removeRouter(id);
}
```

   The comments are to remind us that these operations will be transformed into REST endpoints when integrating Quarkus into the hexagonal system. Both `retrieveRouter` and `removeRouter` receive `Id` as a parameter. Then, the request is forwarded to an input port using a use case reference.

2. Then, we have the operation to create a new router:

```
/**
 * POST /router/create
 * */
public Router createRouter(Vendor vendor,
                               Model,
                               IP,
                               Location,
                               RouterType routerType){
    var router = routerManagementUseCase.createRouter(
            null,
```

```
                vendor,
                model,
                ip,
                location,
                routerType
        );
        return routerManagementUseCase.persistRouter(router);
    }
```

From the `RouterManagementUseCase` reference, we first call the `createRouter` method to create a new router, then we persist it using the `persistRouter` method.

3. Remember that in the topology and inventory system, only core routers can receive connections from both core and edge routers. To allow the addition and removal of routers on a core router, we define the following two operations:

```
    /**
     * POST /router/add
     * */
    public Router addRouterToCoreRouter(
        Id routerId, Id coreRouterId){
        Router = routerManagementUseCase.
        retrieveRouter(routerId);
        CoreRouter =
            (CoreRouter) routerManagementUseCase.
            retrieveRouter(coreRouterId);
        return routerManagementUseCase.
                addRouterToCoreRouter(router, coreRouter);
    }
```

For the `addRouterToCoreRouter` method, we pass the routers' `Id` instances as parameters we intend to add along with the target core router's `Id`. With these IDs, we call the `retrieveRouter` method to get the router objects from our data source. Once we have the `Router` and `CoreRouter` objects, we handle the request to the input port using a use case reference, by calling `addRouterToCoreRouter` to add one router into the other. We'll use the following code for this:

```
    /**
     * POST /router/remove
```

```
  * */
public Router removeRouterFromCoreRouter(
    Id routerId, Id coreRouterId){
    Router =
    routerManagementUseCase.
    retrieveRouter(routerId);
    CoreRouter =
         (CoreRouter) routerManagementUseCase.
         retrieveRouter(coreRouterId);
    return routerManagementUseCase.
            removeRouterFromCoreRouter(router,
              coreRouter);
}
```

For the `removeRouterFromCoreRouter` method, we follow the same steps as those of the `addRouterToCoreRouter` method. The only difference, though, is that at the end, we call `removeRouterFromCoreRouter` from the use case in order to remove one router from the other.

Let's create now the adapter that handles switch-related operations.

Switch management input adapter

Before we define the methods that expose the switch-related operations, we need to configure the proper initialization of the `SwitchManagementGenericAdapter` class:

```
package dev.davivieira.topologyinventory.framework.adapters.
input.generic;
import dev.davivieira.topologyinventory.application.ports.
input.*
import dev.davivieira.topologyinventory.application.usecases.*;
import dev.davivieira.topologyinventory.domain.entity.*;
import dev.davivieira.topologyinventory.domain.vo.*;
import dev.davivieira.topologyinventory.framework.adapters.
output.h2.*;

public class SwitchManagementGenericAdapter {

```

```
    private SwitchManagementUseCase
      switchManagementUseCase;
    private RouterManagementUseCase
      routerManagementUseCase;

    public SwitchManagementGenericAdapter(){
        setPorts();
    }
```

`SwitchManagementGenericAdapter` is connected to two input ports – the first input port is `SwitchManagementInputPort` from `SwitchManagementUseCase`, and the second input port is `RouterManagementInputPort` from `RouterManagementUseCase`. That's why we start the class implementation by declaring the attributes for `SwitchManagementUseCase` and `RouterManagementUseCase`. We are connecting the switch adapter to the router input port because we want to enforce any persistence activity to happen only through a router. The `Router` entity, as an aggregate, controls the life cycle of the objects that are related to it.

Next, we implement the `setPorts` method:

```
private void setPorts(){
    this.switchManagementUseCase =
            new SwitchManagementInputPort(
            SwitchManagementH2Adapter.getInstance()
    );
    this.routerManagementUseCase =
            new RouterManagementInputPort(
            RouterManagementH2Adapter.getInstance()
    );
}
** Code omitted **
```

With the `setPorts` method, we initialize both input ports with the `SwitchManagementH2Adapter` and `RouterManagementH2Adapter` adapters to allow access to the H2 in-memory database.

Let's see how to implement the methods that expose the switch-related operations:

1. We start with a simple operation that just retrieves a switch:

```
/**
 * GET /switch/retrieve/{id}
 * */
public Switch retrieveSwitch(Id switchId) {
    return switchManagementUseCase.
retrieveSwitch(switchId);
}
```

   The `retrieveSwitch` method receives `Id` as a parameter. Then, it utilizes a use case reference to forward the request to the input port.

2. Next, we have a method that lets us create and add a switch to an edge router:

```
/**
 * POST /switch/create
 * */
public EdgeRouter createAndAddSwitchToEdgeRouter(
       Vendor,
       Model,
       IP,
       Location,
       SwitchType, Id routerId
) {
    Switch newSwitch = switchManagementUseCase.
    createSwitch(vendor, model, ip, location,
      switchType);

    Router edgeRouter = routerManagementUseCase.
    retrieveRouter(routerId);
    if(!edgeRouter.getRouterType().equals
      (RouterType.EDGE))
        throw new UnsupportedOperationException(
    "Please inform the id of an edge router to add a
     switch");
```

```
        Router = switchManagementUseCase.
        addSwitchToEdgeRouter(newSwitch, (EdgeRouter)
          edgeRouter);

        return (EdgeRouter)
        routerManagementUseCase.persistRouter(router);
    }
```

We call the switch input port method, `createSwitch`, by passing the parameters received by the `createAndAddSwitchToEdgeRouter` method to create a switch. With `routerId`, we retrieve the edge router by calling the `retrieveRouter` method from the `router` input port. Once we have the `Switch` and `EdgeRouter` objects, we can call the `addSwitchToEdgeRouter` method to add the switch into the edge router. As the last step, we call the `persistRouter` method to persist the operation in the data source.

3. Finally, we have the `removeSwitchFromEdgeRouter` method that allows us to remove a switch from an edge router:

```
    /**
     * POST /switch/remove
     * */
    public EdgeRouter removeSwitchFromEdgeRouter(
    Id switchId, Id edgeRouterId) {
        EdgeRouter =
                (EdgeRouter) routerManagementUseCase.
                             retrieveRouter(edgeRouterId);
        Switch networkSwitch = edgeRouter.
                               getSwitches().
                               get(switchId);
        Router = switchManagementUseCase.
                         removeSwitchFromEdgeRouter(
                         networkSwitch, edgeRouter);
        return (EdgeRouter) routerManagementUseCase.
        persistRouter(router);
    }
```

`removeSwitchFromEdgeRouter` receives `Id` as a parameter for the switch and another `Id` for the edge router. Then, it retrieves the router by calling the `retrieveRouter` method. With the switch ID, it retrieves the `switch` object from the edge router object. Once it gets the `Switch` and `EdgeRouter` objects, it calls the `removeSwitchFromEdgeRouter` method to remove the switch from the edge router.

What's left now is to implement the adapter that deals with the topology and inventory networks.

Network management input adapter

As we did with the router and switch adapters, let's implement the `NetworkManagementGenericAdapter` class by defining first the ports it needs:

```
package dev.davivieira.topologyinventory.framework.adapters.
input.generic;
import dev.davivieira.topologyinventory.application.ports.
input.*;
import dev.davivieira.topologyinventory.application.usecases.*;
import dev.davivieira.topologyinventory.domain.entity.Switch;
import dev.davivieira.topologyinventory.domain.vo.*;
import dev.davivieira.topologyinventory.framework.adapters.
output.h2.*;

public class NetworkManagementGenericAdapter {

    private SwitchManagementUseCase
      switchManagementUseCase;
    private NetworkManagementUseCase
    networkManagementUseCase;
    public NetworkManagementGenericAdapter(){
        setPorts();
    }
```

Besides NetworkManagementUseCase, we also use SwitchManagementUseCase. We need to call the setPorts method from the constructor of NetworkManagementGenericAdapter to properly initialize the input ports objects and assign them to their respective use case references. The following is how we implement the setPorts method:

```
private void setPorts(){
    this.switchManagementUseCase =
             new SwitchManagementInputPort(
             SwitchManagementH2Adapter.getInstance());
    this.networkManagementUseCase =
             new NetworkManagementInputPort(
             RouterManagementH2Adapter.getInstance());
}
/** Code omitted **/
```

As we have done in previous input adapter implementations, we configure the setPorts method to initialize input port objects and assign them to use case references.

Let's implement the network-related methods:

1. First, we implement the addNetworkToSwitch method to add a network to a switch:

```
/**
 * POST /network/add
 * */
public Switch addNetworkToSwitch(Network network, Id
switchId) {
    Switch networkSwitch = switchManagementUseCase.
                           retrieveSwitch(switchId);
    return networkManagementUseCase.
           addNetworkToSwitch(
           network, networkSwitch);
}
```

The addNetworkToSwitch method receives the Network and Id objects as parameters. To proceed, we need to retrieve the Switch object by calling the retrieveSwitch method. Then, we can call the addNetworkToSwitch method to add the network to the switch.

2. Then, we implement the method to remove a network from a switch:

```
/**
 * POST /network/remove
 * */
public Switch removeNetworkFromSwitch(
String networkName, Id switchId) {
    Switch networkSwitch = switchManagementUseCase.
                           retrieveSwitch(switchId);
    return networkManagementUseCase.
           removeNetworkFromSwitch(
           networkName, networkSwitch);
}
```

   First, we get a `Switch` object by calling the `retrieveSwitch` method with the `Id` parameter. To remove a network from a switch, we use the network name to find it from a list of networks attached to the switch. We do that by calling the `removeNetworkFromSwitch` method.

The adapter to manage networks is the last input adapter we had to implement. With these three adapters we can now manage routers, switches, and networks from the Framework hexagon. To make sure these adapters are working well, let's create some tests for them.

Testing the Framework hexagon

By testing the Framework hexagon, we have not just the opportunity to check whether the input and output adapters are working well, but we can also test whether the other hexagons, Domain and Application, are doing their part in response to the requests coming from the Framework hexagon.

To test, we call the input adapters to trigger the execution of everything necessary in downstream hexagons to fulfill the request. We start by implementing tests for the router management adapters. The tests for switches and networks follow the same pattern and are available in the GitHub repository of this book.

For routers, we will put our tests inside the `RouterTest` class:

```
public class RouterTest extends FrameworkTestData {

    RouterManagementGenericAdapter
    routerManagementGenericAdapter;

```

```
    public RouterTest() {
        this.routerManagementGenericAdapter =
        new RouterManagementGenericAdapter();
        loadData();
    }
    /** Code omitted **/
}
```

In the `RouterTest` constructor, we instantiate the `RouterManagementGenericAdapter` input adapter class that we use to perform the tests. The `loadData` method loads some test data from the `FrameworkTestData` parent class.

Once we have correctly configured the requirements of the tests, we can proceed with the testing:

1. First, we test router retrieval:

   ```
   @Test
   public void retrieveRouter() {
       var id = Id.withId(
       "b832ef4f-f894-4194-8feb-a99c2cd4be0c");
       var actualId = routerManagementGenericAdapter.
                      retrieveRouter(id).getId();
       assertEquals(id, actualId);
   }
   ```

   We call the input adapter, informing it of the router `id` we want to retrieve. With `assertEquals`, we compare the expected ID with the actual ID to see if they match.

2. To test router creation, we have to implement the `createRouter` test method:

   ```
   @Test
   public void createRouter() {
       var ipAddress = "40.0.0.1";
       var routerId  = this.

       routerManagementGenericAdapter.createRouter(
               Vendor.DLINK,
               Model.XYZ0001,
   ```

```
                IP.fromAddress(ipAddress),
                locationA,
                RouterType.EDGE).getId();
        var router = this.routerManagementGenericAdapter.
        retrieveRouter(routerId);
        assertEquals(routerId, router.getId());
        assertEquals(Vendor.DLINK, router.getVendor());
        assertEquals(Model.XYZ0001, router.getModel());
        assertEquals(ipAddress,
        router.getIp().getIpAddress());
        assertEquals(locationA, router.getLocation());
        assertEquals(RouterType.EDGE,
        router.getRouterType());
    }
```

From the router input adapter, we call the `createRouter` method to create and persist a new router. Then, we call the `retrieveRouter` method with the ID previously generated by the router we have just created. Finally, we run `assertEquals` to confirm whether the router retrieved from the data source is indeed the router we created.

3. To test the addition of a router to a core router, we have the `addRouterToCoreRouter` test method:

```
    @Test
    public void addRouterToCoreRouter() {
        var routerId = Id.withId(
        "b832ef4f-f894-4194-8feb-a99c2cd4be0b");
        var coreRouterId = Id.withId(
        "b832ef4f-f894-4194-8feb-a99c2cd4be0c");
        var actualRouter =
        (CoreRouter) this.routerManagementGenericAdapter.
        addRouterToCoreRouter(routerId,coreRouterId);
        assertEquals(routerId,
        actualRouter.getRouters().get(routerId).getId());
    }
```

We pass the variables, `routerId` and `coreRouterId`, as parameters to the input adapter's `addRouterToCoreRouter` method that returns a core router. `assertEquals` checks whether the core router has the router we added.

4. To test the removal of a router from a core router, we'll use this code:

```
@Test
public void removeRouterFromCoreRouter(){
    var routerId = Id.withId(
    "b832ef4f-f894-4194-8feb-a99c2cd4be0a");
    var coreRouterId = Id.withId(
    "b832ef4f-f894-4194-8feb-a99c2cd4be0c");
    var removedRouter =
    this.routerManagementGenericAdapter.
    removeRouterFromCoreRouter(routerId,
    coreRouterId);
    var coreRouter =
    (CoreRouter)this.routerManagementGenericAdapter.
    retrieveRouter(coreRouterId);
    assertEquals(routerId, removedRouter.getId());
    assertFalse(
    coreRouter.getRouters().containsKey(routerId));
}
```

This test is very similar to the previous one. We again use the `routerId` and `coreRouterId` variables, but now we also use the `removeRouterFromCoreRouter` method, which returns the removed router. `assertEquals` checks whether the removed router's ID matches the ID from the `routerId` variable.

To run these tests, execute the following command in the Maven project root directory:

```
mvn test
```

The output should be similar to the one here:

```
[INFO]  T E S T S
[INFO] -------------------------------------------------------
[INFO] Running dev.davivieira.topologyinventory.framework.
NetworkTest
```

```
[INFO] Tests run: 2, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 0.654 s - in dev.davivieira.topologyinventory.
framework.NetworkTest
[INFO] Running dev.davivieira.topologyinventory.framework.
RouterTest
[INFO] Tests run: 4, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 0.014 s - in dev.davivieira.topologyinventory.
framework.RouterTest
[INFO] Running dev.davivieira.topologyinventory.framework.
SwitchTest
[INFO] Tests run: 3, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 0.006 s - in dev.davivieira.topologyinventory.
framework.SwitchTest
```

Along with `RouterTest`, we also have tests from `SwitchTest` and `NetworkTest` that you can find in the book's GitHub repository, as mentioned before.

By implementing the Framework hexagon tests, we conclude the development of the Framework hexagon and the whole topology and inventory system's backend. Taking what we've learned from this chapter and the previous chapters, we could apply all the techniques covered to create a system following the hexagonal architecture principles.

Summary

We started the Framework hexagon construction by implementing first the output adapters to enable the topology and inventory system to use as its primary data source an H2 in-memory database.

Then, we created three input adapters: one for router operations, another one for switch operations, and the last one for network-related operations. To conclude, we implemented tests to ensure that the adapters and the whole hexagonal system work as expected. By completing the development of the Framework hexagon, we finished the development of our overall hexagonal system.

We can improve the hexagonal system we have created by exploring the possibilities offered by the **Java Platform Module System** (**JPMS**). For example, we can leverage the hexagonal modular structure to apply the **Dependency Inversion Principle** (**DIP**). By doing so, we can make the hexagonal system more loosely coupled. We shall examine the DIP and other exciting features in the next chapter.

Questions

1. Which other Java modules does the `Framework hexagon` Java module depend on?
2. Why do we need to create the output adapters?
3. In order to communicate with the input ports, the input adapters instantiate input port objects and assign them to an interface reference. What's that interface?
4. When we test a Framework hexagon's input adapter, we are also testing other hexagons. Why does that happen?

9
Applying Dependency Inversion with Java Modules

In the previous chapters, we learned how to develop each hexagon as a Java module. By doing that, we started to enforce the scope and responsibilities of each hexagon in the architecture. But we did not go too far in exploiting the Java module's features, such as encapsulation and dependency inversion, and how these features can enhance the overall structure of a hexagonal system by making it more robust and loosely coupled.

To understand the role that's played by the **Java Platform Module System** (**JPMS**) in developing a hexagonal system, we need to understand what problems JPMS aims to solve. Once we know what we can do with JPMS in terms of encapsulation and dependency inversion, we can apply these techniques in conjunction with the hexagonal architecture.

So, in this chapter, we will learn how to combine JPMS with the hexagonal architecture to create a well-encapsulated system with clearly defined boundaries that are reinforced by the system's modular structure and dependency inversion techniques. We'll cover the following topics:

- Introducing JPMS
- Inverting dependencies on a hexagonal application
- Using the Java platform's `ServiceLoader` class to retrieve JPMS provider implementations

By the end of this chapter, you will have learned how to use services, consumers, and providers from JPMS to apply dependency inversion and encapsulation principles for a hexagonal system.

Technical requirements

To compile and run the code examples presented in this chapter, you will need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. They are all available for the Linux, Mac, and Windows operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter09`.

Introducing JPMS

Before **Java SE 9**, the only mechanism we had to handle dependencies in Java was the `classpath` parameter. The `classpath` parameter is where we put dependencies in the form of **JAR files**. However, the problem is that there is no way to determine which JAR file a particular dependency came from. If you have two classes with the same name, in the same package, and present in two different JAR files, one of the JAR files would be loaded first, causing one JAR file to be shadowed by the other.

Shadowing is the term we use to refer to a situation where two or more JAR files that contain the same dependency are put into the `classpath` parameter, but only one of the JAR files is loaded, shadowing the rest. This JAR dependency entanglement issue is also known as **JAR hell**. A symptom that indicates that things are not so good with dependencies that have been loaded into the `classpath` parameter is when we see unexpected `ClassNotFoundException` exceptions at system runtime.

JPMS cannot completely prevent JAR hell issues related to dependency version mismatches and shadowing. Still, the modular approach helps us have a better view of the dependencies that are needed by a system. This broader dependency perspective is helpful to prevent and diagnose such dependency issues.

Before JPMS, there was no way to control access to public types from different JAR files. The default behavior of a **Java Virtual Machine** (**JVM**) is to always make these public types available between other JAR files, which often leads to collisions involving classes with the same name and package.

JPMS introduced the `module` path and a strict encapsulation policy that restricts, by default, access to all public types between different modules. No longer can all public types be accessed from other dependencies. With JPMS, `module` has to state which packages that contain public types are available to other modules. We did that by using the `exports` directive on the `domain` hexagon module:

```
module domain {
    exports dev.davivieira.topologyinventory.domain.entity;
    exports dev.davivieira.topologyinventory.domain.entity
      .factory;
    exports dev.davivieira.topologyinventory.domain
      .service;
    exports dev.davivieira.topologyinventory.domain
      .specification;
    exports dev.davivieira.topologyinventory.domain.vo;
    requires static lombok;
}
```

Then, to access the `domain` hexagon module, we used the `requires` directive in the `application` hexagon module:

```
module application {
    requires domain;
}
```

This modularization mechanism assembles code in a new Java construct called a `module`. As we saw previously, `module` may have to determine which package it intends to export and which other modules it requires. In this arrangement, we have more control over the things our application exposes and consumes.

If you're targeting development on cloud-based environments and care for performance and cost, the `module` system's nature allows you to construct a customized Java runtime (known in the past as **JRE**) containing just the modules required to run the application. With a smaller Java runtime, both the application startup time and memory usage will decrease. Let's say we're talking about hundreds – even thousands – of Kubernetes Pods running Java in the cloud. With a smaller Java runtime, we can achieve a considerable economy regarding computational resource consumption.

Now that we are more acquainted with JPMS's motivations and benefits, let's go back to developing our topology and inventory system. We will learn how to use more advanced JPMS features to enhance encapsulation and adherence to dependency inversion principles.

Inverting dependencies on a hexagonal application

The **Dependency Inversion Principle** (**DIP**), as introduced by Robert C. Martin, states that high-level components should not depend on low-level components. Instead, both of them should depend on abstractions. At first glance, for some, it may not be so obvious to understand such a concept. *After all, what do high- and low-level components mean? And what kind of abstractions are we talking about?*

A high-level component has a set of operations orchestrated to enable a major system behavior. A high-level component may rely on low-level components to provide a major system behavior. A low-level component, in turn, utilizes a specialized behavior that supports the goals of a high-level component. Let's consider a client code that acts as the high-level component because it depends on and consumes the functionalities provided by the low-level component.

The high-level component can be either a concrete or abstract element, while the low-level component should be concrete because it always provides implementation details.

Let's consider some client code as a high-level component that calls methods on serving code. The serving code, in turn, can be regarded as a low-level component. This low-level component contains the implementation details. In procedural programming designs, it's common to see high-level components depending directly on the implementation details provided by low-level components. Martin says that this direct dependency on implementation details is bad because it makes the system rigid. For example, if we change these implementation details on the low-level components, such changes can cause immediate problems on the high-level components that depend directly on them. That's where this rigidity comes from: we cannot change one part of the code without causing side effects in other parts.

To invert the dependency, we need to make the high-level component depend on the same abstraction that the low-level component is derived from. In object-oriented designs, we can achieve this feat by using abstract classes or interfaces. The low-level component implements an abstraction, whereas the high-level component refers to that abstraction instead of the low-level implementation. So, this is what we have to do to invert the dependencies properly.

JPMS introduced a mechanism to help us avoid this dependency on implementation details. This mechanism is based on consumers, services, and providers. In addition to these three JPMS elements, there is one more, already known in previous Java versions, called `ServiceLoader`, which enables the system to find and retrieve implementations of a given abstraction.

We call a consumer with a module that declares the need to consume a service provided by a provider module through the `uses` directive. This `uses` directive states the name of an interface or abstract class that represents the service we intend to use. The service, in turn, is the object that implements the interface or extends the abstract class that's informed in the `uses` directive. The provider is a module that declares the service interface and its implementations with the providers and directives, respectively.

Let's see how we can use JPMS to apply this DIP to our hexagonal system, topology and inventory. We'll also see a representation for inverting dependencies using input adapters, use cases, and input ports.

Providing services with use cases and input ports

When developing the topology and inventory system, we designed use cases as interfaces and input ports as implementations for these interfaces. We can consider use cases and input ports as the hexagonal architecture components that match the JPMS definition for a service. The Application hexagon module can be regarded as the module that provides the service. *And what about the consumer?* The Framework hexagon module is the direct consumer of the Application hexagon module.

Based on that reasoning, we'll re-implement both the Application and Framework hexagon modules so that the input adapters from the Framework hexagon will no longer need to depend on the input port implementations from the Application hexagon. Instead, the input adapters will only depend on the use case interface types, rather than the input ports concrete types. In such a context, we can regard input adapters as high-level components and input port as low-level components. Input adapters refer to use case interfaces.

Input ports implement these use cases. The following diagram illustrates this:

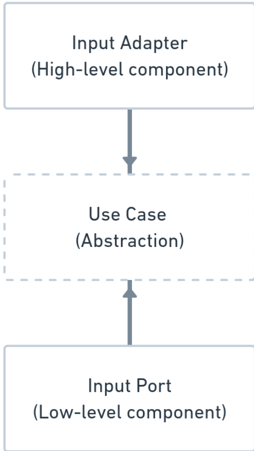

Figure 9.1 – Dependency inversion with an input adapter, use case, and input port

The preceding diagram illustrates how we can approach dependency inversion in the hexagonal architecture. This example considers the dependency inversion between the Framework and Application hexagons, but we can do the same thing with the Domain hexagon as well.

Let's consider how `RouterManagementGenericAdapter` is currently accessing the implementation details instead of the abstraction:

```
private RouterManagementUseCase;

public RouterManagementGenericAdapter(){
    setPorts();
}

private void setPorts(){
    this.routerManagementUseCase = new
      RouterManagementInputPort(
            RouterManagementH2Adapter.getInstance()
    );
}
```

By calling `new RouterManagementInputPort(RouterManagementH2Adapter.getInstance())`, we are making the input adapter depend on the implementation details of both the `RouterManagementInputPort` input port and the output adapter expressed by `RouterManagementH2Adapter`.

To make an input port class eligible to be used as a provider class in JPMS, we need to do the following:

1. First, we must add a no-arguments constructor:

```
@NoArgsConstructor
public class RouterManagementInputPort implements
RouterManagementUseCase {
/** Code omitted **/
}
```

2. Then, we must declare the `setOutputPort` method in the use case interface:

```
public interface RouterManagementUseCase {
    void setOutputPort(
    RouterManagementOutputPort
      routerManagementOutputPort);
}
```

3. Lastly, we must implement the `setOutputPort` method in the input port:

```
@Override
public void setOutputPort(RouterManagementOutputPort
routerManagementOutputPort) {
    this.routerManagementOutputPort =
    routerManagementOutputPort;
}
```

Now, we can update the Application hexagon's `module` descriptor to define the services that we'll provide by using the use case interfaces and their input port implementations:

```
module application {
    requires domain;
    requires static lombok;

    exports dev.davivieira.topologyinventory.application
      .ports.
```

```
    input;
    exports dev.davivieira.topologyinventory.application
      .ports.
    output;
    exports dev.davivieira.topologyinventory.application
      .usecases;
/** Code omitted **/
}
```

We start by declaring the dependency that the `application` module has on the Domain hexagon and `lombok` modules. Then, we use `exports` to enable access to the input ports, output ports, and use cases.

Next, we must declare the services we want to provide. We can accomplish this service declaration by providing a use case interface and the input port that implements it. Let's declare the service provider for router management:

```
    provides dev.davivieira.topologyinventory.application
      .usecases.
    RouterManagementUseCase
    with dev.davivieira.topologyinventory.application.ports
      .input.
    RouterManagementInputPort;
```

In the preceding code, `RouterManagementUseCase` is being provided by `RouterManagementInputPort`.

Next, we must define the service provider for switch management:

```
    provides dev.davivieira.topologyinventory.application
      .usecases.
    SwitchManagementUseCase
    with dev.davivieira.topologyinventory.application.ports
      .input.
    SwitchManagementInputPort;
```

In the preceding code, `SwitchManagementUseCase` is being provided by `SwitchManagementInputPort`.

Finally, we must declare the service provider for network management:

```
    provides dev.davivieira.topologyinventory.application
      .usecases.
    NetworkManagementUseCase
    with dev.davivieira.topologyinventory.application.ports
      .input.
    NetworkManagementInputPort;
```

Here, we have `NetworkManagementUseCase` being provided by `NetworkManagementInputPort`.

Before we learn how to access these input ports through JPMS services in input adapters, let's learn how we can invert dependencies when working with output ports and output adapters.

Providing services with output ports and output adapters

In the Framework hexagon, we have output ports as interfaces and output adapters as their implementations. Input ports depend on output ports. In that sense, input ports can be regarded as high-level components because they depend on the abstractions provided by output ports. Output adapters act as low-level components that provide implementations for output port abstractions. The following diagram shows an illustration of this dependency inversion arrangement:

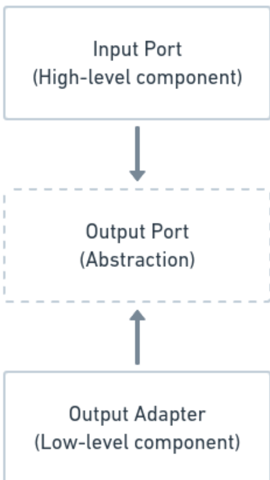

Figure 9.2 – Dependency inversion with an input port, output port, and output adapter

Note that both the input port and the output adapter point to the same output port abstraction. This means that we can use JPMS to apply the dependency inversion principle with these architecture components.

However, there is one requirement we have to meet to use output adapters as implementation providers. This requirement requires every provider class to have a public constructor with no parameters, which is not the case for the output adapters we implemented in the previous chapters:

```
private RouterManagementH2Adapter(){
    setUpH2Database();
}
```

We implemented the `RouterManagementH2Adapter` constructor as a `private` one to enforce a singleton pattern. To show how to use this output adapter as a JPMS service provider, we need to disable the singleton pattern by changing the constructor's access modifier from `private` to `public`:

```
public RouterManagementH2Adapter(){
    setUpH2Database();
}
```

Now, we can update the `framework` hexagon's `module` (the `info.java` file) to define the services:

```
module framework {
    requires domain;
    requires application;

    /** Code omitted **/

    exports dev.davivieira.topologyinventory.framework
      .adapters.
    output.h2.data;
    opens dev.davivieira.topologyinventory.framework
      .adapters.
    output.h2.data;

    provides dev.davivieira.topologyinventory.application
      .ports.
```

```
    output.RouterManagementOutputPort
    with dev.davivieira.topologyinventory.framework
      .adapters.output.
    h2.RouterManagementH2Adapter;

    provides dev.davivieira.topologyinventory.application
      .ports.
    output.SwitchManagementOutputPort
    with dev.davivieira.topologyinventory.framework
      .adapters.output.
    h2.SwitchManagementH2Adapter;
}
```

We start by using the `requires` directive to declare the module dependencies on the Domain and Application hexagon modules. Then, we use the `exports` directive to enable access to all public types in the `dev.davivieira.topologyinventory.framework.adapters.output.h2.data` package. We use the `opens` directive to allow runtime reflective access to the output adapters. We need this reflective access because of the database library dependencies that these output adapters have.

Finally, we use the `provides` and `with` directives to inform the output port interfaces, `RouterManagementOutputPort` and `SwitchManagementOutputPort`, along with their respective output adapter implementations, `RouterManagementH2Adapter` and `SwitchManagementH2Adapter`.

Now that we are done with the configuration that's required to enable dependency inversion between the output ports and adapters, let's learn how to configure input adapters to access dependencies through their abstractions.

Making the input adapters dependent on abstractions

The first step in consuming the services we have exposed with the `provides` and `with` directives is to update the `module` descriptor of the consumer's `framework` hexagon module by utilizing the `uses` directive. We'll execute the following steps to do so:

1. Let's start by updating the module descriptor:

```
module framework {
    /** Code omitted **/
    uses dev.davivieira.topologyinventory.application
      .usecases
```

```
        .RouterManagementUseCase;
        uses dev.davivieira.topologyinventory.application
          .usecases
        .SwitchManagementUseCase;
        uses dev.davivieira.topologyinventory.application
          .usecases
        .NetworkManagementUseCase;
        uses dev.davivieira.topologyinventory.application
          .ports.output
        .RouterManagementOutputPort;
        uses dev.davivieira.topologyinventory.application
          .ports.output
        .SwitchManagementOutputPort;
    }
```

The first three `uses` directives point to the services provided by the Application hexagon module. The last two `uses` directives refer to the services we exposed in the Framework hexagon module.

Now that we have the `module` descriptors adequately configured to allow the system to depend on interfaces instead of implementations, we need to refactor the input adapters to rely only on use case interfaces from the Application hexagon module.

2. First, we must configure the `RouterManagementGenericAdapter` adapter:

```
  public class RouterManagementGenericAdapter {

      private RouterManagementUseCase
        routerManagementUseCase;

      public RouterManagementGenericAdapter(
      RouterManagementUseCase routerManagementUseCase) {
          this.routerManagementUseCase =
            routerManagementUseCase;
      }
      /** Code omitted **/
  }
```

Note that `RouterManagementGenericAdapter` no longer depends on `RouterManagementInputPort` and `RouterManagementH2Adapter`, as it did previously. There is only one dependency on the `RouterManagementUseCase` interface.

3. For the `SwitchManagementGenericAdapter` input adapter, this is how we should configure the dependency:

```
public class SwitchManagementGenericAdapter {

    private SwitchManagementUseCase
      switchManagementUseCase;
    private RouterManagementUseCase
      routerManagementUseCase;

    public SwitchManagementGenericAdapter (
    RouterManagementUseCase,
    SwitchManagementUseCase switchManagementUseCase){
        this.routerManagementUseCase =
          routerManagementUseCase;
        this.switchManagementUseCase =
          switchManagementUseCase;
    }
    /** Code omitted **/
}
```

The `SwitchManagementGenericAdapter` input adapter depends on both the `RouterManagementUseCase` and `SwitchManagementUseCase` use case interfaces to perform its activities.

4. To conclude, we have to adjust the `NetworkManagementGenericAdapter` adapter class:

```
public class NetworkManagementGenericAdapter {

    private SwitchManagementUseCase
      switchManagementUseCase;
    private NetworkManagementUseCase
      networkManagementUseCase;

```

```
    public NetworkManagementGenericAdapter(
    SwitchManagementUseCase,
    NetworkManagementUseCase networkManagementUseCase) {
        this.switchManagementUseCase =
          switchManagementUseCase;
        this.networkManagementUseCase =
          networkManagementUseCase;
    }
    /** Code omitted **/
}
```

The `NetworkManagementGenericAdapter` input adapter follows the same pattern we used in the previous input adapters and requires use case references in the input adapter's constructor. Here, we're making use of the `SwitchManagementUseCase` and `NetworkManagementUseCase` use case interfaces.

In this section, we touched on a crucial JPMS feature: service providers. By using them, we can bind input port implementations to the use case interfaces. That's how we arrange the code. So, the input adapters can rely on use case abstractions to trigger operations on the Application hexagon.

Now, let's learn how to use `ServiceLoader` to retrieve service implementations based on the JPMS providers we have defined.

Using the Java platform's ServiceLoader class to retrieve JPMS provider implementations

So far, we have configured the `module` descriptor of the Application and Framework hexagon modules. We have refactored the input adapters so that they only depend on the abstractions provided by use cases interfaces. *But how can we retrieve the concrete instances that implement those use cases interfaces?* That's exactly what the `ServiceLoader` class does.

`ServiceLoader` is not a new class made solely to support JPMS features. Instead, `ServiceLoader` has been present in Java since version **1.6**. From **Java 9** onward, this class was enhanced to work with the Java modules' services. It relies on the configuration provided by the `module` descriptor to find implementations for a given service provider interface.

To illustrate how we can use `ServiceLoader`, let's update the `FrameworkTestData` test class by creating a method called `loadPortsAndUseCases`. This method uses `ServiceLoader` to retrieve the objects we need to instantiate the input adapters. We need to create the `loadPortsAndUseCases` method because we'll call it to initialize the input adapters through `ServiceLoader`. Before creating the `loadPortsAndUseCases` method, we need to declare the input adapter variables that we'll use to assign the objects that are instantiated with the aid of `ServiceLoader`:

```
public class FrameworkTestData {
  protected RouterManagementGenericAdapter
  routerManagementGenericAdapter;
  protected SwitchManagementGenericAdapter
  switchManagementGenericAdapter;
  protected NetworkManagementGenericAdapter
  networkManagementGenericAdapter;
  /** Code omitted **/
}
```

The variables we've declared here are used to store references for the input adapters we'll create using the input port and output adapter objects that we obtained from the `ServiceLoader` class.

Let's start by initializing `RouterManagementGenericAdapter`.

Initializing RouterManagementGenericAdapter

We will start the `loadPortsAndUseCases` method's implementation by using a `ServiceLoader` instance to retrieve the objects that are necessary for instantiating `RouterManagementGenericAdapter`. We'll perform the following steps to do this:

1. The following code shows the `loadPortsAndUseCases` method's initial implementation:

```
protected void loadPortsAndUseCases() {
  // Load router implementations
  ServiceLoader<RouterManagementUseCase>
    loaderUseCaseRouter =
  ServiceLoader.load(RouterManagementUseCase.class);
  RouterManagementUseCase =
```

```
    loaderUseCaseRouter.findFirst().get();
    // Code omitted //
  }
```

The `load` method from `ServiceLoader` receives a `RouterManagementUseCase.class` file as a parameter. This method can find all the implementations for the `RouterManagementUseCase` interface. Since `RouterManagementInputPort` is the only implementation that's available for the use case interface, we can call `loaderUseCaseRouter.findFirst().get()` to get that implementation.

Aside from a proper implementation for the `RouterManagementUseCase` interface, we also need to provide an implementation for the `RouterManagementOutputPort` interface.

2. The following code shows how to retrieve a `RouterManagementOutputPort` object:

```
ServiceLoader<RouterManagementOutputPort>
loaderOutputRouter =
ServiceLoader.load(RouterManagementOutputPort.class);
RouterManagementOutputPort = loaderOutputRouter.
findFirst().get();
```

The call on `loaderOutputRouter.findFirst().get()` retrieves a `RouterManagementH2Adapter` object, which is the only implementation that's available for the `RouterManagementOutputPort` interface.

With the `RouterManagementInputPort` and `RouterManagementH2Adapter` objects loaded from `ServiceLoader`, we have the required objects to create an input adapter. But first, we need to set up the output port for the use case.

3. This is how we can set a `RouterManagementOutputPort` object in `RouterManagementUseCase`:

```
routerManagementUseCase.
setOutputPort(routerManagementOutputPort);
```

By calling `routerManagementUseCase.setOutputPort(routerManagementOutputPort)`, we are setting `RouterManagementOutputPort` in `RouterManagementUseCase`.

4. Now, we can create a new `RouterManagementGenericAdapter` adapter by passing `RouterManagementUseCase`, which we have just created, to its constructor:

```
this.routerManagementGenericAdapter =
new
RouterManagementGenericAdapter(routerManagementUseCase);
```

Now, let's move on and learn how to initialize `SwitchManagementGenericAdapter`.

Initializing SwitchManagementGenericAdapter

Still inside the `loadPortsAndUseCases` method, we need to use `ServiceLoader` to find an available implementation for `SwitchManagementUseCase`. We'll perform the following steps for the same reason:

1. In the following code, we are retrieving a `SwitchManagementUseCase` implementation:

```
ServiceLoader<SwitchManagementUseCase> loaderUseCaseSwitch
= ServiceLoader.load(SwitchManagementUseCase.class);
SwitchManagementUseCase = loaderUseCaseSwitch.
findFirst().get();
```

   By calling `ServiceLoader.load(SwitchManagementUseCase.class)`, we are retrieving a `ServiceLoader` object containing all the available implementations for `SwitchManagementUseCase`. In our case, the only available implementation is the `SwitchManagementInputPort` input port. To load such an implementation, we must call `loaderUseCaseSwitch.findFirst().get()`.

   We also need an implementation for the `SwitchManagementOutputPort` output port.

2. The following code shows how we can get a `SwitchManagementOutputPort` implementation:

```
ServiceLoader<SwitchManagementOutputPort>
loaderOutputSwitch = ServiceLoader.
load(SwitchManagementOutputPort.class);
SwitchManagementOutputPort = loaderOutputSwitch.
findFirst().get();
```

Output adapters implement output ports. So, to get an output port implementation, we should call `ServiceLoader.load(SwitchManagementOutputPort.class)` to load the `SwitchManagementH2Adapter` implementation and then call `loaderOutputSwitch.findFirst().get()` to retrieve that implementation object.

3. Now, we can use the output port object to set it in the use case:

```
switchManagementUseCase.
setOutputPort(switchManagementOutputPort);
```

4. Finally, we can initiate the input adapter:

```
this.switchManagementGenericAdapter =
new SwitchManagementGenericAdapter(
routerManagementUseCase, switchManagementUseCase);
```

To instantiate `SwitchManagementGenericAdapter`, we need to pass references for both the `RouterManagementUseCase` and `SwitchManagementUseCase` use cases.

Now, let's move on and learn how to initialize `NetworkManagementGenericAdapter`.

Initializing NetworkManagementGenericAdapter

For `NetworkManagementGenericAdapter`, we only need to load an implementation for `NetworkManagementUseCase`. Follow these steps to do so:

1. The following code shows how we should use `ServiceLoader` to get a `NetworkManagementUseCase` object:

```
ServiceLoader<NetworkManagementUseCase>
loaderUseCaseNetwork = ServiceLoader.
load(NetworkManagementUseCase.class);
NetworkManagementUseCase = loaderUseCaseNetwork.
findFirst().get()
```

2. Then, we must reuse `RouterManagementOutputPort`, which we loaded previously, to set `NetworkManagementUseCase`:

```
networkManagementUseCase.
setOutputPort(routerManagementOutputPort);
```

3. Finally, we can initiate `NetworkManagementGenericAdapter`:

```
this.networkManagementGenericAdapter = new
NetworkManagementGenericAdapter(switchManagementUseCase,
networkManagementUseCase);
```

To initiate a new `NetworkManagementGenericAdapter` adapter, we must pass references for the `SwitchManagementUseCase` and `NetworkManagementUseCase` use cases.

This section taught us how to retrieve interface implementations using `ServiceLoader` in conjunction with JPMS service providers. With this technique, we can structure code that only relies on abstractions rather than implementations.

Summary

In this chapter, we started by looking into the motivations and benefits behind JPMS. We discovered that one of the problems JPMS helps to solve is that of JAR hell, where it's difficult to control the dependencies that an application should expose and use. JPMS addresses this problem by closing access to every public type in a module, requiring the developer to explicitly state which packages containing public types should be visible to other modules. Also, the developer should state the modules that a given module depends on in the `module` descriptor.

We discussed the DIP and recognized the use cases, input ports, input adapters, and output adapters as components that we can apply to the DIP. Then, we used JPMS features such as consumers, services, and providers to refactor the topology and inventory system to enable dependency inversion in conjunction with hexagonal architecture components.

By employing DIP, we created a more supple design, an important characteristic when it comes to building change-tolerant systems. We learned that JPMS is a Java technology that we can use to implement DIP. Such technology also enables us to provide robust encapsulation by isolating related code into modules. This capability is paramount if we wish to establish and enforce boundaries between the Domain, Application, and Framework hexagons.

In the next chapter, we'll start our journey into the cloud-native world by learning about the Quarkus framework and how to use it to prepare and optimize a hexagonal system to run in a cloud-native environment.

Questions

1. Which JAR dependency problem does JPMS aim to solve?
2. Which JPMS directive should we use to enable access to a package containing public types?
3. To declare a dependency on a module, which JPMS directive should we use?
4. When applying dependency inversion on the hexagonal architecture, which components can be regarded as high-level, abstraction, and low-level?

Further reading

- *The Dependency Inversion Principle*, by Robert C. Martin, C++ Report, 1996.

Section 3: Becoming Cloud-Native

In this section, you will integrate the Quarkus framework into this hexagonal application, making it truly modern cloud-native software ready to be deployed on cloud environments. We'll learn how to add Quarkus to our existing topology and inventory system.

Then, we'll explore some of the exciting Quarkus features, such as CDI Beans, RESTEasy Reactive, and Hibernate Reactive. After combining Quarkus and hexagonal architecture, we'll learn how to dockerize and create Kubernetes objects to deploy our hexagonal application to a Kubernetes cluster. And to finish the book, we'll discuss some good design practices you can follow to create robust hexagonal systems.

This section comprises the following chapters:

10
Adding Quarkus to a Modularized Hexagonal Application

This chapter expands our horizons by exploring the concepts and technologies needed to turn our hexagonal application into a cloud-native one. To support us in our journey to the cloud, we have Quarkus as the key technology, which is a prominent Java cloud-native framework. To understand Quarkus and learn how to leverage its features to enhance a hexagonal system, we need to revisit some fundamental knowledge related to the inner workings of the **Java Virtual Machine** (**JVM**). By understanding the main JVM characteristics and how they work, we can better understand the problems Quarkus aims to solve.

In this chapter, we'll also conduct a brief tour of Quarkus' main features to have an idea of what we can do with such a fine piece of software. Once we're acquainted with Quarkus, we'll take our first step in transforming our hexagonal system into a cloud-native one. To accomplish that, we'll create a brand-new Java module and configure Quarkus dependencies.

These are the topics that we'll cover in this chapter:

- Revisiting the JVM
- Introducing Quarkus
- Adding Quarkus to a modularized hexagonal application

By the end of this chapter, you'll know how to configure Quarkus to work with a hexagonal application. That's the first step in preparing the system to receive all the cloud-native features Quarkus has to offer.

Technical requirements

To compile and run the code examples presented in this chapter, you need the latest **Java Standard Edition (SE) Development Kit** and **Maven 3.6** installed on your computer. They are all available for Linux, Mac, and Windows operating systems. You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter10`.

Revisiting the JVM

The **Virtual Machine** (**VM**) concept wasn't something new when Java arrived back in 1995. Before that time, many other languages used VMs, though they weren't so popular among developers. Java architects decided to use VMs because they wanted a mechanism to create platform independence to improve developer productivity.

Before elaborating on the VM concept, let's first check what we can run inside a VM for Java. In languages such as C or C++, we compile source code into a native code tailored for a specific operating system and CPU architecture. When programming in Java, we compile the source code into bytecode. The JVM understands the instructions contained in bytecode.

The VM idea comes from a concept where it is possible to run programs in an intermediate or virtual environment sitting atop the real machine. In such an arrangement, the program does not need to communicate directly with the underlying operating system—the program deals only with a VM. The VM then converts bytecode instructions into native-code ones.

We can express one of the JVM's advantages with a well-known Java motto: *write once, run anywhere*. Back in the day, and I think even now, it was very appealing to use a language that allowed you to develop software that, without recompilation, could run in different operating systems and CPU architectures. For other languages such as C++, you'd need to adjust your code for every targeted operating system and CPU architecture, prompting more effort to make your program compatible with different platforms.

In today's world of cloud computing, we have services such as Docker and Kubernetes that make software units more portable than ever. To achieve portability in Java, we have the prerogative to execute the same compiled bytecode into different JVMs running in different operating systems and CPU architectures. Portability is possible because every JVM implementation must comply with the JVM specification, no matter where or how it's implemented.

On the other hand, we can use container virtualization to achieve portability by packing the compiled software with its runtime environment and dependencies into a container image. A container engine running on different operating systems and CPU architectures can create containers based on container images.

The JVM's appeal in making portable software at the expense of converting bytecode into native code is no longer attractive when you have faster and cheaper alternatives. Today, you can pack your application—without the need for a JVM and also recompilation—into a Docker image and distribute it across different operating systems and CPU architectures. But we should not forget how robust and time-tested a piece of software such as the JVM is. We'll return to our discussion on Docker and Kubernetes soon, but for now, let's examine some more interesting JVM characteristics.

Another important JVM aspect is related to memory management. With Java, a developer doesn't need to worry about how the program deals with memory release and allocation. Such responsibility is transferred to the JVM, so the developer can focus more on their program's functional details than on the technical ones. Ask any C++ developer how much fun it is to debug memory leaks on large systems.

The feature responsible for managing memory inside the JVM is called a **garbage collector**. Its purpose is to automatically check when an object is no longer used or referenced so that the program can free the unused memory. The JVM may use algorithms that trace object references and mark for releasing those that are no longer referencing any object. This kind of algorithm is called **mark and sweep**.

Garbage collectors are not required to exist in every JVM implementation, but as long as memory resources remain a constraint in computation, we'll often see JVM implementations with garbage collectors.

The JVM is also in charge of the whole life cycle of an application. It all starts with the loading of a Java class file into the VM. When we compile a Java source file, the compiler generates a Java class file containing bytecode. Bytecode is a format recognizable by the JVM. A VM's primary goal is to load and process this bytecode through algorithms and data structures that implement and respect a JVM specification.

The following diagram illustrates what it takes to execute a Java program:

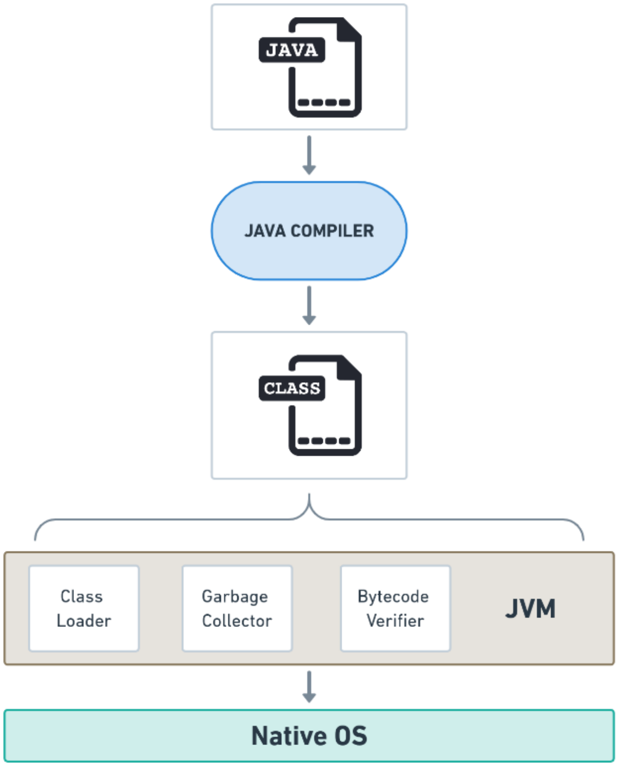

Figure 10.1 – Java compilation and class loading with the JVM

It all starts with the Java source code file that is compiled into a Java class file (bytecode) by the Java compiler. This bytecode is read by the JVM and translated into instructions that are understood by the **Native OS**.

This bytecode thing has been an object of relentless work for people trying to find faster ways to deal with bytecode.

As time went on, the JVM received good improvements and enhanced techniques that considerably improved bytecode loading performance. Among these techniques, we can quote **Just-in-Time** (**JIT**) and **Ahead-of-Time** (**AOT**) compilations. Let's examine both of them.

Speeding up runtime performance with JIT compilation

JIT compilers come from the idea that certain program instructions can be optimized for better performance while the program is running. So, to accomplish such optimization, the JIT compiler seeks program instructions with the potential to be optimized. In general, these instructions are the ones most executed by the program.

Because these instructions are executed so often, they consume a significant amount of computer time and resources. Remember that these instructions are in bytecode format. A traditional compiler would compile all the bytecode into native code before running the program. With a JIT compiler, things are different, as shown in the following diagram:

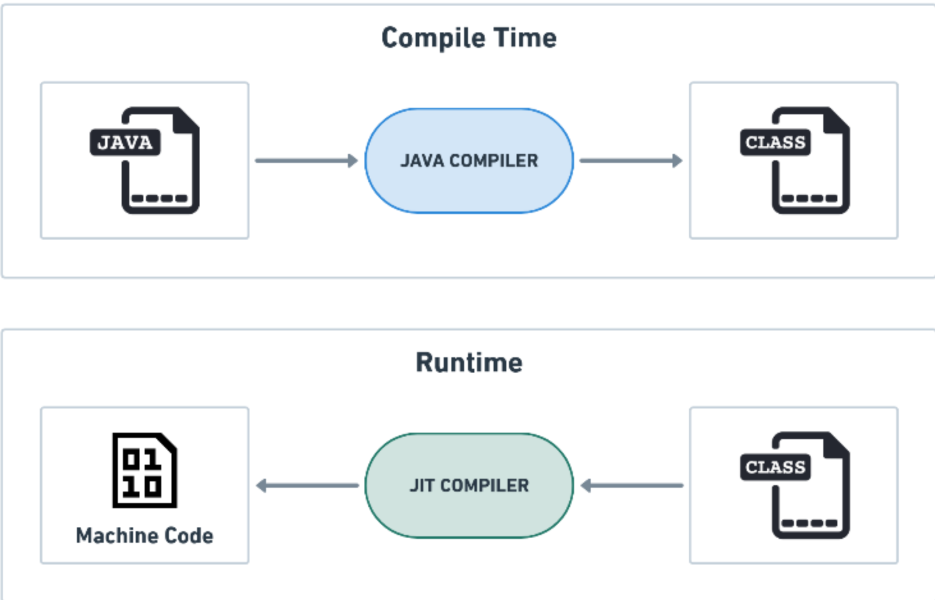

Figure 10.2 – How JIT works

A JIT compiler selects, by using its dynamic optimization algorithms, some parts of the bytecode. Then, it compiles and applies optimizations to these bytecode parts. The result is optimized native code tweaked to provide better performance for the system. The term *just-in-time* is used because the optimizations are done right before the code is executed.

But there is no such thing as a free lunch when using JIT compilers. One of the most well-known drawbacks of JIT compilers is the increased startup time of an application because of the initial optimizations a JIT compiler does before running the program. In order to overcome this startup problem, there is another technique called AOT compilation. Various cloud-native frameworks, including Quarkus, have used this technique. Let's see how AOT compilation works.

Improving startup time with AOT compilation

AOT is so appealing in the Java scene because traditional Java systems—mainly those based on enterprise application servers such as **JBoss** and **WebLogic**—take too much time to initiate. In addition to slower startup times, we have to consider the amount of computing power those application servers consume. These characteristics are a deal-breaker for anyone who wants to migrate Java workloads to the cloud, where instances and Kubernetes Pods are brought up and down frantically. So, by employing AOT in Java, we give up the cross-platform capability provided by the JVM and its bytecode for better performance provided by AOT and its native code. The cross-platform problem is mitigated to some extent with the usage of container technologies such as Docker and Kubernetes.

Here, we have a representation showing how straightforward the AOT compilation process is to transform Java bytecode into **Machine Code**:

Figure 10.3 – How AOT works

Not everything is an advantage with AOT in Java. An AOT compiler spends more time generating a native binary than a Java compiler needs to create bytecode classes. So, AOT compilation can cause a considerable impact on **continuous integration** (**CI**) pipelines. Also, the developer needs to do some additional work to get things working properly to use reflection. **GraalVM** is the AOT compiler used to provide a native binary for Java and other JVM-based languages.

With Quarkus, we have the prerogative to create applications using either JIT or AOT compilation methods. It's up to us to decide which technique suits our needs better. In this section, we gained some background knowledge about the inner workings of the JVM and how it tries to improve bytecode loading with JIT and AOT compilation. Such knowledge is important for understanding how Quarkus works under the hood and achieves considerable performance improvements.

Now that we are acquainted with some JVM fundamentals and essential compilation techniques, let's dive in and learn more about Quarkus' main features.

Introducing Quarkus

Focused on performance, Quarkus comes with built-in support for native executables based on GraalVM, making it possible to achieve swift startup times.

To help developers, it offers valuable things such as live development, a feature that enhances productivity by avoiding the need to restart an application whenever something changes in your code.

Targeting cloud-native environments, Quarkus comes ready with the proper tooling to allow you to deal with constraints and leverage the benefits that come when developing software to run in container-based environments such as Kubernetes.

Borrowing good ideas from enterprise development, Quarkus is built on top of well-established standards such as the **Contexts and Dependency Injection** (**CDI**) framework, the **Jakarta Persistence API** (**JPA**) specification with Hibernate ORM implementation, and the **Jakarta RESTful Web Services** (**JAX-RS**) specification implemented by RESTEasy. For those coming from the Java **Enterprise Edition** (**EE**) world, this means the learning curve to master Quarkus is shallow because much of the already acquired enterprise development knowledge can be reused to develop Quarkus applications.

Created by Red Hat, Quarkus sets itself apart from its competitors by being a software development framework designed from scratch to deal with cloud technologies. Contrary to other older frameworks that bring boilerplate code and features from an older era, Quarkus presents itself as a fresh and modern piece of software.

Built upon other well-established open source projects, Quarkus is the cloud-native framework we'll use to prepare our hexagonal system for the cloud. Before that, though, we'll tour some of the main features this framework provides. Let's get started by looking first at how to create REST endpoints with Quarkus.

Creating REST endpoints with JAX-RS

It's very straightforward to create REST endpoints using Quarkus. In order to do so, the framework relies on a JAX-RS implementation called RESTEasy. This implementation is available in the following Maven dependency:

```
<dependency>
    <groupId>io.quarkus</groupId>
    <artifactId>quarkus-resteasy</artifactId>
</dependency>
```

Look at the following example showing how to use RESTEasy to create REST services:

```
package dev.davivieira.bootstrap.samples;

import javax.ws.rs.GET;
import javax.ws.rs.Path;
import javax.ws.rs.Produces;
import javax.ws.rs.core.MediaType;

@Path("/app")
public class RestExample {

    @GET
    @Path("/simple-rest")
    @Produces(MediaType.TEXT_PLAIN)
    public String simpleRest() {
        return "This REST endpoint is provided by Quarkus";
    }
}
```

We set the endpoint address with the `@Path` annotation. With `@GET`, we set the HTTP method supported by that endpoint. With `@Produces`, we define the return type for the request.

In this same `RestExample` class, we can inject dependencies to be used together with the REST endpoints. Let's see how to accomplish this.

Employing dependency injection with Quarkus DI

Quarkus has its own dependency injection mechanism based on **Quarkus ArC**, which, in turn, comes from the CDI specification, which has its roots back in **Java EE 6**. With CDI, we no longer need to control the creation and life cycle of dependency objects we provide to the system. Without a dependency injection framework, you have to create objects this way:

```
BeanExample beanExample = new BeanExample();
```

When using CDI, you just have to annotate the `class` attribute with the `@Inject` annotation, like this:

```
@Inject
BeanExample beanExample
```

For the `@Inject` annotation to work, we first need to declare the dependency as a managed bean. Take a look at the example here:

```
package dev.davivieira.bootstrap.samples;

import javax.enterprise.context.ApplicationScoped;
import javax.validation.Valid;

@ApplicationScoped
public class BeanExample {
    public String simpleBean() {
        return "This is a simple bean";
    }
}
```

The `@ApplicationScoped` annotation states that this bean will be available as long as the application is not terminated. Also, this bean is accessible from different requests and calls across the entire system. Let's update our `RestExample` to inject this bean, as follows:

```
package dev.davivieira.bootstrap.samples;

import javax.inject.Inject;
import javax.ws.rs.GET;
import javax.ws.rs.Path;
import javax.ws.rs.Produces;
import javax.ws.rs.core.MediaType;

@Path("/app")
public class RestExample {

    @Inject
```

```
    BeanExample beanExample;

    /** Code omitted **/

    @GET
    @Path("/simple-bean")
    @Produces(MediaType.TEXT_PLAIN)
    public String simpleBean() {
        return beanExample.simpleBean();
    }
}
```

Right at the top, we inject the `BeanExample` dependency with the `@Inject` annotation. Then, we call the `simpleBean` method from the injected `BeanExample` dependency.

Next, let's see how to validate objects that are created when the system receives an HTTP request.

Validating objects

We learned how to create REST endpoints and also how to inject dependencies in the application. *But how about object validation? How can we ensure that the data provided by a given request is valid?* Quarkus can help us in that matter. The Quarkus validation mechanism is available in the following Maven dependency:

```
<dependency>
    <groupId>io.quarkus</groupId>
    <artifactId>quarkus-hibernate-validator</artifactId>
</dependency>
```

The Quarkus validation mechanism is based on **Hibernate Validator**.

To see how it works, let's first create a sample object containing the fields we expect in a request, as follows:

```
package dev.davivieira.bootstrap.samples;

import javax.validation.constraints.Min;
import javax.validation.constraints.NotBlank;

```

```
public class SampleObject {
    @NotBlank(message = "The field cannot be empty")
    public String field;

    @Min(message = "The minimum value is 10", value = 10)
    public int value;
}
```

With the `@NotBlank` annotation, we state that the `field` variable should never be empty. Then, by using the `@Min` annotation, we ensure the `value` variable should always contain a number equal or higher than `10`. Let's return to the `RestExample` class and create a new REST endpoint to validate the request, as follows:

```
@POST
@Path("/request-validation")
@Produces(MediaType.APPLICATION_JSON)
@Consumes(MediaType.APPLICATION_JSON)
public Result validation(@Valid SampleObject sampleObject) {
    try {
        return new Result("The request data is valid!");
    } catch (ConstraintViolationException e) {
        return new Result(e.getConstraintViolations());
    }
}
```

When `ConstraintViolationException` is caught, the system returns an `HTTP 400 Bad Request` failure response.

Note the `@Valid` annotation just before `SampleObject`. By using that annotation, we trigger a validation check whenever a request hits the `/app/request-validation` endpoint. Check out the following results:

```
$ curl -H "Content-Type: application/json"  -d '{"field": "",
"value": 10}' localhost:8080/app/request-validation | jq
{
  "exception": null,
  "propertyViolations": [],
  "classViolations": [],
  "parameterViolations": [
```

```
    {
      "constraintType": "PARAMETER",
      "path": "validation.arg0.field",
      "message": "The field cannot be empty",
      "value": ""
    }
  ],
  "returnValueViolations": []
}
```

In the previous `POST` request, the field is empty, which results in a failure response with an `HTTP 400 Bad Request` code.

In the next request, we set `value` to a number less than `10`, as follows:

```
$ curl -s -H "Content-Type: application/json"  -d '{"field":
"test", "value": 9}' localhost:8080/app/request-validation | jq
{
  "exception": null,
  "propertyViolations": [],
  "classViolations": [],
  "parameterViolations": [
    {
      "constraintType": "PARAMETER",
      "path": "validation.arg0.value",
      "message": "The minimum value is 10",
      "value": "9"
    }
  ],
  "returnValueViolations": []
}
```

Again, the constraint was violated and the result showed that the validation had failed. The failure was caused because we sent the number `9`, and the minimum value accepted is `10`.

Here is a proper request with valid data:

```
$ curl -s -H "Content-Type: application/json"  -d '{"field":
"test", "value": 10}' localhost:8080/app/request-validation |
jq
```

```
{
  "message": "The request data is valid!",
  "success": true
}
```

The `field` parameter is not `null`, nor is `value` less than `10`. So, the request returns a valid response.

Configuring a data source and using Hibernate ORM

Quarkus allows you to connect to a data source in two ways. The first and traditional way is based on a JDBC connection. To connect using this method, you need the `agroal` library and the JDBC driver of the specific database type you want to connect. The second—and reactive—way allows you to treat the database connection like a stream of data. For that mode, you need `Vert.x` reactive drivers.

In the following steps, we'll set up a data source connection using the traditional JDBC method:

1. To get started, we need the following dependencies:

```
<dependency>
  <groupId>io.quarkus</groupId>
  <artifactId>quarkus-agroal</artifactId>
</dependency>
<dependency>
  <groupId>io.quarkus</groupId>
  <artifactId>quarkus-jdbc-h2</artifactId>
</dependency>
<dependency>
  <groupId>io.quarkus</groupId>
  <artifactId>quarkus-hibernate-orm</artifactId>
</dependency>
```

   `quarkus-hibernate-orm` refers to the Hibernate ORM implementation of JPA. It is this dependency that provides the capability to map Java objects to database entities.

2. Next, we need to configure the data source settings in the `application.properties` file, as follows:

```
quarkus.datasource.db-kind=h2
quarkus.datasource.jdbc.url=jdbc:h2:mem:default;DB_CLOSE_
DELAY=-1
quarkus.hibernate-orm.dialect=org.hibernate.dialect.
H2Dialect
quarkus.hibernate-orm.database.generation=drop-and-create
```

   `quarkus.datasource.db-kind` is optional, but we use that to emphasize that the application uses an H2 in-memory database. We use `quarkus.datasource.jdbc.url` to inform the connection string. The `quarkus.hibernate-orm.dialect` option sets the dialect used for the data source communication, and `quarkus.hibernate-orm.database.generation=drop-and-create` forces the creation of a database structure at startup.

   If there is an `import.sql` file in `classpath`, this `drop-and-create` option enables the use of that file to load data into the database. Something very interesting about this `drop-and-create` option is that every change on application entities or in the `import.sql` file is picked automatically and applied to the database without restarting the system. For this to work, the system needs to run in the live development mode.

Let's create a `SampleEntity` class to persist in the database, as follows:

```
@Entity
@NamedQuery(name = "SampleEntity.findAll",
        query = "SELECT f FROM SampleEntity f ORDER BY
          f.field",
        hints = @QueryHint(name =
          "org.hibernate.cacheable",
        value = "true") )
public class SampleEntity {

    @Id
    @GeneratedValue(strategy = GenerationType.AUTO)
    private Long id;

```

```
    @Getter
    @Setter
    private String field;

    @Getter
    @Setter
    private int value;
}
```

The `SampleEntity` class corresponds to the `SampleObject` class we created earlier. The requirement to use the `SampleEntity` class as a database entity is to annotate it with the `@Entity` annotation. Following that annotation, we have `@NamedQuery`, which we'll use later to retrieve all entities from the database. To automatically generate ID values, we use `GenerationType.AUTO`. The `field` and `value` variables from `SampleEntity` are mapped to the same variables that exist in the `SampleObject` class.

Let's now create a new bean called `PersistenceExample` to assist us in creating and retrieving database entities. Here's how to do this:

```
package dev.davivieira.bootstrap.samples;

import javax.enterprise.context.ApplicationScoped;
import javax.inject.Inject;
import javax.persistence.EntityManager;
import javax.transaction.Transactional;
import java.util.List;

@ApplicationScoped
public class PersistenceExample {

    @Inject
    EntityManager em;
    /** Code omitted **/
}
```

To interact with the database, the first thing we have to do is to inject `EntityManager`. Quarkus will take care of retrieving an `EntityManager` object with all the database connection settings we provided in the `application.properties` file. Continuing the `PersistenceExample` implementation, let's create a method to persist entities, as follows:

```
@Transactional
public String createEntity(SampleObject sampleObject) {
    SampleEntity sampleEntity = new SampleEntity();
    sampleEntity.setField(sampleObject.field);
    sampleEntity.setValue(sampleObject.value);
    em.persist(sampleEntity);
    return "Entity with field "+sampleObject.field+"
      created!";
}
```

The `createEntity` method persists an entity in the database.

The `@Transactional` annotation above the method declaration will make the `EntityManager` object flush the transaction once the database operation is committed. This is illustrated in the following code snippet:

```
@Transactional
public List<SampleEntity> getAllEntities(){
    return em.createNamedQuery(
    "SampleEntity.findAll", SampleEntity.class)
            .getResultList();
}
```

The `getAllEntities` method retrieves all entities from the database.

Now, let's return to `RestExample` to create REST endpoints to trigger the creation and retrieval of database entities. We start by injecting `PersistenceExample` so that we can use this bean to begin operations on the database. The code is illustrated in the following snippet:

```
@Inject
PersistenceExample persistenceExample;
```

Then, we create a `/create-entity` endpoint, as follows:

```
@POST
@Path("/create-entity")
@Produces(MediaType.TEXT_PLAIN)
@Consumes(MediaType.APPLICATION_JSON)
public String persistData(@Valid SampleObject sampleObject) {
    return persistenceExample.createEntity(sampleObject);
}
```

We pass `SampleObject` as the parameter. This object represents the body of the `POST` request.

Finally, we create a `/request-validation` endpoint to retrieve all entities from the database, as follows:

```
@GET
@Path("/get-all-entities")
public List<SampleEntity> retrieveAllEntities() {
    return persistenceExample.getAllEntities();
}
```

The `retrieveAllEntities` method calls on `getAllEntities` from the `PersistenceExample` bean. The result is a list of `SampleEntity` objects.

Let's see what we get when we hit `/create-entity` to create a new entity. You can see the output here:

```
$ curl -s -H "Content-Type: application/json"  -d '{"field": "item-a", "value": 10}' localhost:8080/app/create-entity
Entity with field item-a created!
$ curl -s -H "Content-Type: application/json"  -d '{"field": "item-b", "value": 20}' localhost:8080/app/create-entity
Entity with field item-b created!
```

To see the entities we've created, we send a request to `/get-all-entities`, as follows:

```
$ curl -s localhost:8080/app/get-all-entities | jq
[
  {
    "field": "item-a",
```

```
      "value": 10
    },
    {
      "field": "item-b",
      "value": 20
    }
 ]
```


As expected, we received all the entities in JSON format that we persisted previously in the database.

Quarkus is a vast and continuously growing framework that's absorbing more and more capabilities. The features we have seen cover some of the basic things required to develop modern applications.

We'll be able to use RESTEasy when reimplementing input adapters to support REST on our hexagonal application. Quarkus DI will enable us to better manage the life cycle of objects from the Framework and Application hexagons. The Quarkus validation mechanisms will contribute to validating the data entering the hexagonal system. The data source configuration and Hibernate ORM will support the restructuring of output adapters.

In this section, we learned how to tweak the `application.properties` file to configure a database connection on Quarkus, and we briefly explored Hibernate's ORM capabilities that help map Java classes to database entities. We'll explore this subject further in *Chapter 13*, *Persisting Data with Output Adapters and Hibernate Reactive*.

Let's now see how to integrate Quarkus into the hexagonal system.

Adding Quarkus to a modularized hexagonal application

To recap, we structured the topology and inventory system in three modularized hexagons: **Domain**, **Application**, and **Framework**. A question that may arise is: *Which module should be responsible for starting the Quarkus engine?* Well, to avoid blurring the responsibilities of each module in the topology and inventory system, we'll create a dedicated module whose sole purpose will be to aggregate the other hexagonal system modules and to bootstrap the Quarkus engine. We name this new module **Bootstrap**, as illustrated in the following diagram:

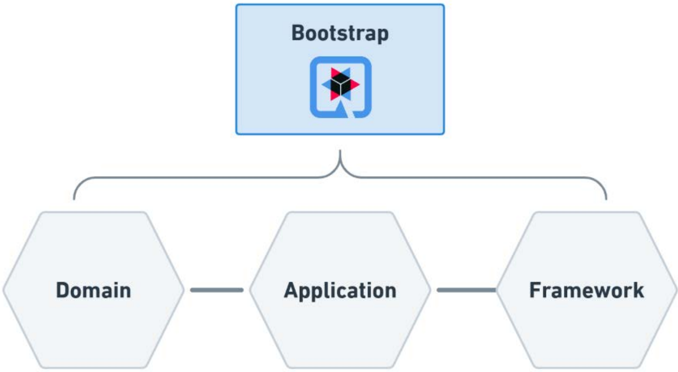

Figure 10.4 – The bootstrap aggregator module

The `bootstrap` module is an aggregator module that provides, from one side, the dependencies required to initialize Quarkus and, from the other side, the `hexagonal` module dependencies to be used in conjunction with Quarkus.

Let's create this new `bootstrap` module in the topology and inventory system, as follows:

1. In the Maven root project of the topology and inventory system, you can execute the following Maven command to create this `bootstrap` module:

```
mvn archetype:generate \
-DarchetypeGroupId=de.rieckpil.archetypes  \
-DarchetypeArtifactId=testing-toolkit \
-DarchetypeVersion=1.0.0 \
-DgroupId=dev.davivieira \
-DartifactId=bootstrap \
-Dversion=1.0-SNAPSHOT \
-Dpackage=dev.davivieira.topologyinventory.bootstrap \
-DinteractiveMode=false
```

This Maven command creates a basic directory structure for the `bootstrap` module. We set `artifactId` to `bootstrap` and `groupId` to `dev.davivieira`, as this module is part of the same Maven project that holds the modules for other topology and inventory system hexagons. The final high-level structure should be similar to the one shown here:

Figure 10.5 – Topology and inventory high-level directory structure

2. Next, we need to set up Quarkus dependencies in the project's root `pom.xml` file, as follows:

```
<dependencyManagement>
  <dependencies>
    <dependency>
      <groupId>io.quarkus</groupId>
      <artifactId>quarkus-universe-bom</artifactId>
      <version>${quarkus.platform.version}</version>
      <type>pom</type>
      <scope>import</scope>
    </dependency>
</dependencyManagement>
```

The `quarkus-universe-bom` dependency makes available all the Quarkus extensions.

Because we're working with a multi-module application, we need to configure Quarkus to discover CDI beans in different modules.

3. So, we need to configure `jandex-maven-plugin` in the Maven project's root `pom.xml` file, as follows:

```
<plugin>
  <groupId>org.jboss.jandex</groupId>
  <artifactId>jandex-maven-plugin</artifactId>
  <version>${jandex.version}</version>
```

```
      <executions>
        <execution>
          <id>make-index</id>
          <goals>
            <goal>jandex</goal>
          </goals>
        </execution>
      </executions>
    </plugin>
```

Without the preceding plugin, we'll have a problem setting up and using CDI beans on both Framework and Application hexagons.

4. Next is the most crucial part: the configuration of `quarkus-maven-plugin`. To make the `bootstrap` module the one that will start the Quarkus engine, we need to configure `quarkus-maven-plugin` in that module properly.

   Here is how we should configure `quarkus-maven-plugin` on `bootstrap/pom.xml`:

```
<build>
  <plugins>
    <plugin>
      <groupId>io.quarkus</groupId>
      <artifactId>quarkus-maven-plugin</artifactId>
      <version>${quarkus-plugin.version}</version>
      <extensions>true</extensions>
      <executions>
        <execution>
          <goals>
            <goal>build</goal>
            <goal>generate-code</goal>
            <goal>generate-code-tests</goal>
          </goals>
        </execution>
      </executions>
    </plugin>
  </plugins>
</build>
```

The important part here is the line containing `<goal>build</goal>`. By setting this build goal for the `bootstrap` module, we're making this module responsible for starting the Quarkus engine.

5. Next, we need to add the Maven dependencies from the topology and inventory system's hexagons. We do that in the `bootstrap/pom.xml` file, as follows:

```
<dependency>
  <groupId>dev.davivieira</groupId>
  <artifactId>domain</artifactId>
</dependency>
<dependency>
  <groupId>dev.davivieira</groupId>
  <artifactId>application</artifactId>
</dependency>
<dependency>
  <groupId>dev.davivieira</groupId>
  <artifactId>framework</artifactId>
</dependency>
```

6. And finally, we create a `module-info.java` Java module descriptor with the `requires` directives for Quarkus and the topology and inventory hexagon modules, as follows:

```
module dev.davivieira.bootstrap {
    requires quarkus.core;
    requires domain;
    requires application;
    requires framework;
}
```

To aggregate the three hexagon modules into one deployment unit, we'll configure Quarkus to generate an uber `.jar` file. This kind of JAR groups all the dependencies required to run an application in one single JAR. To accomplish that, we need to set the following configuration in the project's root `pom.xml` file:

```
<quarkus.package.type>uber-jar</quarkus.package.type>
```

Then, we're ready to compile the application by running the following Maven command:

```
mvn clean package
```

This Maven command will compile the entire application and will create an uber `.jar` file that we can use to start the application by executing the following command:

```
java -jar bootstrap/target/bootstrap-1.0-SNAPSHOT-runner.jar
```

Note that the artifact we use is generated from the `bootstrap` module, which aggregates all the other modules. The following screenshot shows us what a running Quarkus application should look like:

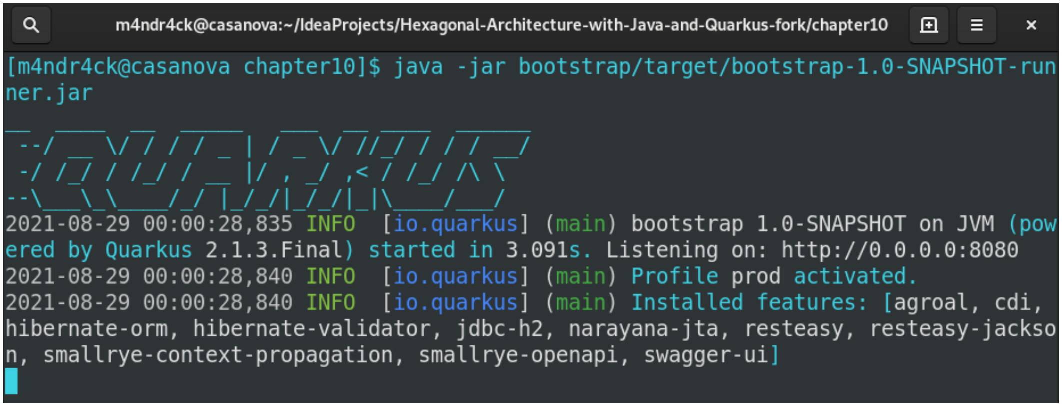

Figure 10.6 – A running Quarkus application

The application seen in the preceding screenshot is running in the `prod` profile. In that profile, some features are deactivated for security purposes. We can also see the installed features running in the application. These features are activated when we add Quarkus extension dependencies on `pom.xml`.

The `bootstrap` module acts as a bridge, allowing us to connect the external development framework to the hexagon modules that comprise the hexagonal system. For the topology and inventory application, we are using Quarkus, but we could also use other development frameworks. We cannot say that we are totally decoupling the system logic from the development framework; after all, there will be some system logic that benefited from framework features. But the approach presented in this chapter shows that part of that system can be developed first, and the development framework introduced only later.

Summary

In this chapter, we revisited the fundamentals of JVM, assessing some of its features related to JIT compilation and AOT compilation. We learned that JIT improves runtime performance, whereas AOT helps boost application startup time, which proves to be an essential feature for frameworks targeting cloud environments, as in this case with Quarkus.

After getting acquainted with some JVM concepts, we moved forward to learn about Quarkus and some important features it offers. Finally, we integrated Quarkus into our already developed hexagonal system topology and inventory. In order to accomplish such an integration, we created a new `bootstrap` module to act as a bridge between the hexagonal system modules and the development framework. We now know what it takes to integrate Quarkus into a modularized hexagonal application.

In the next chapter, we dive deeper into the integration between Quarkus and hexagonal architecture. We will learn how to refactor use cases and ports from the application hexagon to leverage Quarkus DI features.

Questions

1. What is the advantage of using **Just-In-Time** (**JIT**) compilation?
2. What benefit do we get by using **Ahead-Of-Time** (**AOT**) compilation?
3. Quarkus is a development framework specially designed for which kind of environment?
4. What is the role of the `bootstrap` module in hexagonal architecture?

11
Leveraging CDI Beans to Manage Ports and Use Cases

Quarkus provides its own dependency injection solution called **Quarkus DI**. It stems from the **Contexts and Dependency Injection** (**CDI**) for **Java 2.0** specification. We employ CDI to delegate the responsibility to provide object instances to an external dependency and manage their life cycle across the application. Several dependency injection solutions in the market take such responsibility. Quarkus DI is one of them.

The value of using a dependency injection mechanism is that we no longer need to worry about how and when to provide an object instance. A dependency injection solution enables us to automatically create and provide objects as dependencies in classes that declare a dependency in those objects, generally using annotation attributes.

In the context of the hexagonal architecture, the Framework and Application hexagons are good candidates to leverage the benefits a CDI solution can provide. Instead of using constructors that inject dependencies using concrete classes, we can use the CDI discovery mechanisms to automatically look up interface implementations and provide them to the application.

In this chapter, we'll learn how to enhance the provisioning of ports and use cases by turning them into beans. We'll explore bean scopes and their life cycles and understand how and when to use the available bean scopes. Once we know about the CDI fundamentals, we'll learn how to apply them to a hexagonal system.

The following topics will be covered in this chapter:

- Learning about Quarkus DI
- Transforming ports, use cases, and adapters into CDI beans
- Testing use cases with Quarkus and Cucumber

By the end of this chapter, you'll know how to integrate Quarkus DI into a hexagonal application by transforming use cases and ports into managed beans that can be injected across the hexagonal system. You'll also know how to test use cases by using Quarkus in conjunction with Cucumber.

Technical requirements

To compile and run the code examples presented in this chapter, you will need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. They are available for Linux, Mac, and Windows operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter11`.

Learning about Quarkus DI

Quarkus DI is the dependency injection solution provided by the Quarkus framework. This solution, also called **ArC**, is based on the CDI for the **Java 2.0 specification**. Quarkus DI does not completely implement such a specification. Instead, it provides some customized and changed implementations that are more inclined with the Quarkus project's goals. But these changes are more visible when you go deeper into what the Quarkus DI provides. For those working only with the basics and most recurrent features described in the CDI for Java 2.0 specification, the Quarkus DI experience is similar to other CDI implementations.

The advantage we get by using Quarkus DI or any dependency injection solution is that we can focus more on the business aspects of the software we're developing, rather than on the plumbing activities related to the provisioning and life cycle control of the objects that the application needs to provide its features. To enable such an advantage, Quarkus DI deals with so-called beans.

Working with beans

Beans are a special kind of object we can use to inject dependencies or that act as dependencies themselves to be injected in other beans. This injection activity takes place in a container-managed environment. This environment is nothing more than the runtime environment where the application runs.

Beans have a context that influences when and how their instance objects are created. The following are the main contexts that are supported by Quarkus DI:

- `ApplicationScoped`: A bean marked with such a context is available to the entire application. Only one bean instance is created and shared across all system areas that inject this bean. Another important aspect is that the `ApplicationScoped` beans are lazy-loaded. This means that the bean instance is created only when a bean's method is called for the first time. Take a look at this example:

```
@ApplicationScoped
class MyBean {

    public String name = "Test Bean";

    public String getName(){
        return name;
    }
}

class Consumer {

    @Inject
    MyBean myBean;

    public String getName() {
```

```
            return myBean.getName();
        }
    }
```

The `MyBean` class is available not only for the `Consumer` class but also for other classes that inject the bean. The bean instance will be created only once when `myBean.getName()` is called for the first time.

- `Singleton`: Similar to the `ApplicationScoped` beans, for the `Singleton` beans, only one bean object is created and shared across the system. The only difference, though, is that `Singleton` beans are eagerly loaded. This means that once the system is started, the `Singleton` bean instance is started as well. Here is the code that exemplifies this:

```
    @Singleton
    class EagerBean { ... }

    class Consumer {

        @Inject
        EagerBean eagerBean;
    }
```

The `EagerBean` object will be created during the system's initialization.

- `RequestScoped`: We usually mark a bean as `RequestScope` when we want to make that bean available only for as long as the request associated with that bean lives. The following is an example of how we can use `RequestScope`:

```
    @RequestScoped
    class RequestData {

        public String getResponse(){
            return "string response";
        }
    }

    @Path("/")
    class Consumer {

        @Inject
```

```
    RequestData requestData;

    @GET
    @Path("/request")
    public String loadRequest(){
        return requestData.getResponse();
    }
}
```

Every time a request arrives at `/request`, a new `RequestData` bean object will be created and destroyed once the request has finished.

- `Dependent`: Beans marked as `Dependent` have their scope restricted to places where they are used. So, the `Dependent` beans are not shared across other beans in the system. Also, their life cycle is the same as the one defined in the bean injecting them. For example, if you inject a `Dependent` annotated bean into a `RequestScoped` one, the former bean uses the latter's scope:

```
@Dependent
class DependentBean { ... }

@ApplicationScoped
class ConsumerApplication {

    @Inject
    DependentBean dependentBean;
}

@RequestScoped
class ConsumerRequest {

    @Inject
    DependentBean dependentBean;
}
```

The `DependentBean` class will become `ApplicationScoped` when injected into `ConsumerApplication` and `RequestScoped` when injected into `ConsumerRequest`.

- `SessionScoped`: We use this scope to share the bean context among all the requests of the same HTTP session. We need the `quarkus-undertow` extension to enable `SessionScoped` on Quarkus:

```
@SessionScoped
class SessionBean implements Serializable {
    public String getSessionData(){
        return "sessionData";
    }
}

@Path("/")
class Consumer {

    @Inject
    SessionBean sessionBean;

    @GET
    @Path("/sessionData")
    public String test(){
        return sessionBean.getSessionData();
    }
}
```

  In the preceding example, a `SessionBean` instance will be created after the first request is sent to `/sessionData`. This same instance will be available for other requests coming from the same session.

To summarize, Quarkus offers the following bean scopes: `ApplicationScoped`, `RequestScoped`, `Singleton`, `Dependent`, and `SessionScoped`. For stateless applications, most of the time, you may only need `ApplicationScoped` and `RequestScoped`. By understanding how these scopes work, we can select them according to our system needs.

Now that we know about the advantages of Quarkus DI and the basics of how it works, let's learn how to employ dependency injection techniques with the ports and use cases from the hexagonal architecture.

Transforming ports, use cases, and adapters into CDI beans

When designing the Application hexagon for the topology and inventory system, we defined the use cases as interfaces and input ports as their implementations. We also defined output ports as interfaces and output adapters as their implementations in the Framework hexagon. In this section, we'll refactor components from both the Application and Framework hexagons to enable the usage of dependency injection with Quarkus DI.

The first step to working with Quarkus DI is to add the following Maven dependency to the project's root `pom.xml file`:

```
<dependency>
  <groupId>io.quarkus</groupId>
  <artifactId>quarkus-resteasy</artifactId>
</dependency>
```

In addition to the RESTEasy libraries, this `quarkus-resteasy` library also provides the required libraries to work with Quarkus DI.

Let's start our refactoring efforts with the classes and interfaces related to router management.

Implementing CDI for router management objects

When developing the topology and inventory system, we defined a set of ports, use cases, and adapters to manage router-related operations. We'll walk through the required changes to enable dependency injection in such operations:

1. We start by transforming the `RouterManagementH2Adapter` output adapter into a managed bean:

```
import javax.enterprise.context.ApplicationScoped;

@ApplicationScoped
public class RouterManagementH2Adapter implements
RouterManagementOutputPort {
    @PersistenceContext
    private EntityManager em;
   /** Code omitted **/
        private void setUpH2Database() {
```

```
            EntityManagerFactory entityManagerFactory =
            Persistence.createEntityManagerFactory(
              "inventory");
            EntityManager em =
            entityManagerFactory.createEntityManager();
            this.em = em;
        }
    }
```

We turn this class into a managed bean by putting the `@ApplicationScoped` annotation on top of the `RouterManagementH2Adapter` class. Note the `EntityManager` attribute – we can use dependency injection on that attribute as well. We'll do that in *Chapter 13*, *Persisting Data with Output Adapters and Hibernate Reactive*, but we won't touch on it for now.

2. Before changing the `RouterManagementUseCase` interface and its implementation, `RouterManagementInputPort`, let's analyze some aspects of the current implementation:

```
  public interface RouterManagementUseCase {

      void setOutputPort(
      RouterManagementOutputPort
        routerManagementOutputPort);
      /** Code omitted **/
  }
```

We defined the `setOutpuPort` method to receive and set an instance type of `RouterManagementOutputPort`, which is fulfilled by a `RouterManagementH2Adapter` output adapter. As we'll no longer need to explicitly provide this output adapter object (because Quarkus DI will inject it), we can remove the `setOutputPort` method from the `RouterManagementUseCase` interface.

The following code demonstrates how `RouterManagementInputPort` is implemented without Quarkus DI:

```
  @NoArgsConstructor
  public class RouterManagementInputPort implements
  RouterManagementUseCase {

```

```
    private RouterManagementOutputPort
    routerManagementOutputPort;

    @Override
    public void setOutputPort(
    RouterManagementOutputPort
      routerManagementOutputPort) {
        this.routerManagementOutputPort =
        routerManagementOutputPort;
    }
    /** Code omitted **/
}
```

To provide an object of the `RouterManagementOutputPort` type, we need to use the previously mentioned `setOutputPort` method. After implementing Quarkus DI, this will no longer be necessary, as we'll see in the next step.

3. This is what `RouterManagementOutputPort` should look like after implementing Quarkus DI:

```
import javax.enterprise.context.ApplicationScoped;
import javax.inject.Inject;

@ApplicationScoped
public class RouterManagementInputPort implements
RouterManagementUseCase {

    @Inject
    RouterManagementOutputPort
      routerManagementOutputPort;
    /** Code omitted **/
}
```

First, we add `@ApplicationScoped` on top of `RouterManagementInputPort` to enable it to be injected into other system parts. Then, by using the `@Inject` annotation, we inject `RouterManagementOutputPort`. We don't need to refer to the output adapter's implementation. Quarkus DI will find a proper implementation for this output port interface, which happens to be the `RouterManagementH2Adapter` output adapter that we turned into a managed bean earlier.

4. Finally, we must update the `RouterManagementGenericAdapter` input adapter:

```
@ApplicationScoped
public class RouterManagementGenericAdapter {

    @Inject
    private RouterManagementUseCase
      routerManagementUseCase;
    /** Code omitted **/
}
```

   Instead of initializing `RouterManagementUseCase` using a constructor, we must provide the dependency through the `@Inject` annotation. At runtime, Quarkus DI will create and assign a `RouterManagementInputPort` object to that use case reference.

That's it for the changes we must make to the classes and interfaces related to router management. Now, let's learn what we need to change regarding the classes and interfaces for switch management.

Implementing CDI for switch management objects

In this section, we'll follow a similar path to that one we followed when we refactored the ports, uses cases, and adapters related to router management:

1. We start by transforming the `SwitchManagementH2Adapter` output adapter into a managed bean:

```
import javax.enterprise.context.ApplicationScoped;

@ApplicationScoped
public class SwitchManagementH2Adapter implements
SwitchManagementOutputPort {

    @PersistenceContext
    private EntityManager em;
    /** Code omitted **/
}
```

The `SwitchManagementH2Adapter` adapter also makes use of `EntityManager`. We won't modify how the `EntityManager` object is provided, but in *Chapter 13*, *Persisting Data with Output Adapters and Hibernate Reactive*, we will change it to use dependency inversion.

2. We changed the definition of the `SwitchManagementUseCase` interface in *Chapter 9*, *Applying Dependency Inversion with Java Modules*, and defined the `setOutputPort` method:

```
public interface SwitchManagementUseCase {

    void setOutputPort(
    SwitchManagementOutputPort
      switchManagementOutputPort)
/** Code omitted **/
}
```

As Quarkus DI will provide a proper `SwitchManagementOutputPort` instance, we'll no longer need this `setOutputPort` method, so we can remove it.

3. The following code shows how `SwitchManagementInputPort` is implemented without dependency injection:

```
@NoArgsConstructor
public class SwitchManagementInputPort implements
SwitchManagementUseCase {

    private SwitchManagementOutputPort
    switchManagementOutputPort;

    @Override
    public void setOutputPort(
    SwitchManagementOutputPort
      switchManagementOutputPort) {
        this.switchManagementOutputPort =
        switchManagementOutputPort;
    }
    /** Code omitted **/
}
```

We call the `setOutputPort` method to initialize a `SwitchManagementOutputPort` object. When using dependency injection techniques, there is no need to explicitly instantiate or initialize objects.

4. The following is what `SwitchManagementInputPort` should look like after implementing dependency injection:

```
import javax.enterprise.context.ApplicationScoped;
import javax.inject.Inject;

@ApplicationScoped
public class SwitchManagementInputPort implements
SwitchManagementUseCase {

    @Inject
    private SwitchManagementOutputPort
    switchManagementOutputPort;
    /** Code omitted **/
}
```

We use the `@ApplicationScoped` annotation to convert `SwitchManagementInputPort` into a managed bean and the `@Inject` annotation to make Quarkus DI discover a managed bean object that implements the `SwitchManagementOutputPort` interface, which happens to be the `SwitchManagementH2Adapter` output adapter.

5. We still need to adjust the `SwitchManagementGenericAdapter` input adapter:

```
public class SwitchManagementGenericAdapter {

    @Inject
    private SwitchManagementUseCase
      switchManagementUseCase;
    @Inject
    private RouterManagementUseCase
      routerManagementUseCase;
    /** Code omitted **/
}
```

Here, we are injecting dependencies for both the `SwitchManagementUseCase` and `RouterManagementUseCase` objects. Before using annotations, these dependencies were being provided in this way:

```
public SwitchManagementGenericAdapter (
RouterManagementUseCase routerManagementUseCase,
SwitchManagementUseCase switchManagementUseCase){
    this.routerManagementUseCase =
      routerManagementUseCase;
    this.switchManagementUseCase =
      switchManagementUseCase;
}
```

The improvement we get is that we no longer need to rely on the constructor to initialize the `SwitchManagementGenericAdapter` dependencies. Quarkus DI will automatically provide the required instances for us.

The next section is about the operations related to network management. Let's learn how we should change them.

Implementing CDI for network management classes and interfaces

We have fewer things to change for the network part because we did not create a specific output port and adapter for the network-related operations. So, the implementation changes will only take place on the use cases, input ports, and input adapters:

1. Let's start by looking at the `NetworkManagementUseCase` use case interface:

```
public interface NetworkManagementUseCase {

    void setOutputPort(
    RouterManagementOutputPort
      routerNetworkOutputPort);
    /** Code omitted **/
}
```

As we did in the other use cases, we also defined the `setOutputPort` method to allow the initialization of `RouterManagementOutputPort`. After implementing Quarkus DI, this method will no longer be needed.

2. This is how `NetworkManagementInputPort` is implemented without Quarkus DI:

```
import javax.enterprise.context.ApplicationScoped;
import javax.inject.Inject;
public class NetworkManagementInputPort implements
NetworkManagementUseCase {

    private RouterManagementOutputPort
    routerManagementOutputPort;

    @Override
    public void setOutputPort(
    RouterManagementOutputPort
      routerManagementOutputPort) {
        this.routerManagementOutputPort =
       routerManagementOutputPort;
    }
    /** Code omitted **/
}
```

The `NetworkManagementInputPort` input port only relies on `RouterManagementOutputPort`, which, without dependency injection, is initialized by the `setOutputPort` method.

3. This is what `NetworkManagementInputPort` looks like after implementing Quarkus DI:

```
@ApplicationScoped
public class NetworkManagementInputPort implements
NetworkManagementUseCase {

    @Inject
    private RouterManagementOutputPort
    routerManagementOutputPort;
    /** Code omitted **/
}
```

As you can see, the `setOutputPort` method has been removed. Quarkus DI is now providing an implementation for `RouterManagementOutputPort` through the `@Inject` annotation. The `@ApplicationScoped` annotation converts `NetworkManagementInputPort` into a managed bean.

4. Finally, we have to change the `NetworkManagementGenericAdapter` input adapter:

```
import javax.enterprise.context.ApplicationScoped;
import javax.inject.Inject;

@ApplicationScoped
public class NetworkManagementGenericAdapter {

    @Inject
    private SwitchManagementUseCase
      switchManagementUseCase;
    @Inject
    private NetworkManagementUseCase
      networkManagementUseCase;
   /** Code omitted **/
}
```

The `NetworkManagementGenericAdapter` input adapter relies on the `SwitchManagementUseCase` and `NetworkManagementUseCase` use cases to trigger network-related operations on the system. As we did in the previous implementations, here, we are using `@Inject` to provide the dependencies at runtime.

The following code shows how these dependencies were provided before Quarkus DI:

```
public NetworkManagementGenericAdapter(
SwitchManagementUseCase switchManagementUseCase,
NetworkManagementUseCase networkManagementUseCase) {
    this.switchManagementUseCase =
      switchManagementUseCase;
    this.networkManagementUseCase =
      networkManagementUseCase;
}
```

After implementing the injection mechanism, we can safely remove this `NetworkManagementGenericAdapter` constructor.

We have finished making all the necessary changes to convert the input ports, use cases, and adapters into components that can be used for dependency injection. These changes showed us how to integrate the Quarkus CDI mechanisms into our hexagonal application.

Now, let's learn how to adapt the hexagonal system to mock and use managed beans during tests.

Testing use cases with Quarkus and Cucumber

While implementing the Application hexagon in *Chapter 7*, *Building the Application Hexagon*, we used Cucumber to aid us in shaping and testing our use cases. By leveraging the Behavior-Driven Design techniques provided by Cucumber, we could express use cases in a declarative way. Now, we need to integrate Cucumber so that it works with Quarkus:

1. The first step is to add the Quarkus testing dependencies to the `pom.xml` file from the Application hexagon:

```
<dependency>
  <groupId>io.quarkiverse.cucumber</groupId>
  <artifactId>quarkus-cucumber</artifactId>
  <version>0.3.0</version>
  <scope>test</scope>
</dependency>
<dependency>
  <groupId>io.quarkus</groupId>
  <artifactId>quarkus-junit5</artifactId>
  <scope>test</scope>
</dependency>
```

The `quarkus-cucumber` dependency provides the integration we need to run tests with Quarkus. We also need the `quarkus-junit5` dependency, which enables us to use the `@QuarkusTest` annotation.

2. Next, we must add the necessary Cucumber dependencies:

```
<dependency>
  <groupId>io.cucumber</groupId>
  <artifactId>cucumber-java</artifactId>
  <version>${cucumber.version}</version>
  <scope>test</scope>
```

```
  </dependency>
  <dependency>
    <groupId>io.cucumber</groupId>
    <artifactId>cucumber-junit</artifactId>
    <version>${cucumber.version}</version>
    <scope>test</scope>
  </dependency>
  <dependency>
    <groupId>io.cucumber</groupId>
    <artifactId>cucumber-picocontainer</artifactId>
    <version>${cucumber.version}</version>
    <scope>test</scope>
  </dependency>
```

With the `cucumber-java`, `cucumber-junit`, and `cucumber-picocontainer` dependencies, we can enable the Cucumber engine on the system.

Let's see how Cucumber is configured without Quarkus:

```
package dev.davivieira.topologyinventory.application;

import io.cucumber.junit.Cucumber;
import io.cucumber.junit.CucumberOptions;
import org.junit.runner.RunWith;

@RunWith(Cucumber.class)
@CucumberOptions(
        plugin = {"pretty", "html:target/cucumber-result"}
)
public class ApplicationTest {

}
```

The `@RunWith(Cucumber.class)` annotation is used to activate the Cucumber engine. When using Quarkus, this is how `ApplicationTest` should be implemented:

```
package dev.davivieira.topologyinventory.application;

import io.quarkiverse.cucumber.CucumberQuarkusTest;
import io.quarkus.test.junit.QuarkusTest;

@QuarkusTest
public class ApplicationTest extends CucumberQuarkusTest {

}
```

The `@QuarkusTest` annotations activate the Quarkus testing engine. By extending the `CucumberQuarkusTest` class, we also enable the Cucumber testing engine.

There are no tests on the `ApplicationTest` class because this is just a bootstrap class. Remember that Cucumber tests were implemented in separated classes. Before changing these classes, we need to mock the managed beans that are required to provide instances for `RouterManagementOutputPort` and `SwitchManagementOutputPort`.

Let's create a mocked bean object for `RouterManagementOutputPort`:

```
package dev.davivieira.topologyinventory.application.mocks;
import dev.davivieira.topologyinventory.application.ports.
output.RouterManagementOutputPort;
import dev.davivieira.topologyinventory.domain.entity.Router;
import dev.davivieira.topologyinventory.domain.vo.Id;
import io.quarkus.test.Mock;

@Mock
public class RouterManagementOutputPortMock implements
RouterManagementOutputPort {
    @Override
    public Router retrieveRouter(Id id) {
        return null;
    }

```

```
    @Override
    public Router removeRouter(Id id) {
        return null;
    }
    @Override
    public Router persistRouter(Router router) {
        return null;
    }
}
```

This is a dummy mocked bean that we created to prevent Quarkus from throwing `UnsatisfiedResolutionException`. By using the `@Mock` annotation, Quarkus will instantiate the `RouterManagementOutputPortMock` class and serve it as a bean to be injected during the tests.

In the same way, we will mock `SwitchManagementOutputPort`:

```
package dev.davivieira.topologyinventory.application.mocks;

import dev.davivieira.topologyinventory.application.ports.
output.SwitchManagementOutputPort;
import dev.davivieira.topologyinventory.domain.entity.Switch;
import dev.davivieira.topologyinventory.domain.vo.Id;
import io.quarkus.test.Mock;

@Mock
public class SwitchManagementOutputPortMock implements
SwitchManagementOutputPort {
    @Override
    public Switch retrieveSwitch(Id id) {
        return null;
    }
}
```

For `SwitchManagementOutputPort`, we created `SwitchManagementOutputPortMock` to provide a dummy managed bean so that Quarkus can use it for injection during the tests. Without mocks, we'd need real instances from the `RouterManagementH2Adapter` and `SwitchManagementH2Adapter` output adapters.

Although we don't refer directly to output interfaces and output port adapters during tests, Quarkus still tries to perform bean discovery on them. That's why we need to provide the mocks.

Now, we can refactor the tests to use the dependency injection provided by Quarkus DI. Let's learn how to do that on the `RouterAdd` test:

```
public class RouterAdd extends ApplicationTestData {

    @Inject
    RouterManagementUseCase routerManagementUseCase;
   /** Code omitted **/
}
```

Before using Quarkus DI, this is how we got the implementation for `RouterManagementUseCase`:

```
this.routerManagementUseCase = new RouterManagementInputPort();
```

The preceding code can be removed once the `@Inject` annotation has been implemented.

We can follow the same approach of adding the `@Inject` annotation and removing the constructor call to instantiate input port objects when refactoring other test classes.

The output you'll get after running Quarkus tests integrated with Cucumber will be similar to the following:

```
[INFO] -------------------------------------------------------
[INFO]  T E S T S
[INFO] -------------------------------------------------------
[INFO] Running dev.davivieira.topologyinventory.application.
ApplicationTest
2021-09-08 22:44:15,596 INFO  [io.quarkus] (main) Quarkus
2.2.1.Final on JVM started in 1.976s. Listening on: http://
localhost:8081
2021-09-08 22:44:15,618 INFO  [io.quarkus] (main) Profile test
activated.
2021-09-08 22:44:15,618 INFO  [io.quarkus] (main) Installed
features: [cdi, cucumber, smallrye-context-propagation]

```

```
@RouterCreate
Scenario: Creating a new core router
#dev/davivieira/topologyinventory/application/routers/
RouterCreate.feature:4
.  Given I provide all required data to create a core router
#dev.davivieira.topologyinventory.application.RouterCreate.
create_core_router()
.  Then A new core router is created
#dev.davivieira.topologyinventory.application.RouterCreate.a_
new_core_router_is_created()
```

Note that in the installed feature's output entry, Quarkus mentions `CDI` and `Cucumber` as extensions that are being used.

In this section, we learned how to configure Quarkus to work together with Cucumber properly. This configuration was required to configure Quarkus mocks and refactor tests classes to inject input port objects instead of creating them with constructor calls.

Summary

In this chapter, we had the opportunity to learn how Quarkus provides dependency injection through Quarkus DI. We started by reviewing some of the concepts defined by the **Contexts and Dependency Injection** (**CDI**) for **Java 2.0** specification, the specification that Quarkus DI is derived from. Then, we proceeded to implement these concepts in our hexagonal application. We defined the managed beans and injected them while refactoring use cases, ports, and adapters. Finally, we learned how to integrate Quarkus with Cucumber to get the best of both worlds while testing our hexagonal application.

By implementing Quarkus dependency injection mechanisms into a hexagonal system, we are also turning it into a more robust and modern system.

In the next chapter, we'll turn our attention to adapters. Quarkus provides powerful capabilities for creating reactive REST endpoints and we'll learn how to integrate them with hexagonal system adapters.

Questions

1. Quarkus DI is based on which Java specification?
2. What is the difference between the `ApplicationScoped` and `Singleton` scopes?
3. What is the annotation we should use to provide dependencies through Quarkus DI instead of using calling constructors?
4. To enable Quarkus testing capabilities, which annotation should we use?

Answers

1. It's based on the **Contexts and Dependency Injection** (**CDI**) for **Java 2.0** specification.
2. When using `ApplicationScoped`, the objects are lazy-loaded. With `Singleton`, the objects are eagerly loaded.
3. The `@Inject` annotation.
4. The `@QuarkusTest` annotation.

12
Using RESTEasy Reactive to Implement Input Adapters

An **input adapter** is like a front door that exposes all the features provided by a hexagonal system. Whenever a user or other application wants to communicate with a hexagonal system, they reach one of the available input adapters. With such adapters, we can provide different ways to access the same functionality within the hexagonal system. If a client does not support HTTP communication, we can implement an adapter using a different protocol. The significant advantage here is that removing or adding new adapters does not influence the domain logic.

Due to the hexagonal architecture's decoupling and well-encapsulating nature, we can change technologies without major changes, or indeed any changes, occurring in the system domain logic.

In this chapter, we'll continue our journey in exploring the exciting features of Quarkus. One feature that fits quite well with implementing input adapters is the **RESTEasy Reactive JAX-RS implementation**, which is a part of the Quarkus framework. RESTEasy Reactive proposes an asynchronous and event-driven way to expose HTTP endpoints. So, we'll learn how to integrate such Reactive capabilities with input adapters from a hexagonal system.

We'll cover the following topics in this chapter:

- Exploring the approaches to handling server's requests
- Implementing input adapters with RESTEasy Reactive
- Adding OpenAPI and Swagger UI
- Testing Reactive input adapters

By the end of this chapter, you'll know how to implement and test input adapters with reactive behavior. You'll also know how to publish the API for these input adapters using OpenAPI and Swagger UI.

Technical requirements

To compile and run the code examples presented in this chapter, you need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. They are available for the Linux, Mac, and Windows operating systems.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter12`.

Exploring the approaches to handling server's requests

In client-server communication, we have a process flow where a client sends a request, the server receives it, and it starts to do some work. Once the server finishes its work, it replies to the client with a result. From the client's perspective, this flow does not change. It's always about sending a request and receiving a response. What can change, though, is how the server can internally handle how a request is processed.

There are two approaches to handling the server's request processing: **reactive** and **imperative**. So, let's see how a server can handle requests imperatively.

Imperative

In a traditional web application running on **Tomcat**, every request that's received by the server triggers the creation of a worker thread on something called a **thread pool**. In Tomcat, a thread pool is a mechanism that controls the life cycle and availability of worker threads that serve application requests. So, when you make a server request, Tomcat pulls a dedicated thread from the thread pool to serve your request. This worker thread relies on blocking I/O to access databases and other systems. The following diagram illustrates how the imperative approach works:

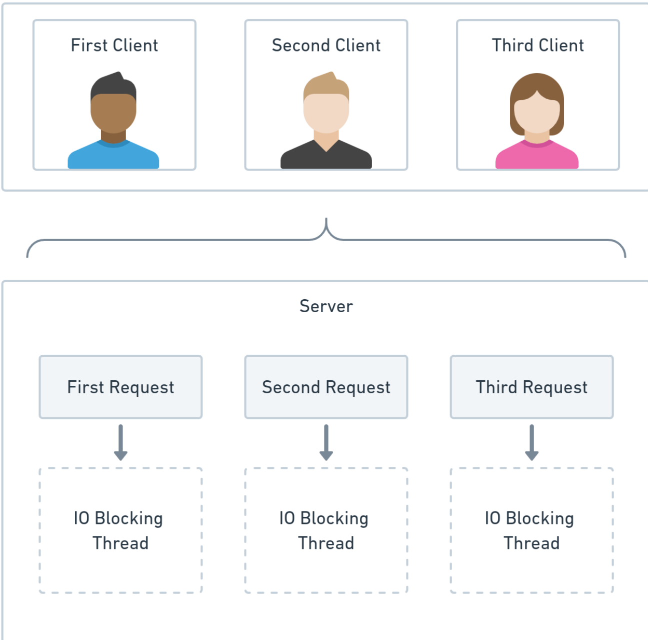

Figure 12.1 – The imperative approach

As shown in the preceding diagram, **Server** needs to create a new I/O blocking worker thread for each request.

Once a worker thread has been created and allocated to serve a request, it is blocked until the request is fulfilled. The server has a limited number of threads. If you have lots of long-running requests and continue to send such requests before the server can finish them, the server will run out of threads, which will lead to system failures.

Thread creation and management is also expensive. **Server** expends valuable resources in creating and switching between threads to serve client requests.

So, the bottom line of the imperative approach is that a worker thread is blocked to serve one – and only one – request at a time. To serve more requests concurrently, you need to provide more worker threads. Also, the imperative approach influences how the code is written. Imperative code is somewhat more straightforward to understand because things are treated sequentially.

Now, let's see how the reactive approach contrasts with the imperative one.

Reactive

As you may imagine, the idea behind the reactive approach is that you don't need to block a thread to fulfill a request. Instead, the system can use the same thread to process different requests simultaneously. In the imperative approach, we have worker threads that handle only one request at a time, while in the reactive approach, we have I/O non-blocking threads that handle multiple requests concurrently. Here, we can see how the reactive approach works:

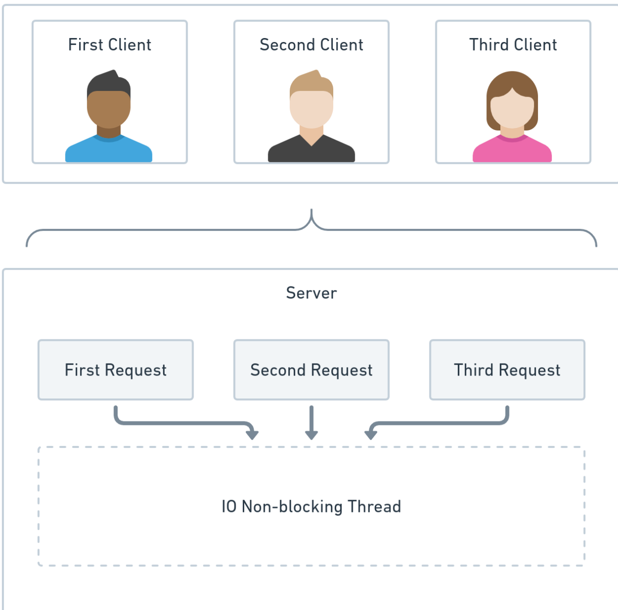

Figure 12.2 – The reactive approach

As shown in the preceding diagram, a single non-blocking thread can handle multiple requests.

In the reactive approach, we have a sense of continuation. Instead of the sequential nature of the imperative approach, with Reactive, we can see that things have continuity. By continuation, we mean that whenever a Reactive-ready server receives a request, that request is dispatched as an I/O operation with an attached continuation. This continuation works like a callback that is triggered and continues to execute the request once the server returns with a response. If this request needs to fetch a database or any remote system, the server won't block the I/O thread while waiting for a response. Instead, the I/O thread will trigger an I/O operation with an attached continuation and will release the I/O thread to accept other requests.

The following diagram illustrates how I/O threads trigger I/O operations:

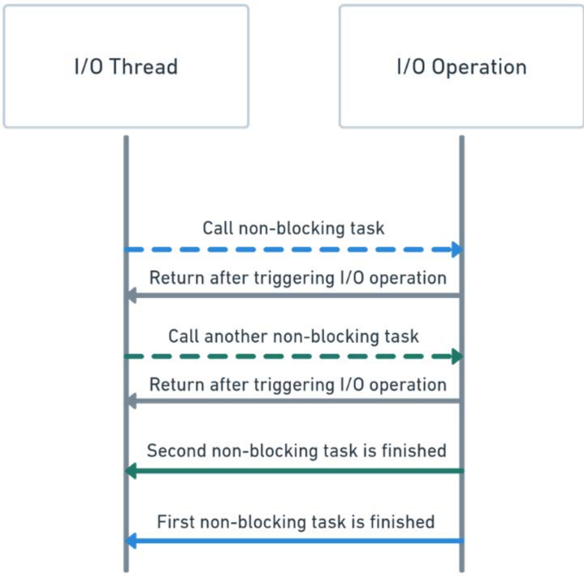

Figure 12.3 – I/O thread flow

As we can see, **I/O Thread** calls a non-blocking task that triggers **I/O Operation** and returns immediately. This happens because **I/O Thread** does not need to wait for the first **I/O Operation** to finish to call a second one. While the first **I/O Operation** is still executing, the same **I/O Thread** calls for another non-blocking task. Once **I/O Operation** has concluded, **I/O Thread** resumes execution by finishing the non-blocking tasks.

By avoiding wasting any time and resources that exist in the imperative approach, the reactive approach makes optimized use of the threads that don't block execution while waiting for an I/O operation to be finished.

Next, we'll learn how to implement reactive input adapters using the RESTEasy Reactive JAX-RS implementation provided by Quarkus.

Implementing input adapters with RESTEasy Reactive

RESTEasy Reactive is a JAX-RS implementation that supports both imperative and reactive HTTP endpoints. Such an implementation integrates with **Vert.x**, which is a toolkit that we can use to build distributed Reactive systems. RESTEasy Reactive and Vert.x work together in Quarkus to provide Reactive capabilities.

To understand what a Reactive endpoint looks like, we will integrate RESTEasy Reactive with the input adapters of the topology and inventory system.

Let's start by configuring the required Maven dependencies:

```
<dependencies>
  <dependency>
    <groupId>io.quarkus</groupId>
    <artifactId>quarkus-resteasy-reactive</artifactId>
  </dependency>
  <dependency>
    <groupId>io.quarkus</groupId>
    <artifactId>quarkus-resteasy-reactive-
      jackson</artifactId>
  </dependency>
</dependencies>
```

With `quarkus-resteasy-reactive`, we bring the Reactive libraries, including Reactive RESTEasy and the `Mutiny` library, which we'll use to create code in a reactive fashion. We will use `quarkus-resteasy-reactive-jackson` for deserialization tasks involving the Reactive responses.

Once we have the dependencies configured, we can start implementing the Reactive input adapter for router management in the topology and inventory system.

Implementing the Reactive input adapter for router management

We'll work on top of the existing input adapters that we created in *Chapter 8*, *Building the Framework Hexagon*. We'll change those input adapters to enable JAX-RS and Reactive capabilities. We'll execute the following steps to do so:

1. Let's start by defining the top-level path for requests related to router management on the `RouterManagementAdapter` class:

```
@ApplicationScoped
@Path("/router")
public class RouterManagementAdapter {

    @Inject
    RouterManagementUseCase routerManagementUseCase;
    /** Code omitted **/
}
```

   We use the `@Path` annotation to map a URL path to a resource in the system. We can use this annotation on top of a class or a method.

   The only field of this class is `RouterManagementUseCase`, which is injected using the `@Inject` annotation. By utilizing this use case reference, we gain access to system features related to router management.

2. Next, let's define a Reactive endpoint to retrieve a router:

```
@GET
@Path("/{id}")
public Uni<Response> retrieveRouter( Id id) {
    return Uni.createFrom()
            .item(
               routerManagementUseCase.
               retrieveRouter(id))
            .onItem()
            .transform(
             router -> router != null ?
             Response.ok(f) :
```

```
                   Response.ok(null))
                  .onItem()
                  .transform(Response.ResponseBuilder::build);
```

The `@GET` annotation says that only `HTTP GET` requests are allowed. The `@Path("/{id}")` annotation from the method level is concatenated with the `@Path("/router")` annotation from the class level. So, to reach this `retrieveRouter` method, we have to send a request to `/router/{id}`.

Also, note the `@PathParam("id")` annotation, which we use to capture a parameter from the URL.

What makes this endpoint a Reactive one is its `Uni<Response>` response type. `Uni` is one of the two types provided by the `Mutiny` library. In addition to `Uni`, there is also the `Multi` type.

We use the `Uni` and `Multi` types to represent what kind of data we're dealing with. For example, if your response returns just one item, you should use `Uni`. Otherwise, if your response is like a stream of data, like those that come from a messaging server, then `Multi` may be more suited for your purpose.

By calling `Uni.createFrom().item(routerManagementUseCase.retrieveRouter(id))`, we're creating a pipeline that executes `routerManagementUseCase.retrieveRouter(id)`. The result is captured on `transform(f -> f != null ? Response.ok(f) : Response.ok(null))`. If the request is successful, we get `Response.ok(f)`; otherwise, we get `Response.ok(null)`. Finally, we call `transform(Response.ResponseBuilder::build)` to transform the result into a `Uni<Response>` object.

The remaining endpoints we are about to implement all follow a similar approach to the one described previously.

3. After implementing an endpoint to retrieve a router, we can implement an endpoint to remove a router from the system:

```
   @DELETE
   @Path("/{id}")
   public Uni<Response> removeRouter(@PathParam("id") Id id)
   {
       return Uni.createFrom()
                  .item(
                   routerManagementUseCase.removeRouter(id))
```

```
                .onItem()
                .transform(
                 router -> router != null ?
                 Response.ok(router) :
                 Response.ok(null))
                .onItem()
                .transform(Response.ResponseBuilder::build);
  }
```

The `@DELETE` annotation corresponds to the `HTTP DELETE` method. Again, we are defining a `Path` parameter on the `@Path("/{id}")` annotation. The method body has a `Uni` pipeline that executes `routerManagementUseCase.removeRouter(id)` and returns `Uni<Response>`.

4. Let's implement the endpoint to create a new router:

```
  @POST
  @Path("/")
  public Uni<Response> createRouter(CreateRouter
  createRouter) {
      /** Code omitted **/
      return Uni.createFrom()
                .item(
                   routerManagementUseCase.
                   persistRouter(router))
                .onItem()
                .transform(
                 router -> router != null ?
                 Response.ok(f) :
                 Response.ok(null))
                .onItem()
                .transform(Response.ResponseBuilder::build);
  }
```

We use the `@POST` annotation because we're creating a new resource. The `@Path("/")` annotation at the method level, when concatenated with the `@Path("/router")` annotation at the class level, generates the `/router/` path. We have the Reactive code in the method body to handle the request and return `Uni<Response>`.

5. Next, we will implement the endpoint so that a router can be added to a core router:

```
@POST
@Path("/add")
public Uni<Response> addRouterToCoreRouter(AddRouter
addRouter) {
    /** Code omitted **/
    return Uni.createFrom()
            .item(routerManagementUseCase.
                    addRouterToCoreRouter(router,
                      coreRouter))
            .onItem()
            .transform(
             router -> router != null ?
             Response.ok(router) :
             Response.ok(null))
            .onItem()
            .transform(Response.ResponseBuilder::build);
}
```

Again, we use the `@POST` annotation here. The `@Path("/add")` annotation at the method level, when concatenated with `@Path("/router")` at the class level, generates the `/router/add` path. The Reactive code creates a pipeline to execute `routerManagementUseCase.addRouterToCoreRouter(router, coreRouter)` and return `Uni<Response>`.

6. Finally, we must implement the endpoint to remove a router from a core router:

```
@DELETE
@Path("/{routerId}/from/{coreRouterId}")
public Uni<Response> removeRouterFromCoreRouter(
    /** Code omitted **/
    return Uni.createFrom()
            .item(routerManagementUseCase.
                    removeRouterFromCoreRouter(
                    router, coreRouter))
            .onItem()
            .transform(
```

```
                router -> router != null ?
                     Response.ok(f) :
                     Response.ok(null))
               .onItem()
               .transform(Response.ResponseBuilder::build);
  }
```

Here, we use the `@DELETE` annotation to require the `HTTP DELETE` method on the request. In the `@Path` annotation, we have two path parameters – `routerId` and `coreRouterId`. We use these two parameters to obtain the `Router` and `CoreRouter` objects when we call `routerManagementUseCase.removeRouterFromCoreRouter(router, coreRouter)` inside the pipeline provided by `Uni`.

As we can see, when using Quarkus, it does not take too much to shift from an imperative to a Reactive way to implementing REST endpoints. Much of the work is done behind the scenes by the framework and its libraries.

Now, let's move on and implement Reactive input adapters for switch management.

Implementing the Reactive input adapter for switch management

Following a similar approach to the one we followed in the previous section, we can implement the Reactive input adapters for switch management by executing the following steps:

1. We will start by enabling JAX-RS on the `SwitchManagementAdapter` class:

```
  @ApplicationScoped
  @Path("/switch")
  public class SwitchManagementAdapter {

      @Inject
      SwitchManagementUseCase switchManagementUseCase;
      @Inject
      RouterManagementUseCase routerManagementUseCase;
      /** Code omitted **/
  }
```

This class is annotated with `@Path("/switch")`, so all the switch management-related requests will be directed to it. Following this, we inject both `SwitchManagementUseCase` and `RouterManagementUseCase` to execute operations on the Application hexagon.

2. To enable switch retrieval in the topology and inventory system, we need to implement the Reactive behavior on the `retrieveSwitch` method:

```
@GET
@Path("/{id}")
public Uni<Response> retrieveSwitch(@PathParam("id") Id
switchId) {
    return Uni.createFrom()
            .item(
             switchManagementUseCase.
             retrieveSwitch(switchId))
            .onItem()
            .transform(
             aSwitch -> aSwitch != null ?
             Response.ok(aSwitch) :
             Response.ok(null))
            .onItem()
            .transform(Response.ResponseBuilder::build);
}
```

By adding the `@GET` and `@Path` annotations, we activate JAX-RS on the `retrieveSwitch` method. We place `switchManagementUseCase.retrieveSwitch(switchId)` so that it's executed inside a Mutiny pipeline that returns `Uni<Response>`.

The call on `item` returns immediately. It triggers the operation that's executed by the `retrieveSwitch` method and allows the thread to continue serving other requests. The result is obtained when we call `onItem`, which represents the continuation of the operation that's triggered when we call `item`.

3. Next, we must add Reactive behavior to the `createAndAddSwitchToEdgeRouter` method:

```
@POST
@Path("/create/{edgeRouterId}")
public Uni<Response> createAndAddSwitchToEdgeRouter(
```

```
                CreateSwitch createSwitch,
                @PathParam("edgeRouterId") String
                  edgeRouterId){
        /** Code omitted **/
        return Uni.createFrom()
                .item((EdgeRouter)
                  routerManagementUseCase.
                  persistRouter(router))
                .onItem()
                .transform(
                 router -> router != null ?
                 Response.ok(f) :
                 Response.ok(null))
                .onItem()
                .transform(Response.ResponseBuilder::build);
    }
```

The preceding method handles the `HTTP POST` requests to create a switch object and add it to an edge router. We call the `routerManagementUseCase.persistRouter(router)` method here, which is wrapped inside a Mutiny pipeline, to return `Uni<Response>`.

4. Finally, we must define the Reactive endpoint to remove a switch from an edge router:

```
    @DELETE
    @Path("/{switchId}/from/{edgeRouterId}")
    public Uni<Response> removeSwitchFromEdgeRouter(
            @PathParam("switchId") String switchId,
            @PathParam("edgeRouterId") String
              edgeRouterId) {
        /** Code omitted **/
        return Uni.createFrom()
                .item(
                 (EdgeRouter)routerManagementUseCase.
                  persistRouter(router))
                .onItem()
                .transform(
```

```
                router -> router != null ?
                Response.ok(f) :
                Response.ok(null))
               .onItem()
               .transform(Response.ResponseBuilder::build);
  }
```

As we did with our previous removal operation, where we removed a router from a core router, we use the `@DELETE` annotation to make the `removeSwitchFromEdgeRouter` method only accept the `HTTP DELETE` requests. We pass the `Path` parameters, `switchId` and `edgeRouterId`, to obtain the switch and edge router objects required for the operation.

After defining the Reactive endpoints for `retrieveSwitch`, `createAndAddSwitchToEdgeRouter`, and `removeSwitchFromEdgeRouter`, we can start implementing the Reactive input adapter for network management.

Implementing the Reactive input adapter for network management

As you may imagine, the `network` Reactive input adapter follows the same standard that's used by the router and switch Reactive adapters. In the following steps, we will enable Reactive behavior for endpoints related to network management:

1. Let's start by enabling JAX-RS on the `NetworkManagementAdapter` input adapter:

```
@ApplicationScoped
@Path("/network")
public class NetworkManagementAdapter {

    @Inject
    SwitchManagementUseCase switchManagementUseCase;
    @Inject
    NetworkManagementUseCase networkManagementUseCase;
    /** Code omitted **/
}
```

At this point, you may be familiar with the `@Path` annotation at the class level. We inject the `SwitchManagementUseCase` and `NetworkManagementUseCase` use cases to assist in the operations that are executed by this input adapter.

2. Next, we must define a Reactive endpoint so that networks can be added to a switch:

```
@POST
@Path("/add/{switchId}")
public Uni<Response> addNetworkToSwitch(AddNetwork
addNetwork, @PathParam("switchId") String switchId) {
    /** Code omitted **/
    return Uni.createFrom()
            .item(
              networkManagementUseCase.
               addNetworkToSwitch(
               network, networkSwitch))
            .onItem()
            .transform(
              f -> f != null ?
              Response.ok(f) :
              Response.ok(null))
            .onItem()
            .transform(Response.ResponseBuilder::build);
}
```

The idea we apply here is the same one we applied to the previous implementations. Inside the `addNetworkToSwitch` method, we add some Reactive code that will use a `Mutiny` pipeline to call `networkManagementUseCase.addNetworkToSwitch(network, networkSwitch)` and return `Uni<Response>`.

3. Finally, we must define the Reactive endpoint to remove a network from a switch:

```
@DELETE
@Path("/{networkName}/from/{switchId}")
public Uni<Response> removeNetworkFromSwitch(@
PathParam("networkName") String networkName, @
PathParam("switchId") String switchId) {
```

```
        /** Code omitted **/
        return Uni.createFrom()
                  .item(
                   networkManagementUseCase.
                   removeNetworkFromSwitch(
                   networkName, networkSwitch))
                  .onItem()
                  .transform(
                    f -> f != null ?
                    Response.ok(f) :
                    Response.ok(null))
                  .onItem()
                  .transform(Response.ResponseBuilder::build);
    }
```

Here, we use the `@DELETE` annotation and two path parameters, `networkName` and `switchId`, to remove a network from a switch. Inside the `Mutiny` pipeline, we call `networkManagementUseCase.removeNetworkFromSwitch( networkName, networkSwitch)`. The pipeline result is `Uni<Response>`.

With that, we have finished implementing the Reactive input adapter for network management. Now, the `RouterManagementAdapter`, `SwitchManagementAdapter`, and `NetworkManagementAdapter` input adapters are ready to serve HTTP requests in a Reactive way.

These three input adapters and their endpoints form the hexagonal system API.

In this section, we learned not just to create ordinary REST endpoints, but we also went the extra mile by using RESTEasy Reactive to enable Reactive behavior on the input adapter's endpoints. That's a fundamental step to tap into the advantages that a Reactive approach can provide. With the Reactive approach, we no longer need to depend on I/O blocking threads, which may consume more computing resources than I/O non-blocking threads. I/O blocking threads need to wait for I/O operations to finish. I/O non-blocking threads are more efficient because the same thread can handle several I/O operations at the same time.

The next section will cover how to use OpenAPI and Swagger UI to document and publish the hexagonal system API.

Adding OpenAPI and Swagger UI

Understanding and interacting with third-party systems is sometimes a non-trivial undertaking. In the best scenario, we may have the system documentation, an organized code base, and a set of APIs that, together, help us understand what the system does. In the worst scenario, we have none of these things. This challenging situation requires courage, patience, and persistence to venture into trying to understand a tangled code base with intricate complexities.

OpenAPI represents an honorable effort to increase our capacity to express and understand what a system does. Originally based on the Swagger specification, the OpenAPI specification standardizes how APIs are documented and described so that anyone can grasp the capabilities offered by a system without much effort.

We spent the previous section implementing the Reactive input adapters that form the API of our hexagonal system. To make this system more understandable to other people and systems, we'll use OpenAPI to describe the functionalities provided by the input adapters and their endpoints. Also, we'll enable **Swagger UI**, a web application that presents a clear and organized view of the system's APIs.

Quarkus comes with built-in support for the **OpenAPI v3** specification. To enable it, we need the following Maven dependency:

```
<dependencies>
  <dependency>
      <groupId>io.quarkus</groupId>
      <artifactId>quarkus-smallrye-openapi</artifactId>
  </dependency>
</dependencies>
```

The `quarkus-smallrye-openapi` dependency provides the libraries that contain the OpenAPI annotations we can use to describe the Reactive endpoints methods on the input adapter classes. This dependency lets us configure Swagger UI, too.

Remember that we configured four Java modules: `domain`, `application`, `framework`, and `bootstrap`. To activate and configure Swagger UI, we need to create the `resource/application.properties` file inside the `bootstrap` module. Here is how we can configure this file:

```
quarkus.swagger-ui.always-include=true

quarkus.swagger-ui.urls-primary-name=Topology & Inventory
quarkus.swagger-ui.theme=material
quarkus.swagger-ui.title=Topology & Inventory - Network
Management System
quarkus.swagger-ui.footer=&#169; 2021 | Davi Vieira
quarkus.swagger-ui.display-operation-id=true

mp.openapi.extensions.smallrye.info.title=Topology & Inventory
API
mp.openapi.extensions.smallrye.info.version=1.0
mp.openapi.extensions.smallrye.info.description=Manage networks
assets
```

We set `quarkus.swagger-ui.always-include` to `true` to ensure that Swagger UI will also be available when the application is started using the `prod` (production) profile – one of the built-in Quarkus profiles. With `quarkus.swagger-ui.theme`, we can configure the interface theme. We will use the remaining properties to provide a high-level description of the API.

Let's learn how to use the OpenAPI annotations to expose and describe the hexagonal system's endpoints. Look at the following example from the `RouterManagementAdapter` class:

```
@ApplicationScoped
@Path("/router")
@Tag(name = "Router Operations", description = "Router
management operations")
public class RouterManagementAdapter {

```

```
    @GET
    @Path("/{id}")
    @Operation(operationId = "retrieveRouter",
    description = "Retrieve a router from the network
      inventory")
    public Uni<Response> retrieveRouter(@PathParam("id")
      Id id) {
     /** Code omitted **/
}
```

The `@Tag` annotation, which is used at the class level, lets us define the metadata information that's applied for all the endpoints defined in the `RouterManagementAdapter` class. This means that the method endpoints, such as the `retrieveRouter` method in the `RouterManagementAdapter` class, will inherit that class-level `@Tag` annotation.

We use the `@Operation` annotation to provide details of an operation. In the preceding code, we're describing the operation that's performed at the `/{id}` path. We have the `operationId` parameter here, which is used to uniquely identify the endpoint, and the `description` parameter, which is used to provide a meaningful operation description.

To make Quarkus and Swagger UI display a fancy UI of our hexagonal system's API, we just need to add these OpenAPI annotations to the classes and methods (properly configured with JAX-RS) that we want to expose on Swagger UI.

You can compile and run the application using the code from this book's GitHub repository. Make sure that you execute the following commands in the `chapter12` directory:

```
$ mvn clean package
$ java -jar bootstrap/target/bootstrap-1.0-SNAPSHOT-runner.jar
```

This will open the following URL in your browser:

```
http://localhost:8080/q/swagger-ui/
```

Also, you'll see something similar to the following screenshot:

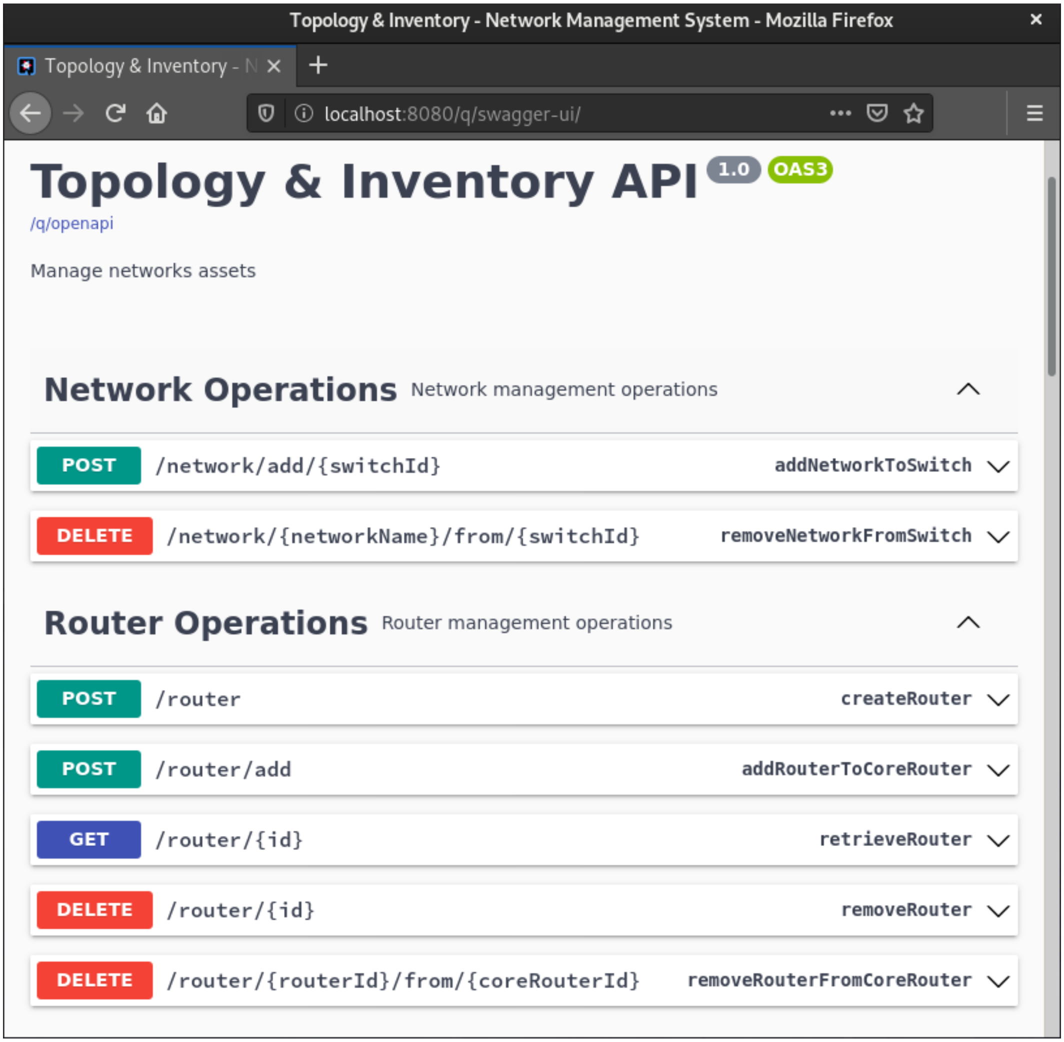

Figure 12.4 – Swagger UI from topology and inventory system

In the preceding screenshot, the operations are grouped into **Network Operations**, **Router Operations**, and **Switch Operations**. These groups come from the `@Tag` annotation we inserted for each of the input adapter classes. Each endpoint inherited its respective `@Tag` metadata information.

So far, we have our hexagonal system properly configured with Reactive endpoints that are well-documented with OpenAPI and Swagger UI. Now, let's learn how to test these endpoints to ensure they are working as expected.

Testing Reactive input adapters

Our testing efforts started on the Domain hexagon by unit testing the core system components. Then, we moved on to the Application hexagon, where we could test the use cases using **behavior driven design** techniques. Now that we have implemented Reactive REST endpoints on the Framework hexagon, we need to find a way to test them.

Fortunately, Quarkus is well equipped when it comes to endpoint testing. To get started, we need the following dependency:

```
<dependencies>
  <dependency>
    <groupId>io.rest-assured</groupId>
    <artifactId>rest-assured</artifactId>
    <scope>test</scope>
  </dependency>
</dependencies>
```

The `rest-assured` dependency allows us to test HTTP endpoints. It provides an intuitive library that's very useful for making requests and extracting responses from HTTP calls.

To see how it works, let's implement a test for the `/router/{routerId}` endpoint:

```
@Test
@Order(1)
public void retrieveRouter() throws IOException {
    var expectedRouterId =
      "b832ef4f-f894-4194-8feb-a99c2cd4be0c";
    var routerStr = given()
            .contentType("application/json")
            .pathParam("routerId", expectedRouterId)
            .when()
            .get("/router/{routerId}")
            .then()
            .statusCode(200)
            .extract()
            .asString();
    var actualRouterId =
```

```
     getRouterDeserialized(routerStr).getId().getUuid()
       .toString();
     assertEquals(expectedRouterId, actualRouterId);
 }
```

To create a request, we can use the static `io.restassured.RestAssured.given` method. We can specify the content type, parameters, HTTP method, and body of a request with the `given` method. After sending the request, we can check its status with `statusCode`. To obtain the response, we call `extract`. In the following example, we're getting the response in the form of a string. This is because the return type of the Reactive endpoint is `Uni<Response>`. So, the result is a JSON string.

We need to deserialize the JSON string into a `Router` object before running assertions. The deserialization work is accomplished by the `getRouterDeserialized` method:

```
public static Router getRouterDeserialized(String jsonStr)
throws IOException {
     var mapper = new ObjectMapper();
     var module = new SimpleModule();
     module.addDeserializer(Router.class, new
       RouterDeserializer());
     mapper.registerModule(module);
     var router = mapper.readValue(jsonStr, Router.class);
     return router;
 }
```

This method receives a JSON string as a parameter. This JSON string is passed to an `ObjectMapper` mapper when we call `mapper.readValue(jsonStr, Router.class)`. In addition to providing a mapper, we also need to extend and implement the `deserialize` method from the `com.fasterxml.jackson.databind.deser.std.StdDeserializer` class. In the preceding example, this implementation is provided by `RouterDeserializer`. This deserializer will transform the JSON string into a `Router` object, as shown in the following code:

```
public class RouterDeserializer extends StdDeserializer<Router>
{

     /** Code omitted **/

     @Override
```

```
     public Router deserialize(JsonParser jsonParser,
     DeserializationContext ctxt)
             throws IOException {
         JsonNode node =
         jsonParser.getCodec().readTree(jsonParser);
         var id = node.get("id").get("uuid").asText();
         var vendor = node.get("vendor").asText();
         var model = node.get("model").asText();
         var ip = node.get("ip").get("ipAddress").asText();
         var location = node.get("location");
         var routerType = RouterType.valueOf(
           node.get("routerType").asText());
         var routersNode = node.get("routers");
         var switchesNode = node.get("switches");
         /** Code omitted **/
 }
```

The `deserialize` method intends to map every relevant JSON attribute to a domain type. We perform this mapping by retrieving the values we want from a `JsonNode` object. After mapping the values that we want, we can create a `router` object, as shown in the following code:

```
var router = RouterFactory.getRouter(
        Id.withId(id),
        Vendor.valueOf(vendor),
        Model.valueOf(model),
        IP.fromAddress(ip),
        getLocation(location),
        routerType);
```

Once all the values have been retrieved, we call `RouterFactory.getRouter` to produce a `Router` object. Because a router may have child routers and switches, we call `fetchChildRouters` and `fetchChildSwitches` so that they also have `StdDeserializer` implementations:

```
fetchChildRouters(routerType, routersNode, router);
fetchChildSwitches(routerType, switchesNode, router);
```

We call the `fetchChildRouters` and `fetchChildSwitches` methods because a router may have child routers and switches that need to be deserialized. These methods will perform the required deserialization.

After deserializing the JSON string response, we can run the assertion on a `Router` object:

```
var actualRouterId = getRouterDeserialized(routerStr).getId().
getUuid().toString();
assertEquals(expectedRouterId, actualRouterId);
```

To test the `/router/{routerId}` endpoint, we are checking if the ID of the router that's been retrieved by the Reactive endpoint is equal to the one we passed in the request.

You can run this and other tests that are available in this book's GitHub repository by executing the following command inside the `chapter12` directory:

```
$ mvn test
```

The output of the preceding code will be similar to the following:

```
[INFO] -------------------------------------------------------
[INFO]  T E S T S
[INFO] -------------------------------------------------------
[INFO] Running dev.davivieira.topologyinventory.framework.
adapters.input.rest.NetworkManagementAdapterTest
2021-09-29 00:47:36,825 INFO  [io.quarkus] (main) Quarkus
2.2.1.Final on JVM started in 2.550s. Listening on: http://
localhost:8081
2021-09-29 00:47:36,827 INFO  [io.quarkus] (main) Profile test
activated.
2021-09-29 00:47:36,827 INFO  [io.quarkus] (main) Installed
features: [cdi, resteasy-reactive, resteasy-reactive-jackson,
smallrye-context-propagation, smallrye-openapi, swagger-ui]
[EL Info]: 2021-09-29 00:47:38.812--ServerSession(751658062)-
-EclipseLink, version: Eclipse Persistence Services -
3.0.1.v202104070723
[INFO] Tests run: 2, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 5.418 s - in dev.davivieira.topologyinventory.
framework.adapters.input.rest.NetworkManagementAdapterTest
[INFO] Running dev.davivieira.topologyinventory.framework.
adapters.input.rest.RouterManagementAdapterTest
[INFO] Tests run: 5, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 0.226 s - in dev.davivieira.topologyinventory.
```

```
framework.adapters.input.rest.RouterManagementAdapterTest
[INFO] Running dev.davivieira.topologyinventory.framework.
adapters.input.rest.SwitchManagementAdapterTest
[INFO] Tests run: 3, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 0.085 s - in dev.davivieira.topologyinventory.
framework.adapters.input.rest.SwitchManagementAdapterTest
2021-09-29 00:47:39,675 INFO  [io.quarkus] (main) Quarkus
stopped in 0.032s
```

The preceding output describes the execution of the Reactive endpoint tests for the `RouterManagementAdapter`, `SwitchManagementAdapter`, and `NetworkManagementAdapter` input adapters.

One benefit of executing these endpoint tests is that we are not only testing the endpoint functionality on the Framework hexagon but we're performing comprehensive tests that check the behavior of all the hexagons of the system.

Summary

In this chapter, we had the opportunity to dive into more Quarkus features, especially RESTEasy Reactive. We started by reviewing what imperative and reactive mean in the context of client-server communication.

Then, we learned that Quarkus provides RESTEasy Reactive as its JAX-RS implementation, enabling us to implement Reactive endpoints on input adapters. After that, we exposed the hexagonal system's API using OpenAPI and Swagger UI. And to ensure we implemented the Reactive endpoints correctly, we wrote the endpoint tests using the `rest-assured` library.

In the next chapter, we'll continue exploring the Reactive capabilities offered by Quarkus and emphasize the data persistence aspects with Hibernate Reactive.

Questions

1. What is the difference between imperative and reactive requests?
2. What is the name of the JAX-RS implementation provided by Quarkus?
3. What is the purpose of OpenAPI?
4. Which library should we use in Quarkus to test HTTP endpoints?

13
Persisting Data with Output Adapters and Hibernate Reactive

In the previous chapter, we learned about some of the advantages that can be brought to a system by using Quarkus reactive capabilities. Out first step on the reactive road was to implement Reactive input adapters using **RESTEasy Reactive**. Although the input adapters' endpoints are being served reactively, we still have the output adapters working in a synchronous and blocking fashion.

To turn the hexagonal system into a more Reactive one, in this chapter, we'll first learn how to configure **Object Relational Mapping** (**ORM**) on system entities by using Hibernate Reactive and Panache. Once the system entities are properly configured, we'll learn how to use these entities to connect to a MySQL database reactively.

The following are the topics we'll cover in this chapter:

- Introducing Hibernate Reactive and Panache
- Enabling reactive behavior on output adapters
- Testing reactive output adapters

As we have already implemented reactive input adapters in the previous chapter, our goal here is to extend the reactive behavior in a hexagonal system by implementing reactive output adapters. Such implementation takes place at the Framework hexagon, which is the architecture element where we concentrate on adapters.

By the end of this chapter, you'll know how to integrate Quarkus with a hexagonal system to access databases in a reactive way. By understanding the required configuration steps and fundamental implementation details, you'll be able to implement reactive output adapters. This knowledge will help you tackle situations where non-blocking I/O requests offer more advantages than I/O-blocking ones.

Technical requirements

To compile and run the code examples presented in this chapter, you need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. They are all available for Linux, Mac, and Windows operating systems.

Also, you'll need **Docker** installed on your machine.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter13`.

Introducing Hibernate Reactive and Panache

The available technologies and techniques to handle database operations in Java have evolved a lot in the last few years. Based on the **Java Persistence API** (**JPA**) specification, we've been presented with different ORM implementations such as Spring Data JPA, EclipseLink, and, of course, Hibernate. These technologies make our lives easier by abstracting away much of the basic work required to deal with databases.

Quarkus is integrated with Hibernate ORM and its reactive counterpart, Hibernate Reactive. Also, Quarkus comes with a library called `Panache` that simplifies our interaction with databases.

Next, we'll take a brief look at Hibernate Reactive and Panache's main features.

Hibernate Reactive features

It's rare, if not impossible, to find a silver-bullet solution that solves all problems related to database access. When we talk about the reactive and imperative approaches for database handling, it's fundamental to understand the advantages and disadvantages of both approaches.

What's so appealing in the imperative approach for database access is the simplicity in which you develop your code. There are fewer things to adjust and think about when you need to read or persist things using the imperative approach. But this approach may cause setbacks when its blocking nature starts to impact the use cases of your system. To avoid such setbacks, we have the reactive approach, enabling us to deal with databases in a non-blocking fashion, but not without additional complexities in our development and the new problems and challenges that arise when handling databases in a reactive way.

The original Hibernate implementation was conceived to deal with the problems that developers had to deal with while mapping Java objects to database entities. The original implementation relies on I/O blocking synchronous communication to interact with databases. It's been and still is the most conventional way to access databases in Java. On the other hand, Hibernate Reactive arose from the urge of reactive programming movements and the need for asynchronous communication to database access. Instead of I/O blocking, Hibernate Reactive relies upon I/O non-blocking communication to interact with databases.

The entity mapping properties remain the same in the reactive implementation. However, what changes is how we open a database's Reactive connections and how we should structure the software code to handle database entities reactively.

To set up Hibernate Reactive, you can follow the standard approach for configuring the `META-INF/persistence.xml` file, as shown in the following example:

```
<persistence-unit name="mysql">

    <provider>
       org.hibernate.reactive.provider
       .ReactivePersistenceProvider
    </provider>

    <class>dev.davivieria.SomeObject</class>

    <properties>
    <property name="javax.persistence.jdbc.url"
```

```
        value="jdbc:mysql://localhost/hreact"/>
    </properties>

</persistence-unit>
```

Note that we're using `ReactivePersistenceProvider` to open a reactive connection to the database. Once the `persistence.xml` file is properly configured, we can start using Hibernate Reactive in our code:

```
import static javax.persistence.Persistence.
createEntityManagerFactory;
SessionFactory factory = createEntityManagerFactory (
persistenceUnitName ( args ) )
.unwrap(SessionFactory.class);

/** Code omitted **/
public static String persistenceUnitName(String[] args) {
    return args.length > 0 ?
    args[0] : "postgresql-example";
}
```

In order to create a `SessionFactory` object, the system uses the properties defined by the `persistence.xml` file. With `SessionFactory`, we can start a reactive communication with the database:

```
SomeObject someObject = new SomeObject();
factory.withTransaction(
     (
org.hibernate.reactive.mutiny.Mutiny.Transaction session,
org.hibernate.reactive.mutiny.Mutiny.Transaction tx) ->
session.persistAll(someObject)).subscribe();
```

To persist data, first we need to create a transaction by calling the `withTransaction` method. Inside a transaction, we call the `persistAll` method from `SessionFactory` to persist an object. We call the `subscribe` method to trigger the persistence operation in a non-blocking way.

By establishing a layer between the application and the database, Hibernate provides all the basic things we need to handle databases in Java.

Now, let's see how Panache can make things even simpler.

Panache features

Panache sits on top of Hibernate and enhances it even more by providing a simple interface to handle the database entities. Panache was primarily developed to work with the Quarkus framework, and it is a library aimed to abstract much of the boilerplate code required to handle the database entities. With Panache, you can easily apply database patterns such as **Active Record** and **Repository**. Let's briefly see how to do that.

Applying the Active Record pattern

In the **Active Record** pattern, we use the class that represents the database entity to make changes in the database. To enable such behavior, we need to extend `PanacheEntity`. Look at the following example:

```
@Entity
@Table(name="locations")
public class Location extends PanacheEntity {

    @Id @GeneratedValue
    private Integer id;

    @NotNull @Size(max=100)
    public String country;

    @NotNull @Size(max=100)
    public String state;

    @NotNull @Size(max=100)
    public String city;
}
```

The preceding `Location` class is a regular Hibernate-based entity that extends `PanacheEntity`. Besides extending `PanacheEntity`, there is nothing new in this `Location` class. We have annotations such as `@NotNull` and `@Size` that we use to validate the data.

The following are some of the things we can do with an Active Record entity:

- To list entities, we can call the `listAll` method. This method is available on `Location` because we're extending the `PanacheEntity` class:

```
List<Location> locations = Location.listAll();
```

- To delete all the `Location` entities, we can call the `deleteAll` method:

```
Location.deleteAll();
```

- To find a specific `Location` entity by its ID, we can use the `findByIdOptional` method:

```
Optional<Location> optional = Location.
findByIdOptional(locationId);
```

- To persist a `Location` entity, we have to call the `persist` method on the `Location` instance we intend to persist:

```
Location location = new Location();
location.country = "Brazil";
location.state = "Sao Paulo";
location.city = "Sao Paulo";
location.persist();
```

Every time we execute one of the preceding described operations, they are immediately committed to the database.

Now, let's see how to use Panache to apply the Repository pattern.

Applying the Repository pattern

Instead of using an entity class to perform actions on the database, we use a separate class that is usually dedicated to providing database operations in the Repository pattern. Such a class works like a repository interface to the database.

To apply the Repository pattern, we should use regular Hibernate entities:

```
@Entity
@Table(name="locations")
public class Location {
/** Code omitted **/
}
```

Note that at this time, we're not extending the `PanacheEntity` class. In the Repository pattern, we don't call the database operations directly through the entity class. Instead, we call them through the repository class. Here is an example of how we can implement a repository class:

```
@ApplicationScoped
public class LocationRepository implements
PanacheRepository<Location> {

   public Location findByCity(String city){
        return find ("city", city).firstResult();
   }

   public Location findByState(String state){
        return find("state", state).firstResult();
   }

   public void deleteSomeCountry(){
        delete ("country", "SomeCountry");
  }
}
```

By implementing `PanacheRepository` on the `LocationRepository` class, we're enabling all the standard operations such as `findById`, `delete`, `persist`, and so on that are present in the `PanacheEntity` class. Also, we can define our own custom queries, as we did in the preceding example, by using the `find` and `delete` methods that are provided by the `PanacheEntity` class.

Note that we annotated the repository class as an `ApplicationScoped` bean. It means we can inject and use it in other classes:

```
@Inject
LocationRepository locationRepository;

public Location findLocationByCity(City city){
    return locationRepository.findByCity(city);
}
```

Here, we have the most common operations available on the repository class:

- To list all the `Location` entities, we need to call the `listAll` method from `LocationRepository`:

```
List<Location> locations = locationRepository.listAll();
```

- By calling `deleteAll` on `LocationRepository`, we remove all the `Location` entities:

```
locationRepository.deleteAll();
```

- To find a `Location` entity by its ID, we call the `findByIdOptional` method on `LocationRepository`:

```
Optional<Location> optional = locationRepository.
findByIdOptional(locationId);
```

- To persist a `Location` entity, we need to pass a `Location` instance to the `persist` method from `LocationRepository`:

```
Location location = new Location();
location.country = "Brazil";
location.state = "Sao Paulo";
location.city = "Sao Paulo";
locationRepository.persist(location);
```

In the preceding examples, we are executing all database operations using the repository class. The methods we call here are the same as those present in the entity class from the Active Record approach. The only difference here is the usage of the repository class.

By learning to use Panache for applying the Active Record and Repository patterns, we increase our capacity to provide good approaches for handling the database entities. There is no better or worse pattern. The project's circumstances will ultimately dictate which pattern is more suitable.

Panache is a library made especially for Quarkus. So, the best way to connect Hibernate Reactive objects such as `SessionFactory` and `Transaction` to Panache is by delegating the database configuration to Quarkus, which will automatically provide these objects.

Now that we're acquainted with Hibernate Reactive and Panache, let's see how we can implement output adapters in a hexagonal system.

Enabling reactive behavior on output adapters

One of the most important benefits of using hexagonal architecture is the improved flexibility to change technologies without significant refactoring. The hexagonal system is designed in such a way that its domain logic and business rules are oblivious about the technologies utilized to execute them.

There is no free lunch – when we decide to use the hexagonal architecture, we have to pay the price for the benefits that such architecture can provide. (By price, I mean a considerable increase in the effort and complexity required to structure the system code by following the hexagonal principles.)

If you're concerned about code reuse, you may find some practices awkward to decouple code from specific technologies. For example, consider a scenario where we have a domain entity class and a database entity class. One can argue by saying, *why not have just one class that serves both purposes?* Well, in the end, it's all a matter of priorities. If the coupling of the domain and technology-specific classes is not an issue for you, go ahead. In this case, you would not have the burden of maintaining a domain model plus all the infrastructure code that supports it. But you'd have the same code serving different purposes, thus violating the **Single Responsibility Principle** (**SRP**). Otherwise, if you see a risk in using the same code for serving different purposes, then the output adapters can help.

In *Chapter 2*, *Wrapping Business Rules inside Domain Hexagon*, we introduced an output adapter that integrated the application with the file system. In *Chapter 4*, *Creating Adapters to Interact with the Outside World*, we created a more elaborated output adapter to communicate with an H2 in-memory database. Now that we have the Quarkus toolkit at our disposal, we can create reactive output adapters.

Configuring reactive data sources

To continue the reactive effort that we started in the previous chapter by implementing reactive input adapters, we'll create and connect reactive output adapters to these reactive input adapters by executing the following steps:

1. Let's get started by configuring the required dependencies in the `pom.xml` file of the Framework hexagon:

```
<dependencies>
  <dependency>
    <groupId>io.quarkus</groupId>
    <artifactId>quarkus-reactive-mysql-client
      </artifactId>
  </dependency>
```

```
    <dependency>
      <groupId>io.quarkus</groupId>
     <artifactId>quarkus-hibernate-reactive-panache</
artifactId>
    </dependency>
  </dependencies>
```

The `quarkus-reactive-mysql-client` dependency contains the libraries we need to open a reactive connection with MySQL databases. And the `quarkus-hibernate-reactive-panache` dependency contains Hibernate Reactive and Panache. It's important to note that this library is especially suited for reactive activities. For non-reactive activities, Quarkus offers a different library.

2. Now, we need to configure the database connection on the `application.properties` file from the Bootstrap hexagon. Let's start with the data source properties:

```
quarkus.datasource.db-kind = mysql
quarkus.datasource.reactive=true
quarkus.datasource.reactive.url=mysql://localhost:3306/
inventory
quarkus.datasource.username = root
quarkus.datasource.password = password
```

The `quarkus.datasource.db-kind` property is not mandatory because Quarkus can infer the database kind by looking into the specific database client that is loaded from Maven dependencies. With `quarkus.datasource.reactive` set to `true`, we're enforcing reactive connections. We need to specify the reactive database connection URL on `quarkus.datasource.reactive.url`.

3. Finally, we have to define the Hibernate configuration:

```
quarkus.hibernate-orm.sql-load-script=inventory.sql
quarkus.hibernate-orm.database.generation = drop-and-
create
quarkus.hibernate-orm.log.sql = true
```

After Quarkus has created the database and its tables, you can load a `.sql` file to execute more instructions on the database. By default, it searches and loads a file called `import.sql`. We can change this behavior by using the `quarkus.hibernate-orm.sql-load-script` property.

Be aware of not using `quarkus.hibernate-orm.database.generation = drop-and-create` on production. Otherwise, it will drop all your database tables. If you don't set any value, the default one, `none`, is used. The default behavior doesn't perform any change on the database.

And, finally, we enable `quarkus.hibernate-orm.log.sql` to see which SQL queries Hibernate is executing under the hood. I recommend you enable the `log` feature only for development purposes. When running the application on production, don't forget to disable this option.

Let's now see how to configure application entities to work with a MySQL database.

Configuring entities

The topology and inventory system requires four database tables to store its data: routers, switches, networks, and location. Each one of these tables will be mapped to a Hibernate entity class properly configured to work with a MySQL data source.

We'll apply the Repository pattern, so we won't have the entities to perform database operations. Instead, we'll create separate repository classes to trigger actions on the database. But before creating repository classes, let's start by implementing Hibernate entities for the topology and inventory system. We'll configure these entities to work with MySQL databases.

Router entity

For this entity and others that will be implemented subsequently, we should create classes on the `dev.davivieira.topologyinventory.framework.adapters.output.mysql.data` package of the Framework hexagon.

This is what the `Router` entity class should look like:

```
@Entity(name="RouterData")
@Table(name = "routers")
@EqualsAndHashCode(exclude = "routers")
public class RouterData implements Serializable {

    @Id
    @Column(name="router_id", columnDefinition =
      "BINARY(16)")
    private UUID routerId;

```

```
    @Column(name="router_parent_core_id",
    columnDefinition = "BINARY(16)")
    private UUID routerParentCoreId;
   /** Code omitted **/
}
```

For the `routerId` and `routerParentCoreId` fields, we must set `columnDefinition`, the `@Column` annotation parameter, to `BINARY(16)`. It's a requirement to make `UUID` attributes work on MySQL databases.

Then, we create the relationship mapping between routers and other tables:

```
{
    /**Code omitted**/
   @ManyToOne(cascade = CascadeType.ALL)
   @JoinColumn(name="location_id")
   private LocationData routerLocation;

   @OneToMany(cascade = {CascadeType.MERGE},
   fetch = FetchType.EAGER)
   @JoinColumn(name="router_id")
   private List<SwitchData> switches;

   @OneToMany(cascade = CascadeType.ALL, fetch =
     FetchType.EAGER)
   @JoinColumn(name="router_parent_core_id")
   private Set<RouterData> routers;
   /**Code omitted**/
}
```

Here, we define a many-to-one relation between routers and location. After that, we have two one-to-many relationships with switches and routers. The `fetch = FetchType.EAGER` property is used to avoid mapping errors that may occur during the reactive connections.

Let's move on to the configuration of the `Switch` entity class.

Switch entity

The following code shows us how we should implement the `Switch` entity class:

```
@Entity
@Table(name = "switches")
public class SwitchData {

    @ManyToOne
    private RouterData router;

    @Id
    @Column(name="switch_id", columnDefinition =
      "BINARY(16)")
    private UUID switchId;

    @Column(name="router_id", columnDefinition =
      "BINARY(16)")
    private UUID routerId;

    @OneToMany(cascade = CascadeType.ALL, fetch =
      FetchType.EAGER)
    @JoinColumn(name="switch_id")
    private Set<NetworkData> networks;

    @ManyToOne
    @JoinColumn(name="location_id")
    private LocationData switchLocation;

    /**Code omitted**/
}
```

We have omitted other column attributes to focus only on the IDs and relationships. We start by defining a many-to-one relationship between switches and a router. The primary key is the `switchId` field, which happens to be a `UUID` attribute. We have another `UUID` attribute to map the `routerId` field.

Also, there is a one-to-many relationship between a switch and networks, and a many-to-one relationship between switches and a location.

Now, let's configure the `Network` entity class.

Network entity

Although we do not consider networks as entities in the domain model, they have a separate table in the database. So, in the Framework hexagon level, we treat them as database entities, but when they reach the Domain hexagon, we treat them as value objects. This example shows that the hexagon system dictates how the data will be treated on the Domain hexagon level. By doing so, the hexagonal system shields the domain model from technical details.

We implement the `Network` entity class as follows:

```
@Entity
@Table(name = "networks")
public class NetworkData {

    @ManyToOne
    @JoinColumn(name="switch_id")
    private SwitchData switchData;

    @Id
    @GeneratedValue(strategy = GenerationType.IDENTITY)
    @Column(name="network_id")
    private int id;

   /**Code omitted**/
}
```

This is a straightforward entity class with a many-to-one relationship between networks and a switch. For networks, we rely on the database to generate network IDs. Also, networks are not considered entities on the domain model. Instead, we treat networks as value objects that are controlled by an aggregate. For aggregates, we need to handle the `UUID`. But for value objects, we do not. That's why we don't handle UUIDs for network database entities.

We still need to implement one last entity for location. Let's do that.

Location entity

In networks, location is not considered an entity on the Domain hexagon level. But because we have a separate table for location, we need to treat it as a database entity on the Framework hexagon level.

The following code is used to implement the `Location` entity class:

```
Entity
@Table(name = "location")
public class LocationData {

    @Id
    @Column(name="location_id")
    @GeneratedValue(strategy = GenerationType.IDENTITY)
    private int locationId;

    @Column(name="address")
    private String address;

    @Column(name="city")
    private String city;

    /**Code omitted**/
}
```

We again rely on the database's built-in ID generation mechanism to handle IDs for location data. After that, we have attributes such as `address` and `city` that are part of a location.

Now that we have all the required entities adequately configured, we can move ahead to use Panache to create reactive repository classes that we'll use to trigger database operations with the entities we've configured.

Implementing reactive repository classes

By implementing the `PanacheRepositoryBase` interface, you create a reactive repository class. We'll need one repository class for router operations and another for switch operations.

It's paramount to define only one repository for aggregate root. In our case, the `Router` entity is the aggregate root for router management operations, and `Switch` is the aggregate root for switch management operations. The purpose of an aggregate is to ensure consistency across all objects that are controlled by such an aggregate. The entry point for any aggregate is always the aggregate root. In order to ensure aggregate consistency in a database transaction, we define only one repository class that is dedicated to controlling the database operations based on the aggregate root.

The classes we're about to implement are located in the `dev.davivieira.topologyinventory.framework.adapters.output.mysql.repository` package:

- The following code implements the `RouterManagementRepository` class:

  ```
  @ApplicationScoped
  public class RouterManagementRepository implements
  PanacheRepositoryBase<RouterData, UUID> {

  }
  ```

  Note that we're passing `RouterData` as the entity we're working on and `UUID` as the attribute type mapped to be used by the ID. If we don't need any custom queries, we can leave this class empty because Panache already provides lots of standard database operations.

  Note that we're also annotating that class with `ApplicationScoped`, so we can inject that component in other places, such as the output adapter, which we'll implement soon.

- The following code implements the `SwitchManagementRepository` class:

  ```
  @ApplicationScoped
  public class SwitchManagementRepository implements
  PanacheRepositoryBase<SwitchData, UUID> {

  }
  ```

  Here, we're following the same approach we did in the `RouterManagementRepository` class.

With reactive repository classes properly implemented, we're ready to create reactive output adapters. Let's do that!

Implementing reactive output adapters

Just to recap, we need to provide an adapter implementation for the `RouterManagementOutputPort` output port interface:

```
public interface RouterManagementOutputPort {
    Router retrieveRouter(Id id);

    Router removeRouter(Id id);

    Router persistRouter(Router router);
}
```

When implementing the MySQL output adapter, we'll provide a reactive implementation for each one of the preceding method declarations.

We also need to implement the `SwitchManagementOutputPort` output adapter interface:

```
public interface SwitchManagementOutputPort {
    Switch retrieveSwitch(Id id);
}
```

It's simpler, as there's just one method for which we need to provide a reactive implementation.

Let's start by implementing the reactive output adapter for router management.

Reactive router management of the MySQL output adapter

In order to enable the hexagonal system to communicate with a MySQL database, we need to create a new output adapter to allow such integration (because we're using Quarkus, such an output adapter implementation is fairly simple). We'll use the following steps to do so:

1. We start by injecting the `RouterManagementRepository` repository class:

```
@ApplicationScoped
public class RouterManagementMySQLAdapter implements
RouterManagementOutputPort {

```

```
    @Inject
    RouterManagementRepository
      routerManagementRepository;
    /** Code omitted **/
}
```

We'll use the `RouterManagementRepository` repository to make database operations.

2. Then, we implement the `retrieveRouter` method:

```
@Override
public Router retrieveRouter(Id id) {
    var routerData =
    routerManagementRepository.findById(id.getUuid())
      .subscribe()
      .asCompletionStage()
      .join();
    return RouterMapper.routerDataToDomain(routerData);
}
```

When we call `routerManagementRepository.findById(id.getUuid())`, the system starts an I/O non-blocking operation. This subscribe call tries to resolve the item produced by the `findById` operation. Then, we call `asCompletionStage` to receive the item. Finally, we call `join`, which returns the result value when the operation is complete.

3. Now, we need to implement the `removeRouter` method:

```
@Override
public Router removeRouter(Id id) {
    var removed =
    routerManagementRepository.deleteById(id.getUuid())
      .subscribe()
      .asCompletionStage()
      .join();
    if(!removed){
        throw new InternalError();
```

```
        }
        return null;
    }
```

Here, we call the `routerManagementRepository.deleteById(id.getUuid())` Panache operation to remove a router from the database. After that, we call `subscribe`, `asCompletionStage`, and `join` to execute the operations in a reactive way.

4. And, finally, we implement the `persistRouter` method:

```
    @Override
    public Router persistRouter(Router router) {
        var routerData =
        RouterH2Mapper.routerDomainToData(router);
        Panache.withTransaction(
        ()->routerManagementRepository.persist
        (routerData));
        return router;
    }
```

The construct is different here. To ensure that the transaction will not be lost between the client and server during the request, we wrap the persistence operation inside `Panache.withTransaction`. This is a requirement for operations where we need to persist data.

Let's now implement the reactive output adapter for switch management.

Reactive switch management of the MySQL output adapter

The approach used here is the same one utilized when we implemented the reactive output adapter for router management. We'll execute the following steps to implement the reactive output adapter:

1. Let's start by injecting the `SwitchManagementRepository` repository class:

```
    @ApplicationScoped
    public class SwitchManagementMySQLAdapter implements
    SwitchManagementOutputPort {

```

```
    @Inject
    SwitchManagementRepository
      switchManagementRepository;
    /** Code omitted **/
}
```

As we've already seen, the injection of a repository class is required so we can use it to trigger database operations.

2. After that, we implement the `retrieveSwitch` method:

```
@Override
public Switch retrieveSwitch(Id id) {
    var switchData =
    switchManagementRepository.findById(id.getUuid())
        .subscribe()
        .asCompletionStage()
        .join();
    return RouterH2Mapper.switchDataToDomain(switchData);
}
```

We use this method to retrieve a `Switch` object in a reactive way. There are no persistence methods because all the write operations should always occur through a router management output adapter.

By implementing reactive output adapters in the hexagonal system, we can tap into the advantages of reactive programming techniques. With hexagonal architecture, it's not a big deal to have both reactive and imperative output adapters serving different needs in the same system.

The Quarkus reactive features for databases are paramount for anyone venturing into developing reactive systems. We can provide a reactive alternative for how our application deals with databases by understanding how to use such features. It does not mean that the reactive approach is always a better choice than the traditional imperative one, but the important point here is that we navigate between both approaches.

Now that we've implemented the `RouterManagementMySQLAdapter` and `SwitchManagementMySQLAdapter` output adapters, let's test them.

Testing the reactive output adapters

We need to implement unit tests to ensure the methods from output adapters are working as expected. Here is an example of how we can create unit tests for `RouterManagementMySQLAdapter`:

```
@QuarkusTest
public class RouterManagementMySQLAdapterTest {

    @InjectMock
    RouterManagementMySQLAdapter
    routerManagementMySQLAdapter;

    @Test
    public void testRetrieveRouter() {
        Router router = getRouter();
        Mockito.when(
        routerManagementMySQLAdapter.
        retrieveRouter(router.getId())).thenReturn(router);
        Router retrievedRouter =
        routerManagementMySQLAdapter.
        retrieveRouter(router.getId());
        Assertions.assertSame(router, retrievedRouter);
    }
   /** Code omitted **/
}
```

It's possible to use the `@InjectMock` annotation to mock the `RouterManagementMySQLAdapter` output adapter. While executing the `testRetrieveRouter` test method, we can mock a call to `routerManagementMySQLAdapter.retrieveRouter(router.getId)` by using `Mockito.when`. The `thenReturn` method returns the object, which our mock test should return. In that case, it is a `Router` object. With `Assertions.assertSame(router, retrievedRouter)`, we can assert the result for the execution of `retrieveRouter(router.getId)`.

We won't need to implement new test classes to execute integration tests for Reactive output adapters. We can rely on the same tests used in the previous chapter to test the reactive input adapters. Such tests call the input adapters, which, in turn, call the output adapters by using the use case operations.

However, what changes is that we'll need a MySQL database to test the reactive output adapters.

Quarkus provides Docker-based containers that we can use for development purposes or testing. In order to enable such a database container, we must not configure a data source connection on the `application.properties` file. This is how we should configure that file for testing purposes:

```
quarkus.datasource.db-kind = mysql
quarkus.datasource.reactive=true
quarkus.hibernate-orm.database.generation=drop-and-create
quarkus.hibernate-orm.sql-load-script=inventory.sql
quarkus.vertx.max-event-loop-execute-time=100
```

Note that we're not informing any database connection URL. By doing that, Quarkus understands that it needs to provide a database. The previously described `application.properties` file should be placed in the `tests/resource/` directory. Inside this directory, we should also place the `inventory.sql` file, which loads data into the database. This `.sql` file is available in this chapter's GitHub repository.

You can override entries on `application.properties` to use environment variables. It may be useful for configurations such as `quarkus.hibernate-orm.database.generation` where you can set the property value based on the application's environment variables. For example, for local or development purposes, you can use `${DB_GENERATION}`, an environment variable that resolves to `drop-and-create`. And for production, this environment variable can resolve to `none`.

After properly setting up the `application.properties` and `inventory.sql` files, we can test the application by running the following command in the project's root directory:

```
$ mvn test
```

The following output shows the MySQL Docker container being brought up to be used during tests:

```
2021-10-10 01:33:40,242 INFO  [  .0.24]] (build-10) Creating
container for image: mysql:8.0.24
2021-10-10 01:33:40,876 INFO  [  .0.24]]
(build-10) Starting container with ID:
67e788aab66f2f2c6bd91c0be1a164117294ac29cc574941ad41ff5760
de918c
```

```
2021-10-10 01:33:41,513 INFO  [  .0.24]] (build-
10) Container mysql:8.0.24 is starting:
67e788aab66f2f2c6bd91c0be1a164117294ac29cc574941ad41ff5760
de918c
2021-10-10 01:33:41,520 INFO  [  .0.24]] (build-10) Waiting
for database connection to become available at jdbc:mysql://
localhost:49264/default using query 'SELECT 1'
2021-10-10 01:34:01,078 INFO  [  .0.24]] (build-10) Container
is started (JDBC URL: jdbc:mysql://localhost:49264/default)
2021-10-10 01:34:01,079 INFO  [  .0.24]] (build-10) Container
mysql:8.0.24 started in PT20.883579S
2021-10-10 01:34:01,079 INFO  [io.qua.dev.mys.dep.
MySQLDevServicesProcessor] (build-10) Dev Services for MySQL
started.
```

Quarkus creates a database called `default`, where the tables are created. The `inventory.sql` file is run against this `default` database.

After the database is ready, Quarkus starts testing the system, providing a result similar to the following one:

```
[INFO] Tests run: 2, Failures: 0, Errors: 0, Skipped: 0, Time
elapsed: 32.672 s - in dev.davivieira.topologyinventory.
framework.adapters.input.rest.NetworkManagementAdapterTest
[INFO] Running dev.davivieira.topologyinventory.framework.
adapters.input.rest.RouterManagementAdapterTest
[INFO] Tests run: 5, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 0.232 s - in dev.davivieira.topologyinventory.
framework.adapters.input.rest.RouterManagementAdapterTest
[INFO] Running dev.davivieira.topologyinventory.framework.
adapters.input.rest.SwitchManagementAdapterTest
[INFO] Tests run: 3, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 0.088 s - in dev.davivieira.topologyinventory.
framework.adapters.input.rest.SwitchManagementAdapterTest
[INFO] Running dev.davivieira.topologyinventory.
framework.adapters.input.rest.outputAdapters.
RouterManagementMySQLAdapterTest
[INFO] Tests run: 3, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 0.116 s - in dev.davivieira.topologyinventory.
framework.adapters.input.rest.outputAdapters.
RouterManagementMySQLAdapterTest
```

```
[INFO] Running dev.davivieira.topologyinventory.
framework.adapters.input.rest.outputAdapters.
SwitchManagementMySQLAdapterTest
[INFO] Tests run: 1, Failures: 0, Errors: 0, Skipped: 0,
Time elapsed: 0.013 s - in dev.davivieira.topologyinventory.
framework.adapters.input.rest.outputAdapters.
SwitchManagementMySQLAdapterTest
```

In order to test the output adapters, we need to call the input adapters. If we can test the input adapters successfully, it means we're also testing the output adapters successfully.

Summary

Hibernate Reactive and Panache make our lives much easier when we need to handle databases using Quarkus in a reactive way. We learned that Hibernate Reactive is built on top of the traditional Hibernate implementation but with the addition of reactive features.

While examining Panache, we learned that it could help us implement the Active Record and Repository patterns to implement database operations. For the hands-on part, we implemented database entities, repositories, and reactive output adapters that we used together to interact with the MySQL database. Finally, we configured the hexagonal system tests to use the MySQL Docker container that Quarkus provides.

In the next chapter, we'll learn about some techniques to package the hexagonal system in a Docker image. We'll also learn how to run the hexagonal system in a Kubernetes cluster. This knowledge will enable us to ready the application to be deployed to cloud-based environments.

Questions

1. Which Java specification does Hibernate Reactive implement?
2. What is the difference between the Active Record and Repository patterns?
3. Which interface should we implement to apply the Repository pattern?
4. Why should we run write operations inside the `withTransaction` method?

14
Setting Up Dockerfile and Kubernetes Objects for Cloud Deployment

We spent the previous chapters exploring some of the amazing features that Quarkus provides to help us create cloud-native applications. Going even further, we also learned how to integrate Quarkus into a hexagonal system.

Now, we need to prepare the hexagonal system so that it can be deployed in cloud environments. Docker and Kubernetes are the leading technologies that dominate the cloud scene nowadays. If your application is prepared to run on these technologies, you're safe to make it run on most cloud providers.

So, in this chapter, we'll learn how to wrap the hexagonal system in a Docker image and run it on a Kubernetes cluster. For Docker images, we'll explore two techniques for creating such images: one that relies on an executable `.jar` and another that uses a native executable. We'll also learn how to deploy the hexagonal system in a local **Minikube**-based Kubernetes cluster.

The following topics will be covered in this chapter:

- Preparing the Docker image
- Creating Kubernetes Objects
- Deploying on Minikube

By the end of this chapter, you'll know how to make the hexagonal system run in a cloud-native environment based on Docker and Kubernetes. Nowadays, most modern applications run on the cloud. By turning the hexagonal system into a cloud-native one, you'll be able to tap into the advantages that exist when you're on the cloud.

Technical requirements

To compile and run the code examples presented in this chapter, you will need the latest **Java SE Development Kit** and **Maven 3.6** installed on your computer. They are available for the Linux, Mac, and Windows operating systems.

You'll also need **Docker** and **Minikube** installed on your machine.

You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter14`.

Preparing the Docker image

Container-based virtualization technology is not something new. Long before Docker, there were technologies such as OpenVZ, which applied the same fundamental concepts that are applied by Docker as well. Even today, we have alternatives such as **Linux Containers** (**LXC**), which provide a robust container-based solution. What sets Docker apart is how easy and intuitive it makes handling containerized applications. Docker takes portability to another level, simplifying and making containers a viable technology for larger audiences.

In the past, other container platforms were not so straightforward to use as Docker is today. Containers were a topic more related to system administrators than to software developers. Today, the scenario is different because of the simple yet powerful container-based solution we have with Docker. Because of its simplicity, Docker rapidly became popular among developers, who started to incorporate it into their projects.

As I mentioned previously, Docker's strength is in its simplicity to use and learn. Take, for example, how Docker abstracts the complexity required to wrap an application inside a container. You just need to define a Dockerfile describing how the application should be configured and executed inside the container. You can do this by using a simple set of instructions. So, Docker shields the user from low-level complexities that existed in previous container technologies.

One of the things that makes Quarkus so special is that it's a container-first framework. It's designed to build container-based applications. So, Quarkus is an excellent choice if you're targeting container-based environments.

With Quarkus, we can generate Docker images using `.jar` artifacts or native executable artifacts. We'll explore both of these approaches next.

Creating a Docker image with an Uber .jar artifact

Our approach here is to wrap the Uber `.jar` artifact in a Docker image so that the container can start and run the application by executing that `.jar` file. To build a Docker image, we need to create a Dockerfile with instructions to build such an image.

The following code shows how to create a Dockerfile for the topology and inventory system that uses the Uber `.jar` file:

```
FROM adoptopenjdk/openjdk11:x86_64-alpine-jre11u-nightly
ENV APP_FILE_RUNNER bootstrap-1.0-SNAPSHOT-runner.jar
ENV APP_HOME /usr/apps
EXPOSE 8080
COPY bootstrap/target/$APP_FILE_RUNNER $APP_HOME/
WORKDIR $APP_HOME
ENTRYPOINT ["sh", "-c"]
CMD ["exec java -jar $APP_FILE_RUNNER"]
```

This Dockerfile should be placed in the project's root directory.

The first line is the base **JDK 11** image that we'll build our image from. Then, we define the `APP_FILE_RUNNER` and `APP_HOME` environment variables to define the artifact's name and path, respectively. Because Quarkus is configured to run on port `8080`, we have to use the `EXPOSE` property to expose this port externally. The `COPY` command will copy the artifact generated by Maven. `WORKDIR` defines the path that the commands will be executed from within the container. With `ENTRYPOINT` and `CMD`, we can define how the container will execute the application's Uber `.jar` file.

Follow these steps to generate the Docker image and start the container:

1. First, we need to compile and generate an Uber `.jar` file:

```
$ mvn clean package
```

2. Then, we can generate the Docker image:

```
$ docker build . -t topology-inventory
Sending build context to Docker daemon  38.68MB
Step 1/8 : FROM adoptopenjdk/openjdk11:x86_64-alpine-
jre11u-nightly
 ---> 9b2a4d2e14f6
Step 2/8 : ENV APP_FILE_RUNNER bootstrap-1.0-SNAPSHOT-
runner.jar
 ---> Using cache
 ---> 753b39c99e78
Step 3/8 : ENV APP_HOME /usr/apps
 ---> Using cache
 ---> 652c7ce2bd47
Step 4/8 : EXPOSE 8080
 ---> Using cache
 ---> 37c6928bcae4
Step 5/8 : COPY bootstrap/target/$APP_FILE_RUNNER $APP_
HOME/
 ---> Using cache
 ---> 389c28dc9fa7
Step 6/8 : WORKDIR $APP_HOME
 ---> Using cache
 ---> 4ac09c0fe8cc
Step 7/8 : ENTRYPOINT ["sh", "-c"]
 ---> Using cache
 ---> 737bbcf2402b
Step 8/8 : CMD ["exec java -jar $APP_FILE_RUNNER"]
 ---> Using cache
 ---> 3b17c3fa0662
Successfully built 3b17c3fa0662
Successfully tagged topology-inventory:latest
```

The preceding output describes all the steps that need to be executed to generate the Docker image. Here, we can see that the Docker Engine starts building our image on top of the `adoptopenjdk/openjdk11` image. Then, it proceeds by defining the environment variables and handling the application artifact by preparing it to be executed every time a new container from that image is created.

3. Now, we can start the container with the following command:

```
$ docker run -p 5555:8080 topology-inventory
```

   With the `-p` parameter, we're mapping the `5555` host port to the `8080` container port. So, we'll need to use the `5555` port to access the system.

4. To confirm that the application is running on the Docker container, we can access the Swagger UI URL at `http://localhost:5555/q/swagger-ui`.

Now, let's learn how to generate a Docker image using the native executable.

Creating a Docker image with a native executable

In *Chapter 10*, *Adding Quarkus to a Modularized Hexagonal Application*, we learned that Quarkus uses **Ahead-Of-Time** (**AOT**) compilation techniques to optimize the bytecode and generate native code that offers improved performance, mainly during application startup.

This native executable is a product of the AOT compilation that's performed by Quarkus. Contrary to the Uber `.jar` file, which can be distributed to run on different operating systems and CPU architectures, the native executable file is platform-dependent. But we can overcome this limitation by wrapping the native executable into a Docker image that can be distributed to different operating systems and CPU architectures.

There are different approaches to generating a native executable. Some of them require us to install a **GraalVM** distribution and other software. However, to keep things simple, we'll follow an uncomplicated and convenient approach where Quarkus generates the native executable for us inside a Docker container that contains GraalVM.

Follow these steps to generate a Docker image with a native executable:

1. In the `pom.xml` file from the `bootstrap` hexagon, we need to include the following code before the `</project>` tag:

```
<profiles>
  <profile>
    <id>native</id>
    <properties>
```

```
        <quarkus.package.type>native
          </quarkus.package.type>
      </properties>
    </profile>
  </profiles>
```

The preceding configuration creates a profile that sets the `quarkus.package.type` property to `native`, causing Quarkus to build a native executable artifact.

2. Then, we must create the `ReflectionConfiguration` class on the `bootstrap` hexagon:

```
@RegisterForReflection(targets = {
        CoreRouter.class,
        EdgeRouter.class,
        Switch.class,
        Id.class,
        IP.class,
        Location.class,
        Model.class,
        Network.class,
        Protocol.class,
        RouterType.class,
        SwitchType.class,
        Vendor.class,
})
public class ReflectionConfiguration {}
```

One of the limitations of the native executable is that it offers partial support for reflection. **Reflection** is a technique that allows us to inspect or modify the runtime attributes of Java components, such as classes and methods. When we're running an application inside a JVM, the system can detect the classes/methods/fields that are indirectly connected. The same is not true when we're running a native executable. The reason for that is only classes that are directly connected are visible for reflection.

To overcome this limitation, we need to register all the classes for reflection that are not directly connected. There are two ways to do that: we can put such classes in a `.json` configuration file, or we can create a class annotated with the `@RegisterForReflection` annotation containing the classes we want to register for reflection. In the preceding code, we are using the latter approach, which relies on the annotated class.

3. To generate a native executable, we have to run the following command:

```
$ mvn clean package -Pnative -Dquarkus.native.container-
build=true -Dnative-image.xmx=6g
```

The compilation process of a native executable is a very expensive one in terms of memory consumption. So, we need to increase memory limits to avoid out-of-memory errors. If `6g` is not enough for you, feel free to increase it to prevent errors.

4. Next, we must create a file called `Dockerfile-native` that contains instructions for building a Docker image with the native executable:

```
FROM registry.access.redhat.com/ubi8/ubi-minimal
ENV APP_FILE_RUNNER bootstrap-1.0-SNAPSHOT-runner
ENV APP_HOME /work
EXPOSE 8080
COPY bootstrap/target/$APP_FILE_RUNNER $APP_HOME/
WORKDIR $APP_HOME
RUN echo $APP_FILE_RUNNER
CMD ["./bootstrap-1.0-SNAPSHOT-runner", "-Dquarkus.http.
host=0.0.0.0"]
```

Instead of the JDK 11 base image, we're using the `ubi-minimal` image from the official **Red Hat** registry. This image is suitable for running native executables.

5. Then, we must generate the Docker image with the following command:

```
$ docker build . -t topology-inventory-native -f
Dockerfile-native
```

You should run the preceding command from the project's root directory.

We use `-t topology-inventory-native:latest` and `-f Dockerfile-native` to create a different Docker image based on the native executable rather than the Uber `.jar` file. The output of this `docker build` command will be similar to that one we generated when we created the Docker image for the Uber `.jar` file. The only difference will be the entries related to the native executable artifact.

6. Tag and upload your image to your personal Docker registry:

```
$ docker tag topology-inventory-native:latest
s4intlaurent/topology-inventory-native:latest
$ docker push s4intlaurent/topology-inventory-
native:latest
The push refers to repository [docker.io/s4intlaurent/
topology-inventory-native]
f3216c6ba268: Pushed
0b911edbb97f: Layer already exists
54e42005468d: Layer already exists
latest: digest: sha256:4037e5d9c2cef01bda9c4bb5722bccbe0d
003336534c28f8245076223ce77273 size: 949
```

   We'll use the system's native image when deploying the application on a Minikube cluster.

7. Now, we can start the container:

```
docker run -p 5555:8080 topology-inventory-native:latest
```

   Note that the application is bootstrapping much faster!

8. To confirm that the application is running on the Docker container, we can access the Swagger UI URL at `http://localhost:5555/q/swagger-ui`.

With that, we have configured the Docker images for both the Uber `.jar` and native executable artifacts. These Docker images can be deployed on a Kubernetes cluster. However, to do that, we need to create the required Kubernetes objects to allow the deployment. So, in the next section, we'll learn to create Kubernetes objects for the containerized hexagonal system.

Creating Kubernetes objects

The Docker Engine does not provide any fault-tolerance or high availability mechanism. It only offers container-based virtualization technology. So, if you plan on running a mission-critical application using Docker, you may either need to work out your solution to ensure the containers are reliable while running or delegate this responsibility to a container orchestrator.

Container orchestrators arose as a response to the increased use of containers in the IT industry. Among these orchestrators, we can quote Docker Swarm, Rancher, and the one that dominates the industry: **Kubernetes**.

Initially conceived at Google as a closed source software called Borg, it was open sourced with the name Kubernetes. It's a powerful technology that can run on your computer for development purposes or control a fleet of hundreds, even thousands, server nodes, providing pods for the running applications.

You may be wondering, *what is a Pod?* We'll find out soon.

It's not our intent here to dive deep into Kubernetes internals, but we'll review some basic concepts to ensure we're on the same page.

Reviewing Kubernetes main objects

As we saw earlier, Kubernetes is a container orchestrator that helps us manage containers. To accomplish this, most – if not all – Kubernetes configuration can be done through `.yaml` files. In Kubernetes, we have a notion of the current state and the desired state. When the former meets the latter, we're fine. Otherwise, we have problems.

The backbone of this currently desired state approach is the Kubernetes configuration mechanism based on YAML files. With these files, we can express the desired state of things inside the cluster. Kubernetes will do its magic to ensure that the current state always matches the desired state. But you may be wondering, *the state of what?* The answer is the state of Kubernetes objects. Let's look at some of them:

- `Pod`: A `Pod` is a Kubernetes object that controls the life cycle of containers in a Kubernetes cluster. It's possible to attach more than one container to the same `Pod`, although this is not a common practice.
- `Deployment`: If a `Pod` controls the life cycle of containers, we can state that a `Deployment` object controls the life cycle of pods. With `Deployment`, you can specify how many pods you want to provide for your application. Kubernetes will take care of finding the available resources in the cluster to bring up these pods. If, for some reason, one of the pods goes down, Kubernetes will try to bring a brand-new `Pod` to ensure the desired state is being met.
- `Service`: When we deploy pods on the Kubernetes cluster, they are not immediately available internally for other pods or externally for clients outside the cluster. To make a deployed `Pod` available in the network, we need to create a `Service` object attached to that `Pod`. This `Service` object acts as a DNS entry point that provides basic load balancing access to the pods. For example, if you have an application running on three pods, the `Service` object will handle application requests for one of the three pods sitting behind the `Service` object. More sophisticated load balancing features can be achieved by using service mesh technologies such as **Istio**.

- `ConfigMap`: If you need to provide environment variables or mount a configuration file inside a `Pod`, `ConfigMap` is the object that can help you with that.
- `Secret`: This works similarly to a `ConfigMap` but can be used to store sensitive information such as credentials or private keys. The data on a `Secret` should be encoded with `base64`.

Now that we're more acquainted with some of the most important Kubernetes objects, let's see how we can use them to prepare our hexagonal system to be deployed on a Kubernetes cluster.

Configuring Kubernetes objects for the hexagonal system

Before creating the Kubernetes objects, first, let's configure Quarkus to enable YAML configuration and also a health check mechanism. We'll need both of these when we're deploying the application on Kubernetes:

```
<dependencies>
  <dependency>
    <groupId>io.quarkus</groupId>
    <artifactId>quarkus-config-yaml</artifactId>
  </dependency>
  <dependency>
    <groupId>io.quarkus</groupId>
    <artifactId>quarkus-smallrye-health</artifactId>
  </dependency>
</dependencies>
```

With `quarkus-config-yaml`, we can use the `application.yaml` file for most of the Quarkus configurations. And to enable health checks endpoints, we can use `quarkus-smallrye-health`.

Before creating the Kubernetes objects, let's configure the `application.yaml` file on the `bootstrap` hexagon:

```
quarkus:
  datasource:
    username: ${QUARKUS_DATASOURCE_USERNAME:root}
    password: ${QUARKUS_DATASOURCE_PASSWORD:password}
```

```
      reactive:
        url: ${QUARKUS_DATASOURCE_REACTIVE_URL:
          mysql://localhost:3306/inventory}
```

This `.yaml` file allows us to use most, but not all, of the configurations available on Quarkus. So, it's normal to use both `application.yaml` and `application.properties`. We're using the YAML configuration because we can employ a technique called **variable interpolation**. Take, for example, the following configuration entry:

```
${QUARKUS_DATASOURCE_USERNAME:root}
```

When the application starts, it will try to resolve an environment variable named `QUARKUS_DATASOURCE_USERNAME`. If the application can't resolve the variable name, it will fall back to the default value of `root`. This technique is very useful for defining default configurations for local development where environment variables may not be set.

You may have noticed the presence of the `QUARKUS_DATASOURCE_USERNAME`, `QUARKUS_DATASOURCE_PASSWORD`, and `QUARKUS_DATASOURCE_REACTIVE_URL` environment variables. Kubernetes will provide these environment variables with the `Secret` and `ConfigMap` objects. So, let's learn how to configure these and the other Kubernetes objects that are required to deploy the topology and inventory system (the files we will describe here are put inside a directory called `k8s` from the project's root directory):

1. We will start by configuring the `configmap.yaml` file:

   ```
   apiVersion: v1
   kind: ConfigMap
   metadata:
     name: topology-inventory
   data:
     QUARKUS_DATASOURCE_REACTIVE_URL:
       "mysql://topology-inventory-mysql:3306/inventory"
   ```

   This `ConfigMap` provides a `QUARKUS_DATASOURCE_REACTIVE_URL` environment variable with the reactive database URL that the application needs to connect to the MySQL database.

2. Then, we must configure the `secret.yaml` file:

   ```
   apiVersion: v1
   kind: Secret
   metadata:
     name: topology-inventory
   ```

```
type: Opaque
data:
  QUARKUS_DATASOURCE_USERNAME: cm9vdAo=
  QUARKUS_DATASOUCE_PASSWORD: cGFzc3dvcmQK
```

In the preceding `Secret`, we define the environment variables, `QUARKUS_DATASOURCE_USERNAME` and `QUARKUS_DATASOUCE_PASSWORD`, as the credentials to connect to the system's MySQL database.

3. To generate `base64`, you can execute the following command on Unix-based systems:

```
$ echo root | base64 && echo password | base64
cm9vdAo=
cGFzc3dvcmQK
```

We use the `root` and `password` values as the credentials to authenticate on the MySQL database.

4. Let's configure the `deployment.yaml` file:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: topology-inventory
  labels:
    app: topology-inventory
spec:
  replicas: 1
  selector:
    matchLabels:
      app: topology-inventory
  template:
    metadata:
      labels:
        app: topology-inventory
/** Code omitted **/
```

Here, we describe some of the metadata entries from the `deployment.yaml` file:

- The `metadata.labels.app` field: A Kubernetes `Service` object can apply load balancing by using the `labels` property to identify the pods that are part of the same `Deployment`. We'll see how the `Service` object references that label shortly.
- The `replicas` field: This defines that this `Deployment` will provide just one `Pod`.

5. Still in the `deployment.yaml` file, we can start defining the entries for the container configuration:

```
      spec:
        initContainers:
          - name: topology-inventory-mysql-init
            image: busybox
            command: [ 'sh', '-c', 'until nslookup
              topology-inventory-mysql; do echo waiting
              for topology-inventory-mysql; sleep 5;
              done;' ]
        containers:
          - name: topology-inventory
            image: s4intlaurent/topology-
              inventory:latest
            envFrom:
            - configMapRef:
                name: topology-inventory
            livenessProbe:
              httpGet:
                path: /q/health/ready
                port: 8080
              initialDelaySeconds: 30
              timeoutSeconds: 5
              periodSeconds: 3
            ports:
  - containerPort: 8080
```

Let's look at the entries that are used for the container configuration:

- The `initContainers` field: This is used when we need to execute some tasks or wait for something before the main container starts. Here, we're using an `init` container to wait for a MySQL database to be available. The `.yaml` file that loads the database is available in this book's GitHub repository for this chapter.

- The `Containers` field: This is where we set the configuration for the container that the pod runs.
- The `image` field: This is where we inform the image location of our application. It can be a public or private registry.
- The `configMapRef` field: This is used to inject `ConfigMap` data into the container.
- The `livenessProbe` field: Kubernetes can send probe packets to check if the application is alive. This is where we'll use the health check mechanism we configured earlier.
- The `containerPort` field: This is where we'll inform the port about the exposed Docker container.

6. Finally, we will configure the `service.yaml` file:

```
apiVersion: v1
kind: Service
metadata:
  name: topology-inventory
  labels:
    app: topology-inventory
spec:
  type: NodePort
  ports:
    - port: 8080
      targetPort: 8080
      nodePort: 30080
      protocol: TCP
  selector:
    app: topology-inventory
```

Kubernetes provides three different service types: `ClusterIP` for internal communication, and `NodePort` and `LoadBalance` for external communication. We're using `NodePort` to access the application from outside the Kubernetes cluster. Let's take a look at the most important fields:

- The `port` field: This field declares the service port that is available internally for other pods in the Kubernetes cluster.

- The `targetPort` field: This field specifies the port that the container is exposing.
- The `nodePort` field: This field specifies the external port, which allows external clients to access the application.

It's not a trivial undertaking to prepare an application to be deployed on a Kubernetes cluster. In this section, we learned about the main objects of Kubernetes. Understanding these objects is essential because they are the building blocks for any application running on a Kubernetes cluster.

With all the required Kubernetes objects adequately configured, we can deploy the hexagonal system in a Kubernetes cluster.

Deploying on Minikube

Minikube is a Kubernetes cluster that was made for development purposes. It allows us to create and destroy clusters with ease. Because of its simplicity, we'll use Minikube to deploy our hexagonal system by following these steps (I recommend following the instructions at `https://minikube.sigs.k8s.io/docs/start/` to install Minikube on your machine):

1. Once you have installed Minikube, you can start your cluster by issuing the following command:

```
$ minikube start
:) minikube v1.4.0 on Fedora 30
   Creating virtualbox VM (CPUs=2, Memory=2000MB, Disk=20000MB) ...
   Preparing Kubernetes v1.16.0 on Docker 18.09.9 ...
   Pulling images ...
   Launching Kubernetes ...
   Waiting for: apiserver proxy etcd scheduler controller dns
   Done! kubectl is now configured to use "minikube"
```

   The default cluster configuration consumes two CPUs, 2 GB of RAM, and 20 GB of disk space.

2. To confirm your cluster is alive, run the following command:

```
$ kubectl get nodes
NAME       STATUS   ROLES    AGE   VERSION
minikube   Ready    master   5m    v1.16.0
```

Nice! Now, we can deploy the topology and inventory system to our local Kubernetes cluster.

3. The deployment process is fairly simple. All we have to do is apply the Kubernetes YAML files we created in the previous section:

```
$ k apply -f k8s/
configmap/topology-inventory created
deployment.apps/topology-inventory-mysql created
service/topology-inventory-mysql created
deployment.apps/topology-inventory created
secret/topology-inventory created
service/topology-inventory created
```

4. Then, we can run the following command to see if the topology and inventory system is up and running:

```
$ k get pods
NAME                                       READY   STATUS
    RESTARTS   AGE
topology-inventory-76f4986846-zq5t8        1/1     Running
   0          73s
topology-inventory-mysql-dc9dbfc4b-
7sct6   1/1     Running
   0          73s
```

5. To access the application, we need to use the Minikube cluster IP. You can use the following code to retrieve that IP on a Unix-based operating system:

```
$ minikube ssh ifconfig | grep eth1 -A1 | grep "inet
addr" | cut -d: -f2| awk '{ print $1 }'
192.168.99.105
```

6. With that IP, we can query the health check endpoint to see if the topology and inventory system is alive:

```
$ curl -s http://192.168.99.105:30080/q/health/ready | jq
{
  "status": "UP",
  "checks": [
    {
      "name": "Reactive MySQL connections health
```

```
              check",
          "status": "UP",
          "data": {
            "<default>": "up"
          }
        }
     ]
   }
```

This shows that both the application and its database connection are healthy.

You can also access the Swagger UI URL at `http://192.168.99.105:30080/q/swagger-ui`, as shown in the following screenshot:

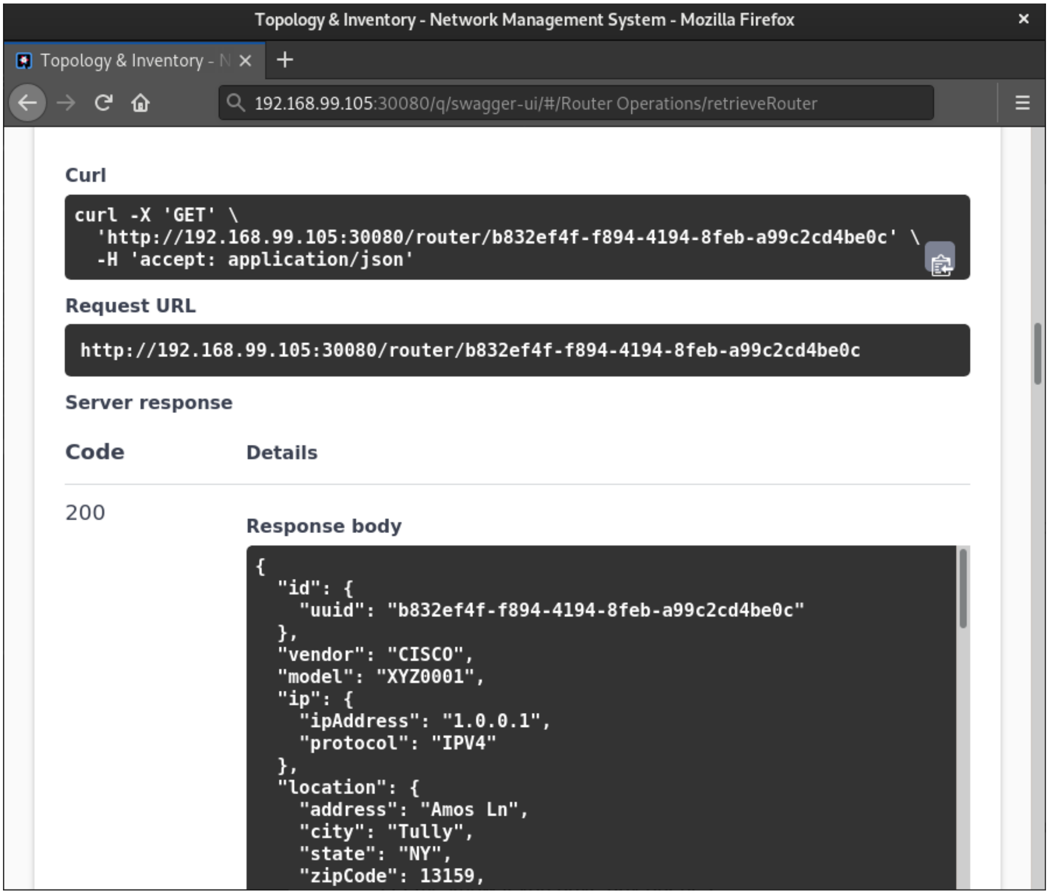

Figure 14.1 – Swagger UI from topology and inventory running on Minikube

Note that we are using port `30080` to access the Swagger UI URL on Minikube. `30080` is the Kubernetes node port that we configured to enable external access to the application.

With that, we have completed the fundamental steps to turn the hexagonal system into a cloud-native one. Our application is ready to be deployed on a local Minikube cluster and any cloud provider that offers Kubernetes clusters.

Summary

We started this chapter by learning about the building blocks that we can use to create a Docker image for the hexagonal system. Then, we created two Docker image types. The first one was based on the Uber `.jar` file, which is used to package and run the application, while the second one was based on native executables, where we could leverage the features Quarkus provides to create a native executable artifact.

Then, we created the Kubernetes objects that were required to deploy the hexagonal system in a Kubernetes cluster. Finally, we deployed the hexagonal system in a local Minikube cluster. More than a hexagonal system, we now have a cloud-native hexagonal system ready to tap into the advantages provided by cloud environments.

As we are nearing the end of this book, in the next chapter, we'll learn about some best practices to help us develop robust hexagonal applications.

Questions

1. What is the advantage of the native executable over the Uber `.jar` artifact?
2. Which Kubernetes object can we use to store environment variables and mount configuration files?
3. What service type is used to make a Kubernetes pod externally available?

15
Good Design Practices for Your Hexagonal Application

While exploring the hexagonal architecture in this book, we learned about some of the principles and techniques that characterize a hexagonal application. By visualizing a system with clearly defined boundaries, we established three hexagons: Domain, Application, and Framework.

Using these hexagons as a guide, we explored how to separate the business code from the technology code. This separation allowed us to explore ways of creating change-tolerant systems. But we did not stop there. Going the extra mile, we learned how the Quarkus framework could be used to turn a hexagonal application into a cloud-native application.

We have reached the end of this book equipped with the fundamental ideas needed to create hexagonal systems. In this chapter, we will explore some helpful design practices we can apply when creating robust hexagonal applications.

In this chapter, we'll cover the following main topics:

- Using **Domain Driven Design** (**DDD**) to shape the Domain hexagon
- The need to create ports and use cases
- Dealing with multiple adapter categories
- Conclusion – the hexagonal journey

By the end of this chapter, you'll be aware of the design practices that can make your hexagonal architecture project more robust. These practices will also help you to decide when and how to employ the hexagonal architecture principles.

Technical requirements

To compile and run the code examples presented in this chapter, you need the latest **Java SE Development Kit** (**JDK 11**) and **Maven 3.6** installed on your computer. They are both available for the **Linux**, **Mac**, and **Windows** operating systems.

You can find the code files for this chapter on GitHub:

`https://github.com/PacktPublishing/Designing-Hexagonal-Architecture-with-Java/tree/main/Chapter15`.

Using Domain Driven Design to shape the Domain hexagon

When employing the hexagonal architecture to design a system's code structure, we cannot stress enough how important it is to first implement the Domain hexagon. It's the Domain hexagon that sets the tone for the development of the entire application.

As long as you keep the code in the Domain hexagon that purely expresses the problem domain—the code that does not merge business concerns with technology ones—you are on the right path to ensuring the encapsulation level that favors a more change-tolerant design. The technique you'll use to develop the Domain hexagon should not be your main concern at this stage—instead, your aim should be to create a Domain hexagon that is focused on the system's purpose, rather than the technology you might use to implement it. So, you can develop the Domain hexagon using your own set of principles, or you can borrow ideas from others who have addressed a similar problem previously.

The advantage of using DDD is that it means you don't need to reinvent the wheel. Most—if not all—of the concepts and principles that you need to model your problem domain are well established in the rich body of knowledge present in DDD techniques. However, this does not mean you must follow all DDD principles to the letter. The recommended approach is to adopt and adapt the things you find helpful for your project.

Next, we'll explore some of the approaches you can follow when using DDD to design the Domain hexagon.

Understanding the business we are in

A good application design reflects a good understanding of the business it is intended to serve. The design journey does not start in the code but by seeking business knowledge. I'm not telling you to become a business expert in the field you intend to build software for. However, I think it's important to understand the fundamentals because if you don't, mistakes made at the start of the design phase can cause irreversible damage that will extend through the software project.

In the best scenario, the project can survive these early mistakes, but not without paying the high cost of tangled and hard-to-maintain software. In the worst scenario, the result is unusable software, and starting a new project from scratch is the best thing to do.

Understanding the business fundamentals is the first thing we should do. The business details are important too, and we should pay close attention to them if we want to make top-notch software. But mistakes relating to details aren't as serious as mistakes relating to fundamentals. The former is generally easier and cheaper to fix than the latter.

Let's revisit the topology and inventory system for a moment. We have a business rule stating that only edge routers from the same country can be connected to each other. We use the edge routers to handle regional traffic because they have less traffic capacity than core routers. The core routers can be located in different countries because they have more traffic capacity.

The whole domain model has been built based on these business premises. We compromise the entire system development if we fail to understand and translate these business premises into a cohesive domain model. Everything we build on top of such a model will be based on weak or wrong assumptions. That's why we need to spend whatever time is necessary to grasp the business fundamentals.

Now, let's see some of the techniques we can use to build business knowledge.

Business Model Canvas

An excellent exercise to understand how the business works can be done with the Business Model Canvas technique. A **Business Model Canvas** is a tool to create business models. It provides instruments to analyze and understand the main elements of a business. By providing a structured and simplified way to identify a business's main aspects, the Business Model Canvas can be the starting point to draw the big picture you and your team need to understand the business fundamentals.

The tool's main benefit is its focus on the key elements that are crucial for the profitability of a business. Another helpful aspect is how it represents customers and partners in the overall business landscape. This helps us to understand how well the business model is fulfilling the expectations of both customers and partners.

A disadvantage is that it does not provide a deep and comprehensive view of how a business should operate to produce good results. Also, it does not touch on the business strategy. Much of its emphasis is on end results instead of long-term goals.

There is a variation of—and an alternative to—the Business Model Canvas called the **Lean Canvas**, which is more directed toward start-ups. The main difference of this approach is that it focuses on the high uncertainty level that start-ups face when they try to develop new ideas and products.

Here is an illustration of the Business Model Canvas:

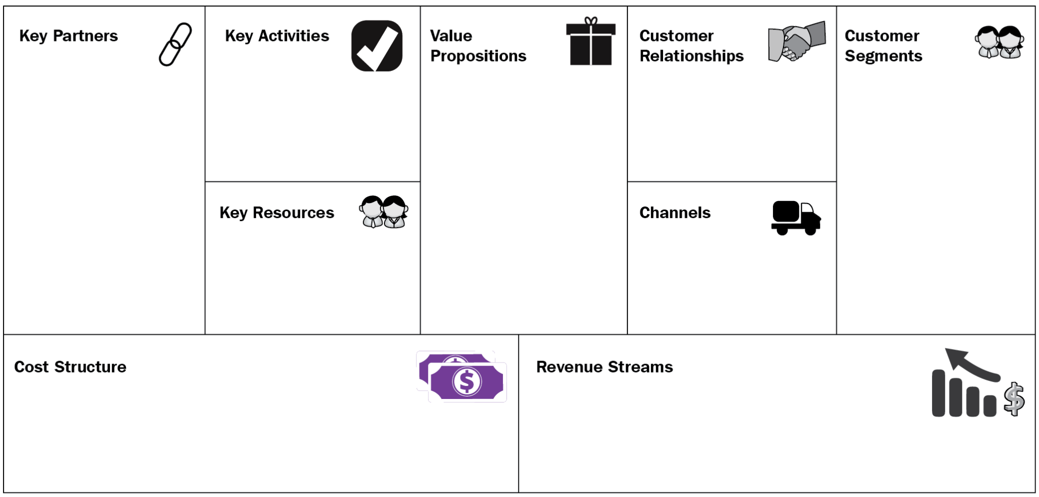

Figure 15.1 – The Business Model Canvas

As we can see in the preceding figure, the Business Model Canvas lets us structure each business aspect in distinct parts. This separation helps us to visualize the main elements comprising the business. Here are the elements of the Business Model Canvas:

- The **Key Partners** element represents our key partners and suppliers and contains information about the key resources or activities that are involved in that relationship.
- In **Key Activities**, we state the value propositions required for the key activities.
- For **Key Resources**, we need to identify the value propositions required to enable the key resources.
- In **Value Propositions**, we describe the elements of value we intend to deliver to the customer.
- The **Customer Relationships** element is about the expectations of each customer segment in establishing and maintaining a relationship with us.
- In **Channels**, we identify the communication channels through which our customer segments will reach us.
- The **Customer Segments** element represents the groups of people we want to deliver value to.
- The **Cost Structure** element describes the highest costs involved in enabling the business model.
- The **Revenue Streams** element shows the value our customers are really willing to pay for.

In addition to the Business Model Canvas, we also have the Event Storming technique as an alternative, which is geared more toward DDD projects. Let's examine it now.

Event Storming

If you do not find the Business Model Canvas a suitable approach, another technique called **Event Storming** can help you understand your business needs. Created by Alberto Brandolini, Event Storming uses colored sticky notes to map business elements into domain events, commands, actors, and aggregates.

Each one of these sticky note elements has its own color, as shown in the following flowchart:

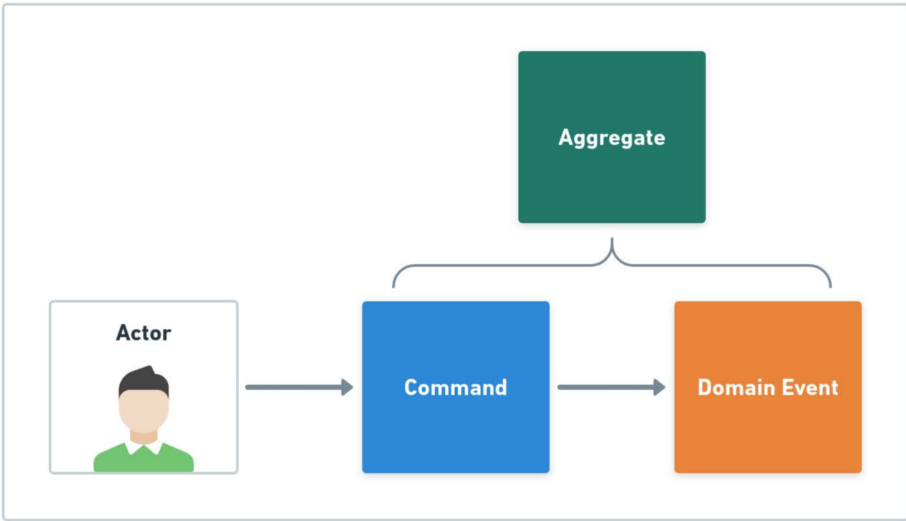

Figure 15.2 – The Event Storming technique

As we can see in the preceding diagram, the sticky notes from Event Storming use the same terminology we encounter when dealing with DDD. That's because Event Storming was created especially for those who use DDD and need to understand the business requirements for their project.

The Event Storming sessions should be conducted by developers, domain experts, and a facilitator who coordinates the session to ensure the mapping efforts go in the right direction.

The starting point of an Event Storming session is usually a challenging business process to model. In these sessions, it's common to discuss how actors and their actions influence the business processes. Another central point is how external systems support and interact with the business processes. Risks and pain points are also essential subjects to map to identify business-critical areas. To learn more about Event Storming, check out its website at `https://www.eventstorming.com`.

Once we understand how the business works, we need to translate that knowledge into a domain model. In the next section, we'll see how collaboration can help us to be better prepared for creating a good domain model.

Promoting collaboration to increase knowledge

The domain model is the outcome of people trying to understand the business and translating that understanding into code. In order to get the most out of this process, collaboration plays a vital role where the degree of complexity is high and things are hard to accomplish. To overcome this complexity, we need to establish a collaborative atmosphere where everyone involved in the project can contribute with relevant information that helps to build the big picture. The collaborative approach helps to ensure that everyone is on the same page regarding the problem domain, leading to a domain model that better reflects the business concerns.

Aside from using the code itself to capture and convey the problem domain knowledge, written documentation is another useful tool for collaboration. I'm not talking about writing long and comprehensive documentation – I mean the opposite. Let me explain.

Concise documentation that is focused on explaining the building blocks of a system can help people who aren't acquainted with the code to take their first steps into understanding the system and, consequently, the problem domain. Sometimes, an introduction to the system's main elements quickly leads to a comprehensive understanding of the problem domain.

What I'm saying may seem obvious, but very often, I've stumbled upon a complex code base with poor or no documentation at all. When the problem domain is complex, it's natural for the code to be complex too. Without documentation to explain the system, what's already complicated becomes even harder to grasp.

I recommend allocating some time at the end of the project to write the system documentation. New joiners, in particular, will benefit from a friendly document providing an overview of the system's big picture.

Now that we know how important it is to have a solid foundation based on an understanding of the business requirements and have discussed the value of collaboration in increasing our knowledge of the problem domain, let's explore some of the DDD techniques adopted when building the Domain hexagon.

Applying DDD techniques to build the Domain hexagon

In this section, we'll explore some design practices to help us establish clear boundaries in the hexagonal system. Complementing what we saw in *Chapter 2*, *Wrapping Business Rules inside Domain Hexagon*, we'll see the importance of creating subdomains, searching for a Ubiquitous Language, and defining bounded contexts to distinguish the different aspects of the problem domain.

Subdomains

The purpose of a **subdomain** is to group the elements that support the core domain but cannot be considered elements that express the core domain. These supporting elements are essential for the activities conducted by the core domain. Without the supporting elements, the core domain cannot work. There are also generic subdomains whose purpose is to provide additional capabilities to both core domains and supporting subdomains. A generic subdomain works as a standalone component that doesn't depend on things provided by other domains.

We can say that in the core domain, we have primary activities. And in the subdomain, we have secondary activities that enable the primary ones. If we blend primary and secondary activities, we'll end up with a domain model with mixed concerns. It may not be a big deal for smaller systems, but in larger ones, it can add a considerable complexity that can undermine the productivity of anyone trying to understand the system. That's why it's a good approach to break a domain into subdomains. We'll always have a core domain concentrating on the most important part of the code.

Let's use a banking system as an example to explore the subdomain idea further. In such a system, it's possible to identify the following domains:

- As a core domain, we have **Transactions** that allow users to receive and send money.
- As supporting subdomains, we may have **Loans** and **Insurances** that add more capabilities to the system but rely on the **Transactions** core domain to enable such capabilities.
- Finally, we have **Authentication** as a generic subdomain, serving both the core domain and supporting subdomains that require every transaction to be authenticated.

The following diagram shows how subdomains relate to the core domain:

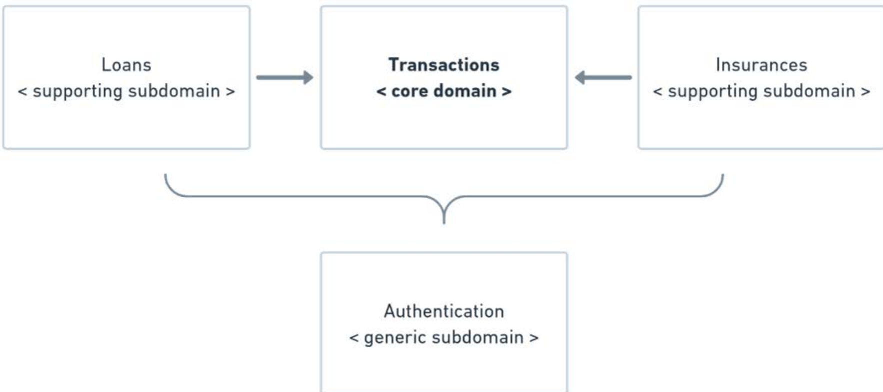

Figure 15.3 – Banking system subdomains

The **Transactions** core domain contains the system's building block elements. These elements are also present in the **Loans** and **Insurances** subdomains, but for different purposes. The generic **Authentication** subdomain knows nothing about the other domains. It only provides an authentication mechanism that is shared across the core domain and supporting subdomains.

Ubiquitous Language

One of DDD's touchstones is its emphasis on how we use language to describe a domain model. This emphasis aims to avoid the pitfall of ambiguities in our general communication seeping into the system code we want to create.

As human beings, we have much more capacity than computers to handle ambiguities in language because we can add context to our words. Computers, on the other hand, don't have this ability unless we provide it for them. In order to decrease the ambiguity level of a system, a Ubiquitous Language seeks precise terminology to describe the things that comprise the domain model.

Defining precise terminology, however, is not enough to ensure that we'll always convey the right meaning in the domain model, as similar words may have a different meaning depending on the context in which they are used. That's why there's another technique in DDD called bounded context that we can use to deal with differences in meaning within a domain model.

Bounded context

The **bounded context** idea is a response to the fact that words have a different meaning depending on the context in which they are used. When we bring this idea to DDD, we may find that a domain model element can have a different meaning or behave differently depending on the context where it's applied. If we do not actively take action to explicitly define a context to clarify the meaning of such a domain model element, we are contributing to the ambiguity within the system.

For example, take the topology and inventory system. Suppose that other than inventory capabilities, we want to allow the system to get real-time status and basic information from routers and other network equipment. This new feature could result in two contexts: one for inventory and the other for status.

From the inventory perspective, a router means a static record in a database. On the other hand, from the status perspective, a router is a *living* thing that issues real-time data. By expressing this distinction in the form of a bounded context, we ensure that our understanding of one context does not blur with another. More than that, by structuring the code within the clear boundaries that a bounded context can provide, we're creating a system that can evolve and receive changes in a more organized way. Also, we are enforcing the Single Responsibility Principle at the level of modules. This means a module should change only for a single reason and not multiple reasons.

The DDD techniques discussed in this session don't offer much value if we don't first grasp our business needs. That's why we started by exploring some of the techniques we can use to enhance our understanding of the business model. Once we know about the business we're in, we can safely employ the DDD techniques (such as subdomains and bounded contexts) to establish boundaries between different system components and remove ambiguities within the domain model.

So, let's see how we can implement bounded contexts and subdomains in a hexagonal system.

Implementing bounded contexts and subdomains in a hexagonal system

Our approach to implementing a bounded context relies on the creation of a subdomain. Following, we discuss both approaches.

Bounded contexts can exist with or without a subdomain. We've already seen that the topology and inventory system can check the status of network equipment. Suppose we determine that the status element is an integral and critical characteristic of the problem domain. In that case, we can make the status element part of the core domain instead of putting it into a supporting subdomain. But we'd still need to deal with the ambiguity of having domain elements serving different purposes. To solve this problem, we'd have to establish two bounded contexts within the core domain: one bounded context for inventory and another for status.

If we decide that the status element is not a part of the core domain, we can model it as a subdomain, as we'll see next.

When developing the topology and inventory system, we placed a single domain model inside the Domain hexagon. This domain model meets the business requirements related to the inventory management of network assets. Consider the scenario where the topology and inventory system can access network equipment to check its status. To avoid mixing concerns between inventory management and status information, we'll break the **Domain Hexagon** into two domain models. The first one is a **Core Domain** serving inventory management needs. The second domain model is a **Subdomain** for status information needs. The following diagram shows the representation of the new **Domain Hexagon**:

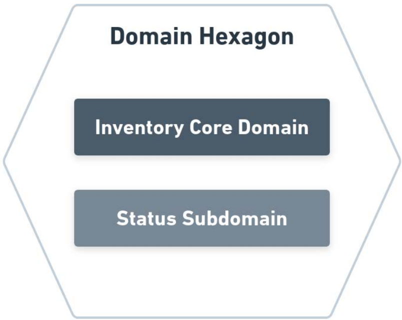

Figure 15.4 – The Domain Hexagon

Inside the **Domain Hexagon**, we now have the **Inventory Core Domain** and the **Status Subdomain**. In the following steps, we'll configure the Domain hexagon module to reflect the new structure:

1. To the project's root `pom.xml` file, we add the new Maven `modules` element, which represents the core domain and subdomains:

```
<modules>
  <module>domain</module>
  <module>domain/inventory-core-domain</module>
  <module>domain/status-sub-domain</module>
  <module>application</module>
  <module>framework</module>
  <module>bootstrap</module>
</modules>
```

   Note, we added the `domain/inventory-core-domain` and `domain/status-sub-domain` Maven modules to the `pom.xml` file.

Before proceeding, please ensure to move all the files from `domain/src/main/java` to `domain/inventory-core-domain/src/main/java`. The `domain` Maven module will be used as a parent project to aggregate both the core domain and subdomain projects.

2. Next, we'll configure the `pom.xml` file from the `domain` Maven module:

```
<?xml version="1.0" encoding="UTF-8"?>
  <!-- Code omitted -->
  <artifactId>domain</artifactId>

  <dependencies>
    <dependency>
      <groupId>dev.davivieira</groupId>
      <artifactId>inventory-core-domain</artifactId>
    </dependency>
    <dependency>
      <groupId>dev.davivieira</groupId>
      <artifactId>status-sub-domain</artifactId>
    </dependency>
  </dependencies>

</project>
```

The `domain` Maven module depends on `inventory-core-domain` and `status-sub-domain`. We maintained the `domain` module but broke it into two parts. With this approach, there will be no need to change anything in the Application and Framework hexagons.

3. We also need to reconfigure the `module-info.java` module descriptor:

```
module domain {
    requires transitive inventory_core_domain;
    requires transitive status_sub_domain;
}
```

The `transitive` keyword is necessary to ensure the exports from `inventory_core_domain` and `status_sub_domain` are visible for other modules depending on the `domain` module.

4. Next, we configure the `pom.xml` file for the `inventory-core-domain` Maven module:

```
<?xml version="1.0" encoding="UTF-8"?>
  <!-- Code omitted -->
  <parent>
    <groupId>dev.davivieira</groupId>
    <artifactId>topology-inventory</artifactId>
    <version>1.0-SNAPSHOT</version>
    <relativePath>../../pom.xml</relativePath>
  </parent>

  <artifactId>inventory-core-domain</artifactId>

</project>
```

The preceding example is a straightforward `pom.xml` file containing only the `artifactId` and `parent` coordinates. In addition to `pom.xml`, we need to provide a `module-info.java` file, as shown here:

```
module inventory_core_domain {
    exports
      dev.davivieira.topologyinventory.domain.entity;
    exports
      dev.davivieira.topologyinventory.domain.service;
    exports
      dev.davivieira.topologyinventory.domain
      .specification;
    exports
      dev.davivieira.topologyinventory.domain.vo;
    exports
      dev.davivieira.topologyinventory.domain.entity
      .factory;
    requires static lombok;
}
```

This Java module provides better encapsulation for the inventory core domain. Note that we're also exporting the `entity`, `service`, `specification`, and `vo` packages. They are all part of the core domain.

5. Next, we configure the `pom.xml` file of the `status-sub-domain` Maven module:

```
<?xml version="1.0" encoding="UTF-8"?>

  <!-- Code omitted -->
  <artifactId>status-sub-domain</artifactId>

  <dependencies>
    <dependency>
      <groupId>dev.davivieira</groupId>
      <artifactId>inventory-core-domain</artifactId>
      <version>1.0-SNAPSHOT</version>
      <relativePath>../../pom.xml</relativePath>
    </dependency>
  </dependencies>
</project>
```

   We declare a dependency on the `inventory-core-domain` Maven module because we use the same entities present in the core domain to provide status information capabilities in the `status-sub-domain` subdomain Maven module. The difference, though, is that the same entity, in the same way as `Router`, can have a different meaning (and also a data model) when we are in the status information context.

6. To finish, we need to configure the `module-info.java` file for `status_sub_domain`:

```
module status_sub_domain {
    exports dev.davivieira.topologyinventory.status;
    requires inventory_core_domain;
}
```

   We're exporting only one package and declaring that this module depends on `inventory_core_domain`.

   Now that we have the Maven and Java modules properly configured to help us enforce the boundaries between the core domain and subdomain, let's explore the use of a bounded context.

Let's consider that the topology and inventory system can now check the status of a router. To isolate this behavior and establish a context for such activities, we will create a class called `RouterInfo` in the subdomain:

```
package dev.davivieira.topologyinventory.status;

import dev.davivieira.topologyinventory.domain.entity.factory.
RouterFactory;
import dev.davivieira.topologyinventory.domain.vo.IP;
import dev.davivieira.topologyinventory.domain.vo.Id;
import dev.davivieira.topologyinventory.domain.vo.Model;
import dev.davivieira.topologyinventory.domain.vo.RouterType;
import dev.davivieira.topologyinventory.domain.vo.Vendor;

public class RouterInfo {

    public String getRouterStatus () {
        var router = RouterFactory.getRouter(
                Id.withoutId(),
                Vendor.CISCO,
                Model.XYZ0004,
                IP.fromAddress("55.0.0.1"),
                null,
                RouterType.CORE);
        return "Router with "+router.getIp()+" is alive!";
    }
}
```

In the `RouterInfo` class, we have a dummy method called `getRouterStatus`, which is just to illustrate that the `Router` entity can assume a different behavior and data model in the context of status information. It's very simple to make this subdomain feature available for the Application and Framework hexagon.

Let's do that to see how the subdomain fits into the overall hexagonal system by executing the following steps:

1. We start by adding a new method definition in `RouterManagementUseCase`:

```
public interface RouterManagementUseCase {

    /** Code omitted **/

    String getRouterStatus();
}
```

   The `getRouterStatus` method integrates with the subdomain to retrieve the router status.

2. Next, we implement `getRouterStatus` in `RouterManagementInputPort`:

```
@Override
public String getRouterStatus() {
    var routerInfo = new RouterInfo();
    return routerInfo.getRouterStatus();
}
```

   Here, we are getting an instance of the `RouterInfo` object from the subdomain and calling the `getRouterStatus` method.

3. Finally, we implement the endpoint in `RouterManagementAdapter`:

```
@Transactional
@GET
@Path("/get-router-status")
@Operation(operationId = "getRouterStatus", description =
"Get router status")
@Produces(MediaType.TEXT_PLAIN)
public Uni<Response> getRouterStatus() {
    return Uni.createFrom()
            .item(routerManagementUseCase
            .getRouterStatus())
            .onItem()
            .transform(
```

```
                router -> router != null ?
                Response.ok(router) :
                Response.ok(null))
              .onItem()
              .transform(Response.ResponseBuilder::build);
  }
```

Here, we are using the RESTEasy Reactive to implement the `/get-router-status` endpoint that will get the router status information from the subdomain:

```
$ curl -X GET http://localhost:8080/router/get-router-status
```

Running the preceding `curl` command gives us the following output:

```
Router with IP(ipAddress=55.0.0.1, protocol=IPV4) is alive!
```

This implementation of DDD elements such as subdomains and bounded contexts helps us understand how we can integrate these elements with the hexagonal architecture. Using Maven and Java modules, we can emphasize the boundaries between the core domain and subdomain even more.

Now, let's shift our attention to the Application hexagon, which is the realm of ports and use cases.

The need to create ports and use cases

After putting some effort into modeling the problem domain in the Domain hexagon, the next step is to move on to the Application hexagon and define how the software system enables the behavior that fulfills the business-related operations that come from the Domain hexagon. Actors—who could be both users and other systems—drive these behaviors. They dictate the system's capabilities.

The moment when we start implementing the Application hexagon is crucial because we begin to think in aspects that are not directly related to the domain model. Instead, these aspects may be related to integrations for communicating with other systems. But we shouldn't go so far as to decide which technologies to use. We don't take decisions related to technology when implementing the Application hexagon. Rather, technology concerns are a subject that we go deep into in the Framework hexagon.

We employ use cases to define what a system can do to meet actors' needs. Without considering specific technical details, we can state that a good moment to create a use case is when we need to express an actor's intent on the system. The actor's intent plays a fundamental role in shaping the system's behaviors. By employing use cases, we can describe such behaviors. Input ports come next by defining how the system will actually accomplish the actor's goals. Input ports can be implemented right away or be implemented later. However, they must be implemented before you decide to move on to the Framework hexagon. If you choose to implement the Framework hexagon before implementing input ports, there will be no way to make the Framework hexagon communicate with the Application hexagon. In other words, use cases and ports are the bridge between both hexagons.

There is not much to be concerned about when it comes to output ports because they are interfaces implemented by output adapters in the Framework hexagon. Output adapters, by their turn, can pose some problems if we have multiple categories of them. Next, we'll assess some of the consequences of having multiple adapter categories.

Dealing with multiple adapter categories

In the context of the hexagonal architecture, adapters help us to increase the hexagonal system's compatibility with different protocols and technology. In the Framework hexagon, we finally decide how the system will expose its features through input adapters and how it will communicate with external systems through output adapters.

In a similar way to what happens in the Application and Domain hexagons, the Framework hexagon is encapsulated in its own Java module. This module approach helps us enforce the boundaries between each system hexagon. From the Framework hexagon's perspective, it's good to group all input and output adapters within the same module. Although modularization can help us delimit boundaries, it is not enough to prevent the maintainability challenges we may face when dealing with multiple adapter categories.

What I mean by adapter category is a classification to group adapters that enable the integration with a specific technology. For example, in the topology and inventory system, we have the `RouterManagementAdapter` and `SwitchManagementAdapter` input adapters. These adapters expose HTTP RESTful endpoints. So, these input adapters comprise the adapter category that provides HTTP support for the hexagonal system. If we want to enable integration with another technology, for example, gRPC, we need to create a new set of adapters in an adapter category that supports exposing gRPC endpoints.

When dealing with input adapters, we don't face a significant maintainability burden by having multiple adapter categories providing support to different technologies in the hexagonal system. However, some issues may arise if we have multiple adapter categories for output adapters.

With output adapters, we can integrate the hexagonal application with external systems. But it's important to pay attention where we need to provide translation mechanisms for every new integration. These translations help us to map data coming in and going out through output adapters. If adapter categories for output adapters grow too large, it can potentially create a maintainability problem. In that scenario, we would need to keep multiple translation mechanisms for every adapter category.

Consider the following scenario. Imagine a system that started out with all of its data being served by a database. As the main system evolved, the developers migrated its parts into smaller subsystems to prevent the main system from becoming too big. But during this migration process, certain use cases could not be fully migrated to the new subsystems, resulting in a situation where the main system still needed to fetch data from both the database and the subsystems in order to fulfill some of its business rules. In this circumstance, the main system requires two output adapters: one for the database and another for the subsystem. Allowing two output adapters to serve the same purpose due to an unfinished migration can potentially increase the maintenance cost. One of the main problems of this approach is the need to translate to the domain model data, which comes from the database and the subsystem.

So, for input adapters, we have a low risk when employing multiple adapter categories. However, the same cannot be said of output adapters. The recommendation here is to be aware of the trade-off in having to maintain several translation mechanisms for multiple adapters.

Conclusion – the hexagonal journey

One of the fascinating things about software development is that we can employ many methods to achieve the same result. This freedom adds to the fun of software development and fosters creativity. Creativity is the main force behind clever solutions for complex problems. That's why we should always leave space for creativity in any software project. But when combined with tight schedules and resources, freedom and creativity should be managed to produce valuable software without adding unnecessary complexity.

I see the hexagonal architecture as an approach that can help us manage these different requirements. It provides a clear set of principles to organize system code within flexible yet consistent boundaries. The hexagonal approach offers a model to direct our creative efforts in an organized and – to a certain extent – standardized way.

The hexagonal architecture is not for everyone, nor is it suitable for every project. However, people seeking ways to standardize their software development practices will find the hexagonal architecture to be a useful blueprint to scaffold their next software project. However, it's important to understand the considerable complexity involved in structuring a system using hexagonal principles. If the project is for a medium or large, long-term, and highly mutable system, I believe the hexagonal architecture is an excellent choice to ensure the system's maintainability in the long run. On the other hand, if we're talking about small applications responsible for, let's say, one or two things, then using the hexagonal architecture would be like using a gun to kill an ant. So, you need to carefully assess the scenario to check whether the hexagonal architecture will bring more solutions than problems to your project.

The hexagonal architecture is not a silver bullet that will magically solve your technical debt and maintainability issues. These problems have more to do with your attitude to keeping things simple than with the software architecture you choose to structure your application. But the hexagonal architecture can help you tackle those issues if you're already committed to an attitude to keep things simple and easy to understand no matter how complex the problem domain you're dealing with is. I encourage you to keep a simple attitude and explore and extend the hexagonal architecture ideas. For me, it's been an unending learning and rewarding experience to design hexagonal systems. I wish the same to you.

Let me finish this book by sincerely thanking you for accompanying me on this hexagonal journey.

Summary

We started this chapter by exploring some ideas relating to DDD, and we discussed the importance of understanding our business needs before jumping straight to development. Here, we learned about the Business Model Canvas and Event Storming.

While on the topic of DDD, we learned how subdomains and bounded contexts are essential to help establish clear boundaries within the Domain hexagon. After that, we discussed use cases and ports. We learned that it's essential to implement input ports before starting to build the Application hexagon.

Next, we learned about the maintainability consequences of having multiple adapter categories, mainly when dealing with output adapters that require translation mechanisms. Finally, we ended the book by reflecting on our hexagonal journey and the importance of keeping software development simple.

When using Quarkus, especially the native image feature, we need to consider the large amount of memory and time required to build a native executable. If your CI environment is constrained, you may face problems caused by insufficient computational resources. Also, bear in mind that compilation time increases considerably when compiling native images. If your priority is a faster compilation over a more rapid system startup, you may have to reconsider using native images. I always recommend checking Quarkus documentation and the Quarkus community through the official mailing list and other channels. This can help you learn more about Quarkus and stay updated on common issues and how to solve them. If the community help is not enough, you can seek Quarkus' official support provided by Red Hat.

The hexagonal architecture provides us with the principles to develop robust and change-tolerant systems. Quarkus is a cutting-edge technology that we can use to apply hexagonal principles to create modern, cloud-native applications. By combining hexagonal architecture with Quarkus, we can produce fantastic software. I encourage you to experiment and further explore the possibilities of such a fascinating combination. The hexagonal journey of this book ends here, but you guys can start a new one by applying, tweaking, and evolving the ideas I have presented to you.

Questions

1. What techniques can we use to understand our business needs?
2. Why should we employ subdomains and bounded contexts?
3. Why is it important to define use cases and create input ports before implementing the Framework hexagon?
4. What are the consequences of having multiple adapter categories for output adapters?

Assessments

Chapter 1, Why Hexagonal Architecture?

Question 1

What are the three hexagons that comprise the hexagonal architecture?

Answer

Domain, Application, and Framework.

Question 2

What's the role of the Domain hexagon?

Answer

It provides the business rules and data in the form of entities, value objects, and any other suitable categories of objects that help model the problem domain. It does not depend on any other hexagon above it.

Question 3

When should we utilize use cases?

Answer

When we want to represent the system's behavior through application-specific operations.

Question 4

The input and output adapters are present in which hexagon?

Answer

The Framework hexagon.

Question 5

What's the difference between *driving* and *driven* operations?

Answer

Driving operations are the ones that request actions to be performed on the software. *Driven* operations are started by the hexagonal application itself. These operations go outside to fetch data from external sources.

Chapter 2, Wrapping Business Rules inside Domain Hexagon

Question 1

What is the main attribute of *entities* not found in *value objects*?

Answer

Contrary to value objects, *entities* have an *identity*.

Question 2

Can value objects be mutable?

Answer

No. The most important property of a value object is its immutability.

Question 3

Every aggregate must have an entry-point object to allow communication with other objects controlled by the aggregate. What is the name of this entry-point object?

Answer

The entry-point object for any aggregate is called an *aggregate root*.

Question 4

Are domain services allowed to call objects on other hexagons?

Answer

No, but objects from other domains and other hexagons can call domain services.

Question 5

What is the difference between a `Policy` and a `Specification`?

Answer

A `Policy` is a pattern that encapsulates part of the problem domain knowledge in a block of code or an algorithm. A `Specification` is a pattern that works with predicates to assert the validity of the properties of objects.

Question 6

What is the benefit of defining business rules as a **Plain Old Java Object** (**POJO**)?

Answer

Because a POJO doesn't depend on external technology details, as these usually come when using libraries from development frameworks. Instead, a POJO relies only on a standard Java API, which makes a POJO a simple and easy-to-reuse object. POJOs are helpful for creating business rule objects that aren't blurred by technology details.

Chapter 3, Handling Behavior with Ports and Use Cases

Question 1

What is the purpose of use cases?

Answer

To define software behaviors by establishing who the actors are and what features they expect from a system.

Question 2

Input ports implement use cases. Why do we have to do this?

Answer

Because in the hexagonal architecture, use cases are interfaces stating the supported software capabilities. Input ports, in turn, describe the actions that will enable those capabilities.

Question 3

Where should output ports be used?

Answer

Output ports appear inside input ports when it is necessary to interact with external systems.

Question 4

What is the advantage of implementing the Application hexagon?

Answer

By implementing the Application hexagon, we're supporting the overall hexagonal application's effort to automate operations without relying on specific technologies to do so.

Chapter 4, Creating Adapters to Interact with the Outside World

Question 1

When should we create an input adapter?

Answer

We create an input adapter when we need to expose software features to be accessed by driving actors. These actors can access the hexagonal application using different technologies or protocols, such as **HTTP REST** or via the command line.

Question 2

What is the benefit of connecting multiple input adapters to the same input port?

Answer

The main benefit is that the same logic contained in an input port can be used to treat data that comes from different input adapters.

Question 3

What interface must we implement to create output adapters?

Answer

Output adapters must always be implemented by output ports. By doing that, we are sure that the adapters are in line with the requirements expressed by the domain model.

Question 4

Which hexagon do the input and output adapters belong to?

Answer

They are both from the Framework hexagon.

Chapter 5, Exploring the Nature of Driving and Driven Operations

Question 1

What are *driving* operations?

Answer

The *driving* operations are requests initiated by the primary actors that drive the hexagonal application's behavior.

Question 2

Give one example of a *driving* operation.

Answer

A frontend application calling a hexagonal system through one of its input adapters is an example of a *driving* operation.

Question 3

What are *driven* operations?

Answer

Driven operations are requests initiated by the hexagonal application itself – generally on behalf of a use case need – toward secondary actors driven by a hexagonal system.

Question 4

Give one example of a *driven* operation.

Answer

When the hexagonal application accesses a database. In this case, the database is *driven* by the hexagonal application.

Chapter 6, Building the Domain Hexagon

Question 1

Which technologies are used to bootstrap the Domain hexagon as a modularized application?

Answer

Maven and the **Java Platform Module System** (**JPMS**).

Question 2

Why did we start developing the Domain hexagon by creating value objects first?

Answer

Because value objects are used to compose other value objects and entities.

Question 3

Once we understand the problem domain, what's the next step?

Answer

We need to translate that problem domain into a domain model.

Question 4

Why is it so important to develop a robust and well-tested Domain hexagon?

Answer

Because a robust Domain hexagon provides a solid foundation for developing the Application and Framework hexagons.

Chapter 7, Building the Application Hexagon

Question 1

What do we call the files where we declare **Cucumber** scenarios?

Answer

They are called *feature files*.

Question 2

On which other Java module does the Application hexagon depend?

Answer

It depends on the Domain hexagon Java module.

Question 3

Which hexagonal architecture component is used to implement use cases?

Answer

Input ports are utilized to implement use cases.

Chapter 8, Building the Framework Hexagon

Question 1

Which other Java modules does the `Framework` hexagon Java module depend on?

Answer

The `Framework` hexagon module depends on the Domain and Application hexagons' Java modules.

Question 2

Why do we need to create the output adapters?

Answer

We create output adapters to enable the hexagonal system to connect to external data sources.

Question 3

In order to communicate with the input ports, the input adapters instantiate input port objects and assign them to an interface reference. What's that interface?

Answer

It's the use case interface.

Question 4

When we test a Framework hexagon's input adapter, we are also testing other hexagons. Why does that happen?

Answer

Because the input adapters depend on the components provided by the Domain and Application hexagons.

Chapter 9, Applying Dependency Inversion with Java Modules

Question 1

Which **JAR** dependency problem does the JPMS aim to solve?

Answer

The JAR hell problem.

Question 2

Which JPMS directive should we use to enable access to a package containing public types?

Answer

The `exports` directive.

Question 3

To declare a dependency on a module, which JPMS directive should we use?

Answer

The `requires` directive.

Question 4

When applying dependency inversion in the hexagonal architecture, which components can be regarded as high-level, abstraction, and low-level?

Answer

Input adapters, use cases, and input ports, respectively.

Chapter 10, Adding Quarkus to a Modularized Hexagonal Application

Question 1

What is the advantage of using **just-in-time** (**JIT**) compilation?

Answer

JIT compilation improves the runtime performance of an application.

Question 2

Which benefit do we get by using the **ahead-of-time** (**AOT**) compilation?

Answer

AOT compilation boosts the startup time of an application.

Question 3

Quarkus is a development framework specially designed for which kind of environment?

Answer

Quarkus was designed to develop applications for cloud environments.

Question 4

What is the role of the `bootstrap` module in hexagonal architecture?

Answer

Its role is to integrate the Quarkus framework with the hexagonal system.

Chapter 11, Leveraging CDI Beans to Manage Ports and Use Cases

Question 1

Quarkus DI is based on which Java specification?

Answer

It's based on the **Contexts and Dependency Injection** (**CDI**) for **Java 2.0** specification.

Question 2

What is the difference between the `ApplicationScoped` and `Singleton` scopes?

Answer

When using `ApplicationScoped`, the objects are *lazy-loaded*. With `Singleton`, the objects are *eagerly loaded*.

Question 3

What is the annotation we should use to provide dependencies through Quarkus DI instead of using calling constructors?

Answer

The `@Inject` annotation.

Question 4

To enable Quarkus testing capabilities, which annotation should we use?

Answer

The `@QuarkusTest` annotation.

Chapter 12, Using RESTEasy Reactive to Implement Input Adapters

Question 1

What is the difference between *imperative* and *reactive* requests?

Answer

Imperative requests can handle only one request at a time using an I/O blocking worker thread. *Reactive* requests can handle multiple requests using I/O non-blocking threads.

Question 2

What is the name of the **JAX-RS** implementation provided by Quarkus?

Answer

It is called RESTEasy Reactive.

Question 3

What is the purpose of OpenAPI?

Answer

It's to standardize the way APIs are described and documented.

Question 4

Which library should we use in Quarkus to test HTTP endpoints?

Answer

We should use the `rest-assured` library.

Chapter 13, Persisting Data with Output Adapters and Hibernate Reactive

Question 1

Which Java specification does Hibernate Reactive implement?

Answer

Hibernate Reactive implements the **Java Persistence API** (**JPA**) specification.

Question 2

What is the difference between the Active Record and Repository patterns?

Answer

The Active Record pattern allows us to use the entity class to perform operations on the database, whereas we have a dedicated class in the Repository pattern to perform such operations.

Question 3

Which interface should we implement to apply the Repository pattern?

Answer

We should implement the `PanacheRepositoryBase` interface.

Question 4

Why should we run write operations inside the `withTransaction` method?

Answer

To ensure the database transaction won't be lost during the reactive operation.

Chapter 14, Setting up Dockerfile and Kubernetes Objects for Cloud Deployment

Question 1

What is the advantage of the native executable over the Uber Jar artifact?

Answer

The startup time is much faster than the traditional Uber Jar artifact.

Question 2

Which **Kubernetes** object can we use to store environment variables and mount configuration files?

Answer

We can use the `ConfigMap` object.

Question 3

What is the service type that is used to make a Kubernetes Pod externally available?

Answer

It's the `NodePort` service type.

Chapter 15, Good Design Practices for Your Hexagonal Application

Question 1

What techniques can we use to understand our business needs?

Answer

The Business Model Canvas and event storming.

Question 2

Why should we employ subdomains and bounded contexts?

Answer

Subdomains and bounded contexts help us establish clear boundaries to prevent mixing the meaning and concerns of the entities in a domain model.

Question 3

Why is it important to define use cases and create input ports before implementing the Framework hexagon?

Answer

Because use cases and input ports are the bridge between the Framework and Application hexagons.

Question 4

What are the consequences of having multiple adapter categories for output adapters?

Answer

It can lead to several translation mechanisms that may be hard to maintain if we have too many of them.

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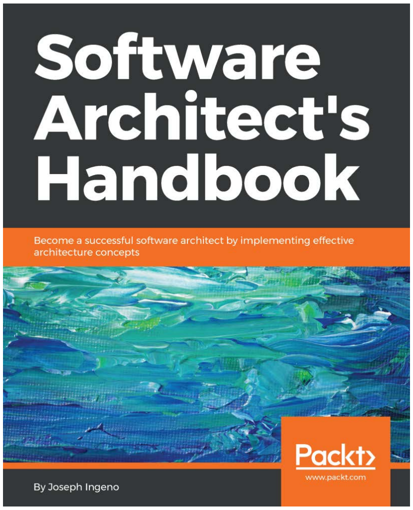

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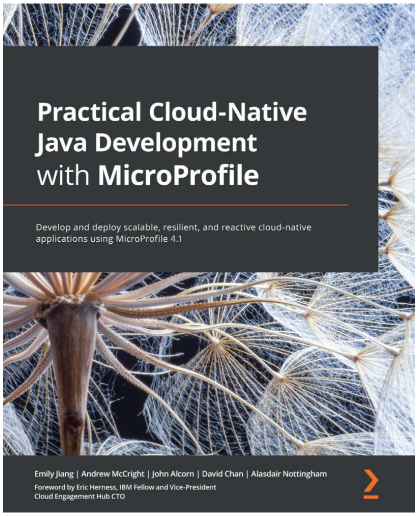

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