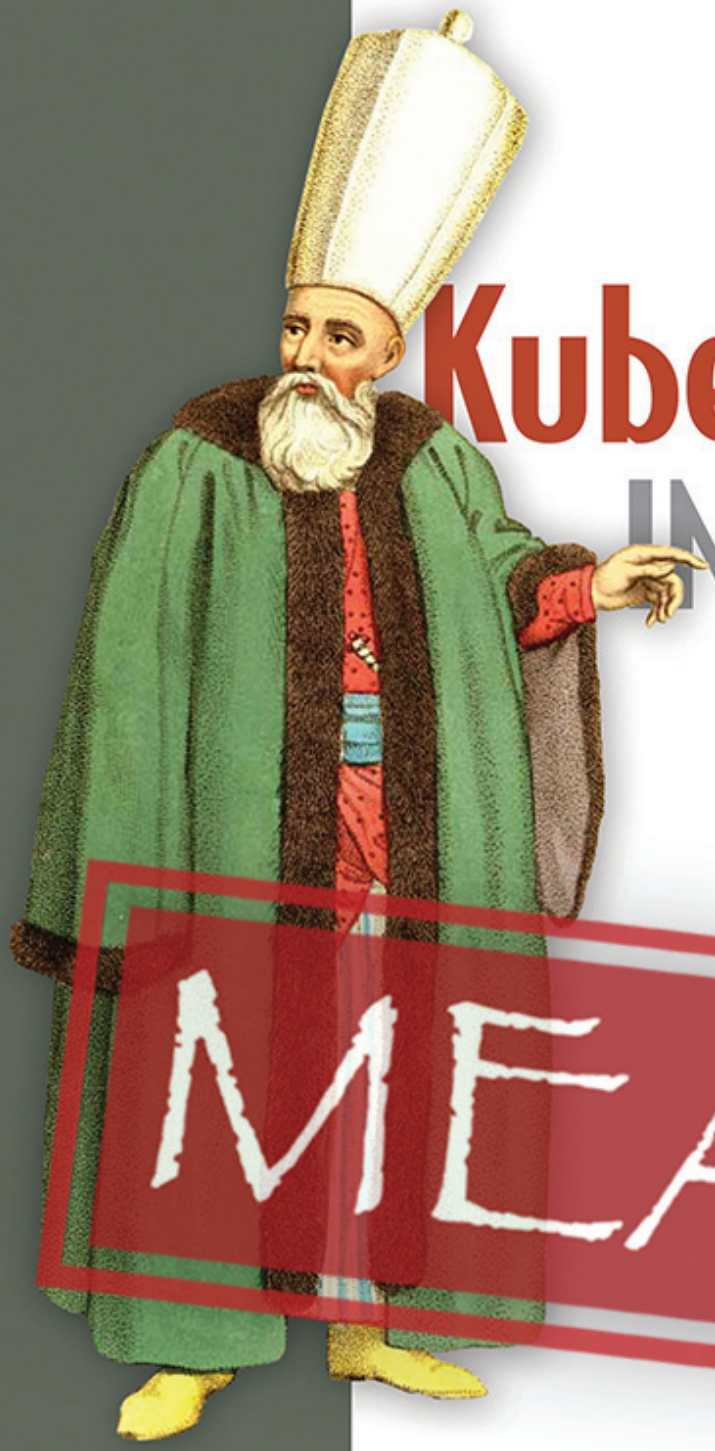


Kubernetes IN ACTION

SECOND EDITION

Marko Lukša

MEAP

MANNING

MEAP Edition
Manning Early Access Program
Kubernetes in Action
Second edition
Version 5

For more information on this and other Manning titles go to
manning.com

welcome

Thank you for purchasing the MEAP for Kubernetes in Action 2nd Edition.

As part of my work at Red Hat, I started using Kubernetes in 2014, even before version 1.0 was released. Those were interesting times. Not many people working in the software industry knew about Kubernetes, and there was no real community yet. There were hardly any blog posts about it and the documentation was still very basic. Kubernetes itself was ridden with bugs. When you combine all these facts, you can imagine that working with Kubernetes was extremely difficult.

In 2015 I was asked by Manning to write the first edition of this book. The originally planned 300-page book grew to over 600 pages full of information. The writing forced me to also research those parts of Kubernetes that I wouldn't have looked at more closely otherwise. I put most of what I learned into the book. Judging by their reviews and comments, readers love a detailed book like this.

The plan for the second edition of the book is to add even more information and to rearrange some of the existing content. The exercises in this book will take you from deploying a trivial application that initially uses only the basic features of Kubernetes to a full-fledged application that incorporates additional features as the book introduces them.

The book is divided into five parts. In the first part, after the introduction of Kubernetes and containers, you'll deploy the application in the simplest way. In the second part you'll learn the main concepts used to describe and deploy your application. After that you'll explore the inner workings of Kubernetes components. This will give you a good foundation to learn the difficult part - how to manage Kubernetes in production. In the last part of the book you'll learn about best practices and how to extend Kubernetes.

I hope you all like this second edition even better than the first, and if you're reading the book for the first time, your feedback will be even more valuable. If any part of the book is difficult to understand, please post your questions, comments or suggestions in the liveBook forum.

Thank you for helping me write the best book possible.

—Marko Lukša

brief contents

1 Introducing Kubernetes

This chapter covers

- Introductory information about Kubernetes and its origins
- Why Kubernetes has seen such wide adoption
- How Kubernetes transforms your data center
- An overview of its architecture and operation
- How and if you should integrate Kubernetes into your own organization

Before you can learn about the ins and outs of running applications with Kubernetes, you must first gain a basic understanding of the problems Kubernetes is designed to solve, how it came about, and its impact on application development and deployment. This first chapter is intended to give a general overview of these topics.

1.1 Introducing Kubernetes

The word *Kubernetes* is Greek for pilot or helmsman, the person who steers the ship - the person standing at the helm (the ship's wheel). A helmsman is not necessarily the same as a captain. A captain is responsible for the ship, while the helmsman is the one who steers it.

After learning more about what Kubernetes does, you'll find that the name hits the spot perfectly. A helmsman maintains the course of the ship, carries out the orders given by the captain and reports back the ship's heading. Kubernetes steers your applications and reports on their status while you - the captain - decide where you want the system to go.

How to pronounce Kubernetes and what is k8s?

The correct Greek pronunciation of Kubernetes, which is *Kie-ver-nee-tees*, is different from the English pronunciation you normally hear in technical conversations. Most often it's *Koo-ber-netties* or *Koo-ber-nay'-tace*, but you may also hear *Koo-ber-nets*, although rarely.

In both written and oral conversations, it's also referred to as *Kube* or *K8s*, pronounced *Kates*, where the 8 signifies the number of letters omitted between the first and last letter.

1.1.1 Kubernetes in a nutshell

Kubernetes is a software system for automating the deployment and management of complex, large-scale application systems composed of computer processes running in containers. Let's learn what it does and how it does it.

ABSTRACTING AWAY THE INFRASTRUCTURE

When software developers or operators decide to deploy an application, they do this through Kubernetes instead of deploying the application to individual computers. Kubernetes provides an abstraction layer over the underlying hardware to both users and applications.

As you can see in the following figure, the underlying infrastructure, meaning the computers, the network and other components, is hidden from the applications, making it easier to develop and configure them.

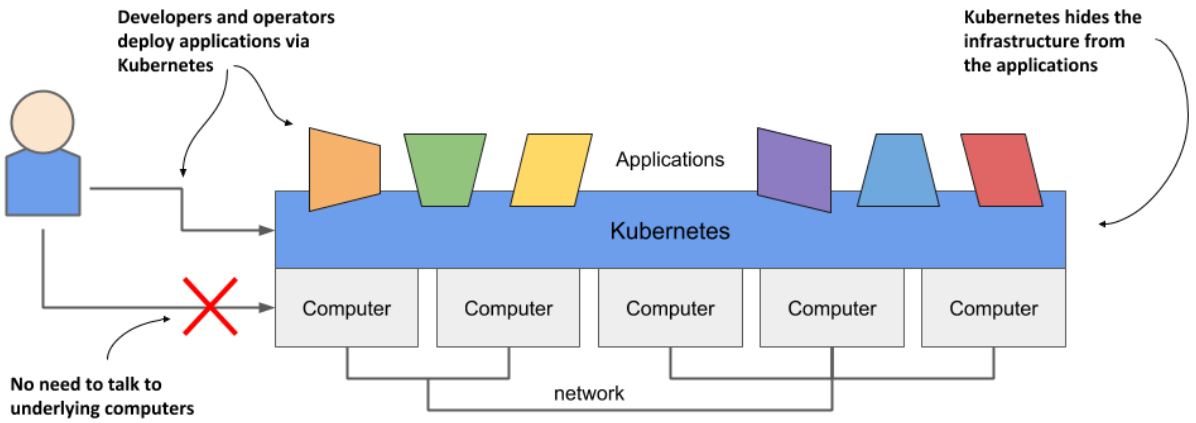


Figure 1.1 Infrastructure abstraction using Kubernetes

STANDARDIZING HOW WE DEPLOY APPLICATIONS

Because the details of the underlying infrastructure no longer affect the deployment of applications, you deploy applications to your corporate data center in the same way as you do in the cloud. A single manifest that describes the application can be used for local deployment and for deploying on any cloud provider. All differences in the underlying infrastructure are handled by Kubernetes, so you can focus on the application and the business logic it contains.

DEPLOYING APPLICATIONS DECLARATIVELY

Kubernetes uses a declarative model to define an application, as shown in the next figure. You describe the components that make up your application and Kubernetes turns this description into a running application. It then keeps the application healthy by restarting or recreating parts of it as needed.

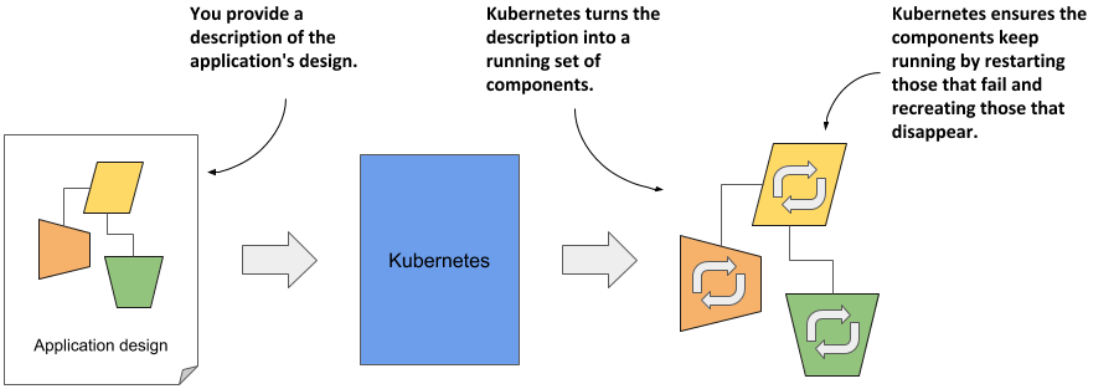


Figure 1.2 The declarative model of application deployment

Whenever you change the description, Kubernetes will take the necessary steps to reconfigure the running application to match the new description, as shown in the next figure.

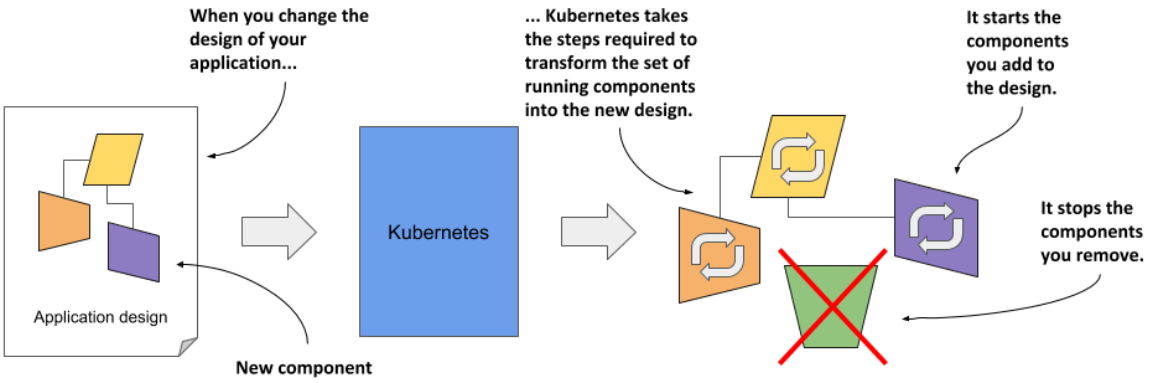


Figure 1.3 Changes in the description are reflected in the running application

TAKING ON THE DAILY MANAGEMENT OF APPLICATIONS

As soon as you deploy an application to Kubernetes, it takes over the daily management of the application. If the application fails, Kubernetes will automatically restart it. If the

hardware fails or the infrastructure topology changes so that the application needs to be moved to other machines, Kubernetes does this all by itself. The engineers responsible for operating the system can focus on the big picture instead of wasting time on the details.

To circle back to the sailing analogy: the development and operations engineers are the ship's officers who make high-level decisions while sitting comfortably in their armchairs, and Kubernetes is the helmsman who takes care of the low-level tasks of steering the system through the rough waters your applications and infrastructure sail through.

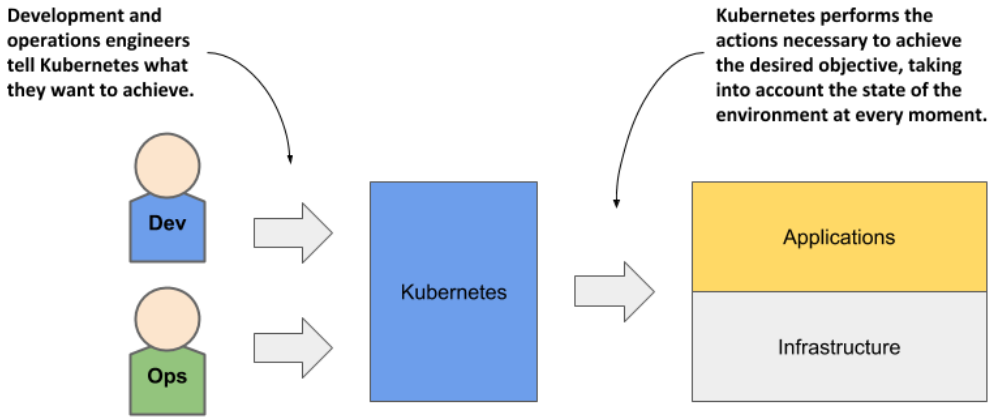


Figure 1.4 Kubernetes takes over the management of applications

Everything that Kubernetes does and all the advantages it brings requires a longer explanation, which we'll discuss later. Before we do that, it might help you to know how it all began and where the Kubernetes project currently stands.

1.1.2 About the Kubernetes project

Kubernetes was originally developed by Google. Google has practically always run applications in containers. As early as 2014, it was reported that they start two billion containers every week. That's over 3,000 containers per second, and the figure is much higher today. They run these containers on thousands of computers distributed across dozens of data centers around the world. Now imagine doing all this manually. It's clear that you need automation, and at this massive scale, it better be perfect.

ABOUT BORG AND OMEGA - THE PREDECESSORS OF KUBERNETES

The sheer scale of Google's workload has forced them to develop solutions to make the development and management of thousands of software components manageable and cost-effective. Over the years, Google developed an internal system called *Borg* (and later a new system called Omega) that helped both application developers and operators manage these thousands of applications and services.

In addition to simplifying development and management, these systems have also helped them to achieve better utilization of their infrastructure. This is important in any organization, but when you operate hundreds of thousands of machines, even tiny improvements in utilization mean savings in the millions, so the incentives for developing such a system are clear.

NOTE Data on Google's energy use suggests that they run around 900,000 servers.

Over time, your infrastructure grows and evolves. Every new data center is state-of-the-art. Its infrastructure differs from those built in the past. Despite the differences, the deployment of applications in one data center should not differ from deployment in another data center. This is especially important when you deploy your application across multiple zones or regions to reduce the likelihood that a regional failure will cause application downtime. To do this effectively, it's worth having a consistent method for deploying your applications.

ABOUT KUBERNETES - THE OPEN-SOURCE PROJECT - AND COMMERCIAL PRODUCTS DERIVED FROM IT

Based on the experience they gained while developing Borg, Omega and other internal systems, in 2014 Google introduced Kubernetes, an open-source project that can now be used and further improved by everyone.

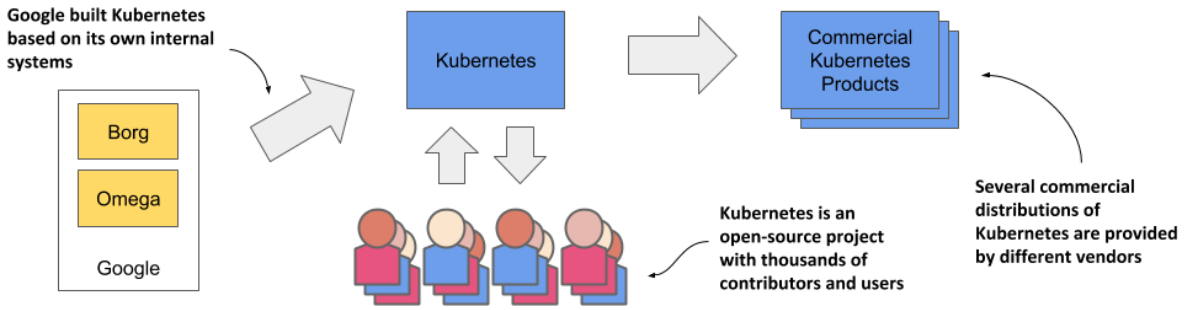


Figure 1.5 The origins and state of the Kubernetes open-source project

As soon as Kubernetes was announced, long before version 1.0 was officially released, other companies, such as Red Hat, who has always been at the forefront of open-source software, quickly stepped on board and helped develop the project. It eventually grew far beyond the expectations of its founders, and today is arguably one of the world's leading open-source projects, with dozens of organizations and thousands of individuals contributing to it.

Several companies are now offering enterprise-quality Kubernetes products that are built from the open-source project. These include Red Hat OpenShift, Pivotal Container Service, Rancher and many others.

How Kubernetes grew a whole new cloud-native eco-system

Kubernetes has also spawned many other related open-source projects, most of which are now under the umbrella of the *Cloud Native Computing Foundation* (CNCF), which is part of the *Linux Foundation*.

CNCF organizes several KubeCon - CloudNativeCon conferences per year - in North America, Europe and China. In 2019, the total number of attendees exceeded 23,000, with KubeCon North America reaching an overwhelming number of 12,000 participants. These figures show that Kubernetes has had an incredibly positive impact on the way companies around the world deploy applications today. It wouldn't have been so widely adopted if that wasn't the case.

1.1.3 Understanding why Kubernetes is so popular

In recent years, the way we develop applications has changed considerably. This has led to the development of new tools like Kubernetes, which in turn have fed back and fuelled further changes in application architecture and the way we develop them. Let's look at concrete examples of this.

Automating the management of microservices

In the past, most applications were large monoliths. The components of the application were tightly coupled, and they all ran in a single computer process. The application was developed as a unit by a large team of developers and the deployment of the application was straightforward. You installed it on a powerful computer and provided the little configuration it required. Scaling the application horizontally was rarely possible, so whenever you needed to increase the capacity of the application, you had to upgrade the hardware - in other words, scale the application vertically.

Then came the microservices paradigm. The monoliths were divided into dozens, sometimes hundreds, of separate processes, as shown in the following figure. This allowed organizations to divide their development departments into smaller teams where each team developed only a part of the entire system - just some of the microservices.

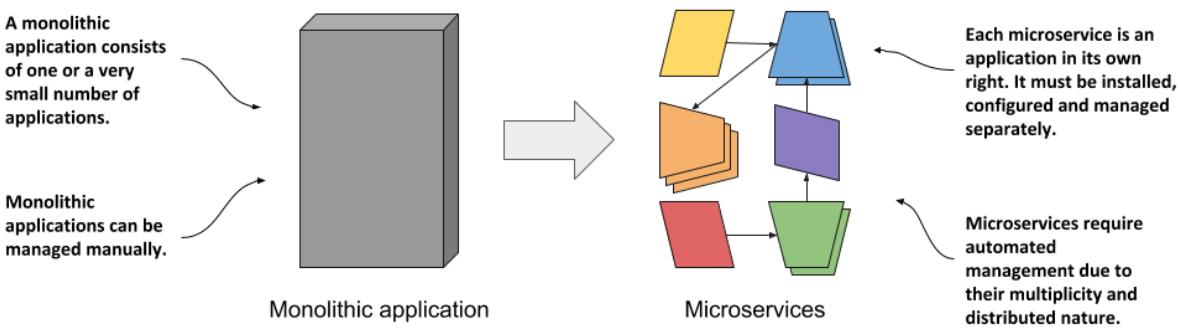


Figure 1.6 Comparing monolithic applications with microservices

Each microservice is now a separate application with its own development and release cycle. The dependencies of different microservices will inevitably diverge over time. One microservice requires one version of a library, while another microservice requires another, possibly incompatible, version of the same library. Running the two applications in the same operating system becomes difficult.

Fortunately, containers alone solve this problem where each microservice requires a different environment, but each microservice is now a separate application that must be managed individually. The increased number of applications makes this much more difficult.

Individual parts of the entire application no longer need to run on the same computer, which makes it easier to scale the entire system, but also means that the applications need to be configured to communicate with each other. For systems with only a handful of components, this can usually be done manually, but it's now common to see deployments with well over a hundred microservices.

When the system consists of many microservices, automated management is crucial. Kubernetes provides this automation. The features it offers make the task of managing hundreds of microservices almost trivial.

BRIDGING THE DEV AND OPS DIVIDE

Along with these changes in application architecture, we've also seen changes in the way teams develop and run software. It used to be normal for a development team to build the software in isolation and then throw the finished product over the wall to the operations team, who would then deploy it and manage it from there.

With the advent of the Dev-ops paradigm, the two teams now work much more closely together throughout the entire life of the software product. The development team is now much more involved in the daily management of the deployed software. But that means that they now need to know about the infrastructure on which it's running.

As a software developer, your primary focus is on implementing the business logic. You don't want to deal with the details of the underlying servers. Fortunately, Kubernetes hides these details.

STANDARDIZING THE CLOUD

Over the past decade or two, many organizations have moved their software from local servers to the cloud. The benefits of this seem to have outweighed the fear of being locked-in to a particular cloud provider, which is caused by relying on the provider's proprietary APIs to deploy and manage applications.

Any company that wants to be able to move its applications from one provider to another will have to make additional, initially unnecessary efforts to abstract the infrastructure and APIs of the underlying cloud provider from the applications. This requires resources that could otherwise be focused on building the primary business logic.

Kubernetes has also helped in this respect. The popularity of Kubernetes has forced all major cloud providers to integrate Kubernetes into their offerings. Customers can now deploy applications to any cloud provider through a standard set of APIs provided by Kubernetes.

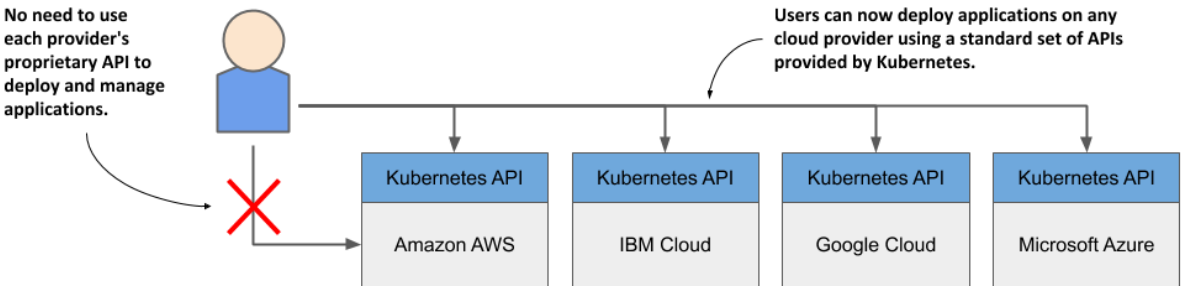


Figure 1.7 Kubernetes has standardized how you deploy applications on cloud providers

If the application is built on the APIs of Kubernetes instead of directly on the proprietary APIs of a specific cloud provider, it can be transferred relatively easily to any other provider.

1.2 Understanding Kubernetes

The previous section explained the origins of Kubernetes and the reasons for its wide adoption. In this section we'll take a closer look at what exactly Kubernetes is.

1.2.1 Understanding how Kubernetes transforms a computer cluster

Let's take a closer look at how the perception of the data center changes when you deploy Kubernetes on your servers.

KUBERNETES IS LIKE AN OPERATING SYSTEM FOR COMPUTER CLUSTERS

One can imagine Kubernetes as an operating system for the cluster. The next figure illustrates the analogies between an operating system running on a computer and Kubernetes running on a cluster of computers.

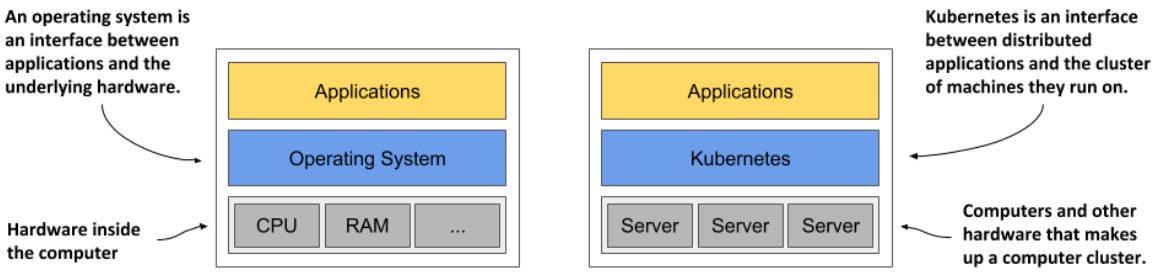


Figure 1.8 Kubernetes is to a computer cluster what an Operating System is to a computer

Just as an operating system supports the basic functions of a computer, such as scheduling processes onto its CPUs and acting as an interface between the application and the computer's hardware, Kubernetes schedules the components of a distributed application onto

individual computers in the underlying computer cluster and acts as an interface between the application and the cluster.

It frees application developers from the need to implement infrastructure-related mechanisms in their applications; instead, they rely on Kubernetes to provide them. This includes things like:

- *service discovery* - a mechanism that allows applications to find other applications and use the services they provide,
- *horizontal scaling* - replicating your application to adjust to fluctuations in load,
- *load-balancing* - distributing load across all the application replicas,
- *self-healing* - keeping the system healthy by automatically restarting failed applications and moving them to healthy nodes after their nodes fail,
- *leader election* - a mechanism that decides which instance of the application should be active while the others remain idle but ready to take over if the active instance fails.

By relying on Kubernetes to provide these features, application developers can focus on implementing the core business logic instead of wasting time integrating applications with the infrastructure.

HOW KUBERNETES FITS INTO A COMPUTER CLUSTER

To get a concrete example of how Kubernetes is deployed onto a cluster of computers, look at the following figure.

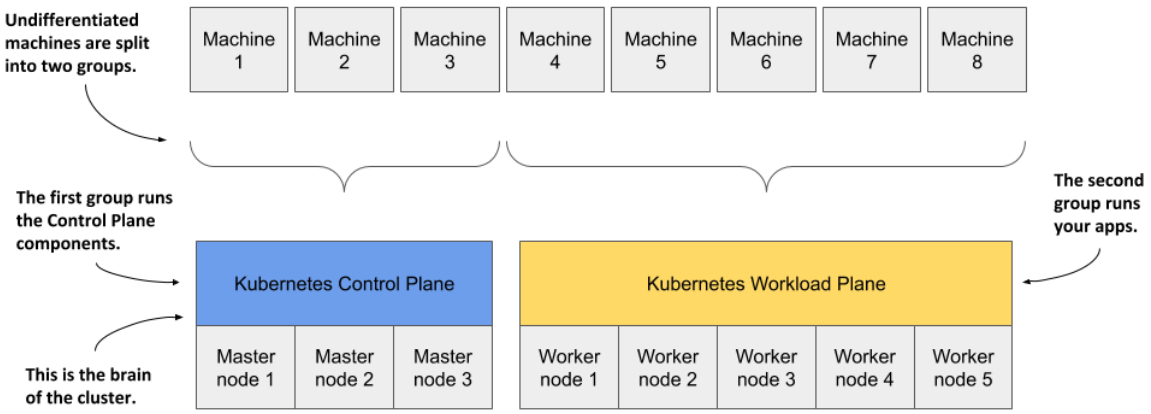


Figure 1.9 Computers in a Kubernetes cluster are divided into the Control Plane and the Workload Plane

You start with a fleet of machines that you divide into two groups - the master and the worker nodes. The master nodes will run the Kubernetes Control Plane, which represents the brain of your system and controls the cluster, while the rest will run your applications - your workloads - and will therefore represent the Workload Plane.

NOTE The Workload Plane is sometimes referred to as the Data Plane, but this term could be confusing because the plane doesn't host data but applications. Don't be confused by the term "plane" either - in this context you can think of it as the "surface" the applications run on.

Non-production clusters can use a single master node, but highly available clusters use at least three physical master nodes to host the Control Plane. The number of worker nodes depends on the number of applications you'll deploy.

HOW ALL CLUSTER NODES BECOME ONE LARGE DEPLOYMENT AREA

After Kubernetes is installed on the computers, you no longer need to think about individual computers when deploying applications. Regardless of the number of worker nodes in your cluster, they all become a single space where you deploy your applications. You do this using the Kubernetes API, which is provided by the Kubernetes Control Plane.

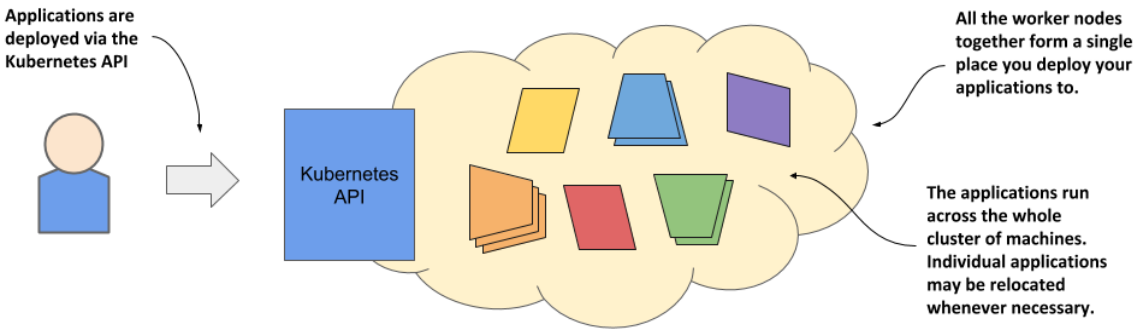


Figure 1.10 Kubernetes exposes the cluster as a uniform deployment area

When I say that all worker nodes become one space, I don't want you to think that you can deploy an extremely large application that is spread across several small machines. Kubernetes doesn't do magic tricks like this. Each application must be small enough to fit on one of the worker nodes.

What I meant was that when deploying applications, it doesn't matter which worker node they end up on. Kubernetes may later even move the application from one node to another. You may not even notice when that happens, and you shouldn't care.

1.2.2 The benefits of using Kubernetes

You've already learned why many organizations across the world have welcomed Kubernetes into their data centers. Now, let's take a closer look at the specific benefits it brings to both development and IT operations teams.

SELF-SERVICE DEPLOYMENT OF APPLICATIONS

Because Kubernetes presents all its worker nodes as a single deployment surface, it no longer matters which node you deploy your application to. This means that developers can

now deploy applications on their own, even if they don't know anything about the number of nodes or the characteristics of each node.

In the past, the system administrators were the ones who decided where each application should be placed. This task is now left to Kubernetes. This allows a developer to deploy applications without having to rely on other people to do so. When a developer deploys an application, Kubernetes chooses the best node on which to run the application based on the resource requirements of the application and the resources available on each node.

REDUCING COSTS VIA BETTER INFRASTRUCTURE UTILIZATION

If you don't care which node your application lands on, it also means that it can be moved to any other node at any time without you having to worry about it. Kubernetes may need to do this to make room for a larger application that someone wants to deploy. This ability to move applications allows the applications to be packed tightly together so that the resources of the nodes can be utilized in the best possible way.

> **NOTE** In chapter 17 you'll learn more about how Kubernetes decides where to place each application and how you can influence the decision.

Finding optimal combinations can be challenging and time consuming, especially when the number of all possible options is huge, such as when you have many application components and many server nodes on which they can be deployed. Computers can perform this task much better and faster than humans. Kubernetes does it very well. By combining different applications on the same machines, Kubernetes improves the utilization of your hardware infrastructure so you can run more applications on fewer servers.

AUTOMATICALLY ADJUSTING TO CHANGING LOAD

Using Kubernetes to manage your deployed applications also means that the operations team doesn't have to constantly monitor the load of each application to respond to sudden load peaks. Kubernetes takes care of this also. It can monitor the resources consumed by each application and other metrics and adjust the number of running instances of each application to cope with increased load or resource usage.

When you run Kubernetes on cloud infrastructure, it can even increase the size of your cluster by provisioning additional nodes through the cloud provider's API. This way, you never run out of space to run additional instances of your applications.

KEEPING APPLICATIONS RUNNING SMOOTHLY

Kubernetes also makes every effort to ensure that your applications run smoothly. If your application crashes, Kubernetes will restart it automatically. So even if you have a broken application that runs out of memory after running for more than a few hours, Kubernetes will ensure that your application continues to provide the service to its users by automatically restarting it in this case.

Kubernetes is a self-healing system in that it deals with software errors like the one just described, but it also handles hardware failures. As clusters grow in size, the frequency of node failure also increases. For example, in a cluster with one hundred nodes and a MTBF

(mean-time-between-failure) of 100 days for each node, you can expect one node to fail every day.

When a node fails, Kubernetes automatically moves applications to the remaining healthy nodes. The operations team no longer needs to manually move the application and can instead focus on repairing the node itself and returning it to the pool of available hardware resources.

If your infrastructure has enough free resources to allow normal system operation without the failed node, the operations team doesn't even have to react immediately to the failure. If it occurs in the middle of the night, no one from the operations team even has to wake up. They can sleep peacefully and deal with the failed node during regular working hours.

SIMPLIFYING APPLICATION DEVELOPMENT

The improvements described in the previous section mainly concern application deployment. But what about the process of application development? Does Kubernetes bring anything to their table? It definitely does.

As mentioned previously, Kubernetes offers infrastructure-related services that would otherwise have to be implemented in your applications. This includes the discovery of services and/or peers in a distributed application, leader election, centralized application configuration and others. Kubernetes provides this while keeping the application Kubernetes-agnostic, but when required, applications can also query the Kubernetes API to obtain detailed information about their environment. They can also use the API to change the environment.

1.2.3 The architecture of a Kubernetes cluster

As you've already learned, a Kubernetes cluster consists of nodes divided into two groups:

- A set of *master nodes* that host the *Control Plane* components, which are the brains of the system, since they control the entire cluster.
- A set of *worker nodes* that form the *Workload Plane*, which is where your workloads (or applications) run.

The following figure shows the two planes and the different nodes they consist of.

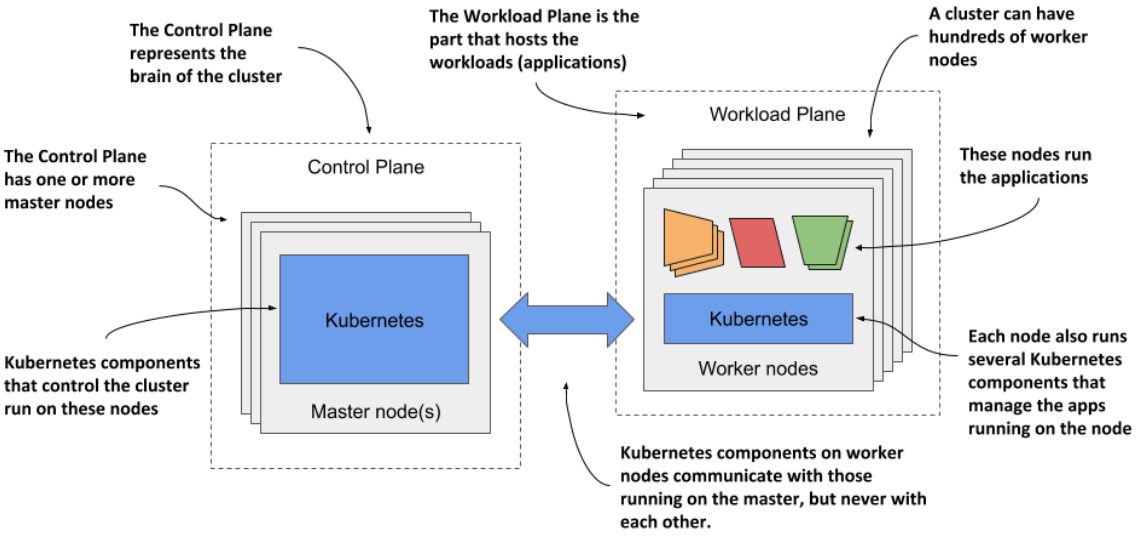


Figure 1.11 The two planes that make up a Kubernetes cluster

The two planes, and hence the two types of nodes, run different Kubernetes components. The next two sections of the book introduce them and summarize their functions without going into details. These components will be mentioned several times in the next part of the book where I explain the fundamental concepts of Kubernetes. An in-depth look at the components and their internals follows in the third part of the book.

CONTROL PLANE COMPONENTS

The Control Plane is what controls the cluster. It consists of several components that run on a single master node or are replicated across multiple master nodes to ensure high availability. The Control Plane's components are shown in the following figure.

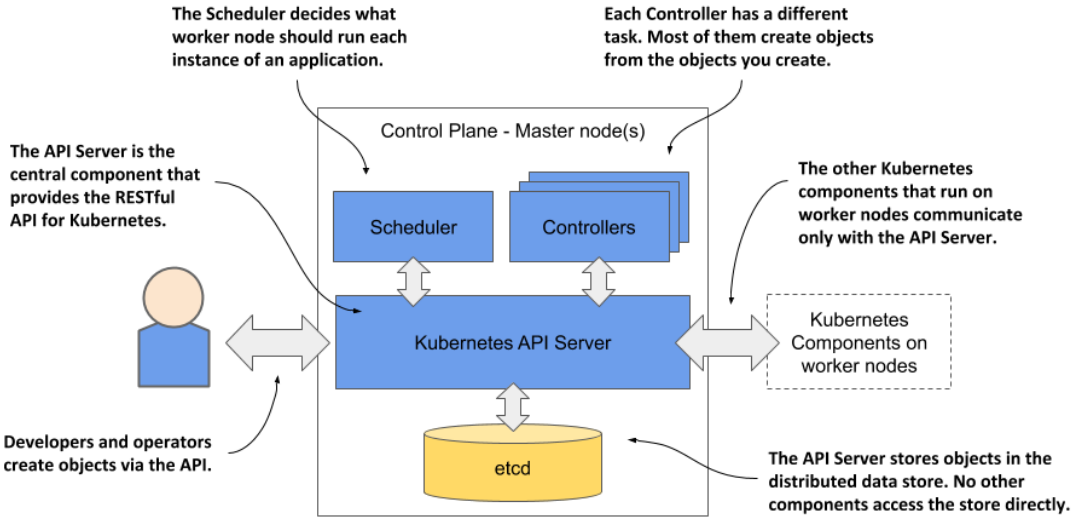


Figure 1.12 The components of the Kubernetes Control Plane

These are the components and their functions:

- The *Kubernetes API Server* exposes the RESTful Kubernetes API. Engineers using the cluster and other Kubernetes components create objects via this API.
- The *etcd* distributed datastore persists the objects you create through the API, since the API Server itself is stateless. The Server is the only component that talks to etcd.
- The *Scheduler* decides on which worker node each application instance should run.
- *Controllers* bring to life the objects you create through the API. Most of them simply create other objects, but some also communicate with external systems (for example, the cloud provider via its API).

The components of the Control Plane hold and control the state of the cluster, but they don't run your applications. This is done by the (worker) nodes.

WORKER NODE COMPONENTS

The worker nodes are the computers on which your applications run. They form the cluster's Workload Plane. In addition to applications, several Kubernetes components also run on these nodes. They perform the task of running, monitoring and providing connectivity between your applications. They are shown in the following figure.

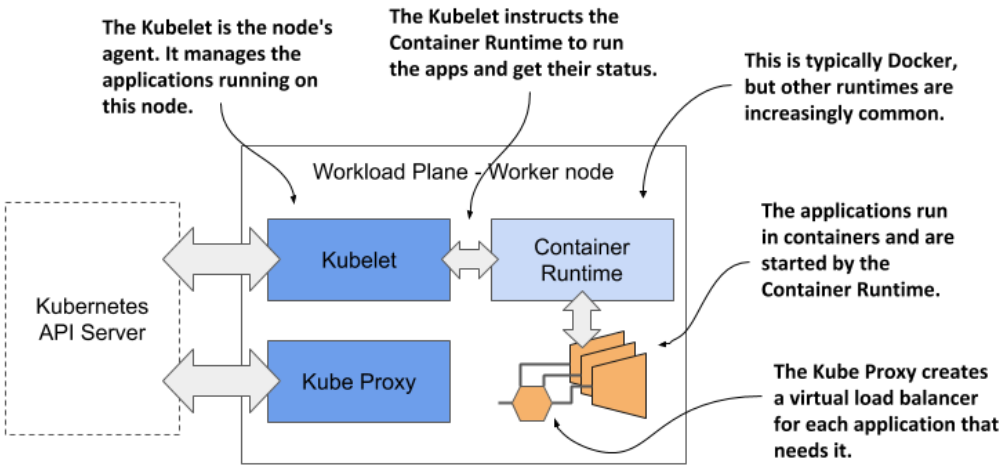


Figure 1.13 The Kubernetes components that run on each node

Each node runs the following set of components:

- The *Kubelet*, an agent that talks to the API server and manages the applications running on its node. It reports the status of these applications and the node via the API.
- The *Container Runtime*, which can be Docker or any other runtime compatible with Kubernetes. It runs your applications in containers as instructed by the Kubelet.
- The *Kubernetes Service Proxy (Kube Proxy)* load-balances network traffic between applications. Its name suggests that traffic flows through it, but that's no longer the case. You'll learn why in chapter 14.

ADD-ON COMPONENTS

Most Kubernetes clusters also contain several other components. This includes a DNS server, network plugins, logging agents and many others. They typically run on the worker nodes but can also be configured to run on the master.

GAINING A DEEPER UNDERSTANDING OF THE ARCHITECTURE

For now, I only expect you to be vaguely familiar with the names of these components and their function, as I'll mention them many times throughout the following chapters. You'll learn snippets about them in these chapters, but I'll explain them in more detail in chapter 14.

I'm not a fan of explaining how things work until I first explain *what* something does and teach you how to use it. It's like learning to drive. You don't want to know what's under the hood. At first, you just want to learn how to get from point A to B. Only then will you be interested in how the car makes this possible. Knowing what's under the hood may one day help you get your car moving again after it has broken down and you are stranded on the

side of the road. I hate to say it, but you'll have many moments like this when dealing with Kubernetes due to its sheer complexity.

1.2.4 How Kubernetes runs an application

With a general overview of the components that make up Kubernetes, I can finally explain how to deploy an application in Kubernetes.

DEFINING YOUR APPLICATION

Everything in Kubernetes is represented by an object. You create and retrieve these objects via the Kubernetes API. Your application consists of several types of these objects - one type represents the application deployment as a whole, another represents a running instance of your application, another represents the service provided by a set of these instances and allows reaching them at a single IP address, and there are many others.

All these types are explained in detail in the second part of the book. At the moment, it's enough to know that you define your application through several types of objects. These objects are usually defined in one or more manifest files in either YAML or JSON format.

> **DEFINITION** YAML was initially said to mean "Yet Another Markup Language", but it was latter changed to the recursive acronym "YAML Ain't Markup Language". It's one of the ways to serialize an object into a human-readable text file.

> **DEFINITION** JSON is short for JavaScript Object Notation. It's a different way of serializing an object, but more suitable for exchanging data between applications.

The following figure shows an example of deploying an application by creating a manifest with two deployments exposed using two services.

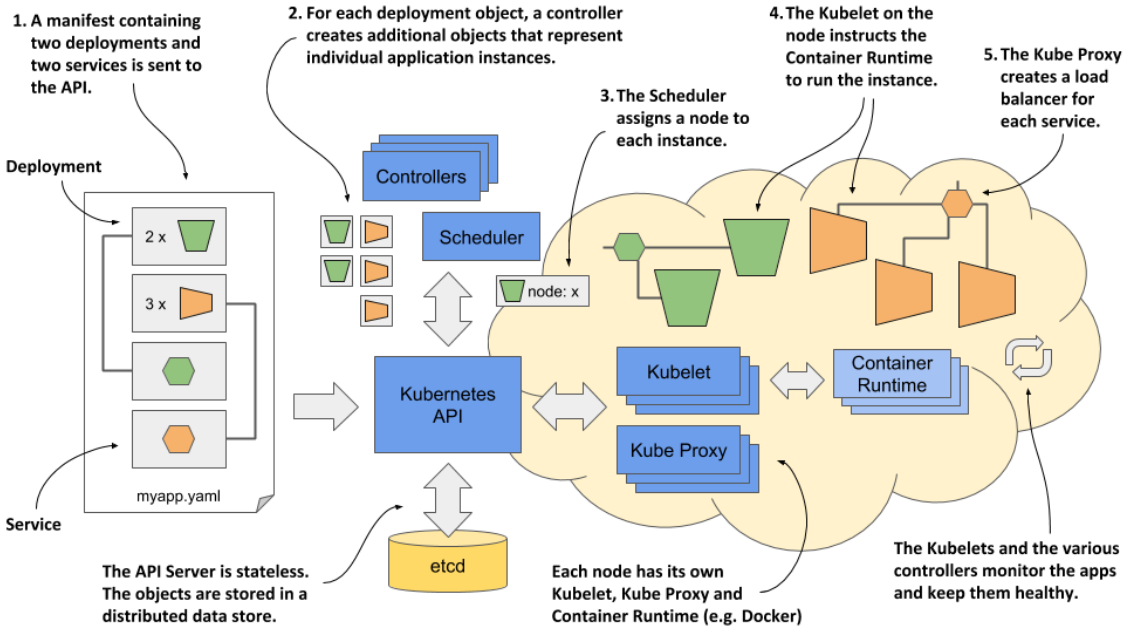


Figure 1.14 Deploying an application to Kubernetes

These actions take place when you deploy the application:

1. You submit the application manifest to the Kubernetes API. The API Server writes the objects defined in the manifest to etcd.
2. A controller notices the newly created objects and creates several new objects - one for each application instance.
3. The Scheduler assigns a node to each instance.
4. The Kubelet notices that an instance is assigned to the Kubelet's node. It runs the application instance via the Container Runtime.
5. The Kube Proxy notices that the application instances are ready to accept connections from clients and configures a load balancer for them.
6. The Kubelets and the Controllers monitor the system and keep the applications running.

The procedure is explained in more detail in the following sections, but the complete explanation is given in chapter 14, after you have familiarized yourself with all the objects and controllers involved.

SUBMITTING THE APPLICATION TO THE API

After you've created your YAML or JSON file(s), you submit the file to the API, usually via the Kubernetes command-line tool called *kubectl*.

> **NOTE** Kubectl is pronounced *kube-control*, but the softer souls in the community prefer to call it *kube-cuddle*. Some refer to it as *kube-C-T-L*.

Kubectl splits the file into individual objects and creates each of them by sending an HTTP PUT or POST request to the API, as is usually the case with RESTful APIs. The API Server validates the objects and stores them in the etcd datastore. In addition, it notifies all interested components that these objects have been created. Controllers, which are explained next, are one of these components.

ABOUT THE CONTROLLERS

Most object types have an associated controller. A controller is interested in a particular object type. It waits for the API server to notify it that a new object has been created, and then performs operations to bring that object to life. Typically, the controller just creates other objects via the same Kubernetes API. For example, the controller responsible for application deployments creates one or more objects that represent individual instances of the application. The number of objects created by the controller depends on the number of replicas specified in the application deployment object.

ABOUT THE SCHEDULER

The scheduler is a special type of controller, whose only task is to schedule application instances onto worker nodes. It selects the best worker node for each new application instance object and assigns it to the instance - by modifying the object via the API.

ABOUT THE KUBELET AND THE CONTAINER RUNTIME

The Kubelet that runs on each worker node is also a type of controller. Its task is to wait for application instances to be assigned to the node on which it is located and run the application. This is done by instructing the Container Runtime to start the application's container.

ABOUT THE KUBE PROXY

Because an application deployment can consist of multiple application instances, a load balancer is required to expose them at a single IP address. The Kube Proxy, another controller running alongside the Kubelet, is responsible for setting up the load balancer.

KEEPING THE APPLICATIONS HEALTHY

Once the application is up and running, the Kubelet keeps the application healthy by restarting it when it terminates. It also reports the status of the application by updating the object that represents the application instance. The other controllers monitor these objects and ensure that applications are moved to healthy nodes if their nodes fail.

You're now roughly familiar with the architecture and functionality of Kubernetes. You don't need to understand or remember all the details at this moment, because internalizing

this information will be easier when you learn about each individual object types and the controllers that bring them to life in the second part of the book.

1.3 Introducing Kubernetes into your organization

To close this chapter, let's see what options are available to you if you decide to introduce Kubernetes in your own IT environment.

1.3.1 Running Kubernetes on-premises and in the cloud

If you want to run your applications on Kubernetes, you have to decide whether you want to run them locally, in your organization's own infrastructure (on-premises) or with one of the major cloud providers, or perhaps both - in a hybrid cloud solution.

RUNNING KUBERNETES ON-PREMISES

Running Kubernetes on your own infrastructure may be your only option if regulations require you to run applications on site. This usually means that you'll have to manage Kubernetes yourself, but we'll come to that later.

Kubernetes can run directly on your bare-metal machines or in virtual machines running in your data center. In either case, you won't be able to scale your cluster as easily as when you run it in virtual machines provided by a cloud provider.

DEPLOYING KUBERNETES IN THE CLOUD

If you have no on-premises infrastructure, you have no choice but to run Kubernetes in the cloud. This has the advantage that you can scale your cluster at any time at short notice if required. As mentioned earlier, Kubernetes itself can ask the cloud provider to provision additional virtual machines when the current size of the cluster is no longer sufficient to run all the applications you want to deploy.

When the number of workloads decreases and some worker nodes are left without running workloads, Kubernetes can ask the cloud provider to destroy the virtual machines of these nodes to reduce your operational costs. This elasticity of the cluster is certainly one of the main benefits of running Kubernetes in the cloud.

USING A HYBRID CLOUD SOLUTION

A more complex option is to run Kubernetes on-premises, but also allow it to spill over into the cloud. It's possible to configure Kubernetes to provision additional nodes in the cloud if you exceed the capacity of your own data center. This way, you get the best of both worlds. Most of the time, your applications run locally without the cost of virtual machine rental, but in short periods of peak load that may occur only a few times a year, your applications can handle the extra load by using the additional resources in the cloud.

If your use-case requires it, you can also run a Kubernetes cluster across multiple cloud providers or a combination of any of the options mentioned. This can be done using a single control plane or one control plane in each location.

1.3.2 To manage or not to manage Kubernetes yourself

If you are considering introducing Kubernetes in your organization, the most important question you need to answer is whether you'll manage Kubernetes yourself or use a Kubernetes-as-a-Service type offering where someone else manages it for you.

MANAGING KUBERNETES YOURSELF

If you already run applications on-premises and have enough hardware to run a production-ready Kubernetes cluster, your first instinct is probably to deploy and manage it yourself. If you ask anyone in the Kubernetes community if this is a good idea, you'll usually get a very definite "no".

Figure 1.14 was a very simplified representation of what happens in a Kubernetes cluster when you deploy an application. Even that figure should have scared you. Kubernetes brings with it an enormous amount of additional complexity. Anyone who wants to run a Kubernetes cluster must be intimately familiar with its inner workings.

The management of production-ready Kubernetes clusters is a multi-billion-dollar industry. Before you decide to manage one yourself, it's essential that you consult with engineers who have already done it to learn about the issues most teams run into. If you don't, you may be setting yourself up for failure. On the other hand, trying out Kubernetes for non-production use-cases or using a managed Kubernetes cluster is much less problematic.

USING A MANAGED KUBERNETES CLUSTER IN THE CLOUD

Using Kubernetes is ten times easier than managing it. Most major cloud providers now offer Kubernetes-as-a-Service. They take care of managing Kubernetes and its components while you simply use the Kubernetes API like any of the other APIs the cloud provider offers.

The top managed Kubernetes offerings include the following:

- Google Kubernetes Engine (GKE)
- Azure Kubernetes Service (AKS)
- Amazon Elastic Kubernetes Service (EKS)
- IBM Cloud Kubernetes Service
- Red Hat OpenShift Online and Dedicated
- VMware Cloud PKS
- Alibaba Cloud Container Service for Kubernetes (ACK)

The first half of this book focuses on just using Kubernetes. You'll run the exercises in a local development cluster and on a managed GKE cluster, as I find it's the easiest to use and offers the best user experience. The second part of the book gives you a solid foundation for managing Kubernetes, but to truly master it, you'll need to gain additional experience.

1.3.3 Using vanilla or extended Kubernetes

The final question is whether to use a vanilla open-source version of Kubernetes or an extended, enterprise-quality Kubernetes product.

USING A VANILLA VERSION OF KUBERNETES

The open-source version of Kubernetes is maintained by the community and represents the cutting edge of Kubernetes development. This also means that it may not be as stable as the other options. It may also lack good security defaults. Deploying the vanilla version requires a lot of fine tuning to set everything up for production use.

USING ENTERPRISE-GRADE KUBERNETES DISTRIBUTIONS

A better option for using Kubernetes in production is to use an enterprise-quality Kubernetes distribution such as OpenShift or Rancher. In addition to the increased security and performance provided by better defaults, they offer additional object types in addition to those provided in the upstream Kubernetes API. For example, vanilla Kubernetes does not contain object types that represent cluster users, whereas commercial distributions do. They also provide additional software tools for deploying and managing well-known third-party applications on Kubernetes.

Of course, extending and hardening Kubernetes takes time, so these commercial Kubernetes distributions usually lag one or two versions behind the upstream version of Kubernetes. It's not as bad as it sounds. The benefits usually outweigh the disadvantages.

1.3.4 Should you even use Kubernetes?

I hope this chapter has made you excited about Kubernetes and you can't wait to squeeze it into your IT stack. But to close this chapter properly, we need to say a word or two about when introducing Kubernetes is not a good idea.

DO YOUR WORKLOADS REQUIRE AUTOMATED MANAGEMENT?

The first thing you need to be honest about is whether you need to automate the management of your applications at all. If your application is a large monolith, you definitely don't need Kubernetes.

Even if you deploy microservices, using Kubernetes may not be the best option, especially if the number of your microservices is very small. It's difficult to provide an exact number when the scales tip over, since other factors also influence the decision. But if your system consists of less than five microservices, throwing Kubernetes into the mix is probably not a good idea. If your system has more than twenty microservices, you will most likely benefit from the integration of Kubernetes. If the number of your microservices falls somewhere in between, other factors, such as the ones described next, should be considered.

CAN YOU AFFORD TO INVEST YOUR ENGINEERS' TIME INTO LEARNING KUBERNETES?

Kubernetes is designed to allow applications to run without them knowing that they are running in Kubernetes. While the applications themselves don't need to be modified to run in Kubernetes, development engineers will inevitably spend a lot of time learning how to use Kubernetes, even though the operators are the only ones that actually need that knowledge.

It would be hard to tell your teams that you're switching to Kubernetes and expect only the operations team to start exploring it. Developers like shiny new things. At the time of writing, Kubernetes is still a very shiny thing.

ARE YOU PREPARED FOR INCREASED COSTS IN THE INTERIM?

While Kubernetes reduces long-term operational costs, introducing Kubernetes in your organization initially involves increased costs for training, hiring new engineers, building and purchasing new tools and possibly additional hardware. Kubernetes requires additional computing resources in addition to the resources that the applications use.

DON'T BELIEVE THE HYPE

Although Kubernetes has been around for several years at the time of writing this book, I can't say that the hype phase is over. The initial excitement has just begun to calm down, but many engineers may still be unable to make rational decisions about whether the integration of Kubernetes is as necessary as it seems.

1.4 Summary

In this introductory chapter, you've learned that:

- Kubernetes is Greek for helmsman. As a ship's captain oversees the ship while the helmsman steers it, you oversee your computer cluster, while Kubernetes performs the day-to-day management tasks.
- Kubernetes is pronounced *koo-ber-netties*. Kubectl, the Kubernetes command-line tool, is pronounced *kube-control*.
- Kubernetes is an open-source project built upon Google's vast experience in running applications on a global scale. Thousands of individuals now contribute to it.
- Kubernetes uses a declarative model to describe application deployments. After you provide a description of your application to Kubernetes, it brings it to life.
- Kubernetes is like an operating system for the cluster. It abstracts the infrastructure and presents all computers in a data center as one large, contiguous deployment area.
- Microservice-based applications are more difficult to manage than monolithic applications. The more microservices you have, the more you need to automate their management with a system like Kubernetes.
- Kubernetes helps both development and operations teams to do what they do best. It frees them from mundane tasks and introduces a standard way of deploying applications both on-premises and in any cloud.
- Using Kubernetes allows developers to deploy applications without the help of system administrators. It reduces operational costs through better utilization of existing hardware, automatically adjusts your system to load fluctuations, and heals itself and the applications running on it.
- A Kubernetes cluster consists of master and worker nodes. The master nodes run the *Control Plane*, which controls the entire cluster, while the worker nodes run the deployed applications or workloads, and therefore represent the *Workload Plane*.
- Using Kubernetes is simple, but managing it is hard. An inexperienced team should use a Kubernetes-as-a-Service offering instead of deploying Kubernetes by itself.

So far, you've only observed the ship from the pier. It's time to come aboard. But before you leave the docks, you should inspect the shipping containers it's carrying. You'll do this next.

2

Understanding containers

This chapter covers

- **Understanding what a container is**
- **Differences between containers and virtual machines**
- **Creating, running, and sharing a container image with Docker**
- **Linux kernel features that make containers possible**

Kubernetes primarily manages applications that run in containers - so before you start exploring Kubernetes, you need to have a good understanding of what a container is. This chapter explains the basics of Linux containers that a typical Kubernetes user needs to know.

2.1 Introducing containers

In Chapter 1 you learned how different microservices running in the same operating system may require different, potentially conflicting versions of dynamically linked libraries or have different environment requirements.

When a system consists of a small number of applications, it's okay to assign a dedicated virtual machine to each application and run each in its own operating system. But as the microservices become smaller and their numbers start to grow, you may not be able to afford to give each one its own VM if you want to keep your hardware costs low and not waste resources.

It's not just a matter of wasting hardware resources - each VM typically needs to be individually configured and managed, which means that running higher numbers of VMs also results in higher staffing requirements and the need for a better, often more complicated automation system. Due to the shift to microservice architectures, where systems consist of hundreds of deployed application instances, an alternative to VMs was needed. Containers are that alternative.

2.1.1 Comparing containers to virtual machines

Instead of using virtual machines to isolate the environments of individual microservices (or software processes in general), most development and operations teams now prefer to use containers. They allow you to run multiple services on the same host computer, while keeping them isolated from each other. Like VMs, but with much less overhead.

Unlike VMs, which each run a separate operating system with several system processes, a process running in a container runs within the existing host operating system. Because there is only one operating system, no duplicate system processes exist. Although all the application processes run in the same operating system, their environments are isolated, though not as well as when you run them in separate VMs. To the process in the container, this isolation makes it look like no other processes exist on the computer. You'll learn how this is possible in the next few sections, but first let's dive deeper into the differences between containers and virtual machines.

COMPARING THE OVERHEAD OF CONTAINERS AND VIRTUAL MACHINES

Compared to VMs, containers are much lighter, because they don't require a separate resource pool or any additional OS-level processes. While each VM usually runs its own set of system processes, which requires additional computing resources in addition to those consumed by the user application's own process, a container is nothing more than an isolated process running in the existing host OS that consumes only the resources the app consumes. They have virtually no overhead.

Figure 2.1 shows two bare metal computers, one running two virtual machines, and the other running containers instead. The latter has space for additional containers, as it runs only one operating system, while the first runs three – one host and two guest OSes.

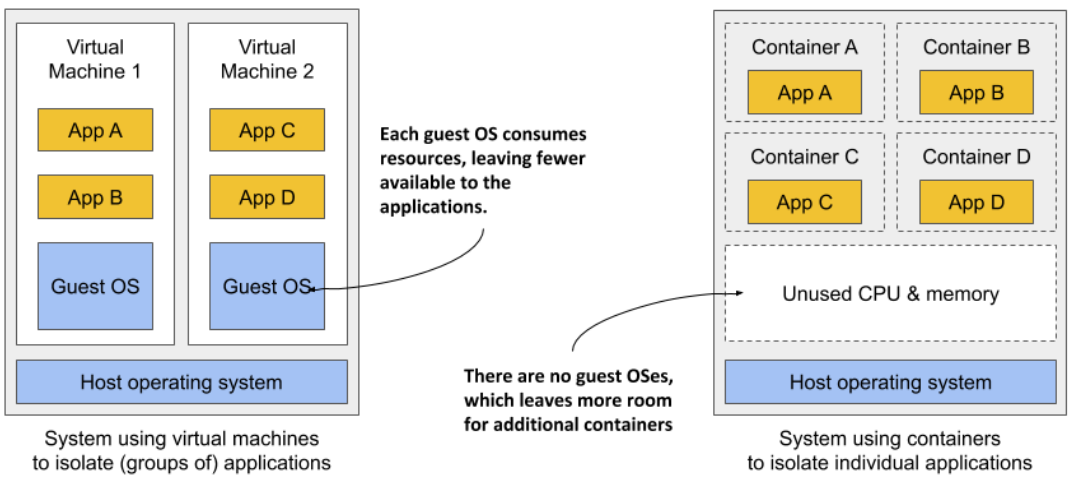


Figure 2.1 Using VMs to isolate groups of applications vs. isolating individual apps with containers

Because of the resource overhead of VMs, you often group multiple applications into each VM. You can't afford to dedicate a whole VM to each app. But containers introduce no overhead, which means you can afford to create a separate container for each application. In fact, you should never run multiple applications in the same container, as this makes managing the processes in the container much more difficult. Moreover, all existing software dealing with containers, including Kubernetes itself, is designed under the premise that there's only one application in a container.

COMPARING THE START-UP TIME OF CONTAINERS AND VIRTUAL MACHINES

In addition to the lower runtime overhead, containers also start the application faster, because only the application process itself needs to be started. No additional system processes need to be started first, as is the case when booting up a new virtual machine.

COMPARING THE ISOLATION OF CONTAINERS AND VIRTUAL MACHINES

You'll agree that containers are clearly better when it comes to the use of resources, but there's also a disadvantage. When you run applications in virtual machines, each VM runs its own operating system and kernel. Underneath those VMs is the hypervisor (and possibly an additional operating system), which splits the physical hardware resources into smaller sets of virtual resources that the operating system in each VM can use. As figure 2.2 shows, applications running in these VMs make system calls (*sys-calls*) to the guest OS kernel in the VM, and the machine instructions that the kernel then executes on the virtual CPUs are then forwarded to the host's physical CPU via the hypervisor.

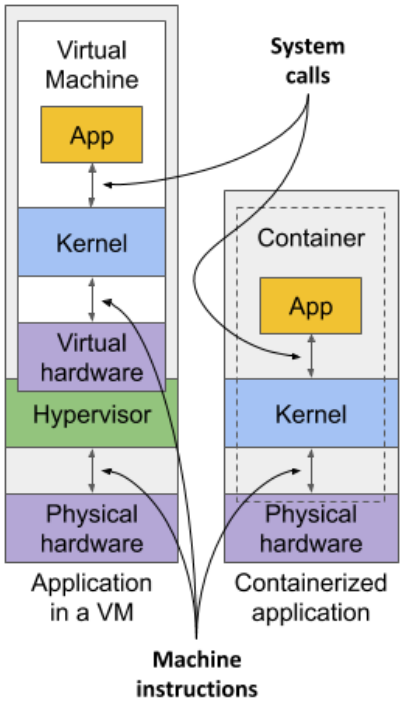


Figure 2.2 How apps use the hardware when running in a VM vs. in a container

> **NOTE** Two types of hypervisors exist. Type 1 hypervisors don't require running a host OS, while type 2 hypervisors do.

Containers, on the other hand, all make system calls on the single kernel running in the host OS. This single kernel is the only one that executes instructions on the host's CPU. The CPU doesn't need to handle any kind of virtualization the way it does with VMs.

Examine figure 2.3 to see the difference between running three applications on bare metal, running them in two separate virtual machines, or running them in three containers.

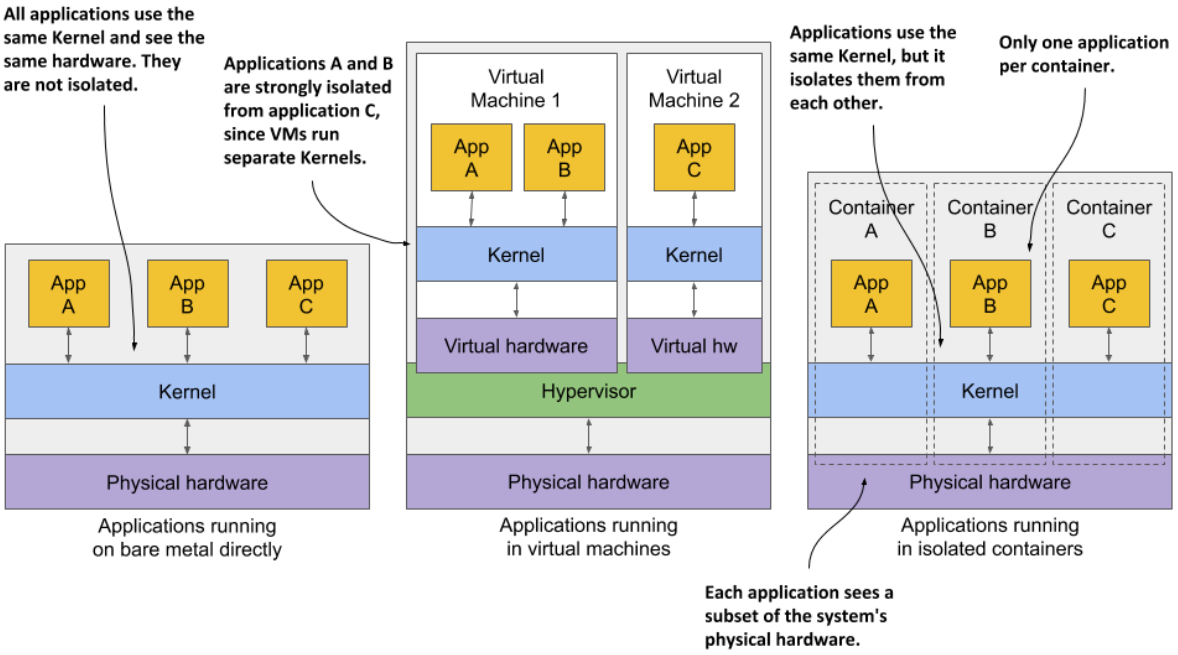


Figure 2.3 The difference between running applications on bare metal, in virtual machines, and in containers

In the first case, all three applications use the same kernel and aren't isolated at all. In the second case, applications A and B run in the same VM and thus share the kernel, while application C is completely isolated from the other two, since it uses its own kernel. It only shares the hardware with the first two.

The third case shows the same three applications running in containers. Although they all use the same kernel, they are isolated from each other and completely unaware of the others' existence. The isolation is provided by the kernel itself. Each application sees only a part of the physical hardware and sees itself as the only process running in the OS, although they all run in the same OS.

UNDERSTANDING THE SECURITY-IMPLICATIONS OF CONTAINER ISOLATION

The main advantage of using virtual machines over containers is the complete isolation they provide, since each VM has its own Linux kernel, while containers all use the same kernel. This can clearly pose a security risk. If there's a bug in the kernel, an application in one container might use it to read the memory of applications in other containers. If the apps run in different VMs and therefore share only the hardware, the probability of such attacks is much lower. Of course, complete isolation is only achieved by running applications on separate physical machines.

Additionally, containers share memory space, whereas each VM uses its own chunk of memory. Therefore, if you don't limit the amount of memory that a container can use, this

could cause other containers to run out of memory or cause their data to be swapped out to disk.

NOTE This can't happen in Kubernetes, because it requires that swap is disabled on all the nodes.

UNDERSTANDING WHAT ENABLES CONTAINERS AND WHAT ENABLES VIRTUAL MACHINES

While virtual machines are enabled through virtualization support in the CPU and by virtualization software on the host, containers are enabled by the Linux kernel itself. You'll learn about container technologies later when you can try them out for yourself. You'll need to have Docker installed for that, so let's learn how it fits into the container story.

2.1.2 Introducing the Docker container platform

While container technologies have existed for a long time, they only became widely known with the rise of Docker. Docker was the first container system that made them easily portable across different computers. It simplified the process of packaging up the application and all its libraries and other dependencies - even the entire OS file system - into a simple, portable package that can be used to deploy the application on any computer running Docker.

INTRODUCING CONTAINERS, IMAGES AND REGISTRIES

Docker is a platform for packaging, distributing and running applications. As mentioned earlier, it allows you to package your application along with its entire environment. This can be just a few dynamically linked libraries required by the app, or all the files that are usually shipped with an operating system. Docker allows you to distribute this package via a public repository to any other Docker-enabled computer.

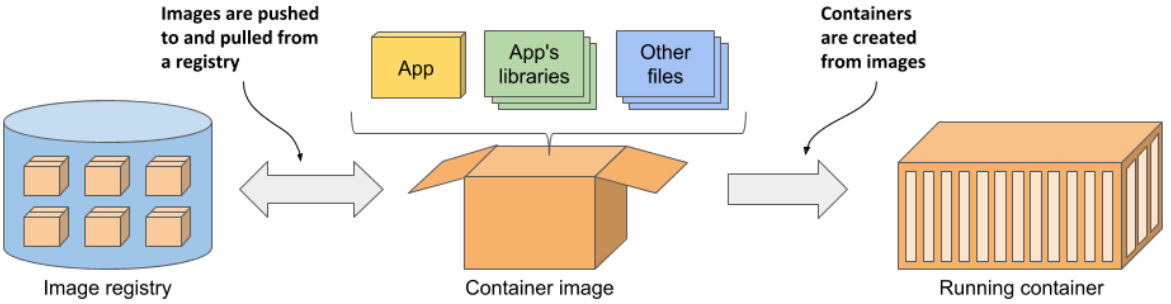


Figure 2.4 The three main Docker concepts are images, registries and containers

Figure 2.4 shows three main Docker concepts that appear in the process I've just described. Here's what each of them is:

- *Images*—A container image is something you package your application and its environment into. Like a zip file or a tarball. It contains the whole filesystem that the application will use and additional metadata, such as the path to the executable file to

run when the image is executed, the ports the application listens on, and other information about the image.

- *Registries*—A registry is a repository of container images that enables the exchange of images between different people and computers. After you build your image, you can either run it on the same computer, or *push* (upload) the image to a registry and then *pull* (download) it to another computer. Certain registries are public, allowing anyone to pull images from it, while others are private and only accessible to individuals, organizations or computers that have the required authentication credentials.
- *Containers*—A container is instantiated from a container image. A running container is a normal process running in the host operating system, but its environment is isolated from that of the host and the environments of other processes. The file system of the container originates from the container image, but additional file systems can also be mounted into the container. A container is usually resource-restricted, meaning it can only access and use the amount of resources such as CPU and memory that have been allocated to it.

BUILDING, DISTRIBUTING, AND RUNNING A CONTAINER IMAGE

To understand how containers, images and registries relate to each other, let's look at how to build a container image, distribute it through a registry and create a running container from the image. These three processes are shown in figures 2.5 to 2.7.

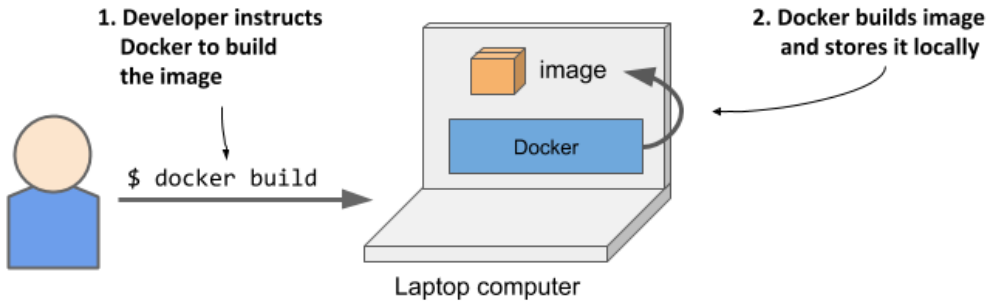


Figure 2.5 Building a container image

As shown in figure 2.5, the developer first builds an image, and then pushes it to a registry, as shown in figure 2.6. The image is now available to anyone who can access the registry.

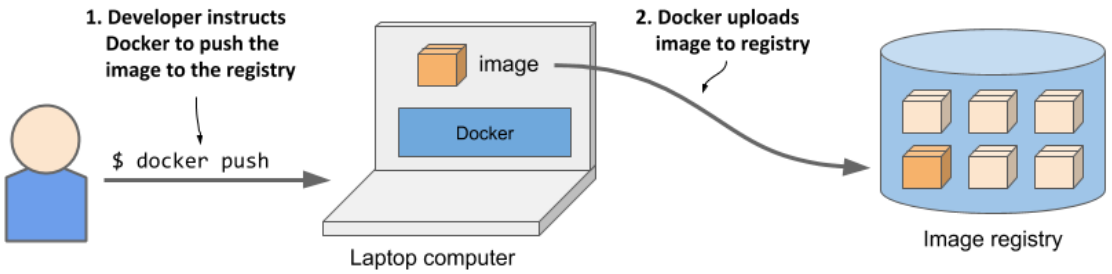


Figure 2.6 Uploading a container image to a registry

As the next figure shows, another person can now pull the image to any other computer running Docker and run it. Docker creates an isolated container based on the image and invokes the executable file specified in the image.

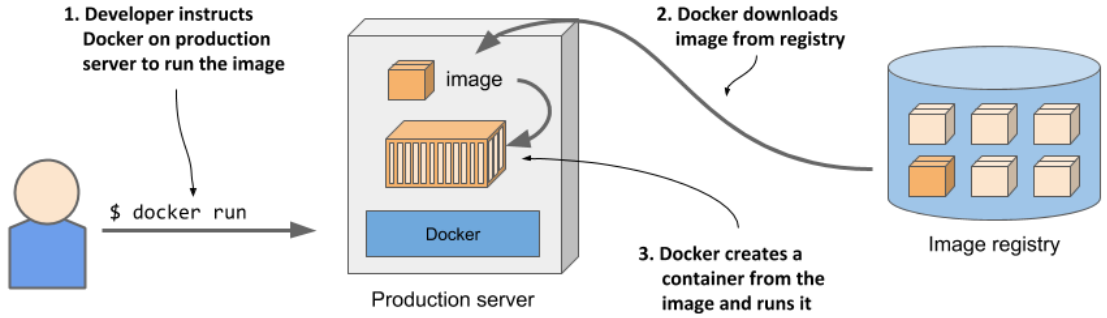


Figure 2.7 Running a container on a different computer

Running the application on any computer is made possible by the fact that the environment of the application is decoupled from the environment of the host.

UNDERSTANDING THE ENVIRONMENT THAT THE APPLICATION SEES

When you run an application in a container, it sees exactly the file system content you bundled into the container image, as well as any additional file systems you mount into the container. The application sees the same files whether it's running on your laptop or a full-fledged production server, even if the production server uses a completely different Linux distribution. The application typically has no access to the files in the host's operating system, so it doesn't matter if the server has a completely different set of installed libraries than your development computer.

For example, if you package your application with the files of the entire Red Hat Enterprise Linux (RHEL) operating system and then run it, the application will think it's running inside RHEL, whether you run it on your Fedora-based or a Debian-based computer.

The Linux distribution installed on the host is irrelevant. The only thing that might be important is the kernel version and the kernel modules it loads. Later, I'll explain why.

This is similar to creating a VM image by creating a new VM, installing an operating system and your app in it, and then distributing the whole VM image so that other people can run it on different hosts. Docker achieves the same effect, but instead of using VMs for app isolation, it uses Linux container technologies to achieve (almost) the same level of isolation.

UNDERSTANDING IMAGE LAYERS

Unlike virtual machine images, which are big blobs of the entire filesystem required by the operating system installed in the VM, container images consist of layers that are usually much smaller. These layers can be shared and reused across multiple images. This means that only certain layers of an image need to be downloaded if the rest were already downloaded to the host as part of another image containing the same layers.

Layers make image distribution very efficient but also help to reduce the storage footprint of images. Docker stores each layer only once. As you can see in figure 2.8, two containers created from two images that contain the same layers use the same files.

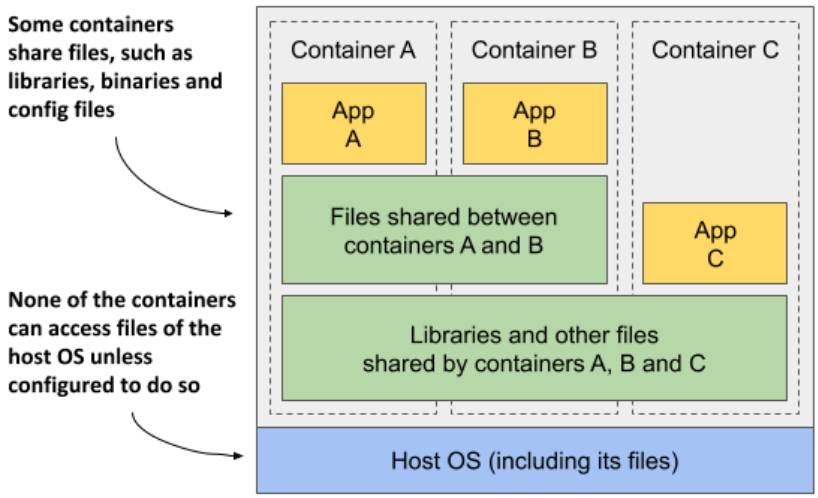


Figure 2.8 Containers can share image layers

The figure shows that containers A and B share an image layer, which means that applications A and B read some of the same files. In addition, they also share the underlying layer with container C. But if all three containers have access to the same files, how can they be completely isolated from each other? Are changes that application A makes to a file stored in the shared layer not visible to application B? They aren't. Here's why.

The filesystems are isolated by the Copy-on-Write (CoW) mechanism. The filesystem of a container consists of read-only layers from the container image and an additional read/write

layer stacked on top. When an application running in container A changes a file in one of the read-only layers, the entire file is copied into the container's read/write layer and the file contents are changed there. Since each container has its own writable layer, changes to shared files are not visible in any other container.

When you delete a file, it is only marked as deleted in the read/write layer, but it's still present in one or more of the layers below. What follows is that deleting files never reduces the size of the image.

> **WARNING** Even seemingly harmless operations such as changing permissions or ownership of a file result in a new copy of the entire file being created in the read/write layer. If you perform this type of operation on a large file or many files, the image size may swell significantly.

UNDERSTANDING THE PORTABILITY LIMITATIONS OF CONTAINER IMAGES

In theory, a Docker-based container image can be run on any Linux computer running Docker, but one small caveat exists, because containers don't have their own kernel. If a containerized application requires a particular kernel version, it may not work on every computer. If a computer is running a different version of the Linux kernel or doesn't load the required kernel modules, the app can't run on it. This scenario is illustrated in the following figure.

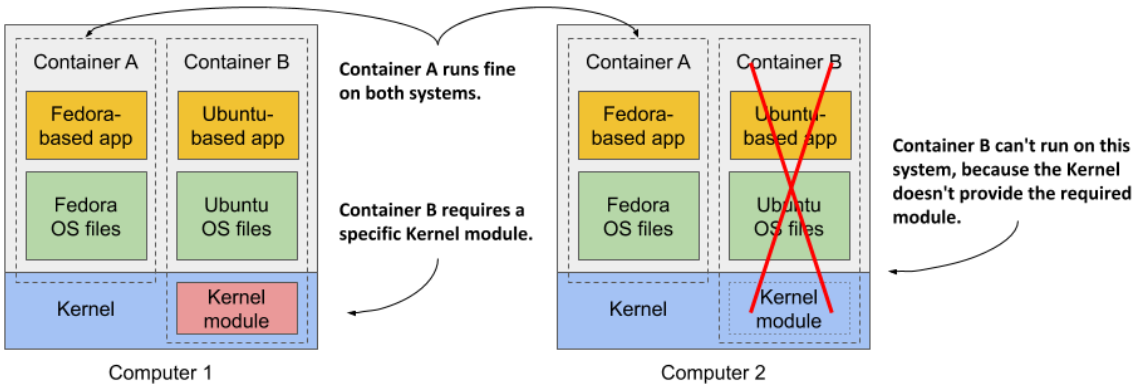


Figure 2.9 If a container requires specific kernel features or modules, it may not work everywhere

Container B requires a specific kernel module to run properly. This module is loaded in the kernel in the first computer, but not in the second. You can run the container image on the second computer, but it will break when it tries to use the missing module.

And it's not just about the kernel and its modules. It should also be clear that a containerized app built for a specific hardware architecture can only run on computers with the same architecture. You can't put an application compiled for the x86 CPU architecture into a container and expect to run it on an ARM-based computer just because Docker is available there. For this you would need a VM to emulate the x86 architecture.

2.1.3 Introducing Docker alternatives and the Open Container Initiative

Docker was the first container platform to make containers mainstream. I hope I've made it clear that Docker itself doesn't provide process isolation. The actual isolation of containers takes place at the Linux kernel level using the mechanisms it provides. Docker just makes it easy to use these mechanisms and allows you to distribute container images to different hosts.

INTRODUCING THE OPEN CONTAINER INITIATIVE (OCI)

After the success of Docker, the Open Container Initiative (OCI) was born to create open industry standards around container formats and runtime. Docker is part of this initiative, as are other container runtimes and a number of organizations with interest in container technologies.

OCI members created the *OCI Image Format Specification*, which prescribes a standard format for container images, and the *OCI Runtime Specification*, which defines a standard interface for container runtimes with the aim of standardizing the creation, configuration and execution of containers.

INTRODUCING THE CONTAINER RUNTIME INTERFACE (CRI) AND ITS IMPLEMENTATION (CRI-O)

This book focuses on using Docker as the container runtime for Kubernetes, as it was initially the only one supported by Kubernetes and is still the most widely used. But Kubernetes now supports many other container runtimes through the Container Runtime Interface (CRI).

One implementation of CRI is CRI-O, a lightweight alternative to Docker that allows you to leverage any OCI-compliant container runtime with Kubernetes. Examples of OCI-compliant runtimes include *rkt* (pronounced Rocket), *runC*, and *Kata Containers*.

2.2 Exploring containers hands-on

You now have a feel for what containers are, but I have yet to explain *how* they work. Before we get to that, you need to create an application, package it into a container image and run it. You'll need Docker, so let's install it and run a Hello world container first.

2.2.1 Installing Docker and running a Hello World container

Ideally, you'll install Docker directly on a Linux computer, so you won't have to deal with the additional complexity of running containers inside a VM running within your host OS. But, if you're using macOS or Windows and don't know how to set up a Linux VM, the Docker Desktop application will set it up for you. The Docker command-line (CLI) tool that you'll use to run containers will be installed in your host OS, but the Docker daemon will run inside the VM, as will all the containers it creates.

The Docker Platform consists of many components, but you only need to install Docker Engine to run containers. If you use macOS or Windows, install Docker Desktop. For details, follow the instructions at http://docs.docker.com/install.

> **NOTE** Docker Desktop for Windows can run either Windows or Linux containers. Make sure that you configure it to use Linux containers.

RUNNING A HELLO WORLD CONTAINER

After the installation is complete, you use the `docker` CLI tool to run Docker commands. First, let's try pulling and running an existing image from Docker Hub, the public image registry that contains ready-to-use container images for many well-known software packages. One of them is the `busybox` image, which you'll use to run a simple `echo "Hello world"` command in your first container.

If you're unfamiliar with `busybox`, it's a single executable file that combines many of the standard UNIX command-line tools, such as `echo`, `ls`, `gzip`, and so on. Instead of the `busybox` image, you could also use any other full-fledged OS container image like Fedora, Ubuntu, or any other image that contains the `echo` executable file.

You don't need to download or install anything to run the `busybox` image. You can do everything with a single `docker run` command, by specifying the image to download and the command to run in it. To run the simple Hello world container, execute the command shown in the following listing.

Listing 2.1 Running a Hello World container with Docker

```
$ docker run busybox echo "Hello World"
Unable to find image 'busybox:latest' locally          #A
latest: Pulling from library/busybox                   #A
7c9d20b9b6cd: Pull complete                            #A
Digest: sha256:fe301db49df08c384001ed752dff6d52b4…     #A
Status: Downloaded newer image for busybox:latest      #A
Hello World                                            #B
```

#A Docker downloads the container image
#B The output produced by the echo command

This doesn't look too impressive, but keep in mind that the entire "application" was downloaded and executed with a single command, without you having to install that application or any of its dependencies.

In your case, the app was just a single executable file, but it could have been an incredibly complex app with dozens of libraries and additional files. The entire process of setting up and running the app would be the same. What isn't obvious is that the app ran in a container, isolated from the other processes on the computer. You'll see that this is true in the exercises that follow.

UNDERSTANDING WHAT HAPPENS WHEN YOU RUN A CONTAINER

Figure 2.10 shows exactly what happened when you executed the `docker run` command.

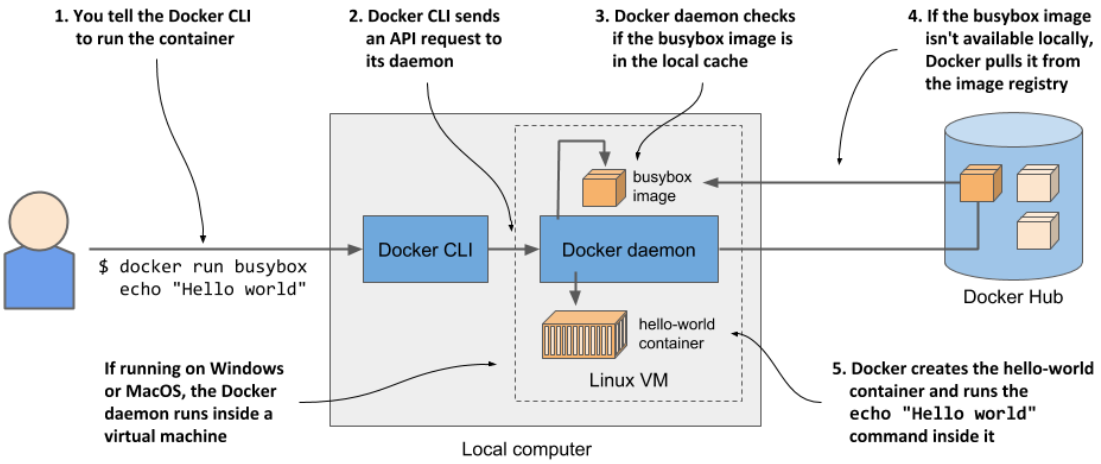


Figure 2.10 Running echo "Hello world" in a container based on the busybox container image

The `docker` CLI tool sent an instruction to run the container to the Docker daemon, which checked whether the `busybox` image was already present in its local image cache. It wasn't, so it pulled it from the Docker Hub registry.

After downloading the image to your computer, the Docker daemon created a container from that image and executed the `echo` command in it. The command printed the text to the standard output, the process then terminated and the container stopped.

If your local computer runs a Linux OS, the Docker CLI tool and the daemon both run in this OS. If it runs macOS or Windows, the daemon and the containers run in the Linux VM.

RUNNING OTHER IMAGES

Running other existing container images is much the same as running the `busybox` image. In fact, it's often even simpler, since you don't normally need to specify what command to execute, as with the echo command in the previous example. The command that should be executed is usually written in the image itself, but you can override it when you run it.

For example, if you want to run the Redis datastore, you can find the image name on http://hub.docker.com or another public registry. In the case of Redis, one of the images is called `redis:alpine`, so you'd run it like this:

```
$ docker run redis:alpine
```

To stop and exit the container, press Control-C (or Command-C on a Mac).

> **NOTE** If you want to run an image from a different registry, you must specify the registry along with the image name. For example, if you want to run an image from the Quay.io registry, which is another publicly accessible image registry, run it as follows: `docker run quay.io/some/image`.

UNDERSTANDING IMAGE TAGS

If you've searched for the Redis image on Docker Hub, you've noticed that there are many image *tags* you can choose from. For Redis, the tags are `latest`, `buster`, `alpine`, but also `5.0.7-buster`, `5.0.7-alpine`, and so on.

Docker allows you to have multiple versions or variants of the same image under the same name. Each variant has a unique tag. If you refer to images without explicitly specifying the tag, Docker assumes that you're referring to the special `latest` tag. When uploading a new version of an image, image authors usually tag it with both the actual version number and with `latest`. When you want to run the latest version of an image, use the `latest` tag instead of specifying the version.

> **NOTE** The `docker run` command only pulls the image if it hasn't already pulled it before. Using the `latest` tag ensures that you get the latest version when you first run the image. The locally cached image is used from that point on.

Even for a single version, there are usually several variants of an image. For Redis I mentioned `5.0.7-buster` and `5.0.7-alpine`. They both contain the same version of Redis, but differ in the base image they are built on. `5.0.7-buster` is based on Debian version "Buster", while `5.0.7-alpine` is based on the Alpine Linux base image, a very stripped-down image that is only 5MB in total – it contains only a small set of the installed binaries you see in a typical Linux distribution.

To run a specific version and/or variant of the image, specify the tag in the image name. For example, to run the `5.0.7-alpine` tag, you'd execute the following command:

```
$ docker run redis:5.0.7-alpine
```

2.2.2 Creating a containerized Node.js web application

Now that you have a working Docker setup, you'll create an app that you'll use throughout the book. You'll create a trivial Node.js web application and package it into a container image. The application will accept HTTP requests and respond with the hostname of the computer it's running on.

This way, you'll see that an app running in a container sees a different hostname and not that of the host computer, even though it runs on the host like any other process. This will be useful later, when you deploy the app on Kubernetes and scale it out (scale it horizontally; that is, run multiple instances of the app). You'll see your HTTP requests hitting different instances of the app.

The app consists of a single file called `app.js` whose contents are shown in the next listing.

Listing 2.2 A simple Node.js web application: app.js

```
const http = require('http');                                    #A
const os = require('os');                                        #A

const listenPort = 8080;                                         #B
```

```
console.log("Kubia server starting...");                                  #C
console.log("Local hostname is " + os.hostname());                        #C
console.log("Listening on port " + listenPort);                           #C

var handler = function(request, response) {                               #D
  let clientIP = request.connection.remoteAddress;                        #E
  console.log("Received request for "+request.url+" from "+clientIP);     #F
  response.writeHead(200);                                                #G
  response.write("Hey there, this is "+os.hostname()+". ");               #G
  response.write("Your IP is "+clientIP+". ");                            #G
  response.end("\n");                                                     #G
};

var server = http.createServer(handler);                                  #H
server.listen(listenPort);                                                #H
```

#A The http and os modules are loaded
#B Define the port the server listens on
#C Print server information to standard output
#D This function handles incoming HTTP requests
#E Get the client IP from the HTTP request
#F Log information about the request to the standard output
#G Create the HTTP response
#H Start the HTTP server

The code in the listing should be easy to understand. It starts an HTTP server on port `8080`. For each request, it logs the request information to standard output and sends a response with status code `200 OK` and the following text:

```
Hey there, this is <server-hostname>. Your IP is <client-IP>.
```

NOTE **The hostname in the response is the server's actual hostname, not the one sent by the client in the request's `Host` header. This detail will be important later.**

You could now download and install Node.js locally and test your app directly, but that's not necessary. It's easier to package it into a container image and run it with Docker. This enables you to run the app on any other Docker-enabled host without installing Node.js there either.

2.2.3 Creating a Dockerfile to build the container image

To package your app into an image, you must first create a file called `Dockerfile`, which contains a list of instructions that Docker should perform when building the image. Create the file in the same directory as the `app.js` file and make sure it contains the three directives in the following listing.

Listing 2.3 A minimal Dockerfile for building a container image for your app

```
FROM node:12                          #A
ADD app.js /app.js                    #B
ENTRYPOINT ["node", "app.js"]         #C
```

#A The base image to build upon
#B Adds the app.js file into the container image
#C Specifies the command to execute when the image is run

The `FROM` line defines the container image that you'll use as the starting point (the base image you're building on top of). In your case, you use the `node` container image, tag `12`. In the second line, you add the `app.js` file from your local directory into the root directory of the image, under the same name (`app.js`). Finally, in the third line, you specify the command that Docker should run when you execute the image. In your case, the command is `node app.js`.

Choosing a base image

You may wonder why use this specific image as your base. Because your app is a Node.js app, you need your image to contain the `node` binary file to run the app. You could have used any image containing this binary, or you could have even used a Linux distribution base image such as `fedora` or `ubuntu` and installed Node.js into the container when building the image. But since the `node` image already contains everything needed to run Node.js apps, it doesn't make sense to build the image from scratch. In some organizations, however, the use of a specific base image and adding software to it at build-time may be mandatory.

2.2.4 Building the container image

The `Dockerfile` and the `app.js` file are everything you need to build your image. You'll now build the image named `kubia:latest` using the command in the next listing:

Listing 2.4 Building the image

```
$ docker build -t kubia:latest .
Sending build context to Docker daemon  3.072kB
Step 1/3 : FROM node:12                                  #A
12: Pulling from library/node
092586df9206: Pull complete                              #B
ef599477fae0: Pull complete                              #B
…                                                        #B
89e674ac3af7: Pull complete                              #B
08df71ec9bb0: Pull complete                              #B
Digest: sha256:a919d679dd773a56acce15afa0f436055c9b9f20e1f28b4469a4bee69e0…
Status: Downloaded newer image for node:12
 ---> e498dabfee1c                                       #C
Step 2/3 : ADD app.js /app.js                            #D
 ---> 28d67701d6d9                                       #D
Step 3/3 : ENTRYPOINT ["node", "app.js"]                   #E
 ---> Running in a01d42eda116                              #E
Removing intermediate container a01d42eda116               #E
 ---> b0ecc49d7a1d                                         #E
Successfully built b0ecc49d7a1d                           #F
Successfully tagged kubia:latest                          #F
```

#A This corresponds to the first line of your Dockerfile
#B Docker is downloading individual layers of the node:12 image
#C This is the ID of image after the first build step is complete

#D The second step of the build and the resulting image ID
#E The final step of the build
#F The final image ID and its tag

The `-t` option specifies the desired image name and tag and the dot at the end specifies the path to the directory that contains the Dockerfile and the build context (all artefacts needed by the build process).

When the build process is complete, the newly created image is available in your computer's local image store. You can see it by listing local images, as in the following listing.

Listing 2.5 Listing locally stored images

```
$ docker images
REPOSITORY    TAG       IMAGE ID          CREATED             VIRTUAL SIZE
kubia         latest    b0ecc49d7a1d      1 minute ago        908 MB
…
```

UNDERSTANDING HOW THE IMAGE WAS BUILT

Figure 2.11 shows what happens during the build process. You tell Docker to build an image called `kubia` based on the contents of the current directory. Docker reads the `Dockerfile` in the directory and builds the image based on the directives in the file.

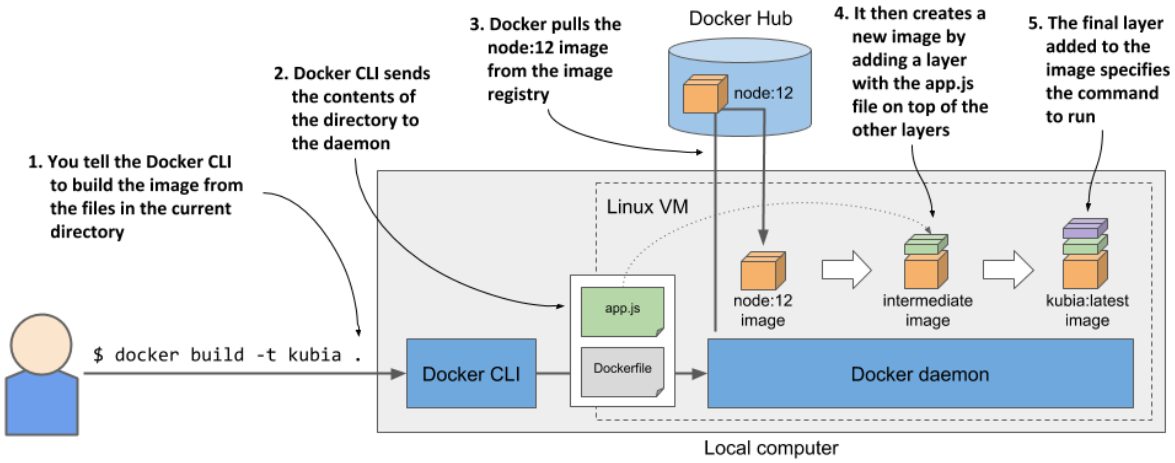


Figure 2.11 Building a new container image using a Dockerfile

The build itself isn't performed by the `docker` CLI tool. Instead, the contents of the entire directory are uploaded to the Docker daemon and the image is built by it. You've already learned that the CLI tool and the daemon aren't necessarily on the same computer. If you're using Docker on a non-Linux system such as macOS or Windows, the client is in your host OS, but the daemon runs inside a Linux VM. But it could also run on a remote computer.

TIP Don't add unnecessary files to the build directory, as they will slow down the build process—especially if the Docker daemon is located on a remote system.

To build the image, Docker first pulls the base image (`node:12`) from the public image repository (Docker Hub in this case), unless the image is already stored locally. It then creates a new container from the image and executes the next directive from the Dockerfile. The container's final state yields a new image with its own ID. The build process continues by processing the remaining directives in the Dockerfile. Each one creates a new image. The final image is then tagged with the tag you specified with the `-t` flag in the `docker build` command.

UNDERSTANDING WHAT THE LAYERS IN THE IMAGE ARE

Some pages ago, you learned that images consist of several layers. One might think that each image consists of only the layers of the base image and a single new layer on top, but that's not the case. When building an image, a new layer is created for each individual directive in the Dockerfile.

During the build of the kubia image, after it pulls all the layers of the base image, Docker creates a new layer and adds the `app.js` file into it. It then creates yet another layer that holds just the command to run when the image is executed. This last layer is then tagged as `kubia:latest`.

You can see the layers of an image and their size by running `docker history`, as shown in the following listing. The top layers are printed first.

Listing 2.6 Displaying the layers of a container image

```
$ docker history kubia:latest
IMAGE         CREATED     CREATED BY                                      SIZE
b0ecc49d7a1d  7 min ago   /bin/sh -c #(nop) ENTRYPOINT ["node"…   0B    #A
28d67701d6d9  7 min ago   /bin/sh -c #(nop) ADD file:2ed5d7753…   367B  #A
e498dabfee1c  2 days ago  /bin/sh -c #(nop) CMD ["node"]          0B    #B
<missing>     2 days ago  /bin/sh -c #(nop) ENTRYPOINT ["docke…   0B    #B
<missing>     2 days ago  /bin/sh -c #(nop) COPY file:23873730…   116B  #B
<missing>     2 days ago  /bin/sh -c set -ex && for key in 6A0…   5.4MB #B
<missing>     2 days ago  /bin/sh -c #(nop)  ENV YARN_VERSION=…   0B    #B
<missing>     2 days ago  /bin/sh -c ARCH= && dpkgArch="$(dpkg…   67MB  #B
<missing>     2 days ago  /bin/sh -c #(nop)  ENV NODE_VERSION=…   0B    #B
<missing>     3 weeks ago /bin/sh -c groupadd --gid 1000 node …   333kB #B
<missing>     3 weeks ago /bin/sh -c set -ex;  apt-get update;…   562MB #B
<missing>     3 weeks ago /bin/sh -c apt-get update && apt-get…   142MB #B
<missing>     3 weeks ago /bin/sh -c set -ex;  if ! command -v…   7.8MB #B
<missing>     3 weeks ago /bin/sh -c apt-get update && apt-get…   23.2MB#B
<missing>     3 weeks ago /bin/sh -c #(nop)  CMD ["bash"]         0B    #B
<missing>     3 weeks ago /bin/sh -c #(nop) ADD file:9788b61de…   101MB #B
```

#A The two layers that you added
#B The layers of the node:12 image and its base image(s)

Most of the layers you see come from the `node:12` image (they also include layers of that image's own base image). The two uppermost layers correspond to the second and third directives in the Dockerfile (`ADD` and `ENTRYPOINT`).

As you can see in the `CREATED BY` column, each layer is created by executing a command in the container. In addition to adding files with the `ADD` directive, you can also use other directives in the Dockerfile. For example, the `RUN` directive executes a command in the container during the build. In the listing above, you'll find a layer where the `apt-get update` and some additional `apt-get` commands were executed. `apt-get` is part of the Ubuntu package manager used to install software packages. The command shown in the listing installs some packages onto the image's filesystem.

To learn about RUN and other directives you can use in a Dockerfile, refer to the Dockerfile reference at https://docs.docker.com/engine/reference/builder/.

> **TIP** Each directive creates a new layer. I have already mentioned that when you delete a file, it is only marked as deleted in the new layer and is not removed from the layers below. Therefore, deleting a file with a subsequent directive won't reduce the size of the image. If you use the `RUN` directive, make sure that the command it executes deletes all temporary files it creates before it terminates.

2.2.5 Running the container image

With the image built and ready, you can now run the container with the following command:

```
$ docker run --name kubia-container -p 1234:8080 -d kubia
9d62e8a9c37e056a82bb1efad57789e947df58669f94adc2006c087a03c54e02
```

This tells Docker to run a new container called `kubia-container` from the `kubia` image. The container is detached from the console (`-d` flag) and runs in the background. Port `1234` on the host computer is mapped to port `8080` in the container (specified by the `-p 1234:8080` option), so you can access the app at http://localhost:1234.

The following figure should help you visualize how everything fits together. Note that the Linux VM exists only if you use macOS or Windows. If you use Linux directly, there is no VM and the box depicting port `1234` is at the edge of the local computer.

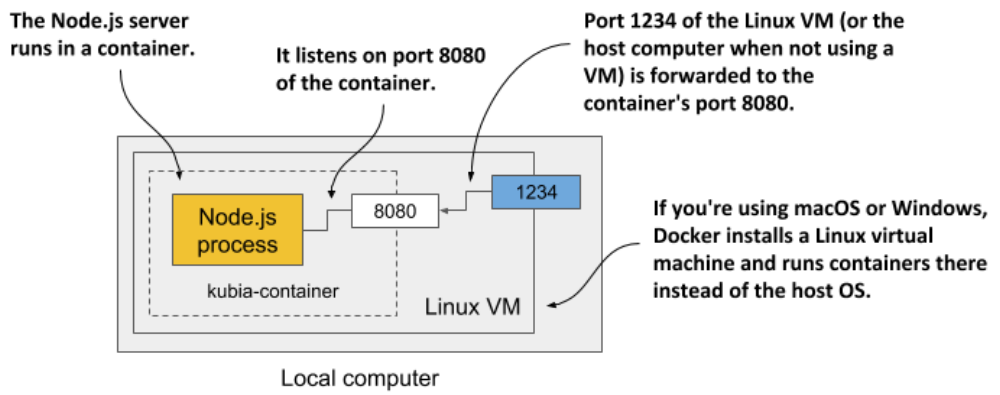


Figure 2.12 Visualizing your running container

ACCESSING YOUR APP

Now access the application at http://localhost:1234 using `curl` or your internet browser:

```
$ curl localhost:1234
Hey there, this is 44d76963e8e1. Your IP is ::ffff:172.17.0.1.
```

NOTE If the Docker Daemon runs on a different machine, you must replace `localhost` with the IP of that machine. You can look it up in the `DOCKER_HOST` environment variable.

If all went well, you should see the response sent by the application. In my case, it returns `44d76963e8e1` as its hostname. In your case, you'll see a different hexadecimal number. This is the ID of the container that is displayed when you list them.

LISTING ALL RUNNING CONTAINERS

To list all the containers that are running on your computer, run the command that appears in the following listing. The output of the command has been edited to fit on the page—the last two lines of the output are the continuation of the first two.

Listing 2.6 Listing running containers

```
$ docker ps
CONTAINER ID    IMAGE           COMMAND          CREATED        ...
44d76963e8e1    kubia:latest    "node app.js"    6 minutes ago  ...

...  STATUS          PORTS                     NAMES
...  Up 6 minutes    0.0.0.0:1234->8080/tcp    kubia-container
```

For each container, Docker prints its ID and name, the image it uses, and the command it executes. It also shows when the container was created, what status it has, and which host ports are mapped to the container.

GETTING ADDITIONAL INFORMATION ABOUT A CONTAINER

The `docker ps` command shows the most basic information about the containers. To see additional information, you can use `docker inspect`:

```
$ docker inspect kubia-container
```

Docker prints a long JSON-formatted document containing a lot of information about the container, such as its state, config, and network settings, including its IP address.

INSPECTING THE APPLICATION LOG

Docker captures and stores everything the application writes to the standard output and error streams. This is typically the place where applications write their logs. You can use the `docker logs` command to see the output, as shown in the next listing.

Listing 2.7 Displaying the container's log

```
$ docker logs kubia-container
Kubia server starting...
```

```
Local hostname is 44d76963e8e1
Listening on port 8080
Received request for / from ::ffff:172.17.0.1
```

You now know the basic commands for executing and inspecting an application in a container. Next, you'll learn how to distribute it.

2.2.6 Distributing container images

The image you've built is currently only available locally. To run it on other computers, you must first push it to an external image registry. Let's push it to the public Docker Hub registry, so that you don't need to set up a private one. You can also use other registries, such as Quay.io, which I've already mentioned, or the Google Container Registry.

Before you push the image, you must re-tag it according to Docker Hub's image naming schema. The image name must include your Docker Hub ID, which you choose when you register at http://hub.docker.com. I'll use my own ID (`luksa`) in the following examples, so remember to replace it with your ID when trying the commands yourself.

TAGGING AN IMAGE UNDER AN ADDITIONAL TAG

Once you have your ID, you're ready to add an additional tag `for` your image. Its current name is `kubia` and you'll now tag it also as `yourid/kubia:1.0` (replace `yourid` with your actual Docker Hub ID). This is the command I used:

```
$ docker tag kubia luksa/kubia:1.0
```

Confirm that your image now has two names by listing images again, as in the following listing.

Listing 2.7 A container image with multiple tags

```
$ docker images | head
REPOSITORY     TAG       IMAGE ID        CREATED              VIRTUAL SIZE
luksa/kubia    1.0       b0ecc49d7a1d    About an hour ago    908 MB
kubia          latest    b0ecc49d7a1d    About an hour ago    908 MB
node           12        e498dabfee1c    3 days ago           908 MB
```

As you can see, both `kubia` and `luksa/kubia:1.0` point to the same image ID, meaning that these aren't two images, but a single image with two names.

PUSHING THE IMAGE TO DOCKER HUB

Before you can push the image to Docker Hub, you must log in with your user ID using the `docker login` command as follows:

```
$ docker login -u yourid -p yourpassword docker.io
```

Once logged in, push the `yourid/kubia:1.0` image to Docker Hub with the following command:

```
$ docker push yourid/kubia:1.0
```

RUNNING THE IMAGE ON OTHER HOSTS

When the push to Docker Hub is complete, the image is available to all. You can now run the image on any Docker-enabled host by running the following command:

```
$ docker run -p 1234:8080 -d luksa/kubia:1.0
```

If the container runs correctly on your computer, it should run on any other Linux computer, provided that the Node.js binary doesn't need any special Kernel features (it doesn't).

2.2.7 Stopping and deleting containers

If you've run the container on the other host, you can now terminate it, as you'll only need the one on your local computer for the exercises that follow.

STOPPING A CONTAINER

Instruct Docker to stop the container with this command:

```
$ docker stop kubia-container
```

This sends a termination signal to the main process in the container so that it can shut down gracefully. If the process doesn't respond to the termination signal or doesn't shut down in time, Docker kills it. When the top-level process in the container terminates, no other process runs in the container, so the container is stopped.

DELETING A CONTAINER

The container is no longer running, but it still exists. Docker keeps it around in case you decide to start it again. You can see stopped containers by running `docker ps -a`. The `-a` option prints all the containers - those running and those that have been stopped. As an exercise, you can start the container again by running `docker start kubia-container`.

You can safely delete the container on the other host, because you no longer need it. To delete it, run the following `docker rm` command:

```
$ docker rm kubia-container
```

This deletes the container. All its contents are removed and it can no longer be started. The image is still there, though. If you decide to create the container again, the image won't need to be downloaded again. If you also want to delete the image, use the `docker rmi` command:

```
$ docker rmi kubia:latest
```

To remove all dangling images, you can also use the `docker image prune` command.

2.3 Understanding what makes containers possible

You should keep the container running on your local computer so that you can use it in the following exercises, in which you'll examine how containers allow process isolation without

using virtual machines. Several features of the Linux kernel make this possible and it's time to get to know them.

2.3.1 Using Namespaces to customize the environment of a process

The first feature called *Linux Namespaces* ensures that each process has its own view of the system. This means that a process running in a container will only see some of the files, processes and network interfaces on the system, as well as a different system hostname, just as if it were running in a separate virtual machine.

Initially, all the system resources available in a Linux OS, such as filesystems, process IDs, user IDs, network interfaces, and others, are all in the same bucket that all processes see and use. But the Kernel allows you to create additional buckets known as namespaces and move resources into them so that they are organized in smaller sets. This allows you to make each set visible only to one process or a group of processes. When you create a new process, you can specify which namespace it should use. The process only sees resources that are in this namespace and none in the other namespaces.

INTRODUCING THE AVAILABLE NAMESPACE TYPES

More specifically, there isn't just a single type of namespace. There are in fact several types – one for each resource type. A process thus uses not only one namespace, but one namespace for each type.

The following types of namespaces exist:

- The Mount namespace (mnt) isolates mount points (file systems).
- The Process ID namespace (pid) isolates process IDs.
- The Network namespace (net) isolates network devices, stacks, ports, etc.
- The Inter-process communication namespace (ipc) isolates the communication between processes (this includes isolating message queues, shared memory, and others).
- The UNIX Time-sharing System (UTS) namespace isolates the system hostname and the Network Information Service (NIS) domain name.
- The User ID namespace (user) isolates user and group IDs.
- The Cgroup namespace isolates the Control Groups root directory. You'll learn about cgroups later in this chapter.

USING NETWORK NAMESPACES TO GIVE A PROCESS A DEDICATED SET OF NETWORK INTERFACES

The network namespace in which a process runs determines what network interfaces the process can see. Each network interface belongs to exactly one namespace but can be moved from one namespace to another. If each container uses its own network namespace, each container sees its own set of network interfaces.

Examine figure 2.13 for a better overview of how network namespaces are used to create a container. Imagine you want to run a containerized process and provide it with a dedicated set of network interfaces that only that process can use.

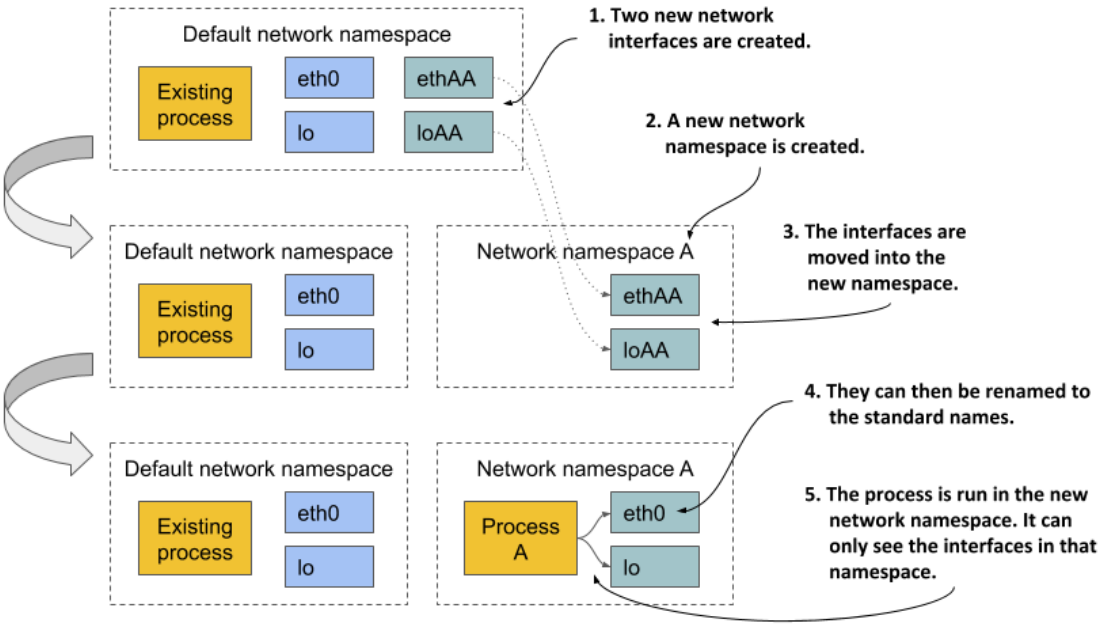


Figure 2.13 The network namespace limits which network interfaces a process uses

Initially, only the default network namespace exists. You then create two new network interfaces for the container and a new network namespace. The interfaces can then be moved from the default namespace to the new namespace. Once there, they can be renamed, because names must only be unique in each namespace. Finally, the process can be started in this network namespace, which allows it to only see the two interfaces that were created for it.

By looking solely at the available network interfaces, the process can't tell whether it's in a container or a VM or an OS running directly on a bare-metal machine.

USING THE UTS NAMESPACE TO GIVE A PROCESS A DEDICATED HOSTNAME

Another example of how to make it look like the process is running on its own host is to use the UTS namespace. It determines what hostname and domain name the process running inside this namespace sees. By assigning two different UTS namespaces to two different processes, you can make them see different system hostnames. To the two processes, it looks as if they run on two different computers.

UNDERSTANDING HOW NAMESPACES ISOLATE PROCESSES FROM EACH OTHER

By creating a dedicated namespace instance for all available namespace types and assigning it to a process, you can make the process believe that it's running in its own OS. The main reason for this is that each process has its own environment. A process can only see and use the resources in its own namespaces. It can't use any in other namespaces. Likewise, other

processes can't use its resources either. This is how containers isolate the environments of the processes that run within them.

SHARING NAMESPACES BETWEEN MULTIPLE PROCESSES

In the next chapter you'll learn that you don't always want to isolate the containers completely from each other. Related containers may want to share certain resources. The following figure shows an example of two processes that share the same network interfaces and the host and domain name of the system, but not the file system.

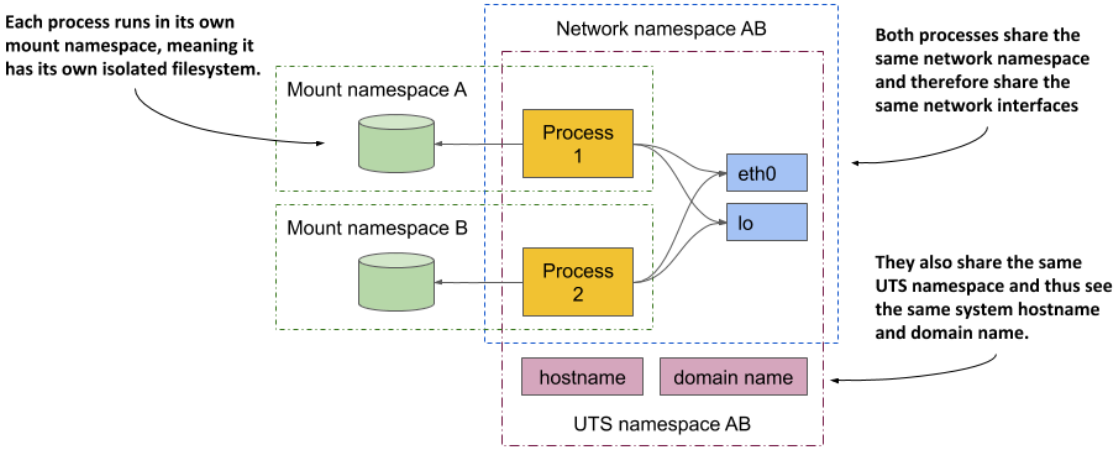


Figure 2.14 Each process is associated with multiple namespace types, some of which can be shared.

Concentrate on the shared network devices first. The two processes see and use the same two devices (`eth0` and `lo`) because they use the same network namespace. This allows them to bind to the same IP address and communicate through the loopback device, just as they could if they were running on a machine that doesn't use containers. The two processes also use the same UTS namespace and therefore see the same system host name. In contrast, they each use their own mount namespace, which means they have separate file systems.

In summary, processes may want to share some resources but not others. This is possible because separate namespace *types* exist. A process has an associated namespace for each type.

In view of all this, one might ask what is a container at all? A process that runs "in a container" doesn't run in something that resembles a real enclosure like a VM. It's only a process to which seven namespaces (one for each type) are assigned. Some are shared with other processes, while others are not. This means that the boundaries between the processes do not all fall on the same line.

In a later chapter, you'll learn how to debug a container by running a new process directly on the host OS, but using the network namespace of an existing container, while using the host's default namespaces for everything else. This will allow you to debug the

container's networking system with tools available on the host that may not be available in the container.

2.3.2 Exploring the environment of a running container

What if you want to see what the environment inside the container looks like? What is the system host name, what is the local IP address, what binaries and libraries are available on the file system, and so on?

To explore these features in the case of a VM, you typically connect to it remotely via ssh and use a shell to execute commands. This process is very similar for containers. You run a shell inside the container.

> **NOTE** The shell's executable file must be available in the container's file system. This isn't always the case with containers running in production.

RUNNING A SHELL INSIDE AN EXISTING CONTAINER

The Node.js image on which your image is based provides the bash shell, meaning you can run it in the container with the following command:

```
$ docker exec -it kubia-container bash
root@44d76963e8e1:/#                #A
```

#A This is the shell's command prompt

This command runs `bash` as an additional process in the existing `kubia-container` container. The process has the same Linux namespaces as the main container process (the running Node.js server). This way you can explore the container from within and see how Node.js and your app see the system when running in the container. The `-it` option is shorthand for two options:

- `-i` tells Docker to run the command in interactive mode.
- `-t` tells it to allocate a pseudo terminal (TTY) so you can use the shell properly.

You need both if you want to use the shell the way you're used to. If you omit the first, you can't execute any commands, and if you omit the second, the command prompt doesn't appear and some commands may complain that the `TERM` variable is not set.

LISTING RUNNING PROCESSES IN A CONTAINER

Let's list the processes running in the container by executing the `ps aux` command inside the shell you ran in the container. The following listing shows the command's output.

Listing 2.8 Listing processes running in the container

```
root@44d76963e8e1:/# ps aux
USER  PID %CPU %MEM    VSZ   RSS TTY STAT START TIME COMMAND
root    1  0.0  0.1 676380 16504 ?   Sl   12:31 0:00 node app.js
root   10  0.0  0.0  20216  1924 ?   Ss   12:31 0:00 bash
root   19  0.0  0.0  17492  1136 ?   R+   12:38 0:00 ps aux
```

The list shows only three processes. These are the only ones that run in the container. You can't see the other processes that run in the host OS or in other containers because the container runs in its own Process ID namespace.

SEEING CONTAINER PROCESSES IN THE HOST'S LIST OF PROCESSES

If you now open another terminal and list the processes in the host OS itself, you *will* also see the processes that run in the container. This confirms that the processes in the container are in fact regular processes that run in the host OS, as you can see in the following listing.

Listing 2.9 A container's processes run in the host OS

```
$ ps aux | grep app.js
USER  PID %CPU %MEM    VSZ   RSS TTY STAT START TIME COMMAND
root  382  0.0  0.1 676380 16504 ?   Sl   12:31 0:00 node app.js
```

NOTE If you use macOS or Windows, you must list the processes in the VM that hosts the Docker daemon, as that's where your containers run. In Docker Desktop, you can enter the VM using the following command: `docker run --net=host --ipc=host --uts=host --pid=host -it --security-opt=seccomp=unconfined --privileged --rm -v /:/host alpine chroot /host`

If you have a sharp eye, you may notice that the process IDs in the container are different from those on the host. Because the container uses its own Process ID namespace it has its own process tree with its own ID number sequence. As the next figure shows, the tree is a subtree of the host's full process tree. Each process thus has two IDs.

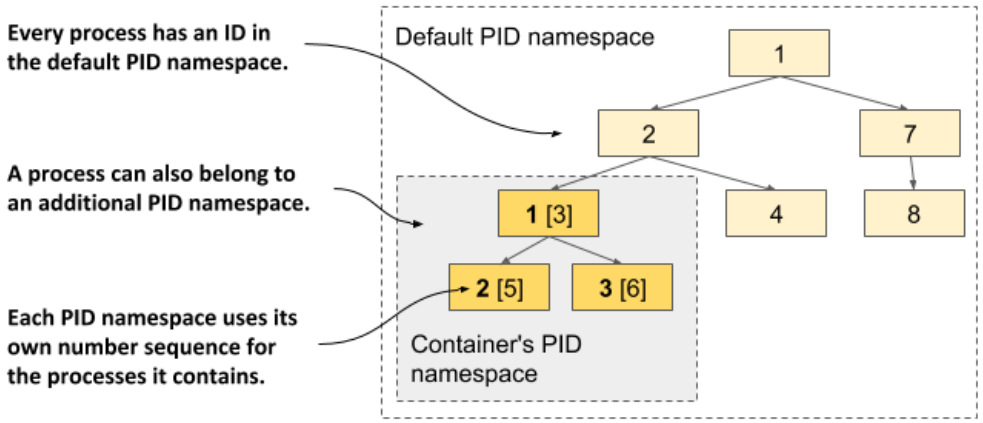


Figure 2.15 The PID namespace makes a process sub-tree appear as a separate process tree with its own numbering sequence

THE CONTAINER'S FILESYSTEM IS ISOLATED FROM THE HOST AND OTHER CONTAINERS

As with an isolated process tree, each container also has an isolated filesystem. If you list the contents of the container's root directory, only the files in the container are displayed. This includes files from the container image and files created during container operation, such as log files. The next listing shows the files in your kubia container.

Listing 2.10 A container has its own filesystem

```
root@44d76963e8e1:/# ls /
app.js  boot  etc   lib    media  opt   root  sbin  sys  usr
bin     dev   home  lib64  mnt    proc  run   srv   tmp  var
```

It contains the `app.js` file and other system directories that are part of the `node:12` base image. You are welcome to browse the container's filesystem. You'll see that there is no way to view files from the host's filesystem. This is great, because it prevents a potential attacker from gaining access to them through vulnerabilities in the Node.js server.

To leave the container, leave the shell by running the `exit` command or pressing Control-D and you'll be returned to your host computer (similar to logging out from an `ssh` session).

> **TIP** Entering a running container like this is useful when debugging an app running in a container. When something breaks, the first thing you'll want to investigate is the actual state of the system your application sees.

2.3.3 Limiting a process' resource usage with Linux Control Groups

Linux Namespaces make it possible for processes to access only some of the host's resources, but they don't limit how much of a single resource each process can consume. For example, you can use namespaces to allow a process to access only a particular network interface, but you can't limit the network bandwidth the process consumes. Likewise, you can't use namespaces to limit the CPU time or memory available to a process. You may want to do that to prevent one process from consuming all the CPU time and preventing critical system processes from running properly. For that, we need another feature of the Linux kernel.

INTRODUCING CGROUPS

The second Linux kernel feature that makes containers possible is called *Linux Control Groups (cgroups)*. It limits, accounts for and isolates system resources such as CPU, memory and disk or network bandwidth. When using cgroups, a process or group of processes can only use the allotted CPU time, memory, and network bandwidth for example. This way, processes cannot occupy resources that are reserved for other processes.

At this point, you don't need to know how Control Groups do all this, but it may be worth seeing how you can ask Docker to limit the amount of CPU and memory a container can use.

LIMITING A CONTAINER'S USE OF THE CPU

If you don't impose any restrictions on the container's use of the CPU, it has unrestricted access to all CPU cores on the host. You can explicitly specify which cores a container can

use with Docker's `--cpuset-cpus` option. For example, to allow the container to only use cores one and two, you can run the container with the following option:

```
$ docker run --cpuset-cpus="1,2" ...
```

You can also limit the available CPU time using options `--cpus`, `--cpu-period`, `--cpu-quota` and `--cpu-shares`. For example, to allow the container to use only half of a CPU core, run the container as follows:

```
$ docker run --cpus="0.5" ...
```

LIMITING A CONTAINER'S USE OF MEMORY

As with CPU, a container can use all the available system memory, just like any regular OS process, but you may want to limit this. Docker provides the following options to limit container memory and swap usage: `--memory`, `--memory-reservation`, `--kernel-memory`, `--memory-swap`, and `--memory-swappiness`.

For example, to set the maximum memory size available in the container to 100MB, run the container as follows (`m` stands for megabyte):

```
$ docker run --memory="100m" ...
```

Behind the scenes, all these Docker options merely configure the cgroups of the process. It's the Kernel that takes care of limiting the resources available to the process. See the Docker documentation for more information about the other memory and CPU limit options.

2.3.4 Strengthening isolation between containers

Linux Namespaces and Cgroups separate the containers' environments and prevent one container from starving the other containers of compute resources. But the processes in these containers use the same system kernel, so we can't say that they are really isolated. A rogue container could make malicious system calls that would affect its neighbours.

Imagine a Kubernetes node on which several containers run. Each has its own network devices and files and can only consume a limited amount of CPU and memory. At first glance, a rogue program in one of these containers can't cause damage to the other containers. But what if the rogue program modifies the system clock that is shared by all containers?

Depending on the application, changing the time may not be too much of a problem, but allowing programs to make any system call to the kernel allows them to do virtually anything. Sys-calls allow them to modify the kernel memory, add or remove kernel modules, and many other things that regular containers aren't supposed to do.

This brings us to the third set of technologies that make containers possible. Explaining them fully is outside the scope of this book, so please refer to other resources that focus specifically on containers or the technologies used to secure them. This section provides a brief introduction to these technologies.

GIVING CONTAINERS FULL PRIVILEGES TO THE SYSTEM

The operating system kernel provides a set of *sys-calls* that programs use to interact with the operating system and underlying hardware. These includes calls to create processes, manipulate files and devices, establish communication channels between applications, and so on.

Some of these sys-calls are fairly safe and available to any process, but others are reserved for processes with elevated privileges only. If you look at the example presented earlier, applications running on the Kubernetes node should be allowed to open their local files, but not change the system clock or modify the kernel in a way that breaks the other containers.

Most containers should run without elevated privileges. Only those programs that you trust and that actually need the additional privileges should run in privileged containers.

> **NOTE** With Docker you create a privileged container by using the `--privileged` flag.

USING CAPABILITIES TO GIVE CONTAINERS A SUBSET OF ALL PRIVILEGES

If an application only needs to invoke some of the sys-calls that require elevated privileges, creating a container with full privileges is not ideal. Fortunately, the Linux kernel also divides privileges into units called *capabilities*. Examples of capabilities are:

- `CAP_NET_ADMIN` allows the process to perform network-related operations,
- `CAP_NET_BIND_SERVICE` allows it to bind to port numbers less than 1024,
- `CAP_SYS_TIME` allows it to modify the system clock, and so on.

Capabilities can be added or removed (*dropped*) from a container when you create it. Each capability represents a set of privileges available to the processes in the container. Docker and Kubernetes drop all capabilities except those required by typical applications, but users can add or drop other capabilities if authorized to do so.

> **NOTE** Always follow the *principle of least privilege* when running containers. Don't give them any capabilities that they don't need. This prevents attackers from using them to gain access to your operating system.

USING SECCOMP PROFILES TO FILTER INDIVIDUAL SYS-CALLS

If you need even finer control over what sys-calls a program can make, you can use *seccomp* (Secure Computing Mode). You can create a custom seccomp profile by creating a JSON file that lists the sys-calls that the container using the profile is allowed to make. You then provide the file to Docker when you create the container.

HARDENING CONTAINERS USING APPARMOR AND SELINUX

And as if the technologies discussed so far weren't enough, containers can also be secured with two additional mandatory access control (MAC) mechanisms: SELinux (Security-Enhanced Linux) and AppArmor (Application Armor).

With SELinux, you attach labels to files and system resources, as well as to users and processes. A user or process can only access a file or resource if the labels of all subjects and objects involved match a set of policies. AppArmor is similar but uses file paths instead of labels and focuses on processes rather than users.

Both SELinux and AppArmor considerably improve the security of an operating system, but don't worry if you are overwhelmed by all these security-related mechanisms. The aim of this section was to shed light on everything involved in the proper isolation of containers, but a basic understanding of namespaces should be more than sufficient for the moment.

2.4 Summary

If you were new to containers before reading this chapter, you should now understand what they are, why we use them, and what features of the Linux kernel make them possible. If you have previously used containers, I hope this chapter has helped to clarify your uncertainties about how containers work, and you now understand that they're nothing more than regular OS processes that the Linux kernel isolates from other processes.

After reading this chapter, you should know that:

- Containers are regular processes, but isolated from each other and the other processes running in the host OS.
- Containers are much lighter than virtual machines, but because they use the same Linux kernel, they aren't as isolated as VMs.
- Docker was the first container platform to make containers popular and the first container runtime supported by Kubernetes. Now, others are supported through the Container Runtime Interface (CRI).
- A container image contains the user application and all its dependencies. It is distributed through a container registry and used to create running containers.
- Containers can be downloaded and executed with a single `docker run` command.
- Docker builds an image from a `Dockerfile` that contains commands that Docker should execute during the build process. Images consist of layers that can be shared between multiple images. Each layer only needs to be transmitted and stored once.
- Containers are isolated by Linux kernel features called Namespaces, Control groups, Capabilities, seccomp, AppArmor and/or SELinux. Namespaces ensure that a container sees only a part of the resources available on the host, Control groups limit the amount of a resource it can use, while other features strengthen the isolation between containers.

After inspecting the containers on this ship, you're now ready to raise the anchor and sail into the next chapter, where you'll learn about running containers with Kubernetes.

3

Deploying your first application

This chapter covers

- **Running a single-node Kubernetes cluster on your laptop**
- **Setting up a Kubernetes cluster on Google Kubernetes Engine**
- **Setting up and using the `kubectl` command-line tool**
- **Deploying an application in Kubernetes and making it available across the globe**
- **Horizontally scaling the application**

The goal of this chapter is to show you how to run a local single-node development Kubernetes cluster or set up a proper, managed multi-node cluster in the cloud. Once your cluster is running, you'll use it to run the container you created in the previous chapter.

3.1 Deploying a Kubernetes cluster

Setting up a full-fledged, multi-node Kubernetes cluster isn't a simple task, especially if you're not familiar with Linux and network administration. A proper Kubernetes installation spans multiple physical or virtual machines and requires proper network setup to allow all containers in the cluster to communicate with each other.

You can install Kubernetes on your laptop computer, on your organization's infrastructure, or on virtual machines provided by cloud providers (Google Compute Engine, Amazon EC2, Microsoft Azure, and so on). Alternatively, most cloud providers now offer managed Kubernetes services, saving you from the hassle of installation and management. Here's a short overview of what the largest cloud providers offer:

- Google offers GKE - Google Kubernetes Engine,
- Amazon has EKS - Amazon Elastic Kubernetes Service,
- Microsoft has AKS – Azure Kubernetes Service,
- IBM has IBM Cloud Kubernetes Service,

- Alibaba provides the Alibaba Cloud Container Service.

Installing and managing Kubernetes is much more difficult than just using it, especially until you're intimately familiar with its architecture and operation. For this reason, we'll start with the easiest ways to obtain a working Kubernetes cluster. You'll learn several ways to run a single-node Kubernetes cluster on your local computer and how to use a hosted cluster running on Google Kubernetes Engine (GKE).

A third option, which involves installing a cluster using the `kubeadm` tool, is explained in Appendix B. The tutorial there will show you how to set up a three-node Kubernetes cluster using virtual machines. But you may want to try that only after you've become familiar with using Kubernetes. Many other options also exist, but they are beyond the scope of this book. Refer to the kubernetes.io website to learn more.

If you've been granted access to an existing cluster deployed by someone else, you can skip this section and go on to section 3.2 where you'll learn how to interact with Kubernetes clusters.

3.1.1 Using the built-in Kubernetes cluster in Docker Desktop

If you use macOS or Windows, you've most likely installed Docker Desktop to run the exercises in the previous chapter. It contains a single-node Kubernetes cluster that you can enable via its Settings dialog box. This may be the easiest way for you to start your Kubernetes journey, but keep in mind that the version of Kubernetes may not be as recent as when using the alternative options described in the next sections.

> **NOTE** Although technically not a cluster, the single-node Kubernetes system provided by Docker Desktop should be enough to explore most of the topics discussed in this book. When an exercise requires a multi-node cluster, I will point this out.

ENABLING KUBERNETES IN DOCKER DESKTOP

Assuming Docker Desktop is already installed on your computer, you can start the Kubernetes cluster by clicking the whale icon in the system tray and opening the Settings dialog box. Click the *Kubernetes* tab and make sure the *Enable Kubernetes* checkbox is selected. The components that make up the Control Plane run as Docker containers, but they aren't displayed in the list of running containers when you invoke the `docker ps` command. To display them, select the *Show system containers* checkbox.

> **NOTE** The initial installation of the cluster takes several minutes, as all container images for the Kubernetes components must be downloaded.

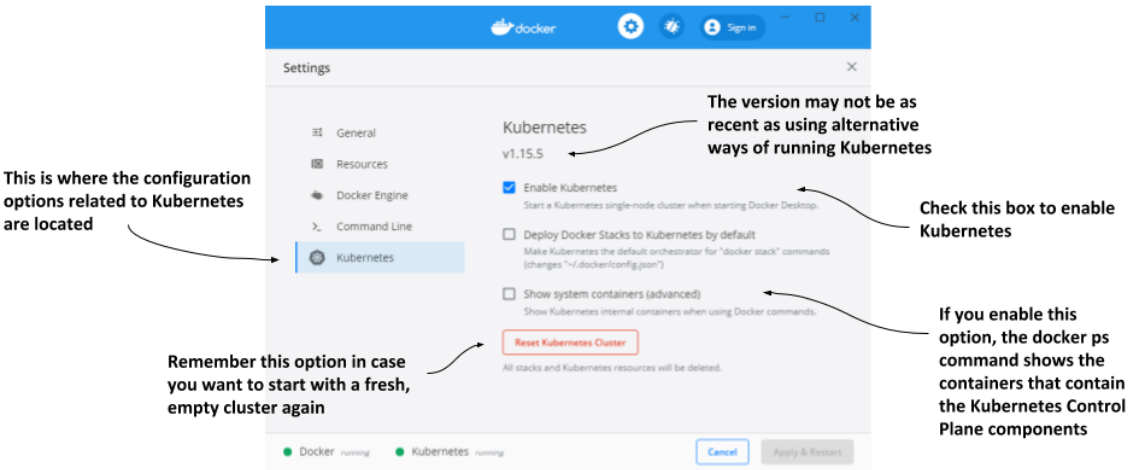


Figure 3.1 The Settings dialog box in Docker Desktop for Windows

Remember the *Reset Kubernetes Cluster* button if you ever want to reset the cluster to remove all the objects you've deployed in it.

VISUALIZING THE SYSTEM

To understand where the various components that make up the Kubernetes cluster run in Docker Desktop, look at the following figure.

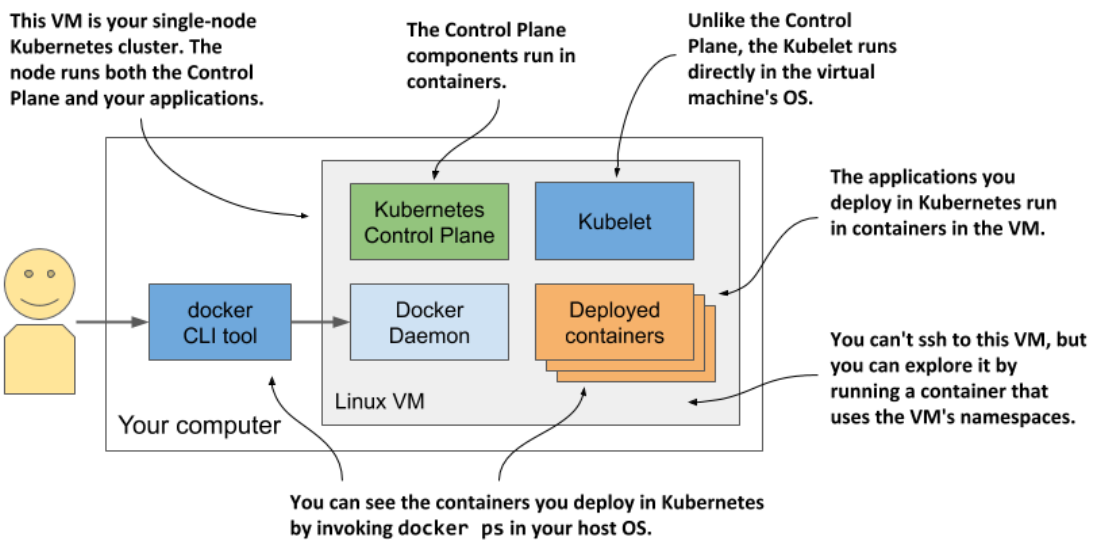


Figure 3.2 Kubernetes running in Docker Desktop

Docker Desktop sets up a Linux virtual machine that hosts the Docker Daemon and all the containers. This VM also runs the Kubelet - the Kubernetes agent that manages the node. The components of the Control Plane run in containers, as do all the applications you deploy.

To list the running containers, you don't need to log on to the VM because the docker CLI tool available in your host OS displays them.

EXPLORING THE VIRTUAL MACHINE FROM THE INSIDE

At the time of writing, Docker Desktop provides no command to log into the VM if you want to explore it from the inside. However, you can run a special container configured to use the VM's namespaces to run a remote shell, which is virtually identical to using SSH to access a remote server. To run the container, execute the following command:

```
$ docker run --net=host --ipc=host --uts=host --pid=host --privileged \
  --security-opt=seccomp=unconfined -it --rm -v /:/host alpine chroot /host
```

This long command requires explanation:

- The container is created from the `alpine` image.
- The `--net`, `--ipc`, `--uts` and `--pid` flags make the container use the host's namespaces instead of being sandboxed, and the `--privileged` and `--security-opt` flags give the container unrestricted access to all sys-calls.
- The `-it` flag runs the container interactive mode and the `--rm` flags ensures the container is deleted when it terminates.
- The `-v` flag mounts the host's root directory to the `/host` directory in the container. The `chroot /host` command then makes this directory the root directory in the container.

After you run the command, you are in a shell that's effectively the same as if you had used SSH to enter the VM. Use this shell to explore the VM - try listing processes by executing the `ps aux` command or explore the network interfaces by running `ip addr`.

3.1.2 Running a local cluster using Minikube

Another way to create a Kubernetes cluster is to use *Minikube*, a tool maintained by the Kubernetes community. The version of Kubernetes that Minikube deploys is usually more recent than the version deployed by Docker Desktop. The cluster consists of a single node and is suitable for both testing Kubernetes and developing applications locally. It normally runs Kubernetes in a Linux VM, but if your computer is Linux-based, it can also deploy Kubernetes directly in your host OS via Docker.

> **NOTE** If you configure Minikube to use a VM, you don't need Docker, but you do need a hypervisor like VirtualBox. In the other case you need Docker, but not the hypervisor.

INSTALLING MINIKUBE

Minikube supports macOS, Linux, and Windows. It has a single binary executable file, which you'll find in the Minikube repository on GitHub (http://github.com/kubernetes/minikube).

It's best to follow the current installation instructions published there, but roughly speaking, you install it as follows.

On macOS you can install it using the Brew Package Manager, on Windows there's an installer that you can download, and on Linux you can either download a .deb or .rpm package or simply download the binary file and make it executable with the following command:

```
$ curl -LO https://storage.googleapis.com/minikube/releases/latest/minikube-linux-
amd64 && sudo install minikube-linux-amd64 /usr/local/bin/minikube
```

For details on your specific OS, please refer to the installation guide online.

STARTING A KUBERNETES CLUSTER WITH MINIKUBE

After Minikube is installed, start the Kubernetes cluster as indicated in the following listing.

Listing 3.1 Starting Kubernetes with Minikube

```
$ minikube start
minikube v1.11.0 on Fedora 31
Using the virtualbox driver based on user configuration
Downloading VM boot image ...
> minikube-v1.11.0.iso.sha256: 65 B / 65 B [-------------] 100.00% ? p/s 0s
> minikube-v1.11.0.iso: 174.99 MiB / 174.99 MiB [] 100.00% 50.16 MiB p/s 4s
Starting control plane node minikube in cluster minikube
Downloading Kubernetes v1.18.3 preload ...
> preloaded-images-k8s-v3-v1.18.3-docker-overlay2-amd64.tar.lz4: 526.01 MiB
Creating virtualbox VM (CPUs=2, Memory=6000MB, Disk=20000MB) ...
Preparing Kubernetes v1.18.3 on Docker 19.03.8 ...
Verifying Kubernetes components...
Enabled addons: default-storageclass, storage-provisioner
Done! kubectl is now configured to use "minikube"
```

The process may take several minutes, because the VM image and the container images of the Kubernetes components must be downloaded.

> **TIP** If you use Linux, you can reduce the resources required by Minikube by creating the cluster without a VM. Use this command: `minikube start --vm-driver none`

CHECKING MINIKUBE'S STATUS

When the `minikube start` command is complete, you can check the status of the cluster by running `minikube status`, as shown in the following listing.

Listing 3.2 Checking Minikube's status

```
$ minikube status
host: Running
kubelet: Running
apiserver: Running
kubeconfig: Configured
```

The output of the command shows that the Kubernetes host (the VM that hosts Kubernetes) is running, and so are the Kubelet – the agent responsible for managing the node – and the Kubernetes API server. The last line shows that the kubectl command-line tool (CLI) is configured to use the Kubernetes cluster that Minikube has provided. Minikube doesn't install the CLI tool, but it does create its configuration file. Installation of the CLI tool is explained in section 3.2.

VISUALIZING THE SYSTEM

The architecture of the system, which is shown in the next figure, is practically identical to the one in Docker Desktop.

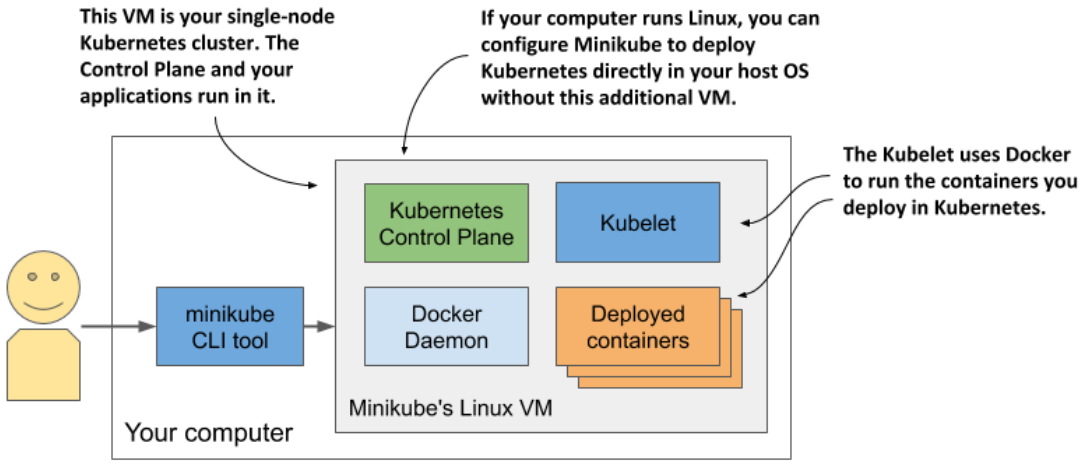


Figure 3.3 Running a single-node Kubernetes cluster using Minikube

The Control Plane components run in containers in the VM or directly in your host OS if you used the `--vm-driver none` option to create the cluster. The Kubelet runs directly in the VM's or your host's operating system. It runs the applications you deploy in the cluster via the Docker Daemon.

You can run `minikube ssh` to log into the Minikube VM and explore it from inside. For example, you can see what's running in the VM by running `ps aux` to list running processes or `docker ps` to list running containers.

> **TIP** If you want to list containers using your local docker CLI instance, as in the case of Docker Desktop, run the following command: `eval $(minikube docker-env)`

3.1.3 Running a local cluster using kind (Kubernetes in Docker)

An alternative to Minikube, although not as mature, is *kind* (Kubernetes-in-Docker). Instead of running Kubernetes in a virtual machine or directly on the host, kind runs each Kubernetes

cluster node inside a container. Unlike Minikube, this allows it to create multi-node clusters by starting several containers. The actual application containers that you deploy to Kubernetes then run within these node containers. The system is shown in the next figure.

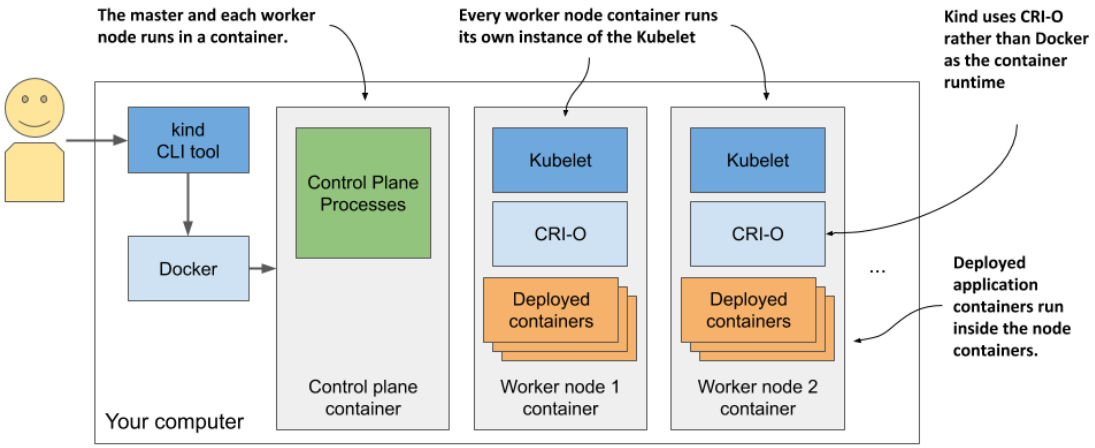


Figure 3.4 Running a multi-node Kubernetes cluster using kind

In the previous chapter I mentioned that a process that runs in a container actually runs in the host OS. This means that when you run Kubernetes using kind, all Kubernetes components run in your host OS. The applications you deploy to the Kubernetes cluster also run in your host OS.

This makes kind the perfect tool for development and testing, as everything runs locally and you can debug running processes as easily as when you run them outside of a container. I prefer to use this approach when I develop apps on Kubernetes, as it allows me to do magical things like run network traffic analysis tools such as Wireshark or even my web browser inside the containers that run my applications. I use a tool called `nsenter` that allows me to run these tools in the network or other namespaces of the container.

If you're new to Kubernetes, the safest bet is to start with Minikube, but if you're feeling adventurous, here's how to get started with kind.

INSTALLING KIND

Just like Minikube, kind consists of a single binary executable file. To install it, refer to the installation instructions at https://kind.sigs.k8s.io/docs/user/quick-start/. On macOS and Linux, the command to install it is as follows:

```
$ curl -Lo ./kind https://github.com/kubernetes-
sigs/kind/releases/download/v0.7.0/kind-$(uname)-amd64 && \chmod +x ./kind && \mv
./kind /some-dir-in-your-PATH/kind
```

Check the documentation to see what the latest version is and use it instead of v0.7.0 in the above example. Also, replace `/some-dir-in-your-PATH/` with an actual directory in your path.

NOTE Docker must be installed on your system to use kind.

STARTING A KUBERNETES CLUSTER WITH KIND

Starting a new cluster is as easy as it is with Minikube. Execute the following command:

```
$ kind create cluster
```

Like Minikube, kind configures kubectl to use the cluster that it creates.

STARTING A MULTI-NODE CLUSTER WITH KIND

Kind runs a single-node cluster by default. If you want to run a cluster with multiple worker nodes, you must first create a configuration file named `kind-multi-node.yaml` with the following content (you can find the file in the book's code archive, directory `Chapter03/`):

Listing 3.3 Config file for running a three-node cluster with kind

```
kind: Cluster
apiVersion: kind.sigs.k8s.io/v1alpha3
nodes:
- role: control-plane
- role: worker
- role: worker
```

With the file in place, create the cluster using the following command:

```
$ kind create cluster --config kind-multi-node.yaml
```

LISTING WORKER NODES

At the time of this writing, kind doesn't provide a command to check the status of the cluster, but you can list cluster nodes using `kind get nodes`, as shown in the next listing.

Listing 3.4 Listing nodes using kind get nodes

```
$ kind get nodes
kind-worker2
kind-worker
kind-control-plane
```

NOTE Due to width restrictions, the node names `control-plane`, `worker1`, and `worker2` are used instead of the actual node names throughout this book.

Since each node runs as a container, you can also see the nodes by listing the running containers using `docker ps`, as the next listing shows.

Listing 3.5 Displaying kind nodes running as containers

```
$ docker ps
CONTAINER ID    IMAGE                  ...    NAMES
45d0f712eac0    kindest/node:v1.18.2   ...    kind-worker2
d1e88e98e3ae    kindest/node:v1.18.2   ...    kind-worker
4b7751144ca4    kindest/node:v1.18.2   ...    kind-control-plane
```

LOGGING INTO CLUSTER NODES PROVISIONED BY KIND

Unlike Minikube, where you use `minikube ssh` to log into the node if you want to explore the processes running inside it, with kind you use `docker exec`. For example, to enter the node called `kind-control-plane`, run:

```
$ docker exec -it kind-control-plane bash
```

Instead of using Docker to run containers, nodes created by kind use the CRI-O container runtime, which I mentioned in the previous chapter as a lightweight alternative to Docker. The `crictl` CLI tool is used to interact with CRI-O. Its use is very similar to that of the `docker` tool. After logging into the node, list the containers running in it by running `crictl ps` instead of `docker ps`. An example of the command's output is shown in the next listing:

Listing 3.6 Listing containers inside a cluster node provisioned with kind

```
root@kind-control-plane:/# crictl ps
CONTAINER ID    IMAGE           CREATED      STATE     NAME
c7f44d171fb72   eb516548c180f   15 min ago   Running   coredns        ...
cce9c0261854c   eb516548c180f   15 min ago   Running   coredns        ...
e6522aae66fcc   d428039608992   16 min ago   Running   kube-proxy     ...
6b2dc4bbfee0c   ef97cccdfdb50   16 min ago   Running   kindnet-cni    ...
c3e66dfe44deb   be321f2ded3f3   16 min ago   Running   kube-apiserver ...
```

3.1.4 Creating a managed cluster with Google Kubernetes Engine

If you want to use a full-fledged multi-node Kubernetes cluster instead of a local one, you can use a managed cluster, such as the one provided by Google Kubernetes Engine (GKE). This way, you don't have to manually set up all the cluster nodes and networking, which is usually too hard for someone taking their first steps with Kubernetes. Using a managed solution such as GKE ensures that you don't end up with an incorrectly configured cluster.

SETTING UP GOOGLE CLOUD AND INSTALLING THE GCLOUD CLIENT BINARY

Before you can set up a new Kubernetes cluster, you must set up your GKE environment. The process may change in the future, so I'll only give you a few general instructions here. For complete instructions, refer to https://cloud.google.com/container-engine/docs/before-you-begin.

Roughly, the whole procedure includes

1. Signing up for a Google account if you don't have one already.
2. Creating a project in the Google Cloud Platform Console.

3. Enabling billing. This does require your credit card info, but Google provides a 12-month free trial with a free $300 credit. And they don't start charging automatically after the free trial is over.
4. Downloading and installing the Google Cloud SDK, which includes the `gcloud` tool.
5. Creating the cluster using the `gcloud` command-line tool.

NOTE Certain operations (the one in step 2, for example) may take a few minutes to complete, so relax and grab a coffee in the meantime.

CREATING A GKE KUBERNETES CLUSTER WITH THREE NODES

Before you create your cluster, you must decide in which geographical region and zone it should be created. Refer to https://cloud.google.com/compute/docs/regions-zones to see the list of available locations. In the following examples, I use the europe-west3 region based in Frankfurt, Germany. It has three different zones - I'll use the zone europe-west3-c. The default zone for all gcloud operations can be set with the following command:

```
$ gcloud config set compute/zone europe-west3-c
```

Create the Kubernetes cluster using the command shown in the next listing. You can choose a name other than `kubia` if you wish.

Listing 3.7 Creating a three-node cluster in GKE

```
$ gcloud container clusters create kubia --num-nodes 3
Creating cluster kubia in europe-west3-c...
...
kubeconfig entry generated for kubia.
NAME   LOCAT.   MASTER_VER  MASTER_IP    MACH_TYPE      ... NODES
STATUS
kubia  eu-w3-c  1.13.11...  5.24.21.22   n1-standard-1  ... 3
RUNNING
```

NOTE I'm creating all three worker nodes in the same zone, but you can also spread them across all zones in the region by setting the `compute/zone` config value to an entire region instead of a single zone. If you do so, note that `--num-nodes` indicates the number of nodes *per zone*. If the region contains three zones and you only want three nodes, you must set `--num-nodes` to `1`.

You should now have a running Kubernetes cluster with three worker nodes. Each node is a virtual machine provided by the Google Compute Engine (GCE) infrastructure-as-a-service platform. You can list GCE virtual machines using the command in the next listing.

Listing 3.8 Listing GCE virtual machines

```
$ gcloud compute instances list
NAME      ZONE         MACHINE_TYPE   INTERNAL_IP  EXTERNAL_IP     STATUS
...-ctlk  eu-west3-c   n1-standard-1  10.156.0.16  34.89.238.55    RUNNING
...-gj1f  eu-west3-c   n1-standard-1  10.156.0.14  35.242.223.97   RUNNING
```

```
...-r01z  eu-west3-c  n1-standard-1  10.156.0.15  35.198.191.189  RUNNING
```

TIP Each VM incurs costs. To reduce the cost of your cluster, you can reduce the number of nodes to one, or even to zero while not using it. See next section for details.

The system is shown in the next figure. Note that only your worker nodes run in GCE virtual machines. The control plane runs elsewhere - you can't access the machines hosting it.

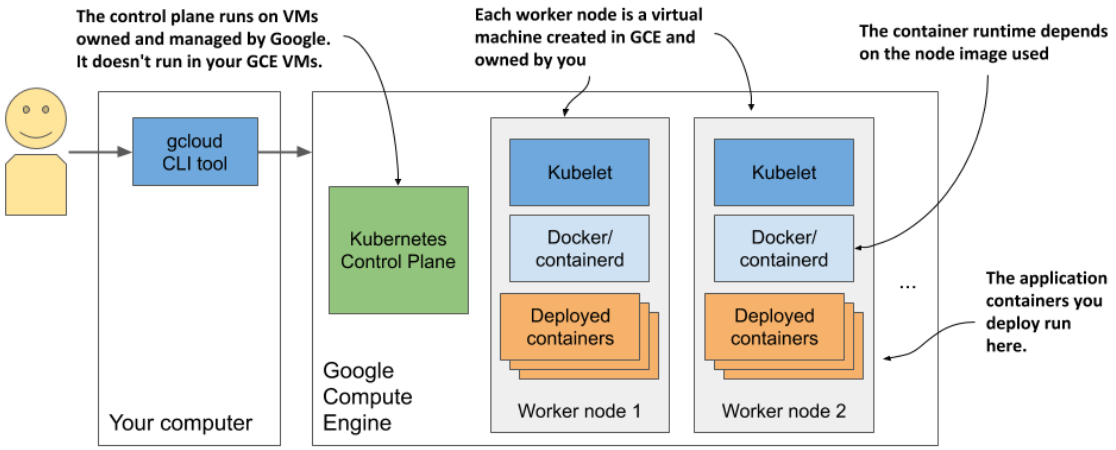


Figure 3.5 Your Kubernetes cluster in Google Kubernetes Engine

SCALING THE NUMBER OF NODES

Google allows you to easily increase or decrease the number of nodes in your cluster. For most exercises in this book you can scale it down to just one node if you want to save money. You can even scale it down to zero so that your cluster doesn't incur any costs.

To scale the cluster to zero, use the following command:

```
$ gcloud container clusters resize kubia --size 0
```

The nice thing about scaling to zero is that none of the objects you create in your Kubernetes cluster, including the applications you deploy, are deleted. Granted, if you scale down to zero, the applications will have no nodes to run on, so they won't run. But as soon as you scale the cluster back up, they will be redeployed. And even with no worker nodes you can still interact with the Kubernetes API (you can create, update, and delete objects).

INSPECTING A GKE WORKER NODE

If you're interested in what's running on your nodes, you can log into them with the following command (use one of the node names from the output of the previous command):

```
$ gcloud compute ssh gke-kubia-default-pool-9bba9b18-4glf
```

While logged into the node, you can try to list all running containers with `docker ps`. You haven't run any applications yet, so you'll only see Kubernetes system containers. What they are isn't important right now, but you'll learn about them in later chapters.

3.1.5 Creating a cluster using Amazon Elastic Kubernetes Service

If you prefer to use Amazon instead of Google to deploy your Kubernetes cluster in the cloud, you can try the Amazon Elastic Kubernetes Service (EKS). Let's go over the basics.

First, you have to install the `eksctl` command-line tool by following the instructions at https://docs.aws.amazon.com/eks/latest/userguide/getting-started-eksctl.html.

CREATING AN EKS KUBERNETES CLUSTER

Creating an EKS Kubernetes cluster using `eksctl` does not differ significantly from how you create a cluster in GKE. All you must do is run the following command:

```
$ eksctl create cluster --name kubia --region eu-central-1 --nodes 3 --ssh-access
```

This command creates a three-node cluster in the `eu-central-1` region. The regions are listed at https://aws.amazon.com/about-aws/global-infrastructure/regional-product-services/.

INSPECTING AN EKS WORKER NODE

If you're interested in what's running on those nodes, you can use SSH to connect to them. The `--ssh-access` flag used in the command that creates the cluster ensures that your SSH public key is imported to the node.

As with GKE and Minikube, once you've logged into the node, you can try to list all running containers with `docker ps`. You can expect to see similar containers as in the clusters we covered earlier.

3.1.6 Deploying a multi-node cluster from scratch

Until you get a deeper understanding of Kubernetes, I strongly recommend that you don't try to install a multi-node cluster from scratch. If you are an experienced systems administrator, you may be able to do it without much pain and suffering, but most people may want to try one of the methods described in the previous sections first. Proper management of Kubernetes clusters is incredibly difficult. The installation alone is a task not to be underestimated.

If you still feel adventurous, you can start with the instructions in Appendix B, which explain how to create VMs with VirtualBox and install Kubernetes using the kubeadm tool. You can also use those instructions to install Kubernetes on your bare-metal machines or in VMs running in the cloud.

Once you've successfully deployed one or two clusters using kubeadm, you can then try to deploy it completely manually, by following Kelsey Hightower's *Kubernetes the Hard Way* tutorial at github.com/kelseyhightower/Kubernetes-the-hard-way. Though you may run into several problems, figuring out how to solve them can be a great learning experience.

3.2 Interacting with Kubernetes

You've now learned about several possible methods to deploy a Kubernetes cluster. Now's the time to learn how to use the cluster. To interact with Kubernetes, you use a command-line tool called `kubectl`, pronounced *kube-control*, *kube-C-T-L* or *kube-cuddle*.

As the next figure shows, the tool communicates with the Kubernetes API server, which is part of the Kubernetes Control Plane. The control plane then triggers the other components to do whatever needs to be done based on the changes you made via the API.

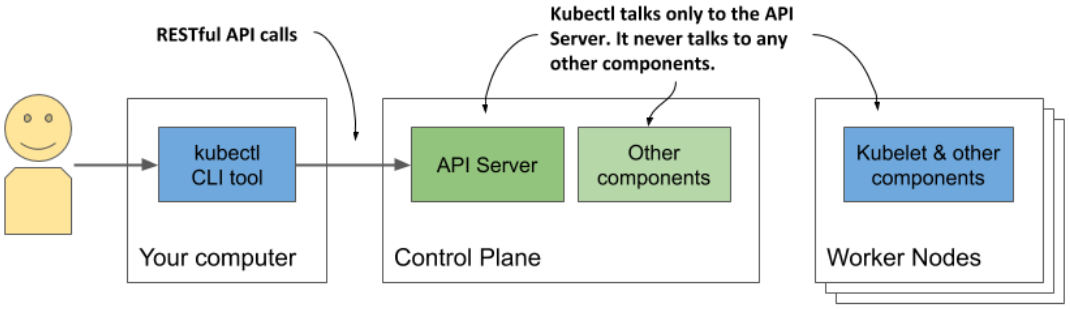


Figure 3.6 How you interact with a Kubernetes cluster

3.2.1 Setting up kubectl - the Kubernetes command-line client

Kubectl is a single executable file that you must download to your computer and place into your path. It loads its configuration from a configuration file called *kubeconfig*. To use kubectl, you must both install it and prepare the kubeconfig file so kubectl knows what cluster to talk to.

DOWNLOADING AND INSTALLING KUBECTL

The latest stable release for Linux can be downloaded and installed with the following command:

```
$ curl -LO https://storage.googleapis.com/kubernetes-release/release/$(curl -s
https://storage.googleapis.com/kubernetes-
release/release/stable.txt)/bin/linux/amd64/kubectl && chmod +x kubectl && sudo mv
kubectl /usr/local/bin/
```

To install `kubectl` on macOS, you can either run the same command, but replace `linux` in the URL with `darwin`, or install the tool via Homebrew by running `brew install kubectl`.

On Windows, download `kubectl.exe` from https://storage.googleapis.com/kubernetes-release/release/v1.18.2/bin/windows/amd64/kubectl.exe. To download the latest version, first go to https://storage.googleapis.com/kubernetes-release/release/stable.txt to see what the latest stable version is and then replace the version number in the first URL with this version. To check if you've installed it correctly, run `kubectl --help`. Note that kubectl may

or may not yet be configured to talk to your Kubernetes cluster, which means most commands may not work yet.

> **TIP** You can always append `--help` to any `kubectl` command to get information on what it does and how to use it.

SETTING UP A SHORT ALIAS FOR KUBECTL

You'll use `kubectl` often. Having to type the full command every time is needlessly time-consuming, but you can speed things up by setting up an alias and tab completion for it.

Most users of Kubernetes use `k` as the alias for kubectl. If you haven't used aliases yet, here's how to define it in Linux and macOS. Add the following line to your `~/.bashrc` or equivalent file:

```
alias k=kubectl
```

On Windows, if you use the Command Prompt, define the alias by executing `doskey k=kubectl $*`. If you use PowerShell, execute `set-alias -name k -value kubectl`.

> **NOTE** You may not need an alias if you used `gcloud` to set up the cluster. It installs the `k` binary in addition to `kubectl`.

CONFIGURING TAB COMPLETION FOR KUBECTL

Even with a short alias like `k`, you'll still have to type a lot. Fortunately, the `kubectl` command can also output shell completion code for both the bash and the zsh shell. It enables tab completion of not only command names but also the object names. For example, later you'll learn how to view details of a particular cluster node by executing the following command:

```
$ kubectl describe node gke-kubia-default-pool-9bba9b18-4glf
```

That's a lot of typing that you'll repeat all the time. With tab completion, things are much easier. You just press TAB after typing the first few characters of each token:

```
$ kubectl desc<TAB> no<TAB> gke-ku<TAB>
```

To enable tab completion in bash, you must first install a package called `bash-completion` and then run the following command (you can also add it to `~/.bashrc` or equivalent):

```
$ source <(kubectl completion bash)
```

But there's one caveat. This will only complete your commands when you use the full `kubectl` command name. It won't work when you use the `k` alias. To make it work with the alias, you must transform the output of the `kubectl completion` command using the `sed` tool:

```
$ source <(kubectl completion bash | sed s/kubectl/k/g)
```

3.2.2 Configuring kubectl to use a specific Kubernetes cluster

The kubeconfig configuration file is located at `~/.kube/config`. If you deployed your cluster using Docker Desktop, Minikube or GKE, the file was created for you. If you've been given access to an existing cluster, you should have received the file. Other tools, such as kind, may have written the file to a different location. Instead of moving the file to the default location, you can also point kubectl to it by setting the `KUBECONFIG` environment variable as follows:

```
$ export KUBECONFIG=/path/to/custom/kubeconfig
```

To learn more about how to manage kubectl's configuration and create a config file from scratch, refer to appendix A.

NOTE If you want to use several Kubernetes clusters (for example, both Minikube and GKE), see appendix A for information on switching between different `kubectl` contexts.

3.2.3 Using kubectl

Assuming you've installed and configured kubectl, you can now use it to talk to your cluster.

VERIFYING IF THE CLUSTER IS UP AND KUBECTL CAN TALK TO IT

To verify that your cluster is working, use the `kubectl cluster-info` command shown in the following listing.

Listing 3.9 Displaying cluster information

```
$ kubectl cluster-info
Kubernetes master is running at https://192.168.99.101:8443
KubeDNS is running at https://192.168.99.101:8443/api/v1/namespaces/...
```

This indicates that the API server is active and responding to requests. The output lists the URLs of the various Kubernetes cluster services running in your cluster. The above example shows that besides the API server, the KubeDNS service, which provides domain-name sevices within the cluster, is another service that runs in the cluster.

LISTING CLUSTER NODES

Now use the `kubectl` command to list all nodes in your cluster. The following listing shows the output that is generated when executing kubectl against a GKE cluster with three nodes.

Listing 3.10 Listing cluster nodes with `kubectl`

```
$ kubectl get nodes
NAME            STATUS  ROLES   AGE   VERSION
control-plane   Ready   <none>  12m   v1.18.2
worker1         Ready   <none>  12m   v1.18.2
worker2         Ready   <none>  12m   v1.18.2
```

Everything in Kubernetes is represented by an object and can be retrieved and manipulated via the RESTful API. The `kubectl get` command retrieves a list of objects of the specified type from the API. You'll use this command all the time, but it only displays summary information about the listed objects.

RETRIEVING ADDITIONAL DETAILS OF AN OBJECT

To see more detailed information about an object, you use the `kubectl describe` command, which shows much more:

```
$ kubectl describe node gke-kubia-85f6-node-0rrx
```

I omit the actual output of the `describe` command because it's quite wide and would be completely unreadable here in the book. If you run the command yourself, you'll see that it displays the status of the node, information about its CPU and memory usage, system information, containers running on the node, and much more.

If you run the `kubectl describe` command without specifying the resource name, information of all nodes will be printed.

> **TIP** Executing the `describe` command without specifying the object name is useful when only one object of a certain type exists. You don't have to type or copy/paste the object name.

You'll learn more about the numerous other kubectl commands throughout the book.

3.2.4 Interacting with Kubernetes through web dashboards

If you prefer using graphical web user interfaces, you'll be happy to hear that Kubernetes also comes with a nice web dashboard. Note, however, that the functionality of the dashboard may lag significantly behind kubectl, which is the primary tool for interacting with Kubernetes.

Nevertheless, the dashboard shows different resources in context and can be a good start to get a feel for what the main resource types in Kubernetes are and how they relate to each other. The dashboard also offers the possibility to modify the deployed objects and displays the equivalent kubectl command for each action - a feature most beginners will appreciate.

Figure 3.7 shows the dashboard with two workloads deployed in the cluster.

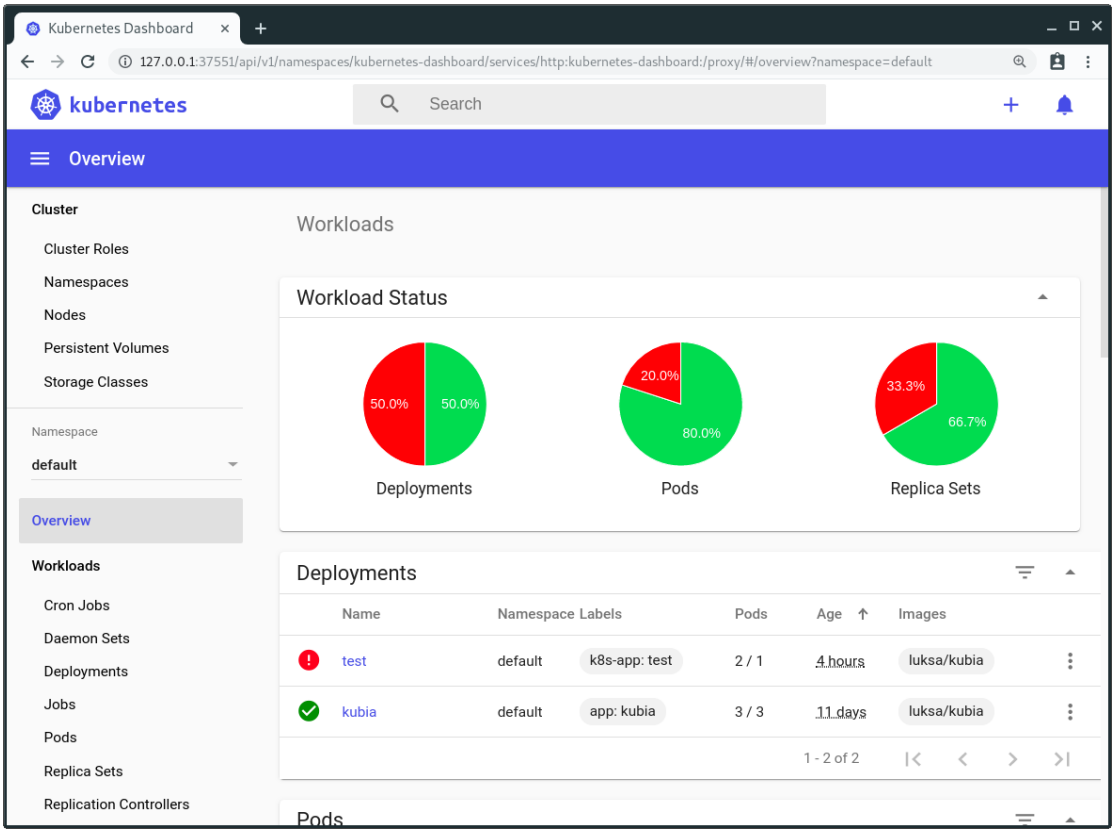


Figure 3.7 Screenshot of the Kubernetes web-based dashboard

Although you won't use the dashboard in this book, you can always open it to quickly see a graphical view of the objects deployed in your cluster after you create them via kubectl.

ACCESSING THE DASHBOARD IN DOCKER DESKTOP

Unfortunately, Docker Desktop does not install the Kubernetes dashboard by default. Accessing it is also not trivial, but here's how. First, you need to install it using the following command:

```
$ kubectl apply -f https://raw.githubusercontent.com/kubernetes/dashboard/v2.0.0-
rc5/aio/deploy/recommended.yaml
```

Refer to github.com/kubernetes/dashboard to find the latest version number. After installing the dashboard, the next command you must run is:

```
$ kubectl proxy
```

This command runs a local proxy to the API server, allowing you to access the services through it. Let the proxy process run and use the browser to open the dashboard at the following URL:

http://localhost:8001/api/v1/namespaces/kubernetes-dashboard/services/https:kubernetes-dashboard:/proxy/

You'll be presented with an authentication page. You must then run the following command to retrieve an authentication token.

```
$ kubectl -n kubernetes-dashboard describe secret $(kubectl -n kubernetes-dashboard
get secret | sls admin-user | ForEach-Object { $_ -Split '\s+' } | Select -First 1)
```

NOTE This command must be run in Windows PowerShell.

Find the token listed under `kubernetes-dashboard-token-xyz` and paste it into the token field on the authentication page shown in your browser. After you do this, you should be able to use the dashboard. When you're finished using it, terminate the `kubectl proxy` process using Control-C.

ACCESSING THE DASHBOARD WHEN USING MINIKUBE

If you're using Minikube, accessing the dashboard is much easier. Run the following command and the dashboard will open in your default browser:

```
$ minikube dashboard
```

ACCESSING THE DASHBOARD WHEN RUNNING KUBERNETES ELSEWHERE

The Google Kubernetes Engine no longer provides access to the open source Kubernetes Dashboard, but it offers an alternative web-based console. The same applies to other cloud providers. For information on how to access the dashboard, please refer to the documentation of the respective provider.

If your cluster runs on your own infrastructure, you can deploy the dashboard by following the guide at kubernetes.io/docs/tasks/access-application-cluster/web-ui-dashboard.

3.3 Running your first application on Kubernetes

Now is the time to finally deploy something to your cluster. Usually, to deploy an application, you'd prepare a JSON or YAML file describing all the components that your application consists of and apply that file to your cluster. This would be the declarative approach.

Since this may be your first time deploying an application to Kubernetes, let's choose an easier way to do this. We'll use simple, one-line imperative commands to deploy your application.

3.3.1 Deploying your application

The imperative way to deploy an application is to use the `kubectl create deployment` command. As the command itself suggests, it creates a *Deployment* object, which represents

an application deployed in the cluster. By using the imperative command, you avoid the need to know the structure of Deployment objects as when you write YAML or JSON manifests.

CREATING A DEPLOYMENT

In the previous chapter, you created a Node.js application that you packaged into a container image and pushed to Docker Hub to make it easily distributable to any computer. Let's deploy that application to your Kubernetes cluster. Here's the command you need to execute:

```
$ kubectl create deployment kubia --image=luksa/kubia:1.0
deployment.apps/kubia created
```

You've specified three things here:

- You want to create a `deployment` object.
- You want the object to be called `kubia`.
- You want the deployment to use the container image `luksa/kubia:1.0`.

By default, the image is pulled from Docker Hub, but you can also specify the image registry in the image name (for example, `quay.io/luksa/kubia:1.0`).

> **NOTE** Make sure that the image is stored in a public registry and can be pulled without access authorization. You'll learn how to provide credentials for pulling private images in chapter 8.

The Deployment object is now stored in the Kubernetes API. The existence of this object tells Kubernetes that the `luksa/kubia:1.0` container must run in your cluster. You've stated your *desired* state. Kubernetes must now ensure that the *actual* state reflects your wishes.

LISTING DEPLOYMENTS

The interaction with Kubernetes consists mainly of the creation and manipulation of objects via its API. Kubernetes stores these objects and then performs operations to bring them to life. For example, when you create a Deployment object, Kubernetes runs an application. Kubernetes then keeps you informed about the current state of the application by writing the status to the same Deployment object. You can view the status by reading back the object. One way to do this is to list all Deployment objects as follows:

```
$ kubectl get deployments
NAME    READY   UP-TO-DATE   AVAILABLE   AGE
kubia   0/1     1            0           6s
```

The `kubectl get deployments` command lists all Deployment objects that currently exist in the cluster. You have only one Deployment in your cluster. It runs one instance of your application as shown in the `UP-TO-DATE` column, but the `AVAILABLE` column indicates that the application is not yet available. That's because the container isn't ready, as shown in the `READY` column. You can see that zero of a total of one container are ready.

You may wonder if you can ask Kubernetes to list all the running containers by running `kubectl get containers`. Let's try this.

```
$ kubectl get containers
error: the server doesn't have a resource type "containers"
```

The command fails because Kubernetes doesn't have a "Container" object type. This may seem odd, since Kubernetes is all about running containers, but there's a twist. A container is not the smallest unit of deployment in Kubernetes. So, what is?

INTRODUCING PODS

In Kubernetes, instead of deploying individual containers, you deploy groups of co-located containers – so-called *pods*. You know, as in *pod of whales*, or a *pea pod*.

A pod is a group of one or more closely related containers (not unlike peas in a pod) that run together on the same worker node and need to share certain Linux namespaces, so that they can interact more closely than with other pods.

In the previous chapter I showed an example where two processes use the same namespaces. By sharing the network namespace, both processes use the same network interfaces, share the same IP address and port space. By sharing the UTS namespace, both see the same system hostname. This is exactly what happens when you run containers in the same pod. They use the same network and UTS namespaces, as well as others, depending on the pod's spec.

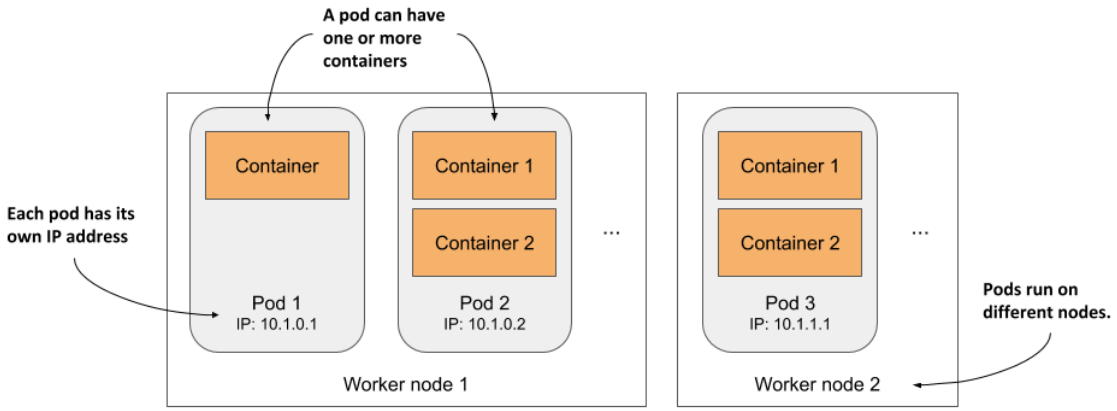


Figure 3.8 The relationship between containers, pods, and worker nodes

As illustrated in figure 3.8, you can think of each pod as a separate logical computer that contains one application. The application can consist of a single process running in a container, or a main application process and additional supporting processes, each running in a separate container. Pods are distributed across all the worker nodes of the cluster.

Each pod has its own IP, hostname, processes, network interfaces and other resources. Containers that are part of the same pod think that they're the only ones running on the computer. They don't see the processes of any other pod, even if located on the same node.

LISTING PODS

Since containers aren't a top-level Kubernetes object, you can't list them. But you can list pods. As the next listing shows, by creating the Deployment object, you've deployed one pod.

Listing 3.11 Listing pods

```
$ kubectl get pods
NAME                     READY     STATUS    RESTARTS   AGE
kubia-9d785b578-p449x    0/1       Pending   0          1m
```

This is the pod that houses the container running your application. To be precise, since the status is still `Pending`, the application, or rather the container, isn't running yet. This is also expressed in the `READY` column, which indicates that the pod has a single container that's not ready.

The reason the pod is pending is because the worker node to which the pod has been assigned must first download the container image before it can run it. When the download is complete, the pod's container is created and the pod enters the `Running` state.

If Kubernetes can't pull the image from the registry, the `kubectl get pods` command will indicate this in the `STATUS` column. If you're using your own image, ensure it's marked as public on Docker Hub. Try pulling the image manually with the `docker pull` command on another computer.

If another issue is causing your pod not to run, or if you simply want to see more information about the pod, you can also use the `kubectl describe pod` command, as you did earlier to see the details of a worker node. If there are any issues with the pod, they should be displayed by this command. Look at the events shown at the bottom of its output. For a running pod, they should be similar to the following listing.

Listing 3.12 The events displayed by kubectl describe pod

```
Events:
Type    Reason     Age   From               Message
----    ------     ----  ----               -------
Normal  Scheduled  25s   default-scheduler  Successfully assigned
                                            default/kubia-9d785b578-p449x
                                            to worker2
Normal  Pulling    23s   kubelet, worker2   Pulling image "luksa/kubia:1.0"
Normal  Pulled     21s   kubelet, worker2   Successfully pulled image
Normal  Created    21s   kubelet, worker2   Created container kubia
Normal  Started    21s   kubelet, worker2   Started container kubia
```

UNDERSTANDING WHAT HAPPENS BEHIND THE SCENES

To help you visualize what happened when you created the Deployment, see figure 3.9.

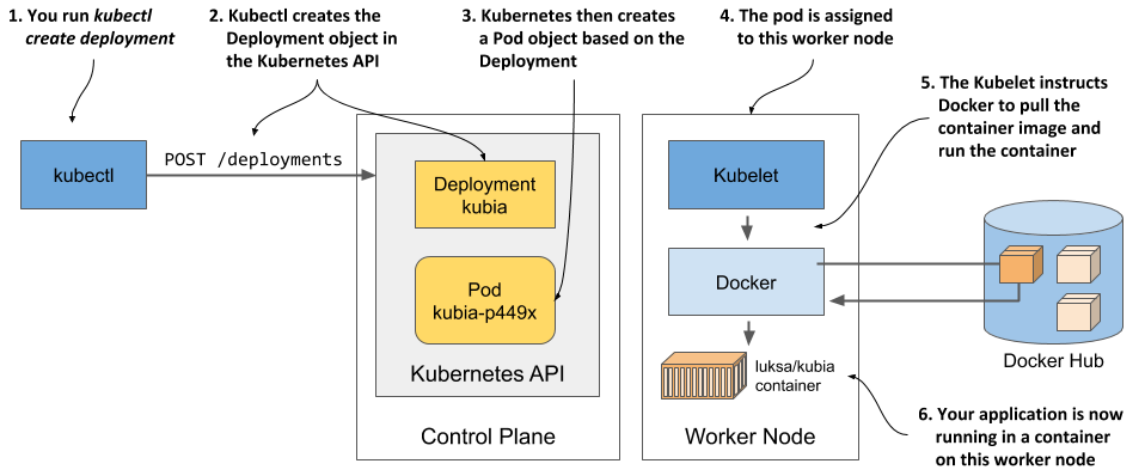


Figure 3.9 How creating a Deployment object results in a running application container

When you ran the `kubectl create` command, it created a new Deployment object in the cluster by sending an HTTP request to the Kubernetes API server. Kubernetes then created a new Pod object, which was then assigned or *scheduled* to one of the worker nodes. The Kubernetes agent on the worker node (the Kubelet) became aware of the newly created Pod object, saw that it was scheduled to its node, and instructed Docker to pull the specified image from the registry, create a container from the image, and execute it.

> **DEFINITION** The term scheduling refers to the assignment of the pod to a node. The pod runs immediately, not at some point in the future. Just like how the CPU scheduler in an operating system selects what CPU to run a process on, the scheduler in Kubernetes decides what worker node should execute each container. Unlike an OS process, once a pod is assigned to a node, it runs only on that node. Even if it fails, this instance of the pod is never moved to other nodes, as is the case with CPU processes, but a new pod instance may be created to replace it.

Depending on what you use to run your Kubernetes cluster, the number of worker nodes in your cluster may vary. The figure shows only the worker node that the pod was scheduled to. In a multi-node cluster, none of the other worker nodes are involved in the process.

3.3.2 Exposing your application to the world

Your application is now running, so the next question to answer is how to access it. I mentioned that each pod gets its own IP address, but this address is internal to the cluster and not accessible from the outside. To make the pod accessible externally, you'll *expose* it by creating a Service object.

Several types of Service objects exist. You decide what type you need. Some expose pods only within the cluster, while others expose them externally. A service with the type

LoadBalancer provisions an external load balancer, which makes the service accessible via a public IP. This is the type of service you'll create now.

CREATING A SERVICE

The easiest way to create the service is to use the following imperative command:

```
$ kubectl expose deployment kubia --type=LoadBalancer --port 8080
service/kubia exposed
```

The `create deployment` command that you ran previously created a Deployment object, whereas the `expose deployment` command creates a Service object. This is what running the above command tells Kubernetes:

- You want to expose all pods that belong to the kubia Deployment as a new service.
- You want the pods to be accessible from outside the cluster via a load balancer.
- The application listens on port 8080, so you want to access it via that port.

You didn't specify a name for the Service object, so it inherits the name of the Deployment.

LISTING SERVICES

Services are API objects, just like Pods, Deployments, Nodes and virtually everything else in Kubernetes, so you can list them by executing `kubectl get services`, as in the next listing.

Listing 3.13 Listing Services

```
$ kubectl get svc
NAME         TYPE           CLUSTER-IP     EXTERNAL-IP   PORT(S)          AGE
kubernetes   ClusterIP      10.19.240.1    <none>        443/TCP          34m
kubia        LoadBalancer   10.19.243.17   <pending>     8080:30838/TCP   4s
```

NOTE Notice the use of the abbreviation `svc` instead of `services`. Most resource types have a short name that you can use instead of the full object type (for example, `po` is short for `pods`, `no` for `nodes` and `deploy` for `deployments`).

The list shows two services with their types, IPs and the ports they expose. Ignore the `kubernetes` service for now and take a close look at the `kubia` service. It doesn't yet have an external IP address. Whether it gets one depends on how you've deployed the cluster.

Listing the available object types with kubectl api-resources

You've used the `kubectl get` command to list various things in your cluster: Nodes, Deployments, Pods and now Services. These are all Kubernetes object types. You can display a list of all supported types by running `kubectl api-resources`. The list also shows the short name for each type and some other information you need to define objects in JSON/YAML files, which you'll learn in the following chapters.

UNDERSTANDING LOAD BALANCER SERVICES

While Kubernetes allows you to create so-called LoadBalancer services, it doesn't provide the load balancer itself. If your cluster is deployed in the cloud, Kubernetes can ask the cloud infrastructure to provision a load balancer and configure it to forward traffic into your cluster. The infrastructure tells Kubernetes the IP address of the load balancer and this becomes the external address of your service.

The process of creating the Service object, provisioning the load balancer and how it forwards connections into the cluster is shown in the next figure.

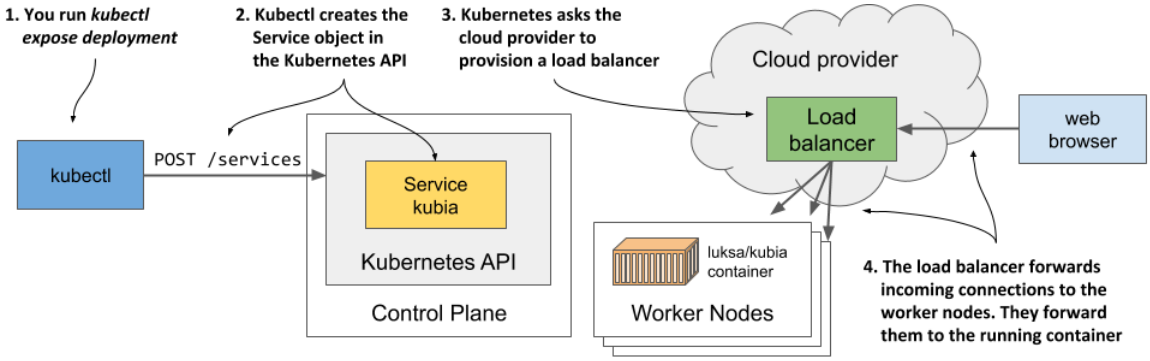


Figure 3.10 How creating a Service object with the type LoadBalancer works

Provisioning of the load balancer takes some time, so let's wait a few more seconds and check again whether the IP address is already assigned. This time, instead of listing all services, you'll only display the kubia service by using its name, as shown in the next listing.

Listing 3.14 Getting a single service

```
$ kubectl get svc kubia
NAME         TYPE           CLUSTER-IP    EXTERNAL-IP    PORT(S)          AGE
kubia        LoadBalancer   10.19.243.17  35.246.179.22  8080:30838/TCP   82s
```

The external IP is now displayed. This means that the load balancer is ready to forward requests to your application for clients around the world.

> **NOTE** If you deployed your cluster with Docker Desktop, the load balancer's IP address is shown as `localhost`, referring to your Windows or macOS machine, not the VM where Kubernetes and the application runs. If you use Minikube to create the cluster, no load balancer is created, but you can access the service in another way. More on this later.

ACCESSING YOUR APPLICATION THROUGH THE LOAD BALANCER

You can now send requests to your application through the external IP and port of the service:

```
$ curl 35.246.179.22:8080
Hey there, this is kubia-9d785b578-p449x. Your IP is ::ffff:1.2.3.4.
```

NOTE If you use Docker Desktop, the service is available at `localhost:8080` from within your host operating system. Use curl or your browser to access it.

Congratulations! If you use Google Kubernetes Engine, you've successfully published your application to users across the globe. Anyone who knows its IP and port can now access it. If you don't count the steps needed to deploy the cluster itself, only two simple commands were needed to deploy your application:

- `kubectl create deployment` and
- `kubectl expose deployment`.

ACCESSING YOUR APPLICATION WHEN A LOAD BALANCER ISN'T AVAILABLE

Not all Kubernetes clusters have mechanisms to provide a load balancer. The cluster provided by Minikube is one of them. If you create a service of type LoadBalancer, the service itself works, but there is no load balancer. Kubectl always shows the external IP as `<pending>` and you must use a different method to access the service.

Several methods of accessing services exist. You can even bypass the service and access individual pods directly, but this is mostly used for troubleshooting. You'll learn how to do this in chapter 5. For now, let's explore the next easier way to access your service if no load balancer is available.

As the next listing shows, Minikube can tell you where to access the service:

Listing 3.15 Getting the service URL when using Minikube

```
$ minikube service kubia --url
http://192.168.99.102:30838
```

The command prints out the URL of the service. You can now point `curl` or your browser to that URL to access your application:

```
$ curl http://192.168.99.102:30838
Hey there, this is kubia-9d785b578-p449x. Your IP is ::ffff:172.17.0.1.
```

TIP If you omit the `--url` option when running the `minikube service` command, your browser opens and loads the service URL.

You may wonder where this IP address and port come from. This is the IP of the Minikube virtual machine. You can confirm this by executing the `minikube ip` command. The Minikube VM is also your single worker node. The port `30838` is the so-called *node port*. It's the port on the worker node that forwards connections to your service. You may have noticed the port in the service's port list when you ran the `kubectl get svc` command:

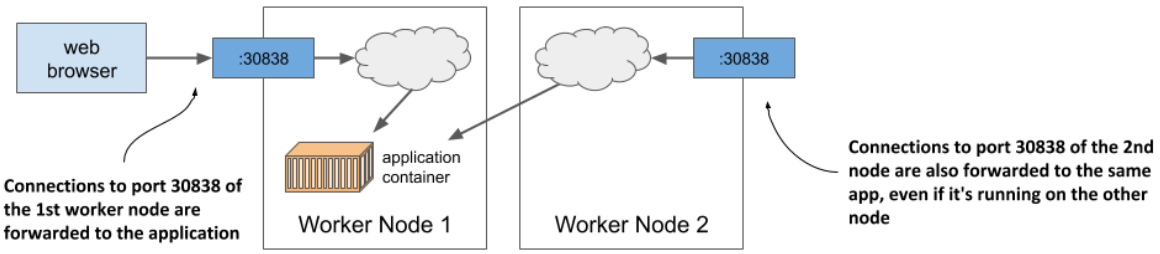
```
$ kubectl get svc kubia
NAME         TYPE           CLUSTER-IP    EXTERNAL-IP    PORT(S)          AGE
kubia        LoadBalancer   10.19.243.17  <pending>      8080:30838/TCP   82s
```

Your service is accessible via this port number on all your worker nodes, regardless of whether you're using Minikube or any other Kubernetes cluster.

> **NOTE** If you use Docker Desktop, the VM running Kubernetes can't be reached from your host OS through the VM's IP. You can access the service through the node port only within the VM by logging into it using the special container as described in section 3.1.1.

If you know the IP of at least one of your worker nodes, you should be able to access your service through this `IP:port` combination, provided that firewall rules do not prevent you from accessing the port.

The next figure shows how external clients access the application via the node ports.



Figgure 3.11 Connection routing through a service's node port

To connect this to what I mentioned earlier about the load balancer forwarding connections to the nodes and the nodes then forwarding them to the containers: the node ports are exactly where the load balancer sends incoming requests to. Kubernetes then ensures that they are forwarded to the application running in the container. You'll learn how it does this in chapter 10, as we delve deeper into services. Don't lose too much time thinking about it until then. Instead, let's play a little more with our cluster to see what else Kubernetes can do.

3.3.3 Horizontally scaling the application

You now have a running application that is represented by a Deployment and exposed to the world by a Service object. Now let's create some additional magic.

One of the major benefits of running applications in containers is the ease with which you can scale your application deployments. You're currently running a single instance of your application. Imagine you suddenly see many more users using your application. The single instance can no longer handle the load. You need to run additional instances to distribute the load and provide service to your users. This is known as *scaling out*. With Kubernetes, it's trivial to do.

INCREASING THE NUMBER OF RUNNING APPLICATION INSTANCES

To deploy your application, you've created a Deployment object. By default, it runs a single instance of your application. To run additional instances, you only need to scale the Deployment object with the following command:

```
$ kubectl scale deployment kubia --replicas=3
deployment.apps/kubia scaled
```

You've now told Kubernetes that you want to run three exact copies or *replicas* of your pod. Note that you haven't instructed Kubernetes what to do. You haven't told it to add two more pods. You just set the new desired number of replicas and let Kubernetes determine what action it must take to reach the new desired state.

This is one of the most fundamental principles in Kubernetes. Instead of telling Kubernetes what to do, you simply set a new desired state of the system and let Kubernetes achieve it. To do this, it examines the current state, compares it with the desired state, identifies the differences and determines what it must do to reconcile them.

SEEING THE RESULTS OF THE SCALE-OUT

Although it's true that the `kubectl scale deployment` command seems imperative, since it apparently tells Kubernetes to scale your application, what the command actually does is modify the specified Deployment object. As you'll see in a later chapter, you could have simply edited the object instead of giving the imperative command. Let's view the Deployment object again to see how the scale command has affected it:

```
$ kubectl get deploy
NAME    READY   UP-TO-DATE   AVAILABLE   AGE
kubia   3/3     3            3           18m
```

Three instances are now up to date and available and three of three containers are ready. This isn't clear from the command output, but the three containers are not part of the same pod instance. There are three pods with one container each. You can confirm this by listing pods:

```
$ kubectl get pods
NAME                    READY   STATUS    RESTARTS   AGE
kubia-9d785b578-58vhc   1/1     Running   0          17s
kubia-9d785b578-jmnj8   1/1     Running   0          17s
kubia-9d785b578-p449x   1/1     Running   0          18m
```

As you can see, three pods now exist. As indicated in the `READY` column, each has a single container, and all the containers are ready. All the pods are `Running`.

DISPLAYING THE PODS' HOST NODE WHEN LISTING PODS

If you use a single-node cluster, all your pods run on the same node. But in a multi-node cluster, the three pods should be distributed throughout the cluster. To see which nodes the pods were scheduled to, you can use the `-o wide` option to display a more detailed pod list:

```
$ kubectl get pods -o wide
NAME                    ...  IP           NODE
```

```
kubia-9d785b578-58vhc  ...  10.244.1.5  worker1 #A
kubia-9d785b578-jmnj8  ...  10.244.2.4  worker2 #B
kubia-9d785b578-p449x  ...  10.244.2.3  worker2 #B
```

#A Pod scheduled to one node
#B Two pods scheduled to another node

NOTE You can also use the `-o wide` output option to see additional information when listing other object types.

The wide output shows that one pod was scheduled to one node, whereas the other two were both scheduled to a different node. The Scheduler usually distributes pods evenly, but it depends on how it's configured. You'll learn more about scheduling in chapter 21.

Understanding why the worker node a pod is scheduled to is not important

Regardless of the node they run on, all instances of your application have an identical OS environment, because they run in containers created from the same container image. You may remember from the previous chapter that the only thing that might be different is the OS kernel, but this only happens when different nodes use different kernel versions or load different kernel modules.

In addition, each pod gets its own IP and can communicate in the same way with any other pod - it doesn't matter if the other pod is on the same worker node, another node located in the same server rack or even a completely different data center.

So far, you've set no resource requirements for the pods, but if you had, each pod would have been allocated the requested amount of compute resources. It shouldn't matter to the pod which node provides these resources, as long as the pod's requirements are met.

Therefore, you shouldn't care where a pod is scheduled to. It's also why the default `kubectl get pods` command doesn't display information about the worker nodes for the listed pods. In the world of Kubernetes, it's just not that important.

As you can see, scaling an application is incredibly easy. Once your application is in production and there is a need to scale it, you can add additional instances with a single command without having to manually install, configure and run additional copies.

NOTE The app itself must support horizontal scaling. Kubernetes doesn't magically make your app scalable; it merely makes it trivial to replicate it.

OBSERVING REQUESTS HITTING ALL THREE PODS WHEN USING THE SERVICE

Now that multiple instances of your app are running, let's see what happens when you hit the service URL again. Will the response come from the same instance every time? The next listing shows what happens.

Listing 3.16 Requests sent to the service are spread across all the pods

```
$ curl 35.246.179.22:8080
Hey there, this is kubia-9d785b578-58vhc. Your IP is ::ffff:1.2.3.4.    #A
$ curl 35.246.179.22:8080
```

```
Hey there, this is kubia-9d785b578-p449x. Your IP is ::ffff:1.2.3.4.    #B
$ curl 35.246.179.22:8080
Hey there, this is kubia-9d785b578-jmnj8. Your IP is ::ffff:1.2.3.4.    #C
$ curl 35.246.179.22:8080
Hey there, this is kubia-9d785b578-p449x. Your IP is ::ffff:1.2.3.4.    #D
```

#A Request reaches the first pod
#B Request reaches the third pod
#C Request reaches the second pod
#D Request reaches the third pod again

If you look closely at the responses, you'll see that they correspond to the names of the pods. Each request arrives at a different pod in random order. This is what services in Kubernetes do when more than one pod instance is behind them. They act as load balancers in front of the pods. Let's visualize the system using the following figure.

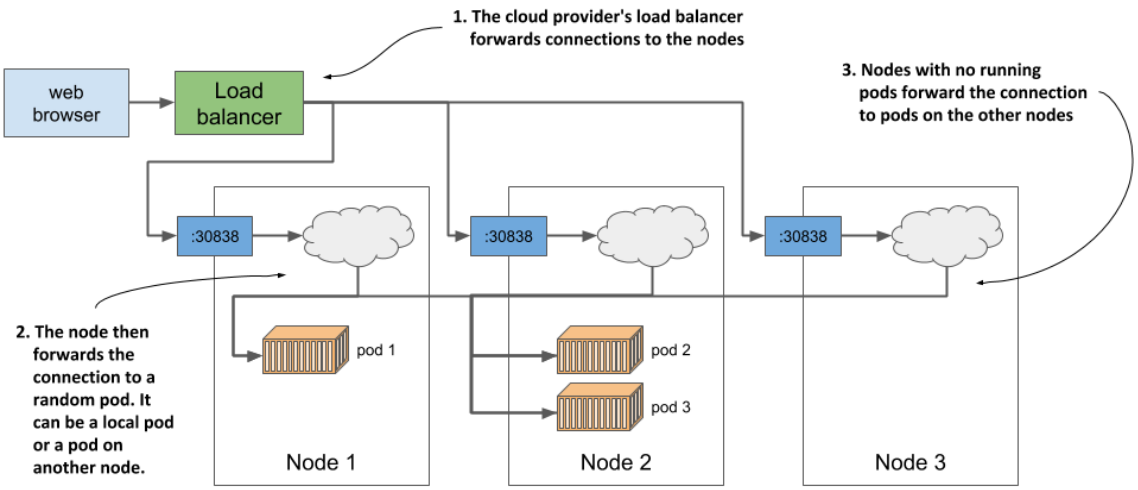


Figure 3.12 Load balancing across multiple pods backing the same service

As the figure shows, you shouldn't confuse this load balancing mechanism, which is provided by the Kubernetes service itself, with the additional load balancer provided by the infrastructure when running in GKE or another cluster running in the cloud. Even if you use Minikube and have no external load balancer, your requests are still distributed across the three pods by the service itself. If you use GKE, there are actually *two* load balancers in play. The figure shows that the load balancer provided by the infrastructure distributes requests across the nodes, and the service then distributes requests across the pods.

I know this may be very confusing right now, but it should all become clear in chapter 10.

3.3.4 Understanding the deployed application

To conclude this chapter, let's review what your system consists of. There are two ways to look at your system – the logical and the physical view. You've just seen the physical view in figure 3.12. There are three running containers that are deployed on three worker nodes (a single node when using Minikube). If you run Kubernetes in the cloud, the cloud infrastructure has also created a load balancer for you. Docker Desktop also creates a type of local load balancer. Minikube doesn't create a load balancer, but you can access your service directly through the node port.

While differences in the physical view of the system in different clusters exist, the logical view is always the same, whether you use a small development cluster or a large production cluster with thousands of nodes. If you're not the one who manages the cluster, you don't even need to worry about the physical view of the cluster. If everything works as expected, the logical view is all you need to worry about. Let's take a closer look at this view.

UNDERSTANDING THE API OBJECTS REPRESENTING YOUR APPLICATION

The logical view consists of the objects you've created in the Kubernetes API – either directly or indirectly. The following figure shows how the objects relate to each other.

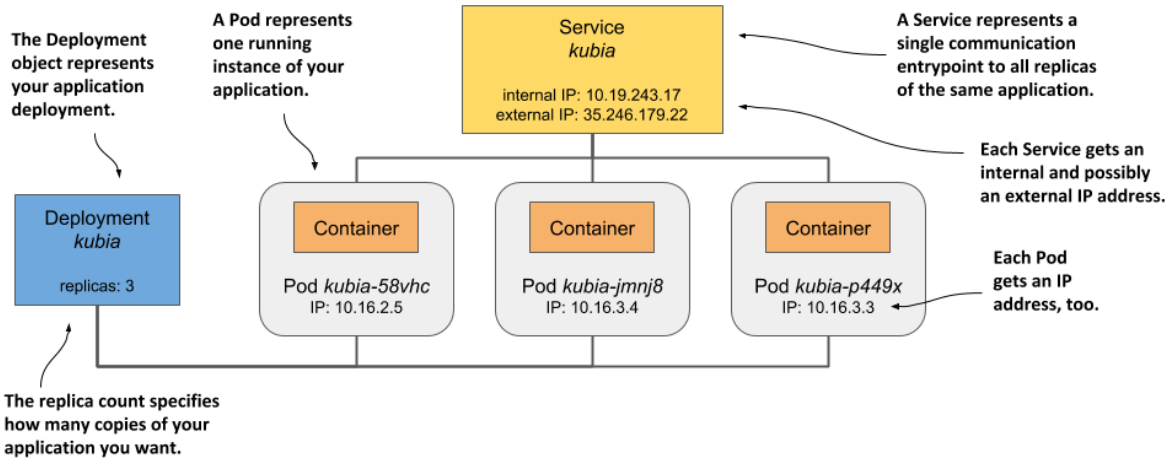


Figure 3.13 Your deployed application consists of a Deployment, several Pods, and a Service.

The objects are as follows:

- the Deployment object you created,
- the Pod objects that were automatically created based on the Deployment, and
- the Service object you created manually.

There are other objects between the three just mentioned, but you don't need to know them yet. You'll learn about them in the following chapters.

Remember when I explained in chapter 1 that Kubernetes abstracts the infrastructure? The logical view of your application is a great example of this. There are no nodes, no complex network topology, no physical load balancers. Just a simple view that only contains your applications and the supporting objects. Let's look at how these objects fit together and what role they play in your small setup.

The Deployment object represents an application deployment. It specifies which container image contains your application and how many replicas of the application Kubernetes should run. Each replica is represented by a Pod object. The Service object represents a single communication entry point to these replicas.

UNDERSTANDING THE PODS

The essential and most important part of your system are the pods. Each pod definition contains one or more containers that make up the pod. When Kubernetes brings a pod to life, it runs all the containers specified in its definition. As long as a Pod object exists, Kubernetes will do its best to ensure that its containers keep running. It only shuts them down when the Pod object is deleted.

UNDERSTANDING THE ROLE OF THE DEPLOYMENT

When you first created the Deployment object, only a single Pod object was created. But when you increased the desired number of replicas on the Deployment, Kubernetes created additional replicas. Kubernetes ensures that the actual number of pods always matches the desired number.

If one or more pods disappear or their status is unknown, Kubernetes replaces them to bring the actual number of pods back to the desired number of replicas. A pod disappears when someone or something deletes it, whereas a pod's status is unknown when the node it is running on no longer reports its status due to a network or node failure.

Strictly speaking, a Deployment results in nothing more than the creation of a certain number of Pod objects. You may wonder if you can create Pods directly instead of having the Deployment create them for you. You can certainly do this, but if you wanted to run multiple replicas, you'd have to manually create each pod individually and make sure you give each one a unique name. You'd then also have to keep a constant eye on your pods to replace them if they suddenly disappear or the node on which they run fails. And that's exactly why you almost never create pods directly but use a Deployment instead.

UNDERSTANDING WHY YOU NEED A SERVICE

The third component of your system is the Service object. By creating it, you tell Kubernetes that you need a single communication entry point to your pods. The service gives you a single IP address to talk to your pods, regardless of how many replicas are currently deployed. If the service is backed by multiple pods, it acts as a load balancer. But even there is only one pod, you still want to expose it through a service. To understand why, you need to learn an important detail about pods.

Pods are ephemeral. A pod may disappear at any time. This can happen when its host node fails, when someone inadvertently deletes the pod, or when the pod is evicted from an otherwise healthy node to make room for other, more important pods. As explained in the previous section, when pods are created through a Deployment, a missing pod is

immediately replaced with a new one. This new pod is not the same as the one it replaces. It's a completely new pod, with a new IP address.

If you weren't using a service and had configured your clients to connect directly to the IP of the original pod, you would now need to reconfigure all these clients to connect to the IP of the new pod. This is not necessary when using a service. Unlike pods, services aren't ephemeral. When you create a service, it is assigned a static IP address that never changes during lifetime of the service.

Instead of connecting directly to the pod, clients should connect to the IP of the service. This ensures that their connections are always routed to a healthy pod, even if the set of pods behind the service is constantly changing. It also ensures that the load is distributed evenly across all pods should you decide to scale the deployment horizontally.

3.4 Summary

In this hands-on chapter, you've learned:

- Virtually all cloud providers offer a managed Kubernetes option. They take on the burden of maintaining your Kubernetes cluster, while you just use its API to deploy your applications.
- You can also install Kubernetes in the cloud yourself, but this has often proven not to be the best idea until you master all aspects of managing Kubernetes.
- You can install Kubernetes locally, even on your laptop, using tools such as Docker Desktop or Minikube, which run Kubernetes in a Linux VM, or kind, which runs the master and worker nodes as Docker containers and the application containers inside those containers.
- Kubectl, the command-line tool, is the usual way you interact with Kubernetes. A web-based dashboard also exists but is not as stable and up to date as the CLI tool.
- To work faster with kubectl, it is useful to define a short alias for it and enable shell completion.
- An application can be deployed using `kubectl create deployment`. It can then be exposed to clients by running `kubectl expose deployment`. Horizontally scaling the application is trivial: `kubectl scale deployment` instructs Kubernetes to add new replicas or removes existing ones to reach the number of replicas you specify.
- The basic unit of deployment is not a container, but a pod, which can contain one or more related containers.
- Deployments, Services, Pods and Nodes are Kubernetes objects/resources. You can list them with `kubectl get` and inspect them with `kubectl describe`.
- The Deployment object deploys the desired number of Pods, while the Service object makes them accessible under a single, stable IP address.
- Each service provides internal load balancing in the cluster, but if you set the type of service to `LoadBalancer`, Kubernetes will ask the cloud infrastructure it runs in for an additional load balancer to make your application available at a publicly accessible address.

You've now completed your first guided tour around the bay. Now it's time to start learning the ropes, so that you'll be able to sail independently. The next part of the book focuses on

the different Kubernetes objects and how/when to use them. You'll start with the most important one – the Pod.

4

Introducing the Kubernetes API objects

This chapter covers

- Managing a Kubernetes cluster and the applications it hosts via its API
- Understanding the structure of Kubernetes API objects
- Retrieving and understanding an object's YAML or JSON manifest
- Inspecting the status of cluster nodes via Node objects
- Inspecting cluster events through Event objects

The previous chapter introduced three fundamental objects that make up a deployed application. You created a Deployment object that spawned multiple Pod objects representing individual instances of your application and exposed them to the world by creating a Service object that deployed a load balancer in front of them.

The chapters in the second part of this book explain these and other object types in detail. In this chapter, the common features of Kubernetes objects are presented using the example of Node and Event objects.

4.1 Getting familiar with the Kubernetes API

In a Kubernetes cluster, both users and Kubernetes components interact with the cluster by manipulating objects through the Kubernetes API, as shown in figure 4.1.

These objects represent the configuration of the entire cluster. They include the applications running in the cluster, their configuration, the load balancers through which they are exposed within the cluster or externally, the underlying servers and the storage used by these applications, the security privileges of users and applications, and many other details of the infrastructure.

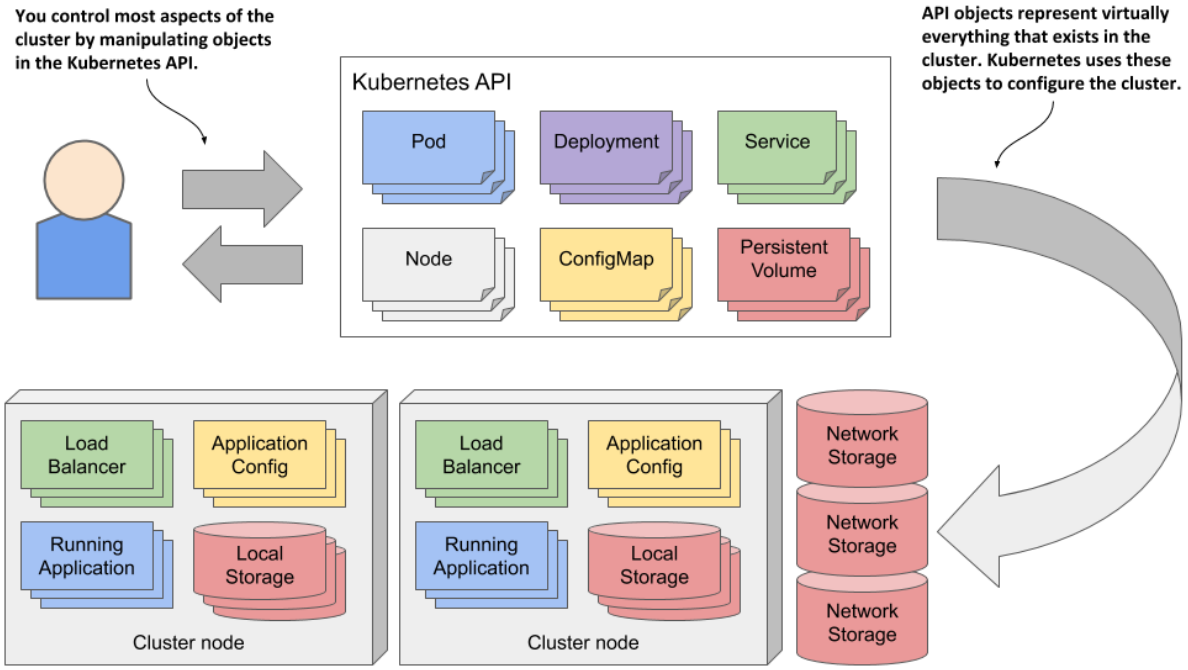


Figure 4.1 A Kubernetes cluster is configured by manipulating objects in the Kubernetes API

4.1.1 Introducing the API

The Kubernetes API is the central point of interaction with the cluster, so much of this book is dedicated to explaining this API. The most important API objects are described in the following chapters, but a basic introduction to the API is presented here.

UNDERSTANDING THE ARCHITECTURAL STYLE OF THE API

The Kubernetes API is an HTTP-based RESTful API where the state is represented by *resources* on which you perform CRUD operations (Create, Read, Update, Delete) using standard HTTP methods such as `POST`, `GET`, `PUT`/`PATCH` or `DELETE`.

> **DEFINITION** REST is Representational State Transfer, an architectural style for implementing interoperability between computer systems via web services using stateless operations, described by Roy Thomas Fielding in his doctoral dissertation. To learn more, read the dissertation at https://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm.

It is these resources (or objects) that represent the configuration of the cluster. Cluster administrators and engineers who deploy applications into the cluster therefore influence the configuration by manipulating these objects.

In the Kubernetes community, the terms "resource" and "object" are used interchangeably, but there are subtle differences that warrant an explanation.

UNDERSTANDING THE DIFFERENCE BETWEEN RESOURCES AND OBJECTS

The essential concept in RESTful APIs is the resource, and each resource is assigned a URI or Uniform Resource Identifier that uniquely identifies it. For example, in the Kubernetes API, application deployments are represented by deployment resources.

The collection of all deployments in the cluster is a REST resource exposed at `/api/v1/deployments`. When you use the `GET` method to send an HTTP request to this URI, you receive a response that lists all deployment instances in the cluster.

Each individual deployment instance also has its own unique URI through which it can be manipulated. The individual deployment is thus exposed as another REST resource. You can retrieve information about the deployment by sending a `GET` request to the resource URI and you can modify it using a `PUT` request.

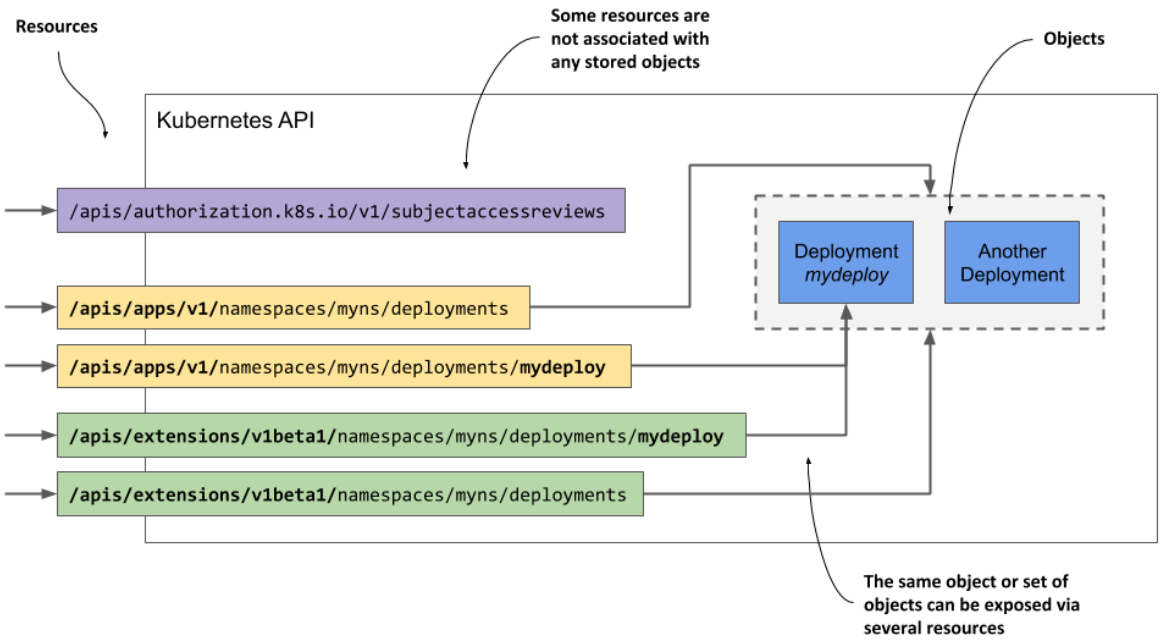


Figure 4.2 A single object can be exposed by two or more resources

An object can therefore be exposed through more than one resource. As shown in figure 4.2, the Deployment object instance named `mydeploy` is returned both as an element of a collection when you query the `deployments` resource and as a single object when you query the individual resource URI directly.

In addition, a single object instance can also be exposed via multiple resources if multiple API versions exist for an object type. Up to Kubernetes version 1.15, two different

representations of Deployment objects were exposed by the API. In addition to the `apps/v1` version, exposed at `/apis/apps/v1/deployments`, an older version, `extensions/v1beta1`, exposed at `/apis/extensions/v1beta1/deployments` was available in the API. These two resources didn't represent two different sets of Deployment objects, but a single set that was represented in two different ways - with small differences in the object schema. You could create an instance of a Deployment object via the first URI and then read it back using the second.

In some cases, a resource doesn't represent any object at all. An example of this is the way the Kubernetes API allows clients to verify whether a subject (a person or a service) is authorized to perform an API operation. This is done by submitting a `POST` request to the `/apis/authorization.k8s.io/v1/subjectaccessreviews` resource. The response indicates whether the subject is authorized to perform the operation specified in the request body. The key thing here is that no object is created by the `POST` request.

The examples described above show that a resource isn't the same as an object. If you are familiar with relational database systems, you can compare resources and object types with views and tables. Resources are views through which you interact with objects.

> **NOTE** Because the term "resource" can also refer to compute resources, such as CPU and memory, to reduce confusion, the term "objects" is used in this book to refer to API resources.

UNDERSTANDING HOW OBJECTS ARE REPRESENTED

When you make a `GET` request for a resource, the Kubernetes API server returns the object in structured text form. The default data model is JSON, but you can also tell the server to return YAML instead. When you update the object using a `POST` or `PUT` request, you also specify the new state with either JSON or YAML.

The individual fields in an object's manifest depend on the object type, but the general structure and many fields are shared by all Kubernetes API objects. You'll learn about them next.

4.1.2 Understanding the structure of an object manifest

Before you are confronted with the complete manifest of a Kubernetes object, let me first explain its major parts, because this will help you to find your way through the sometimes hundreds of lines it is composed of.

INTRODUCING THE MAIN PARTS OF AN OBJECT

The manifest of most Kubernetes API objects consists of the following four sections:

- *Type Metadata* contains information about the type of object this manifest describes. It specifies the object type, the group to which the type belongs, and the API version.
- *Object Metadata* holds the basic information about the object instance, including its name, time of creation, owner of the object, and other identifying information. The fields in the Object Metadata are the same for all object types.
- *Spec* is the part in which you specify the desired state of the object. Its fields differ between different object types. For pods, this is the part that specifies the pod's

containers, storage volumes and other information related to its operation.

- *Status* contains the current actual state of the object. For a pod, it tells you the condition of the pod, the status of each of its containers, its IP address, the node it's running on, and other information that reveals what's happening to your pod.

A visual representation of an object manifest and its four sections is shown in the next figure.

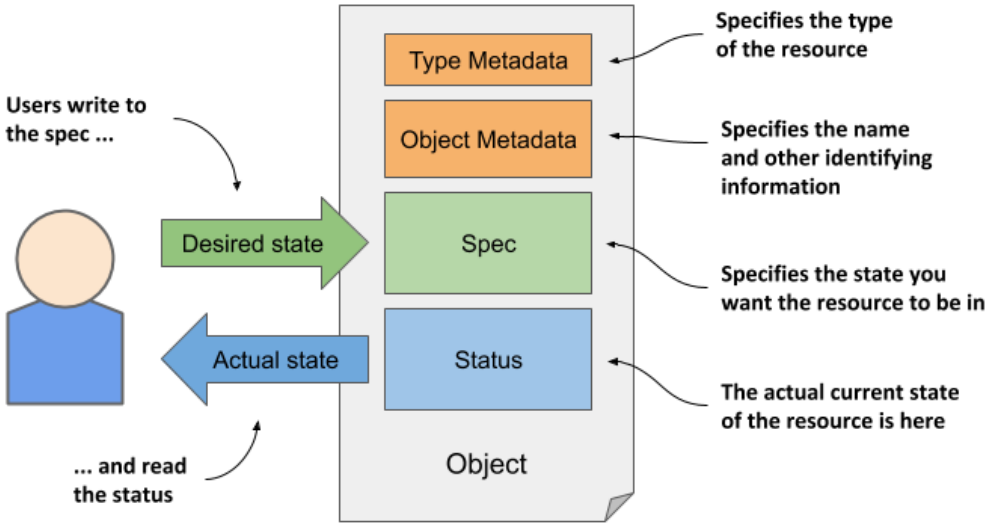


Figure 4.3 The main sections of a Kubernetes API object.

> **NOTE** Although the figure shows that users write to the object's Spec section and read its Status, the API server always returns the entire object when you perform a GET request; to update the object, you also send the entire object in the PUT request.

You'll see an example later to see which fields exist in these sections but let me first explain the Spec and Status sections, as they represent the flesh of the object.

UNDERSTANDING THE SPEC AND STATUS SECTIONS

As you may have noticed in the previous figure, the two most important parts of an object are the Spec and Status sections. You use the Spec to specify the desired state of the object and read the actual state of the object from the Status section. So, you are the one who writes the Spec and reads the Status, but who or what reads the Spec and writes the Status?

The Kubernetes Control Plane runs several components called *controllers* that manage the objects you create. Each controller is usually only responsible for one object type. For example, the *Deployment controller* manages Deployment objects.

As shown in figure 4.4, the task of a controller is to read the desired object state from the object's Spec section, perform the actions required to achieve this state, and report back the actual state of the object by writing to its Status section.

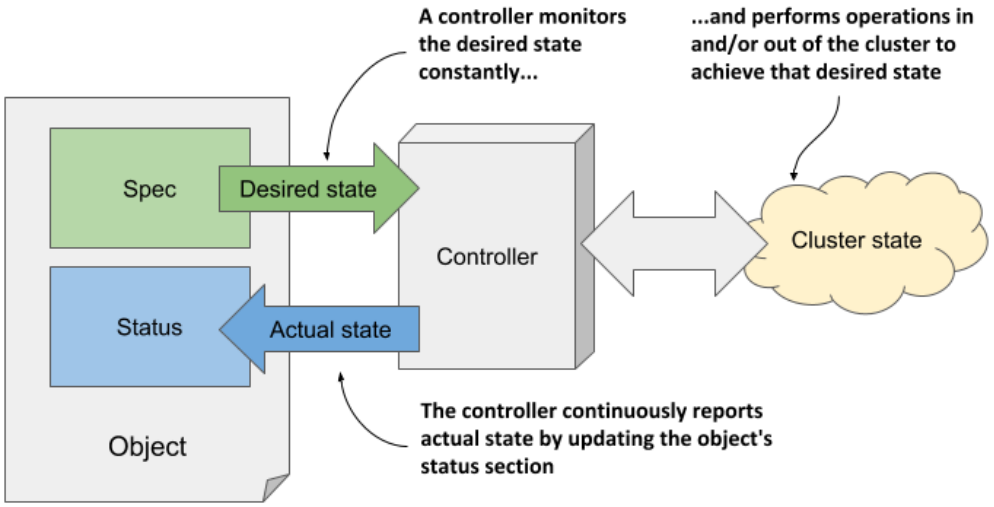


Figure 4.4 How a controller manages an object

Essentially, you tell Kubernetes what it has to do by creating and updating API objects. Kubernetes controllers use the same API objects to tell you what they have done and what the status of their work is.

You'll learn more about the individual controllers and their responsibilities in chapter 13. For now, just remember that a controller is associated with most object types and that the controller is the thing that reads the Spec and writes the Status of the object.

Not all objects have the spec and status sections

All Kubernetes API objects contain the two metadata sections, but not all have the Spec and Status sections. Those that don't, typically contain just static data and don't have a corresponding controller, so it is not necessary to distinguish between the desired and the actual state of the object.

An example of such an object is the Event object, which is created by various controllers to provide additional information about what is happening with an object that the controller is managing. The Event object is explained in section 4.3.

You now understand the general outline of an object, so the next section of this chapter can finally explore the individual fields of an object.

4.2 Examining an object's individual properties

To examine Kubernetes API objects up close, we'll need a concrete example. Let's take the Node object, which should be easy to understand because it represents something you might be relatively familiar with - a computer in the cluster.

My Kubernetes cluster provisioned by the kind tool has three nodes - one master and two workers. They are represented by three Node objects in the API. I can query the API and list these objects using `kubectl get nodes`, as shown in the next listing.

Listing 4.1 Listing Node objects

```
$ kubectl get nodes
NAME                 STATUS   ROLES    AGE    VERSION
kind-control-plane   Ready    master   1h     v1.18.2
kind-worker          Ready    <none>   1h     v1.18.2
kind-worker2         Ready    <none>   1h     v1.18.2
```

The following figure shows the three Node objects and the actual cluster machines that make up the cluster. Each Node object instance represents one host. In each instance, the Spec section contains (part of) the configuration of the host, and the Status section contains the state of the host.

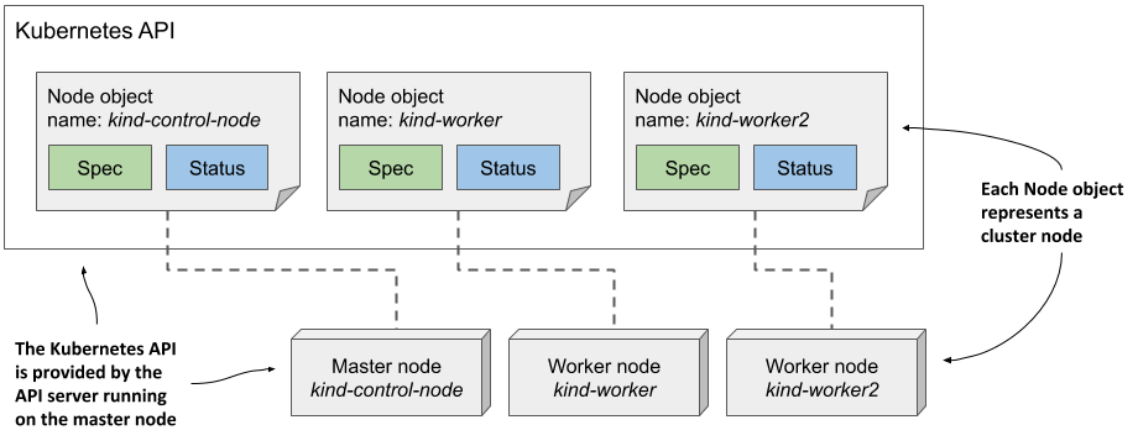


Figure 4.5 Cluster nodes are represented by Node objects

NOTE Node objects are slightly different from other objects because they are usually created by the Kubelet - the node agent running on the cluster node - rather than by users. When you add a machine to the cluster, the Kubelet registers the node by creating a Node object that represents the host. Users can then edit (some of) the fields in the Spec section.

4.2.1 Exploring the full manifest of a Node object

Let's take a close look at one of the Node objects. List all Node objects in your cluster by running the `kubectl get nodes` command and select one you want to inspect. Then, execute the `kubectl get node <node-name> -o yaml` command, where you replace `<node-name>` with the name of the node, as shown in the following listing.

Listing 4.2 Displaying the complete YAML manifest of an object

```
$ kubectl get node kind-control-plane -o yaml
apiVersion: v1            #A
kind: Node                #A
metadata:                                                    #B
  annotations: ...                                           #B
  creationTimestamp: "2020-05-03T15:09:17Z"                  #B
  labels: ...                                                #B
  managedFields: ...                                         #B
  name: kind-control-plane                            #C     #B
  resourceVersion: "3220054"                                 #B
  selfLink: /api/v1/nodes/kind-control-plane                 #B
  uid: 16dc1e0b-8d34-4cfb-8ade-3b0e91ec838b                  #B
spec:                                                        #D
  podCIDR: 10.244.0.0/24                              #E     #D
  podCIDRs:                                           #E     #D
  - 10.244.0.0/24                                     #E     #D
  taints:                                                    #D
  - effect: NoSchedule                                       #D
    key: node-role.kubernetes.io/master                      #D
status:                                                      #F
  addresses:                                          #G     #F
  - address: 172.18.0.2                               #G     #F
    type: InternalIP                                  #G     #F
  - address: kind-control-plane                       #G     #F
    type: Hostname                                    #G     #F
  allocatable: ...                                           #F
  capacity:                                           #H     #F
    cpu: "8"                                          #H     #F
    ephemeral-storage: 401520944Ki                    #H     #F
    hugepages-1Gi: "0"                                #H     #F
    hugepages-2Mi: "0"                                #H     #F
    memory: 32720824Ki                                #H     #F
    pods: "110"                                       #H     #F
  conditions:                                                #F
  - lastHeartbeatTime: "2020-05-17T12:28:41Z"                #F
    lastTransitionTime: "2020-05-03T15:09:17Z"               #F
    message: kubelet has sufficient memory available         #F
    reason: KubeletHasSufficientMemory                       #F
    status: "False"                                          #F
    type: MemoryPressure                                     #F
    ...                                                      #F
  daemonEndpoints:                                           #F
    kubeletEndpoint:                                         #F
      Port: 10250                                            #F
  images:                                             #I     #F
  - names:                                            #I     #F
    - k8s.gcr.io/etcd:3.4.3-0                         #I     #F
    sizeBytes: 289997247                              #I     #F
```

```
  ...                                                          #I      #F
nodeInfo:                                                      #J      #F
  architecture: amd64                                          #J      #F
  bootID: 233a359f-5897-4860-863d-06546130e1ff                 #J      #F
  containerRuntimeVersion: containerd://1.3.3-14-g449e9269     #J      #F
  kernelVersion: 5.5.10-200.fc31.x86_64                        #J      #F
  kubeProxyVersion: v1.18.2                                    #J      #F
  kubeletVersion: v1.18.2                                      #J      #F
  machineID: 74b74e389bb246e99abdf731d145142d                  #J      #F
  operatingSystem: linux                                       #J      #F
  osImage: Ubuntu 19.10                                        #J      #F
  systemUUID: 8749f818-8269-4a02-bdc2-84bf5fa21700             #J      #F
```

#A The Type Metadata specifies the type of object and the API version of this object manifest.
#B The Object Metadata section
#C The object name (the node's name)
#D The node's desired state is specified here
#E The IP range reserved for the pods on this node
#F The node's actual state is shown here
#G The IP(s) and hostname of the node
#H The nodes capacity (the amount of compute resources it has)
#I The list of cached container images on this node
#J Information about the node's operating system and the Kubernetes components running on it

NOTE Use the `-o json` option to display the object in JSON instead of YAML.

In the listing, the four main sections of the object definition and the more important properties of the node are annotated to help you distinguish between the more and less important fields. Some lines have been omitted to reduce the length of the manifest.

Accessing the API directly

You may be interested in trying to access the API directly instead of through kubectl. As explained earlier, the Kubernetes API is web based, so you can use a web browser or the curl command to perform API operations, but the API server uses TLS and you typically need a client certificate or token for authentication. Fortunately, kubectl provides a special proxy that takes care of this, allowing you to talk to the API through the proxy using plain HTTP.

To run the proxy, execute the command:

```
$ kubectl proxy
Starting to serve on 127.0.0.1:8001
```

You can now access the API using HTTP at 127.0.0.1:8001. For example, to retrieve the node object, open the URL http://127.0.0.1:8001/api/v1/nodes/kind-control-plane (replace kind-control-plane with one of your nodes' names).

Now let's take a closer look at the fields in each of the four main sections.

THE TYPE METADATA FIELDS

As you can see, the listing starts with the `apiVersion` and `kind` fields, which specify the API version and type of the object that this object manifest specifies. The API version is the schema used to describe this object. As mentioned before, an object type can be associated

with more than one schema, with different fields in each schema being used to describe the object. However, usually only one schema exists for each type.

The `apiVersion` in the previous listing is simply `v1`, but you'll see in the following chapters that the `apiVersion` in other object types contains more than just the version number. For Deployment objects, for example, the `apiVersion` is `apps/v1`. Whereas the field was originally used only to specify the API version, it is now also used to specify the API group to which the resource belongs. Node objects belong to the core API group, which is conventionally omitted from the `apiVersion` field.

The type of object defined in the manifest is specified by the field `kind`. The object kind in the previous listing is Node, and so far in this book you've also dealt with the following kinds: Deployment, Service, and Pod.

FIELDS IN THE OBJECT METADATA SECTION

The `metadata` section contains the metadata of this object instance. It contains the `name` of the instance, along with additional attributes such as `labels` and `annotations`, which are explained in chapter 9, and fields such as `resourceVersion`, `managedFields`, and other low-level fields, which are explained at depth in chapter 12.

FIELDS IN THE SPEC SECTION

Next comes the `spec` section, which is specific to each object kind. It is relatively short for Node objects compared to what you find for other object kinds. The `podCIDR` fields specify the pod IP range assigned to the node. Pods running on this node are assigned IPs from this range. The `taints` field is not important at this point, but you'll learn about it in chapter 18.

Typically, an object's spec section contains many more fields that you use to configure the object.

FIELDS IN THE STATUS SECTION

The `status` section also differs between the different kinds of object, but its purpose is always the same - it contains the last observed state of the thing the object represents. For Node objects, the status reveals the node's IP address(es), host name, capacity to provide compute resources, the current conditions of the node, the container images it has already downloaded and which are now cached locally, and information about its operating system and the version of Kubernetes components running on it.

4.2.2 Understanding individual object fields

To learn more about individual fields in the manifest, you can refer to the API reference documentation at http://kubernetes.io/docs/reference/ or use the `kubectl explain` command as described next.

USING KUBECTL EXPLAIN TO EXPLORE API OBJECT FIELDS

The kubectl tool has a nice feature that allows you to look up the explanation of each field for each object type (kind) from the command line. Usually, you start by asking it to provide the basic description of the object kind by running `kubectl explain <kind>`, as shown here:

Listing 4.3 Using kubectl explain to learn about an object kind

```
$ kubectl explain nodes
KIND:     Node
VERSION:  v1

DESCRIPTION:
     Node is a worker node in Kubernetes. Each node will have a unique
     identifier in the cache (i.e. in etcd).

FIELDS:
   apiVersion   <string>
     APIVersion defines the versioned schema of this representation of an
     object. Servers should convert recognized schemas to the latest...

   kind <string>
     Kind is a string value representing the REST resource this object
     represents. Servers may infer this from the endpoint the client...

   metadata     <Object>
     Standard object's metadata. More info: ...

   spec <Object>
     Spec defines the behavior of a node...

   status       <Object>
     Most recently observed status of the node. Populated by the system.
     Read-only. More info: ...
```

The command prints the explanation of the object and lists the top-level fields that the object can contain.

DRILLING DEEPER INTO AN API OBJECT'S STRUCTURE

You can then drill deeper to find subfields under each specific field. For example, you can use the following command to explain the node's `spec` field:

Listing 4.4 Using kubectl explain to learn about a specific object field and sub-fields

```
$ kubectl explain node.spec
KIND:     Node
VERSION:  v1

RESOURCE: spec <Object>

DESCRIPTION:
     Spec defines the behavior of a node.

     NodeSpec describes the attributes that a node is created with.

FIELDS:
   configSource <Object>
     If specified, the source to get node configuration from The
     DynamicKubeletConfig feature gate must be enabled for the Kubelet...

   externalID   <string>
     Deprecated. Not all kubelets will set this field...
```

```
  podCIDR      <string>
    PodCIDR represents the pod IP range assigned to the node.

  ...
```

Please note the API version given at the top. As explained earlier, multiple versions of the same kind can exist. Different versions can have different fields or default values. If you want to display a different version, specify it with the `--api-version` option.

> **NOTE** If you want to see the complete structure of an object (the complete hierarchical list of fields without the descriptions), try `kubectl explain pods --recursive`.

4.2.3 Understanding an object's status conditions

The set of fields in both the `spec` and `status` sections is different for each object kind, but the `conditions` field is found in many of them. It gives a list of conditions the object is currently in. They are very useful when you need to troubleshoot an object, so let's examine them more closely. Since the Node object is used as an example, this section also teaches you how to easily identify problems with a cluster node.

INTRODUCING THE NODE'S STATUS CONDITIONS

Let's print out the YAML manifest of the one of the node objects again, but this time we'll only focus on the `conditions` field in the object's `status`, as shown in the following listing.

Listing 4.5 The current status conditions in a Node object

```
$ kubectl get node kind-control-plane -o yaml
...
status:
  ...
  conditions:
  - lastHeartbeatTime: "2020-05-17T13:03:42Z"
    lastTransitionTime: "2020-05-03T15:09:17Z"
    message: kubelet has sufficient memory available
    reason: KubeletHasSufficientMemory
    status: "False"                                          #A
    type: MemoryPressure                                     #A
  - lastHeartbeatTime: "2020-05-17T13:03:42Z"
    lastTransitionTime: "2020-05-03T15:09:17Z"
    message: kubelet has no disk pressure
    reason: KubeletHasNoDiskPressure
    status: "False"                                          #B
    type: DiskPressure                                       #B
  - lastHeartbeatTime: "2020-05-17T13:03:42Z"
    lastTransitionTime: "2020-05-03T15:09:17Z"
    message: kubelet has sufficient PID available
    reason: KubeletHasSufficientPID
    status: "False"                                          #C
    type: PIDPressure                                        #C
  - lastHeartbeatTime: "2020-05-17T13:03:42Z"
    lastTransitionTime: "2020-05-03T15:10:15Z"
    message: kubelet is posting ready status
```

```
    reason: KubeletReady
    status: "True"                                #D
    type: Ready                                   #D
```

#A Node is not running out of memory
#B Node is not running out of disk space
#C Node has not run out of unused process Ids
#D Node is ready

TIP The `jq` tool is very handy if you want to see only a part of the object's structure. For example, to display the node's status conditions, you can run `kubectl get node <name> -o json | jq .status.conditions`. The equivalent tool for YAML is `yq`.

There are four conditions that reveal the state of the node. Each condition has a `type` and a `status` field, which can be `True`, `False` or `Unknown`, as shown in the figure 4.6. A condition can also specify a machine-facing `reason` for the last transition of the condition and a human-facing `message` with details about the transition. The `lastTransitionTime` field indicates when the condition moved from one status to another, whereas the `lastHeartbeatTime` field reveals the last time the controller received an update on the given condition.

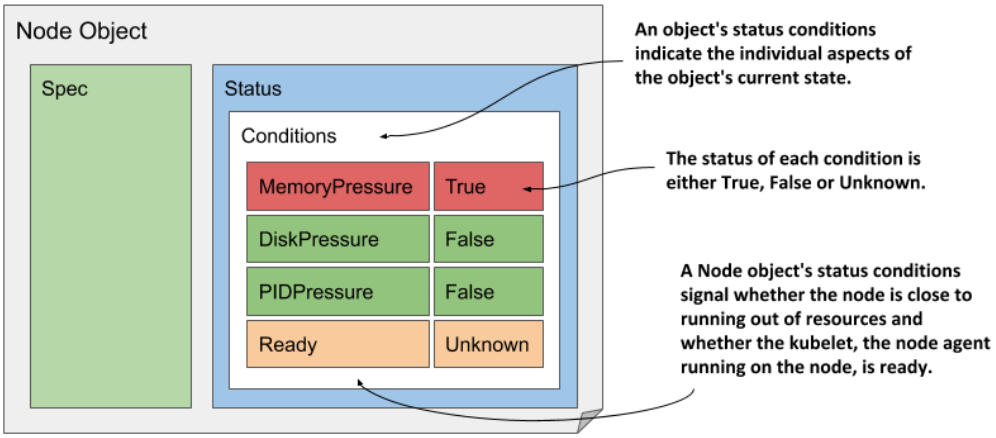


Figure 4.6 The status conditions indicating the state of a Node object

Although it's the last condition in the list, the `Ready` condition is probably the most important, as it signals whether the node is ready to accept new workloads (pods). The other conditions (`MemoryPressure`, `DiskPressure` and `PIDPressure`) signal whether the node is running out of resources. Remember to check these conditions if a node starts to behave strangely - for example, if the applications running on it start running out of resources and/or crash.

UNDERSTANDING CONDITIONS IN OTHER OBJECT KINDS

A condition list such as that in Node objects is also used in many other object kinds. The conditions explained earlier are a good example of why the state of most objects is represented by multiple conditions instead of a single field.

> **NOTE** Conditions are usually orthogonal, meaning that they represent unrelated aspects of the object.

If the state of an object were represented as a single field, it would be very difficult to subsequently extend it with new values, as this would require updating all clients that monitor the state of the object and perform actions based on it. Some object kinds originally used such a single field, and some still do, but most now use a list of conditions instead.

Since the focus of this chapter is to introduce the common features of the Kubernetes API objects, we've focused only on the `conditions` field, but it is far from being the only field in the status of the Node object. To explore the others, use the `kubectl explain` command as described in the previous sidebar. The fields that are not immediately easy for you to understand should become clear to you after reading the remaining chapters in this part of the book.

> **NOTE** As an exercise, use the command `kubectl get <kind> <name> -o yaml` to explore the other objects you've created so far (deployments, services, and pods).

4.2.4 Inspecting objects using the kubectl describe command

To give you a correct impression of the entire structure of the Kubernetes API objects, it was necessary to show you the complete YAML manifest of an object. While I personally often use this method to inspect an object, a more user-friendly way to inspect an object is the `kubectl describe` command, which typically displays the same information or sometimes even more.

UNDERSTANDING THE KUBECTL DESCRIBE OUTPUT FOR A NODE OBJECT

Let's try running the `kubectl describe` command on a Node object. To keep things interesting, let's now take one of the worker nodes instead of the master. The following listing shows what the `kubectl describe` command displays for one of my two worker nodes.

Listing 4.6 Inspecting a Node object with kubectl describe

```
$ kubectl describe node kind-worker-2
Name:               kind-worker2
Roles:              <none>
Labels:             beta.kubernetes.io/arch=amd64
                    beta.kubernetes.io/os=linux
                    kubernetes.io/arch=amd64
                    kubernetes.io/hostname=kind-worker2
                    kubernetes.io/os=linux
Annotations:        kubeadm.alpha.kubernetes.io/cri-socket: /run/contain...
                    node.alpha.kubernetes.io/ttl: 0
```

```
                    volumes.kubernetes.io/controller-managed-attach-deta...
CreationTimestamp:  Sun, 03 May 2020 17:09:48 +0200
Taints:             <none>
Unschedulable:      false
Lease:
  HolderIdentity:  kind-worker2
  AcquireTime:     <unset>
  RenewTime:       Sun, 17 May 2020 16:15:03 +0200
Conditions:
  Type             Status  ...  Reason                       Message
  ----             ------  ---  ------                       -------
  MemoryPressure   False   ...  KubeletHasSufficientMemory   ...
  DiskPressure     False   ...  KubeletHasNoDiskPressure     ...
  PIDPressure      False   ...  KubeletHasSufficientPID      ...
  Ready            True    ...  KubeletReady                 ...
Addresses:
  InternalIP:  172.18.0.4
  Hostname:    kind-worker2
Capacity:
  cpu:                8
  ephemeral-storage:  401520944Ki
  hugepages-1Gi:      0
  hugepages-2Mi:      0
  memory:             32720824Ki
  pods:               110
Allocatable:
  ...
System Info:
  ...
PodCIDR:                      10.244.1.0/24
PodCIDRs:                     10.244.1.0/24
Non-terminated Pods:          (2 in total)
  Namespace     Name               CPU Requests  CPU Limits  ...  AGE
  ---------     ----               ------------  ----------  ...  ---
  kube-system   kindnet-4xmjh      100m (1%)     100m (1%)   ...  13d
  kube-system   kube-proxy-dgkfm   0 (0%)        0 (0%)      ...  13d
Allocated resources:
  (Total limits may be over 100 percent, i.e., overcommitted.)
  Resource           Requests   Limits
  --------           --------   ------
  cpu                100m (1%)  100m (1%)
  memory             50Mi (0%)  50Mi (0%)
  ephemeral-storage  0 (0%)     0 (0%)
  hugepages-1Gi      0 (0%)     0 (0%)
  hugepages-2Mi      0 (0%)     0 (0%)
Events:
  Type    Reason                   Age    From                     Message
  ----    ------                   ----   ----                     -------
  Normal  Starting                 3m50s  kubelet, kind-worker2    ...
  Normal  NodeAllocatableEnforced  3m50s  kubelet, kind-worker2    ...
  Normal  NodeHasSufficientMemory  3m50s  kubelet, kind-worker2    ...
  Normal  NodeHasNoDiskPressure    3m50s  kubelet, kind-worker2    ...
  Normal  NodeHasSufficientPID     3m50s  kubelet, kind-worker2    ...
  Normal  Starting                 3m49s  kube-proxy, kind-worker2 ...
```

As you can see, the `kubectl describe` command displays all the information you previously found in the YAML manifest of the Node object, but in a more readable form. You can see the

name, IP address, and hostname, as well as the conditions and available capacity of the node.

INSPECTING OTHER OBJECTS RELATED TO THE NODE

In addition to the information stored in the Node object itself, the `kubectl describe` command also displays the pods running on the node and the total amount of compute resources allocated to them. Below is also a list of events related to the node.

This additional information isn't found in the Node object itself, but is collected by the kubectl tool from other API objects. For example, the list of pods running on the node is obtained by retrieving Pod objects via the `pods` resource.

If you run the `describe` command yourself, no events may be displayed. This is because only events that have occurred recently are shown. For Node objects, unless the node has resource capacity issues, you'll only see events if you've recently (re)started the node.

Virtually every API object kind has events associated with it. Since they are crucial for debugging a cluster, they warrant a closer look before you start exploring other objects.

4.3 Observing cluster events via Event objects

As controllers perform their task of reconciling the actual state of an object with the desired state, as specified in the object's `spec` field, they generate events to reveal what they have done. Two types of events exist: Normal and Warning. Events of the latter type are usually generated by controllers when something prevents them from reconciling the object. By monitoring this type of events, you can be quickly informed of any problems that the cluster encounters.

4.3.1 Introducing the Event object

Like everything else in Kubernetes, events are represented by Event objects that are created and read via the Kubernetes API. As the following figure shows, they contain information about what happened to the object and what the source of the event was. Unlike other objects, each Event object is deleted one hour after its creation to reduce the burden on etcd, the data store for Kubernetes API objects.

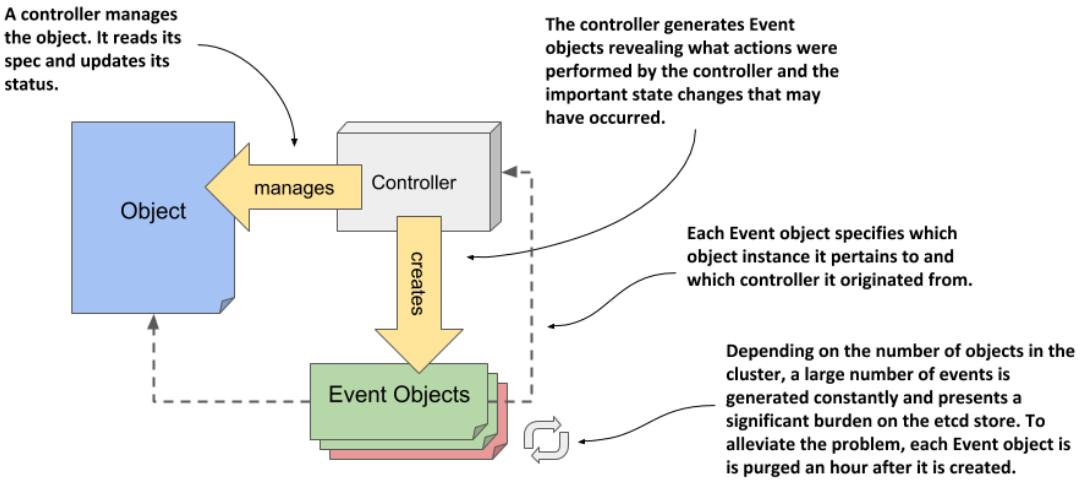


Figure 4.7 The relationship between Event objects, controllers, and other API objects.

NOTE The amount of time to retain events is configurable via the API server's command-line options.

LISTING EVENTS USING KUBECTL GET EVENTS

The events displayed by `kubectl describe` refer to the object you specify as the argument to the command. Due to their nature and the fact that many events can be created for an object in a short time, they aren't part of the object itself. You won't find them in the object's YAML manifest, as they exist on their own, just like Nodes and the other objects you've seen so far.

NOTE If you want to follow the exercises in this section in your own cluster, you may need to restart one of the nodes to ensure that the events are recent enough to still be present in etcd. If you can't do this, don't worry, and just skip doing these exercises yourself, as you'll also be generating and inspecting events in the exercises in the next chapter.

Because Events are standalone objects, you can list them using `kubectl get events`, as shown in the next listing.

Listing 4.7 Listing events using kubectl get events

```
$ kubectl get ev
LAST
SEEN   TYPE    REASON                   OBJECT             MESSAGE
48s    Normal  Starting                 node/kind-worker2  Starting kubelet.
48s    Normal  NodeAllocatableEnforced  node/kind-worker2  Updated Node A...
48s    Normal  NodeHasSufficientMemory  node/kind-worker2  Node kind-work...
48s    Normal  NodeHasNoDiskPressure    node/kind-worker2  Node kind-work...
48s    Normal  NodeHasSufficientPID     node/kind-worker2  Node kind-work...
47s    Normal  Starting                 node/kind-worker2  Starting kube-...
```

NOTE The previous listing uses the short name `ev` in place of `events`.

You'll notice that some events displayed in the listing match the status conditions of the Node. This is often the case, but you'll also find additional events. The two events with the reason `Starting` are two such examples. In the case at hand, they signal that the Kubelet and the Kube Proxy components have been started on the node. You don't need to worry about these components yet. They are explained in the third part of the book.

UNDERSTANDING WHAT'S IN AN EVENT OBJECT

As with other objects, the `kubectl get` command only outputs the most important object data. To display additional information, you can enable additional columns by executing the command with the `-o wide` option:

```
$ kubectl get ev -o wide
```

The output of this command is extremely wide and is not listed here in the book. Instead, the information that is displayed is explained in the following table.

Property	Description
Name	The name of this Event object instance. Useful only if you want to retrieve the given object from the API.
Type	The type of the event. Either `Normal` or `Warning`.
Reason	The machine-facing description why the event occurred.
Source	The component that reported this event. This is usually a controller.
Object	The object instance to which the event refers. For example, node/xyz.
Sub-object	The sub-object to which the event refers. For example, what container of the pod.
Message	The human-facing description of the event.
First seen	The first time this event occurred. Remember that each Event object is deleted after a while, so this may not be the first time that the event actually occurred.
Last seen	Events often occur repeatedly. This field indicates when this event last occurred.
Count	The number of times this event has occurred.

Table 4.1 Properties of the Event object

TIP As you complete the exercises throughout this book, you may find it useful to run the `kubectl get events` command each time you make changes to one of your objects. This will help you learn what happens beneath the surface.

DISPLAYING ONLY WARNING EVENTS

Unlike the `kubectl describe` command, which only displays events related to the object you're describing, the `kubectl get events` command displays all events. This is useful if

you want to check if there are events that you should be concerned about. You may want to ignore events of type `Normal` and focus only on those of type `Warning`.

The API provides a way to filter objects through a mechanism called field selectors. Only objects where the specified field matches the specified selector value are returned. You can use this to display only Warning events. The `kubectl get` command allows you to specify the field selector with the `--field-selector` option. To list only events that represent warnings, you execute the following command:

```
$ kubectl get ev --field-selector type=Warning
No resources found in default namespace.
```

If the command does not print any events, as in the above case, no warnings have been recorded in your cluster recently.

You may wonder how I knew the exact name of the field to be used in the field selector and what its exact value should be (perhaps it should have been lower case, for example). Hats off if you guessed that this information is provided by the `kubectl explain events` command. Since events are regular API objects, you can use it to look up documentation on the event objects' structure. There you'll learn that the `type` field can have two values: either `Normal` or `Warning`.

4.3.2 Examining the YAML of the Event object

To inspect the events in your cluster, the commands `kubectl describe` and `kubectl get events` should be sufficient. Unlike other objects, you'll probably never have to display the complete YAML of an Event object. But I'd like to take this opportunity to show you an annoying thing about Kubernetes object manifests that the API returns.

EVENT OBJECTS HAVE NO SPEC AND STATUS SECTIONS

If you use the `kubectl explain` to explore the structure of the Event object, you'll notice that it has no `spec` or `status` sections. Unfortunately, this means that its fields are not as nicely organized as in the Node object, for example.

Inspect the following listing and see if you can easily find the object kind, metadata and other fields.

Listing 4.8 The YAML manifest of an Event object

```
apiVersion: v1                                                    #A
count: 1
eventTime: null
firstTimestamp: "2020-05-17T18:16:40Z"
involvedObject:
  kind: Node
  name: kind-worker2
  uid: kind-worker2
kind: Event                                                       #B
lastTimestamp: "2020-05-17T18:16:40Z"
message: Starting kubelet.
metadata:                                                         #C
  creationTimestamp: "2020-05-17T18:16:40Z"                       #C
```

```
  managedFields:                                                    #C
  - ...                                                             #C
  name: kind-worker2.160fe38fc0bc3703            #D                 #C
  namespace: default                                                #C
  resourceVersion: "3528471"                                        #C
  selfLink: /api/v1/namespaces/default/events/kind-worker2.160f...  #C
  uid: da97e812-d89e-4890-9663-091fd1ec5e2d                         #C
reason: Starting
reportingComponent: ""
reportingInstance: ""
source:
  component: kubelet
  host: kind-worker2
type: Normal
```

#A The apiVersion field is easy to spot
#B The kind field is hard to find
#C The object's metadata is here
#D The object's name is hidden here

You will surely agree that the YAML manifest in the listing is disorganized. The fields are listed alphabetically instead of being organized into coherent groups. This makes it difficult for us humans to read. It looks so chaotic that it's no wonder that many people hate to deal with Kubernetes YAML or JSON manifests, since both suffer from this problem.

In contrast, the earlier YAML manifest of the Node object was relatively easy to read, because the order of the top-level fields is what one would expect: `apiVersion`, `kind`, `metadata`, `spec`, and `status`. You'll notice that this is simply because the alphabetical order of the five fields just happens to make sense. But the fields under those fields suffer from the same problem, as they are also sorted alphabetically.

YAML is supposed to be easy for people to read, but the alphabetical field order in Kubernetes YAML breaks this. Fortunately, most objects contain the `spec` and `status` sections, so at least the top-level fields in these objects are well organized. As for the rest, you'll just have to accept this unfortunate aspect of dealing with Kubernetes manifests.

4.4 Summary

In this chapter, you've learned:

- Kubernetes provides a RESTful API for interaction with a cluster. API Objects map to actual components that make up the cluster, including applications, load balancers, nodes, storage volumes, and many others.
- An object instance can be represented by many resources. A single object type can be exposed through several resources that are just different representations of the same thing.
- Kubernetes API objects are described in YAML or JSON manifests. Objects are created by posting a manifest to the API. The status of the object is stored in the object itself and can be retrieved by requesting the object from the API with a `GET` request.
- All Kubernetes API objects contain Type and Object Metadata, and most have a `spec` and `status` sections. A few object types don't have these two sections, because they

only contain static data.

- Controllers bring objects to life by constantly watching for changes in their `spec`, updating the cluster state and reporting the current state via the object's `status` field.
- As controllers manage Kubernetes API objects, they emit events to reveal what actions they have performed. Like everything else, events are represented by Event objects and can be retrieved through the API. Events signal what is happening to a Node or other object. They show what has recently happened to the object and can provide clues as to why it is broken.
- The `kubectl explain` command provides a quick way to look up documentation on a specific object kind and its fields from the command line.
- The status in a Node object contains information about the node's IP address and hostname, its resource capacity, conditions, cached container images and other information about the node. Which pods are running on the node is not part of the node's status, but the `kubectl describe node` commands gets this information from the `pods` resource.
- Many object types use status conditions to signal the state of the component that the object represents. For nodes, these conditions are `MemoryPressure`, `DiskPressure` and `PIDPressure`. Each condition is either `True`, `False`, or `Unknown` and has an associated `reason` and `message` that explain why the condition is in the specified state.

You should now be familiar with the general structure of the Kubernetes API objects. In the next chapter, you'll learn about the Pod object, the fundamental building block which represents one running instance of your application.

5

Running applications in Pods

This chapter covers

- Understanding how and when to group containers
- Running an application by creating a Pod object from a YAML file
- Communicating with an application, viewing its logs, and exploring its environment
- Adding a sidecar container to extend the pod's main container
- Initializing pods by running init containers at pod startup

Let me refresh your memory with a diagram that shows the three types of objects you created in chapter 3 to deploy a minimal application on Kubernetes. Figure 5.1 shows how they relate to each other and what functions they have in the system.

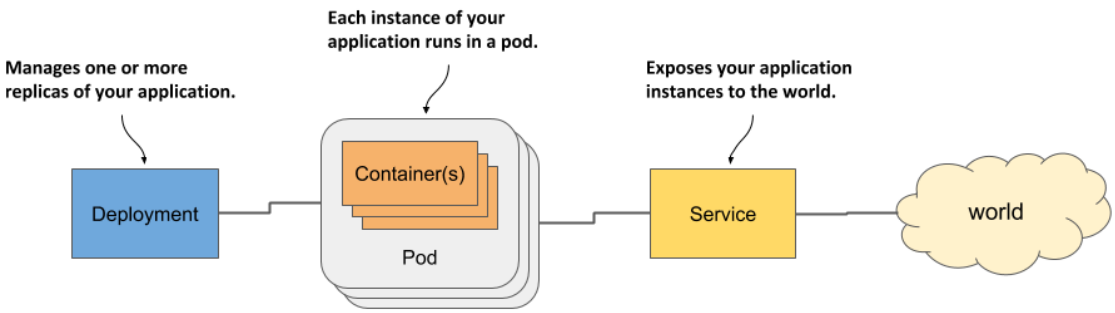


Figure 5.1 Three basic object types comprising a deployed application

You now have a basic understanding of how these objects are exposed via the Kubernetes API. In this and the following chapters, you'll learn about the specifics of each of them and

many others that are typically used to deploy a full application. Let's start with the Pod object, as it represents the central, most important concept in Kubernetes - a running instance of your application.

5.1 Understanding pods

You've already learned that a pod is a co-located group of containers and the basic building block in Kubernetes. Instead of deploying containers individually, you deploy and manage a group of containers as a single unit — a pod. Although pods may contain several, it's not uncommon for a pod to contain just a single container. When a pod has multiple containers, all of them run on the same worker node — a single pod instance never spans multiple nodes. Figure 5.2 will help you visualize this information.

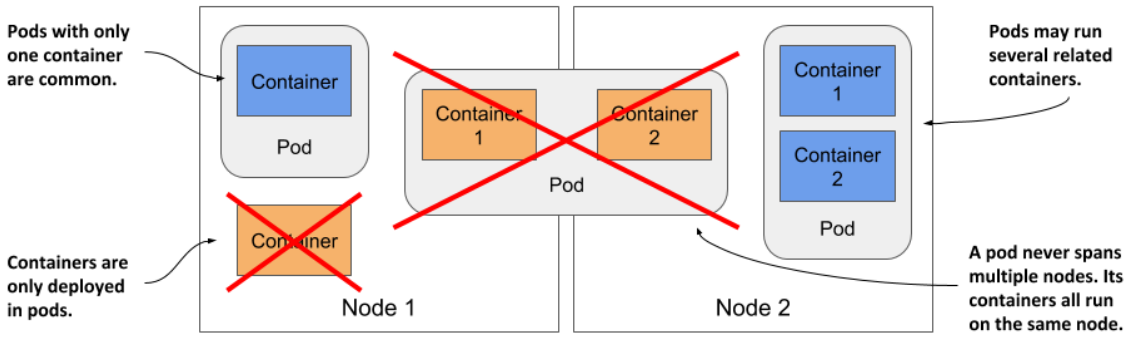


Figure 5.2 All containers of a pod run on the same node. A pod never spans multiple nodes.

5.1.1 Understanding why we need pods

Let's discuss why we need to run multiple containers together, as opposed to, for example, running multiple processes in the same container.

UNDERSTANDING WHY ONE CONTAINER SHOULDN'T CONTAIN MULTIPLE PROCESSES

Imagine an application that consists of several processes that communicate with each other via *IPC* (Inter-Process Communication) or shared files, which requires them to run on the same computer. In chapter 2, you learned that each container is like an isolated computer or virtual machine. A computer typically runs several processes; containers can also do this. You can run all the processes that make up an application in just one container, but that makes the container very difficult to manage.

Containers are *designed* to run only a single process, not counting any child processes that it spawns. Both container tooling and Kubernetes were developed around this fact. For example, a process running in a container is expected to write its logs to standard output. Docker and Kubernetes commands that you use to display the logs only show what has been captured from this output. If a single process is running in the container, it's the only writer, but if you run multiple processes in the container, they all write to the same output. Their

logs are therefore intertwined, and it is difficult to tell which process each logged line belongs to.

Another indication that containers should only run a single process is the fact that the container runtime only restarts the container when the container's root process dies. It doesn't care about any child processes created by this root process. If it spawns child processes, it alone is responsible for keeping all these processes running.

To take full advantage of the features provided by the container runtime, you should consider running only one process in each container.

UNDERSTANDING HOW A POD COMBINES MULTIPLE CONTAINERS

Since you shouldn't run multiple processes in a single container, it's evident you need another higher-level construct that allows you to run related processes together even when divided into multiple containers. These processes must be able to communicate with each other like processes in a normal computer. And that is why pods were introduced.

With a pod, you can run closely related processes together, giving them (almost) the same environment as if they were all running in a single container. These processes are somewhat isolated, but not completely - they share some resources. This gives you the best of both worlds. You can use all the features that containers offer, but also allow processes to work together. A pod makes these interconnected containers manageable as one unit.

In the second chapter, you learned that a container uses its own set of Linux namespaces, but it can also share some with other containers. This sharing of namespaces is exactly how Kubernetes and the container runtime combine containers into pods.

As shown in figure 5.3, all containers in a pod share the same Network namespace and thus the network interfaces, IP address(es) and port space that belong to it.

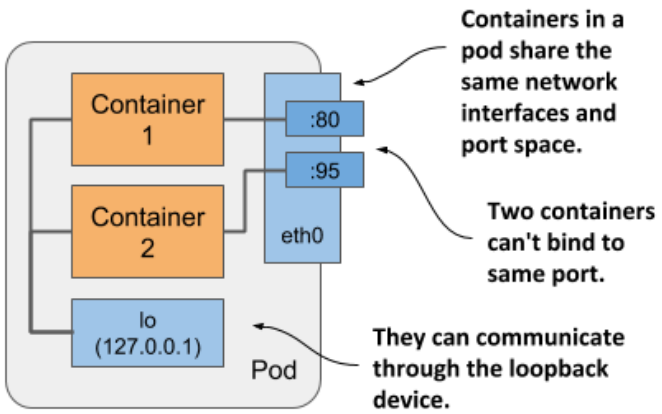


Figure 5.3 Containers in a pod share the same network interfaces

Because of the shared port space, processes running in containers of the same pod can't be bound to the same port numbers, whereas processes in other pods have their own network interfaces and port spaces, eliminating port conflicts between different pods.

All the containers in a pod also see the same system hostname, because they share the UTS namespace, and can communicate through the usual IPC mechanisms because they share the IPC namespace. A pod can also be configured to use a single PID namespace for all its containers, which makes them share a single process tree, but you must explicitly enable this for each pod individually.

> **NOTE** When containers of the same pod use separate PID namespaces, they can't see each other or send process signals like `SIGTERM` or `SIGINT` between them.

It's this sharing of certain namespaces that gives the processes running in a pod the impression that they run together, even though they run in separate containers.

In contrast, each container always has its own Mount namespace, giving it its own file system, but when two containers must share a part of the file system, you can add a *volume* to the pod and mount it into both containers. The two containers still use two separate Mount namespaces, but the shared volume is mounted into both. You'll learn more about volumes in chapter 7.

5.1.2 Organizing containers into pods

You can think of each pod as a separate computer. Unlike virtual machines, which typically host multiple applications, you typically run only one application in each pod. You never need to combine multiple applications in a single pod, as pods have almost no resource overhead. You can have as many pods as you need, so instead of stuffing all your applications into a single pod, you should divide them so that each pod runs only closely related application processes.

Let me illustrate this with a concrete example.

SPLITTING A MULTI-TIER APPLICATION STACK INTO MULTIPLE PODS

Imagine a simple system composed of a front-end web server and a back-end database. I've already explained that the front-end server and the database shouldn't run in the same container, as all the features built into containers were designed around the expectation that not more than one process runs in a container. If not in a single container, should you then run them in separate containers that are all in the same pod?

Although nothing prevents you from running both the front-end server and the database in a single pod, this isn't the best approach. I've explained that all containers of a pod always run co-located, but do the web server and the database have to run on the same computer? The answer is obviously no, as they can easily communicate over the network. Therefore you shouldn't run them in the same pod.

If both the front-end and the back-end are in the same pod, both run on the same cluster node. If you have a two-node cluster and only create this one pod, you are using only a single worker node and aren't taking advantage of the computing resources available on the second node. This means wasted CPU, memory, disk storage and bandwidth. Splitting the

containers into two pods allows Kubernetes to place the front-end pod on one node and the back-end pod on the other, thereby improving the utilization of your hardware.

SPLITTING INTO MULTIPLE PODS TO ENABLE INDIVIDUAL SCALING

Another reason not to use a single pod has to do with horizontal scaling. A pod is not only the basic unit of deployment, but also the basic unit of scaling. In chapter 2 you scaled the Deployment object and Kubernetes created additional pods – additional replicas of your application. Kubernetes doesn't replicate containers within a pod. It replicates the entire pod.

Front-end components usually have different scaling requirements than back-end components, so we typically scale them individually. When your pod contains both the front-end and back-end containers and Kubernetes replicates it, you end up with multiple instances of both the front-end and back-end containers, which isn't always what you want. Stateful back-ends, such as databases, usually can't be scaled. At least not as easily as stateless front ends. If a container has to be scaled separately from the other components, this is a clear indication that it must be deployed in a separate pod.

The following figure illustrates what was just explained.

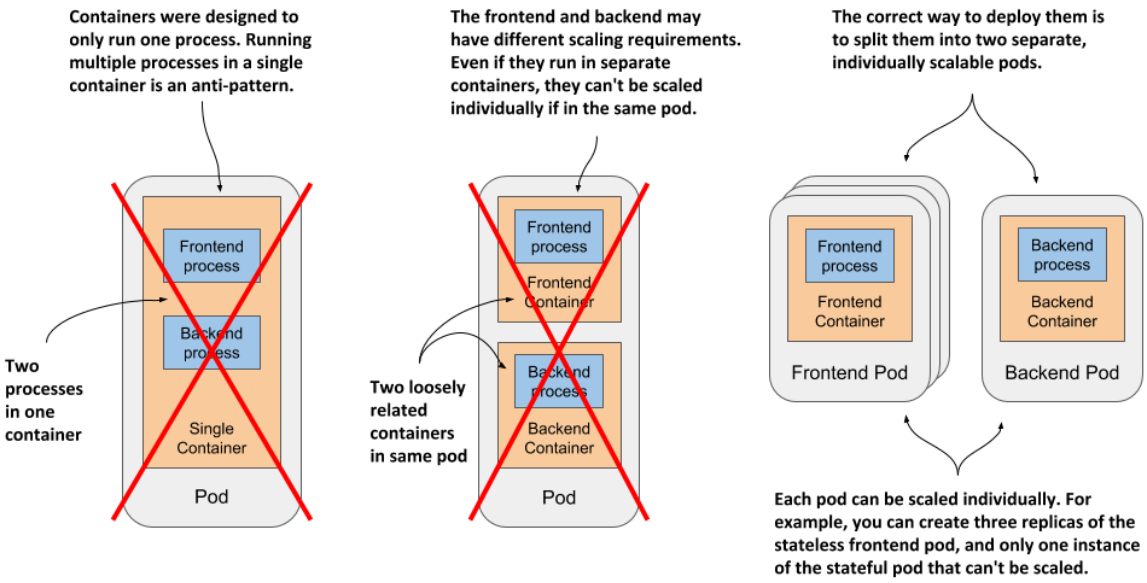


Figure 5.4 Splitting an application stack into pods

Splitting application stacks into multiple pods is the correct approach. But then, when does one run multiple containers in the same pod?

INTRODUCING SIDECAR CONTAINERS

Placing several containers in a single pod is only appropriate if the application consists of a primary process and one or more processes that complement the operation of the primary

process. The container in which the complementary process runs is called a *sidecar container* because it's analogous to a motorcycle sidecar, which makes the motorcycle more stable and offers the possibility of carrying an additional passenger. But unlike motorcycles, a pod can have more than one sidecar, as shown in figure 5.5.

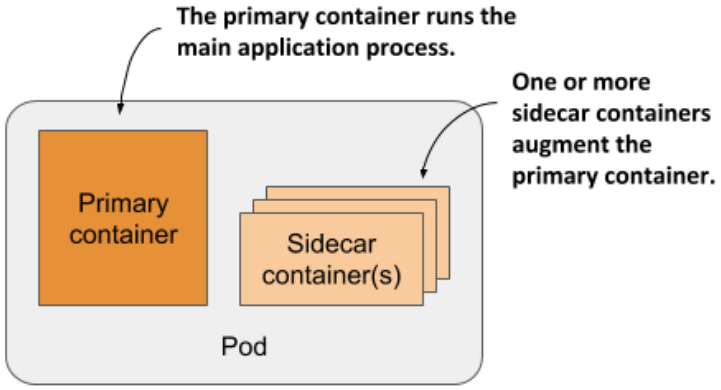


Figure 5.5 A pod with a primary and sidecar container(s)

It's difficult to imagine what constitutes a complementary process, so I'll give you some examples. In chapter 2, you deployed pods with one container that runs a Node.js application. The Node.js application only supports the HTTP protocol. To make it support HTTPS, we could add a bit more JavaScript code, but we can also do it without changing the existing application at all - by adding an additional container to the pod – a reverse proxy that converts HTTPS traffic to HTTP and forwards it to the Node.js container. The Node.js container is thus the primary container, whereas the container running the proxy is the sidecar container. Figure 5.6 shows this example.

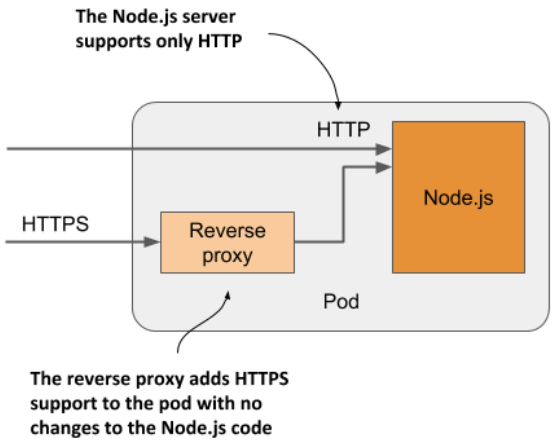


Figure 5.6 A sidecar container that converts HTTPS traffic to HTTP

NOTE You'll create this pod in section 5.4.

Another example, shown in figure 5.7, is a pod where the primary container runs a web server that serves files from its webroot directory. The other container in the pod is an agent that periodically downloads content from an external source and stores it in the web server's webroot directory. As I mentioned earlier, two containers can share files by sharing a volume. The webroot directory would be located on this volume.

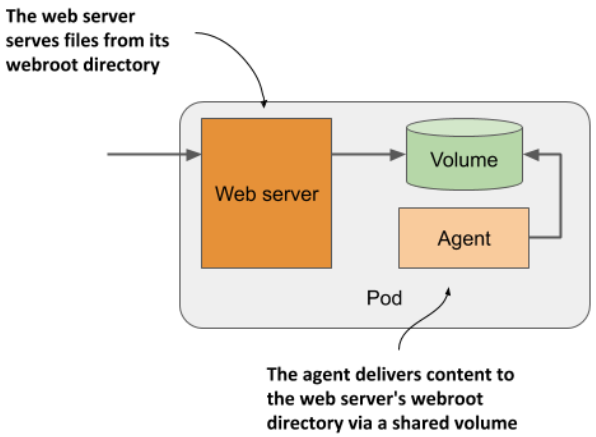


Figure 5.7 A sidecar container that delivers content to the web server container via a volume

NOTE You'll create this pod in the chapter 7.

Other examples of sidecar containers are log rotators and collectors, data processors, communication adapters, and others.

Unlike changing the application's existing code, adding a sidecar increases the pod's resources requirements because an additional process must run in the pod. But keep in mind that adding code to legacy applications can be very difficult. This could be because its code is difficult to modify, it's difficult to set up the build environment, or the source code itself is no longer available. Extending the application by adding an additional process is sometimes a cheaper and faster option.

HOW TO DECIDE WHETHER TO SPLIT CONTAINERS INTO MULTIPLE PODS

When deciding whether to use the sidecar pattern and place containers in a single pod, or to place them in separate pods, ask yourself the following questions:

- Do these containers have to run on the same host?
- Do I want to manage them as a single unit?
- Do they form a unified whole instead of being independent components?
- Do they have to be scaled together?
- Can a single node meet their combined resource needs?

If the answer to all these questions is yes, put them all in the same pod. As a rule of thumb, always place containers in separate pods unless a specific reason requires them to be part of the same pod.

5.2 Creating pods from YAML or JSON files

With the information you learned in the previous sections, you can now start creating pods. In chapter 3, you created them using the imperative command `kubectl create`, but pods and other Kubernetes objects are usually created by creating a JSON or YAML manifest file and posting it to the Kubernetes API, as you've already learned in the previous chapter.

> **NOTE** The decision whether to use YAML or JSON to define your objects is yours. Most people prefer to use YAML because it's slightly more human-friendly and allows you to add comments to the object definition.

By using YAML files to define the structure of your application, you don't need shell scripts to make the process of deploying your applications repeatable, and you can keep a history of all changes by storing these files in a VCS (Version Control System). Just like you store code.

In fact, the application manifests of the exercises in this book are all stored in a VCS. You can find them on GitHub at github.com/luksa/kubernetes-in-action-2ed.

5.2.1 Creating a YAML manifest for a pod

In the previous chapter you learned how to retrieve and examine the YAML manifests of existing API objects. Now you'll create an object manifest from scratch.

You'll start by creating a file called `kubia.yaml` on your computer, in a file directory of your choice. You can also find the file in the book's code archive, available on GitHub. The file is in the `Chapter04/` directory. The following listing shows its contents.

Listing 5.1 A basic pod manifest: kubia.yaml

```
apiVersion: v1                #A
kind: Pod                     #B
metadata:
  name: kubia                 #C
spec:
  containers:
  - name: kubia               #D
    image: luksa/kubia:1.0    #E
    ports:
    - containerPort: 8080     #F
```

#A This manifest uses the v1 API version to define the object
#B The object specified in this manifest is a pod
#C The name of the pod
#D The name of the container
#E Container image to create the container from
#F The port the app is listening on

I'm sure you'll agree that this pod manifest is much easier to understand than the mammoth of a manifest representing the Node object, which you saw in the previous chapter. But once you post this pod object manifest to the API and then read it back, it won't be much different.

The manifest in listing 5.1 is short only because it does not yet contain all the fields that a pod object gets after it is created through the API. For example, you'll notice that the `metadata` section contains only a single field and that the `status` section is completely missing. Once you create the object from this manifest, this will no longer be the case. But we'll get to that later.

Before you create the object, let's examine the manifest in detail. It uses version `v1` of the Kubernetes API to describe the object. The object is a `Pod` called `kubia`. The pod consists of a single container called `kubia`, based on the `luksa/kubia:1.0` image. The pod definition also specifies that the application in the container listens on port `8080`.

> **TIP** Whenever you want to create a pod manifest from scratch, you can also use the following command to create the file and then edit it to add more fields: `kubectl run kubia --image=luksa/kubia:1.0 --dry-run=client -o yaml > mypod.yaml`. The `--dry-run=client` flag tells kubectl to output the definition instead of actually creating the object via the API.

The fields in the YAML file are self-explanatory, but if you want more information about each field or want to know what additional fields you can add, remember to use the `kubectl explain pods` command.

5.2.2 Creating the Pod object from the YAML file

After you've prepared the manifest file for your pod, you can now create the object by posting the file to the Kubernetes API.

CREATING OBJECTS BY APPLYING THE MANIFEST FILE TO THE CLUSTER

When you post the manifest to the API, you are directing Kubernetes to *apply* the manifest to the cluster. That's why the `kubectl` sub-command that does this is called `apply`. Let's use it to create the pod:

```
$ kubectl apply -f kubia.yaml
pod "kubia" created
```

UPDATING OBJECTS BY MODIFYING THE MANIFEST FILE AND RE-APPLYING IT

The `kubectl apply` command is used for creating objects as well as for making changes to existing objects. If you later decide to make changes to your pod object, you can simply edit the `kubia.yaml` file and run the apply command again. Some of the pod's fields aren't mutable, so the update may fail, but you can always delete the pod and then create it again. You'll learn how to delete pods and other objects at the end of this chapter.

Retrieving the full manifest of a running pod

The pod object is now part of the cluster configuration. You can now read it back from the API to see the full object manifest with the following command:

```
$ kubectl get po kubia -o yaml
```

If you run this command, you'll notice that the manifest has grown considerably compared to the one in the `kubia.yaml` file. You'll see that the `metadata` section is now much bigger, and the object now has a `status` section. The `spec` section has also grown by several fields. You can use `kubectl explain` to learn more about these new fields, but most of them will be explained in this and the following chapters.

5.2.3 Checking the newly created pod

Let's use the basic `kubectl` commands to see how the pod is doing before we start interacting with the application running inside it.

QUICKLY CHECKING THE STATUS OF A POD

Your Pod object has been created, but how do you know if the container in the pod is actually running? You can use the `kubectl get` command to see a summary of the pod:

```
$ kubectl get pod kubia
NAME     READY   STATUS    RESTARTS   AGE
kubia    1/1     Running   0          32s
```

You can see that the pod is running, but not much else. To see more, you can try the `kubectl get pod -o wide` or the `kubectl describe` command that you learned in the previous chapter.

USING KUBECTL DESCRIBE TO SEE POD DETAILS

To display a more detailed view of the pod, use the `kubectl describe` command:

Listing 5.2 Using kubectl describe pod to inspect a pod

```
$ kubectl describe pod kubia
Name:         kubia
Namespace:    default
Priority:     0
Node:         worker2/172.18.0.4
Start Time:   Mon, 27 Jan 2020 12:53:28 +0100
...
```

The listing doesn't show the entire output, but if you run the command yourself, you'll see virtually all information that you'd see if you print the complete object manifest using the `kubectl get -o yaml` command.

INSPECTING EVENTS TO SEE WHAT HAPPENS BENEATH THE SURFACE

As in the previous chapter where you used the `describe node` command to inspect a Node object, the `describe pod` command should display several events related to the pod at the bottom of the output.

If you remember, these events aren't part of the object itself, but are separate objects. Let's print them to learn more about what happens when you create the pod object. The following listing shows all the events that were logged after creating the pod.

Listing 5.3 Events recorded after deploying a Pod object

```
$ kubectl get events
LAST SEEN   TYPE     REASON      OBJECT      MESSAGE
<unknown>   Normal   Scheduled   pod/kubia   Successfully assigned default/
                                             kubia to worker2
5m          Normal   Pulling     pod/kubia   Pulling image luksa/kubia:1.0
5m          Normal   Pulled      pod/kubia   Successfully pulled image
5m          Normal   Created     pod/kubia   Created container kubia
5m          Normal   Started     pod/kubia   Started container kubia
```

These events are printed in chronological order. The most recent event is at the bottom. You see that the pod was first assigned to one of the worker nodes, then the container image was pulled, then the container was created and finally started.

No warning events are displayed, so everything seems to be fine. If this is not the case in your cluster, you should read section 5.4 to learn how to troubleshoot pod failures.

5.3 Interacting with the application and the pod

Your container is now running. In this section, you'll learn how to communicate with the application, inspect its logs, and execute commands in the container to explore the application's environment. Let's confirm that the application running in the container responds to your requests.

5.3.1 Sending requests to the application in the pod

In chapter 2, you used the `kubectl expose` command to create a service that provisioned a load balancer so you could talk to the application running in your pod(s). You'll now take a

different approach. For development, testing and debugging purposes, you may want to communicate directly with a specific pod, rather than using a service that forwards connections to randomly selected pods.

You've learned that each pod is assigned its own IP address where it can be accessed by every other pod in the cluster. This IP address is typically internal to the cluster. You can't access it from your local computer, except when Kubernetes is deployed in a specific way – for example, when using kind or Minikube without a VM to create the cluster.

In general, to access pods, you must use one of the methods described in the following sections. First, let's determine the pod's IP address.

GETTING THE POD'S IP ADDRESS

You can get the pod's IP address by retrieving the pod's full YAML and searching for the `podIP` field in the `status` section. Alternatively, you can display the IP with `kubectl describe`, but the easiest way is to use `kubectl get` with the `wide` output option:

```
$ kubectl get pod kubia -o wide
NAME    READY   STATUS    RESTARTS   AGE   IP           NODE      ...
kubia   1/1     Running   0          35m   10.244.2.4   worker2   ...
```

As indicated in the IP column, my pod's IP is `10.244.2.4`. Now I need to determine the port number the application is listening on.

GETTING THE PORT THE APPLICATION IS BOUND TO

If I wasn't the author of the application, it would be difficult for me to find out which port the application listens on. I could inspect its source code or the Dockerfile of the container image, as the port is usually specified there, but I might not have access to either. If someone else had created the pod, how would I know which port it was listening on?

Fortunately, you can specify a list of ports in the pod definition itself. It isn't necessary to specify any ports, but it is a good idea to always do so. See sidebar for details.

Why specify container ports in pod definitions

Specifying ports in the pod definition is purely informative. Their omission has no effect on whether clients can connect to the pod's port. If the container accepts connections through a port bound to its IP address, anyone can connect to it, even if the port isn't explicitly specified in the pod spec or if you specify an incorrect port number. Despite this, it's a good idea to always specify the ports so that anyone who has access to your cluster can see which ports each pod exposes. By explicitly defining ports, you can also assign a name to each port, which is very useful when you expose pods via services.

The pod manifest says that the container uses port 8080, so you now have everything you need to talk to the application.

CONNECTING TO THE POD FROM THE WORKER NODES

The Kubernetes network model dictates that each pod is accessible from any other pod and that each *node* can reach any pod on any node in the cluster.

Because of this, one way to communicate with your pod is to log into one of your worker nodes and talk to the pod from there. You've already learned that the way you log on to a node depends on what you used to deploy your cluster. In Minikube, you can run `minikube ssh` to log in to your single node. On GKE use the `gcloud compute ssh` command. For other clusters refer to their documentation.

Once you have logged into the node, use the `curl` command with the pod's IP and port to access your application. My pod's IP is 10.244.2.4 and the port is 8080, so I run the following command:

```
$ curl 10.244.2.4:8080
Hey there, this is kubia. Your IP is ::ffff:10.244.2.1.
```

Normally you don't use this method to talk to your pods, but you may need to use it if there are communication issues and you want to find the cause by first trying the shortest possible communication route. In this case, it's best to log into the node where the pod is located and run `curl` from there. The communication between it and the pod takes place locally, so this method always has the highest chances of success.

CONNECTING FROM A ONE-OFF CLIENT POD

The second way to test the connectivity of your application is to run `curl` in another pod that you create specifically for this task. Use this method to test if other pods will be able to access your pod. Even if the network works perfectly, this may not be the case. In chapter 24, you'll learn how to lock down the network by isolating pods from each other. In such a system, a pod can only talk to the pods it's allowed to.

To run `curl` in a one-off pod, use the following command:

```
$ kubectl run --image=tutum/curl -it --restart=Never --rm client-pod curl
10.244.2.4:8080
Hey there, this is kubia. Your IP is ::ffff:10.244.2.5.
pod "client-pod" deleted
```

This command runs a pod with a single container created from the `tutum/curl` image. You can also use any other image that provides the `curl` binary executable. The `-it` option attaches your console to the container's standard input and output, the `--restart=Never` option ensures that the pod is considered Completed when the `curl` command and its container terminate, and the `--rm` options removes the pod at the end. The name of the pod is `client-pod` and the command executed in its container is `curl 10.244.2.4:8080`.

> **NOTE** You can also modify the command to run the `bash` shell in the client pod and then run `curl` from the shell.

Creating a pod just to see if it can access another pod is useful when you're specifically testing pod-to-pod connectivity. If you only want to know if your pod is responding to requests, you can also use the method explained in the next section.

CONNECTING TO PODS VIA KUBECTL PORT FORWARDING

During development, the easiest way to talk to applications running in your pods is to use the `kubectl port-forward` command, which allows you to communicate with a specific pod through a proxy bound to a network port on your local computer, as shown in the next figure.

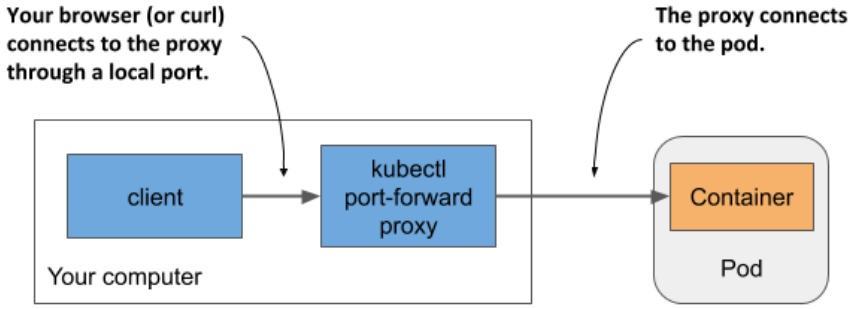


Figure 5.8 Connecting to a pod through the kubectl port-forward proxy

To open a communication path with a pod, you don't even need to look up the pod's IP, as you only need to specify its name and the port. The following command starts a proxy that forwards your computer's local port `8080` to the `kubia` pod's port `8080`:

```
$ kubectl port-forward kubia 8080
... Forwarding from 127.0.0.1:8080 -> 8080
... Forwarding from [::1]:8080 -> 8080
```

The proxy now waits for incoming connections. Run the following `curl` command in another terminal:

```
$ curl localhost:8080
Hey there, this is kubia. Your IP is ::ffff:127.0.0.1.
```

As you can see, `curl` has connected to the local proxy and received the response from the pod. While the `port-forward` command is the easiest method for communicating with a specific pod during development and troubleshooting, it's also the most complex method in terms of what happens underneath. Communication passes through several components, so if anything is broken in the communication path, you won't be able to talk to the pod, even if the pod itself is accessible via regular communication channels.

> **NOTE** The `kubectl port-forward` command can also forward connections to services instead of pods and has several other useful features. Run `kubectl port-forward --help` to learn more.

Figure 5.9 shows how the network packets flow from the `curl` process to your application and back.

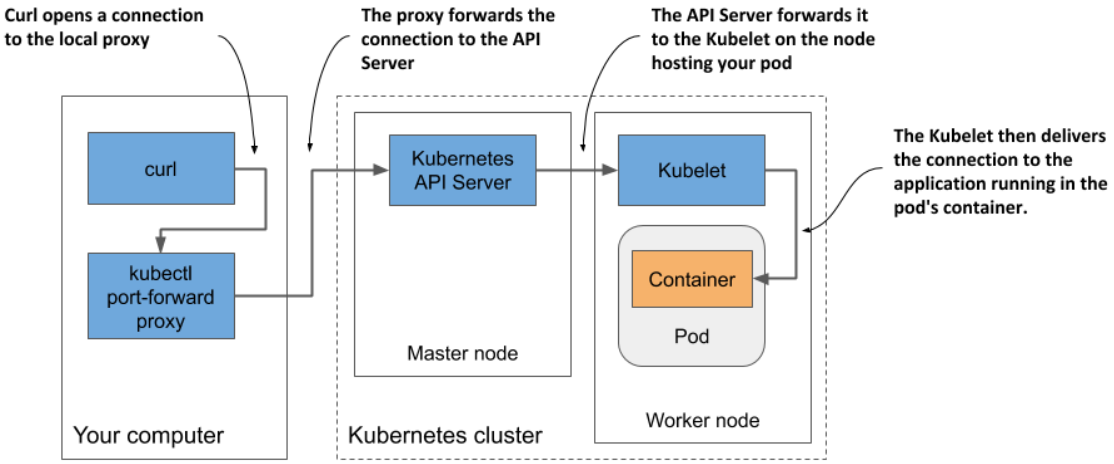


Figure 5.9 The long communication path between curl and the container when using port forwarding

As shown in the figure, the `curl` process connects to the proxy, which connects to the API server, which then connects to the Kubelet on the node that hosts the pod, and the Kubelet then connects to the container through the pod's loopback device (in other words, through the localhost address). I'm sure you'll agree that the communication path is exceptionally long.

> **NOTE** The application in the container must be bound to a port on the loopback device for the Kubelet to reach it. If it listens only on the pod's `eth0` network interface, you won't be able to reach it with the `kubectl port-forward` command.

5.3.2 Viewing application logs

Your Node.js application writes its log to the standard output stream. Instead of writing the log to a file, containerized applications usually log to the standard output (*stdout*) and standard error streams (*stderr*). This allows the container runtime to intercept the output, store it in a consistent location (usually `/var/log/containers`) and provide access to the log without having to know where each application stores its log files.

When you run an application in a container using Docker, you can display its log with `docker logs <container-id>`. When you run your application in Kubernetes, you could log into the node that hosts the pod and display its log using `docker logs`, but Kubernetes provides an easier way to do this with the `kubectl logs` command.

RETRIEVING A POD'S LOG WITH KUBECTL LOGS

To view the log of your pod (more specifically, the container's log), run the command shown in the following listing on your local computer:

Listing 5.4 Displaying a pod's log

```
$ kubectl logs kubia
Kubia server starting...
Local hostname is kubia
Listening on port 8080
Received request for / from ::ffff:10.244.2.1    #A
Received request for / from ::ffff:10.244.2.5    #B
Received request for / from ::ffff:127.0.0.1     #C
```

#A Request you sent from within the node
#B Request from the one-off client pod
#C Request sent through port forwarding

STREAMING LOGS USING KUBECTL LOGS -F

If you want to stream the application log in real-time to see each request as it comes in, you can run the command with the `--follow` option (or the shorter version `-f`):

```
$ kubectl logs kubia -f
```

Now send some additional requests to the application and have a look at the log. Press ctrl-C to stop streaming the log when you're done.

DISPLAYING THE TIMESTAMP OF EACH LOGGED LINE

You may have noticed that we forgot to include the timestamp in the log statement. Logs without timestamps have limited usability. Fortunately, the container runtime attaches the current timestamp to every line produced by the application. You can display these timestamps by using the `--timestamps=true` option, as shown in the next listing.

Listing 5.5 Displaying the timestamp of each log line

```
$ kubectl logs kubia --timestamps=true
2020-02-01T09:44:40.954641934Z Kubia server starting...
2020-02-01T09:44:40.955123432Z Local hostname is kubia
2020-02-01T09:44:40.956435431Z Listening on port 8080
2020-02-01T09:50:04.978043089Z Received request for / from ...
2020-02-01T09:50:33.640897378Z Received request for / from ...
2020-02-01T09:50:44.781473256Z Received request for / from ...
```

TIP You can display timestamps by only typing `--timestamps` without the value. For boolean options, merely specifying the option name sets the option to `true`. This applies to all kubectl options that take a Boolean value and default to `false`.

DISPLAYING RECENT LOGS

The previous feature is great if you run third-party applications that don't include the timestamp in their log output, but the fact that each line is timestamped brings us another benefit: filtering log lines by time. Kubectl provides two ways of filtering the logs by time.

The first option is when you want to only display logs from the past several seconds, minutes or hours. For example, to see the logs produced in the last two minutes, run:

```
$ kubectl logs kubia --since=2m
```

The other option is to display logs produced after a specific date and time using the `--since-time` option. The time format to be used is RFC3339. For example, the following command is used to print logs produced after February 1st, 2020 at 9:50 a.m.:

```
$ kubectl logs kubia --since-time=2020-02-01T09:50:00Z
```

DISPLAYING THE LAST SEVERAL LINES OF THE LOG

Instead of using time to constrain the output, you can also specify how many lines from the end of the log you want to display. To display the last ten lines, try:

```
$ kubectl logs kubia --tail=10
```

NOTE Kubectl options that take a value can be specified with an equal sign or with a space. Instead of `--tail=10`, you can also type `--tail 10`.

UNDERSTANDING THE AVAILABILITY OF THE POD'S LOGS

Kubernetes keeps a separate log file for each container. They are usually stored in `/var/log/containers` on the node that runs the container. A separate file is created for each container. If the container is restarted, its logs are written to a new file. Because of this, if the container is restarted while you're following its log with `kubectl logs -f`, the command will terminate, and you'll need to run it again to stream the new container's logs.

The `kubectl logs` command displays only the logs of the current container. To view the logs from the previous container, use the `--previous` (or `-p`) option.

NOTE Depending on your cluster configuration, the log files may also be rotated when they reach a certain size. In this case, `kubectl logs` will only display the new log file. When streaming the logs, you must restart the command to switch to the new file.

When you delete a pod, all its log files are also deleted. To make pods' logs available permanently, you need to set up a central, cluster-wide logging system. Chapter 23 explains how.

WHAT ABOUT APPLICATIONS THAT WRITE THEIR LOGS TO FILES?

If your application writes its logs to a file instead of stdout, you may be wondering how to access that file. Ideally, you'd configure the centralized logging system to collect the logs so you can view them in a central location, but sometimes you just want to keep things simple

and don't mind accessing the logs manually. In the next two sections, you'll learn how to copy log and other files from the container to your computer and in the opposite direction, and how to run commands in running containers. You can use either method to display the log files or any other file inside the container.

5.3.3 Copying files to and from containers

Sometimes you may want to add a file to a running container or retrieve a file from it. Modifying files in running containers isn't something you normally do - at least not in production - but it can be useful during development.

Kubectl offers the `cp` command to copy files or directories from your local computer to a container of any pod or from the container to your computer. For example, to copy the `/etc/hosts` file from the container of the `kubia` pod to the `/tmp` directory on your local file system, run the following command:

```
$ kubectl cp kubia:/etc/hosts /tmp/kubia-hosts
```

To copy a file from your local file system to the container, run the following command:

```
$ kubectl cp /path/to/local/file kubia:path/in/container
```

NOTE The `kubectl cp` command requires the `tar` binary to be present in your container, but this requirement may change in the future.

5.3.4 Executing commands in running containers

When debugging an application running in a container, it may be necessary to examine the container and its environment from the inside. Kubectl provides this functionality, too. You can execute any binary file present in the container's file system using the `kubectl exec` command.

INVOKING A SINGLE COMMAND IN THE CONTAINER

For example, you can list the processes running in the container in the `kubia` pod by running the following command:

Listing 5.6 Processes running inside a pod container

```
$ kubectl exec kubia -- ps aux
USER  PID %CPU %MEM    VSZ   RSS TTY STAT START TIME COMMAND
root    1  0.0  1.3 812860 27356 ?   Ssl  11:54 0:00 node app.js #A
root  120  0.0  0.1  17500  2128 ?   Rs   12:22 0:00 ps aux      #B
```

#A The Node.js server
#B The command you've just invoked

This is the Kubernetes equivalent of the Docker command you used to explore the processes in a running container in chapter 2. It allows you to remotely run a command in any pod

without having to log in to the node that hosts the pod. If you've used `ssh` to execute commands on a remote system, you'll see that `kubectl exec` is not much different.

In section 5.3.1 you executed the `curl` command in a one-off client pod to send a request to your application, but you can also run the command inside the `kubia` pod itself:

```
$ kubectl exec kubia -- curl -s localhost:8080
Hey there, this is kubia. Your IP is ::1.
```

Why use a double dash in the kubectl exec command?

The double dash (`--`) in the command delimits kubectl arguments from the command to be executed in the container. The use of the double dash isn't necessary if the command has no arguments that begin with a dash. If you omit the double dash in the previous example, the `-s` option is interpreted as an option for `kubectl exec` and results in the following misleading error:

```
$ kubectl exec kubia curl -s localhost:8080
The connection to the server localhost:8080 was refused - did you specify the right host or port?
```

This may look like the Node.js server is refusing to accept the connection, but the issue lies elsewhere. The curl command is never executed. The error is reported by `kubectl` itself when it tries to talk to the Kubernetes API server at `localhost:8080`, which isn't where the server is. If you run the `kubectl options` command, you'll see that the `-s` option can be used to specify the address and port of the Kubernetes API server. Instead of passing that option to curl, kubectl adopted it as its own. Adding the double dash prevents this.

Fortunately, to prevent scenarios like this, newer versions of kubectl are set to return an error if you forget the double dash.

RUNNING AN INTERACTIVE SHELL IN THE CONTAINER

The two previous examples showed how a single command can be executed in the container. When the command completes, you are returned to your shell. If you want to run several commands in the container, you can run a shell in the container as follows:

```
$ kubectl exec -it kubia -- bash
root@kubia:/#         #A
```

#A The command prompt of the shell running in the container

The `-it` is short for two options: `-i` and `-t`, which indicate that you want to execute the `bash` command interactively by passing the standard input to the container and marking it as a terminal (TTY).

You can now explore the inside of the container by executing commands in the shell. For example, you can view the files in the container by running `ls -la`, view its network interfaces with `ip link`, or test its connectivity with `ping`. You can run any tool available in the container.

NOT ALL CONTAINERS ALLOW YOU TO RUN SHELLS

The container image of your application contains many important debugging tools, but this isn't the case with every container image. To keep images small and improve security in the container, most containers used in production don't contain any binary files other than those required for the container's primary process. This significantly reduces the attack surface, but also means that you can't run shells or other tools in production containers. Fortunately, a new Kubernetes feature called *ephemeral containers* allows you to debug running containers by attaching a debug container to them.

> **NOTE TO MEAP READERS** Ephemeral containers are currently an alpha feature, which means they may change or even be removed at any time. This is also why they are currently not explained in this book. If they graduate to beta before the book goes into production, a section explaining them will be added.

5.3.5 Attaching to a running container

The `kubectl attach` command is another way to interact with a running container. It attaches itself to the standard input, output and error streams of the main process running in the container. Normally, you only use it to interact with applications that read from the standard input.

USING KUBECTL ATTACH TO SEE WHAT THE APPLICATION PRINTS TO STANDARD OUTPUT

If the application doesn't read from standard input, the `kubectl attach` command is only an alternative way to stream the application logs, as these are typically written to the standard output and error streams, and the `attach` command streams them just like the `kubectl logs -f` command does.

Attach to your `kubia` pod by running the following command:

```
$ kubectl attach kubia
Defaulting container name to kubia.
Use 'kubectl describe pod/kubia -n default' to see all of the containers in this
pod.
If you don't see a command prompt, try pressing enter.
```

Now, when you send new HTTP requests to the application using `curl` in another terminal, you'll see the lines that the application logs to standard output also printed in the terminal where the `kubectl attach` command is executed.

USING KUBECTL ATTACH TO WRITE TO THE APPLICATION'S STANDARD INPUT

The kubia application doesn't read from the standard input stream, but you'll find another version of the application that does this in the book's code archive. You can change the greeting with which the application responds to HTTP requests by writing it to the standard input stream of the application. Let's deploy this version of the application in a new pod and use the `kubectl attach` command to change the greeting.

You can find the artifacts required to build the image in the `kubia-stdin-image/` directory, or you can use the pre-built image `docker.io/luksa/kubia:1.0-stdin`. The pod manifest is in the file `kubia-stdin.yaml`. It is only slightly different from the pod manifest in

`kubia.yaml` that you deployed previously. The differences are highlighted in the following listing.

Listing 5.7 Enabling standard input for a container

```
apiVersion: v1
kind: Pod
metadata:
  name: kubia-stdin                   #A
spec:
  containers:
  - name: kubia
    image: luksa/kubia:1.0-stdin      #B
    stdin: true                       #C
    ports:
    - containerPort: 8080
```

#A This pod is named kubia-stdin
#B It uses the special version of the kubia app
#C The application needs to read from the standard input stream

As you can see in the listing, if the application running in a pod wants to read from standard input, you must indicate this in the pod manifest by setting the `stdin` field in the container definition to `true`. This tells Kubernetes to allocate a buffer for the standard input stream, otherwise the application will always receive an `EOF` when it tries to read from it.

Create the pod from this manifest file with the `kubectl apply` command:

```
$ kubectl apply -f kubia-stdin.yaml
pod/kubia-stdin created
```

To enable communication with the application, use the `kubectl port-forward` command again, but because the local port `8080` is still being used by the previously executed `port-forward` command, you must either terminate it or choose a different local port to forward to the new pod. You can do this as follows:

```
$ kubectl port-forward kubia-stdin 8888:8080
Forwarding from 127.0.0.1:8888 -> 8080
Forwarding from [::1]:8888 -> 8080
```

The command-line argument `8888:8080` instructs the command to forward local port `8888` to the pod's port `8080`.

You can now reach the application at http://localhost:8888:

```
$ curl localhost:8888
Hey there, this is kubia-stdin. Your IP is ::ffff:127.0.0.1.
```

Let's change the greeting from "Hey there" to "Howdy" by using `kubectl attach` to write to the standard input stream of the application. Run the following command:

```
$ kubectl attach -i kubia-stdin
```

Note the use of the additional option `-i` in the command. It instructs `kubectl` to pass its standard input to the container.

> **NOTE** Like the `kubectl exec` command, `kubectl attach` also supports the `--tty` or `-t` option, which indicates that the standard input is a terminal (TTY), but the container must be configured to allocate a terminal through the `tty` field in the container definition.

You can now enter the new greeting into the terminal and press the ENTER key. The application should then respond with the new greeting:

```
Howdy                          #A
Greeting set to: Howdy         #B
```

#A Type the greeting and press <ENTER>
#B This is the application's response

To see if the application now responds to HTTP requests with the new greeting, re-execute the `curl` command or refresh the page in your web browser:

```
$ curl localhost:8888
Howdy, this is kubia-stdin. Your IP is ::ffff:127.0.0.1.
```

There's the new greeting. You can change it again by typing another line in the terminal with the `kubectl attach` command. To exit the `attach` command, press Control-C or the equivalent key.

> **NOTE** An additional field in the container definition, `stdinOnce`, determines whether the standard input channel is closed when the attach session ends. It's set to `false` by default, which allows you to use the standard input in every `kubectl attach` session. If you set it to `true`, standard input remains open only during the first session.

5.4 Running multiple containers in a pod

The kubia application you deployed in section 5.2 only supports HTTP. Let's add TLS support so it can also serve clients over HTTPS. You could do this by writing additional code, but an easier option exists where you don't need to touch the code at all.

You can run a reverse proxy alongside the Node.js application in a sidecar container, as explained in section 5.1.2, and let it handle HTTPS requests on behalf of the application. A very popular software package that can provide this functionality is *Envoy*. The Envoy proxy is a high-performance open source service proxy originally built by Lyft that has since been contributed to the Cloud Native Computing Foundation. Let's add it to your pod.

5.4.1 Extending the kubia Node.js application using the Envoy proxy

Let me briefly explain what the new architecture of the application will look like. As shown in the next figure, the pod will have two containers - the Node.js and the new Envoy container. The Node.js container will continue to handle HTTP requests directly, but the HTTPS requests

will be handled by Envoy. For each incoming HTTPS request, Envoy will create a new HTTP request that it will then send to the Node.js application via the local loopback device (via the localhost IP address).

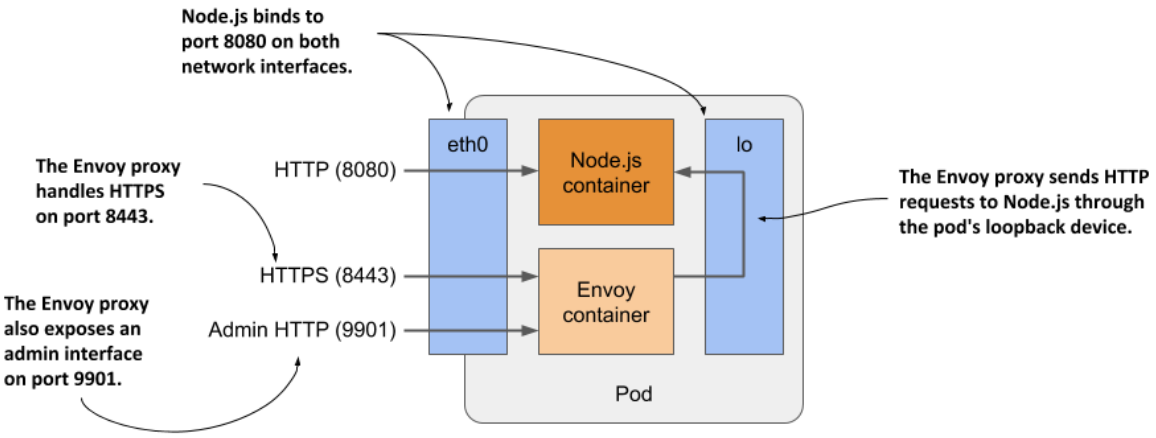


Figure 5.10 Detailed view of the pod's containers and network interfaces

Envoy also provides a web-based administration interface that will prove handy in some of the exercises in the next chapter.

It's obvious that if you implement TLS support within the Node.js application itself, the application will consume less computing resources and have lower latency because no additional network hop is required, but adding the Envoy proxy could be a faster and easier solution. It also provides a good starting point from which you can add many other features provided by Envoy that you would probably never implement in the application code itself. Refer to the Envoy proxy documentation at envoyproxy.io to learn more.

5.4.2 Adding Envoy proxy to the pod

You'll create a new pod with two containers. You've already got the Node.js container, but you also need a container that will run Envoy.

CREATING THE ENVOY CONTAINER IMAGE

The authors of the proxy have published the official Envoy proxy container image at Docker Hub. You could use this image directly, but you would need to somehow provide the configuration, certificate, and private key files to the Envoy process in the container. You'll learn how to do this in chapter 7. For now, you'll use an image that already contains all three files.

I've already created the image and made it available at `docker.io/luksa/kubia-ssl-proxy:1.0`, but if you want to build it yourself, you can find the files in the `kubia-ssl-proxy-image` directory in the book's code archive.

The directory contains the `Dockerfile`, as well as the private key and certificate that the proxy will use to serve HTTPS. It also contains the `envoy.conf` config file. In it, you'll see that the proxy is configured to listen on port `8443`, terminate TLS, and forward requests to port `8080` on `localhost`, which is where the Node.js application is listening. The proxy is also configured to provide an administration interface on port `9901`, as explained earlier.

CREATING THE POD MANIFEST

After building the image, you must create the manifest for the new pod, as shown in the following listing.

Listing 5.8 Manifest of pod kubia-ssl (kubia-ssl.yaml)

```
apiVersion: v1
kind: Pod
metadata:
  name: kubia-ssl
spec:
  containers:
  - name: kubia                                #A
    image: luksa/kubia:1.0                     #A
    ports:                                     #A
    - name: http                #B             #A
      containerPort: 8080       #B             #A
  - name: envoy                                #C
    image: luksa/kubia-ssl-proxy:1.0           #C
    ports:                                     #C
    - name: https               #D             #C
      containerPort: 8443       #D             #C
    - name: admin               #E             #C
      containerPort: 9901       #E             #C
```

#A The container running the Node.js app
#B Node.js listens on port 8080
#C The container running the Envoy proxy
#D The proxy's HTTPS port
#E The proxy's admin interface port

The name of this pod is `kubia-ssl`. It has two containers: `kubia` and `envoy`. The manifest is only slightly more complex than the manifest in section 5.2.1. The only new fields are the port names, which are included so that anyone reading the manifest can understand what each port number stands for.

CREATING THE POD

Create the pod from the manifest using the command `kubectl apply -f kubia-ssl.yaml`. Then use the `kubectl get` and `kubectl describe` commands to confirm that the pod's containers were successfully launched.

5.4.3 Interacting with the two-container pod

When the pod starts, you can start using the application in the pod, inspect its logs and explore the containers from within.

COMMUNICATING WITH THE APPLICATION

As before, you can use the `kubectl port-forward` to enable communication with the application in the pod. Because it exposes three different ports, you enable forwarding to all three ports as follows:

```
$ kubectl port-forward kubia-ssl 8080 8443 9901
Forwarding from 127.0.0.1:8080 -> 8080
Forwarding from [::1]:8080 -> 8080
Forwarding from 127.0.0.1:8443 -> 8443
Forwarding from [::1]:8443 -> 8443
Forwarding from 127.0.0.1:9901 -> 9901
Forwarding from [::1]:9901 -> 9901
```

First, confirm that you can communicate with the application via HTTP by opening the URL http://localhost:8080 in your browser or by using `curl`:

```
$ curl localhost:8080
Hey there, this is kubia-ssl. Your IP is ::ffff:127.0.0.1.
```

If this works, you can also try to access the application over HTTPS at https://localhost:8443. With `curl` you can do this as follows:

```
$ curl https://localhost:8443 --insecure
Hey there, this is kubia-ssl. Your IP is ::ffff:127.0.0.1.
```

Success! The Envoy proxy handles the task perfectly. Your application now supports HTTPS using a sidecar container.

Why it is necessary to use the --insecure option

There are two reasons why you must use the `--insecure` option when accessing the service. The certificate used by the Envoy proxy is self-signed and was issued for the domain name `example.com`. You access the service via the local `kubectl proxy` and use `localhost` as the domain name in the URL, which means that it doesn't match the name in the server certificate. To make it match, you'd have to use the following command:

```
$ curl https://example.com:8443 --resolve example.com:8443:127.0.0.1
```

This ensures that the certificate matches the requested URL, but because the certificate is self-signed, `curl` still can't verify the legitimacy of the server. You must either replace the server's certificate with a certificate signed by a trusted authority or use the `--insecure` flag anyway; in this case, you also don't need to bother with using the `--resolve` flag.

DISPLAYING LOGS OF PODS WITH MULTIPLE CONTAINERS

The `kubia-ssl` pod contains two containers, so if you want to display the logs, you must specify the name of the container using the `--container` or `-c` option. For example, to view the logs of the `kubia` container, run the following command:

```
$ kubectl logs kubia-ssl -c kubia
```

The Envoy proxy runs in the container named `envoy`, so you display its logs as follows:

```
$ kubectl logs kubia-ssl -c envoy
```

Alternatively, you can display the logs of both containers with the `--all-containers` option:

```
$ kubectl logs kubia-ssl --all-containers
```

You can also combine these commands with the other options explained in section 5.3.2.

RUNNING COMMANDS IN CONTAINERS OF MULTI-CONTAINER PODS

If you'd like to run a shell or another command in one of the pod's containers using the `kubectl exec` command, you also specify the container name using the `--container` or `-c` option. For example, to run a shell inside the envoy container, run the following command:

```
$ kubectl exec -it kubia-ssl -c envoy -- bash
```

NOTE If you don't provide the name, `kubectl exec` defaults to the first container specified in the pod manifest.

5.5 Running additional containers at pod startup

When a pod contains more than one container, all the containers are started in parallel. Kubernetes doesn't yet provide a mechanism to specify whether a container depends on another container, which would allow you to ensure that one is started before the other. However, Kubernetes allows you to run a sequence of containers to initialize the pod before its main containers start. This special type of container is explained in this section.

5.5.1 Introducing init containers

A pod manifest can specify a list of containers to run when the pod starts and before the pod's normal containers are started. These containers are intended to initialize the pod and are appropriately called *init containers*. As the following figure shows, they run one after the other and must all finish successfully before the main containers of the pod are started.

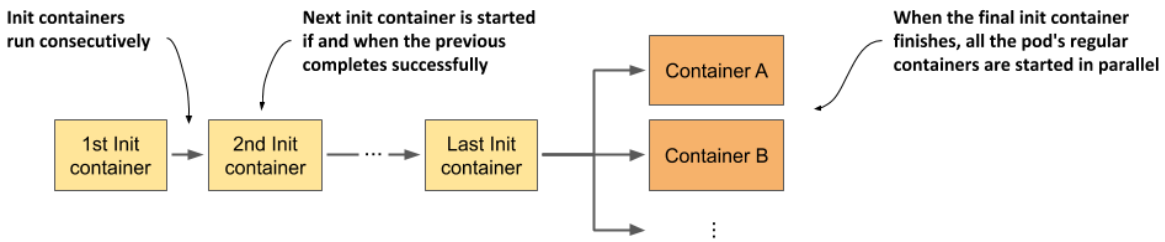


Figure 5.11 Time sequence showing how a pod's init and regular containers are started

Init containers are like the pod's regular containers, but they don't run in parallel - only one init container runs at a time.

UNDERSTANDING WHAT INIT CONTAINERS CAN DO

Init containers are typically added to pods to achieve the following:

- Initialize files in the volumes used by the pod's main containers. This includes retrieving certificates and private keys used by the main container from secure certificate stores, generating config files, downloading data, and so on.
- Initialize the pod's networking system. Because all containers of the pod share the same network namespaces, and thus the network interfaces and configuration, any changes made to it by an init container also affect the main container.
- Delay the start of the pod's main containers until a precondition is met. For example, if the main container relies on another service being available before the container is started, an init container can block until this service is ready.
- Notify an external service that the pod is about to start running. In special cases where an external system must be notified when a new instance of the application is started, an init container can be used to deliver this notification.

You could perform these operations in the main container itself but using an init container is sometimes a better option and can have other advantages. Let's see why.

UNDERSTANDING WHEN MOVING INITIALIZATION CODE TO INIT CONTAINERS MAKES SENSE

Using an init container to perform initialization tasks doesn't require the main container image to be rebuilt and allows a single init container image to be reused with many different applications. This is especially useful if you want to inject the same infrastructure-specific initialization code into all your pods. Using an init container also ensures that this initialization is complete before any of the (possibly multiple) main containers start.

Another important reason is security. By moving tools or data that could be used by an attacker to compromise your cluster from the main container to an init container, you reduce the pod's attack surface.

For example, imagine that the pod must be registered with an external system. The pod needs some sort of secret token to authenticate against this system. If the registration procedure is performed by the main container, this secret token must be present in its filesystem. If the application running in the main container has a vulnerability that allows an attacker to read arbitrary files on the filesystem, the attacker may be able to obtain this token. By performing the registration from an init container, the token must be available only in the filesystem of the init container, which an attacker can't easily compromise.

5.5.2 Adding init containers to a pod

In a pod manifest, init containers are defined in the `initContainers` field in the spec section, just as regular containers are defined in its `containers` field.

ADDING TWO CONTAINERS TO THE KUBIA-SSL POD

Let's look at an example of adding two init containers to the kubia pod. The first init container emulates an initialization procedure. It runs for 5 seconds, while printing a few lines of text to standard output.

The second init container performs a network connectivity test by using the `ping` command to check if a specific IP address is reachable from within the pod. If the IP address is not specified, the address 1.1.1.1 is used. You'll find the `Dockerfile`s and other artifacts for both images in the book's code archive, if you want to build them yourself. Alternatively, you can use the pre-build images specified in the following listing.

A pod manifest containing these two init containers is in the `kubia-init.yaml` file. The following listing shows how the init containers are defined.

Listing 5.9 Defining init containers in a pod manifest: kubia-init.yaml

```
apiVersion: v1
kind: Pod
metadata:
  name: kubia-init
spec:
  initContainers:                                    #A
  - name: init-demo                                  #B
    image: luksa/init-demo:1.0                       #B
  - name: network-check                              #C
    image: luksa/network-connectivity-checker:1.0    #C
  containers:                                        #D
  - name: kubia                                      #D
    image: luksa/kubia:1.0                           #D
    ports:                                           #D
    - name: http                                     #D
      containerPort: 8080                            #D
  - name: envoy                                      #D
    image: luksa/kubia-ssl-proxy:1.0                 #D
    ports:                                           #D
    - name: https                                    #D
      containerPort: 8443                            #D
    - name: admin                                    #D
      containerPort: 9901                            #D
```

#A Init containers are specified in the initContainers field
#B This container runs first
#C This container runs after the first one completes
#D These are the pod's regular containers. They run at the same time.

As you can see, the definition of an init container is almost trivial. It's sufficient to specify only the `name` and `image` for each container.

NOTE **Container names must be unique within the union of all init and regular containers.**

DEPLOYING A POD WITH INIT CONTAINERS

Before you create the pod from the manifest file, run the following command in a separate terminal so you can see how the pod's status changes as the init and regular containers start:

```
$ kubectl get pods -w
```

You'll also want to watch events in another terminal using the following command:

```
$ kubectl get events -w
```

When ready, create the pod by running the apply command:

```
$ kubectl apply -f kubia-init.yaml
```

INSPECTING THE STARTUP OF A POD WITH INIT CONTAINERS

As the pod starts up, inspect the events that the `kubectl get events -w` command prints. The following listing shows what you should see.

Listing 5.10 Pod events showing how the execution of init containers

```
TYPE     REASON      MESSAGE
Normal   Scheduled   Successfully assigned pod to worker2
Normal   Pulling     Pulling image "luksa/init-demo:1.0"       #A
Normal   Pulled      Successfully pulled image                 #A
Normal   Created     Created container init-demo               #A
Normal   Started     Started container init-demo               #A
Normal   Pulling     Pulling image "luksa/network-connec...    #B
Normal   Pulled      Successfully pulled image                 #B
Normal   Created     Created container network-check           #B
Normal   Started     Started container network-check           #B
Normal   Pulled      Container image "luksa/kubia:1.0"         #C
                     already present on machine                #C
Normal   Created     Created container kubia                   #C
Normal   Started     Started container kubia                   #C
Normal   Pulled      Container image "luksa/kubia-ssl-         #C
                     proxy:1.0" already present on machine     #C
Normal   Created     Created container envoy                   #C
Normal   Started     Started container envoy                   #C
```

#A The first init container's image is pulled and the container is started
#B After the first init container completes, the second is started
#C The pod's two main containers are then started in parallel

The listing shows the order in which the containers are started. The `init-demo` container is started first. When it completes, the `network-check` container is started, and when it completes, the two main containers, `kubia` and `envoy`, are started.

Now inspect the transitions of the pod's status in the other terminal. They are shown in the next listing.

Listing 5.11 Pod status changes during startup involving init containers

```
NAME          READY   STATUS            RESTARTS   AGE
kubia-init    0/2     Pending           0          0s
kubia-init    0/2     Pending           0          0s
kubia-init    0/2     Init:0/2          0          0s          #A
kubia-init    0/2     Init:0/2          0          1s          #A
kubia-init    0/2     Init:1/2          0          6s          #B
kubia-init    0/2     PodInitializing   0          7s          #C
kubia-init    2/2     Running           0          8s          #D
```

#A The first init container is running
#B The first init container is complete, the second is now running
#C All init containers have completed successfully
#D The pod's main containers are running

As the listing shows, when the init containers run, the pod's status shows the number of init containers that have completed and the total number. When all init containers are done, the pod's status is displayed as `PodInitializing`. At this point, the images of the main containers are pulled. When the containers start, the status changes to `Running`.

5.5.3 Inspecting init containers

While the init containers run and after they have finished, you can display their logs and enter the running container, just as you can with regular containers.

DISPLAYING THE LOGS OF AN INIT CONTAINER

The standard and error output, into which each init container can write, are captured exactly as they are for regular containers. The logs of an init container can be displayed using the `kubectl logs` command by specifying the name of the container with the `-c` option. To display the logs of the `network-check` container in the `kubia-init` pod, run the command shown in the following listing.

Listing 5.12 Displaying the logs of an init container

```
$ kubectl logs kubia-init -c network-check
Checking network connectivity to 1.1.1.1 ...
Host appears to be reachable
```

The logs show that the `network-check` init container ran without errors. In the next chapter, you'll see what happens if an init container fails.

ENTERING A RUNNING INIT CONTAINER

You can use the `kubectl exec` command to run a shell or a different command inside an init container the same way you can with regular containers, but you can only do this before the init container terminates. If you'd like to try this yourself, create a pod from the `kubia-init-slow.yaml` file, which makes the `init-demo` container run for 60 seconds. When the pod starts, run a shell in the container with the following command:

```
$ kubectl exec -it kubia-init-slow -c init-demo -- sh
```

You can use the shell to explore the container from the inside, but not for long. When the container's main process exits after 60 seconds, the shell process is also terminated.

You typically enter a running init container only when it fails to complete in time, and you want to find the cause. During normal operation, the init container terminates before you can run the `kubectl exec` command.

5.6 Deleting pods and other objects

If you've tried the exercises in this chapter and in chapter 2, several pods and other objects now exist in your cluster. To close this chapter, you'll learn various ways to delete them. Deleting a pod will terminate its containers and remove them from the node. Deleting a Deployment object causes the deletion of its pods, whereas deleting a LoadBalancer-typed Service deprovisions the load balancer if one was provisioned.

5.6.1 Deleting a pod by name

The easiest way to delete an object is to delete it by name.

DELETING A SINGLE POD

Use the following command to remove the `kubia` pod from your cluster:

```
$ kubectl delete po kubia
pod "kubia" deleted
```

By deleting a pod, you state that you no longer want the pod or its containers to exist. The Kubelet shuts down the pod's containers, removes all associated resources, such as log files, and notifies the API server after this process is complete. The Pod object is then removed.

> **TIP** By default, the `kubectl delete` command waits until the object no longer exists. To skip the wait, run the command with the `--wait=false` option.

While the pod is in the process of shutting down, its status changes to `Terminating`:

```
$ kubectl get po kubia
NAME    READY   STATUS        RESTARTS   AGE
kubia   1/1     Terminating   0          35m
```

Knowing exactly how containers are shut down is important if you want your application to provide a good experience for its clients. This is explained in the next chapter, where we dive deeper into the life cycle of the pod and its containers.

> **NOTE** If you're familiar with Docker, you may wonder if you can stop a pod and start it again later, as you can with Docker containers. The answer is no. With Kubernetes, you can only remove a pod completely and create it again later.

DELETING MULTIPLE PODS WITH A SINGLE COMMAND

You can also delete multiple pods with a single command. If you ran the `kubia-init` and the `kubia-init-slow` pods, you can delete them both by specifying their names separated by a space, as follows:

```
$ kubectl delete po kubia-init kubia-init-slow
pod "kubia-init" deleted
pod "kubia-init-slow" deleted
```

5.6.2 Deleting objects defined in manifest files

Whenever you create objects from a file, you can also delete them by passing the file to the `delete` command instead of specifying the name of the pod.

DELETING OBJECTS BY SPECIFYING THE MANIFEST FILE

You can delete the `kubia-ssl` pod, which you created from the `kubia-ssl.yaml` file, with the following command:

```
$ kubectl delete -f kubia-ssl.yaml
pod "kubia-ssl" deleted
```

In your case, the file contains only a single pod object, but you'll typically come across files that contain several objects of different types that represent a complete application. This makes deploying and removing the application as easy as executing `kubectl apply -f app.yaml` and `kubectl delete -f app.yaml`, respectively.

DELETING OBJECTS FROM MULTIPLE MANIFEST FILES

Sometimes, an application is defined in several manifest files. You can specify multiple files by separating them with a comma. For example:

```
$ kubectl delete -f kubia.yaml,kubia-ssl.yaml
```

NOTE You can also apply several files at the same time using this syntax (for example: `kubectl apply -f kubia.yaml,kubia-ssl.yaml`).

I've never actually used this approach in the many years I've been using Kubernetes, but I often deploy all the manifest files from a file directory by specifying the directory name instead of the names of individual files. For example, you can deploy all the pods you created in this chapter again by running the following command in the base directory of this book's code archive:

```
$ kubectl apply -f Chapter05/
```

This applies all files in the directory that have the correct file extension (`.yaml`, `.json`, and others). You can then delete the pods using the same method:

```
$ kubectl delete -f Chapter05/
```

NOTE Use the `--recursive` flag to also scan subdirectories.

5.6.3 Deleting all pods

You've now removed all pods except `kubia-stdin` and the pods you created in chapter 3 using the `kubectl create deployment` command. Depending on how you've scaled the deployment, some of these pods should still be running:

```
$ kubectl get pods
NAME                    READY   STATUS    RESTARTS   AGE
kubia-stdin             1/1     Running   0          10m
kubia-9d785b578-58vhc   1/1     Running   0          1d
kubia-9d785b578-jmnj8   1/1     Running   0          1d
```

Instead of deleting these pods by name, we can delete them all using the `--all` option:

```
$ kubectl delete po --all
pod "kubia-stdin" deleted
pod "kubia-9d785b578-58vhc" deleted
pod "kubia-9d785b578-jmnj8" deleted
```

Now confirm that no pods exist by executing the `kubectl get pods` command again:

```
$ kubectl get po
NAME                    READY   STATUS    RESTARTS   AGE
kubia-9d785b578-cc6tk   1/1     Running   0          13s
kubia-9d785b578-h4gml   1/1     Running   0          13s
```

That was unexpected! Two pods are still running. If you look closely at their names, you'll see that these aren't the two you've just deleted. The `AGE` column also indicates that these are *new* pods. You can try to delete them as well, but you'll see that no matter how often you delete them, new pods are created to replace them.

The reason why these pods keep popping up is because of the Deployment object. The controller responsible for bringing Deployment objects to life must ensure that the number of pods always matches the desired number of replicas specified in the object. When you delete a pod associated with the Deployment, the controller immediately creates a replacement pod.

To delete these pods, you must either scale the Deployment to zero or delete the object altogether. This would indicate that you no longer want this deployment or its pods to exist in your cluster.

5.6.4 Deleting objects of most kinds

You can delete everything you've created so far - including the deployment, its pods, and the service - with the command shown in the next listing.

Listing 5.13 Deleting most objects regardless of type

```
$ kubectl delete all --all
pod "kubia-9d785b578-cc6tk" deleted
pod "kubia-9d785b578-h4gml" deleted
```

```
service "kubernetes" deleted
service "kubia" deleted
deployment.apps "kubia" deleted
replicaset.apps "kubia-9d785b578" deleted
```

The first `all` in the command indicates that you want to delete objects of all types. The `--all` option indicates that you want to delete all instances of each object type. You used this option in the previous section when you tried to delete all pods.

When deleting objects, `kubectl` prints the type and name of each deleted object. In the previous listing, you should see that it deleted the pods, the deployment, and the service, but also a so-called replica set object. You'll learn what this is in chapter 11, where we take a closer look at deployments.

You'll notice that the delete command also deletes the built-in `kubernetes` service. Don't worry about this, as the service is automatically recreated after a few moments.

Certain objects aren't deleted when using this method, because the keyword `all` does not include all object kinds. This is a precaution to prevent you from accidentally deleting objects that contain important information. The Event object kind is one example of this.

> **NOTE** **You can specify multiple object types in the `delete` command. For example, you can use `kubectl delete events,all --all` to delete events along with all object kinds included in `all`.**

5.7 Summary

In this chapter, you've learned:

- Pods run one or more containers as a co-located group. They are the unit of deployment and horizontal scaling. A typical container runs only one process. Sidecar containers complement the primary container in the pod.
- Containers should only be part of the same pod if they must run together. A frontend and a backend process should run in separate pods. This allows them to be scaled individually.
- When a pod starts, its init containers run one after the other. When the last init container completes, the pod's main containers are started. You can use an init container to configure the pod from within, delay startup of its main containers until a precondition is met, or notify an external service that the pod is about to start running.
- The `kubectl` tool is used to create pods, view their logs, copy files to/from their containers, execute commands in those containers and enable communication with individual pods during development.

In the next chapter, you'll learn about the lifecycle of the pod and its containers.

6

Managing the lifecycle of the Pod's containers

This chapter covers

- **Inspecting the pod's status**
- **Keeping containers healthy using liveness probes**
- **Using lifecycle hooks to perform actions at container startup and shutdown**
- **Understanding the complete lifecycle of the pod and its containers**

After reading the previous chapter, you should be able to deploy, inspect and communicate with pods containing one or more containers. In this chapter, you'll gain a much deeper understanding of how the pod and its containers operate.

6.1 Understanding the pod's status

After you create a pod object and it runs, you can see what's going on with the pod by reading the pod object back from the API. As you've learned in chapter 4, the pod object manifest, as well as the manifests of most other kinds of objects, contain a section, which provides the status of the object. A pod's `status` section contains the following information:

- the IP addresses of the pod and the worker node that hosts it
- when the pod was started
- the pod's quality-of-service (QoS) class
- what phase the pod is in,
- the conditions of the pod, and
- the state of its individual containers.

The IP addresses and the start time don't need any further explanation, and the QoS class isn't relevant now - you'll learn about it in chapter 19. However, the phase and conditions of the pod, as well as the states of its containers are important for you to understand the pod lifecycle.

6.1.1 Understanding the pod phase

In any moment of the pod's life, it's in one of the five phases shown in the following figure.

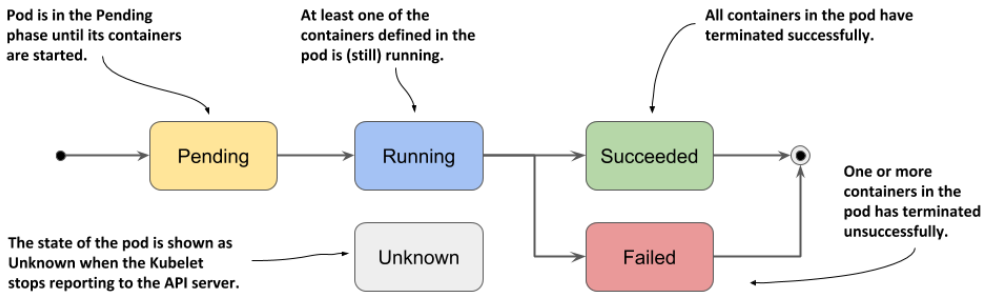


Figure 6.1 The phases of a Kubernetes pod

The meaning of each phase is explained in the following table.

Table 6.1 List of phases a pod can be in

Pod Phase	Description
`Pending`	After you create the Pod object, this is its initial phase. Until the pod is scheduled to a node and the images of its containers are pulled and started, it remains in this phase.
`Running`	At least one of the pod's containers is running.
`Succeeded`	Pods that aren't intended to run indefinitely are marked as `Succeeded` when all their containers complete successfully.
`Failed`	When a pod is not configured to run indefinitely and at least one of its containers terminates unsuccessfully, the pod is marked as Failed.
`Unknown`	The state of the pod is unknown because the Kubelet has stopped reporting communicating with the API server. Possibly the worker node has failed or has disconnected from the network.

The pod's phase provides a quick summary of what's happening with the pod. Let's deploy the `kubia` pod again and inspect its phase. Create the pod by applying the `kubia.yaml` manifest to your cluster again, as in the previous chapter:

```
$ kubectl apply -f kubia.yaml
```

DISPLAYING A POD'S PHASE

The pod's phase is one of the fields in the pod object's `status` section. You can see it by displaying its manifest and optionally grepping the output to search for the field:

```
$ kubectl get po kubia -o yaml | grep phase
phase: Running
```

TIP Remember the `jq` tool? You can use it instead to print out the value of the `phase` field like this:

```
kubectl get po kubia -o json | jq .status.phase
```

You can also see the pod's phase using `kubectl describe`:

```
$ kubectl describe po kubia | grep Status:
Status:       Running
```

Although it may appear that the `STATUS` column displayed by `kubectl get pods` also shows the phase, this is only true for pods that are healthy:

```
$ kubectl get po kubia
NAME    READY   STATUS    RESTARTS   AGE
kubia   1/1     Running   0          40m
```

For unhealthy pods, the `STATUS` column indicates what's wrong with the pod. You'll see this later in this chapter.

6.1.2 Understanding pod conditions

The phase of a pod says little about the condition of the pod. You can learn more by looking at the pod's list of conditions, just as you did for the node object in the chapter 4. A pod's conditions indicate whether a pod has reached a certain state or not, and why that's the case.

In contrast to the phase, a pod has several conditions at the same time. Four condition *types* are known at the time of writing. They are explained in the following table.

Table 6.2 List of pod conditions

Pod Condition	Description
`PodScheduled`	Indicates whether or not the pod has been scheduled to a node.
`Initialized`	The pod's init containers have all completed successfully.
`ContainersReady`	All containers in the pod indicate that they are ready. This is a necessary but not sufficient condition for the entire pod to be ready.
`Ready`	The pod is ready to provide services to its clients. The containers in the pod and the pod's readiness gates are all reporting that they are ready. Note: this is explained in chapter 10.

Each condition is either fulfilled or not. As you can see in the following figure, the `PodScheduled` and `Initialized` conditions start as unfulfilled, but are soon fulfilled and remain so throughout the life of the pod. In contrast, the `Ready` and `ContainersReady` conditions can change many times during the pod's lifetime.

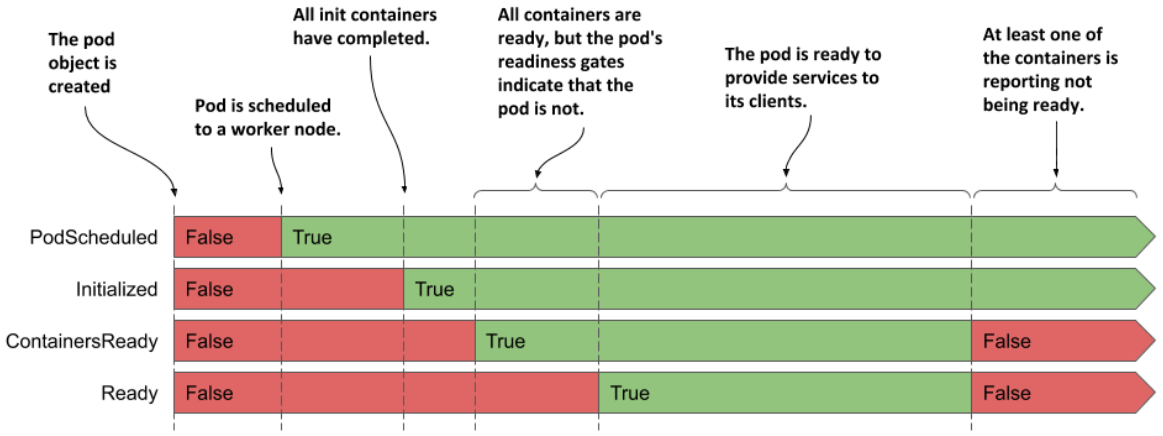


Figure 6.2 The transitions of the pod's conditions during its lifecycle

Do you remember the conditions you can find in a node object? They are `MemoryPressure`, `DiskPressure`, `PIDPressure` and `Ready`. As you can see, each object has its own set of condition types, but many contain the generic `Ready` condition, which typically indicates whether everything is fine with the object.

INSPECTING THE POD'S CONDITIONS

To see the conditions of a pod, you can use `kubectl describe` as in the next listing:

Listing 6.1 Displaying a pod's conditions using kubectl describe

```
$ kubectl describe po kubia | grep Conditions: -A5
Conditions:
  Type              Status
  Initialized       True        #A
  Ready             True        #B
  ContainersReady   True        #B
  PodScheduled      True        #C
```

#A The pod has been initialized
#B The pod and its containers are ready
#C The pod has been scheduled to a node

The `kubectl describe` command only shows whether each condition is true or not. To find out why a condition is false, you must inspect the pod manifest, as shown in the next listing.

Listing 6.2 Displaying a pod's conditions using kubectl and jq

```
$ kubectl get po kubia -o json | jq .status.conditions
[
  {
    "lastProbeTime": null,
    "lastTransitionTime": "2020-02-02T11:42:59Z",
    "status": "True",
    "type": "Initialized"
  },
  ...
```

Each condition has a `status` field that indicates whether the condition is `True`, `False` or `Unknown`. In the case of the `kubia` pod, the status of all conditions is `True`, which means they are all fulfilled. The condition can also contain a `reason` field that specifies a machine-facing reason for the last change of the condition's status, and a `message` field that explains the change in detail. The `lastTransitionTime` field shows when the change occurred, while the `lastProbeTime` indicates when this condition was last checked.

6.1.3 Understanding the status of the containers

Also contained in the status of the pod is the status of each of its containers. Inspecting the status provides better insight into the operation of each individual container.

The status contains several fields. The `state` field indicates the container's current state, whereas the `lastState` field shows the state of the previous container after it has terminated. The container status also indicates the internal ID of the container (`containerID`), the `image` and `imageID` the container is running, whether the container is `ready` or not and how often it has been restarted (`restartCount`).

UNDERSTANDING THE CONTAINER STATE

The most important part of a container's status is its `state`. A container can be in one of the states shown in the following figure.

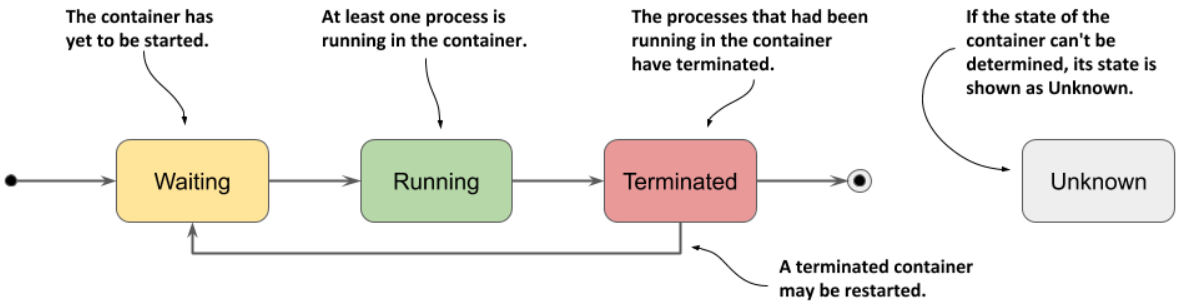


Figure 6.3 The possible states of a container

Individual states are explained in the following table.

Table 6.3 Possible container states

Container State	Description
`Waiting`	The container is waiting to be started. The `reason` and `message` fields indicate why the container is in this state.
`Running`	The container has been created and processes are running in it. The `startedAt` field indicates the time at which this container was started.
`Terminated`	The processes that had been running in the container have terminated. The `startedAt` and `finishedAt` fields indicate when the container was started and when it terminated. The exit code with which the main process terminated is in the `exitCode` field.
`Unknown`	The state of the container couldn't be determined.

DISPLAYING THE STATUS OF THE POD'S CONTAINERS

The pod list displayed by `kubectl get pods` shows only the number of containers in each pod and how many of them are ready. To see the status of individual containers, you must use `kubectl describe`, as shown in the following listing.

Listing 6.3 Inspecting a container's status using kubectl describe

```
$ kubectl describe po kubia | grep Containers: -A15
Containers:
  kubia:
    Container ID:   docker://c64944a684d57faacfced0be1af44686...
    Image:          luksa/kubia:1.0
    Image ID:       docker-pullable://luksa/kubia@sha256:3f28...
    Port:           8080/TCP
    Host Port:      0/TCP
    State:          Running                             #A
      Started:      Sun, 02 Feb 2020 12:43:03 +0100     #A
    Ready:          True                                #B
    Restart Count:  0                                   #C
    Environment:    <none>
    Mounts:
      ...
```

#A The current state of the container and when it was started
#B Whether the container is ready to provide its services
#C How many times the container has been restarted

Focus on the annotated lines in the listing, as they indicate whether the container is healthy. The `kubia` container is `Running` and is `Ready`. It has never been restarted.

> **TIP** You can also display the container status(es) using `jq` like this: `kubectl get po kubia -o json | jq .status.containerStatuses`

INSPECTING THE STATUS OF AN INIT CONTAINER

In the previous chapter, you learned that in addition to regular containers, a pod can also have init containers that run when the pod starts. As with regular containers, the status of these containers is available in the `status` section of the pod object manifest, but in the `initContainerStatuses` field.

Inspecting the status of the kubia-init pod

As an additional exercise you can try on your own, create the pod defined in the `kubia-init.yaml` file from the previous chapter and inspect its phase, conditions and the status of its two regular and two init containers using `kubectl describe` and by retrieving the pod manifest using the `kubectl get po kubia-init -o json | jq .status` command.

6.2 Keeping containers healthy

The pods you created in the previous chapter ran without any problems. But what if one of the containers dies? What if all the containers in a pod die? How do you keep the pods healthy and their containers running? That's the focus of this section.

6.2.1 Understanding container auto-restart

When a pod is scheduled to a node, the Kubelet on that node starts its containers and from then on keeps them running for as long as the pod object exists. If the main process in the container terminates for any reason, the Kubelet restarts the container. If an error in your application causes it to crash, Kubernetes automatically restarts it, so even without doing anything special in the application itself, running it in Kubernetes automatically gives it the ability to heal itself. Let's see this in action.

OBSERVING A CONTAINER FAILURE

In the previous chapter, you created the `kubia-ssl` pod, which contains the Node.js and the Envoy containers. Create the pod again and enable communication with the pod by running the following two commands:

```
$ kubectl apply -f kubia-ssl.yaml
$ kubectl port-forward kubia-ssl 8080 8443 9901
```

You'll now cause the Envoy container to terminate to see how Kubernetes deals with the situation. Run the following command in a separate terminal so you can see how the pod's status changes when one of its containers terminates:

```
$ kubectl get pods -w
```

You'll also want to watch events in another terminal using the following command:

```
$ kubectl get events -w
```

You could emulate a crash of the container's main process by sending it the `KILL` signal, but you can't do this from inside the container because the Linux Kernel doesn't let you kill the root process (the process with PID 1). You would have to SSH to the pod's host node and kill the process from there. Fortunately, Envoy's administration interface allows you to stop the process via its HTTP API.

To terminate the `envoy` container, open the URL http://localhost:9901 in your browser and click the *quitquitquit* button or run the following `curl` command in another terminal:

```
$ curl -X POST http://localhost:9901/quitquitquit
OK
```

To see what happens with the container and the pod it belongs to, examine the output of the `kubectl get pods -w` command you ran earlier. It's shown in the next listing.

Listing 6.4 Pod state transitions when a container terminates

```
$ kubectl get po -w
NAME           READY   STATUS     RESTARTS   AGE
kubia-ssl      2/2     Running    0          1s
kubia-ssl      1/2     NotReady   0          9m33s
kubia-ssl      2/2     Running    1          9m34s
```

The listing shows that the pod's `STATUS` changes from `Running` to `NotReady`, while the `READY` column indicates that only one of the two containers is ready. Immediately thereafter, Kubernetes restarts the container and the pod's status returns to `Running`. The `RESTARTS` column indicates that one container has been restarted.

NOTE If one of the pod's containers fails, the other containers continue to run.

Now examine the output of the `kubectl get events -w` command you ran earlier. It is shown in the next listing.

Listing 6.6 Events emitted when a container terminates

```
$ kubectl get ev -w
LAST SEEN   TYPE      REASON      OBJECT           MESSAGE
0s          Normal    Pulled      pod/kubia-ssl    Container image already
                                                   present on machine
0s          Normal    Created     pod/kubia-ssl    Created container envoy
0s          Normal    Started     pod/kubia-ssl    Started container envoy
```

The events show that the new `envoy` container has been started. You should be able to access the application via HTTPS again. Please confirm with your browser or `curl`.

The events in the listing also expose an important detail about how Kubernetes restarts containers. The second event indicates that the entire `envoy` container has been recreated. Kubernetes never restarts a container, but instead discards it and creates a new container. Regardless, we call this *restarting* a container.

NOTE Any data that the process writes to the container's filesystem is lost when the container is recreated. This behavior is sometimes undesirable. To persist data, you must add a storage volume to the pod, as explained in the next chapter.

NOTE If init containers are defined in the pod and one of the pod's regular containers is restarted, the init containers are not executed again.

CONFIGURING THE POD'S RESTART POLICY

By default, Kubernetes restarts the container regardless of whether the process in the container exits with a zero or non-zero exit code - in other words, whether the container completes successfully or fails. This behavior can be changed by setting the `restartPolicy` field in the pod's `spec`.

Three restart policies exist. They are explained in the following figure.

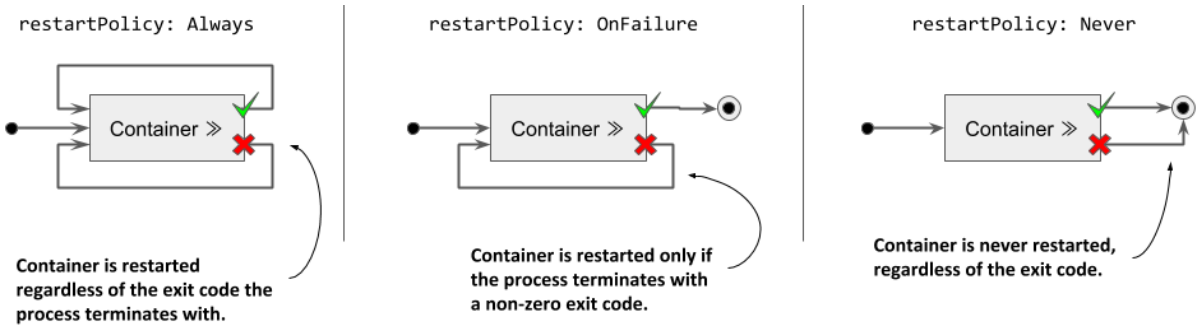


Figure 6.4 The pod's restartPolicy determines whether its containers are restarted or not

The following table describes the three restart policies.

Table 6.4 Pod restart policies

Restart Policy	Description
`Always`	Container is restarted regardless of the exit code the process in the container terminates with. This is the default restart policy.
`OnFailure`	The container is restarted only if the process terminates with a non-zero exit code, which by convention indicates failure.
`Never`	The container is never restarted - not even when it fails.

NOTE Surprisingly, the restart policy is configured at the pod level and applies to all its containers. It can't be configured for each container individually.

UNDERSTANDING THE TIME DELAY INSERTED BEFORE A CONTAINER IS RESTARTED

If you call Envoy's `/quitquitquit` endpoint several times, you'll notice that each time it takes longer to restart the container after it terminates. The pod's status is displayed as either `NotReady` or `CrashLoopBackOff`. Here's what it means.

As shown in the following figure, the first time a container terminates, it is restarted immediately. The next time, however, Kubernetes waits ten seconds before restarting it again. This delay is then doubled to 20, 40, 80 and then to 160 seconds after each subsequent termination. From then on, the delay is kept at five minutes. This delay that doubles between attempts is called exponential back-off.

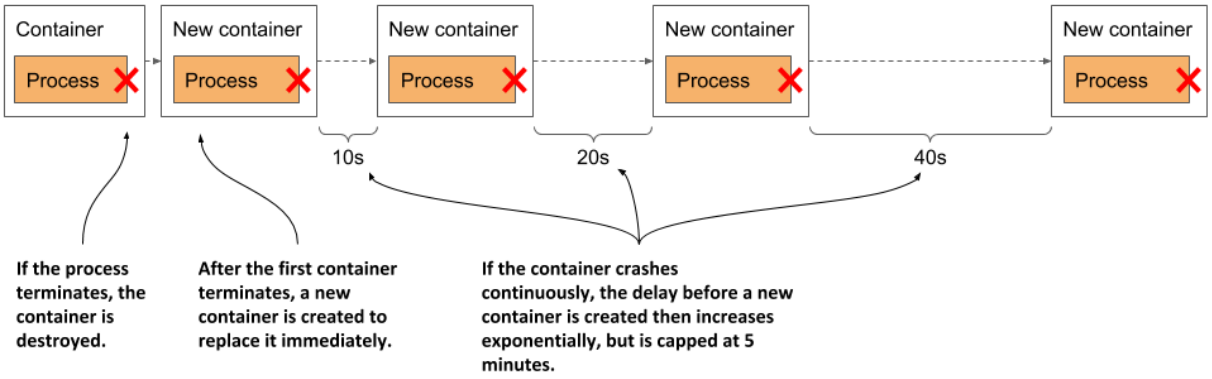


Figure 6.5 Exponential back-off between container restarts

In the worst case, a container can therefore be prevented from starting for up to five minutes.

> **NOTE** The delay is reset to zero when the container has run successfully for 10 minutes. If the container must be restarted later, it is restarted immediately.

As you can see in the following listing, the container is in the `Waiting` state while it waits to be restarted, and the `reason` is shown as `CrashLoopBackOff`. The `message` field indicates how long it will take for the container to be restarted.

Listing 6.7 The state of a container that's waiting to be restarted

```
$ kubectl get po kubia-ssl -o json | jq .status.containerStatuses
...
"state": {
  "waiting": {
    "message": "back-off 40s restarting failed container=envoy ...",
    "reason": "CrashLoopBackOff"
```

NOTE When you tell Envoy to terminate, it terminates with exit code zero, which means it hasn't crashed. The `CrashLoopBackOff` status can therefore be misleading.

6.2.2 Checking the container's health using liveness probes

In the previous section, you learned that Kubernetes keeps your application healthy by restarting it when its process terminates. But applications can also become unresponsive without terminating. For example, a Java application with a memory leak eventually starts spewing out OutOfMemoryErrors, but its JVM process continues to run. Ideally, Kubernetes should detect this kind of error and restart the container.

The application could catch these errors by itself and immediately terminate, but what about the situations where your application stops responding because it gets into an infinite loop or deadlock? What if the application can't detect this? To ensure that the application is restarted in such cases, it may be necessary to check its state from the outside.

INTRODUCING LIVENESS PROBES

Kubernetes can be configured to check whether an application is still alive by defining a *liveness probe*. You can specify a liveness probe for each container in the pod. Kubernetes runs the probe periodically to ask the application if it's still alive and well. If the application doesn't respond, an error occurs, or the response is negative, the container is considered unhealthy and is terminated. The container is then restarted if the restart policy allows it.

NOTE Liveness probes can only be used in the pod's regular containers. They can't be defined in init containers.

TYPES OF LIVENESS PROBES

Kubernetes can probe a container with one of the following three mechanisms:

- An *HTTP GET* probe sends a GET request to the container's IP address, on the network port and path you specify. If the probe receives a response, and the response code doesn't represent an error (in other words, if the HTTP response code is `2xx` or `3xx`), the probe is considered successful. If the server returns an error response code, or if it doesn't respond in time, the probe is considered to have failed.
- A *TCP Socket* probe attempts to open a TCP connection to the specified port of the container. If the connection is successfully established, the probe is considered successful. If the connection can't be established in time, the probe is considered failed.
- An *Exec* probe executes a command inside the container and checks the exit code it terminates with. If the exit code is zero, the probe is successful. A non-zero exit code is considered a failure. The probe is also considered to have failed if the command fails to terminate in time.

NOTE In addition to a liveness probe, a container may also have a *startup* probe, which is discussed in section 6.2.6, and a *readiness* probe, which is explained in chapter 10.

6.2.3 Creating an HTTP GET liveness probe

Let's look at how to add a liveness probe to each of the containers in the `kubia-ssl` pod. Because they both run applications that understand HTTP, it makes sense to use an HTTP GET probe in each of them. The Node.js application doesn't provide any endpoints to explicitly check the health of the application, but the Envoy proxy does. In real-world applications, you'll encounter both cases.

DEFINING LIVENESS PROBES IN THE POD MANIFEST

The following listing shows an updated manifest for the pod, which defines a liveness probe for each of the two containers, with different levels of configuration.

Listing 6.8 Adding a liveness probe to a pod: kubia-liveness.yaml

```
apiVersion: v1
kind: Pod
metadata:
  name: kubia-liveness
spec:
  containers:
  - name: kubia
    image: luksa/kubia:1.0
    ports:
    - name: http
      containerPort: 8080
    livenessProbe:                          #A
      httpGet:                              #A
        path: /                             #A
        port: 8080                          #A
  - name: envoy
    image: luksa/kubia-ssl-proxy:1.0
    ports:
    - name: https
      containerPort: 8443
    - name: admin
      containerPort: 9901
    livenessProbe:                          #B
      httpGet:                              #B
        path: /ready                        #B
        port: admin                         #B
      initialDelaySeconds: 10               #B
      periodSeconds: 5                      #B
      timeoutSeconds: 2                     #B
      failureThreshold: 3                   #B
```

#A The liveness probe definition for the container running Node.js
#B The liveness probe for the Envoy proxy

These liveness probes are explained in the next two sections.

DEFINING A LIVENESS PROBE USING THE MINIMUM REQUIRED CONFIGURATION

The liveness probe for the `kubia` container is the simplest version of a probe for HTTP-based applications. The probe simply sends an HTTP `GET` request for the path `/` on port `8080` to

determine if the container can still serve requests. If the application responds with an HTTP status between `200` and `399`, the application is considered healthy.

The probe doesn't specify any other fields, so the default settings are used. The first request is sent 10s after the container starts and is repeated every 10s. If the application doesn't respond within one second, the probe attempt is considered failed. If it fails three times in a row, the container is considered unhealthy and is terminated.

UNDERSTANDING LIVENESS PROBE CONFIGURATION OPTIONS

The administration interface of the Envoy proxy provides the special endpoint `/ready` through which it exposes its health status. Instead of targeting port `8443`, which is the port through which Envoy forwards HTTPS requests to Node.js, the liveness probe for the `envoy` container targets this special endpoint on the `admin` port, which is port number `9901`.

> **NOTE** As you can see in the `envoy` container's liveness probe, you can specify the probe's target port by name instead of by number.

The liveness probe for the `envoy` container also contains additional fields. These are best explained with the following figure.

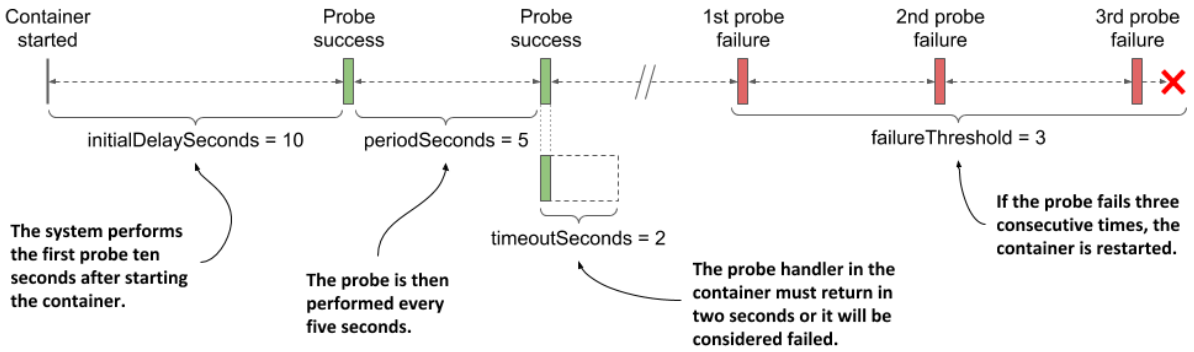


Figure 6.6 The configuration and operation of a liveness probe

The parameter `initialDelaySeconds` determines how long Kubernetes should delay the execution of the first probe after starting the container. The `periodSeconds` field specifies the amount of time between the execution of two consecutive probes, whereas the `timeoutSeconds` field specifies how long to wait for a response before the probe attempt counts as failed. The `failureThreshold` field specifies how many times the probe must fail for the container to be considered unhealthy and potentially restarted.

6.2.4 Observing the liveness probe in action

To see Kubernetes restart a container when its liveness probe fails, create the pod from the `kubia-liveness.yaml` manifest file using `kubectl apply`, and run `kubectl port-forward`

to enable communication with the pod. You'll need to stop the `kubectl port-forward` command still running from the previous exercise. Confirm that the pod is running and is responding to HTTP requests.

OBSERVING A SUCCESSFUL LIVENESS PROBE

The liveness probes for the pod's containers starts firing soon after the start of each individual container. Since the processes in both containers are healthy, the probes continuously report success. As this is the normal state, the fact that the probes are successful is not explicitly indicated anywhere in the status of the pod nor in its events.

The only indication that Kubernetes is executing the probe is found in the container logs. The Node.js application in the `kubia` container prints a line to the standard output every time it handles an HTTP request. This includes the liveness probe requests, so you can display them using the following command:

```
$ kubectl logs kubia-liveness -c kubia -f
```

The liveness probe for the `envoy` container is configured to send HTTP requests to Envoy's administration interface, which doesn't log HTTP requests to the standard output, but to the file `/var/log/envoy.admin.log` in the container's filesystem. To display the log file, you use the following command:

```
$ kubectl exec kubia-liveness -c envoy -- tail -f /var/log/envoy.admin.log
```

OBSERVING THE LIVENESS PROBE FAIL

A successful liveness probe isn't interesting, so let's cause Envoy's liveness probe to fail. To see what will happen behind the scenes, start watching events by executing the following command in a separate terminal:

```
$ kubectl get events -w
```

Using Envoy's administration interface, you can configure its health check endpoint to succeed or fail. To make it fail, open URL http://localhost:9901 in your browser and click the *healthcheck/fail* button, or use the following `curl` command:

```
$ curl -X POST localhost:9901/healthcheck/fail
```

Immediately after executing the command, observe the events that are displayed in the other terminal. When the probe fails, a `Warning` event is recorded, indicating the error and the HTTP status code returned:

```
Warning  Unhealthy  Liveness probe failed: HTTP probe failed with code 503
```

Because the probe's `failureThreshold` is set to three, a single failure is not enough to consider the container unhealthy, so it continues to run. You can make the liveness probe succeed again by clicking the *healthcheck/ok* button in Envoy's admin interface, or by using `curl` as follows:

```
$ curl -X POST localhost:9901/healthcheck/ok
```

If you are fast enough, the container won't be restarted.

OBSERVING THE LIVENESS PROBE REACH THE FAILURE THRESHOLD

If you let the liveness probe fail multiple times, you should see events like the ones in the next listing (note that some columns are omitted due to page width constraints).

Listing 6.9 Events recorded when a liveness probe fails

```
$ kubectl get events -w
TYPE     REASON     MESSAGE
Warning  Unhealthy  Liveness probe failed: HTTP probe failed with code 503
Warning  Unhealthy  Liveness probe failed: HTTP probe failed with code 503
Warning  Unhealthy  Liveness probe failed: HTTP probe failed with code 503
Normal   Killing    Container envoy failed liveness probe, will be
                    restarted
Normal   Pulled     Container image already present on machine
Normal   Created    Created container envoy
Normal   Started    Started container envoy
```

Remember that the probe failure threshold is set to three, so when the probe fails three times in a row, the container is stopped and restarted. This is indicated by the events in the listing.

The `kubectl get pods` command shows that the container has been restarted:

```
$ kubectl get po kubia-liveness
NAME             READY   STATUS    RESTARTS   AGE
kubia-liveness   2/2     Running   1          5m
```

The `RESTARTS` column shows that one container restart has taken place in the pod.

UNDERSTANDING HOW A CONTAINER THAT FAILS ITS LIVENESS PROBE IS RESTARTED

If you're wondering whether the main process in the container was gracefully stopped or killed forcibly, you can check the pod's status by retrieving the full manifest using `kubectl get` or using `kubectl describe` as shown in the following listing.

Listing 6.10 Inspecting the restarted container's last state with kubectl describe

```
$ kubectl describe po kubia-liveness
Name:           kubia-liveness
...
Containers:
  ...
  envoy:
    ...
    State:          Running                                  #A
      Started:      Sun, 31 May 2020 21:33:13 +0200          #A
    Last State:     Terminated                               #B
      Reason:       Completed                                #B
      Exit Code:    0                                        #B
      Started:      Sun, 31 May 2020 21:16:43 +0200          #B
      Finished:     Sun, 31 May 2020 21:33:13 +0200          #B
    ...
```

#A This is the state of the new container.
#B The previous container terminated with exit code 0.

The exit code zero shown in the listing implies that the application process gracefully exited on its own. If it had been killed, the exit code would have been 137.

> **NOTE** Exit code `128+n` indicates that the process exited due to external signal `n`. Exit code `137` is `128+9`, where `9` represents the `KILL` signal. You'll see this exit code whenever the container is killed. Exit code `143` is `128+15`, where 15 is the `TERM` signal. You'll typically see this exit code when the container runs a shell that has terminated gracefully.

Let's examine Envoy's log to confirm that it caught the `TERM` signal and has terminated by itself. You must use the `kubectl logs` command with the `--container` or the shorter `-c` option to specify what container you're interested in.

Also, because the container has been replaced with a new one due to the restart, you must request the log of the previous container using the `--previous` or `-p` flag. The next listing shows the full command and the last four lines of its output.

Listing 6.11 The last few lines of Envoy's log when killed due to a failed liveness probe

```
$ kubectl logs kubia-liveness -c envoy -p
...
...[warning][main] [source/server/server.cc:493] caught SIGTERM
...[info][main] [source/server/server.cc:613] shutting down server instance
...[info][main] [source/server/server.cc:560] main dispatch loop exited
...[info][main] [source/server/server.cc:606] exiting
```

The log confirms that Kubernetes sent the `TERM` signal to the process, allowing it to shut down gracefully. Had it not terminated by itself, Kubernetes would have killed it forcibly.

After the container is restarted, its health check endpoint responds with HTTP status `200 OK` again, indicating that the container is healthy.

6.2.5 Using the exec and the tcpSocket liveness probe types

For applications that don't expose HTTP health-check endpoints, the `tcpSocket` or the `exec` liveness probes should be used.

ADDING A TCPSOCKET LIVENESS PROBE

For applications that accept non-HTTP TCP connections, a `tcpSocket` liveness probe can be configured. Kubernetes tries to open a socket to the TCP port and if the connection is established, the probe is considered a success, otherwise it's considered a failure.

An example of a `tcpSocket` liveness probe is shown in the following listing.

Listing 6.12 An example of a tcpSocket liveness probe

```
    livenessProbe:
      tcpSocket:              #A
        port: 1234            #A
```

```
    periodSeconds: 2        #B
    failureThreshold: 1     #C
```

#A This tcpSocket probe uses TCP port 1234
#B The probe runs every 2s
#C A single probe failure is enough to restart the container

The probe in the listing is configured to check if the container's network port `1234` is open. An attempt to establish a connection is made every two seconds and a single failed attempt is enough to consider the container as unhealthy.

ADDING AN EXEC LIVENESS PROBE

Applications that do not accept TCP connections may provide a command to check their status. For these applications, an `exec` liveness probe is used. As shown in the next figure, the command is executed inside the container and must therefore be available on the container's file system.

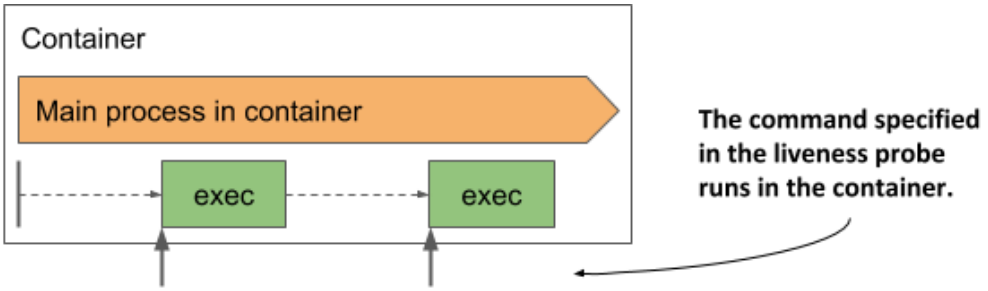


Figure 6.7 The exec liveness probe runs the command inside the container

The following listing shows an example of a probe that runs `/usr/bin/healthcheck` every two seconds to determine if the application running in the container is still alive.

Listing 6.13 An example of an exec liveness probe

```
  livenessProbe:
    exec:
      command:                  #A
      - /usr/bin/healthcheck    #A
    periodSeconds: 2            #B
    timeoutSeconds: 1           #C
    failureThreshold: 1         #D
```

#A The command to run and its arguments
#B The probe runs every second
#C The command must return within one second
#D A single probe failure is enough to restart the container

If the command returns exit code zero, the container is considered healthy. If it returns a non-zero exit code or fails to complete within one second as specified in the `timeoutSeconds` field, the container is terminated immediately, as configured in the `failureThreshold` field, which indicates that a single probe failure is sufficient to consider the container as unhealthy.

6.2.6 Using a startup probe when an application is slow to start

The default liveness probe settings give the application between 20 and 30 seconds to start responding to liveness probe requests. If the application takes longer to start, it is restarted and must start again. If the second start also takes as long, it is restarted again. If this continues, the container never reaches the state where the liveness probe succeeds and gets stuck in an endless restart loop.

To prevent this, you can increase the `initialDelaySeconds`, `periodSeconds` or `failureThreshold` settings to account for the long start time, but this will have a negative effect on the normal operation of the application. The higher the result of `periodSeconds * failureThreshold`, the longer it takes to restart the application if it becomes unhealthy. For applications that take minutes to start, increasing these parameters enough to prevent the application from being restarted prematurely may not be a viable option.

INTRODUCING STARTUP PROBES

To deal with the discrepancy between the start and the steady-state operation of an application, Kubernetes also provides *startup probes*.

If a startup probe is defined for a container, only the startup probe is executed when the container is started. The startup probe can be configured to take into account the slow start of the application. When the startup probe succeeds, Kubernetes switches to using the liveness probe, which is configured to quickly detect when the application becomes unhealthy.

ADDING A STARTUP PROBE TO A POD'S MANIFEST

Imagine that the kubia Node.js application needs more than a minute to warm up, but you want it to be restarted within 10 seconds after it has become unhealthy during normal operation. The following listing shows how you'd configure the startup and the liveness probes.

Listing 6.14 Using a combination of startup and liveness probes

```
containers:
- name: kubia
  image: luksa/kubia:1.0
  ports:
  - name: http
    containerPort: 8080
  startupProbe:
    httpGet:
      path: /                    #A
      port: http                 #A
    periodSeconds: 10            #B
    failureThreshold:  12        #B
```

```
    livenessProbe:
      httpGet:
        path: /                    #A
        port: http                 #A
      periodSeconds: 5             #C
      failureThreshold: 2          #C
```

#A The startup and the liveness probes typically use the same endpoint
#B The application gets 120 seconds to start
#C After startup, the application's health is checked every 5 seconds, and is restarted when it fails the liveness probe twice

When the container defined in the listing starts, the application has 120 seconds to start responding to requests. Kubernetes performs the startup probe every 10 seconds and makes a maximum of 12 attempts.

As shown in the following figure, unlike liveness probes, it's perfectly normal for a startup probe to fail. A failure only indicates that the application hasn't yet been completely started. A successful startup probe indicates that the application has started successfully, and Kubernetes should switch to the liveness probe. The liveness probe is then typically executed using a shorter period of time, which allows for faster detection of non-responsive applications.

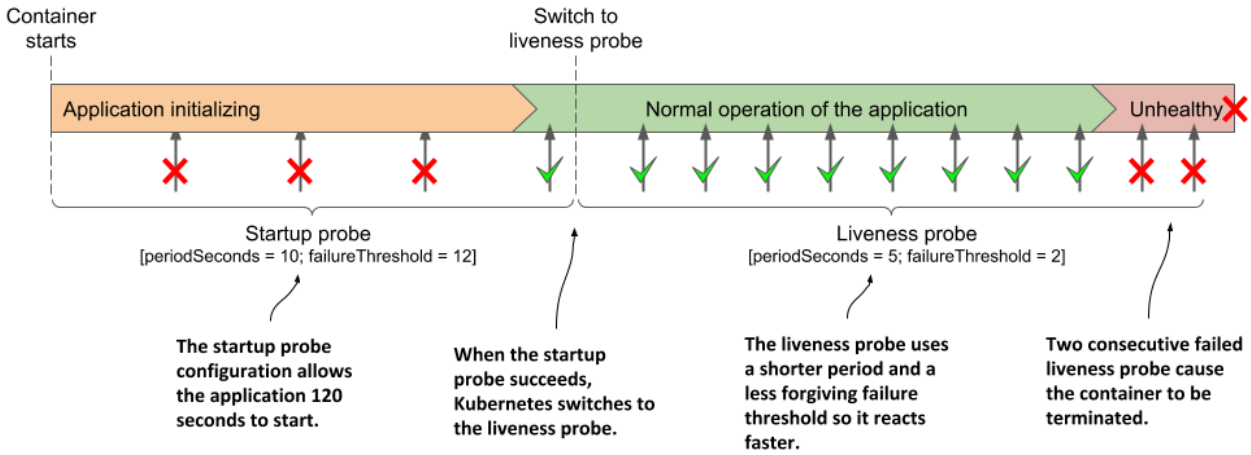


Figure 6.8 Fast detection of application health problems using a combination of startup and liveness probe

> **NOTE** If the startup probe fails often enough to reach the `failureThreshold`, the container is terminated as it the liveness probe had failed.

Usually, the startup and liveness probes are configured to use the same HTTP endpoint, but different endpoints can be used. You can also configure the startup probe as an `exec` or `tcpSocket` probe instead of an `httpGet` probe.

6.2.7 Creating effective liveness probe handlers

You should define a liveness probe for all your pods. Without one, Kubernetes has no way of knowing whether your app is still alive or not, apart from checking whether the application process has terminated.

CAUSING UNNECESSARY RESTARTS WITH BADLY IMPLEMENTED LIVENESS PROBE HANDLERS

When you implement a handler for the liveness probe, either as an HTTP endpoint in your application or as an additional executable command, be very careful to implement it correctly. If a poorly implemented probe returns a negative response even though the application is healthy, the application will be restarted unnecessarily. Many Kubernetes users learn this the hard way. If you can make sure that the application process terminates by itself when it becomes unhealthy, it may be safer not to define a liveness probe.

WHAT A LIVENESS PROBE SHOULD CHECK

The liveness probe for the `kubia` container isn't configured to call an actual health-check endpoint, but only checks that the Node.js server responds to simple HTTP requests for the root URI. This may seem overly simple, but even such a liveness probe works wonders, because it causes a restart of the container if the server no longer responds to HTTP requests, which is its main task. If no liveness probe was defined, the pod would remain in an unhealthy state where it doesn't respond to any requests and would have to be restarted manually. A simple liveness probe like this is better than nothing.

To provide a better liveness check, web applications typically expose a specific health-check endpoint, such as `/healthz`. When this endpoint is called, the application performs an internal status check of all the major components running within the application to ensure that none of them have died or are no longer doing what they should.

> **TIP** Make sure that the `/healthz` HTTP endpoint doesn't require authentication; otherwise the probe will always fail, causing your container to be restarted indefinitely.

Make sure that the application checks only the operation of its internal components and nothing that is influenced by an external factor. For example, the health-check endpoint of a frontend service should never respond with failure when it can't connect to a backend service. If the backend service fails, restarting the frontend will not solve the problem. Such a liveness probe will fail again after the restart, so the container will be restarted repeatedly until the backend is repaired. If many services are interdependent in this way, the failure of a single service can result in cascading failures across the entire system.

KEEPING PROBES LIGHT

The handler invoked by a liveness probe shouldn't use too much computing resources and shouldn't take too long to complete. By default, probes are executed relatively often and only given one second to complete.

Using a handler that consumes a lot of CPU or memory can seriously affect the main process of your container. Later in the book you'll learn how to limit the CPU time and total memory available to a container. The CPU and memory consumed by the probe handler

invocation count towards the resource quota of the container, so using a resource-intensive handler will reduce the CPU time available to the main process of the application.

> **TIP** When running a Java application in your container, you may want to use an HTTP GET probe instead of an exec liveness probe that starts an entire JVM. The same applies to commands that require considerable computing resources.

AVOIDING RETRY LOOPS IN YOUR PROBE HANDLERS

You've learned that the failure threshold for the probe is configurable. Instead of implementing a retry loop in your probe handlers, keep it simple and instead set the `failureThreshold` field to a higher value so that the probe must fail several times before the application is considered unhealthy. Implementing your own retry mechanism in the handler is a waste of effort and represents another potential point of failure.

6.3 Executing actions at container start-up and shutdown

In the previous chapter you learned that you can use init containers to run containers at the start of the pod lifecycle. You may also want to run additional processes every time a container starts and just before it stops. You can do this by adding *lifecycle hooks* to the container. Two types of hooks are currently supported:

- *Post-start* hooks, which are executed when the container is started, and
- *Pre-stop* hooks, which are executed shortly before the container stops.

These lifecycle hooks are specified per container, as opposed to init containers, which are specified at the pod level. The next figure should help you visualize how lifecycle hooks fit into the lifecycle of a container.

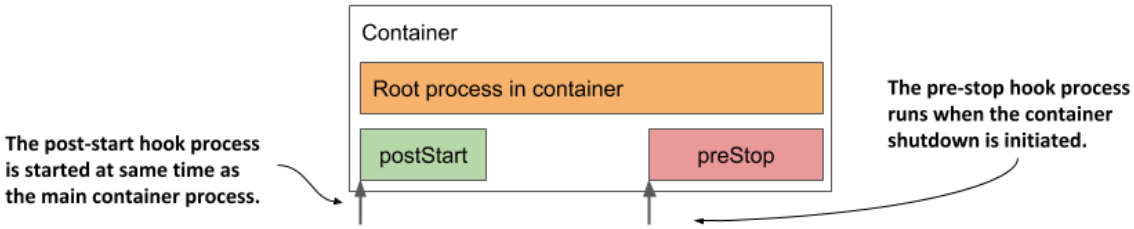


Figure 6.9 How the post-start and pre-stop hook fit into the container's lifecycle

Like liveness probes, lifecycle hooks can be used to either

- execute a command inside the container, or
- send an HTTP GET request to the application in the container.

> **NOTE** The same as with liveness probes, lifecycle hooks can only be applied to regular containers and not to init containers. Unlike probes, lifecycle hooks do not support `tcpSocket` handlers.

Let's look at the two types of hooks individually to see what you can use them for.

6.3.1 Using post-start hooks to perform actions when the container starts

The post-start lifecycle hook is invoked immediately after the container is created. You can use the `exec` type of the hook to execute an additional process as the main process starts, or you can use the `httpGet` hook to send an HTTP request to the application running in the container to perform some type of initialization or warm-up procedure.

If you're the author of the application, you could perform the same operation within the application code itself, but if you need to add it to an existing application that you didn't create yourself, you may not be able to do so. A post-start hook provides a simple alternative that doesn't require you to change the application or its container image.

Let's look at an example of how a post-start hook can be used in a new service you'll create.

USING A POST-START CONTAINER LIFECYCLE HOOK TO RUN A COMMAND IN THE CONTAINER

During my first steps with Unix in the 1990s, one of the things I found amusing was the random, sometimes funny message that the `fortune` command displayed every time I logged into our high school's server, which was running the Solaris OS at the time. Nowadays, you'll rarely see the `fortune` command installed on Unix/Linux systems anymore, but you can still install it and run it whenever you're bored. Here's an example of what it may display:

```
$ fortune
Dinner is ready when the smoke alarm goes off.
```

In the following exercise, you'll combine the `fortune` program with the Nginx web server to create a web-based fortune service.

For the first version of the service, the `fortune` command will write the message to a file, which will then be served by Nginx. Although this means that the same message is returned in every request, this is a perfectly good start. You'll later improve the service iteratively.

The Nginx web server is available as a container image, so let's use it. Because the fortune command is not available in the image, you'd normally build a new image based on the Nginx image and install the fortune package during the container build process.

Let's keep things ultra simple for now and both install and run the `fortune` command when the container starts. Although this is not something you should normally do, a post-start hook can be used for this. The following listing shows the pod manifest that defines a post-start hook that does this.

Listing 6.15 Pod with a post-start lifecycle hook

```
apiVersion: v1
kind: Pod
metadata:
  name: fortune-poststart                          #A
spec:
  containers:
  - name: nginx                                    #B
```

```
    image: nginx:alpine                                #B
    lifecycle:                                         #C
      postStart:                                       #C
        exec:                                          #C
          command:                                     #C
          - sh                                                                  #D
          - -c                                                                  #D
          - "apk add fortune && fortune > /usr/share/nginx/html/quote"          #D
    ports:                                             #E
    - name: http                                       #E
      containerPort: 80                                #E
```

#A Let's name this pod fortune-poststart
#B The nginx:alpine container image is used in this single-container pod
#C A post-start lifecycle hook is used to run a command when the container starts
#D This is the shell command that is executed
#E The Nginx server runs on port 80

The pod is named `fortune-poststart` and contains a single container based on the `nginx:alpine` image. A `postStart` lifecycle hook is defined for the container. It executes the following command when the Nginx server is started:

```
sh -c "apk add fortune && fortune > /usr/share/nginx/html/quote"
```

Let me break the command down for you. It executes the `sh` shell that runs the following two commands:

1. The `apk add fortune` command installs the `fortune` package.
2. The `fortune` command is executed, and its output is redirected to the `/usr/share/nginx/html/quote` file.

The command runs parallel to the main process. The `postStart` name is somewhat misleading, because the hook isn't called after the main process is fully started, but as soon as the container is created, at roughly the same time as when the main process starts. When the `postStart` hook is finished, the quote produced by the `fortune` command is stored in the file and is ready to be served by Nginx.

Use the `kubectl apply` command to create the pod from the `fortune-poststart.yaml` file, and you should then be able to use `curl` or your browser to get the quote at URI `/quote` on port `80` of the `fortune-poststart` pod. You've already learned how to do this, but you may want to refer to the sidebar because there is a caveat.

Accessing the fortune-poststart pod

To retrieve the quote from the `fortune-poststart` pod, you must first run the `kubectl port-forward` command, which may fail as shown here:

```
$ kubectl port-forward fortune-poststart 80
Unable to listen on port 80: Listeners failed to create with the following errors: [unable
to create listener: Error listen tcp4 127.0.0.1:80: bind: permission denied unable to
create listener: Error listen tcp6 [::1]:80: bind: permission denied]
```

```
error: unable to listen on any of the requested ports: [{80 80}]
```

The command fails if your operating system doesn't allow you to run processes that bind to port numbers 0-1023. To fix this, you must use a higher local port number as follows:

```
$ kubectl port-forward fortune-poststart 1080:80
```

The last argument tells `kubectl` to use port `1080` locally and forward it to port `80` of the pod.
You can now access the fortune service at http://localhost:1080/quote.

UNDERSTANDING HOW A POST-START HOOK AFFECTS THE CONTAINER

Although the post-start hook runs asynchronously with the main container process, it affects the container in two ways.

First, the container remains in the `Waiting` state with the reason `ContainerCreating` until the hook invocation is completed. The phase of the pod is `Pending`. If you run the `kubectl logs` command at this point, it refuses to show the logs, even though the container is running. The `kubectl port-forward` command also refuses to forward ports to the pod.

If you want to see this for yourself, deploy the `fortune-poststart-slow.yaml` pod manifest file that you can find in the code archive of the book. It defines a post-start hook that takes 60 seconds to complete. Immediately after the pod is created, inspect its state, and display the logs with the following command:

```
 $ kubectl logs fortune-poststart-slow
Error from server (BadRequest): container "nginx" in pod "fortune-poststart-slow" is
waiting to start: ContainerCreating
```

The error message returned implies that the container hasn't started yet, which isn't the case. To prove this, use the command in the following listing to list processes in the container:

Listing 6.16 Processes running in a container while the post-start hooks runs

```
$ kubectl exec fortune-poststart-slow -- ps x
PID   USER     TIME  COMMAND
  1 root      0:00 nginx: master process nginx -g daemon off;          #A
  7 root      0:00 sh -c sleep 60 && apk add fortune && fortune > ...  #B
 13 nginx     0:00 nginx: worker process                               #A
...                                                                    #A
 20 nginx     0:00 nginx: worker process                               #A
 21 root      0:00 sleep 60                                            #B
 22 root      0:00 ps x
```

#A Nginx is running
#B The post-start hook processes

The other way a post-start hook can affect the container is if the command used in the hook can't be executed or returns a non-zero exit code. If this happens, the entire container is

restarted. To see an example of a post-start hook that fails, deploy the pod manifest `fortune-poststart-fail.yaml`.

If you watch the pod's status using kubectl get pods -w, you'll see the following status:

```
fortune-poststart-fail   0/1     PostStartHookError: command 'sh -c echo 'Emulating
a post-start hook failure'; exit 1' exited with 1:
```

It shows the command that was executed and the code with which it terminated. When you review the pod events shown in the following listing, you'll see a `FailedPostStartHook` warning event that indicates the exit code and what the command printed to the standard or error output.

Listing 6.17 Event showing the exit code and output of a failed postStart hook

```
Warning  FailedPostStartHook  Exec lifecycle hook ([sh -c ...]) for
                              Container "nginx" in Pod "fortune-poststart-
                              fail_default(...)" failed - error: command
                                 '...' exited with 1: , message: "Emulating a
                                 post-start hook failure\n"
```

The same information is also contained in the `containerStatuses` field in the pod's `status` field, but only for a short time, as the container status changes to `CrashLoopBackOff` shortly afterwards.

> **TIP** Because the state of a pod can change quickly, inspecting just its status may not tell you everything you need to know. Rather than inspecting the state at a particular moment in time, reviewing the pod's events is usually a better way to get the full picture.

CAPTURING THE OUTPUT PRODUCED BY THE PROCESS INVOKED VIA A POST-START HOOK

As you've just learned, the output of the command defined in the post-start hook can be inspected if it fails. In cases where the command completes successfully, the output of the command is not logged anywhere. To see the output, the command must log to a file instead of the standard or error output. You can then view the contents of the file with a command like the following:

```
$ kubectl exec my-pod cat logfile.txt
```

USING AN HTTP GET POST-START HOOK

In the previous example, you configured the post-start hook to invoke a command inside the container. Alternatively, you can have Kubernetes send an HTTP GET request when it starts the container by using an `httpGet` post-start hook.

> **NOTE** You can't specify both an `exec` and an `httpGet` post-start hook for a container. You can only specify one.

For example, when starting a web application inside a container, you may want to use a post-start hook to send an initial request to the application so that it can initialize its caches

or warm up its other internal components, which allows the first request sent by an actual client to be processed more quickly.

The following listing shows an example of a post-start hook definition that does this:

Listing 6.18 Using an httpGet post-start hook to warm up a web server

```
    lifecycle:                #A
      postStart:              #A
        httpGet:              #A
          port: 80            #B
          path: /warmup       #C
```

#A This is a post-start lifecycle hook that performs an HTTP GET request
#B The request is sent to port 80 of the pod
#C The URI requested in the HTTP GET request

The example in the listing shows an `httpGet` post-start hook that calls the `/warmup` URI on port `80` of the pod. You can find this example in the `poststart-httpget.yaml` file in the book's code archive.

In addition to the `port` and `path` shown in the listing, you can also specify the `scheme` (`HTTP` or `HTTPS`) and `host` fields, as well as the `httpHeaders` to be sent in the request. The `host` field defaults to the pod IP. Be careful not to set it to `localhost`, because `localhost` refers to the node hosting the pod, not the pod itself.

As with command-based post-start hooks, the HTTP GET post-start hook is executed immediately when the container's main process starts. This can be problematic if the process doesn't start up immediately. As you've already learned, the container is restarted if the post-start hook fails. To see this for yourself, try creating the pod defined in `poststart-httpget-slow.yaml`.

> **WARNING** Using an HTTP GET post-start hook with applications that don't immediately start accepting connections can cause the container to enter an endless restart loop.

Interestingly, Kubernetes doesn't treat the hook as failed if the HTTP server responds with an HTTP error code like `404 Not Found`. Make sure you specify the correct URI in your HTTP GET hook, otherwise you might not even notice that the post-start hook does nothing.

6.3.2 Running a process just before the container terminates

Besides executing a command or sending an HTTP request at container startup, Kubernetes also allows the definition of a *pre-stop* hook in your containers.

A pre-stop hook is executed immediately before a container is terminated. To terminate a process, the `TERM` signal is usually sent to it. This tells the application to finish what it's doing and shut down. The same happens with containers. Whenever a container needs to be stopped or restarted, the `TERM` signal is sent to the main process in the container. Before this happens, however, Kubernetes first executes the pre-stop hook, if one is configured for the container. The `TERM` signal is not sent until the pre-stop hook completes unless the process has already terminated due to the invocation of the pre-stop hook handler itself.

NOTE When container termination is initiated, the liveness and other probes are no longer invoked.

A pre-stop hook can be used to initiate a graceful shutdown of the container or to perform additional operations without having to implement them in the application itself. As with post-start hooks, you can either execute a command within the container or send an HTTP request to the application running in it.

USING A PRE-STOP LIFECYCLE HOOK TO SHUT DOWN A CONTAINER GRACEFULLY

The Nginx web server used in the fortune pod responds to the `TERM` signal by immediately closing all open connections and terminating the process. This is not ideal, as the client requests that are being processed at this time aren't allowed to complete.

Fortunately, you can instruct Nginx to shut down gracefully by running the command `nginx -s quit`. When you run this command, the server stops accepting new connections, waits until all in-flight requests have been processed, and then quits.

When you run Nginx in a Kubernetes pod, you can use a pre-stop lifecycle hook to run this command and ensure that the pod shuts down gracefully. The following listing shows the definition of this pre-stop hook. You can find it in the `fortune-prestop.yaml` pod manifest.

Listing 6.19 Defining a pre-stop hook for Nginx

```
    lifecycle:              #A
      preStop:              #A
        exec:               #B
          command:          #B
          - nginx           #C
          - -s              #C
          - quit            #C
```

#A This is a pre-stop lifecycle hook
#B It executes a command
#C This is the command that gets executed

Whenever a container using this pre-stop hook is terminated, the command `nginx -s quit` is executed in the container before the main process of the container receives the `TERM` signal.

Unlike the post-start hook, the container is terminated regardless of the result of the pre-stop hook - a failure to execute the command or a non-zero exit code does not prevent the container from being terminated. If the pre-stop hook fails, you'll see a `FailedPreStopHook` warning event among the pod events, but you might not see any indication of the failure if you are only monitoring the status of the pod.

TIP If successful completion of the pre-stop hook is critical to the proper operation of your system, make sure that it runs successfully. I've experienced situations where the pre-stop hook didn't run at all, but the engineers weren't even aware of it.

Like post-start hooks, you can also configure the pre-stop hook to send an HTTP GET request to your application instead of executing commands. The configuration of the HTTP GET pre-stop hook is the same as for a post-start hook. For more information, see section 6.3.1.

Application not receiving the TERM signal

Many developers make the mistake of defining a pre-stop hook just to send a `TERM` signal to their applications in the pre-stop hook. They do this when they find that their application never receives the `TERM` signal. The root cause is usually not that the signal is never sent, but that it is swallowed by something inside the container. This typically happens when you use the *shell* form of the `ENTRYPOINT` or the `CMD` directive in your Dockerfile. Two forms of these directives exist.

The *exec* form is: `ENTRYPOINT ["/myexecutable", "1st-arg", "2nd-arg"]`

The *shell* form is: `ENTRYPOINT /myexecutable 1st-arg 2nd-arg`

When you use the exec form, the executable file is called directly. The process it starts becomes the root process of the container. When you use the shell form, a shell runs as the root process, and the shell runs the executable as its child process. In this case, the shell process is the one that receives the `TERM` signal. Unfortunately, it doesn't pass this signal to the child process.

In such cases, instead of adding a pre-stop hook to send the `TERM` signal to your app, the correct solution is to use the exec form of `ENTRYPOINT` or `CMD`.

Note that the same problem occurs if you use a shell script in your container to run the application. In this case, you must either intercept and pass signals to the application or use the `exec` shell command to run the application in your script.

Pre-stop hooks are only invoked when the container is requested to terminate, either because it has failed its liveness probe or because the pod has to shut down. They are not called when the process running in the container terminates by itself.

UNDERSTANDING THAT LIFECYCLE HOOKS TARGET CONTAINERS, NOT PODS

As a final consideration on the post-start and pre-stop hooks, I would like to emphasize that these lifecycle hooks apply to containers and not to pods. You shouldn't use a pre-stop hook to perform an action that needs to be performed when the entire pod is shut down, because pre-stop hooks run every time the container needs to terminate. This can happen several times during the pod's lifetime, not just when the pod shuts down.

6.4 Understanding the pod lifecycle

So far in this chapter you've learned a lot about how the containers in a pod run. Now let's take a closer look at the entire lifecycle of a pod and its containers.

When you create a pod object, Kubernetes schedules it to a worker node that then runs its containers. The pod's lifecycle is divided into the three stages shown in the next figure:

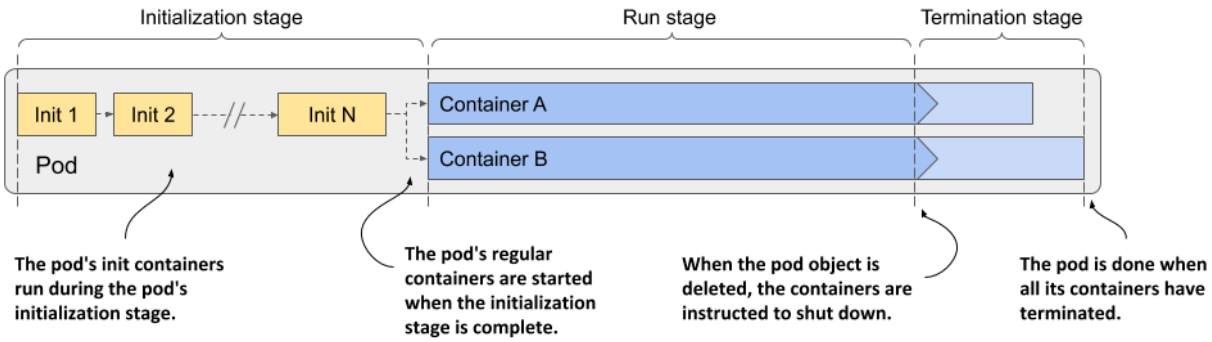


Figure 6.10 The three stages of the pod's lifecycle

The three stages of the pod's lifecycle are:

1. The initialization stage, during which the pod's init containers run.
2. The run stage, in which the regular containers of the pod run.
3. The termination stage, in which the pod's containers are terminated.

Let's see what happens in each of these stages.

6.4.1 Understanding the initialization stage

As you've already learned, the pod's init containers run first. They run in the order specified in the `initContainers` field in the pod's `spec`. Let me explain everything that unfolds.

PULLING THE CONTAINER IMAGE

Before each init container is started, its container image is pulled to the worker node. The `imagePullPolicy` field in the container definition in the pod specification determines whether the image is pulled every time, only the first time, or never.

Image pull policy	Description
Not specified	If the `imagePullPolicy` is not explicitly specified, it defaults to `Always` if the `:latest` tag is used in the image. For other image tags, it defaults to `IfNotPresent`.
`Always`	The image is pulled every time the container is (re)started. If the locally cached image matches the one in the registry, it is not downloaded again, but the registry still needs to be contacted.
`Never`	The container image is never pulled from the registry. It must exist on the worker node beforehand. Either it was stored locally when another container with the same image was deployed, or it was built on the node itself, or simply downloaded by someone or something else.
`IfNotPresent`	Image is pulled if it is not already present on the worker node. This ensures that the

image is only pulled the first time it's required.

Table 6.5 List of image-pull policies

The image-pull policy is also applied every time the container is restarted, so a closer look is warranted. Examine the following figure to understand the behavior of these three policies.

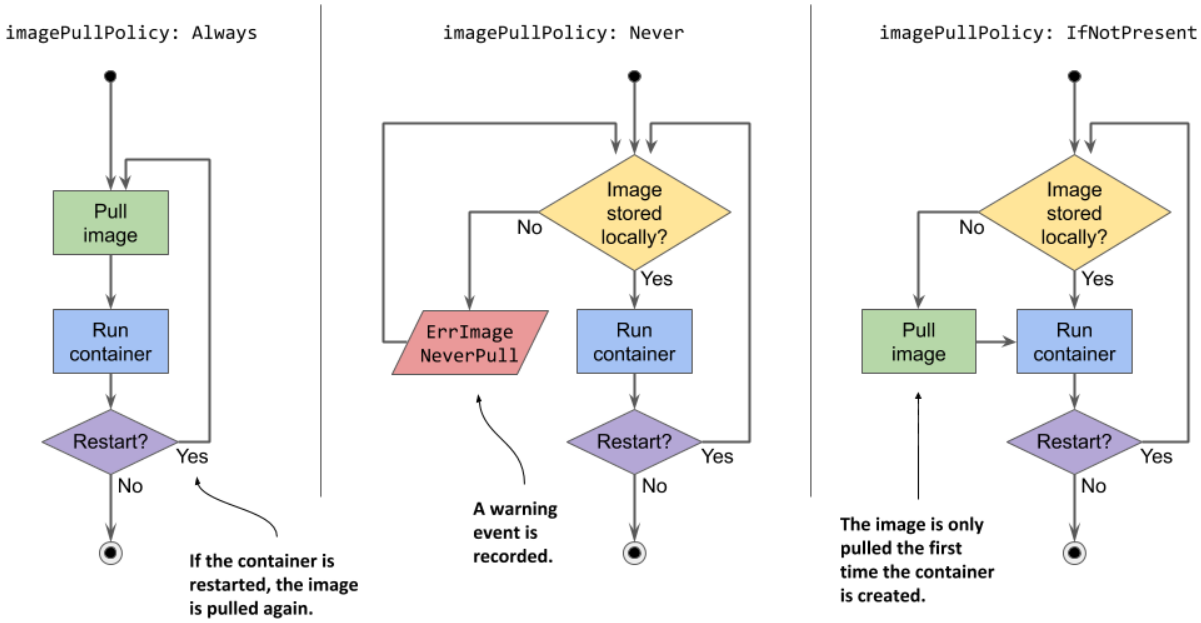


Figure 6.11 An overview of the three different image-pull policies

WARNING If the `imagePullPolicy` is set to `Always` and the image registry is offline, the container will not run even if the same image is already stored locally. A registry that is unavailable may therefore prevent your application from (re)starting.

RUNNING THE CONTAINERS

When the first container image is downloaded to the node, the container is started. When the first init container is complete, the image for the next init container is pulled and the container is started. This process is repeated until all init containers are successfully completed. Containers that fail might be restarted, as shown in the following figure.

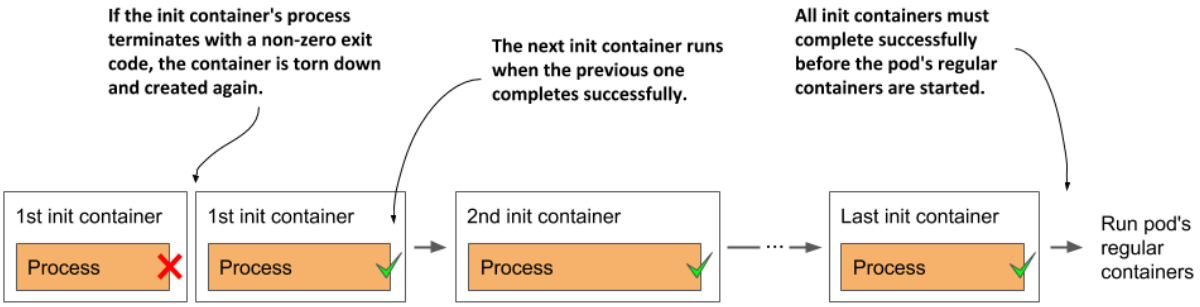


Figure 6.12 All init containers must run to completion before the regular containers can start

RESTARTING FAILED INIT CONTAINERS

If an init container terminates with an error and the pod's restart policy is set to `Always` or `OnFailure`, the failed init container is restarted. If the policy is set to `Never`, the subsequent init containers and the pod's regular containers are never started. The pod's status is displayed as `Init:Error` indefinitely. You must then delete and recreate the pod object to restart the application. For an example of such a pod, see the `fortune-init-fail-norestart.yaml` file in the book's code archive.

> **NOTE** If the container needs to be restarted and `imagePullPolicy` is set to `Always`, the container image is pulled again. If the container had terminated due to an error and you push a new image with the same tag that fixes the error, you don't need to recreate the pod, as the updated container image will be pulled before the container is restarted.

RE-EXECUTING THE POD'S INIT CONTAINERS

Init containers are normally only executed once. Even if one of the pod's main containers is terminated later, the pod's init containers are not re-executed. However, in exceptional cases, such as when Kubernetes must restart the entire pod, the pod's init containers might be executed again. This means that the operations performed by your init containers must be idempotent.

6.4.2 Understanding the run stage

When all init containers are successfully completed, the pod's regular containers are all created in parallel. In theory, the lifecycle of each container should be independent of the other containers in the pod, but this is not quite true. See sidebar for more information.

A container's post-start hook blocks the creation of the next container

The Kubelet doesn't start all containers of the pod at the same time. It creates and starts the containers synchronously in the order they are defined in the pod's `spec`. If a post-start hook is defined for a container, it runs

asynchronously with the main container process, but the execution of the post-start hook handler blocks the creation and start of the subsequent containers.

This is an implementation detail that might change in the future.

In contrast, the termination of containers is performed in parallel. A long-running pre-stop hook does block the shutdown of the container in which it is defined, but it does not block the shutdown of other containers. The pre-stop hooks of the containers are all invoked at the same time.

The following sequence runs independently for each container. First, the container image is pulled, and the container is started. When the container terminates, it is restarted, if this is provided for in the pod's restart policy. The container continues to run until the termination of the pod is initiated. A more detailed explanation of this sequence is presented next.

PULLING THE CONTAINER IMAGE

Before the container is created, its image is pulled from the image registry, following the pod's `imagePullPolicy`. Once the image is pulled, the container is created.

> **NOTE** If one of the container images can't be pulled, the other containers run anyway.

> **WARNING** Containers don't necessarily start at the same moment. If pulling the image takes a long time, the container may start well after all the others have already started. Bear this in mind if one of your containers depends on another.

RUNNING THE CONTAINER

The container starts when the main container process starts. If a post-start hook is defined in the container, it is invoked in parallel with the main container process. The post-start hook runs asynchronously and must be successful for the container to continue running.

Together with the main container and the potential post-start hook process, the startup probe, if defined for the container, is started. When the startup probe is successful, or if the startup probe is not configured, the liveness probe is started.

TERMINATING AND RESTARTING THE CONTAINER ON FAILURES

If the startup or the liveness probe fails so often that it reaches the configured failure threshold, the container is terminated. As with init containers, the pod's `restartPolicy` determines whether the container is then restarted or not.

Perhaps surprisingly, if the restart policy is set to `Never` and the startup hook fails, the pod's status is shown as `Completed` even though the post-start hook failed. You can see this for yourself by creating the pod in the `fortune-poststart-fail-norestart.yaml` file.

INTRODUCING THE TERMINATION GRACE PERIOD

If a container must be terminated, the container's pre-stop hook is called so that the application can shut down gracefully. When the pre-stop hook is completed, or if no pre-stop hook is defined, the `TERM` signal is sent to the main container process. This is another hint to the application that it should shut down.

The application is given a certain amount of time to terminate. This time can be configured using the `terminationGracePeriodSeconds` field in the pod's `spec` and defaults to 30 seconds. The timer starts when the pre-stop hook is called or when the `TERM` signal is sent if no hook is defined. If the process is still running after the termination grace period has expired, it's terminated by force via the `KILL` signal. This terminates the container.

The following figure illustrates the container termination sequence.

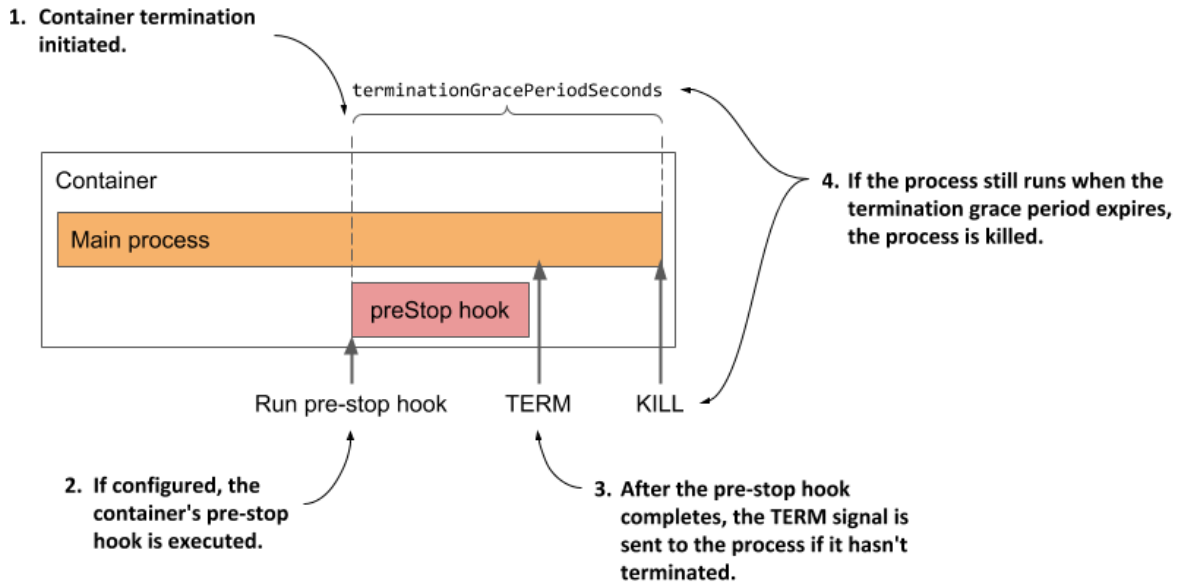


Figure 6.13 A container's termination sequence

After the container has terminated, it will be restarted if the pod's restart policy allows it. If not, the container will remain in the `Terminated` state, but the other containers will continue running until the entire pod is shut down or until they fail as well.

6.4.3 Understanding the termination stage

The pod's containers continue to run until you finally delete the pod object. When this happens, termination of all containers in the pod is initiated and its status is changed to `Terminating`.

INTRODUCING THE DELETION GRACE PERIOD

The termination of each container at pod shutdown follows the same sequence as when the container is terminated because it has failed its liveness probe, except that instead of the termination grace period, the pod's *deletion grace period* determines how much time is available to the containers to shut down on their own.

This grace period is defined in the pod's `metadata.deletionGracePeriodSeconds` field, which gets initialized when you delete the pod. By default, it gets its value from the `spec.terminationGracePeriodSeconds` field, but you can specify a different value in the `kubectl delete` command. You'll see how to do this later.

UNDERSTANDING HOW THE POD'S CONTAINERS ARE TERMINATED

As shown in the next figure, the pod's containers are terminated in parallel. For each of the pod's containers, the container's pre-stop hook is called, the `TERM` signal is then sent to the main container process, and finally the process is terminated using the `KILL` signal if the deletion grace period expires before the process stops by itself. After all the containers in the pod have stopped running, the pod object is deleted.

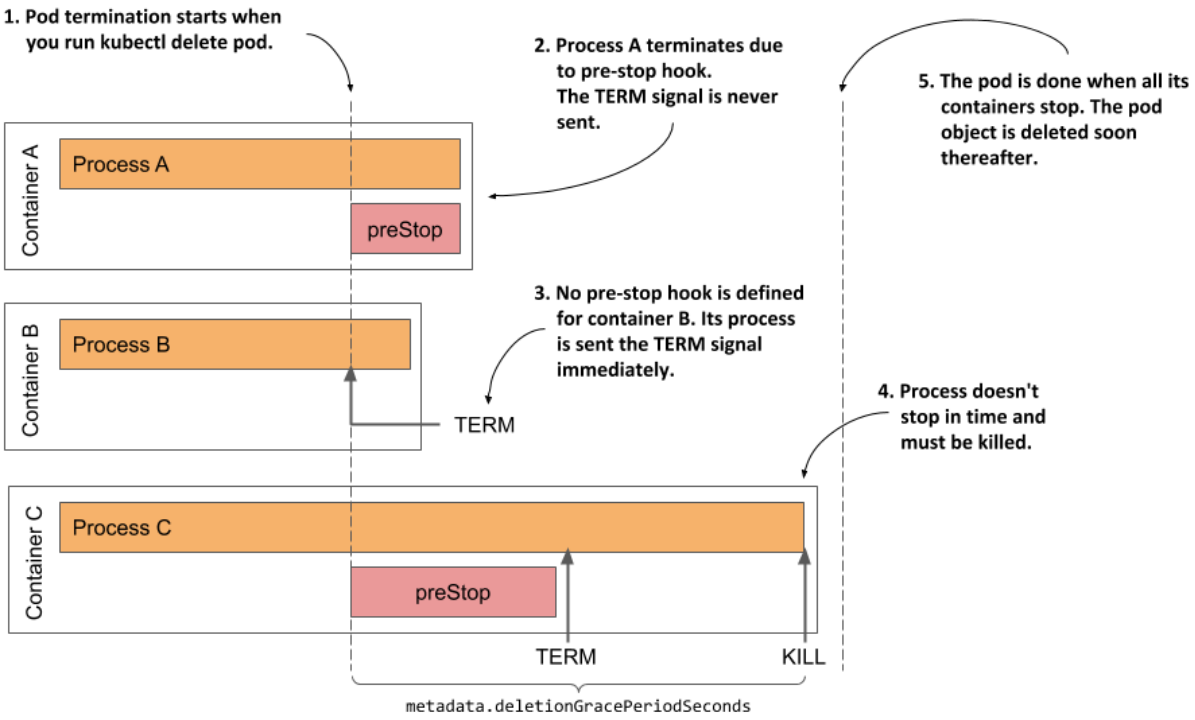


Figure 6.14 The termination sequence inside a pod

INSPECTING THE SLOW SHUTDOWN OF A POD

Let's look at this last stage of the pod's life on one of the pods you created previously. If the `kubia-ssl` pod doesn't run in your cluster, please create it again. Now delete the pod by running `kubectl delete kubia-ssl`.

It takes surprisingly long to delete the pod, doesn't it? I counted at least 30 seconds. This is neither normal nor acceptable, so let's fix it.

Considering what you've learned in this section, you may already know what's causing the pod to take so long to finish. If not, let me help you analyze the situation.

The `kubia-ssl` pod has two containers. Both must stop before the pod object can be deleted. Neither container has a pre-stop hook defined, so both containers should receive the `TERM` signal immediately when you delete the pod. The 30s I mentioned earlier match the default termination grace period value, so it looks like one of the containers, if not both, doesn't stop when it receives the `TERM` signal, and is killed after the grace period expires.

CHANGING THE TERMINATION GRACE PERIOD

You could set the pod's `terminationGracePeriodSeconds` field to a lower value, as shown in the following listing, and see if the pod shuts down faster.

Listing 6.20 Setting a lower terminationGracePeriodSeconds for faster pod shutdown

```
apiVersion: v1
kind: Pod
metadata:
  name: kubia-ssl-shortgraceperiod
spec:
  terminationGracePeriodSeconds: 5              #A
  containers:
  ...
```

#A This pod's containers have 5 seconds to terminate after receiving the TERM signal or they will be killed

In the listing above, the pod's `terminationGracePeriodSeconds` is set to `5`. If you create and then delete this pod, you'll see that its containers are terminated within 5s of receiving the `TERM` signal.

> **TIP** A reduction of the termination grace period is rarely necessary. However, it is advisable to extend it if the application usually needs more time to shut down gracefully.

SPECIFYING THE DELETION GRACE PERIOD WHEN DELETING THE POD

Any time you delete a pod, the pod's `terminationGracePeriodSeconds` determines the amount of time the pod is given to shut down, but you can override this time when you execute the `kubectl delete` command using the `--grace-period` command line option.

For example, to give the pod 10s to shut down, you run the following command:

```
$ kubectl delete po kubia-ssl --grace-period 10
```

> **NOTE** If you set this grace period to zero, the pod's pre-stop hooks are not executed.

FIXING THE SHUTDOWN BEHAVIOR OF THE KUBIA APPLICATION

Considering that the shortening of the grace period leads to a faster shutdown of the pod, it's clear that at least one of the two containers doesn't terminate by itself after it receives the

TERM signal. To see which one, recreate the pod, then run the following commands to stream the logs of each container before deleting the pod again:

```
$ kubectl logs kubia-ssl -c kubia -f
$ kubectl logs kubia-ssl -c envoy -f
```

The logs show that the Envoy proxy catches the signal and immediately terminates, whereas the Node.js application doesn't seem to respond to the signal. To fix this, you need to add the code shown in the following listing to the end of the app.js file. You can find the modified file in the Chapter06/kubia-v2-image directory in the code archive of the book.

Listing 6.21 Handling the TERM signal in the kubia application

```
process.on('SIGTERM', function () {
  console.log("Received SIGTERM. Server shutting down...");
  server.close(function () {
    process.exit(0);
  });
});
```

After you make the change to the code, create a new container image with the tag :1.1, push it to your image registry, and deploy a new pod that uses the new image. If you don't want to bother to create the image, you can also use the image luksa/kubia:1.1, which is published on Docker Hub. To create the pod, apply the manifest in the file kubia-ssl-v1-1.yaml, which you can find in the book's code archive.

If you delete this new pod, you'll see that it shuts down considerably faster. From the logs of the kubia container, you can see that it begins to shut down as soon as it receives the TERM signal.

TIP You should make sure that your init containers also handle the TERM signal so that they shut down immediately if you delete the pod object while it's still being initialized.

6.4.4 Visualizing the full lifecycle of the pod's containers

To conclude this chapter on what goes on in a pod, I present a final overview of everything that happens during the life of a pod. The following two figures summarize everything that has been explained in this chapter. The initialization of the pod is shown in the next figure.

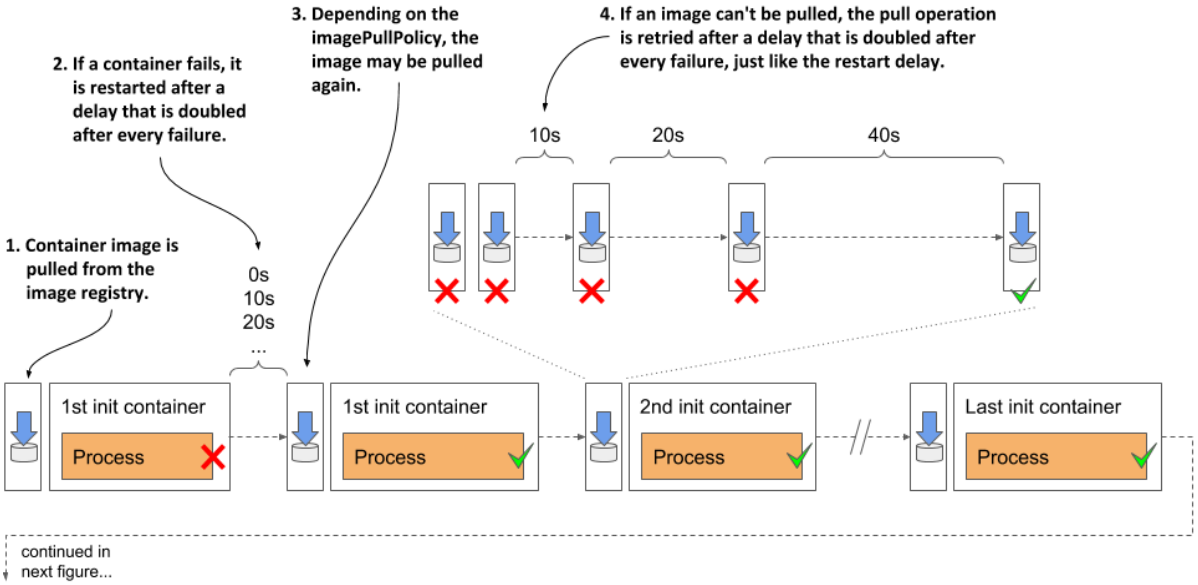


Figure 6.15 Complete overview of the pod's initialization stage

When initialization is complete, normal operation of the pod's containers begins. This is shown in the next figure.

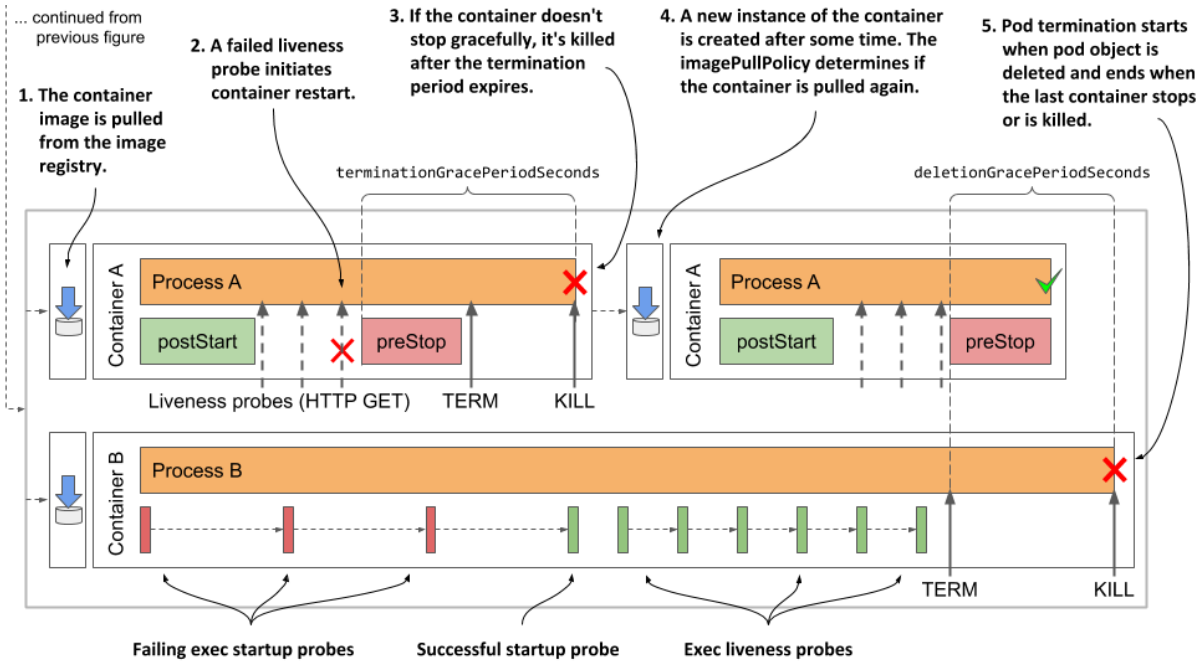


Figure 6.16 Complete overview of the pod's normal operation

6.5 Summary

In this chapter, you've learned:

- The status of the pod contains information about the phase of the pod, its conditions, and the status of each of its containers. You can view the status by running the `kubectl describe` command or by retrieving the full pod manifest using the command `kubectl get -o yaml`.
- Depending on the pod's restart policy, its containers can be restarted after they are terminated. In reality, a container is never actually restarted. Instead, the old container is destroyed, and a new container is created in its place.
- If a container is repeatedly terminated, an exponentially increasing delay is inserted before each restart. There is no delay for the first restart, then the delay is 10 seconds and then doubles before each subsequent restart. The maximum delay is 5 minutes and is reset to zero when the container has been running properly for at least twice this time.
- An exponentially increasing delay is also used after each failed attempt to download a container image.
- Adding a liveness probe to a container ensures that the container is restarted when it stops responding. The liveness probe checks the state of the application via an HTTP GET request, by executing a command in the container, or opening a TCP connection

to one of the network ports of the container.

- If the application needs a long time to start, a startup probe can be defined with settings that are more forgiving than those in the liveness probe to prevent premature restarting of the container.
- You can define lifecycle hooks for each of the pod's main containers. A post-start hook is invoked when the container starts, whereas a pre-stop hook is invoked when the container must shut down. A lifecycle hook is configured to either send an HTTP GET request or execute a command within the container.
- If a pre-stop hook is defined in the container and the container must terminate, the hook is invoked first. The `TERM` signal is then sent to the main process in the container. If the process doesn't stop within `terminationGracePeriodSeconds` after the start of the termination sequence, the process is killed.
- When you delete a pod object, all its containers are terminated in parallel. The pod's `deletionGracePeriodSeconds` is the time given to the containers to shut down. By default, it's set to the termination grace period, but can be overridden with the `kubectl delete` command.
- If shutting down a pod takes a long time, it is likely that one of the processes running in it doesn't handle the `TERM` signal. Adding a `TERM` signal handler is a better solution than shortening the termination or deletion grace period.

You now understand everything about the operation of containers in pods. In the next chapter you'll learn about the other important component of pods - storage volumes.

7

Mounting storage volumes into the Pod's containers

This chapter covers

- **Persisting files across container restarts**
- **Sharing files between containers of the same pod**
- **Sharing files between pods**
- **Attaching network storage to pods**
- **Accessing the host node filesystem from within a pod**

The previous two chapters focused on the pod's containers, but they are only half of what a pod typically contains. They are typically accompanied by storage volumes that allow a pod's containers to store data for the lifetime of the pod or beyond, or to share files with the other containers of the pod. This is the focus of this chapter.

7.1 Introducing volumes

A pod is like a small logical computer that runs a single application. This application can consist of one or more containers that run the application processes. These processes share computing resources such as CPU, RAM, network interfaces, and others. In a typical computer, the processes use the same filesystem, but this isn't the case with containers. Instead, each container has its own isolated filesystem provided by the container image.

When a container starts, the files in its filesystem are those that were added to its container image during build time. The process running in the container can then modify those files or create new ones. When the container is terminated and restarted, all changes it made to its files are lost, because the previous container is not really restarted, but completely replaced, as

explained in the previous chapter. Therefore, when a containerized application is restarted, it can't continue from the point where it was when it stopped. Although this may be okay for some types of applications, others may need the filesystem or at least part of it to be preserved on restart.

This is achieved by adding a *volume* to the pod and *mounting* it into the container.

> **DEFINITION** *Mounting* is the act of attaching the filesystem of some storage device or volume into a specific location in the operating system's file tree, as shown in figure 7.1. The contents of the volume are then available at that location.

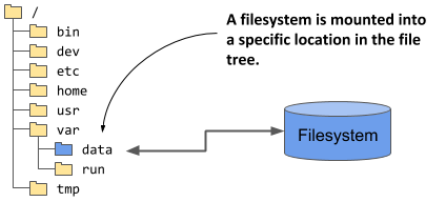


Figure 7.1 Mounting a filesystem into the file tree

7.1.1 Understanding how volumes fit into pods

Like containers, volumes aren't top-level resources like pods or nodes, but are a component within the pod and thus share its lifecycle. As the following figure shows, a volume is defined at the pod level and then mounted at the desired location in the container.

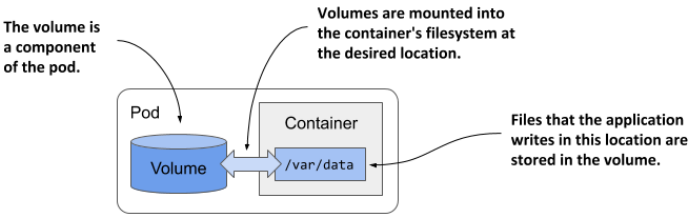


Figure 7.2 Volumes are defined at the pod level and mounted in the pod's containers

The lifecycle of a volume is tied to the lifecycle of the entire pod and is independent of the lifecycle of the container in which it is mounted. Due to this fact, volumes are also used to persist data across container restarts.

PERSISTING FILES ACROSS CONTAINER RESTARTS

All volumes in a pod are created when the pod is set up - before any of its containers are started. They are torn down when the pod is shut down.

Each time a container is (re)started, the volumes that the container is configured to use are mounted in the container's filesystem. The application running in the container can read from the volume and write to it if the volume and mount are configured to be writable.

A typical reason for adding a volume to a pod is to the persistence of data across container restarts. If no volume is mounted in the container, the entire filesystem of the container is ephemeral. Since a container restart replaces the entire container, its filesystem is also re-created from the container image. As a result, all files written by the application are lost.

If, on the other hand, the application writes data to a volume mounted inside the container, as shown in the following figure, the application process in the new container can access the same data after the container is restarted.

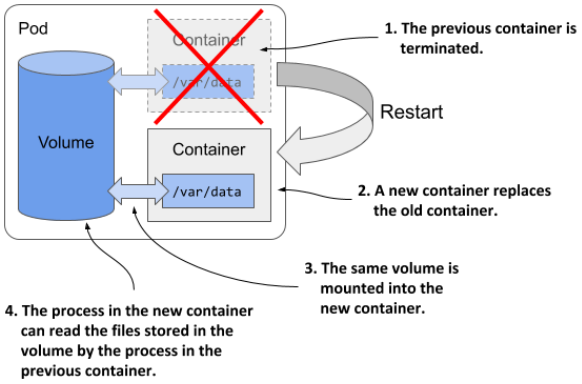


Figure 7.3 Volumes ensure that part of the container's filesystem is persisted across restarts

It is up to the author of the application to determine which files must be retained on restart. Normally you want to preserve data representing the application's state, but you may not want to preserve files that contain the application's locally cached data, as this prevents the container from starting fresh when it's restarted. Starting fresh every time may allow the application to heal itself when corruption of the local cache causes it to crash. Just restarting the container and using the same corrupted files could result in an endless crash loop.

> **TIP** Before you mount a volume in a container to preserve files across container restarts, consider how this affects the container's self-healing capability.

MOUNTING MULTIPLE VOLUMES IN A CONTAINER

A pod can have multiple volumes and each container can mount zero or more of these volumes in different locations, as shown in the following figure.

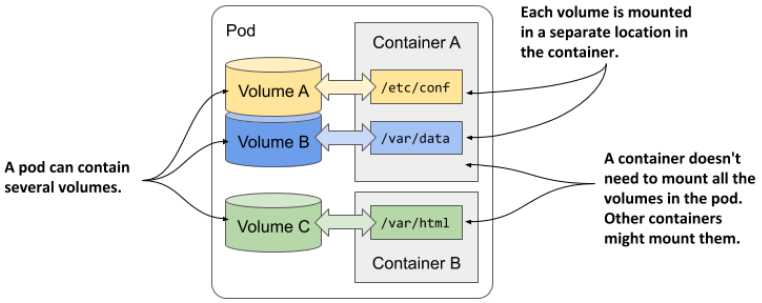


Figure 7.4 A pod can contain multiple volumes and a container can mount multiple volumes

The reason why you might want to mount multiple volumes in one container is that these volumes may serve different purposes and can be of different types with different performance characteristics.

In pods with more than one container, some volumes can be mounted in some containers but not in others. This is especially useful when a volume contains sensitive information that should only be accessible to some containers.

SHARING FILES BETWEEN MULTIPLE CONTAINERS

A volume can be mounted in more than one container so that applications running in these containers can share files. As discussed in chapter 5, a pod can combine a main application container with sidecar containers that extend the behavior of the main application. In some cases, the containers must read or write the same files.

For example, you could create a pod that combines a web server running in one container with a content-producing agent running in another container. The content agent container generates the static content that the web server then delivers to its clients. Each of the two containers performs a single task that has no real value on its own. However, as the next figure shows, if you add a volume to the pod and mount it in both containers, you enable these containers to become a complete system that provides a valuable service and is more than the sum of its parts.

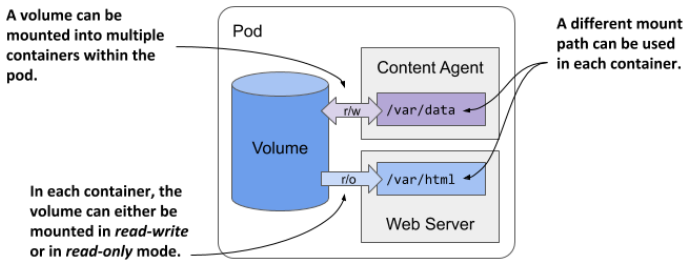


Figure 7.5 A volume can be mounted into more than one container

The same volume can be mounted at different places in each container, depending on the needs of the container itself. If the content agent writes content to `/var/data`, it makes sense to mount the volume there. Since the web server expects the content to be in `/var/html`, the container running it has the volume mounted at this location.

In the figure you'll also notice that the volume mount in each container can be configured either as read/write or as read-only. Because the content agent needs to write to the volume whereas the web server only reads from it, the two mounts are configured differently. In the interest of security, it's advisable to prevent the web server from writing to the volume, since this could allow an attacker to compromise the system if the web server software has a vulnerability that allows attackers to write arbitrary files to the filesystem and execute them.

Other examples of using a single volume in two containers are cases where a sidecar container runs a tool that processes or rotates the web server logs or when an init container creates configuration files for the main application container.

PERSISTING DATA ACROSS POD RESTARTS

A volume is tied to the lifecycle of the pod and only exists for as long as the pod exists, but depending on the volume type, the files in the volume can remain intact after the pod and volume disappear and can later be mounted into a new volume.

As the following figure shows, a pod volume can map to persistent storage outside the pod. In this case, the file directory representing the volume isn't a local file directory that persists data only for the duration of the pod, but is instead a mount to an existing, typically network-attached storage volume (NAS) whose lifecycle isn't tied to any pod. The data stored in the volume is thus persistent and can be used by the application even after the pod it runs in is replaced with a new pod running on a different worker node.

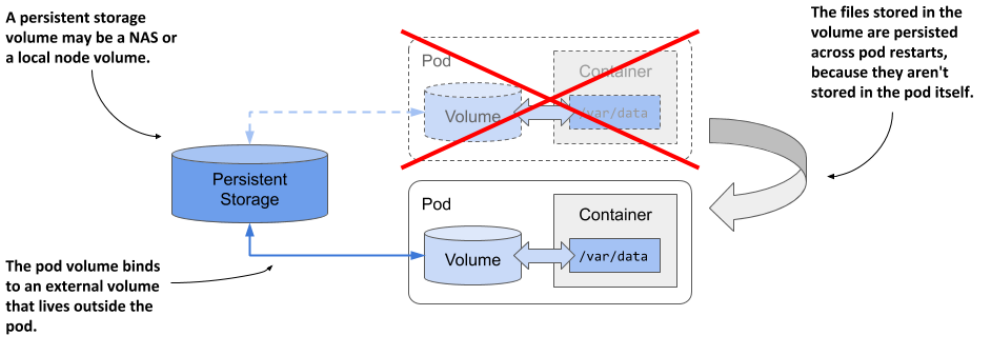


Figure 7.6 Pod volumes can also map to storage volumes that persist across pod restarts

If the pod is deleted and a new pod is created to replace it, the same network-attached storage volume can be attached to the new pod instance so that it can access the data stored there by the previous instance.

SHARING DATA BETWEEN PODS

Depending on the technology that provides the external storage volume, the same external volume can be attached to multiple pods simultaneously, allowing them to share data. The following figure shows a scenario where three pods each define a volume that is mapped to the same external persistent storage volume.

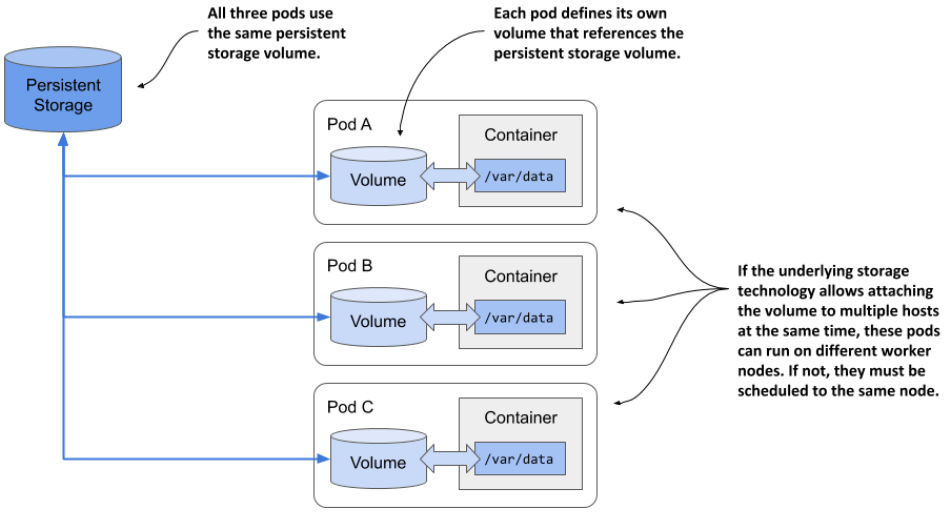


Figure 7.7 Using volumes to share data between pods

In the simplest case, the persistent storage volume could be a simple local directory on the worker node's filesystem, and the three pods have volumes that map to that directory. If all three pods are running on the same node, they can share files through this directory.

If the persistent storage is a network-attached storage volume, the pods may be able to use it even when they are deployed to different nodes. However, this depends on whether the underlying storage technology supports attaching the network volume to more than one computer simultaneously.

While technologies such as Network File System (NFS) allow attaching the volume in read/write mode on multiple computers, other technologies typically available in cloud environments, such as the Google Compute Engine Persistent Disk, allow the volume to be used either in read/write mode on a single cluster node, or in read-only mode on many nodes.

7.1.2 Introducing volume types

When you add a volume to a pod, you must specify the volume type. A wide range of volume types is available. Some are generic, while others are specific to the storage technologies used underneath. Here's a non-exhaustive list of the supported volume types:

- `emptyDir`—A simple directory that allows the pod to store data for the duration of its life cycle. The directory is created just before the pod starts and is initially empty - hence the name. The `gitRepo` volume, which is now deprecated, is similar, but is initialized by cloning a Git repository. Instead of using a `gitRepo` volume, it is recommended to use an `emptyDir` volume and initialize it using an init container.
- `hostPath`—Used for mounting files from the worker node's filesystem into the pod.
- `nfs`—An NFS share mounted into the pod.
- `gcePersistentDisk` (Google Compute Engine Persistent Disk), `awsElasticBlockStore` (Amazon Web Services Elastic Block Store), `azureFile` (Microsoft Azure File Service), `azureDisk` (Microsoft Azure Data Disk)—Used for mounting cloud provider-specific storage.
- `cephfs`, `cinder`, `fc`, `flexVolume`, `flocker`, `glusterfs`, `iscsi`, `portworxVolume`, `quobyte`, `rbd`, `scaleIO`, `storageos`, `photonPersistentDisk`, `vsphereVolume`—Used for mounting other types of network storage.
- `configMap`, `secret`, `downwardAPI`, and the `projected` volume type—Special types of volumes used to expose information about the pod and other Kubernetes objects through files. They are typically used to configure the application running in the pod. You'll learn about them in chapter 9.
- `persistentVolumeClaim`—A portable way to integrate external storage into pods. Instead of pointing directly to an external storage volume, this volume type points to a `PersistentVolumeClaim` object that points to a `PersistentVolume` object that finally references the actual storage. This volume type requires a separate explanation, which you'll find in the next chapter.
- `csi`—A pluggable way of adding storage via the Container Storage Interface. This volume type allows anyone to implement their own storage driver that is then referenced in the `csi` volume definition. During pod setup, the CSI driver is called to attach the volume to the pod.

These volume types serve different purposes. The following sections cover the most representative volume types and help you to gain a general understanding of volumes.

7.2 Using volumes

The simplest volume type is `emptyDir`. This is the volume type you normally use when you need to persist files across container restarts, as explained in section 7.1.1.

7.2.1 Using an emptyDir volume to persist files across container restarts

Remember the fortune pod from the previous chapter? It uses a post-start hook to write a fortune quote to a file that is then served by the Nginx web server. This file is stored in the container's filesystem, which means that it's lost whenever the container is restarted.

You can confirm this by deploying the pod in the `fortune-no-volume.yaml` file, retrieving the quote, and then restarting the container by telling Nginx to stop. The following listing shows the commands you need to run.

Listing 7.1 Testing the behavior of the fortune-no-volume pod

```
$ kubectl apply -f fortune-no-volume.yaml            #A
pod/fortune-no-volume created                        #A

$ kubectl exec fortune-no-volume -- cat /usr/share/nginx/html/quote #B
Quick!! Act as if nothing has happened!              #B

$ kubectl exec fortune-no-volume -- nginx -s stop        #C
[notice] 71#71: signal process started                   #C

$ kubectl exec fortune-no-volume -- cat /usr/share/nginx/html/quote #D
Hindsight is an exact science.                       #D
```

#A Create the pod
#B Fetch the quote
#C Stop Nginx and cause container to restart
#D Fetch the quote again to see that is has changed

When you retrieve the quote after restarting the container, you'll see that it has changed. If you want the pod to serve the same quote no matter how often its container is restarted, you must ensure the file in stored in a volume. An `emptyDir` volume is perfect for this.

INTRODUCING THE EMPTYDIR VOLUME TYPE

The `emptyDir` volume is the simplest type of volume. As the name suggests, it starts as an empty directory. When this type of volume is mounted in a container, files written by the application to the path where the volume is mounted are preserved for the duration of the pod's existence.

This volume type is used in single-container pods when data must be preserved even if the container is restarted. It's also used when the container's filesystem is marked read-only and you want to make only part of it writable. In pods with two or more containers, an `emptyDir` volume is used to exchange data between them.

ADDING AN EMPTYDIR VOLUME TO THE FORTUNE POD

Let's change the definition of the fortune pod so that the post-start hook writes the file to the volume instead of to the ephemeral filesystem of the container. Two changes to the pod manifest are required to achieve this:

1. An `emptyDir` volume must be added to the pod.
2. The volume must be mounted into the container.

However, since the post-start hook is executed every time the container is started, you also need to change the command that the post-start hook executes if you want to prevent it from

overwriting the file if it already exists. The operation of the new command is explained in the sidebar.

Understanding the new command in the fortune post-start hook

The post-start hook executes the following shell command:

```
ls /usr/share/nginx/html/quote || (apk add fortune &&
[CA] fortune > /usr/share/nginx/html/quote)
```

If you're not familiar with the Linux shell, it may not be obvious what this command does. Let me explain.

First, the `ls` command, which is typically used to list directory contents, is used in an untypical way to check whether the `quote` file exists. What you may not know is that the `ls` command succeeds (returns exit code zero) if the specified file exists, and fails (returns a non-zero exit code) if it doesn't.

Since in our case the entire command is an *or* expression, as denoted by the double pipe character, the right side of the expression is never evaluated if the left side of the expression evaluates to true (which is when the `ls` command succeeds). When this happens, the `apk` and `fortune` commands are never executed. Therefore, if the `quote` file already exists, it's not overwritten.

If the file doesn't exist, the `ls` command fails, causing the left side of the expression to be false, which means that the right side must be evaluated to resolve the expression. The `apk` and `fortune` commands are therefore executed and they generate the `quote` file.

This new command ensures that the quote file is only written once - at the first start of the container, not at subsequent restarts

The following listing shows the new pod manifest that incorporates all the changes.

Listing 7.2 A pod with an emptyDir volume: fortune-emptydir.yaml

```
kind: Pod
metadata:
  name: fortune-emptydir
spec:
  volumes:                          #A
  - name: content                     #A
    emptyDir: {}                    #A
  containers:
  - name: nginx
    image: nginx:alpine
    volumeMounts:                     #B
    - name: content                   #B
      mountPath: /usr/share/nginx/html      #B
    lifecycle:
      postStart:
        exec:
          command:
          - sh
          - -c
          - "ls /usr/share/nginx/html/quote || (apk add fortune &&  #C
[CA] fortune > /usr/share/nginx/html/quote)"                        #C
    ports:
    - name: http
      containerPort: 80
```

#A The volume is defined here
#B The volume is mounted into the container here
#C The new post-start command

The listing shows that an `emptyDir` volume named `content` is defined in the `spec.volumes` array of the pod manifest.

CONFIGURING THE VOLUME

In general, each volume definition must include a `name` and a type, which is indicated by the name of the nested field (for example: `emptyDir`, `gcePersistentDisk`, `nfs`, and so on). This field is typically an object with additional sub-fields that allow you to configure the volume and are specific to each volume type.

For example, the `emptyDir` volume type supports two fields for configuring the volume. They are explained in the following table.

Field	Description
medium	The type of storage medium to use for the directory. If left empty, the default medium of the host node is used (the directory is created on one of the node's disks). The only other supported option is `Memory`, which causes the volume to use `tmpfs`, a virtual memory filesystem where the files are kept in memory instead of on the hard disk.
sizeLimit	The total amount of local storage required for the directory, whether on disk or in memory. For example, to set the maximum size to ten mebibytes, you set this field to `10Mi`.

Table 7.1 Configuration options for an emptyDir volume

> **NOTE** The `emptyDir` field in the volume definition defines neither of these properties. The curly braces `{}` have been added to indicate this explicitly, but they can be omitted.

MOUNTING THE VOLUME IN THE CONTAINER

Defining a volume in the pod is only half of what you need to do to make it available in a container. The volume must also be mounted in the container. This is done by referencing the volume by name in the `volumeMounts` array within the container definition.

In addition to the `name`, a volume mount definition must also include the `mountPath` - the path within the container where the volume should be mounted. In the example, the volume is mounted at `/usr/share/nginx/html` because that's where the post-start hook writes the `quote` file.

Since the `quote` file is now written to the volume, which exists for the duration of the pod, the pod should always serve the same quote, even when the container is restarted.

OBSERVING THE EMPTYDIR VOLUME IN ACTION

If you deploy the pod in the listing, you'll notice that the quote will remain the same throughout the life of the pod, regardless of how often the container is restarted, because the `/usr/share/nginx/html` directory where the file is stored is mounted from somewhere else. You can tell this by listing the mount points in the container. Run the `mount` command to see that the directory is mounted into the container from elsewhere:

```
$ kubectl exec fortune-emptydir -- mount --list | grep nginx/html
/dev/mapper/fedora_t580-home on /usr/share/nginx/html type ext4 (rw)
```

7.2.2 Using an emptyDir volume to share files between containers

An `emptyDir` volume is also useful for sharing files between containers of the same pod (it can't be used to share files between containers of different pods). Let's see how this is done.

The fortune pod currently serves the same quote throughout the lifetime of the pod. This isn't so interesting. Let's build a new version of the pod, where the quote changes every 30 seconds.

You'll retain Nginx as the web server, but will replace the post-start hook with a container that periodically runs the `fortune` command to update the quote stored in the file. The container is available at `docker.io/luksa/fortune:1.0`, but you can also build it yourself by following the instructions in the sidebar.

Building the fortune container image

You need two files to build the image. First is the `docker_entrypoint.sh` script that has the following contents:

```
#!/bin/sh
trap "exit" INT

INTERVAL=${INTERVAL:-30}
OUTPUT_FILE=${1:-/var/local/output/quote}

echo "Fortune Writer 1.0"
echo "Configured to write fortune to $OUTPUT_FILE every $INTERVAL seconds"

while :
do
  echo "$(date) Writing fortune..."
  fortune > $OUTPUT_FILE
  sleep $INTERVAL
done
```

This is the script that is executed when you run this container. To build the container image, you'll also need a `Dockerfile` with the following contents:

```
FROM alpine
RUN apk add fortune
```

```
COPY docker_entrypoint.sh /docker_entrypoint.sh
VOLUME /var/local/output
ENTRYPOINT ["/docker_entrypoint.sh"]
```

You can build the image and push it to Docker Hub by running the following two commands (replace `luksa` with your own Docker Hub user ID):

```
$ docker build -t luksa/fortune-writer:1.0 .
$ docker push luksa/fortune-writer:1.0
```

If you've downloaded the code from the book's code repository at GitHub, you'll find both files in the `Chapter07/fortune-writer-image` directory. To build and push the image you can also run the following command in the `Chapter07/` directory:

```
$ PREFIX=luksa/ PUSH=true ./build-fortune-writer-image.sh
```

Again, replace `luksa/` with your Docker Hub user ID.

CREATING THE POD

Now that you have both images required to run the pod, create the pod manifest. Its contents are shown in the following listing.

Listing 7.3 Two containers sharing the same volume: fortune.yaml

```
apiVersion: v1
kind: Pod
metadata:
  name: fortune
spec:
  volumes:                          #A
  - name: content                     #A
    emptyDir: {}                      #A
  containers:
  - name: fortune                     #B
    image: luksa/fortune-writer:1.0       #B
    volumeMounts:                     #B
    - name: content                   #B
      mountPath: /var/local/output    #C    #B
  - name: nginx
    image: nginx:alpine
    volumeMounts:
    - name: content                   #D
      mountPath: /usr/share/nginx/html      #D
      readOnly: true                  #D
    ports:
    - name: http
      containerPort: 80
```

#A The emptyDir volume shared by the two containers
#B The container that writes the fortune to the volume
#C In this container, the volume is mounted at this location
#D In the nginx container, the volume is mounted as read-only in a different location

The pod consists of two containers and a single volume, which is mounted in both containers, but at different locations within each container. The reason for this is that the `fortune` container

writes the `quote` file into the `/var/local/output` directory, whereas the `nginx` container serves files from the `/usr/share/nginx/html` directory.

RUNNING THE POD

When you create the pod from the manifest, the two containers start and continue running until the pod is deleted. The `fortune` container writes a new quote to the file every 30 seconds, and the `nginx` container serves this file. After you create the pod, use the `kubectl port-forward` command to open a communication tunnel to the pod and test if the server responds with a different quote every 30 seconds.

Alternatively, you can also display the contents of the file using either of the following two commands:

```
$ kubectl exec fortune -c fortune -- cat /var/local/output/quote
$ kubectl exec fortune -c nginx -- cat /usr/share/nginx/html/quote
```

As you can see, one of them prints the contents of the file from within the `fortune` container, whereas the other command prints the contents from within the `nginx` container. Because the two paths point to the same `quote` file on the shared volume, the output of the commands is identical.

SPECIFYING THE STORAGE MEDIUM TO USE IN THE EMPTYDIR VOLUME

The emptyDir volume in the previous example created a directory on the actual drive of the worker node hosting your pod, so its performance depends on the type of drive installed on the node. If you need to perform the I/O operations on the volume as quickly as possible, you can instruct Kubernetes to create the volume using the *tmpfs* filesystem, which keeps its files in memory. To do this, set the emptyDir's `medium` field to `Memory` as in the following snippet:

```
volumes:
 - name: content
   emptyDir:
     medium: Memory    #A
```

#A This directory should be stored in memory.

Creating the `emptyDir` volume in memory is also a good idea whenever it's used to store sensitive data. Because the data is not written to disk, there is less chance that the data will be compromised and persisted longer than desired. As you'll learn in chapter 9, Kubernetes uses the same in-memory approach when data stored in the *Secret* API object type needs to be exposed to the application in the container.

SPECIFYING THE SIZE LIMIT FOR THE EMPTYDIR VOLUME

The size of an `emptyDir` volume can be limited by setting the `sizeLimit` field. Setting this field is especially important for in-memory volumes when the overall memory usage of the pod is limited by so-called *resource limits*. You'll learn about this in chapter 20.

7.2.3 Specifying how a volume is to be mounted in the container

In the previous section, the focus was mainly on the volume type. The volume was mounted in the container with the minimum configuration required, as shown in the following listing.

Listing 7.4 The minimal configuration of a volumeMount

```
containers:
- name: my-container
  ...
  volumeMounts:
  - name: my-volume              #A
    mountPath: /path/in/container    #B
```

#A The name of the volume to mount into this container
#B Where in the container's filesystem to mount the volume

As you can see in the listing, the absolute minimum is to specify the name of the volume and the path where it should be mounted. But other configuration options for mounting volumes exist. The full list of volume mount options is shown in the following table.

Field	Description
name	The name of the volume to mount. This must match one of the volumes defined in the pod.
mountPath	The path within the container at which to mount the volume.
readOnly	Whether to mount the volume as read-only. Defaults to false.
mountPropagation	Specifies what should happen if additional filesystem volumes are mounted inside the volume. Defaults to None, which means that the container won't receive any mounts that are mounted by the host, and the host won't receive any mounts that are mounted by the container. HostToContainer means that the container will receive all mounts that are mounted into this volume by the host, but not the other way around. Bidirectional means that the container will receive mounts added by the host, and the host will receive mounts added by the container.
subPath	Defaults to "" which means that the entire volume is mounted into the container. When set to a non-empty string, only the specified subPath within the volume is mounted into the container.
subPathExpr	Just like subPath but can have environment variable references using the syntax $(ENV_VAR_NAME). Only environment variables that are explicitly defined in the container definition are applicable. Implicit variables such as HOSTNAME will not be resolved. You'll learn how to specify environment variables in chapter 9.

Table 7.2 Configuration options for a volume mount

In most cases, you only specify the `name`, `mountPath` and whether the mount should be `readOnly`. The `mountPropagation` option comes into play for advanced use-cases where additional mounts are added to the volume's file tree later, either from the host or from the container. The `subPath` and `subPathExpr` options are useful when you want to use a single volume with multiple directories that you want to mount to different containers instead of using multiple volumes.

The `subPathExpr` option is also used when a volume is shared by multiple pod replicas. In chapter 9, you'll learn how to use the Downward API to inject the name of the pod into an environment variable. By referencing this variable in `subPathExpr`, you can configure each replica to use its own subdirectory based on its name.

7.3 Integrating external storage into pods

An `emptyDir` volume is basically a dedicated directory created specifically for and used exclusively by the pod that contains the volume. When the pod is deleted, the volume and its contents are deleted. However, other types of volumes don't create a new directory, but instead mount an existing external directory in the filesystem of the container. The contents of this volume can survive multiple instantiations of the same pod and can even be shared by multiple pods. These are the types of volumes we'll explore next.

To learn how external storage is used in a pod, you'll create a pod that runs the document-oriented database MongoDB. To ensure that the data stored in the database is persisted, you'll add a volume to the pod and mount it in the container at the location where MongoDB writes its data files.

The tricky part of this exercise is that the type of persistent volumes available in your cluster depends on the environment in which the cluster is running. At the beginning of this book, you learned that Kubernetes can reschedule a pod to another node at will. To ensure that the MongoDB pod can still access its data, it should use some kind of network-attached storage instead of the worker node's local drive.

Ideally, you should use a proper Kubernetes cluster, such as GKE, for the following exercises. Unfortunately, clusters provisioned with Minikube or kind don't provide any kind of network storage volume out of the box. So, if you're using either of these tools, you'll need to resort to using node-local storage provided by the so-called `hostPath` volume type, even though this volume type is explained later, in section 7.4.

7.3.1 Using a Google Compute Engine Persistent Disk in a pod volume

If you use Google Kubernetes Engine to run the exercises in this book, your cluster nodes run on Google Compute Engine (GCE). In GCE, persistent storage is provided via GCE Persistent Disks. Kubernetes supports adding the to your pods via the `gcePersistentDisk` volume type.

NOTE To adapt this exercise for use with other cloud providers, use the appropriate volume type supported by the cloud provider. Consult the documentation provided by the cloud provider to determine how to create the storage volume and how to mount it into the pod.

CREATING A GCE PERSISTENT DISK

Before you can use the GCE persistent disk volume in your pod, you must create the disk itself. It must reside in the same zone as your Kubernetes cluster. If you don't remember in which zone you created the cluster, you can see it by listing your Kubernetes clusters using the `gcloud` command as follows:

```
$ gcloud container clusters list
NAME   ZONE         MASTER_VERSION  MASTER_IP     ...
kubia  europe-west3-c  1.14.10-gke.42  104.155.84.137  ...
```

In my case, this shows that the cluster is located in the zone `europe-west3-c`, so I have to create the GCE persistent disk in the same zone as well. The zone must be specified when creating the disk as follows:

```
$ gcloud compute disks create --size=1GiB --zone=europe-west3-c mongodb
WARNING: You have selected a disk size of under [200GB]. This may result in poor I/O performance. For more information,
         see: https://developers.google.com/compute/docs/disks#pdperformance.
Created [https://www.googleapis.com/compute/v1/projects/rapid-pivot-136513/zones/europe-west3-c/disks/mongodb].
NAME    ZONE         SIZE_GB TYPE       STATUS
mongodb  europe-west3-c  1       pd-standard  READY
```

This command creates a GCE persistent disk called `mongodb` with 1GiB of space. You can freely ignore the disk size warning, because it doesn't affect the exercises you're about to run. You may also see an additional warning that the disk is not yet formatted. You can ignore that, too, because formatting is done automatically when you use the disk in your pod.

CREATING A POD WITH A GCEPERSISTENTDISK VOLUME

Now that you have set up your physical storage, you can use it in a volume inside your MongoDB pod. You'll create the pod from the YAML shown in the following listing.

Listing 7.5 A pod using a gcePersistentDisk volume: mongodb-pod-gcepd.yaml

```
apiVersion: v1
kind: Pod
metadata:
  name: mongodb
spec:
  volumes:
  - name: mongodb-data        #A
    gcePersistentDisk:        #B
      pdName: mongodb         #C
      fsType: ext4            #D
  containers:
  - image: mongo
    name: mongodb
```

```
  volumeMounts:
  - name: mongodb-data       #A
    mountPath: /data/db      #E
  ports:
  - containerPort: 27017
    protocol: TCP
```

#A The name of the volume (also referenced in the volumeMounts section below)
#B The volume type is GCE Persistent Disk.
#C The name of the persistent disk must match the actual disk you created earlier.
#D The filesystem type is ext4.
#E The path where MongoDB stores its data

> **NOTE** If you're using Minikube or kind, you can't use a GCE Persistent Disk, but you can deploy `mongodb-pod-hostpath.yaml`, which uses a `hostPath` volume instead of a GCE PD. This uses node-local instead of network storage, so you must ensure that the pod is always deployed to the same node. This is always true in Minikube because it creates a single node cluster. If you're using kind, create the pod from the file `mongodb-pod-hostpath-kind.yaml`, which ensures that the pod is always deployed on the same node.

The pod is visualized in the following figure. It consists of a single container and a single volume backed by the GCE Persistent Disk you created earlier. Within the container, the volume is mounted at `/data/db`, since this is the place where MongoDB stores its data. This ensures that the data will be written to the persistent disk.

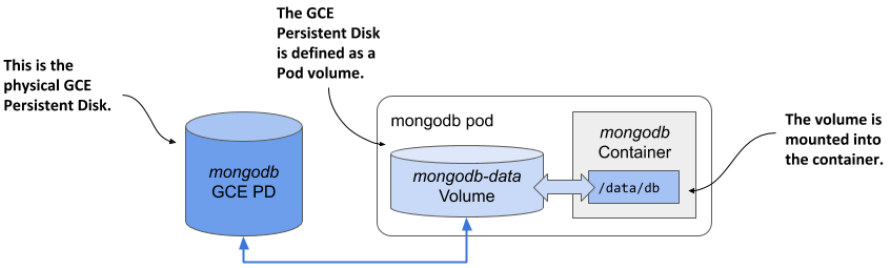


Figure 7.8 A GCE Persistent Disk used as a pod Volume and mounted into one of its containers

WRITING TO THE VOLUME

After you create the pod, run the MongoDB client inside the container and add some data to the database. To do this, run the client as shown in the following listing.

Listing 7.6 Entering the MongoDB shell inside the mongodb pod

```
$ kubectl exec -it mongodb -- mongo
MongoDB shell version v4.4.0
connecting to: mongodb://127.0.0.1:27017/...
Implicit session: session { "id" : UUID("42671520-0cf7-...") }
MongoDB server version: 4.4.0
...
```

```
>
```

To insert a document into the database, enter the following commands:

```
> use mystore
switched to db mystore
> db.foo.insert({name:'foo'})
WriteResult({ "nInserted" : 1 })
```

This inserts a document with a single property called `name`. You can also specify additional properties in the document if you wish, or add additional documents. Now, use the `find()` command to retrieve the document you inserted:

```
> db.foo.find()
{ "_id" : ObjectId("57a61eb9de0cfd512374cc75"), "name" : "foo" }
```

This document should now be stored in MongoDB's data files, which are located in the `/data/db` directory. Since this is where you mounted the GCE Persistent Disk, the document should be stored permanently.

RE-CREATING THE POD AND VERIFYING THAT IT CAN READ THE DATA PERSISTED BY THE PREVIOUS POD

You can now exit the `mongodb` client (type `exit` and press Enter), after which you can delete the pod and recreate it:

```
$ kubectl delete pod mongodb
pod "mongodb" deleted
$ kubectl create -f mongodb-pod-gcepd.yaml
pod "mongodb" created
```

Since the new pod is an exact replica of the previous, it points to the same GCE persistent disk as the previous pod, so the MongoDB container running inside it should see the exact same files, even if the new pod is scheduled to another node.

> **TIP** You can see what node a pod is scheduled to by running `kubectl get po -o wide`.

Once the container starts up, you can run the MongoDB client again and check if the previously stored document(s) can still be retrieved, as shown in the following listing.

Listing 7.7 Retrieving MongoDB's persisted data in a new pod

```
$ kubectl exec -it mongodb mongo
...
> use mystore
switched to db mystore
> db.foo.find()
{ "_id" : ObjectId("57a61eb9de0cfd512374cc75"), "name" : "foo" }
```

As expected, the data still exists even though you deleted and recreated the pod. This confirms that you can use a GCE persistent disk to persist data across multiple instantiations of the same

pod. To be more precise, it isn't the same pod. They are two different pods pointing to the same underlying persistent storage.

You might wonder if you can use the same persistent disk in two or more pods at the same time. The answer to this question is not trivial, because it requires that you understand exactly how external volumes are mounted in pods. I'll explain this in section 7.3.3. Before I do, I need to explain how to mount external storage when your cluster isn't running on Google's infrastructure.

7.3.2 Using other persistent volume types

In the previous exercise, I explained how to add persistent storage to a pod running in Google Kubernetes Engine. If you are running your cluster elsewhere, you should use whatever volume type is supported by the underlying infrastructure.

For example, if your Kubernetes cluster runs on Amazon's AWS EC2, you can use an `awsElasticBlockStore` volume. If your cluster runs on Microsoft Azure, you can use the `azureFile` or the `azureDisk` volume. I won't go into detail about how to do this, but it's practically the same as in the previous example. You first need to create the actual underlying storage and then set the right fields in the volume definition.

USING AN AWS ELASTIC BLOCK STORE VOLUME

For example, if you want to use an AWS elastic block store volume instead of the GCE Persistent Disk, you only need to change the volume definition as shown in the following listing.

Listing 7.8 A pod using an awsElasticBlockStore volume: mongodb-pod-aws.yaml

```
apiVersion: v1
kind: Pod
metadata:
  name: mongodb
spec:
  volumes:
  - name: mongodb-data
      awsElasticBlockStore:            #A
        volumeId: mongodb              #B
        fsType: ext4                   #C
  containers:
  - ...
```

#A Using awsElasticBlockStore instead of gcePersistentDisk
#B Specify the ID of the EBS volume you created.
#C The filesystem type is ext4.

USING AN NFS VOLUME

If your cluster runs on your own servers, you have a range of other supported options for adding external storage to your pods. For example, to mount a simple NFS share, you only need to specify the NFS server and the path exported by the server, as shown in the following listing.

Listing 7.9 A pod using an nfs volume: mongodb-pod-nfs.yaml

```
volumes:
- name: mongodb-data
    nfs:                          #A
      server: 1.2.3.4             #B
      path: /some/path            #C
```

#A This volume is backed by an NFS share.
#B The IP of the NFS server
#C The path exported by the server

> **NOTE** Although Kubernetes supports nfs volumes, the operating system running on the worker nodes provisioned by Minikube or kind might not support mounting nfs volumes.

USING OTHER STORAGE TECHNOLOGIES

Other supported options are `iscsi` for mounting an ISCSI disk resource, `glusterfs` for a GlusterFS mount, `rbd` for a RADOS Block Device, `flexVolume`, `cinder`, `cephfs`, `flocker`, `fc` (Fibre Channel), and others. You don't need to understand all these technologies. They're mentioned here to show you that Kubernetes supports a wide range of these technologies, and you can use the technologies that are available in your environment or that you prefer.

For details on what properties you need to set for each of these volume types, you can either refer to the Kubernetes API definitions in the Kubernetes API reference or look up the information by running `kubectl explain pod.spec.volumes`. If you're already familiar with a particular storage technology, you should be able to use the `explain` command to easily find out how to configure the correct volume type.

WHY DOES KUBERNETES FORCE SOFTWARE DEVELOPERS TO UNDERSTAND LOW-LEVEL STORAGE?

If you're a software developer and not a system administrator, you might wonder if you really need to know all this low-level information about storage volumes? As a developer, should you have to deal with infrastructure-related storage details when writing the pod definition, or should this be left to the cluster administrator?

At the beginning of this book, I explained that Kubernetes abstracts away the underlying infrastructure. The configuration of storage volumes explained earlier clearly contradicts this. Furthermore, including infrastructure-related information, such as the NFS server hostname directly in a pod manifest means that this manifest is tied to this particular Kubernetes cluster. You can't use the same manifest without modification to deploy the pod in another cluster.

Fortunately, Kubernetes offers another way to add external storage to your pods. One that divides the responsibility for configuring and using the external storage volume into two parts. The low-level part is managed by cluster administrators, while software developers only specify the high-level storage requirements for their applications. Kubernetes then connects the two parts.

You'll learn about this in the next chapter, but first you need a basic understanding of pod volumes. You've already learned most of it, but I still need to explain some details.

7.3.3 Understanding how external volumes are mounted

To understand the limitations of using external volumes in your pods, whether a pod references the volume directly or indirectly, as explained in the next chapter, you must be aware of the caveats associated with the way network storage volumes are actually attached to the pods.

Let's return to the issue of using the same network storage volume in multiple pods at the same time. What happens if you create a second pod and point it to the same GCE Persistent Disk?

I've prepared a manifest for a second MongoDB pod that uses the same GCE Persistent Disk. The manifest can be found in the file `mongodb2-pod-gcepd.yaml`. If you use it to create the second pod, you'll notice that it never runs. Even after a few minutes, its status is still shown as `ContainerCreating`:

```
$ kubectl get po
NAME      READY  STATUS              RESTARTS  AGE
mongodb   1/1    Running             0         10m
mongodb2  0/1    ContainerCreating   0         2m15s
```

You can see why this is the case with the `kubectl describe` command. At the very bottom, you see a `FailedAttachVolume` event generated by the `attachdetach-controller`. The event has the following message:

```
AttachVolume.Attach failed for volume "mongodb-data" : googleapi: Error 400:
        RESOURCE_IN_USE_BY_ANOTHER_RESOURCE - The disk resource 'projects/-xyz/zones/europe-west3-
        c/disks/mongodb' is already being used by 'projects/ xyz/zones/europe-west3-
        c/instances/gke-kubia-default-pool-xyz-1b27'
```

The message indicates that the node hosting the `mongodb2` pod can't attach the external volume because it's already in use by another node. If you check where the two pods are scheduled, you'll see that they are not on the same node:

```
$ kubectl get po -o wide
NAME      READY  STATUS              ... NODE
mongodb   1/1    Running             ... gke-kubia-default-pool-xyz-1b27
mongodb2  0/1    ContainerCreating   ... gke-kubia-default-pool-xyz-gqbj
```

The `mongodb` pod is running on node `1b27`, while the `mongodb2` pod is scheduled to node `gqbj`. As is typically the case in cloud environments, you can't mount the same GCE Persistent Disk on multiple hosts simultaneously in read/write mode. You can only mount it on multiple hosts in read-only mode.

Interestingly, the error message doesn't say that the disk is being used by the `mongodb` pod, but by the node hosting the pod. And this is a very important detail about how external volumes are mounted into pods.

As the following figure shows, a network volume is mounted by the host node, and then the pod is given access to the mount point. Typically, the underlying storage technology doesn't allow a volume to be attached to more than one node at a time in read/write mode, but multiple pods on the same node *can* all use the volume in read/write mode.

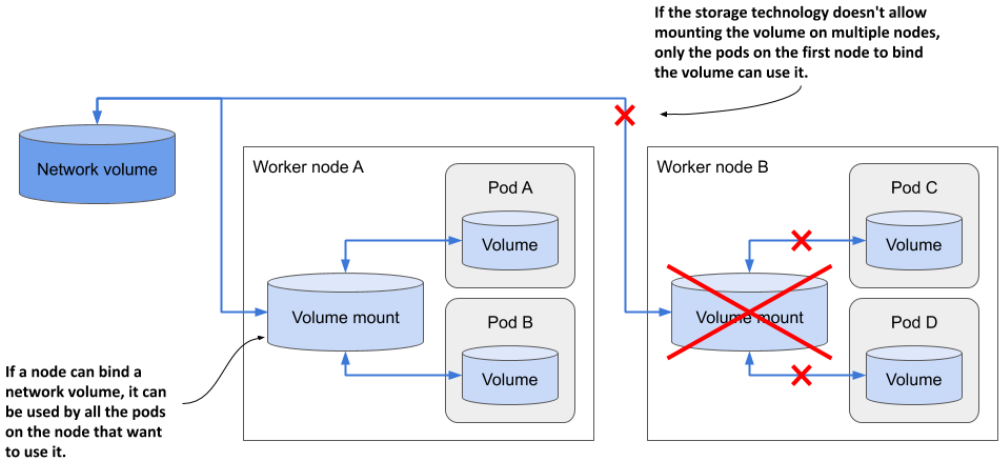


Figure 7.9 Network volumes are mounted by the host node and then exposed in pods

For most storage technologies available in the cloud, the only way to use the same network volume on multiple nodes simultaneously is to mount them in read-only mode. For example, pods scheduled to different nodes can use the same GCE Persistent Disk if it is mounted in read-only mode, as shown in the next listing:

Listing 7.10 Mounting a GCE Persistent Disk in read-only mode

```
kind: Pod
spec:
  volumes:
  - name: my-volume
    gcePersistentDisk:
      pdName: my-volume
      fsType: ext4
      readOnly: true     #A
```

#A This GCE Persistent Disk is mounted in read-only mode

It is important to consider this network storage limitation when designing the architecture of your distributed application. Replicas of the same pod typically can't use the same network volume in read/write mode. Fortunately, Kubernetes takes care of this, too. In chapter 13, you'll learn how to deploy stateful applications, where each pod instance gets its own network storage volume.

You're now done playing with the MongoDB pods, so delete them both, but hold off on deleting the underlying GCE persistent disk. You'll use it again in the next chapter.

7.4 Accessing files on the worker node's filesystem

Most pods shouldn't care which host node they are running on, and they shouldn't access any files on the node's filesystem. System-level pods are the exception. They may need to read the node's files or use the node's filesystem to access the node's devices or other components via the filesystem. Kubernetes makes this possible through the `hostPath` volume type. I already mentioned it in the previous section, but this is where you'll learn when to actually use it.

7.4.1 Introducing the hostPath volume

A `hostPath` volume points to a specific file or directory in the filesystem of the host node, as shown in the next figure. Pods running on the same node and using the same path in their `hostPath` volume see the same files.

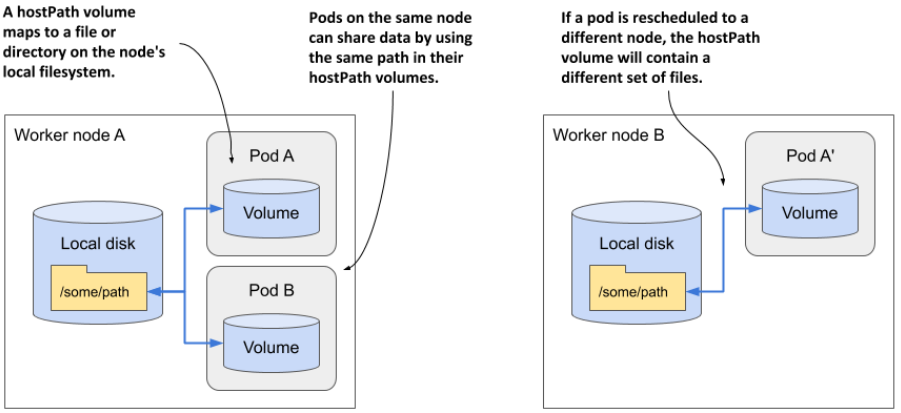


Figure 7.10 A `hostPath` volume mounts a file or directory from the worker node's filesystem into the container.

A `hostPath` volume is not a good place to store the data of a database. Because the contents of the volume are stored on the filesystem of a specific node, the database pod will not be able to see the data if it gets rescheduled to another node.

Typically, a `hostPath` volume is used in cases where the pod actually needs to read or write files written or read by the node itself, such as system-level logs.

The `hostPath` volume type is one of the most dangerous volume types in Kubernetes and is usually reserved for use in privileged pods only. If you allow unrestricted use of the `hostPath` volume, users of the cluster can do anything they want on the node. For example, they can use it to mount the Docker socket file (typically `/var/run/docker.sock`) in their container and then

run the Docker client within the container to run any command on the host node as the root user. You'll learn how to prevent this in chapter 24.

7.4.2 Using a hostPath volume

To demonstrate how dangerous `hostPath` volumes are, let's deploy a pod that allows you to explore the entire filesystem of the host node from within the pod. The pod manifest is shown in the following listing.

Listing 7.11 Using a hostPath volume to gain access to the host node's filesystem

```
apiVersion: v1
kind: Pod
metadata:
  name: node-explorer
spec:
  volumes:
  - name: host-root                #A
    hostPath:                      #A
      path: /                      #A
  containers:
  - name: node-explorer
    image: alpine
    command: ["sleep", "9999999999"]
    volumeMounts:                  #B
    - name: host-root              #B
      mountPath: /host             #B
```

#A The hostPath volume points to the root directory on the node's filesystem
#B The volume is mounted in the container at /host

As you can see in the listing, a `hostPath` volume must specify the `path` on the host that it wants to mount. The volume in the listing will point to the root directory on the node's filesystem, providing access to the entire filesystem of the node the pod is scheduled to.

After creating the pod from this manifest using kubectl apply, run a shell in the pod with the following command:

```
$ kubectl exec -it node-explorer -- sh
```

You can now navigate to the root directory of the node's filesystem by running the following command:

```
/ # cd /host
```

From here, you can explore the files on the host node. Since the container and the shell command are running as root, you can modify any file on the worker node. Be careful not to break anything.

Now imagine you're an attacker that has gained access to the Kubernetes API and are able to deploy this type of pod in a production cluster. Unfortunately, at the time of writing, Kubernetes doesn't prevent regular users from using `hostPath` volumes in their pods and is

therefore totally unsecure. As already mentioned, you'll learn how to secure the cluster from this type of attack in chapter 24.

SPECIFYING THE TYPE FOR A HOSTPATH VOLUME

In the previous example, you only specified the path for the `hostPath` volume, but you can also specify the `type` to ensure that the path represents what that the process in the container expects (a file, a directory, or something else).

The following table explains the supported `hostPath` types:

Type	Description
<empty>	Kubernetes performs no checks before it mounts the volume.
Directory	Kubernetes checks if a directory exists at the specified path. You use this type if you want to mount a pre-existing directory into the pod and want to prevent the pod from running if the directory doesn't exist.
DirectoryOrCreate	Same as Directory, but if nothing exists at the specified path, an empty directory is created.
File	The specified path must be a file.
FileOrCreate	Same as File, but if nothing exists at the specified path, an empty file is created.
BlockDevice	The specified path must be a block device.
CharDevice	The specified path must be a character device.
Socket	The specified path must be a UNIX socket.

Table 7.3 Supported hostPath volume types

If the specified path doesn't match the type, the pod's containers don't run. The pod's events explain why the hostPath type check failed.

> **NOTE** When the type is `FileOrCreate` or `DirectoryOrCreate` and Kubernetes needs to create the file/directory, its file permissions are set to `644` (`rw-r--r--`) and `755` (`rwxr-xr-x`), respectively. In either case, the file/directory is owned by the user and group used to run the Kubelet.

7.5 Summary

This chapter has explained the basics of adding volumes to pods, but this was only the beginning. You'll learn more about this topic in the next chapter. So far you've learned this:

- Pods consist of containers and volumes. Each volume can be mounted at the desired location in the container's filesystem.
- Volumes are used to persist data across container restarts, share data between the containers in the pod, and even share data between the pods.
- Many volume types exist. Some are generic and can be used in any cluster regardless of the cluster environment, while others, such as the `gcePersistentDisk`, can only be used if the cluster runs on a particular cloud provider infrastructure.

- An `emptyDir` volume is used to store data for the duration of the pod. It starts as an empty directory just before the pod's containers are started and is deleted when the pod terminates.
- The `gitRepo` volume is a deprecated volume type that is initialized by cloning a Git repository. Alternatively, an `emptyDir` volume can be used in combination with an init container that initializes the volume from Git or any other source.
- Network volumes are typically mounted by the host node and then exposed to the pod(s) on that node.
- Depending on the underlying storage technology, you may or may not be able to mount a network storage volume in read/write mode on multiple nodes simultaneously.
- By using a proprietary volume type in a pod manifest, the pod manifest is tied to a specific Kubernetes cluster. The manifest must be modified before it can be used in another cluster. Chapter 8 explains how to avoid this issue.
- The `hostPath` volume allows a pod to access any path in filesystem of the worker node. This volume type is dangerous because it allows users to make changes to the configuration of the worker node and run any process they want on the node.

In the next chapter, you'll learn how to abstract the underlying storage technology away from the pod manifest and make the manifest portable to any other Kubernetes cluster.