Kubernetes for Developers

William Denniss

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welcome

Thank you for purchasing *Kubernetes for Developers*. I'm writing this book to help developers like you take their application and get it running on Kubernetes, whether it's your first web app, or you're moving an existing deployment onto Kubernetes.

Kubernetes is a highly capable platform, able to represent a wide range of application deployments and configurations, but this flexibility can make it seem vast and complex at first. My focus is to teach you the most important bits to get your application deployed, and to take advantage of everything it has to offer, like automated operations and rollouts to keep your application running and up to date. This book isn't intended as a general reference on Kubernetes, for that I recommend *Kubernetes in Action* also published by Manning, as well as the project documentation itself.

When you get to the end of Part 1, you should have all you need to know to confidently deploy your application into a Kubernetes cluster and keep it running. Part 2 then goes into some more advanced topics and troubleshooting for when you need to do something a little more complex, like retain state in an application, or even deploy your own database (if you really need to).

One of the reasons why I wanted to publish this book with Manning was their fantastic Author Online forum where you can give your feedback and ask questions. I've given feedback in these forums as a reader and was thrilled to see the authors adopt my suggestions, so now I'm hoping to do the same with your feedback. So please visit the liveBook's Discussion Forum and leave your comments.

—William Denniss

brief contents

1 Kubernetes for Application Deployment

This chapter covers

- The benefits of packaging applications in containers
- What makes Kubernetes an ideal platform to deploy containers with
- Deciding when to use Kubernetes

In the past, developers would choose between ease of managing deployments, and the customizability of their environment. If you wanted a self-driving automated platform with easy scaling, you could choose a Platform as a Service (PaaS) like Heroku or AppEngine, enabling easy deployments, but limiting what you could do, such as which languages or libraries could be used. Conversely, you could fully customize your application environment and run whatever you wanted if your target was a raw Linux or Windows box, but then management and scaling was complex.

Enter Containers and Kubernetes. Containers allow you to package up your application and its dependencies into a lightweight package that can be run mostly independently of the host operating system, and Kubernetes helps you manage all those containers, to keep them running and scale as needed, without you needing to manage each minute detail of the underlying hosts.

This combination has proved incredibly powerful, and gained a loyal following among developers looking to gain the most flexibility to deploy whatever software they like, while keeping operations as simple as possible.

While Kubernetes is still more complex than a traditional PaaS today, the flexibility to represent all different kinds of workloads; from web applications, serverless functions, stateful databases, and batch processing jobs, and run all those workloads on the same pool of compute resources makes it a powerful tool. Learning Kubernetes and deploying your applications there sets you up for the future, as it can scale as you grow, and handle future more complex workloads.

1.1 Containers: The Ideal Application Package

You need to deploy multiple applications onto a single machine, or collection of machines. What are your choices?

Before virtualization, you might have installed each into a different directory on the host, and serve each on a separate port. This presents a few problems in that the various applications need to cooperate with each other to some extent, when it comes to sharing dependencies and the resources of the machine like CPU, memory and available ports. It can also be hard to scale: if you have one application that suddenly is receiving more traffic, how do you scale just that application, while leaving the others as they are?

A more modern solution is to package each application into a virtual machine of its own. In this way, each application effectively has its own machine so dependencies can be isolated, and resources divided up and allocated. Since each virtual machine, is essentially a machine though, you now need to maintain the operating system and all packages for each application creating a large and complex to maintain package.

This brings us to containers. Containers are a way to package up just your application and it's required dependencies, for hosting in an isolated environment much like a virtual machine, but without needing to install and manage a separate operating system for each container.

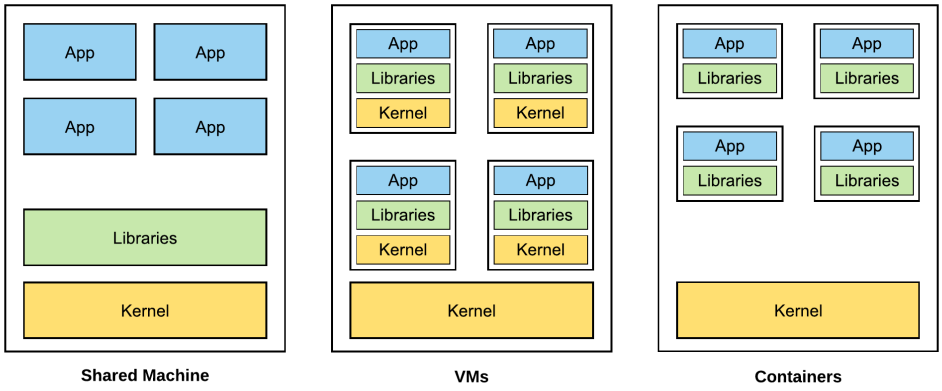


Figure 1.1: evolution of shared hosting architectures

The above diagram illustrates the evolution of hosting services, from running multiple workloads on a single host, to running them on separate VMs, and finally containers. As you can see, Containers provide many of the benefits of VMs but without the overheads of running another operating system kernel, making them the logical modern path forward.

Another approach entirely is to use a Platform as a Service (PaaS). As long as your application fits within the scope of what the PaaS offers in terms of languages, dependencies, how it handles state, etc., you can launch each application into the PaaS, and not worry about the machines underneath. However, what happens when you need to highly customize your dependencies like

using a specific version of Java? Can you host a stateful backend alongside your stateless frontends? And is it cost effective when you have many applications, each needing many replicas? At a certain point, the limitations of a PaaS can be prohibitive, and once you move out of the PaaS world, you have to start over from scratch – a daunting prospect.

If you love your PaaS, then there may not be a need to move to Kubernetes. However, a common issue I've seen is that teams hit a certain level of complexity with what their hosting where they run into the limits and then exceed what the PaaS is capable of. One of the scariest things about being in that position, is that you can't simply "break the glass" and assume more control yourselves (as you could say when moving from VMs to bare metal), often you'll need to re-architect the entire system, losing even the bits you were happy with, in order to build the new parts that you need. In this book, I'll show you how Kubernetes can run PaaS-type workloads with marginal added complexity, while setting you up for success in the future by enabling you to apply more complex requirements.

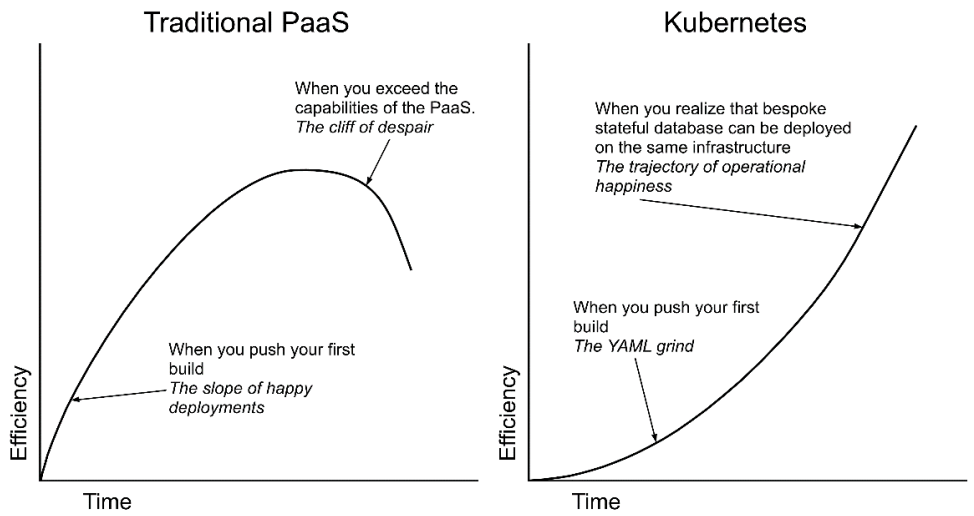


Figure 1.2: developer efficiency using a traditional PaaS and Kubernetes

A traditional PaaS is often fast to learn but slows down as you mature, and there's potential cliff if you exceed the capabilities of the system and need to start from scratch. Kubernetes has a slower learning curve at the beginning, but expansive possibilities as you grow.

In the following sub-sections, we'll look at several specific benefits of containers in detail.

1.1.1 Language flexibility

Containers unbind you from language or library requirements from your deployment systems. You can bring any language, and update any package. No longer are you locked into specific languages

and versions, or stuck with some outdated version of a critical dependency that shipped in the operating system years ago, as you might be on a traditional PaaS.

There are no shared libraries between two containers running on the same host, meaning the configuration of one will not interfere with the other. Need two different versions of java, or some random dependency? no problem. This isolation extends beyond just the libraries of the containers, each container can use a completely different base OS and package manager, for example one using Debian and apt-get, while another uses CentOS and rpm.

This flexibility makes it simpler to potentially string together a system from multiple services (a pattern known as microservices), each maintained by separate teams, with their own dependencies or even languages.

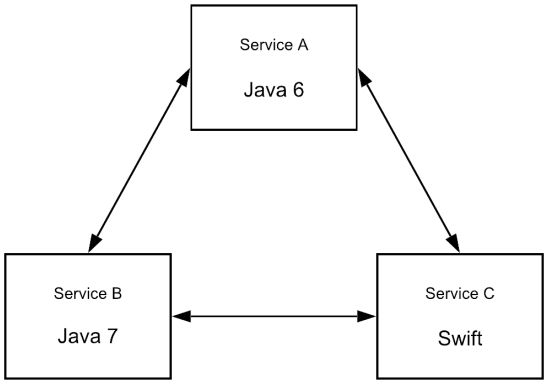


Figure 1.3: 3 services written in different languages deployed as a single application

1.1.2 Isolation Without Overhead

In the past, to achieve isolation between multiple apps running on the same host, you would use virtual machines (VMs). VMs are heavier weight, both in image size, and CPU / memory resource overhead, as the kernel and much of the OS is duplicated in each VM.

While Containers are lighter weight than VMs, they still offer most of the same resource isolation benefits. You can limit your containers on Kubernetes to use only some of the resources of the host, and the system will restrict them from using more. This ultimately means you can pack more applications onto a single host, reducing your infrastructure costs.

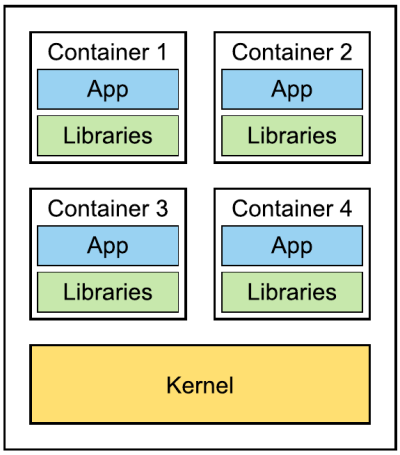


Figure 1.4: Four containers running on the same host, fully isolated but sharing the kernel.

1.1.3 Developer Efficiency

What makes containers great for production by isolating dependencies also makes them great for development, as you can develop a myriad of applications on a developer machine without needing to configure the host with the dependencies of each.

In addition to developing Linux applications directly on Linux, with Docker you can use macOS, or Windows workstations to develop a Linux container, without needing to create a version of the app that runs natively on those platforms, eliminating platform-specific configurations for development.

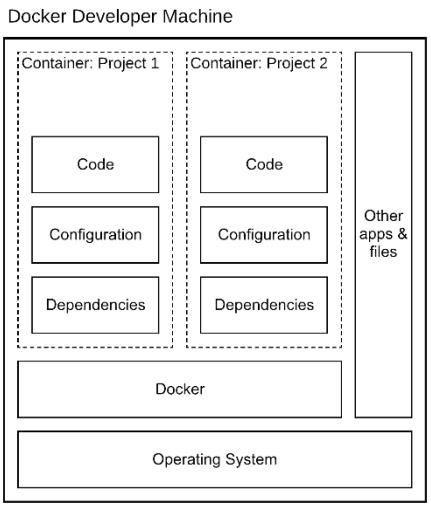


Figure 1.5: Developer Machine with two container-based projects

No longer do you need to have pages of setup instructions for developers to get started either, as setup is now as easy as install Docker, checkout the code, build and run. Working on multiple projects within a team or for different teams is now simple as well as each project is nicely isolated in its container without needing a particular host configuration.

With containers, your development and production app looks very similar, and can be the exact same container. No more development idiosyncrasies getting in the way like MacOS having a different MySQL library, or subtle differences in the way the code is packaged for production. Trying to diagnose a production issue? Download that exact container, run it against your development environment and see what's up.

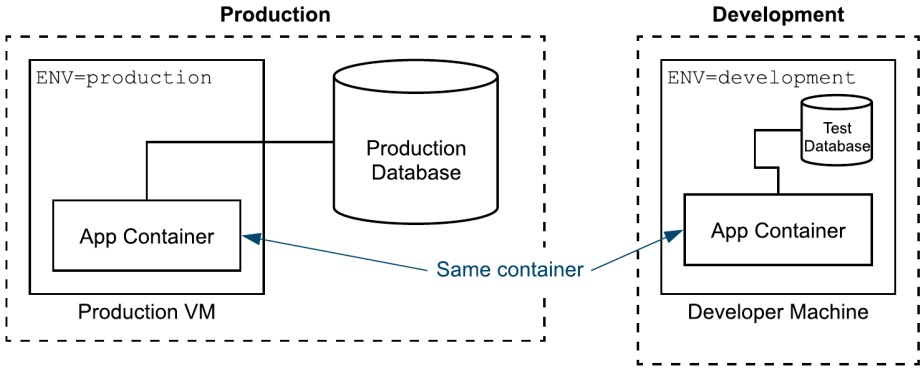


Figure 1.6: Same container being deployed in the production and development environments

1.1.4 Reproducibility

Containers make it easier to reproduce your application environment. Imagine you have a VM on which your application is deployed, and you need to configure TLS for secure "https" connections. You SSH into the machine, add the TLS certificates to a folder. It didn't work, so you add them to another folder. Soon they're in 3 folders and it's working so you don't touch it. A year later, you need to update the TLS certificate. Can you remember how, and which of the 3 locations need to be updated?

Containers solve this. Rather than SSHing and tweaking the state, you would add the TLS certificate as a build step in the container. If it didn't work, you'd tweak that build step until it does – but crucially only keeping the step (or steps) that actually do work. The files added in this step are also nicely isolated from the rest of the system, essentially you're capturing the "delta" over the base system, just those modifications you needed to make. This means that a year later when you need to update the certificate, you just replace the certificate file, and re-run the container build, and it will put it in the right place.

```
Use the Debian OS
Copy and configure TLS certificate
Copy application
```

Above is a "psudocode" example of a Dockerfile, that is, where the code to configure the container is expressed in plain English. In Chapter 2, we'll present this same concept in the Docker script itself.

NOTE Docker as a tool for creating containers isn't perfect for reproducibility. Commands like "apt-get" to install a dependency operate on a live system, so you won't actually get the same output for the same input, as those dependent systems (like the apt-get repository) may have changed in between builds. Tools like Bazel, open sourced by Google, are designed to solve this problem and more, but come with their own complexities and are more recommended for sophisticated enterprise deployments. Despite this limitation, Docker's build system is still a heck of a lot more reproducible than trying to remember what you did a year ago when you SSH'd into that Linux box to fix an issue, and is good enough for most.

1.2 Running Containers on Kubernetes

If containers sound like a great idea for packaging your application, you'll still need a way to actually run and manage those containers. Sure, you could just run a container or a handful of containers on each host, in much the same way it is possible run a bunch of different applications from folders, or VM images, but operating like this tends to create unique "pets" of your machines. Pets in this context are machines that you know by name, and that you care and feed with regular interaction (like SSHing to install or update an application).

The "pet" model of operating tends to limit your ability to scale, due to the high-touch requirements to configure new hosts, which means you'll need an operations team and one that grows at a roughly linear scale to the number of hosts under management.

The way Google, and many other large scale companies run is to treat applications and the machines on which they run more as a herd of cattle. You look after the herd, but the individual machines ("cattle") do not have special names or needs that require high-touch maintenance.

Kubernetes, originally developed by Google and still heavily maintained by engineers in Google Cloud, offers a way to manage containers as a herd. Container deployments can be scaled up, and down, and be replaced all in a low-touch automated way, where you are more concerned about the high-level metrics like how many machines you're running, the availability of your containers, and what the request latency is, than the individual characteristics of the application or the machine on which it runs.

Previously systems that could flexibly orchestrate containers at scale were the domain of large companies. Kubernetes, and in particular managed Kubernetes offerings on public clouds make this operations model accessible to deployments of all sizes, from a single container application running on 1 machine, to set of microservices each published by a different team running on a 5000 machine behemoth.

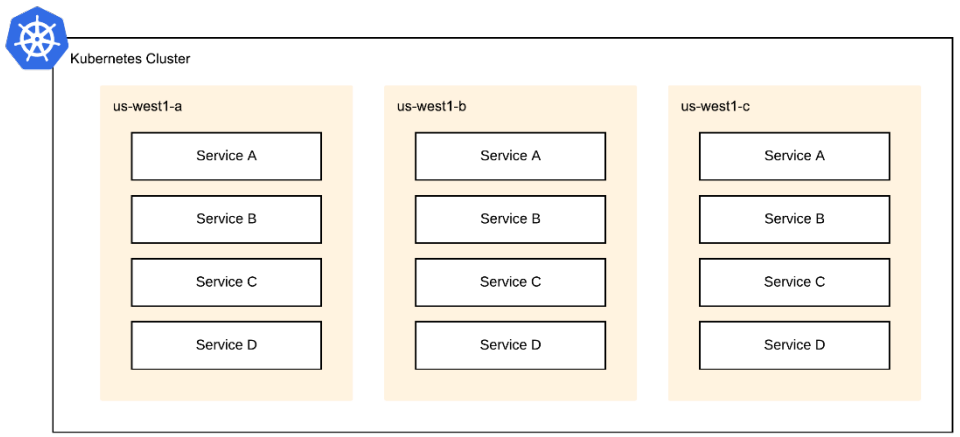


Figure 1.7: a Kubernetes cluster operating in 3 zones, managing 4 services

The above diagram shows a large Kubernetes cluster running on three availability zones, hosting 4 separate services in a highly available fashion – where the loss of an entire zone would not result in downtime. While this may seem complex, that cluster can be created from the Google Kubernetes Engine (GKE) UI in about 2 minutes, and each deployment is contained in a single configuration file consisting of the container name, the desired number of replicas, the load balancer configuration, the resources it needs and it's deployment strategy. All told, that's a few minutes in the UI to create the cluster, and about 20 lines of config boilerplate per service. Of course, tweaking that config so it runs *just right* can take some practice (hence this book), but imagine how you would have deployed this on bare VMs, and then how would you update it later?

The best part is that updating a service in Kubernetes requires a single line of config to be changed, and Kubernetes will handle the roll out of the update to each of the zones for you, per your requirements. Updates to Kubernetes itself happen in a similar, automated fashion, where nodes are replaced gradually with updated versions, and your workload migrated to avoid downtime.

If your app isn't big enough to require a high-availability multi-zone deployment, fear not – Kubernetes (and GKE) can run at small scale too, with the added benefit that you can scale up when you need.

Some more modern PaaSes support containers, so you could run there, and get the best of both worlds: the flexibility of containers, with the easy deployments. A downside of this is that even modern PaaSes come with many restrictions on the types of workloads you can run. Take for example the case where you have a legacy application that requires state to operate (in the form of an attached disk that persists between reboots), or you wish to run a bespoke database, one not provided by your cloud provider. Cost is another factor, with Kubernetes you operate lower down the stack, so you can decide how tightly to pack the containers unlocking significant cost saving potential.

Kubernetes isn't the only place to orchestrate containers today, other options include a container-based PaaS, or just running Docker directly. Container-based PaaSes, while certainly simpler than Kubernetes are generally targeted to running and scaling applications in single-container units (i.e. no mixing of containers on the same machine), and you may still run into the "break glass" issue discussed earlier. Running Docker directly can be fine for a container or two, but once you have a few to deploy, or you need to represent a more complex workload like a Job, it can quickly get out of hand (and it's worth noting, Docker itself now ships with Kubernetes out of the box).

1.2.1 Kubernetes Architecture: Life of a Container

In Kubernetes, containers are grouped into what are called "Pods". A Pod is simply a group of containers that get scheduled together and treated as a single unit, quite often this is just a single container, but it could be multiple in the case your app consists of multiple connected parts. Conceptually, the Pod is your application and its dependencies.

You will create a "Deployment" manifest, which specifies your desired configuration, for example the version of your app's containers, how many replicas (instances) you want, etc. Kubernetes then does the heavy lifting of finding space in your cluster to place the Pods. A Load Balancer is typically attached (via a "Service" manifest) to route incoming traffic to one of your replicas.

Kubernetes uses a declarative resource model. You describe your workload in configuration files (typically YAML formatted), and the system seeks to enact your configuration and make it a reality. For example, if you say you want 3 replicas (copies) of your application, connected by a load balancer to the outside world, Kubernetes will find space in your cluster to run those 3 replicas, and attach a load balancer.

This isn't a one-time deal either. Kubernetes will continually seek to ensure that your declared state has been realized. So if your containers crash and thus reduce the number of replicas to below what you configured, it will restart them. If a machine fails, all the Pods on that machine will be rescheduled. Of course, it can't be perfect and can't fix an application that continually crashes, or schedule containers on a cluster with no compute resources left and in those cases where it can't deliver your declared state, it will log the reasons why for you to investigate.

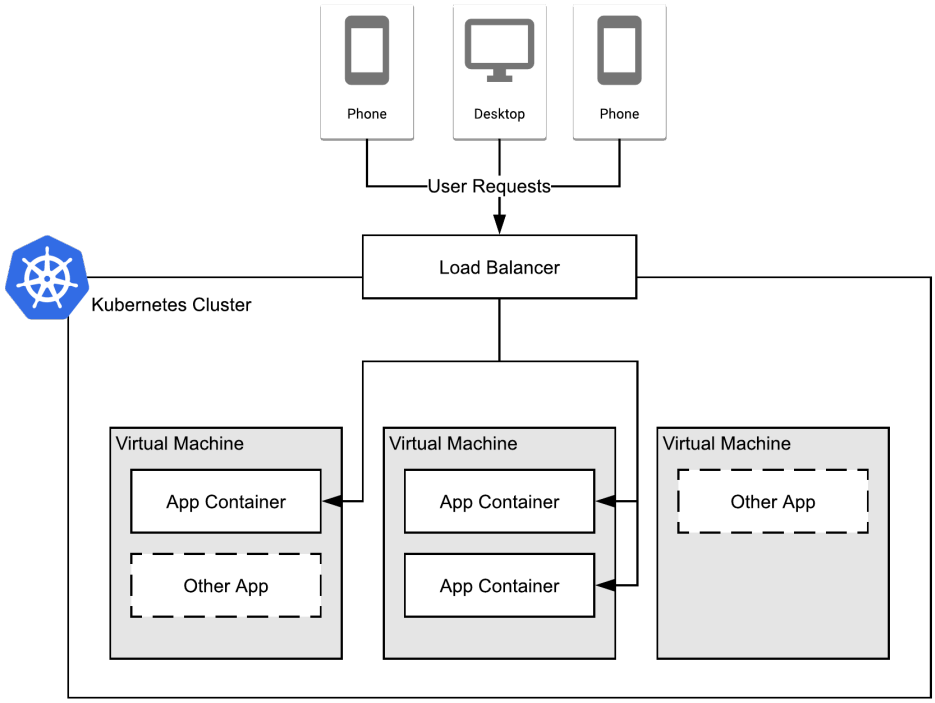


Figure 1.8: A single-container Pod with 3 replicas deployed into 2 nodes of a 3-node cluster. The cluster may have other application containers running as well.

The types of workloads you can describe in Kubernetes configuration is wide and varied, and includes:

- Stateless applications, like those that meet the "12 factor" requirements.[1]
- Applications with state, like one that formerly ran in a VM and requires a disk to be attached that persists between restarts, or a full database instance like Redis or MySQL.
- A batch process you wish to run at a certain schedule.
- A task you want to run to completion, like rendering frames of a movie, or training a Machine Learning (ML) model.

In all cases, the applications are containerized and grouped in Pods, and you describe to Kubernetes in configuration files how you want your workload to be run.

[1] https://12factor.net/

1.3 Benefits of using Kubernetes

Kubernetes has gained popularity as it automates much of the operational aspects of scheduling and running containers on a pool of resources, provides the level of abstraction to developers that seems to have hit the sweet spot. It isn't too low-level that you are worried about individual machines, but it doesn't go too high level either in ways that limit what workloads you can deploy.

1.3.1 Automated Operations

Provided you configure your deployment correctly, Kubernetes will automate various aspects of your deployment. Processes running on the node restart containers that crash, while liveness and readiness probes from continue to monitor the container's health and ability to serve live traffic. Pod auto-scalers can be configured on your deployments to automatically increase the number of replicas based on metrics like CPU utilization.

Kubernetes itself doesn't currently repair compute node level issues, however you can choose a platform that will provide additional automated operations. Take for example GKE: it can automatically scale up to provide enough compute capacity for your pods when you schedule more, and scale back down to save money as your replica count reduces, and monitor the same nodes for issues and replace them if needed.

1.3.2 A Workload Abstraction

Abstraction layers are great, until they aren't. It is a challenge to find tools that abstract away precisely those things you do not want to care about, without hiding details you do care about, but in my experience, Kubernetes comes the closest to achieving exactly that.

Infrastructure as a Service (IaaS) is a hardware-level abstraction. Rather than interacting with actual machines with spinning disks and network cards, you interact with an API that provides software that implements those same interfaces.

Kubernetes by comparison is a workload-level abstraction. Meaning that you describe your application in workload terms. For example, I have a server that needs to run in a distributed fashion; I have a database that requires certain disk volumes to be attached; I have a logging utility that needs to run on every node; or maybe I have a movie to render, one frame at a time on the cheapest resources available. All these deployment constructs and more can be represented natively in Kubernetes.

It sits above compute instances (VMs), freeing you from the need to manage or care about individual machines. You specify what resources your container needs: CPU, memory, disk, GPU, etc – and if you're using good implementation managed by a cloud provider, it will provision you the machines to handle your workloads. You don't need to worry about individual machines, but you can still do things that you would expect at a machine level, like write to a persistent local disk, tasks that until recently were often not possible at this level of abstraction.

The abstraction layer is also quite clean, by not interfering with your application. Unlike many traditional PaaSes, Kubernetes does not modify how your app runs, for example, no code is injected or changed, and very little restrictions are placed on what your app can do. If the app can be run in a container, then it can likely be run on Kubernetes.

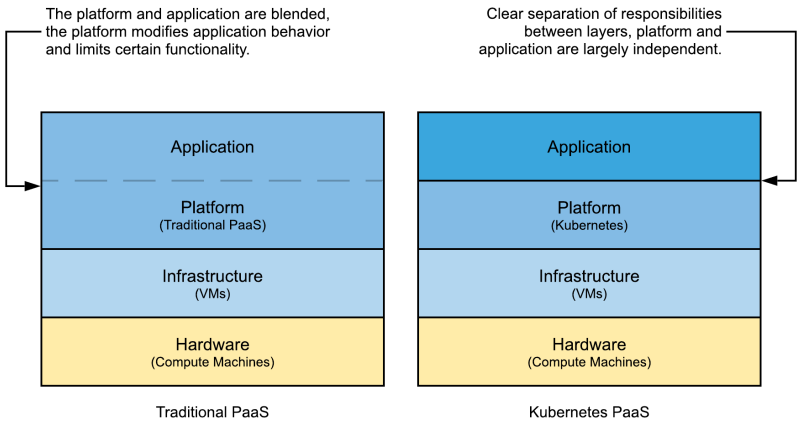


Figure 1.9: Illustration of the separation of concerns between the different compte layers

A word on simplicity

I like to say; be wary of tools that make the simple easier, but the complex harder. Sure it's nice when something helps you get up and running sooner, but is it leaving you in a good state, with the right knowledge and tools to get the job done? Kubernetes is easy enough to get started with (though not too many people would say it's "easy" in an absolute sense), and powerful enough to serve your needs as you grow and expand. When choosing your platforms, prioritize making hard tasks possible over making simple tasks easier.

Kubernetes will enable you to run a simple, 12-factor stateless application, migrate in a bespoke stateful custom application previously installed on a VM, or even run your own database. The abstraction layer doesn't limit what you can do, while still allowing you to get started using only the bits you need at first.

1.3.3 The Ability to Scale Up

No matter the size of your application, you will want to think about how it will scale. Whether you are deploying a huge enterprise application, or you are a bootstrapping startup, you will need a solution that can scale as you do. The time when you need to scale, is not the time to start thinking about how you are going to scale!

It is hard enough to create a successful product; the last thing you want is that in your moment of success when everyone is beating down your door trying to use your product is for your application to go offline. In that moment and perhaps even in the months and years to come, you're likely not going to be able to rearchitect your application for scale.

Kubernetes can handle applications of any size. You can create a single-node cluster with a single CPU and a bunch of memory, or a multi-thousand node behemoth like the 10s of thousands of cores used to run Pokemon Go when it launched[2].

Of course, your application itself will need to have properties that enable it to scale, and so will any dependencies, particularly database ones - but at least you can rest assured that your compute platform will scale as you do.

1.3.4 Cost Efficient Deployments

Kubernetes takes the lowest-level compute building blocks - virtual machines - and makes them easy to manage. Whereas in the past, you might have assigned one app per virtual machine for maintenance reasons, Kubernetes allows you to host multiple instances of an app or apps on a single machine for high efficiency (so-called bin-packing). The combination of using commodity building blocks (raw compute nodes) with robust orchestration of the workloads is what makes Google Kubernetes Engine very attractive from a price perspective. In a typical platform as a service system you are paying several multiples over the raw compute power, in GKE you pay only for that compute, and for exactly what you use.

Compared to Functions as a Service, Kubernetes Engine may often work out cheaper as well (and is definitely cheaper comparing raw compute cycles) though it all depends on utilization. If you have enough load to fully utilize a machine, or even half a machine then GKE will likely be cheaper. If you have only a few requests a day, then a FaaS will almost certainly be cheaper.

GKE allows for custom machine types as well allowing you to further optimize your virtual hardware to meet your needs. Is your app memory hungry, but fairly light on the CPU (common for a web server), use higher-memory machines. Do you need grunty machines to process batch workloads? Use a high-CPU machine instead. This highly customizable configuration helps maximize resource usage, and can be combined with deep discounts if you commit to using the resources for longer terms.

Beyond bin-packing (running multiple services on one machine), resource pooling is another benefit of Kubernetes that improves efficiency. Your workloads can be configured in a way where they have guaranteed resources, and can opportunistically use unused resources on the machine.

1.3.5 Extensibility

When you need to do something that Kubernetes can't, you can source or even write your own Kubernetes-style API to implement it. This isn’t for everyone, and definitely isn’t needed to deploy most workloads like stateless or stateful web applications, but it can be extremely handy when you need to add particular business logic, or some new construct that Kubernetes doesn't support. The Custom Resource Definition (CRD) object, and operator patterns allow you to create your own Kubernetes-style APIs.

1.3.6 Open Source

Kubernetes is open source, and available on all major clouds as a managed offering, and just about every platform (including those on the 3 largest public clouds), distribution and installer out there

[2] https://cloud.google.com/blog/products/gcp/bringing-pokemon-go-to-life-on-google-cloud

has passed conformance checks to be badged "Certified Kubernetes" by the CNCF program (Certified Kubernetes is a registered trademark of The Linux

Foundation). You can even run Kubernetes yourself from scratch - so your workloads can be as portable as you make them. By sticking with other standard open source APIs, you can ensure the portability of your workloads.

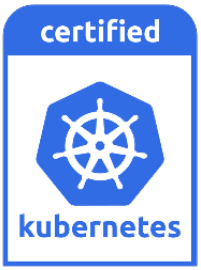


Figure 1.10: The certified Kubernetes logo

And if you do run Kubernetes yourself, then the quality of the code will matter to you. Not all open source is created equal. While open source does typically remove you from propriety lockin, sometimes you'll end up defacto-maintaining the code just for your own use. I have a motto: if we import it, we own it. The exception is for massive-scale, well maintained open source projects, in the caliber of say Linux, where so many people depend on it, and so many people use it that you can rest assured you won't need to take over maintenance. Kubernetes, as GitHub's 8th highest project by contributor count fits into this bucket. It is the leading open source container orchestrator, so rest assured you won't need to contribute (unless you want to, in which case the community is extremely welcoming).

> **NOTE** While it is possible to host Kubernetes yourself whether on a public cloud, or on a cluster of Raspberry Pi's I don't recommend this for production use (i.e. outside of learning how to manage a cluster) in most cases. Spend the time doing what you do best: building great applications, and let someone else handle the minutiae of running Kubernetes for you.

Beyond the project itself being open source, Kubernetes is surrounded by a vibrant community. There are open source tools for accomplishing pretty much anything, so you typically have the option to go with a managed service, or deploy an open source tool yourself. This is a break from proprietary-only marketplaces in PaaS systems of the past, where your only option for any type of component was a paid one. Do you get value from a managed monitoring tool? Use Stackdriver. Want to just manage it yourself? Go install Prometheus.

Kubernetes has a large and growing number of practitioners as well, so whatever the topic is, you should be able to find help on Stack Overflow, or in books like this one.

1.3.7 Customized Workflows

Kubernetes is very unopinionated about how you setup your own, or your company's, development workflows. Want a "git push to deploy" style workflow? There are a bunch of ways to do that, some with only minimal setup. Typically you'll start with a bunch of CI/CD building blocks which you assemble into your desired workflow, from simple push-to-deploy, to complex pipelines with admissions control, auto-injecting secrets and security scanning. The downside is that it's not quite as ready to go out of the box as say a traditional PaaS, but this book will show you it's not that hard to get going.

Particularly for larger teams, the flexibility provided by Kubernetes in this area is often a huge advantage. Companies with a central core platforms teams will create opinionated pipelines for their application developer (app dev) teams to use. The pipeline can be used to ensure certain development practices around things like security, resource usage, etc.

1.4 Deciding when to use Kubernetes

Like most tools, the goal of Kubernetes is to improve your efficiency, in this case managing your applications. It's best to ignore the hype and really consider whether Kubernetes will help or hinder your ability to run your service. Even with a managed Kubernetes service theoretically keeping your cluster components running smoothly, there is a significant amount of operations work that you will be performing inside the cluster. These operations include tasks like allocating CPU and memory resources to containers, updating deployments, configuring your network, and keeping everything up to date without disrupting your running services.

Where I've seen Kubernetes really excel is:

- running stateless applications at high density
- running mixed workloads on the same cluster like a modern 12-factor application and a legacy stateful monolith
- migrating one-off services running on crufty outdated systems or unifying a bunch of disparate services under one roof
- hosting custom stateful services; and high scale job processing for data analytics, ML, and rendering.

In each of these cases, Kubernetes brings a lot to the table, by enabling high efficiency, unifying your hosting platform, automating your systems, and running your jobs.

On the flip side, Kubernetes does introduce a new level of management overhead which needs to be considered. There's a risk of simply replacing one problem with another if you take what you're doing (assuming it's working well) and throw it onto Kubernetes. Some cases where you may want to consider carefully would be: replacing a stateless system *if* it's already handling your scale and complexity; moving standardized stateful workloads that have well-established deployment patterns like SQL databases. While you may see benefits in Kubernetes for such workloads, the advantages may not be as many, and so the trade-off needs to be more carefully considered.

To help decide, I suggest weighing up the benefits of moving to containers and unifying your compute platform around one orchestration system suitable for mixed workloads, with the added knowledge needed to administer Kubernetes. If what you're starting with is a bunch of services

running on bespoke VMs in various stages of disrepair – it's likely not going to be a hard choice. Similarly, if you've outgrown your PaaS, or have a highly proficient team wanting to deploy faster with modern tools – go for it. But that MySQL cluster that's running like a charm on a custom clustering setup with 4 nines of reliability? Maybe that one's OK to leave for now.

Going to Kubernetes doesn't need to be an all or nothing decision. I'd suggest starting with those workloads that make the most sense and gradually migrate them as you and your team builds up knowledge in operating Kubernetes.

Kubernetes can run a wide variety of workloads, from stateless apps, to batch jobs, and stateful databases. It's worth reviewing each deployment on a case-by-case basis for fit. In the following sections, we will take an in-depth look at some specific use-cases.

1.4.1 Running a Stateful Database

While Kubernetes can be used to run a complete stateful database, this isn't for the faint at heart. Installation is generally quite simple, there are various packages to make this easier for you like operators and helm charts (a simple `helm install stable/mysql` will boot up MySQL using the Helm package manager for example), the challenge comes later in updating and managing the availability of the service.

If you're operating in a managed Cloud environment, my recommendation is to use Cloud managed products wherever possible, so you can focus on what you do best: building great applications.

On the other hand, if you do find yourself needing to run your own stateful services and no managed offering is available, Kubernetes is a popular choice to orchestrate those services as managing stateful applications is even harder without any tooling.

1.4.2 Functions as a Service

The flexibility of Kubernetes draws a lot of developers in, and you can certainly configure it to run your own Functions as a Service (FaaS) such as Knative, which is popular when operating in a mixed environment with some stateful services, other stateless ones and functions.

If you plan to exclusively use higher-order compute types like functions, and don't expect that your needs may broaden in the future, then a managed FaaS may be the simpler choice, as this is likely simpler to operate than running a FaaS on Kubernetes.

1.4.3 Pure Stateless Applications

If all you run are stateless applications, this is a use-case well covered by many traditional Platform as a Service (PaaS) products on the market. They will likely be able to handle this basic case of running a stateless application simpler than you doing the same thing in Kubernetes. After all, when you design your system to handle a specific use-case, it can be really optimized at doing that one thing well.

There are nevertheless some advantages of starting with Kubernetes even if all you have today are stateless servers.

Kubernetes doesn't limit what you can run. If in the future you need to run a stateful workload, like a custom database or maybe you're migrating a legacy application that used to run in a

bespoke VM, these workloads can slot right in and run along side your stateless apps, without you needing to run a parallel system, or migrate to something more capable.

It also gives you unprecedented control over your hardware. You specify what the hardware configuration looks like, what operating system to run, and how tightly packed in your application replicas are. Want to run on a tight budget? Simply tune your resource requests and reduce the number of servers (see ch. X).

1.5 Summary

Kubernetes is a deployment platform for containerized applications. It has a bit of a learning curve (hence this book), but it enables you to express a vast variety of deployment constructs and takes care of much of the hassle of configuring infrastructure and keeping applications running.

- Containers are the modern way to run applications that achieves isolation between multiple applications running on the same host, and does so with low overhead compared to virtual machines.
- When deploying containerized applications, it is common to use a "container orchestrator" of which Kubernetes is a popular choice.
- Kubernetes can seem complex at first, but hosted platforms (like Google Kubernetes Engine) take the burden out of managing it, allowing you to focus on your application.
- Application developers focus on describing their app configuration in Kubernetes terms, the system then has the task to run the application in the way you describe.
- A key benefit of Kubernetes is that it allows you to grow as your needs evolve, you likely won't need to change platforms due to new requirements like an application needing to have its own local state.
- Most applications can be deployed onto Kubernetes without major modification.
- When you need to scale up due to increased demand, Kubernetes can help you do this in an efficient way.

In the next chapter, we'll get started by containerizing an application so it's ready for deployment to Kubernetes.

2

Containerizing Apps

This chapter covers

- How to containerize apps
- Running your container locally
- Executing commands in the container context

Containerizing your application, that is, packaging your application and its dependencies into an executable container is a required step before adopting Kubernetes. The good news is that containerizing your application has benefits beyond being able to deploy it into Kubernetes, it's a valuable step on its own right, as you're packaging up the application's dependencies and can then run it anywhere without needing to install those dependencies on the host machine.

Regardless of how you deploy your app, containerizing it means that your developers can start working on it locally using Docker, enabling them to get started on a new project with no setup beyond installing Docker. It provides easy context switching between the different applications developers are working on, as the environments are completely isolated. These properties make it a valuable way to improve developer productivity even if you don't end up deploying your app into production with containers (though you'll probably want to do that too).

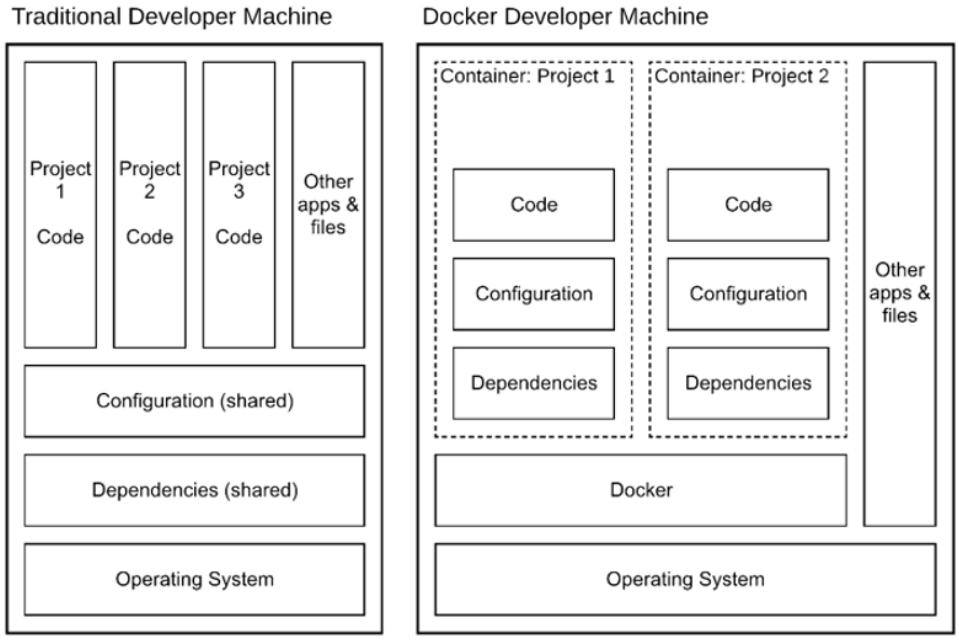


Figure 2.1: Comparison of multiple projects on a development machine with and without containerization

Having your application packaged into containers means that all your dependencies and configuration are captured by a standard Dockerfile configuration file, rather than a mix of bash scripts, text based instructions, human memory and other non-standard configuration systems. It makes it possible to deploy multiple applications on a single host machine without worrying that they will interfere with each other, but with greater performance and less overhead than full virtualization.

2.1 Building Docker Containers

2.1.1 Developer Setup

Docker is distributed as a developer tool that is available for most platforms. For Windows and Mac, it's available as Docker Desktop, on other platforms it's Docker CE (Community Edition). Docker Desktop adds a few convenient utilities, including a local Kubernetes environment (covered in Chapter 3).

Docker runs more performantly on Linux and Windows, due to superior virtualization capacities.

To view and edit the samples, an IDE like VS Code is a great choice, and available for most platforms as well.

WINDOWS 10

On Windows, I highly recommend first configuring the Windows Subsystem for Linux (WSL) first (https://docs.microsoft.com/en-us/windows/wsl/install-win10). Version 2.0 is the one you want, so that Docker can use it as well. With WSL 2.0 installed, you can also install a distribution of Linux like Ubuntu (https://www.microsoft.com/store/apps/9n6svws3rx71) which gives you a bash shell and is a convenient way to run the local (non-containerized) samples presented in this section.

MAC

On Mac, simply install Docker Desktop (https://www.docker.com/products/docker-desktop).

LINUX

On Linux, you will instead get Docker from your distro. For Ubuntu, Docker is available as docker-ce (the CE stands for Community Edition), follow the instructions here: https://docs.docker.com/engine/install/ubuntu/

2.1.2 Running Commands in Docker

To explore how Docker works before we build our own application container in Docker, we can bring up a containerized linux shell like so:

```
$ docker run -it ubuntu bash
root@18e78382b32e:/#
```

What this does is download the base "ubuntu" image, start a container and run the bash command against it. The `-it` parameters make it an interactive bash terminal. Now we are in the container, and anything we run will happen in the container.

Since we're going to be building an application on Ubuntu, let's install the language package. I'm going to be using Python for many of the examples in this chapter, but the concept applies equally to any other language.

Run the following two commands in the container shell:

```
# apt-get update
# apt-get install -y python3
```

Now we can try out python interactively, for example:

```
# python3
>>> print("Hello Docker")
Hello Docker
>>> exit()
#
```

And we can capture that most basic of commands into our own python script:

```
# echo 'print("Hello Docker")' > hello.py
# python3 hello.py
Hello Docker
```

When you're done playing around in this container, exit using `exit`.

The beauty of this, is that we installed Python and ran our Python command on the container, not on our local system.

The docker run command actually create a *container*, from our *image*. The image, ubuntu, is a prebuilt filesystem from which the container process runs in. When we exited our interactive session with the container, it will be stopped, but you can easily start it up again using `docker ps -a` to get the container id, `docker start` *`CONTAINER_ID`* to boot it, and `docker attach` *`CONTAINER_ID`* to reconnect our shell.

```
$ docker ps -a
CONTAINER ID   IMAGE     COMMAND    CREATED         STATUS
c5e023cab033   ubuntu    "bash"     5 minutes ago   Exited (0) 1 second ago
$ docker start c5e023cab033
4 docker attach c5e023cab033
# echo "run more commands"
# exit
```

After running a lot of Docker containers, you'll end up with a pretty big list of stopped containers (and lots of hard drive space used). To clean up these build images which typically you don't need to keep, at any time, run:

```
$ docker system prune -a
```

Container Image vs Container Instance

In Docker terminology, the container *image* is the file artifact (whether downloaded from a registry as in this section, or built locally), and the container instance (or just container) is an invocation of the container. Analogous to a VM image: the operating system and configuration, and the VM instance: the machine, as configured. Kubernetes mostly deals with images, as instances are ephemeral by design, but when using Docker locally, the instance concept is important. Not least, because every invocation creates a container instance, that eventually you'll need to clean up to recover the disk space.

We now have a Linux environment on which we can use for testing and running random commands, all without needing to install anything (beyond Docker) on our local machine. Want two Linux container environments with a different config? No worries—just run another container!

If you've ever setup a VM before, you'll appreciate just how fast this is to setup! Containers are simple to create. As you'll see in the next section, they are also easy to build on, and expand.

2.1.3 Building our own Images

In the previous section, we started a linux container, installed Python and created a simple python script which we ran in the container. Let's say we want to make this repeatable. That is, to capture the configuration of the container (installing Python), and our application (the python script) in our own container image. Such an image would be useful so we don't have to remember the steps we took, and also so that others can deploy our amazing application!

While this example uses only a simple python script, you can imagine that the application can be as large and complex as you want to make it. It doesn't just have to be Python either, these steps work for any interpreted language (see section 2.1.7 for how to deal with compiled applications), just substitute the Python configuration for whatever language you are using.

The process of building our container image so we can make a repeatable application deployment uses a Dockerfile. The Dockerfile is a set of procedural instructions used to build your container. Think of it like a bash script that configures a virtual machine image with your app and its dependencies, only that the output is a container image.

Starting with the basic Python program we created in the previous section:

Listing 2.1 Chapter02/2.1.3_Dockerfile/hello.py

```
print("Hello Docker")
```

To build our own container image setup with python and containing this script, you'll need to create a Dockerfile, pick a base container image to use as the starting point, and add your program. For now we'll start with the generic base image `ubuntu`, which provides a containerized Linux environment.

Here is a basic Dockerfile to capture our steps:

Listing 2.2 Chapter02/2.1.3_Dockerfile/Dockerfile

```
FROM ubuntu #A
RUN apt-get update #B
RUN apt-get install -y python3 #B
COPY . /app #C
WORKDIR /app #D
```

#A Specify base container image
#B Configure our environment
#C Copy the app to the container
#D Set the current working directory

To build and run this container, execute the following from the command line, from the sample root directory:

```
$ cd Chapter02/2.1.3_Dockerfile/
$ docker build . -t hello
$ docker run hello python3 hello.py
Hello Docker
```

Notice how the commands in our Dockerfile are essentially the same as the ones we used in the previous section. Rather than starting the ubuntu container image, we use it as our base image (with FROM). Then we run the same two apt-get commands as before, to configure python. COPY is used to copy our python script into the image, and WORKDIR simply sets the current working directly so that when we run a command, that's the directory it will be run in.

Also notice that the command we use after the image is built is the same "python3 hello.py", just prefixed with our new container image.

We've now encapsulated the environment we build, and our script into a neat package that we can use and run, or share with others. The wonderful thing about containers, they encapsulate the configuration steps along with the program itself. The best part is that when ubuntu is updated, we can rebuilt our image by simply building it again.

Compare this to installing Python on your host and running everything locally. For one, if you'd done that you would now have Python installed. You probably would be happy with install Python locally, but imagine a more complex application that brings with it dozens of tools and libraries. Do you really want all these on your system? Furthermore, what if you're developing a few different applications, all with their own dependencies, and sometimes with the same dependency, but requiring particular versions of that dependency making it impossible to satisfy both simultaneously (a situation referred to as "dependency hell" if you're familiar with the concept).

Containers solve this, by isolating each application along with their dependencies in their own container images. You can happily work on multiple projects, share Dockerfiles with your development team, and upload container images to your production environment, all without messing up your developer machine.

To see how this looks for Ruby, the setup is fairly similar:

Listing 2.3 Chapter02-ruby/2.1.3_Dockerfile/hello.rb

```
puts "Hello Docker"
```

Listing 2.4 Chapter02-ruby/2.1.3_Dockerfile/Dockerfile

```
FROM ubuntu
RUN apt-get update
RUN apt-get install -y ruby
COPY . /app
WORKDIR /app
```

To run, the only difference is the command that is passed:

```
$ cd Chapter02-ruby/2.1.3_Dockerfile
$ docker build . -t hello_ruby
$ docker run hello_ruby ruby hello.rb
Hello Docker
```

2.1.4 Using Base Images

The above example uses the linux container `ubuntu` as a base to configure our linux-based app. Base images including `ubuntu` and other distributions such as like `centos`, and `alpine` base image is a good starting point for configuring any linux-based app. However, for convenience the container community has created several more specific images designed for various languages and environments.

Instead of installing Python ourselves on to `ubuntu` base image, we can just start with the `python` image, and save some steps. The added bonus is that these base images are generally created by experts, and thus are well configured to run Python apps.

Here's the same container, but starting with the `python` base image:

Listing 2.5 Chapter02/2.1.4_BaseImage/Dockerfile

```
FROM python:3
COPY . /app
WORKDIR /app
```

Simpler, right? Building and running it is the same:

```
$ cd Chapter02/2.1.4_BaseImage
$ docker build . -t hello2
$ docker run hello2 python3 hello.py
Hello Docker
```

What is a base image really?

The base image used in this example, `python`, is itself built with a `Dockerfile` and configures an environment everything needed to run Python programs. For container images from Docker Hub, their `Dockerfile` sources are linked so you can see how they are composed. Base images often start with another base image, and so on, until one which starts with the completely blank `scratch` container.

If you're using Ruby instead of Python, setup is pretty similar, just using the `ruby` base image.

Listing 2.6 Chapter02-ruby/2.1.4_BaseImage/hello.rb

```
puts "Hello Docker"
```

Listing 2.7 Chapter02-ruby/2.1.4_BaseImage/Dockerfile

```
FROM ruby
COPY . /app
WORKDIR /app
```

To build and run:

```
$ cd Chapter02-ruby/2.1.4_BaseImage
$ docker build . -t hello_ruby2
$ docker run hello_ruby2 ruby hello.rb
Hello Docker
```

Languages are not the only images available either. If you're using an environment like Apache, you can start with the `httpd` base image. Sometimes you'll have a situation where there are multiple base images that could serve as the base. The best rule of thumb is to pick the one that saves you the most configuration (and you can always crib from the `Dockerfile` of the one you didn't pick!).

Base images, or at least public examples that you can copy, exist for pretty much every common language, environment or application. Before building your own from scratch, it is wise to search Docker Hub for base image, or Google to see if someone has an example for your environment that you can use as a starting point.

2.1.5 Adding a Default Command

Typically, the command executed in the container (`python3 hello.py` in the earlier Python example) is the same each time, so you can specify that in the `Dockerfile`, rather than at runtime:

Listing 2.8 Chapter02/2.1.5_DefaultCommand/Dockerfile

```
FROM python:3
COPY . /app
WORKDIR /app
CMD python3 hello.py
```

To build and run this container, execute the following from the command line:

```
$ cd Chapter02/2.1.5_DefaultCommand
$ docker build . -t hello3
$ docker run hello3
Hello Docker
```

Unlike the other lines in the `Dockerfile` we've used so far, `CMD` is unique as it doesn't actually change how the container is built, but merely saves the default command to run if you call `docker run` without a command specified (you can still override it, even when `CMD` is specified).

Since we've moved the command into the Dockerfile, running the ruby version is exactly the same:

```
$ cd Chapter02-ruby/2.1.5_DefaultCommand
$ docker build . -t hello_ruby3
$ docker run hello_ruby3
Hello Docker
```

2.1.6 Adding Dependencies

Most non-trivial applications will have their own dependencies, not included in the base image. To load those dependencies, you can run commands during the container build process to configure the image as you need. This was how we added ruby to the linux base image in the example above, and this method can be used to install all the dependencies that your application needs.

If your application establishes a database connection to a MariaDB database, here's how you might build your container:

Listing 2.9 Chapter02/2.1.6_Dependencies/Dockerfile

```
FROM python:3
RUN apt-get update #A
RUN apt-get install -y mariadb-client #A
COPY . /app
WORKDIR /app
CMD python3 hello.py
```

#A Configure your linux container with everything your app needs

The `python` base image is built from Debian, a distribution of Linux widely used for Containers, which uses the apt-get package manager, so we can use apt-get to install pretty much any other dependency we need.

You don't just have to use apt-get either. Say you have a service that's creating PDF files, and you need to include a Unicode font, you can build an image that includes Google's "Noto" free font like so:

Listing 2.10 Chapter02/2.1.6_Dependencies-2/Dockerfile

```
FROM python:3
RUN apt-get update
RUN apt-get install -y bsdtar #A
RUN mkdir -p ~/.fonts; cd ~/.fonts #B
RUN curl "https://noto-website-2.storage.googleapis.com/pkgs/Noto-hinted.zip" | bsdtar -
      xvf- #C
RUN fc-cache -f -v #D
COPY . /app
WORKDIR /app
CMD python3 hello.py
```

#A Install bsdtar
#B Create a new directory and cd into it. Notice how multiple commands can be combined on one line.
#C Download the font package and extract it
#D Install the fonts

It is common for containers to have many dependencies, and you can configure any part of the operating system you need to in this way, such as, installing fonts, or TLS certificates.

2.1.7 Compiling Code in Docker

What about programs that need compilation, like Java, .NET, Swift, or C++? Obviously a `COPY` command will not suffice in the Dockerfile, unless you already have compiled binaries lying around.

Pre-compiling the application locally would be one option, but why not leverage Docker to compile your application as well! Let's re-implement our hello world example in Java, and compile it into our container.

Listing 2.11 Chapter02/2.1.7_CompiledCode/Hello.java

```
class Hello {
    public static void main(String[] args) {
        System.out.println("Hello Docker");
    }
}
```

Listing 2.12 Chapter02/2.1.7_CompiledCode/Dockerfile

```
FROM openjdk
COPY . /app
WORKDIR /app
RUN javac Hello.java #A
CMD java Hello
```

#A The compile command

The Dockerfile is similar to the previous ones, we start with the swift base image, and copy the app. In this case however we'll use the `RUN` command to build the app, prefaced with a `WORKDIR` directive to specify where this action (and subsequent actions) should be performed.

To build and run this example:

```
$ cd Chapter02/2.1.7_CompiledCode
$ docker build . -t compiled_code
$ docker run compiled_code
Hello Docker
```

Another example that compiles a server-side Swift application is given in the `Chapter02-swift/2.1.7_CompiledCode` folder. It can be built and run in the same way.

2.1.8 Compiling Code with a Multi-stage Build

Using `RUN` to compile code or perform other actions is a viable path, however the drawback is that you end up configuring your container image with tools it needs to execute the RUN command. These tools end up in the final container image along with any source code.

For example, if you look at the image we created in the previous section, and run ls:

```
$ docker run compiled_code ls
Dockerfile
Hello.class
Hello.java
```

You'll see that the source code remains. Also, the Java Compiler (javac) is still present in the image, even though it will never be used again (we don't need the compiler when running our image).

This mixing of responsibilities of the container image: to both build, and run is less than ideal. Not only do all those extra binaries bloat the container image, but they also needlessly increase the attack surface area of the container (as any process running in the container

now has a compiler to work with). You *could* clean up the container with a bunch of additional Docker commands (e.g., deleting the source code, uninstalling tools that are no longer needed) but it's not always practical, particularly if all these extra tools came from the base image.

A better way to solve this problem is to use a multi-stage container build. With a multi-stage build, we first configure a temporary container with everything needed to *build* the program, and then a final container configured with everything needed to *run* the program. This keeps the concerns separated and neatly isolated to their own containers.

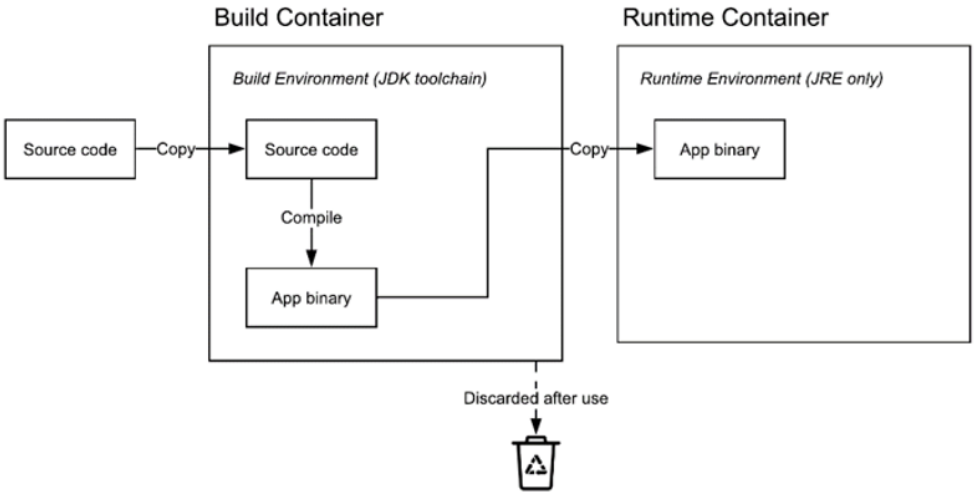


Figure 2.2: A multi-stage container build, where an intermediate container is used to build the binary

Let's rework the example in the previous section to be built using a multi-stage `Dockerfile`.

Listing 2.13 Chapter02/2.1.8_MultiStage/Dockerfile

```
FROM openjdk:11 AS buildstage #A
COPY . /app
WORKDIR /app
RUN javac Hello.java

FROM openjdk:11-jre-slim #B
COPY --from=buildstage /app/Hello.class /app/ #C
WORKDIR /app
CMD java Hello
```

#A The "build" container is named 'buildstage' and has the responsibility to build the code
#B The runtime container uses a slimmed down base image, without the compile tools
#C "–from=" is used to reference files from the build container.

As you can see from this example, there are what looks like two `Dockerfile`s in one (each beginning with a `FROM` command). The first is configured and built purely to compile the app, using the full OpenJDK base image which includes the java compiler, and the second has only what is needed to run the app and is built from the JRE base image, which only includes the Java runtime environment.

This `Dockerfile` produces as its final artifact, a production container that only contains the compiled Java class and dependencies needed to run it. The intermediate artifact of the first container that build the app is effectively discarded after the build completes (technically it's saved in your docker cache, but no part is included in the final artifact that you would use in production).

To run this example:

```
$ cd Chapter02/2.1.8_MultiStage
$ docker build . -t compiled_code2
$ docker run compiled_code2
Hello Docker
```

Another example that compiles a server-side Swift application with the multi-stage build process is given in the `Chapter02-swift/2.1.8_MultiStage` folder. It can be built and run in the same way.

2.2 Containerizing a Server Application

The examples in the previous section were all simple programs that run once. This is a common use-case for containers: for command line programs, batch workloads or even to serve requests in a Functions as a Service environment.

One of the most common workloads to deploy in Kubernetes however are HTTP services, that is an application that listens for, and processes incoming requests a.k.a web servers.

A server application is no different to any other application from Docker's perspective. There's a few differences to how you start and connect to the container owing to the fact that you likely want to keep the container running (so it can serve requests), and you'll likely want to forward ports from your local machine so you can connect to it.

2.2.1 Containerizing an Application Server

Until now, the example program was a basic "Hello World" Python script. To demonstrate how to containerize HTTP servers, we'll need something that is a HTTP server. The following code is purely an example of a bare-bones HTTP server in Python that returns the current date and time. Don't worry too much about the code itself—this book is language agnostic, and the Python used here is purely an example—you can apply these principles to any HTTP server.

Listing 2.14 Chapter02/timeserver_app/Server.py

```
from http.server import ThreadingHTTPServer, BaseHTTPRequestHandler
from datetime import datetime

class RequestHandler(BaseHTTPRequestHandler):
    def do_GET(self):
        self.send_response(200)
        self.send_header('Content-type', 'text/plain')
        self.end_headers()
        now = datetime.now()
        response_string = now.strftime("%Y-%m-%d %H:%M:%S")
        self.wfile.write(bytes(response_string,"utf-8"))

def startServer():
    try:
        server = ThreadingHTTPServer(('',80), RequestHandler)
        server.serve_forever()
    except KeyboardInterrupt:
        server.shutdown()

if __name__== "__main__":
    startServer()
```

Containerizing this server application is actually the same as our simple command line program.

Listing 2.15 Chapter02/timeserver_app/Dockerfile

```
FROM python:3
COPY . /app
WORKDIR /app
CMD python3 server.py
```

If at this stage you're containerizing your own application, then follow these generic steps:

- Find an ideal base image, being one that provides as much of your configuration as possible. For a Ruby on Rails app, start with `ruby` and not the more generic `ubuntu`. For Django, use `python`, and so on.
- Configure any application specific dependencies you need (via `RUN` statements, as we did above)
- Copy your application

I find that Google is really your friend for this. Unless you're doing something new and exotic, someone's probably figured out and shared and example Dockerfile of how to configure an application using your framework. If you're using a popular framework like Django, Ruby on Rails, WordPress, Node.JS, SpringBoot I can say with certainty that there are a lot of resources for you to draw on. Every application is different—your dependencies won't exactly match everyone elses all the time—but you can get a huge head start this way.

Now that we have our HTTP server, we can build it like usual:

```
$ cd Chapter02/timeserver_app
$ docker build . -t server_app
```

Running it is a little different this time, since we'll need to forward ports from the host machine to the container, so we can actually try this application in our browser. Let's forward port 8080 on our local machine to port 80 in the container that the application is listening on.

```
$ docker run -it -p 8080:80 server_app
```

Now you should be able to browse to http://localhost:8080 and view the application.

The `-it` parameter (actually two parameters but normally used together) allows us to terminate by sending SIGTERM (often Ctrl/Command+C). This makes the typical developer loop of build, run, fix, repeat easy (run, Ctrl+C, fix, repeat). Alternatively you can run docker in the background with `docker run -d -p 8080:80 server_app`. Without using `-it`, you'll need to stop the process manually: `docker ps` to list the process, and `docker stop CONTAINER_ID` to stop it.

For a neat development loop, I like to use the following one-liner that will build and run the image in one go. When you need to rebuild, you can just hit Ctrl+C (or equivalent), press up to show the last used command, and enter, to do it all again. Just be sure to watch the console output for any errors during the build stage, as otherwise it will run the last built image.

```
$ docker build . -t server_app; docker run -it -p 8080:80 server_app
```

That's it! We now have a containerized application running in Docker. In the next section, 2.3, I cover how use Docker Compose to configure and run a local debug setup (useful if your application consists of a few different containers), and in the next chapter, how to deploy this web application into Kubernetes.

2.2.2 Debugging

If you're having trouble getting your app to run after configuring a Dockerfile, it can be useful to shell into in the container's environment to poke around and see what's going wrong. When the container is running using the previous instructions, you can shell into the running container from a new console window like so:

```
$ docker container ls
$ docker exec -it CONTAINER_ID sh
# ls
Dockerfile  server.py
# exit
$
```

You can run any other command other than `sh` too, for example on a Ruby on Rails project you might run `bundle exec rails console` here to directly bring up the rails console without an intermediate step.

Without enumerating every docker command which you can find in the docs, the other one I find especially useful for debugging is `docker cp`. It allows you to copy files between your host and the container. Here's an example:

```
$ docker cp server.py CONTAINER_ID:/app
```

Or to copy a file out of the container:

```
$ docker cp CONTAINER_ID:/app/server.py .
```

If you do fix anything through running commands via exec, or copying files, be sure to capture the change in the Dockerfile. The Dockerfile is your primary specification, not the container instance. If you rely on manual changes to the container instance, it's no better than the old "shell into a VM and change things" model that we're moving away from.

2.3 Using Docker Compose for Local Testing

At this point, we have built a container image and are ready to start using Kubernetes. If you like, skip ahead to the next chapter and deploy this newly built container into Kubernetes right away, both on the cloud and in local environments. If you're interested in using Docker for local testing, this section is for you.

In the previous section we booted our server application using docker, and forwarded ports to our host for testing. Using this approach for testing has a couple of drawbacks. You have to setup the ports to forward each time, and if you're developing an application with a few containers, it can be complex to get everything running.

This is where Docker Compose comes in. Compose is a mini container orchestrator that can bring up and tear down multiple containers in a logical group, and preserve the runtime settings in between runs which is useful for local testing.

To run the web server container from section 2.2.1 with compose, we can configure a `docker-compose.yaml` file such as the following

Listing 2.16 Chapter02/2.3_Compose/docker-compose.yaml

```
version: '1'
services:
  web:
    build: ../timeserver_app #A
    command: python3 server.py #B
    ports:
      - "8080:80" #C
```

#A The path to the directory containing the docker container to be built
#B Command that will be run on the container. Can be skipped if your Dockerfile specifies CMD
#C Ports to forward to the container from the local machine. In this case, port 8080 on the local machine will be forwarded to the container's port 80.

To build and run the container:

```
$ cd Chapter02/2.3_Compose
$ docker-compose build
$ docker-compose up
```

When developing, I tend to run both these steps as one so I can create a tight rebuild loop.

```
$ docker-compose build; docker-compose up
```

With this simple configuration, there's no need to remember the specific docker command to boot and test the application—everything is stored neatly in the compose file. With this example, that mostly consists of some ports to forward, but this benefit will become apparent as you add more configuration and dependencies.

2.3.1 Mapping Folders Locally

Earlier we used `docker cp` to copy files in to and out of container instances. One really useful feature of Compose is that you can actually map local folders right into the container. In other words, instead of the container having a copy of your application, it will actually just link to the same folder on your hard drive. During development this can be really handy, as it allows you to work on the files in the container right from your desktop, without needing to copy things back and forth, or rebuild the container.

For non-compiled markup like HTML and CSS, and interpreted languages like ruby, python, or PHP, this means you can just hit save in your editor, and refresh the page. You may need to configure your container for hot-reloads (where it reads the file from disk each time), something that if you're using a higher-order framework like Rails is easily configured. Such a setup avoids a docker build each time you make a change, and makes for a super tight development loop.

For compiled languages, you could use the same trick if you're building the binary locally (where the binary output goes into the mapped folder), but if you prefer to build everything through docker then this won't help, although you can use other developer tools like Skaffold[1] to give you a tight development loop.

Let's update our timeserver app to support reloading the code while it's running, and configure a local mount in Compose. The steps here will vary by language and framework. For Python we can use the reloading library to have our GET function reloaded from disk each time there is a new request.

[1] https://skaffold.dev/

Listing 2.17 Chapter02/2.3.1_VolumeMount/server.py

```
from reloading import reloading
from http.server import ThreadingHTTPServer, BaseHTTPRequestHandler
from datetime import datetime

class RequestHandler(BaseHTTPRequestHandler):
    @reloading
    def do_GET(self):
        self.send_response(200)
        self.send_header('Content-type', 'text/plain')
        self.end_headers()
        now = datetime.now()
        response_string = now.strftime("%Y-%m-%d %H:%M:%S")
        self.wfile.write(bytes(response_string,"utf-8"))

def startServer():
    try:
        server = ThreadingHTTPServer(('',80), RequestHandler)
        server.serve_forever()
    except KeyboardInterrupt:
        server.shutdown()

if __name__== "__main__":
    startServer()
```

#A By adding the @reloading tag to our method, it will be reloaded from disk every time it runs so we can change nour do_GET function while its running

Recall from the Dockerfile that our server app is copied into the `/app` directory within the container. What we want to do now is mount our local directory into the container at that same directory. This is done through volume binding.

Listing 2.18 Chapter02/2.3.1_VolumeMount/docker-compose.yaml

```
services:
  frontend:
    build: .
    command: python3 server.py
    volumes: #A
      - type: bind #A
        source: . #A
        target: /app #A
    environment:
      KEY:  value
    ports:
      - "8080:80"
```

#A This configuration binds the current directory to the container's /app directory so that changes are sync'd.

```
$ cd Chapter02/2.3.1_VolumeMount
$ docker compose build; docker-compose up
Creating network "231_volumemount_default" with the default driver
Creating 231_volumemount_frontend_1 ... done
Attaching to 231_volumemount_frontend_1
```

As before, browse to the app at http://localhost:8080/. This time, open up the server.py code, and make a change to the response. For example, add the text "The time is" to the HTTP response, like so:

```
response_string = "The time is " + now.strftime("%Y-%m-%d %H:%M:%S")
```

Save the file in your editor, and reload the page. You should see the new text in the response! That's how you get a local development loop. In this example we had to make some code changes to make it work, if you're using a standard development framework that will likely not be necessary, as you'll be able to configure it to perform reloads automatically.

Being able to map local folders into the container to create a development loop that is as fast as hitting save in your code editor, then reloading a page on the browser has to be one of my favorite features of Docker Compose, and containers in general. You have all the benefits of containers, where you don't need to mess around installing the developer tools locally, with the same efficiency as if you were running it locally without any build step.

The binding works both ways too, if you make any changes in the container within the bound volume, it will be reflected on your local disk. This can be useful when you want to run commands in the container and save their output. In fact with this approach, you can completely avoid having the developer tools installed on your local machine at all. For example, a Rails developer will from time to time run `gem update rails` to keep the framework up to date. With a volume binding you can run that in the container, and get the changed package list on your hard drive ready to commit to version control.

2.3.2 Adding Service Dependencies

In the case where your app is completely standalone, congratulations, you are done. The rest of the time though, you'll likely have other services that you need to bring up alongside your application. These might be other separate servers that you build, or standard components that might be run by your cloud provider, like a database. In both cases, you can add these dependencies in Compose, to create a local development environment.

Compose or Kubernetes For Local Development?

Why use consider Compose rather than Kubernetes itself to bring up dependent services for development? Kubernetes certainly can be used for local development, and if you want to replicate your production environment it's the best option (Chapter 3 includes a section on local development). What makes Compose popular however for this task is its simplicity.

Compose is easy to setup for local use if you just need a handful of dependent services, which for many simple applications is the case. In production, where you're not just running a few single instance services on one machine, is a different (more complex) story, which is where Kubernetes comes in.

This duality means it's not uncommon to see Compose for local dev, and Kubernetes in production. It does mean that your runtime configuration is essentially duplicated, but this configuration has two separate purposes: development, and production, so it likely won't look identical even if it was all in Kubernetes.

Multiple services can easily be added to the Compose. These can reference standard images (in the case of a dependency like MySQL), or other projects on your hard drive. A common project structure is to have one root folder for all services, with each checked out in a sub-folder, and a docker-compose file that can reference them all.

Here's an example of a compose file with two containerized services, our app that's built locally, and a database instance using the public MySQL container. The demo app here doesn't actually use MySQL, but hopefully you can see how easy it is to add the dependencies that your app needs here. You can add all the services you need here, including multiple locally built containers, and multiple external images.

Listing 2.19 Chapter02/2.3.2_MultipleServices/docker-compose.yaml

```
services:
  frontend: #A
    build: ../timeserver_app #A
    command: python3 server.py
    environment: #A
      KEY:  value #A
    ports: #A
      - "8080:80" #A

  db:
    image: mysql:5.7 #B
    volumes: #B
      - db_data:/var/lib/mysql #B
    restart: always #B
    environment: #B
      MYSQL_ROOT_PASSWORD: 123456 #B
      MYSQL_DATABASE: my_database #B
      MYSQL_USER: dev_user #B
      MYSQL_PASSWORD: 123456 #B

volumes: #C
    db_data: #C
```

#A Our app that is built locally, you can have multiple locally built apps
#B A service running a public image, you can have multiple such services as well.
#C Volume definition for the development database so that it will persist between restarts

This is one of the key reasons to use Compose, rather than just Docker for local testing—the ability to bring up a complete testing environment, and tear it down all with a single command.

When configuring your application for local development, and production all configuration changes should be made by environment variables. Even a single environment variable that indicates "prod" or "dev" to select which configuration file to use can suffice. Configuration should not be baked into the container in such a way that you need to modify it between environments. This allows you to reuse the same container in all environments, and also means that you are testing the production artifact.

2.3.3 Faking External Dependencies

If to date you've been testing against remote dependencies (like a cloud storage API), now might be a good time to see if you can replace those remote dependencies with fakes. Fakes are lightweight implementations of the same API of the external dependency, which speed up development and testing by providing a local service.

In the past, you might have been constrained to finding a fake written in the same language as your application (for practical reasons, like not wanting to support multiple different environments for one project). Once of the benefits of containers, is that just like how you probably don't care what language a cloud service you consume is written in, you no longer need to care about what language your fake is written in either as you don't need to maintain the environment, it runs in its own container.

This also brings the opportunity for high quality fakes, that are really just implementations of the same API. Just like in the earlier section how we used real MySQL in a container (rather than a fake), you can use a real object storage provider to test against, even if you ultimately use a cloud provider service like Google Cloud Storage or AWS S3.

Taking the object storage example, say your application does cloud storage using S3-compatible APIs (e.g. with S3 itself, or one of the many object stores that support the API, like Google Cloud Storage). To setup a local fake for fast iteration, you could get a container like Adobe's S3Mock[2], but with containers it's equally easy to use a fully-fledged S3-comptaible local storage solution like MinIO[3]. MinIO is not really a fake – you can deploy it into production for cases when you want to manage your own block storage service – but you can still use it as a high quality fake, and get benefits like a convenient UI.

The ubiquity of the S3 API for object storage

Like SQL standardized database query languages, S3's API is surprisingly popular for object storage providers. For example, Google, Azure, and (of course) AWS all implement the S3 API, along with most other clouds and several bare metal storage options as well. The benefit of this ubiquity is you can easily switch between providers, and, have several fakes to choose from to develop locally.

Earlier I discussed how containers makes it easy to mix and match services all running in their own environments. Here we see how this ability can make development better as well – rather than implementing yourself, or finding a basic API fake for your environment, you can either use locally the same API as in production (like with MySQL), or a find a production-grade replacement for another cloud service that you use (like with MinIO subbing in for cloud object sotrage).

Let's add MinIO as another service to our Docker Compose file:

[2] https://github.com/adobe/S3Mock
[3] https://min.io/

Listing 2.20 Chapter02/2.3.3_Fakes/docker-compose.yaml

```
version: '1'
services:
  app:
    build: .
    command: bundle exec puma -C config/puma.rb
    environment:
      DATABASE_URL:
       mysql2://dev_user:123456@db/my_database?encoding=utf8mb4&collation=utf8mb4_unicode_c
       i
      LANG:                     en_US.UTF-8
      RAILS_ENV:                development
      RACK_ENV:                 development
      RACK_TIMEOUT_LOG_LEVEL:   DEBUG
      S3_ENDPOINT:              http://storage:9000 #B
      S3_USE_PATH_STYLE:        "1" #B
      S3_ACCESS_KEY_ID:        fakeaccesskey #B
      S3_SECRET_ACCESS_KEY:    fakesecretkey #B
    ports:
      - "8080:80"

  db:
    image: mysql:5.7
    volumes:
      - db_data:/var/lib/mysql
    restart: always
    environment:
      MYSQL_ROOT_PASSWORD: 123456
      MYSQL_DATABASE: my_database
      MYSQL_USER: dev_user
      MYSQL_PASSWORD: 123456

  storage: #A
    image: minio/minio #A
    command: minio server /data #A
    volumes: #A
      - storage_data:/data #A
    restart: always #A
    environment: #A
      MINIO_ACCESS_KEY: fakeaccesskey #A
      MINIO_SECRET_KEY: fakesecretkey #A
    ports: #A
      - "9000:9000" #A

volumes:
    db_data:
    storage_data: #A
```

#A The new storage mock
#B The application configured to use the new mock

Typically with services used as fakes, as we are MySQL and MinIO here, you can specify the secrets that it will use, then simply specify those same secrets to the application. The details of how the application described by this docker compose configuration is using MinIO is beyond the scope of this chapter.

2.4 Summary

Containerization is essentially scripting your app's build, environment and configuration into a standardized format that can then be run with VM-like properties on a host, but without the VM overhead.

- Containerization is key step towards adopting Kubernetes, as this is the executable environment that Kubernetes supports.
- Not just for production, containers help developers work on multiple projects at once, without the environments conflicting and without needing complex setup instructions.
- Docker Compose is a lightweight container orchestrator that can give you a quick container-based development environment for multiple services.
- Mapping folders locally with Compose enables the editing of non-compiled applications in real time, for a tight development loop

In the next chapter, we'll introduce Kubernetes for orchestrating these same containers in production.

3

Deploying to Kubernetes

This chapter covers

- Deploying a containerized application to Kubernetes on a public cloud and exposing it to the Internet
- Understanding the Kubernetes terms and concepts related to specifying and hosting application deployments
- Updating deployments with a new version of the application
- Running a version of Kubernetes locally for testing and development

In chapter 2, we covered how to containerize your application. If you stop there, you would have a portable, reproducible environment for your app, not to mention a convenient developer setup, but you may have trouble scaling that app when you go to production.

If your deployment model looks incredibly simple, like one container per VM then you're more or less set. You can deploy that container directly into a system that simply scales the VMs as needed, with an instance of your container running on each. In such a setup, your container is logically acting like a VM image, just with better tooling, and more convenient packaging. For most, the world is more complex than that.

Running more than a single container on a machine is typically done with what the industry calls a container orchestrator, which is a fancy way of saying *tooling that schedules and monitors your containers on your machines*. A good such system can pool the resources of your machines, work out how to fit the containers into the desired capacity, and monitor those containers for issues like a crash or hung process.

Being able to run (i.e. orchestrate) multiple containers on your compute instances gives many benefits including scaling at a sub-VM level (being able to allocate 0.2, 0.4, 0.6 etc. CPU cores to a workload), which leads to bin packing and cost optimization: cramming as many containers onto your machines as possible. It also enables other interesting patterns like co-locating critical

workloads together for low-latency, and enabling workloads to temporarily take advantage of unused resources on the machine (known as bursting).

It's hard to understate the benefit of bin-packing that can be achieved by a robust container orchestrator. For enterprises of all scales, from a single-person weekend startup, to a fortune 500 company, cost is an ever present concern. Even for a well-funded venture that isn't too concerned about their infra costs today, they'll still need to have some idea on how to contain costs if their product is wildly successful and the bill becomes material. A good container orchestrator can provide this path, whether you need to apply the optimizations immediately, or just have the ability to in the future.

The other important property to a container orchestrator is automating some of the operations. Given it's possible to programmatically determine if a process has crashed or hung, you'll want a system that can automatically handle situations like this without human intervention.

Kubernetes is a such a container orchestrator, capable of arranging your containers onto your resources in a myriad of different ways (according to your specifications) to get the most out of your cluster. At the time of writing, it's the most popular open source container orchestrator in the world, with all the benefits this brings like multiple cloud offerings and a wide array of tools and documentation.

3.1 Kubernetes Architecture

Before we get to a demo, it is important to understand some of the core components of Kubernetes. Kubernetes at its heart is a container orchestrator, and a workload-level abstraction on raw compute primitives. For example, a machine (be it virtual or bare metal) is referred to as a "node", and containers are actually grouped and scheduled as "pods". In this section, we'll cover the fundamental building blocks key to deploying a standard web application on Kubernetes. Future chapters will look at other building blocks, like Chapter 8 which covers the Job workload.

3.1.1 The Kubernetes Cluster

The Kubernetes cluster of compute resources consists of several components: the user (or "worker") nodes, and the control plane (or "master") nodes.

Nodes in Kubernetes are just the computers on which the containers run. Typically these are virtual machine instances, but can be bare metal (with the operating system running directly without virtualization).

Nodes run a special Kubernetes process called the "kubelet" which is responsible for communicating with the control plane, and managing the lifecycle of the containers which run on the nodes, and a container runtime responsible for booting the containers. Other than the operating system, kubelet and the container runtime environment, the remaining processes—whether they are Kubernetes system components or your own application—run in containers.

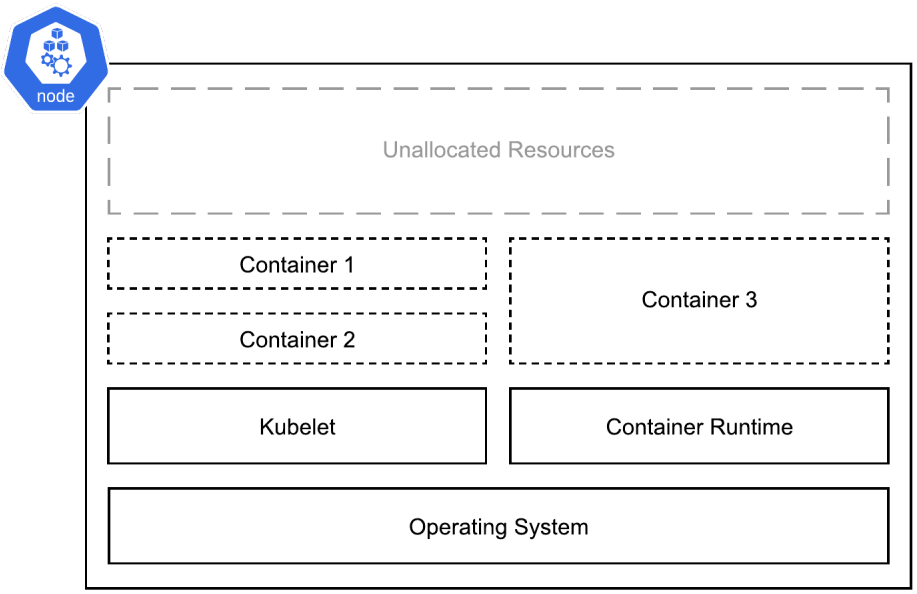


Figure 3.1: Processes running on a virtual machine, which Kubernetes calls a "node"

For self-managed Kubernetes (like that which you install on your developer machine, or deploy manually to the cloud), one of the Kubernetes nodes has a special responsibility: running the Kubernetes orchestrator program itself. In a high availability environment, there may be several master nodes to provide failover. This node, referred to as the "master node" or "control plane", has several responsibilities:

- Run the API which you use to interact with the cluster (using tools such as the Kubernetes CLI tool)
- Store the state of the cluster
- Coordinate with all the nodes in the cluster to schedule (start, stop, restart) containers on them.

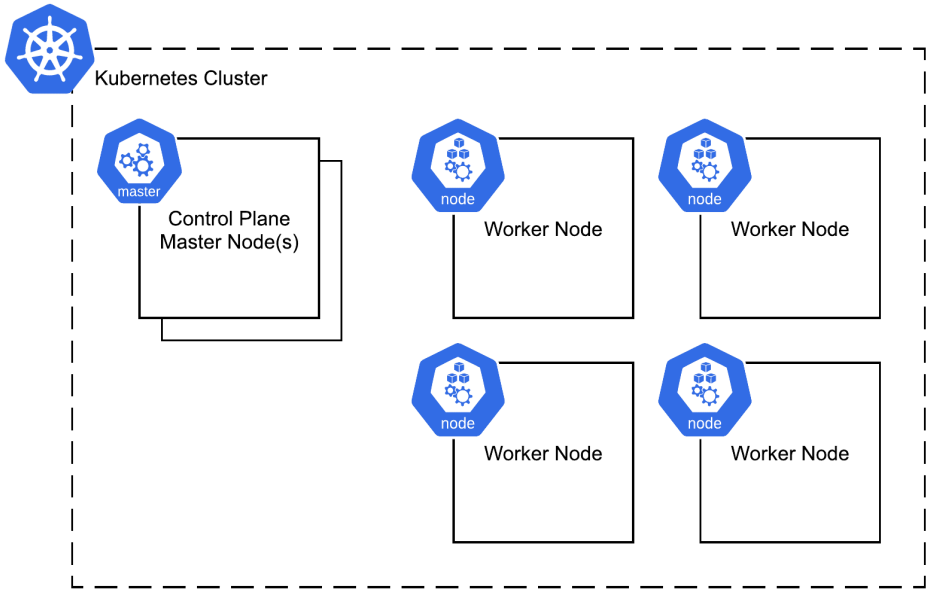


Figure 3.2: Self-managed Kubernetes cluster with the control plane (master nodes) and worker nodes

In most cloud environments, the control plane is offered as a managed service. It still performs the same functions as the control plane run on master nodes as in a self-installed setup, but whether or not the control plane is actually hosted on a virtual machine node in such an environment is implementation detail that you can safely ignore. For a hosted control plane, worker nodes (herein referred to simply as "nodes", as this is unambiguous in a cloud environment) are typically connected automatically, and you communicate with it via an API endpoint (much like any other hosted API).

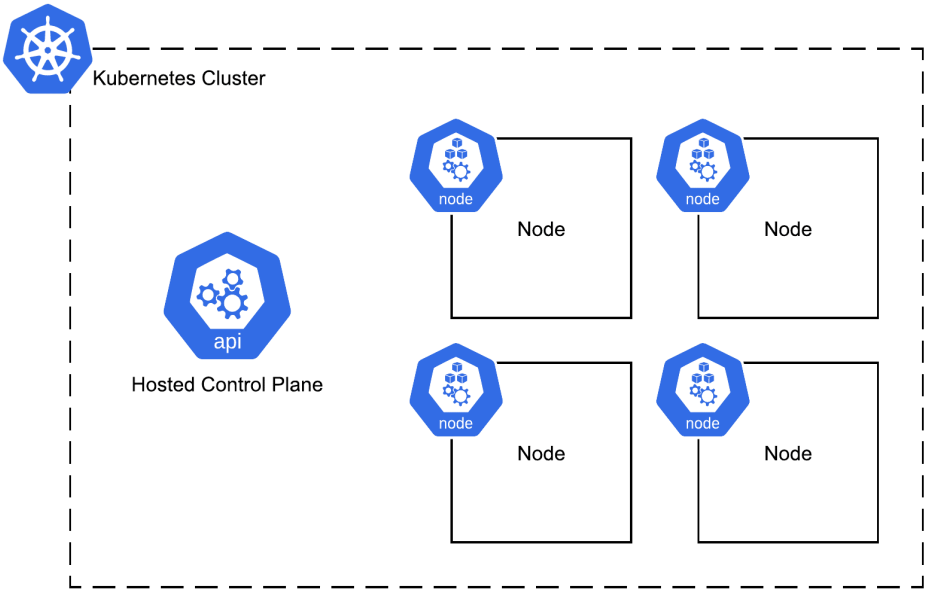


Figure 3.3: Cloud-hosted Kubernetes Cluster with nodes connecting to a hosted control plane.

Nodes are attached/connected to the control plane, and have the responsibility for managing the lifecycle of containers that run, such as starting and stopping containers. The control plane will instruct the node to run a certain container, for example. The node also takes some actions by themselves without needing to check in with the control plane, like restart a container that has crashed, or reclaiming memory when the node is running low.

Collectively, the control plane and nodes form the "Kubernetes Cluster", and provide the Kubernetes service on which you can schedule your workloads, like running an application server.

3.1.2 Kubernetes Objects

Once the cluster is created, you interact with Kubernetes primarily by reading and modifying Kubernetes Objects through the Kubernetes API run from the master node. Each of these objects represent a particular deployment construct in the system, for example there is an object that represents a group of containers (Pod), one that represents a deployment of pods (Deployment), one for service IPs and so on.

One such object is the Node, which represents the compute instance attached to the cluster, as described above.

To deploy a stateless workload onto the cluster's nodes, you'll use 3 objects: the Pod, Deployment, and Service.

Pod

The **Pod** is simply a collection of containers. Often this will just be a single container, but could be multiple in the case where tightly coupled containers need to be deployed together.

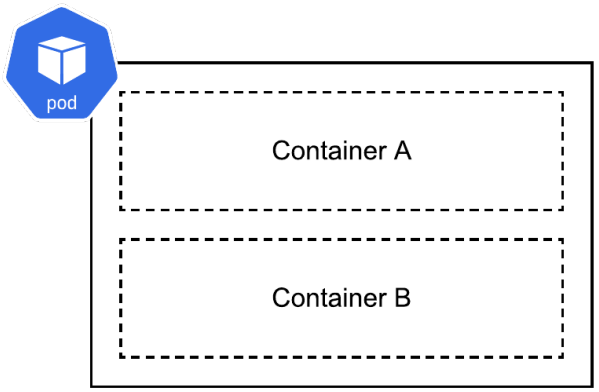


Figure 3.4: The Kubernetes pod. A pod can have one or many containers

The Pod is used as the primary scheduling unit in Kubernetes. Encompassing your application and its containers, it's the unit of compute that Kubernetes schedules onto your hardware resources according to its defined needs. For example, if your workload requires 2 CPUs to run, it will find a machine with 2 available CPU resources. The scheduler is pretty sophisticated, and will even move other workloads around to accommodate if need be.

How many containers to a Pod?

Except for in simple cases where a tightly coupled dependency exists between multiple containers, most containers are deployed individually with one container per Pod. This type of deployment is known as the "micro service architecture" owing to the fact that each service has its own deployment (and typically development) lifecycle.

Situations where multi-container pods are often used is for include so-called sidecars, where a second container is used for authorization, logging or some other function, and similar situations where the application has a tightly-coupled container dependency.

The Pod itself has no operating system representation. It's just a logical encapsulation of the containers (which themselves are groups of operating system processes). Were you to inspect the processes running on the node, you would not see the Pod itself, just see a bunch of processes in containers. It's Kubernetes that binds these containers together, ensuring that they share a

common lifecycle: that they are created together, that if one fails they are restarted together, and that they are terminated together.

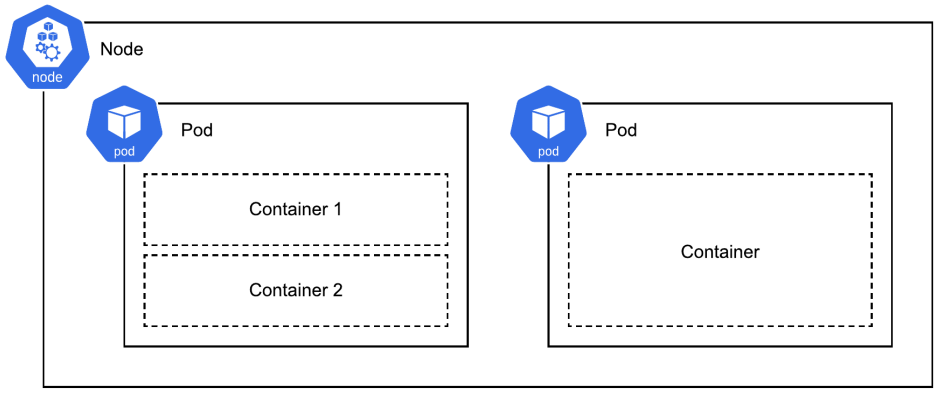


Figure 3.5: Multiple Pods on a Node

DEPLOYMENT

While you can instruct Kubernetes to run Pods directly, this is rarely what you'll do. Applications crash, machines fail and so Pods need to be restarted and/or rescheduled. Instead of directly scheduling Pods, it's better to wrap them into a higher order object that manages the Pod lifecycle.

For services that need to run continuously, that object is a *Deployment*. Other options include a *Job* for running batch processes to completion, covered in a later chapter. In the deployment, you specify how many replicas of the Pod you wish to be running, and other information like how updates should be rolled out.

A Deployment is a statement about the desired state of the system, which Kubernetes seeks to actuate. For example, your deployment may say "I want 3 instances of container A, split evenly over the cluster". Kubernetes takes this, and will do it's best to always ensure that this is satisfied. These automated operations for scaling and repairing are the primary reason for using Deployment to manage the lifecycle of a service, rather than running Pods directly. For now we'll focus on the 2 key attributes of the Deployment: the container image, and replicas.

Kubernetes' actuation of the deployment isn't just when it's created, it constantly runs in a loop, verifying that the constraints are met. For example, were a Pod to become unavailable, or the node itself to fail, causing the number of instances of the Pod to be lower than the specified amount, Kubernetes will schedule new instances of the Pod to once again meet the user's requirements.

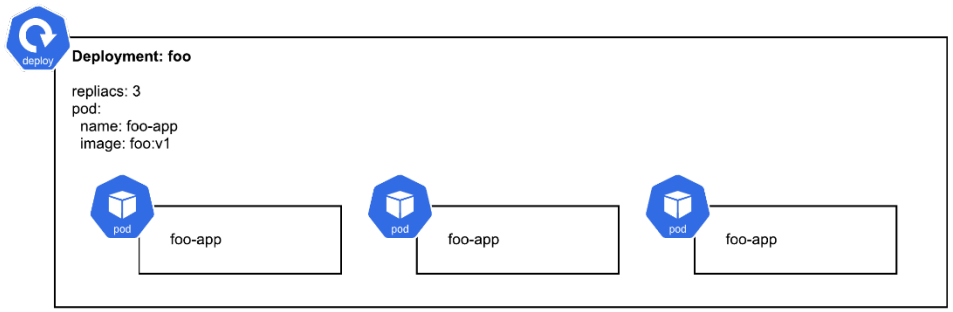


Figure 3.6: A deployment with 3 replicas of pod "foo-app"

SERVICE

Services pair with Deployments and describe how the Pods in the Deployment can be addressed and accessed. Options for internal access include a virtual IP (ClusterIP), virtual port number (NodePort), and external access being a LoadBalancer.

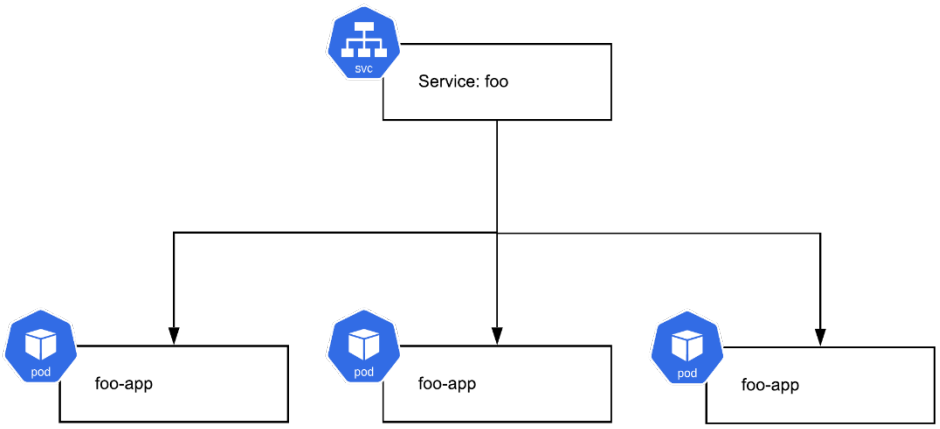


Figure 3.7: A Kubernetes Service

3.2 Deploying an Application

Let's get started by deploying an application and making it available on the internet, and later updating it with a new version, i.e. perform a basic application development release and update

lifecycle. To do this we'll be using the 3 Kubernetes objects discussed in the prior section; a *Pod*, which will be contained in a *Deployment*, and referenced in a *Service*.

3.2.1 Creating a Cluster

Before getting started you'll need a Kubernetes cluster to use. I recommend starting with one on a public cloud, as it's less hassle to get setup *and* people can check out your creations immediately as you can get a public IP. Many cloud providers have free trials and the following instructions should work pretty much anywhere you find Kubernetes. There are also inherent differences in the environment of a local Kubernetes, and a cloud one, particularly around things like load balancing and ingress (covered in later chapters). I prefer to learn the environment I ultimately plan to deploy my work to, hence my suggestion to pick a cloud provider and start learning Kubernetes there.

If you'd prefer to use a local distribution, follow the steps in Section 3.4 (Local Development with Kubernetes) to get your kubectl command connected to a local cluster, then come back to Section 3.2.3 (Deploying) and continue.

To be clear though, all you will need to run these examples is a cluster somewhere, and the Kubernetes command line tool known as `kubectl` (pronounced: "cube cuttle") authenticated to use that cluster, which any competent getting started guide will get you.

GOOGLE KUBERNETES ENGINE

Google Kubernetes Engine (GKE) was the first Kubernetes product to market and is a popular choice for trying out Kubernetes due to its maturity and ease of use. I work on the GKE team, and this is the platform that I know best, so it's the one I'll be using for those places in the book where there are platform-specific requirements, like creating a cluster.

To be clear though, I've written this book to be applicable anywhere you find Kubernetes, and I expect that it will be useful for learning Kubernetes whether you're using GKE, AKS (Azure Kubernetes Engine), Open Shift, EKS (Elastic Kubernetes Service), or any one of the other Kubernetes platforms and distributions out there. There are a few places where the platform plays a role (like now, when creating a cluster), and in those instances I'll demonstrate the action with instructions for GKE, but I'll also providing pointers on how to find the equivalents on other platforms.

Creating a Kubernetes Cluster on Any Cloud

All you need to run the examples in this chapter after this setup section is the `kubectl` tool authenticated to the Kubernetes cluster of your choice. Creating and authenticating `kubectl` is the goal, as you will see for GKE this can be done with 2 commands. You can substitute those commands for the equivalent cluster creation and authentication for the platform of your choice.

To run the following examples on any provider, follow the cluster creation guide for the provider of your choice, then continue to the section "Uploading Your Container". Uploading containers is also another provider-specific action, but I've got you covered with some general tips there on how to achieve it on any platform.

To start with GKE, you'll need a Google Account (if you have a @gmail.com address, then you have a Google Account) setup with Google Cloud. Head over to https://console.cloud.google.com/, select your account, and review the terms. Activate your free trial, or add billing info so you can run these samples (again, if you wish to run the samples locally, you can instead follow the steps in section 3.4 to get a local-only cluster instead).

With your account setup, head over to Kubernetes Engine in the console (direct link: https://console.cloud.google.com/kubernetes), and create a cluster.

Most of the settings you can leave as default. If you plan to operate the cluster for a while, it's worth reviewing the size of the node pool (how many VMs you will get), the machine type, and the size of the disk. For example, a really minimal cluster would be a size of 1, machine type of e2-small, and a boot disk of 30GB. But for most, the defaults are suitable for a test – and you can clean up the resources once you're done. Later when you're getting ready for a production workload, you'll want to carefully review every option as some can only be set during creation, and you could highly optimize the cluster to try and fit everything on a single node if you'd prefer too, but for now it's simplest to start with the default.

Next, we'll need to have the command line tooling setup. Even if you plan to use the UI to interact with GKE (which is totally fine, and a very common pattern), you'll still need the gcloud CLI (command line interface) for certain tasks, like authenticating the Kubernetes CLI tool: `kubectl`. While we use the UI for cluster creation, we'll be using the Kubernetes CLI tool for most other operations, as this is the standard way to interact with Kubernetes and will give you portable skills that will be applicable to any Kubernetes provider.

Download the gcloud SDK at https://cloud.google.com/sdk/install. Once installed, run the following commands:

```
gcloud init
gcloud components install kubectl
```

If you have more than one Google Account, be sure to select the same account during the initialization that you created the cluster in.

Installing kubectl for use with any provider

If your cloud provider bundles kubectl, it might be simplest to use their distribution, as we do above for Google Cloud, as it's easy to stay up to date with the right versions. Another option is to install the Kubernetes toolchain directly from the Kubernetes project at https://kubernetes.io/docs/tasks/tools/install-kubectl/. There shouldn't be any difference between the two options other than which version you get, how it's updated, and in some cases whether or not some authentication tools are preconfigured.

Once the cluster is ready and `gcloud` is configured, tap "Connect" in the UI, and copy and the gcloud command into your shell to authenticate `kubectl`. That command will look like this:

```
gcloud container clusters get-credentials [CLUSTER_NAME] --zone [ZONE] --project [PROJECT_NAME]
```

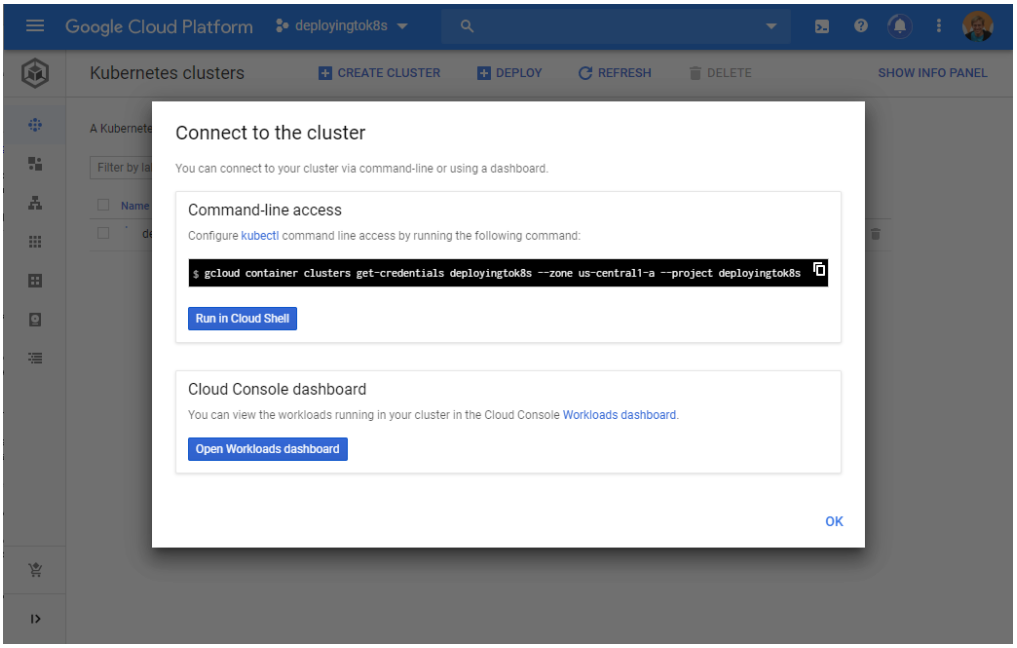


Figure 3.8: GKE's cluster connection UI

That command is the glue between the Google Cloud world and the Kubernetes one, and authenticates the kubectl command with the right credentials to be able to access your GKE cluster.

Rather than using the UI, you can do both the creation and connection steps from the command line like so (assuming you set the default zone during the initialization step above):

```
gcloud container clusters create [CLUSTER_NAME]
gcloud container clusters get-credentials [CLUSTER_NAME]
```

The reason I suggest the UI for the creation step is that you'll find there is a plethora of options to configure, which can be tedious to do on the command line, particularly if you only need to do it once. In cases where you need a reproducible command, the UI has a feature that can show you the equivalent gcloud command (and even the REST API call), that you can save for later reference or scripting. Generally, I recommend using the UI for cluster creation, or at least using it to build the gcloud command which you can then paste into your shell.

With your cluster created, and kubectl authenticated – you're ready to get going with your first application! To make sure everything is working, run `kubectl get nodes`.

You should see something like the following:

```
> kubectl get nodes
NAME                                   STATUS    ROLES     AGE       VERSION
gke-demo-default-pool-a91beea0-5ngr   Ready     <none>    7m55s     v1.14.6-gke.1
gke-demo-default-pool-a91beea0-lfxd   Ready     <none>    7m51s     v1.14.6-gke.1
gke-demo-default-pool-a91beea0-phcn   Ready     <none>    7m55s     v1.14.6-gke.1
```

If you get an error, it is likely that your cluster wasn't created or authenticated correctly – try repeating the above steps, or Google the error message.

3.2.2 Uploading your Container

Till now, the containers we've created have been stored and run locally on your machine. Before you can deploy the container into Kubernetes running in the cloud, you'll need to upload your container to a container registry. This is simply a place that stores the container data, optionally with authentication so that only your project can access it, and provides a way for Kubernetes to fetch the image.

If you prefer, you can skip this step and use an existing public image with the examples below (an example container will be given), but I always think it's best to have your own code deployed, after all — you'll likely need to deploy some custom code, and not only public images.

For public images, Docker Hub[1] is a popular choice, and Kubernetes can pull images from Docker hub without any additional authentication configuration. For the majority of applications that are private however, you'll likely want to use the container registry provided by your Kubernetes cloud. By hosting the image by the same cloud where you use Kubernetes, things like authentication and toolchain integration are typically a lot simpler.

To upload to your cloud's private container registry, you'll need to do the following:

1. Authenticate the docker tool to be able to access the container registry
2. Tag your image with a special path, for indexing
3. Push the image

AUTHENTICATE

To upload your image to a container, you'll need to authenticate the docker client with your container registry of choice. The default choice for most users who wish to keep their images private is to use the container registry of your cloud provider, as this generally gives you efficiencies in terms of image pull time, reduced data costs, and simpler authentication. For Google Cloud, that's Google Container Registry (GCR), on AWS it's Amazon Elastic Container Registry (ECR), on Azure it's Azure Container Registry and so on.

DockerHub is another popular choice, particularly when it comes to public images. This includes the base images (like the ones we used in the previous chapter), open source software like MariaDB, or perhaps your own software and demos you wish to share with the world. You can also access private container images from DockerHub (and other registries) with any Kubernetes platform with a bit of extra configuration.

In the case of GCR, run the following command to install a credential helper to the docker tool so that it can talk to GCR:

```
gcloud auth configure-docker
```

[1] https://hub.docker.com/

For DockerHub:

```
docker login
```

Authenticate Docker with Any Cloud

Authenticating Docker with the Cloud of your choice is typically an easy operation, just find the equivalent command to configure docker with the needed credentials. The search query "authenticate docker with [your cloud provider] container registry" should do the trick!

TAG

By default, docker images are assigned a random hash-based name, like `82ca16cefe84`. Generally, it is a good idea to add your own tag that is somewhat meaningful so you can easily refer to your own images. In the previous chapter, we used these tags so we could run our images locally using nice names like `docker run hello_container` instead of docker run `82ca16cefe84`.

To upload containers into container registries, the tag takes on an additional purpose. You are required to tag the image with a name that follows a specific path convention dictated by the container registry in order for it to know which account and path to store the image in (and so that your local docker client knows which registry to upload it to).

GCR requires these tags to be in a particular format:

```
gcr.io/[PROJECT_ID]/[CONTAINER_NAME]:[VERSION_TAG]
```

Where `PROJECT_ID` is your Google Cloud Project ID, and `CONTAINER_NAME` is any name you wish to give your container (it does not need to be pre-registered). The version tag is an unstructured string used to refer to the version of the image, with one convention being to use an incrementing build number like v1, v2, etc. A special version tag `:latest` can be used to refer to the most recent image (but don't use this when tagging for upload). Putting that all together, if your project id is `deployingtok8s, and` your container is named `pluscode`, the image tag would be:

```
gcr.io/deployingtok8s/pluscode:v1
```

DockerHub uses the following convention:

```
docker.io/[USERNAME]/[REPOSITORY]:[ VERSION_TAG]
```

Where USERNAME is your docker username, and REPOSITORY is the name of the repository that needs to be created ahead of time on DockerHub. The version tag logic is the same for all container repositories. Putting it together for this book's example code, it is:

```
docker.io/wdenniss/pluscode-demo:v1
```

Container Registry Tag Conventions

Every private container registry has its own magic string concatenation that you need to do to create the right tag, and they're all different. For example `Azure` provides the following example[2]: `<acrLoginServer>/hello-world:v1`, and AWS documents[3] `<aws_account_id>.dkr.ecr.<region>.amazonaws.com/my-web-app`. One thing I'm sure about: make sure you follow the guidelines of whatever container registry you're using, otherwise Kubernetes won't know where to push the image. The search term I use is "[cloud provider] registry container tag name"

Once you've worked out the right image tag to use (which we'll refer to as IMAGE_TAG in the remaining examples), you can go and can tag any existing docker image for uploading. To upload one of the images we built in the earlier chapter to a container registry, you can reference the image from it's previous tag and add a container registry tag (images can have multiple tags). Our example in section 2.2 was built with docker build . -t railsapp, so has the tag railsapp already, which means we can re-tag it for the container registry like so:

```
docker tag railsapp IMAGE_TAG
```

In this way, we can take the image we were trying out locally and tag it for deployment to the cloud. It's also possible to tag an image based on the unique Image ID that docker assigns all images. You can view all images with `docker image ls` to find the image id, then add a tag with:

```
docker tag IMAGE_ID IMAGE_TAG
```

For example:

```
$ docker image ls
REPOSITORY          TAG                 IMAGE ID            CREATED
<none>              <none>              d78903e7fe24        13 hours ago
$ docker tag b373ab446718 gcr.io/deployingtok8s/pluscode:v1
```

You may find that if you don't tag the image when building, they become rather hard to distinguish later (since they all look the same). You can easily find the very last one you built (based on the creation time), but when you have multiple images from multiple projects it's not so easy. Therefore, it's good hygiene to always tag the images when you build them.

Since you can run the build again (and Docker has a decent caching mechanism which makes this pretty fast), it's often simpler to just build the image rather than spend the time looking for the previous one you built, and by rebuilding, you can be sure it's the current version.

To rebuild the app for deployment to the cloud, and going forward for an app you plan to deploy publicly, simply tag the image with the container registry tag at build time:

```
docker build . -t IMAGE_TAG
```

PUSH

Once authenticated and tagged, you can push the image simply with:

```
docker push IMAGE_TAG
```

[2] https://docs.microsoft.com/en-us/azure/container-registry/container-registry-get-started-azure-cli
[3] https://docs.aws.amazon.com/AmazonECR/latest/userguide/docker-push-ecr-image.html

The authentication step installed a helper into the docker configuration which enables Docker to speak with your cloud's container registry, whatever that may be.

With the image uploaded, you're now ready to deploy!

3.2.3 Deploying

With kubectl authenticated to a cluster, we can deploy our first application. Primarily, you interact with Kubernetes via YAML-formatted configuration files. To get started, we'll use a simple template as a starting point, and customize it from there. Such templates for various objects can be found in the official documentation for those objects on kubernetes.io, for example the documentation for Deployment (https://kubernetes.io/docs/concepts/workloads/controllers/deployment/).

Configuration Representations

Kubernetes also supports the JSON format for configuration (with the same key-value pairs as the YAML representation), and direct (or "imperative") commands. JSON is less human-friendly, so is typically used for automation and scripted interactions with Kubernetes rather than human-edited configuration, while imperative commands have a few drawbacks like the lack of reproducibility (discussed further in Section 3.3). This book focuses primarily on the YAML-formatted configuration files option.

Here's a minimal Deployment specification:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-deploy
spec:
  replicas: 3 #A
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: docker.io/wdenniss/pluscode-demo:latest #B
```

#A How many Pod replicas (instances) to deploy
#B Which container image to deploy and run

This deployment specifies that you will have 3 replicas (instances) of the container image `docker.io/wdenniss/pluscode-demo:latest`. Those are the two most important attributes, defining *what* we are deploying, and *how many* copies we want.

The container image path like is a URL that references where to find the container. If you uploaded your container following the previous section, you already have this image path from that step. The above example is using `docker.io` which is the DockerHub container registry, a popular place to host public container images such as base images, and examples for a book. When you

see image paths without the domain, like `ubuntu`, or `wdenniss/pluscode-demo:latest`, it's shorthand for images hosted on DockerHub.

But what about the rest of the lines? Isn't it a bit verbose just to define that fairly simple requirement of deploying 3 replicas of a given container image? Well… kinda. Kubernetes config isn't known for its terseness. Of the config I presented, the only optional field is actually the replica count (replicas: 3) which defaults to 1, the rest are required. So what the heck do these required fields do? There is method to the madness, and while you can ignore it for now, I believe it is important to understand what each does as you'll need this knowledge.

Let's cover the easy ones first, the names. The Deployment here is given a name (`name: pluscode-deploy`), and so is the container (`name: pluscode-container`). These names are used mostly for display purposes, for example when looking at a list of Deployments (`kubectl get deployment`), or a list of Pods (`kubectl get pods`). Pods can have multiple containers, so the container name is used in places when you need to reference a particular container (like when you want to stream container logs).

Now for the rest of the config. You might notice that there are two instances of "metadata" and "spec" which at first brush looks a bit duplicative: why does a "spec" need a child "spec"? The duplication is actually because there is a Pod object (technically, a Pod object template) embedded in the Deployment. Remember above how the Deployment consists of Pods. The Deployment here has fully encapsulated the Pod, rather than duplicating its fields, which is useful as you can look at the documentation for Pod, and literally any values defined for Pod can be used in the Deployment's Pod template. As we cover in later chapters, Deployment isn't the only construct for creating Pods in a managed way either, so this pattern holds throughout the system.

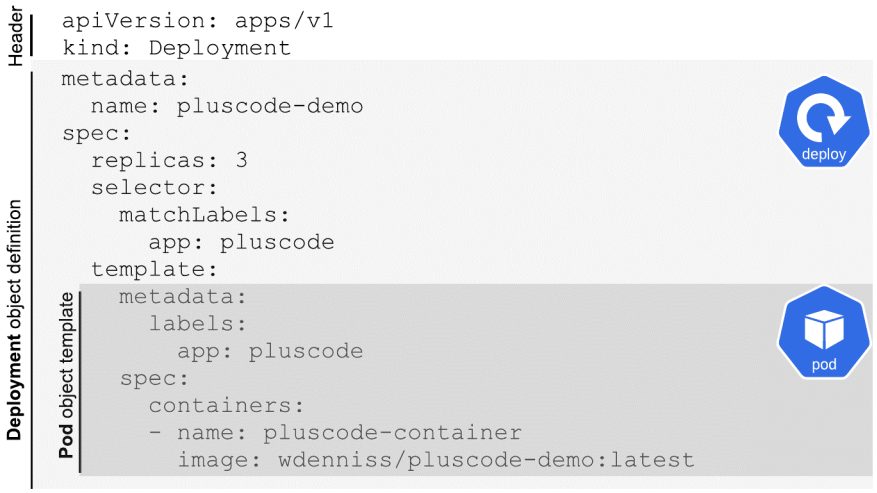


Figure 3.9: Pod object embedded in the Deployment object

In fact, you can extract the fields from the Pod template and place them in their own Pod manifest by adding the appropriate header, which would look like so:

```
apiVersion: v1
kind: Pod
metadata:
  name: pluscode-demo
  labels:
    app: pluscode
spec:
  containers:
    - name: pluscode-container
      image: wdenniss/pluscode-demo:latest
```

While you could go ahead and create that Pod directly, this is almost never done. Manually created Pods can't be scaled easily (as they represent single Pod instances), and Kubernetes isn't managing the lifecycle for you like rescheduling them if the hardware node is replaced. Basically the whole point of Kubernetes is to have high level constructs to take care of scaling and availability for you, so generally you'll define Pods as templates inside higher level Kubernetes constructs, like Deployments.

The final item to cover is the `selector` of the Deployment and the `labels` of the Pod template. Labels in Kubernetes are a way to annotate different attributes of an object with user defined semantics. In our example, we gave the Pod template the label app: `pluscode`, which was intended to be a unique name (labels can also be used by multiple Deployments, to represent other concepts like "these Pods are all front-end Pods"). *Selectors* are used to apply target groups of Pods, identifying them by their labels. In the case of the deployment, the deployment is selecting (targeting) its own Pods, to indicate that these are the Pods that it manages.

You might argue a Deployment doesn't need to select its own Pods since the Pod is defined as a child template, and you would be right! There are other objects that can interact with your Pods though, as you'll see later with Services, and in those cases the Pod template isn't embedded. So the reason for the Deployment to declare the selection of its own Pods is just for consistency with other objects in the system.

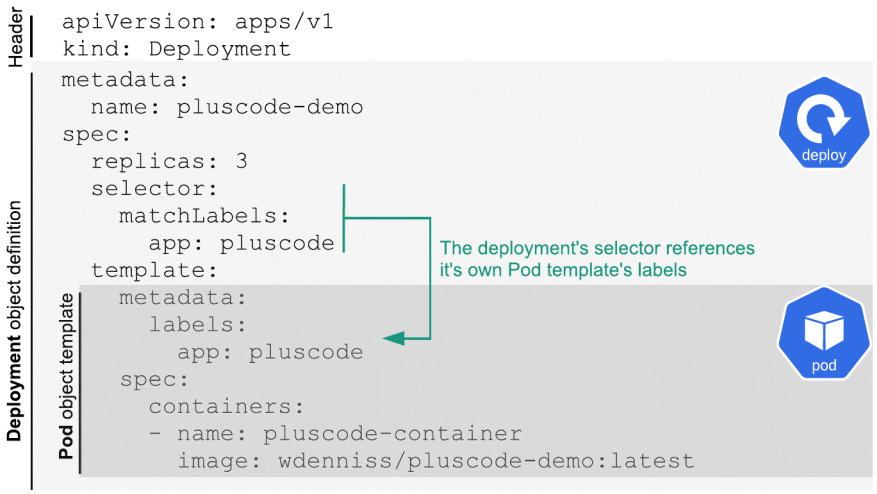


Figure 3.10: Relationship of the Deployment's selector, and the Pod template's labels

The Deployment's selector and the Pod template's labels must match (don't worry: Kubernetes will give you an error if they don't), and generally should be unique among all deployments. If the labels are not unique, any selector will get the Pods from multiple deployments, so be sure that's what you intend, if you don't make them unique. Kubernetes doesn't enforce uniqueness (since there is a valid use for it not being unique), so that's up to you.

Let's put this into action. Make a local copy of the above template, naming it `deploy.yaml` (the file name doesn't matter, but the steps below will assume that name). From the editor of your choice, for example VS Code[4], replace the value on the "image" line with your own container image (such as one built in 3.2.2 Uploading Your Container), or leave it for now and you can deploy my example container.

For the examples in this chapter, we assume the container is a web service that answers HTTP requests on port 80. If you don't have your own container to use, then you can instead use some examples I've built. For the sever application documented in Chapter 2, Section 2 you can try: `wdenniss/railsdemo`. Or, for a container that is a little more interesting: `wdenniss/pluscode-demo`.

To create the deployment object in Kubernetes, execute the following from the directory containing the configuration file you created earlier:

```
kubectl create -f deploy.yaml
```

This instructs Kubernetes to create the object defined by the configuration file. If you need to make changes once it's deployed, you can instead update the object with:

[4] https://code.visualstudio.com/

```
kubectl apply –f deploy.yaml
```

Note that `apply` is actually doing a 3-way merge, and applying the differences between the original and updated configuration. It will also create objects that do not exist at all.

To observe the state of the deployment, run:

```
kubectl get deploy
```

Example output:

```
NAME       READY     UP-TO-DATE   AVAILABLE   AGE
pluscode   3/3       3            3           17d
```

This shows the state of the deployment. As mentioned earlier, the deployment is the statement of the desired state of the system, for example, I want 3 copies of the pod. When you created the deployment and the system returned a success response, this simply meant that it accepted your deployment for scheduling – not that everything had already been scheduled in the manner you desired. Querying the deployment with `get` will show you the current status such as how many of the Pods are ready to serve traffic, and later when you update the deployment, how many of the pods are running the latest version during a roll out of a new version.

To see more detail about the Pods which form your deployment, you can also query the Pods themselves:

```
kubectl get pods
```

Example output:

```
NAME                        READY     STATUS    RESTARTS   AGE
pluscode-bf9f9fb49-svc5h   1/1       Running   0          1m
pluscode-bf9f9fb49-avd5d   1/1       Running   0          1m
pluscode-bf9f9fb49-bvc1c   1/1       Running   0          1m
```

This command actually returns the state of all pods in the active namespace, so once you have a lot of deployments, this might get a big jumbled. Instead, you can use a more verbose form where you pass the deployment's label (discussed earlier in this chapter) as a selector. Here's a complete example, using the label of our earlier example deployment

```
kubectl get pods  --selector="app: pluscode"
```

Your pods should, after a short time, display "Running". Once the pod is Running, you can view it's logs to inspect any debug messages the code is outputting using the kubectl log command. This command operates on a single Pod, so copy one of the names from your `kubectl get pods` command, and run:

```
kubectl logs [POD_NAME]
```

Where POD_NAME is the name of your pod from the `get` command. Example invocation:

```
kubectl logs pluscode-bf9f9fb49-svc5h
```

This log so far should show any debug output printed as your container boots up. It's a good idea to include a boot message in your own apps so that you can be assured the container really did start as expected.

TROUBLESHOOTING

If, after a short time, your Pods report as "Running" you're good to move on to the next step: exposing the service. If you're seeing something else when you run `kubectl get pods`, here are some common error statuses and resolutions:

Image Pull Error (ErrImagePull / ErrImagePullBackoff)

This error means that Kubernetes was unable to download the container image. This typically means that either the image name was misspelt in you configuration, the image doesn't exist in the image repository, or your cluster doesn't have the required credentials to access the repository.

Check the spelling of your image, and verify that the image is in the repository. Any fixes can be applied using `kubectl apply –f deploy.yaml`

Stuck in Pending

If you see a pod stuck in the "Pending" state for more than a minute or so, it typically means that the Kubernetes scheduler is unable to find space on your cluster to deploy the images to. Often this can be resolved by adding additional resources to your cluster, like an extra, or larger compute node.

You can see the details of the pending Pod by "describing" it, as follows:

```
kubectl get pods
kubectl describe pod [POD_NAME]
```

Where [POD_NAME] is one of the pods in the Pending state. The "Events" section contains a list of any errors that Kubernetes has encountered. If you attempted to schedule a deployment and there were no resources available, you'll see a warning like "FailedScheduling". Here's the complete events section for a Pod that I attempted to schedule, but where there were not enough resources:

```
Events:
  Type     Reason            Age                From               Message
  ----     ------            ----               ----               -------
  Warning  FailedScheduling  26s (x2 over 26s)  default-scheduler  0/2 nodes are available: 2
       Insufficient cpu.
```

As long as at least 1 of your Pods is not pending, you don't need to worry for now, as your service should still run as long as there exists one Pod to answer requests, but if they are all pending, you'll need to take action – likely by adding more compute resources.

Crashing (CrashLoopBackOff)

Another common error is a crashing container. There can be various reasons for a crashing container, including that the container failed to start (possibly due to a configuration error, for example), or one that crashes soon after starting.

For the purposes of Kubernetes deployments, a "crash" is any process that terminates, even one that terminates with a success exit code. Deployments are designed for long-running processes, not once-off tasks (Kubernetes does have a way to represent a Pod that should be scheduled to run as a once-off task, and that is the Job type, covered in a later chapter).

The occasional crash of a container in a Deployment-managed Pod like the ones we are deploying here is handled gracefully, by restarting it. In fact, when you run kubectl get pods, you can see how many times a container has been restarted. You can have a container that crashes every hour, and as far as Kubernetes is concerned that's totally fine, it will keep restarting it and it will go on its merry way.

A container that either instantly crashes at boot, or quickly after however is put into an exponential back off loop, where rather than continuing to restart it instantly (consuming the resources of the system), there is a delay between restart attempts that increases exponentially (i.e. 10s, then 20s, 40s, etc).

When a container crashes the first time it will have a status like `RunContainerError` (for a container that errored at start), or `Completed` for one that exited. Once the crash has been repeated a couple of times, the status will move to CrashLoopBackOff.

The chances are, any container in the CrashLoopBackOff state has a fatal issue that needs you're attention. If there was some peculiar external dependency issue that once resolved would allow the container not to crash, then in that case the container might be able to start – but 99% of the time, it's a coding or configuration error that you need to look into.

To debug crashed containers, I'd always start with `kubectl describe pod [POD_NAME]` like the earlier issues to view the events for clues there. The container's logs are another good place to check. As described earlier, you can retrieve these with `kubectl logs [POD_NAME]`. When dealing with crashing containers you may wish to view the logs from the *prior* instantiation of the container (before it was restarted after crashing), so as to see any error printed when it crashed, as this often will indicate the cause. To do that, add `--previous` (or just `-p`), to your log request.

```
kubectl logs [POD_NAME] -p
```

Running one-off commands

Just as we can run one-off commands on the docker image using the `docker exec` command (covered in Chapter 2), we can also run one-off commands on our Pods with `kubectl exec`. A common command to run to diagnose issues in the container is `sh` which will give you an interactive shell on the container (provided that `sh` is available in the container), and from there you can perform whatever other debugging steps you need to do inside the container.

```
kubectl exec -it $POD_NAME sh
```

You can run any command on the container in this way, for example

```
kubectl exec -it $POD_NAME echo "Hello World"
```

In the case of a Rails app, you can use `exec` to get a ruby shell directly, without going through sh.

```
kubectl exec -it $POD_NAME bundle exec rails c
```

Copying files to/from the container

Again, similar to docker, kubectl has a `cp` command allowing you to copy files between your system and the container. This command requires that the `tar` binary be present in your container image. This can be useful when you want to download your application logs or other diagnostic information.

```
kubectl cp $POD_NAME:/path/to/file .
```

You can also copy files in the other direction

```
kubectl cp $FILE $POD_NAME:/path/
```

3.2.4 Publishing your Service

With your container successfully deployed, no doubt you'll want to interact with it!

While Pods can be accessed from inside the cluster via a cluster-local (internal) IP address, and there exist some tricks to expose pods on public IPs, the point of having a Kubernetes deployment manage your Pods is to avoid dealing with Pods individually. A Pod could fail and be replaced by one with a new IP. And you'll likely have more than 1 Pod in a deployment to handle the expected load, if you addressed Pods individually you'd need to keep track of the list and know which ones are under load.

That's where the Service comes in to play. The Service aggregates the pods in your deployment and represents them behind a single IP address. The service will keep track of which Pods are available to receive traffic, and load balance traffic between them. Services have a cluster-local IP, but can also be exposed publicly with an external load balancer, and optionally on a port on every node to simplify discovery. We'll be focusing on the external load balancer initially, so we can try out our application on the browser and later get our deployment in the hands of end-users (using Services internally such as with a microservice architecture is covered in Chapter 6).

As with the deployment we'll start with a skeleton YAML configuration:

```
apiVersion: v1
kind: Service
metadata:
  name: pluscode-service
spec:
  selector:
    app: pluscode
  ports:
  - port: 80
    targetPort: 80
    protocol: TCP
  type: LoadBalancer
```

Notice the same "selector" pattern as before. The Service isn't directly connected with the Deployment, rather it's connected with the set of Pods that all have that label (which in this case, were created by the deployment). Unlike the deployment object, the selector is defined without using `matchLabels`. They're both selectors, Deployment happens to use a newer, more expressive syntax which requires you to specify which matching rule to use (`matchLabels` has the same behavior as the selector used here, to match Pods with that label).

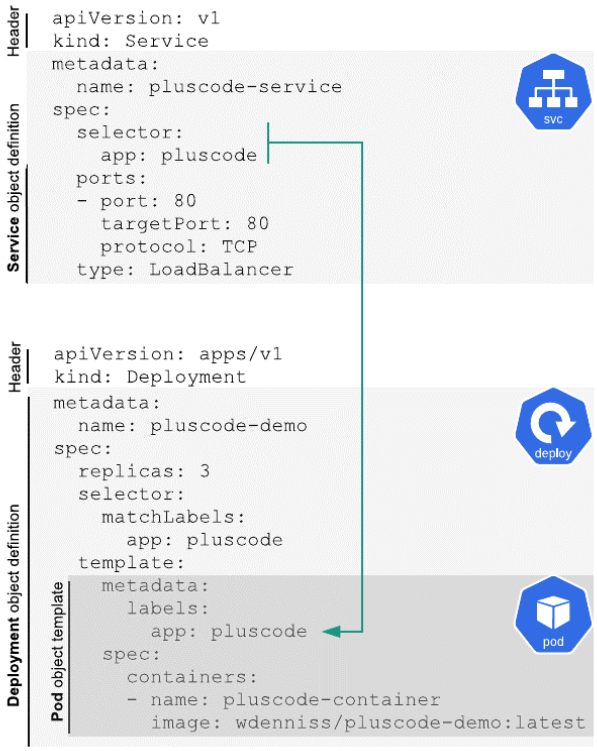


Figure 3.11 Relationship between the Service and the Pods it targets (selects)

So that's the selector, what about the rest?

```
apiVersion: v1
kind: Service
metadata:
  name: pluscode-service
spec:
  selector:
    app: pluscode
  ports:
  - port: 80 #A
    targetPort: 80 #B
    protocol: TCP #C
  type: LoadBalancer #D
```

#A The port the service will be exposed on
#B The container's port that traffic will be forwarded to
#C The network protocol
#D Type of Service, in this case an external load balancer

The port list allows you configure which port to expose for users of the service (`port`), and what port of the Pod that this traffic will be sent to (`targetPort`). This allows you to say expose a service on port 80 (the default HTTP port), and connect it to an application in a container running on port 8080.

Each Pod, and Service in Kubernetes have their own internal cluster IP, so you don't need to worry about port conflicts (except for multiple containers in a single Pod). This means that you can run your application on whatever port you like (such as port 80 for a HTTP service), and use the same number for `port`, and `targetPort` for simplicity, as with the example above. If you do this you can omit `targetPort` completely as the default is to use the `port` value.

Finally the type indicates whether this service will be exposed publicly as in the case of `LoadBalancer`, or be an internal only Service of which there are few options (discussed in Chapter 6).

Once you have updated this config with your own details, save it as `service.yaml`. Then you can create the Service object on your cluster with:

```
kubectl create –f service.yaml
```

Notice how the creation command (`kubectl create`) is the same for the Deployment as the Service. All Kubernetes objects can be created, read, updated, and deleted (so-called CRUD operations) with 4 kubectl commands: `kubectl create`, `kubectl get`, `kubectl apply` and `kubectl delete`.

To see the status of your Service, as before, run a kubectl get. This time, on the service object type:

```
kubectl get service
```

Example invocation:

```
kubectl get service
NAME               TYPE           CLUSTER-IP    EXTERNAL-IP    PORT(S)        AGE
kubernetes         ClusterIP      10.64.0.1     <none>         443/TCP        17d
pluscode-service   LoadBalancer   10.64.13.46   203.0.113.82   80:31943/TCP   17d
```

Notice that your service is there (in this example, `pluscode-service`), as well as another service named `kubernetes`. You can ignore the `kubernetes` service if one is shown, as that's that Kubernetes API service itself running in your cluster.

If the External IP in the output indicates "Pending" for the external IP, this just means it's waiting for the Load Balancer to come on line. Note that this is a different type of "Pending" than the pending scheduling state for Pods in a Deployment. Unlike for Pods, seeing a LoadBalancer with an External IP in the Pending state for a number of minutes is not cause for concern. Rather than repeating the `get service` command repeatedly, add `--watch` (`-w`), i.e. `kubectl get service -w` to watch the status, and have updates (like the provisioning of the Load Balancer's external IP) streamed to your console.

To have an external IP provisioned, you must be running Kubernetes on a cloud provider, as the provider is provisioning a network load balancer behind the scenes. If you're developing locally, see the next section for tips on accessing the service.

Once the IP comes online, try accessing the service by visiting the URL, in this example our external IP was http://203.0.113.82 (but replace with your own external IP from `kubectl get service!`). Curl is great for testing HTTP requests from the command line (`curl http://203.0.113.82`), viewing it in a browser works just as well tool.

TROUBLESHOOTING

Unable to connect

Two common reasons for this: 1) the selector is incorrect, or 2) your ports are wrong. Triple check that the selector matches the labels in your deployment's Pod template. Verify that the target port is indeed the port your container is listening on (a boot-time debug message in the container printing the port can be a good idea to help verify this), and that you're connecting to the right port from your browser.

See if you can connect to one of your Pod directly on the `targetPort` using kubectl's port forwarding capability. If you can't connect to the Pod directly, then the issue is likely with the Pod, and if it does work then the issue could be an incorrect Service definition. You can set up a port forward to one of the Pods in the deployment like so:

```
kubectl port-forward deploy/[DEPLOYMENT_NAME] [FROM_PORT]:[TO_PORT]
```

Where `FROM_PORT` is the port you'll use locally, and `TO_PORT` is the `targetPort` that you defined in your service. Using our example earlier, this would be:

```
kubectl port-forward deploy/pluscode-demo 8080:80
```

Then browse to http://localhost:8080. This will select one of the Pods in the deployment automatically (bypassing the Service). You can also specify a specific pod to connect to directly with:

```
kubectl port-forward pod/[POD_NAME] [FROM_PORT]:[TO_PORT]
```

External IP stuck in pending

It can take a little while to get an external IP, so give it a few minutes. Verify that your cloud provider will provision external IPs for Services of type `LoadBalanacer`. Check the provider's documentation for any additional information around setting up load balancers in Kubernetes.

If you're running locally, check out section 3.4 below.

3.2.5 Updating your Application

Now that your application has been deployed published to the world, no doubt you'll want to be able to update it!

Make a code change to the sample app, then build and push the container image to the container repository, with a new version tag. For example, if you used `gcr.io/deployingtok8s/pluscode:v1` before, your new image could be `gcr.io/deployingtok8s/pluscode:v2`. You can make this label anything you like, but it's a good convention to use `v1`, `v2`, etc for manually labeled images.

Once the container image is in the repository (as covered in 3.2.2), update your `deploy.yaml` file with the new image name.

For example (emphasis added):

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-demo
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: foo
        image: gcr.io/deployingtok8s/pluscode:v2 #A
```

#A New image version

Save the file, and apply it with:

```
kubectl apply –f deploy.yaml
```

When you apply this change, an interesting thing happens. Remember how Kubernetes seeks constantly to actuate your specifications, driving the state it observes in the system to the state you required, and this is why it replaces failed pods? Well since you just declared that the deployment is now using the image with label :v2, and all the Pods are :v1, Kubernetes will seek to update the live state so that all Pods are :v2.

We can see this in action by running `kubectl get deploy`. Here's some example output:

```
NAME            READY   UP-TO-DATE   AVAILABLE   AGE
pluscode-demo   3/3     2            3           13s
```

The "READY" column shows how many pods of the are serving traffic, and how many we requested. In this case, we have all 3 that are ready. The "UP-TO-DATE" column however indicates that only 2 of these Pods are the current version. This is because, rather than replacing all the pods at once, something that would cause some downtime to the application, by default pods are updated with a so-called rolling update strategy, that is, one or several at a time.

Rolling update and other rollout strategies are covered in detail in the next chapter, as well as important health checks that need to be configured to avoid glitches during the rollout. For now it's enough to know that Kubernetes will actuate your changes and will replace the old v1 pods, with the new v2 ones.

Once the "UP-TO-DATE" count is equal to the ready count, the rollout is complete. You can also observe the individual pods being created and replaced with `kubectl get pods`, which will show a list of all Pods in the deployment, both new and old.

MONITORING THE ROLLOUT

Since the output of the `kubectl get` commands display the moment-in-time information, but the deployment is continuously changing, most operators will monitor the deployment in an automated way, avoiding the need to constantly re-run the same command

Kubernetes includes one such option, the --watch (-w) flag, which can be added to most kubectl commands. For example, `kubectl get pods -w`, and `kubectl get deploy -w`. The watch flag will print any changed lines to the console.

The disadvantage of the watch flag is that it kind of jumbles the output. If you have many pods changing, you'll see line after line printed and it's easy to lose sight of the current state of the system. My preference is to use the linux watch command instead. Unlike the watch flag, the watch command refreshes the entire output, optionally showing you what changed between the current and the last update. This command is available in most linux distros, macOS, and the Windows Subsystem for Linux (WSL), and can be found wherever you get your packages.

When watch is installed, you can simply prepend it to any kubectl command, e.g.:

```
watch kubectl get deploy
```

My favorite watch flag is -d, which will highlight any changes, i.e.:

```
watch -d kubectl get deploy
```

With a terminal window (or tmux session window) opened for watching each command you can put together a real time status dashboard with just kubectl.

WATCHING THE DEPLOYMENT

The `get deploy` and `get pods` commands above return all deployments and pods respectively in the current cluster namespace (the namespace is a way to partition the cluster between different deployments, which we cover in Ch. X – for now, you'll just be using a single namespace anyway so these are effectively returning all deployments in the cluster).

As you make more deployments, you may want to specify just the deployment you're interested in with:

```
kubectl get deploy [name]
```

Where [name] is the name of your deployment, specified in the metadata: name: field in the YAML configuration (in the above example, this was "pluscode"). kubectl commands that return a list of objects can be used in this fashion to return only the objects specified.

Viewing all pods from a single deployment is a little more tricky, however you can use the label selector, just as the deployment does, like so:

```
kubectl get pods --selector app=pluscode
```

Where app=pluscode was the label selector specified in the deployment.

3.2.6 Cleaning Up

To clean up the object's we've created, simply use the delete command on the configuration.

```
kubectl delete –f deploy.yaml service.yaml
```

If you regret, you can simply create them again: `kubectl create -f deploy.yaml service.yaml`. That's the beauty of capturing your configuration in files, you don't need to remember any tweaks you made to the live state, because everything is updated first in the configuration.

3.3 Declarative or Imperative Style

Kubernetes offers two approaches for interacting with the system; declaratively where you specify (declare) in configuration files the state that you want, and apply those configurations to the cluster, and imperatively where you instruct the API one command (imperative) at a time to perform your wishes. The configuration driven declarative model is the approach that is strongly preferred by most practitioners (including myself), and what you'll most often encounter in a workplace.

In fact, it would have been possible to perform the actions in the previous section with the following 3 commands:

Create a deployment named "pluscide" with the image "wdenniss/pluscode-demo":

```
kubectl create deployment pluscode --image=wdenniss/pluscode-demo
```

Create a load balancer on port 80 targeting that deployment:

```
kubectl expose deployment pluscode --type=LoadBalancer --name=pluscode-service --port 80
```

Update the image of the container named "pluscode-demo" in the deployment "pluscode" to a new version:

```
kubectl set image deployment pluscode pluscode-demo=wdenniss/pluscode-demo:v1
```

That looks a lot simpler at first brush, when compared to controlling Kubernetes using configuration files that are frankly a little verbose at times. However, there are good reasons to prefer the configuration-based approach. The first is reproducibility. Let's say you need to reproduce the configuration on another environment like production and staging, a pretty common case, with the declarative approach you can just apply the same exact config in the new environment (with any needed tweaks). Whereas if you went the imperative route, you would need to remember the commands, perhaps storing them in a batch file.

It's also harder to make changes. With configuration files, if you need to change a setting you can just update the configuration and re-apply it, after which Kubernetes will dutifully carry out your wishes. With a command based approach, each change is itself a different command; `kubectl set image` to change the image, `kubectl scale` to change the number of replicas and so on. You also run the risk that the command could fail like due to a network timeout, whereas with configuration the changes will be picked up the next time you apply.

In a future chapter, we'll discuss taking configuration files and treating them just as you do the source code for your application, so-called configuration as code where imperative commands would not be an option at all.

If you encounter a system previously built with imperative commands (or you ignore this advice and use them anyway), fear not, configuration can be exported from the cluster with the `kubectl`

`get -o yaml [RESOURCE_NAME]` command when you're ready to adopt the configuration as code best practice for your project, so it's never too late to switch.

3.4 Local Kubernetes Environments

This chapter so far has used a cloud-based Kubernetes provider as the deployment environment. You can of course run Kubernetes locally as well. I made the choice to lead with a public cloud provider instead of a local development cluster to demonstrate deploying on Kubernetes, as I assume for most the goal is to publish your service and make it accessible beyond your own machine. Indeed, if you're following the examples in this chapter in order, then congratulations you can now deploy your apps to the world using Kubernetes! In future chapters you'll learn how to operationalize them, scale it up and more.

Local Kubernetes development clusters however definitely have their place. They are useful during development when you want to rapidly deploy and iterate on code while running in a Kubernetes cluster, particularly when your application consists of several different services. They're a great place to try out and learn Kubernetes constructs without paying for a cloud service and are a convenient option for testing your deployment configuration locally.

There a lot of differences using Kubernetes locally on a machine in a non-production grade environment with a fixed set of resources, and a production-grade cloud service with dynamic provisioning. In the cloud you can scale up massively using multiple machines spread over a geographical region, while your local machine has a fixed set of resources. In the cloud you can get a production-grade routable public IP for your service, not so much on your local machine. Due to these differences and many more, I believe learning directly in your target product environment is more efficient, hence the focus in this book on production-grade clusters. That being said, as long as you understand the differences then a local development cluster can be a useful tool indeed.

Do you need a Kubernetes cluster for application development?

There's no requirement to use Kubernetes during application development just because you use it for production deployment. A fairly common app development pattern I've observed is using Docker Compose (covered in Section 2.3) for local development and testing, with the resulting application deployed to Kubernetes for production.

Docker Compose works pretty well for development of apps with only a handful of inter-service dependencies. The downside is you need to define the application config twice (once for development with Compose, once for production in Kubernetes), but this overhead is minor for apps with only a few service dependencies. The upside is that Docker has some useful tools for development, in particular, being able to mount local folders into the container which means for interpreted languages like Python and Ruby you can change code without a container rebuild. It's also simple to configure since you can skip all the production-related config like replica count, and resource requirements (Chapter 4).

Its hard to understate the usefulness of Compose being able to mount your local app folder as a rear/write volume. Edit code without a container rebuild, get output from commands you run in the container like log files and perform database upgrades right in your development folder. Kubernetes does have some tools like to level the playing field here, like Skaffold which gets you a tight development loop with Kubernetes (local or cloud) as the target, but Docker has a sterling reputation among developers for a reason.

I always say, use the best tool for the job. Decide whether a local Kubernetes cluster, or a Docker Compose setup works best for application development and use what works for you. Even if you choose to use Compose for application development, you may still utilize a local Kubernetes cluster for deployment testing.

There are a bunch of options for running a local Kubernetes cluster. The two most popular are *Docker Desktop*, and *Minikube*. In fact, if you have *Docker Desktop* installed, then you already have a local single-node Kubernetes cluster! *Minikube*, created by the Kubernetes project is also trivial to setup, and offers a few more advanced options like multiple nodes, useful when you want to test more advanced Kubernetes constructs like pod spread policies and affinity (Chapter 5).

3.4.1 Docker Desktop's Kubernetes Cluster

Docker Desktop comes with its own single-node Kubernetes development environment. If you have Docker Desktop installed, then you already have a local Kubernetes environment. Follow the instructions at https://docs.docker.com/desktop/kubernetes/ to get going in two simple steps:

1. Enable Kubernetes in Docker Desktop options, and ensure it's running
2. Using `kubectl`, switch contexts to the Docker Desktop cluster

DIFFERENT FLAVORS OF DOCKER Be aware that Docker's local Kubernetes option is only for the newer "Docker Desktop" distribution for Mac and Windows. If you are using the legacy "Docker Toolbox" or another distribution of Docker such as those on Linux, it will not have this functionality. For Linux, your best bet will be MiniKube

Once Docker Desktop is running with Kubernetes enabled, you can view the context and switch to it like so:

```
kubectl config get-contexts
kubectl config use-context docker-desktop
```

In fact, these commands are what you use to switch to any cluster that you connected like we did with GKE in section X. Any time you wish to switch clusters, simply run:

```
kubectl config get-contexts
kubectl config use-context CONTEXT
```

I find those two commands a bit tedious to type when switching between clusters a lot, so I highly recommend the `kubectx` tool (https://github.com/ahmetb/kubectx) which makes it a lot quicker. To switch contexts with kubectx:

```
kubectx
kubectx CONTEXT
```

3.4.2 Minikube

Minikube is another great choice for testing locally, and is maintained by the open source Kubernetes community. Follow the instructions at https://minikube.sigs.k8s.io/docs/start/ to install Minikube for your system.

Once Minikube, you can boot it like so:

```
minikube start
```

To boot a virtual multi-node cluster (which I recommend, as it more closely resembles a production Kubernetes environment), pass the number of nodes you desire like so:

```
minikube start --nodes 3
```

The start command will automatically configure `kubectl` to use the Minikube context, meaning any kubectl commands will operate on the minikube cluster. To change the context back to a different cluster, like your production cluster, use the `kubectl config` or `kubectx` commands described in the previous section.

Once minikube is running, you can go ahead and use it like a regular Kubernetes cluster following the instructions in this chapter. Before you start using it, to verify that things are running as expected, run `kubectl get nodes` to check that you can connect to the cluster.

If you're done using Minikube and want to get your machine's CPU and memory resources back, run:

```
minikube delete
```

3.4.3 Using your Local Kubernetes Cluster

With `kubectl` setup to point to your preferred local Kubernetes cluster, you can deploy your application locally using the same `kubectl` commands shown earlier in this chapter. Two important differences however will be in how you expose and access services, and how you reference container images built locally.

To deploy the example in section 3.2.3, the same command is used:

```
kubectl create –f deploy.yaml
```

Benefit of declarative configuration

Throughout this book, the examples are giving using declarative configuration rather than imperative commands. In other words, to create a deployment, we first create the configuration of the deployment, then apply it, as opposed to using kubectl to create the deployment directly.

One of the many benefits of this approach is it means you can test out your configuration locally, then deploy it confidently to production later, without needing to remember a bunch of one-off commands. Notice how we can deploy the same configuration files against the local cluster, as we did against the production cluster. Neat!

ACCESSING THE SERVICE

Unlike when developing on a cloud Kubernetes provider, when creating a `LoadBalancer` service locally, such as in section 3.2.4, you won't get an external IP.

For Docker Desktop, Minikube, and in fact any Kubernetes cluster, you can also use `kubectl` to forward ports from your local machine to the Service inside the cluster. This is useful for testing against a local Kubernetes cluster, and also debugging your cloud cluster. The following command exposes the Service locally:

```
kubectl port-forward service/[SERVICE_NAME] FROM_PORT:TO_PORT
```

Where `FROM_PORT` is the port you'll access the service on locally, and `TO_PORT` is the IP of the Service. For our demo, choosing `8080` as a high level port, the command can look like:

```
kubectl port-forward service/pluscode-service 8080:80
```

You can then browse to http://localhost:8080 to connect to the service. See the docs[5] for a range of useful options for `port-forward`, including `--address 0.0.0.0` to bind to all network interfaces so you can access the forwarded service from all interfaces. As discussed in the troubleshooting section of 3.2.4, this is also a very useful debugging command.

Minikube offers an additional way[6] to route traffic to your Service. They can be accessed with:

```
service [SERVICE_NAME]
```

For the sample in the earlier section, that would be:

```
minikube service pluscode-service
```

[5] https://kubernetes.io/docs/reference/generated/kubectl/kubectl-commands#port-forward
[6] https://kubernetes.io/docs/setup/learning-environment/minikube/#services

Accessing Kubernetes Services locally from Docker

Are you running a Service in Kubernetes that you want to access directly from a Docker container running outside of a Kubernetes for some reason? Maybe you're too lazy to deploy that container itself into Kubernetes and/or you're doing some rapid iterating on it—I won't judge.

The solution is easy. Forward the service so that the port is open on your local machine as described above. You can then reference it in containers running directly in Docker using the host `host.docker.internal` on whatever port you forwarded. `host.docker.internal` is how containers can talk to services on the local machine, and since you forwarded the port to your local machine the connection can go through.

For example, if you deploy Redis in Kubernetes (see Chapter 9), and forward the ports like so `kubectl port-forward service/pluscode-service 6379:6379`, and then want to connect to it from a local container in Docker running python, using the redis-py library, you can do that like so: `redis.Redis(host='host.docker.internal', port='6379')`

Happy coding!

DEPLOYING LOCAL IMAGES

By default, a local Kubernetes cluster will attempt to pull container images from the internet—behaving just like a production Kubernetes cluster. For public images like `ubuntu` or my sample image `docker.io/wdenniss/pluscode-demo`, everything will just work. But for your own images built locally, you'll need to supply them to the local cluster. Of course you could upload them to a public container registry as you would for production, you're your local cluster will pull them like in production.

Uploading every image you build during development however is a bit of a hassle. It slows down your development as you wait for the push and pull, and unless you're using public images, you'll need to provision credentials so your local cluster can access them (a step that is typically done for you when you're pulling private images from the container registry of your Kubernetes provider).

To get your local cluster to use a local image, you need to make two changes to your Kubernetes deployment configuration. Firstly, add a `imagePullPolicy` parameter, set to `Never`, and secondly refer to your image using its local image name without any repository prefix.

The path for locally built images is simply their repository and tag, with no repository URL prefix. If you've built an image with `docker build . -t server_app` as we did in Chapter 2 (which tags it with `latest` by default), you would reference this in your Pod spec as `image: server_app:latest` in your config file. Run `docker images` to view a list of available local images. Here's an example of a deployment referencing this locally built image:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-demo
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: server_app:latest #A
        imagePullPolicy: Never #B
```

Images consist of a "repository" (in this case "pluscode-demo"), and a tag (typically the tag is the version). Both docker and Kubernetes default the version to `latest` if you don't specify it. You can also specify the version when building, like `docker build . -t pluscode-demo:v1` and reference it in the Kubernetes configuration as `image: pluscode-demo:v1`.

LOCAL IMAGES ONLY

Only apply the `imagePullPolicy: Never` configuration to images you plan to provide locally. You don't want to set this on remote images, as they won't be pulled and will error with a `ErrImageNeverPull` status. If you see that error, it means the image isn't available locally yet the deployment was configured to use a local image.

There is one more step if you're using Minikube. While Docker Desktop has access to all the images you built locally with docker, Minikube does not (it has its own independent container runtime, and doesn't share images with your local install of docker). To push local images you want to use into minikube. Simply run the following command:

```
minikube image load REPOSITORY:TAG
```

For example, to push the image we built in Chapter 2:

```
minikube image load server_app:latest
```

Now that your configuration is setup to use local image Simply apply the config in your new context:

```
kubectl apply –f deploy.yaml service.yaml
```

When all the configuration related to the deployment is in its own folder, you can apply the entire folder with:

```
kubectl apply -f *
```

3.5 Summary

Kubernetes is a workload-level, rather than infrastructure-level abstraction. It exposes several object types that enable you to define your deployments in workload terms, like Pods (groups of containers that are scheduled together), Nodes (the computers that actually run the Pod's containers), Deployments (which handle the lifecycle of application Pods), and Services (defining how the deployment can be accessed, e.g. via a public IP).

- Before deploying an application, the container image needs to be uploaded to a container registry
- Container registries have their own registry-specific tags that must be followed for this to work.
- Deployments are created using a configuration file (typically YAML) which specifies
- Configuration is submitted to the cluster using the `kubectl` CLI tool
- Kubernetes does the heavy lifting of booting and running the containers as described.
- Updating the application is as simple as modifying the configuration to point to the new image version, and resubmitting to Kubernetes
- Kubernetes will compare changes across configuration versions and actuate any changes specified.

In the next chapter we build reliability into our deployments through health checks, and discuss zero-downtime update strategies.

4

Automated Operations

This chapter covers

- Creating long-lasting reliable deployments
- Have Kubernetes keep your applications running without your intervention
- Updating applications without downtime

Kubernetes can automate many operations like restarting your code on application failure, or migrating your application in the case of hardware failure, all which work to make your deployment more reliable without you needing to monitor it 24/7. These automated operations are one of the key value propositions of Kubernetes, and an essential step to taking full advantage of everything it has to offer.

Kubernetes can also help you update your application without outages and glitches by booting the new version of the application and monitoring its status to ensure it's ready to serve traffic, before removing the old version.

To help Kubernetes help keep your application running without downtime during normal operations and upgrades, you need to provide certain information about the state of your application with a process known as Health Checks. In the next section we'll go through adding the various health checks to your application, and in the later section, how these can be used with Kubernetes' in-built roll out strategies to update your application without glitches or downtime.

4.1 Automated Uptime with Health Checks

There are some conditions that Kubernetes can detect and repair on its own, such as a crashed container. If your application crashes, this condition can be detected and repaired automatically by Kubernetes. Likewise, if the machine running your code were to fail, Kubernetes can detect that and migrate your application another machine.

But what about other types of application failure like a hung process, a web service that stops accepting connections, or an application that depends on an external service when that service

becomes inaccessible? Kubernetes can gracefully detect and attempt to recover from all these conditions, but it needs you to provide signals to the health of your code and whether or not it is ready to receive traffic. The process used to provide these signals are named health checks, which Kubernetes performs through probes.

Since Kubernetes can't know what it means for each and every service that runs on the platform to be down or up, ready or unready to receive traffic – apps must themselves implement this test. Simply put, the probe queries the container for its status, the container checks its own internal state, and returns a success code if everything is good. If the request times out (e.g. if the container is under stress), or the container determines that there's a problem, the probe is considered a fail.

4.1.1 Liveness and Readiness Probes

In Kubernetes, the health of a container is determined by two separate probes: *liveness* that determines if the container is running, and *readiness* which indicates when the container is able to receive traffic. Both probes use the same techniques to perform the checks, but how Kubernetes uses the result of the probe is different.

	Liveness	Readiness
Semantic meaning	Is the container running?	Is the container ready to receive traffic?
Implication of probe failures exceeding threshold	Pod is terminated and replaced.	Pod is removed from receiving traffic until the probe passes.
Time to recovery	Slow; Pod is rescheduled on failure and needs time to boot.	Fast; Pod is already running and can immediately receive traffic again.
Default state at container boot	Passing (Live).	Failing (Unready).

There are a few reasons for having the two probe types. One is the state at boot. Note how the Liveness probe starting state is that the Pod is live (container is assumed to be live, until the pod proves otherwise), whereas the Readiness probe starts in the unready state (container is assumed to not be able to serve traffic until it proves it can).

Without a readiness check, Kubernetes has no way to know when the container is ready to receive traffic, so it has to assume it's ready the moment the container starts up, and it will be added to the Service's load balancing rotation immediately. Most containers take tens of seconds, or even minutes to start up – so sending traffic right away would result in partial traffic loss during startup. The readiness check solves this by only reporting "Ready" when the internal tests are passing.

Likewise, with a Liveness check, the conditions that require a container restart may be different to those which indicate the container is not ready to receive traffic. The best example is a container that is waiting for an external dependency, like a database connection. Until the container has the database connection, it should not be serving traffic (therefore is "Unready"), but internally the container is good to go. You don't want to replace this container too hastily so that it has enough time to establish the database connection which it needs.

Another reason for having two types of probes is the sensitivity and recovery times. Readiness checks are typically tuned to quickly remove the Pod from the load balancer (as this is a fast, and

cheap operation to initiate, and also reverse if it comes back up), whereas Liveness checks are often tuned to be a little less hasty as the time needed to re-create a container is longer.

4.1.2 Adding a Readiness Probe

For a web service, a rudimentary health check could simple be "is the service serving traffic?" Before building a dedicated health check endpoint for your service, you could just find any endpoint on the service that returns a HTTP 200 status code, and use it as the health check.

If the root path returns HTTP 200 on all responses, you can even just use that. As it happens, the examples in the book do that, so the following readiness probe will work just fine.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        readinessProbe:
          initialDelaySeconds: 15 #A
          periodSeconds: 30 #B
          httpGet: #C
            path: / #C
            port: 80 #C
            scheme: HTTP #C
          timeoutSeconds: 2 #D
          failureThreshold: 1 #E
          successThreshold: 1 #F
```

#A After an initial delay
#B Every 30 seconds
#C Perform this HTTP request
#D Timing out after 2 seconds
#E And consider 1 error response to indicate the container is not ready
#F And consider 1 successful response to indicate the container is ready after being considered unready

Apply the changes with:

```
kubectl apply -f deploy.yaml
```

Now, any time the container fails to respond to the readiness check, that Pod will be temporarily removed from the service. Say you have 3 replicas of a Pod, and one of them fails to respond, then any traffic to the service (which could be a service exposed externally, or a private one available only to other Pods in the cluster), will be routed to the remaining 2 healthy Pods. Once the Pod returns success (a HTTP 200 response in this case), it will be added back into service.

This is particularly important during updates, as you don't want Pods to be receiving traffic while they are booting (as these requests will fail). With correctly implemented readiness checks, you can get zero-downtime updates, as traffic is only routed to those Pods which are ready, and not ones in the process of being created.

Observing the Difference

If you want to see the difference between having a readiness check and not with your own experimentation, try the following test.

In one shell window, create a deployment without a readiness check (let's use the one from Chapter 3).

```
cd 03/3_2_3
kubectl create -f .
```

Wait for the service to be assigned an External IP:

```
kubectl get svc -w
```

Now setup a watch on the service endpoint in a separate console window:

```
watch -n 0.25 -d curl "http://[YOUR_IP]"
```

Back in the first window, trigger a rollout:

```
kubectl rollout restart -f deploy.yaml
```

As the pods restart, you should see some intermittent connection issues in the curl window

Now update the deployment with a readiness check (like the one in this section), and apply:

```
cd ../../04/4_1_2
kubectl apply -f deploy.yaml
```

This time, since the deployment has a readiness check, you shouldn't see any connection issues on the curl window.

4.1.3 Adding a Liveness Probe

Liveness probes have the same specification as readiness, but under the key `livenessProbe`. How the probes are *used* on the other hand is quite different. The result of the readiness probe govern whether the Pod receives traffic, a failing liveness probe on the other hand will cause the Pod to be restarted (once the failure threshold is met).

The readiness check we added to our deployment in the previous section was rudimentary in that it just used the root path of the service rather than a dedicated endpoint. We can continue

that practice for now, and use the same endpoint from the readiness probe for the liveness probe in the following example, with minor changes to increase the failure tolerance. Since the container gets restarted when the liveness probe fails the threshold, and can take some time to come back, we don't want the liveness probe setup on a hair trigger. Let's add a liveness probe to our deployment which will restart it if it fails for 180 seconds (6 failures at a 30s interval).

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        readinessProbe:
          initialDelaySeconds: 15
          periodSeconds: 30
          httpGet:
            path: /
            port: 80
            scheme: HTTP
          timeoutSeconds: 2
          failureThreshold: 1
          successThreshold: 1
        livenessProbe: #A
          initialDelaySeconds: 30 #B
          periodSeconds: 30 #C
          httpGet: #D
            path: / #D
            port: 80 #D
            scheme: HTTP #D
          timeoutSeconds: 5 #E
          failureThreshold: 10 #F
          successThreshold: 1 #G
```

#A Specify a liveness probe this time
#B After an initial delay of 30 seconds
#C Every 30 seconds
#D Perform this HTTP request
#E Timing out after 5 seconds (more tolerant than the readiness check)
#F And consider 10 error responses in a row to indicate the container is not ready
#G And consider 1 successful response to indicate the container is ready after being considered unready

Now, your deployment has a Readiness and Liveness probe. Even these rudimentary probes improve the reliability of your deployment drastically, and if you stop here it's probably enough for a hobby application. The next section details some further design considerations to bulletproof your probes for production use.

4.1.4 Designing Good Health Checks

While using an existing endpoint as we did in the previous two sections as the health check path is better than nothing, it's generally better to add dedicated health check endpoints to your application. These health checks should implement the specific semantics of readiness and liveness, and be as lightweight as possible. Without understanding the semantic differences between liveness and readiness you could see instability due to excessive restarts and cascading failures, and if you're re-using some other endpoint, chances are it's heavier-weight than needed – why pay the cost of rendering an entire HTML page when a simple HTTP header response would suffice?

When creating the HTTP endpoints to implement these checks, it's important to take into account any external dependencies being tested. Generally, you don't want external dependencies to be checked in the liveness probe, rather it should test only whether the container itself is running (assuming your container will retry the connections to its external connections). This is because there's not really any value in restarting a container that's running just fine, and only because it can't connect to another service which is having trouble. This could cause unnecessary restarts that creates churn and could lead to cascading failures, particularly if you have a complex dependency graph. There is an exception to this principle of not testing dependencies in liveness probes which I cover later in the section.

Since the liveness is only testing whether or not the server is responding, the result can and should be extremely simple. By way of illustration, here is the implementation of the healthz implementation for a Ruby on Rails app, and the associated routing rule

routes.rb

```
get "/healthz" => "probez#healthz"
```

probez_controller.rb

```
class ProbezController < ApplicationController
  def healthz
      render text: 'OK', status: 200
   end
end
```

A you can see, the entire method consists of a single line of code: if the app can respond to this request, it's live. I choose to send some text to make it more user friendly, but a HTTP header-only response would also work.

For Readiness probes on the other hand it's generally desirable that they test their external dependencies (like a database connection). This is useful because if you have say 3 replicas of a Pod, and only 2 of them can connect to your database, it makes sense to only have those 2 fully functional pods in the load balancer rotation. Here's an example of a readiness check in a Ruby on Rails app that relies on an external database.

routes.rb

```
  get '/readyz', :to => 'probez#readyz'
```

probez_controller.rb

```
class ProbezController < ApplicationController
  def readyz
    begin
      connection = ActiveRecord::Base.connection
      result = connection.execute("SELECT id FROM users LIMIT 1;")
      render text: 'Ready', status: 200
    rescue Mysql2::Error
      logger.debug "readyz: " + $!.inspect
      render text: 'Not Ready', status: 503
    end
  end
end
```

This example implementation performs a simple SQL query to ensure that the database is both connected, and responsive. Rather than performing a SELECT query, you could perform any other database operation, but I personally like the legitimacy of a SELECT statement as if this works, then I'm confident the other queries will work too. Your implementation of this endpoint will of course vary, based on your own dependencies.

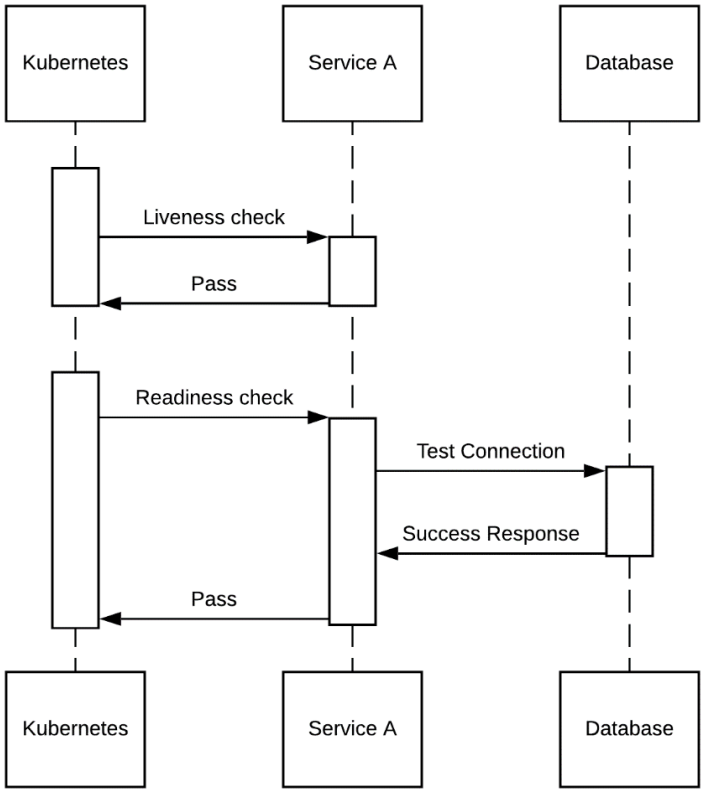


Figure 4.1: Liveness and Readiness checks and external dependencies

Updating our Deployment configuration for these new endpoints, we get:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        readinessProbe:
          initialDelaySeconds: 15
          periodSeconds: 30
          httpGet:
            path: /readyz #A
            port: 80
            scheme: HTTP
          timeoutSeconds: 2
          failureThreshold: 1
          successThreshold: 1
        livenessProbe:
          initialDelaySeconds: 30
          periodSeconds: 30
          httpGet:
            path: /healthz #A
            port: 80
            scheme: HTTP
          timeoutSeconds: 3
          failureThreshold: 3 #B
          successThreshold: 1
```

#A Updated endpoints
#B Now the liveness probe is lightweight, we can tighten up the failure threshold

The above is the standard way to setup liveness and readiness checks in Kubernetes, however there is a small catch by not testing dependencies in the liveness check. If you completely separate the concerns into Readiness: "is the container ready to receive traffic" and Liveness: "is the container running", there could be a condition where the container is running, but due to a bug in the container's retry logic, the external connections will never be resolved.

If this possibility concerns you (and it definitely concerns me: some conditions are only solved by turning it off and on again), it may be desirable to restart the container if it were to fail its readiness conditions for a prolonged period of time. Today, Kubernetes doesn't offer the opportunity to use an extended Readiness probe failure to also restart the container, but you can implement this yourself.

One way to do this which is fairly simple is to simply record the time in your readiness check each time it passes. Then in your liveness check, you add an addition condition that if that "last

ready" time was more than X minutes ago, you fail the liveness check. This avoids the anti-pattern of testing for your external dependencies in every liveness check, giving the container some time to self-heal, while also creating a safety net that will reboot it eventually.

Expanding on the previous example implementations of these probes, let's add this extra logic to fail the liveness check after 5 minutes of the Pod not being ready:

```
class ProbezController < ApplicationController
  @@last_readyz = Time.now #A

  # Readiness
  def readyz
    begin
      connection = ActiveRecord::Base.connection
      result = connection.execute("SELECT id FROM users LIMIT 1;")
      @@last_readyz = Time.now
      render text: 'Ready', status: 200
    rescue Mysql2::Error
      logger.debug "readyz: " + $!.inspect
      render text: 'Not Ready', status: 503
    end
  end

  # Liveness
  def healthz
    if (Time.now > @@last_readyz + 5.minutes) #C
      render text: 'Not Healthy', status: 503 #C
    else
      render text: 'OK', status: 200
    end
  end
end
```

#A The last ready time is initialized at the current time to allow for 5 minutes since startup
#B Each time the readiness passes, the time is updated
#C If 5 minutes have passed since the last successful readiness result (or since boot), fail the liveness check.

An alternative approach to achieve this (restarting the container after a prolonged period of unreadiness) is to use the readiness endpoint for both Liveness and Readiness probes, but with different tolerances (e.g. the Readiness would fail after 30 seconds, but Liveness only after 5 minutes). This approach still gives the container some time to resolve any inter-dependent services, before eventually rebooting in the event of continued downtime which may indicate a problem with the container itself. This is not technically idiomatic Kubernetes, as you're still testing dependencies in the Liveness check, but it gets the job done.

In conclusion, these two probes are incredibly important to giving Kubernetes the information it needs to automate the reliability of your application. Understanding the difference between them, and implementing appropriate checks that take into account the specific details of your application is crucial.

4.1.5 Probe Types

To now, the examples have assumed a HTTP service, and the probes therefore were implemented as HTTP requests. Kubernetes can be used to host many different types of services, as well as

batch jobs with no service endpoints at all. Fortunately there are a number of ways to expose health checks:

HTTP. Recommended for any container that provides a HTTP service, the service exposes an endpoint, such as /healthz. A HTTP 200 response indicates success, any other response (or timeout) indicates a failure.

TCP. Recommended for TCP-based services other than HTTP (for example, a SMTP service). The probe succeeds if the connection can be opened.

```
readinessProbe:
  initialDelaySeconds: 15
  periodSeconds: 30
  tcpSocket: #A
    port: 25 #A
  successThreshold: 1
  failureThreshold: 1
```

#A TCP probe specification

Bash Script. Recommended for any container not falling into the above categories like batch jobs that don't run service endpoints (covered in a later chapter). Kubernetes will execute the script you specify, allowing you to perform whatever tests you need. A non-zero exit code indicates failure.

4.2 Updating Live Applications

Once you've implemented Readiness checks, you can now roll out changes to your application without downtime. Kubernetes uses the Readiness check during updates to know when the new Pod is ready to receive traffic, and to govern the rate of the rollout according to parameters you set.

This chapter lays out three rollout strategies that are possible to use with Kubernetes out of the box, two of which can avoid downtime during the rollouts.

4.2.1 Rolling Update Strategy

The simplest zero-downtime update strategy that works with Kubernetes is a "rolling update". In a rolling update, Pods with the new version are created in groups, Kubernetes waits for them to become available, then terminates the same number of Pods running the old version, repeating this until all Pods are running the new version (the exact cadence at which this happens is tunable by the user).

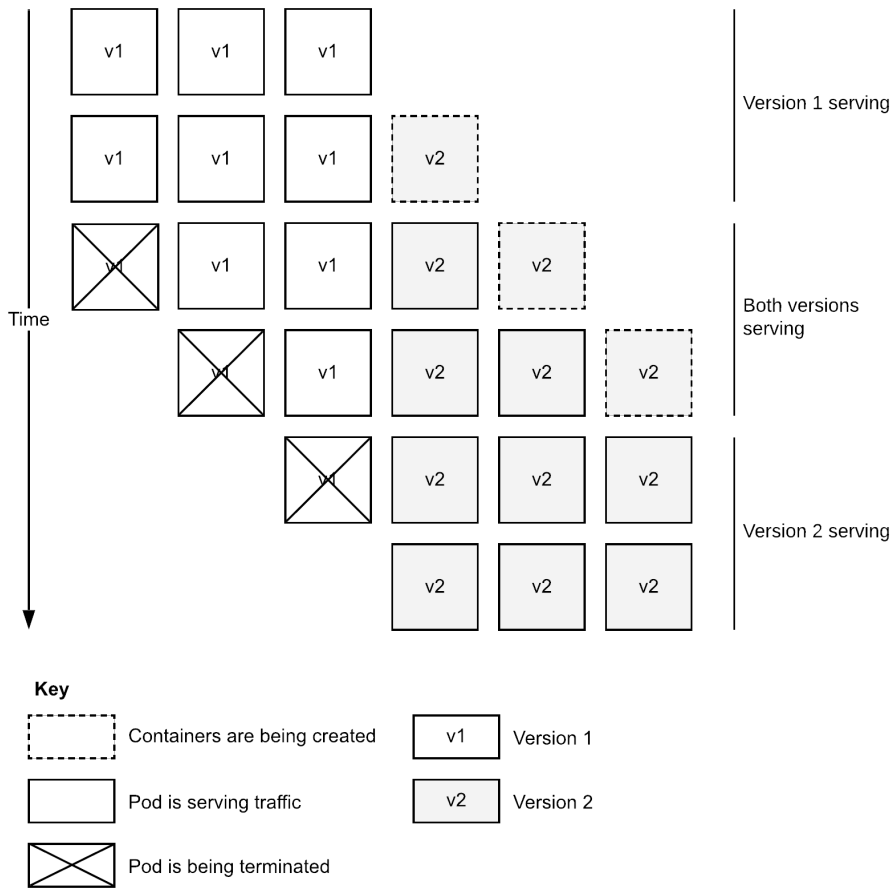


Figure 4.2: Pod status during a rolling update. With this strategy, requests can be served by either the old or the new version of the app until the rollout is complete.

The goal of such a strategy is two-fold:

a) Provide continuous uptime during the rollout
b) Use as few extra resources as possible during the update

The drawbacks of this strategy is that it requires that both versions of your application are capable of co-existing. That is, your backend or any other dependencies must be able to handle these two different versions (which frankly is a really smart move, otherwise rollbacks are very scary), and that users may get alternating versions when they make different request. Imagine reloading the page and seeing the new version, reloading it and seeing the old version again. Depending on how many replicas you have, a RollingUpdate can take a while to complete (and therefore, any rollback can also take a while).

Let's configure our deployment to use the `rolling` update rollout strategy:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  selector:
    matchLabels:
      app: pluscode
  replicas: 3
  strategy:
    type: RollingUpdate #A
    rollingUpdate: #B
      maxSurge: 2 #B
      maxUnavailable: 1 #B
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
```

 # A rolling update strategy
 # B optional configuration

The optional configuration can be used to govern how quickly the rollout happens.

MAXSURGE

"maxSurge" governs how many more Pods you're willing to create during the rollout. For example, if you set a replica count of 5, and a `maxSurge` of 2, then it may be possible to have 7 Pods (of different versions) scheduled.

The tradeoff is that the higher this number is, the faster the rollout will complete, but the more resources it will (temporarily) use. If you're highly optimizing your costs, you could set this to 0. Alternatively, for a large deployment you could temporarily increase the resources available in your cluster during the rollout by adding nodes, and removing them when the rollout is complete.

MAXUNAVAILABLE

"maxUnavailable" sets the maximum number of Pods that can be unavailable during updates (percentage values are also accepted, and are rounded down to the nearest integer). If you've tuned your replica count to handle your expected traffic, you may not want to set this value much higher than zero, as your service quality could degrade during updates.

The trade off here is that the higher the value, the more Pods can be replaced at once and the faster the rollout completes, while reducing the number of Ready pods temporarily that are able to process traffic.

Given that a rollout could coincide with another event that lowers availability like a node failure, for production workloads I would recommend setting this to 0. The caveat is that if you set it to 0, and your cluster has no schedulable resources, the rollout will get stuck and you will see Pods in the "Pending" state until resources become available. When the maxUnavailable is 0, `maxSurge` cannot also be zero (the system needs to surge, i.e. add create new pods, that are by definition not ready as they are booting).

RECOMMENDATION

RollingUpdate is a good go-to strategy for most services. For production services, `maxUnavailable` is best set to 0. `maxSurge` should be at least 1, or higher if you have enough spare capacity and want faster rollouts.

DEPLOYING CHANGES WITH ROLLING UPDATE

Once your deployment is configured to use Rolling Update, deploying your changes is as simple as updating the deployment manifest with your changes, for example, a new container image name, and applying the changes.

To apply your changes, run:

```
kubectl apply -f deploy.yaml
```

Rolling update doesn't just govern changes related to new container images. Changes you make in the manifest like tweaking the Readiness and Liveness checks are also versioned, and will be rolled out just like a new container image version.

4.2.2 Replacement Strategy

Another approach, some might say the old fashion approach, is to cut the application over directly – delete all Pods of the old version, and schedule replacements of the new version. Unlike the other strategies discussed here, this is **not** zero-downtime. It will almost certainly result in some unavailability. With the right readiness checks in place, this downtime could be as short as the time to boot the first Pod, assuming it can handle the client traffic at that moment in time.

The benefit of this strategy is does not require compatibility between the new version and the old version (since the two versions won't be running at the same time), nor does it require any additional compute capacity at all (since it's a direct replacement).

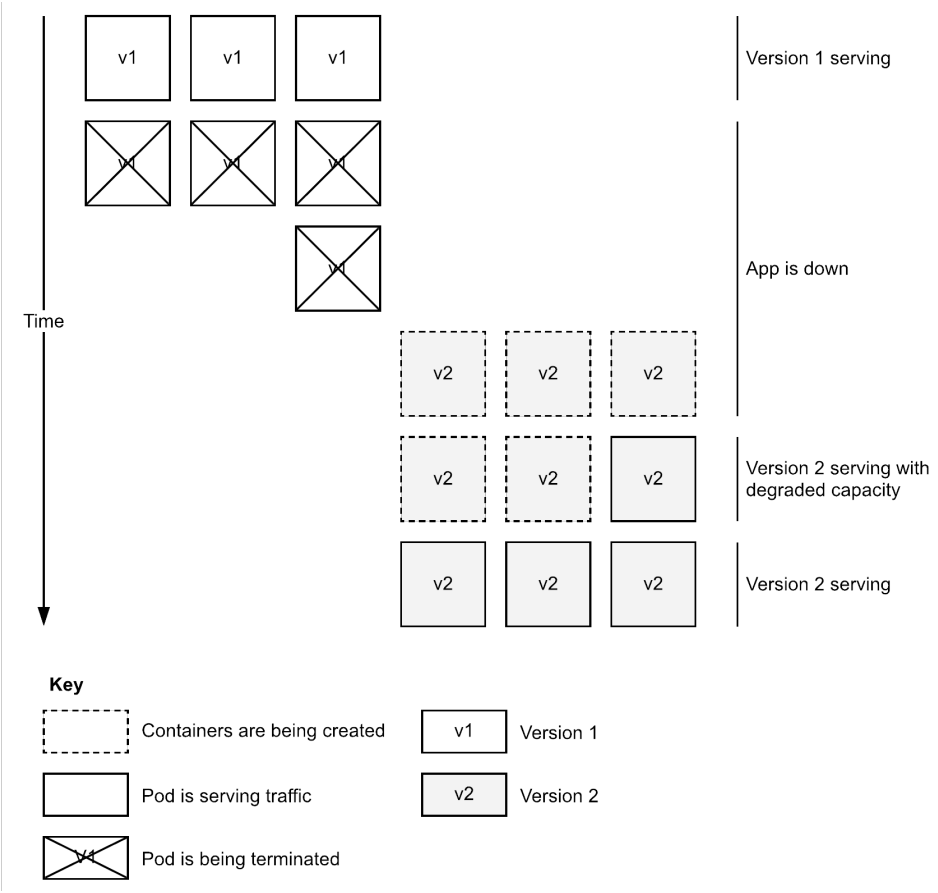


Figure 4.3: pod status during a rollout with the replacement strategy. During this type of rollout, the app will experience a period of total downtime, and a period of degraded capacity.

For development and staging, this strategy may be useful to avoid needing to slightly overprovision compute capacity to handle rolling updates, and for its speed, but otherwise should generally be avoided.

```
strategy:
  type: Recreate
```

Changes can be applied as with Rolling Update, using `kubectl apply`.

4.2.3 Blue / Green Strategy

The Blue/Green strategy (sometimes referred to as Red/Black particularly in the context of Netflix, a strong proponent of the pattern) is a rollout strategy where the new application version is deployed alongside the existing version. These versions are given the names "blue" and "green".

When the new version is fully deployed, tested, and ready to go – the service is cut over. If there's a problem, it can be immediately cut back, and after a time if everything looks good, the old version can be removed. Unlike the prior two strategies, the old version remains ready to serve and is removed only when the new version is validated (and often with a human decision involved).

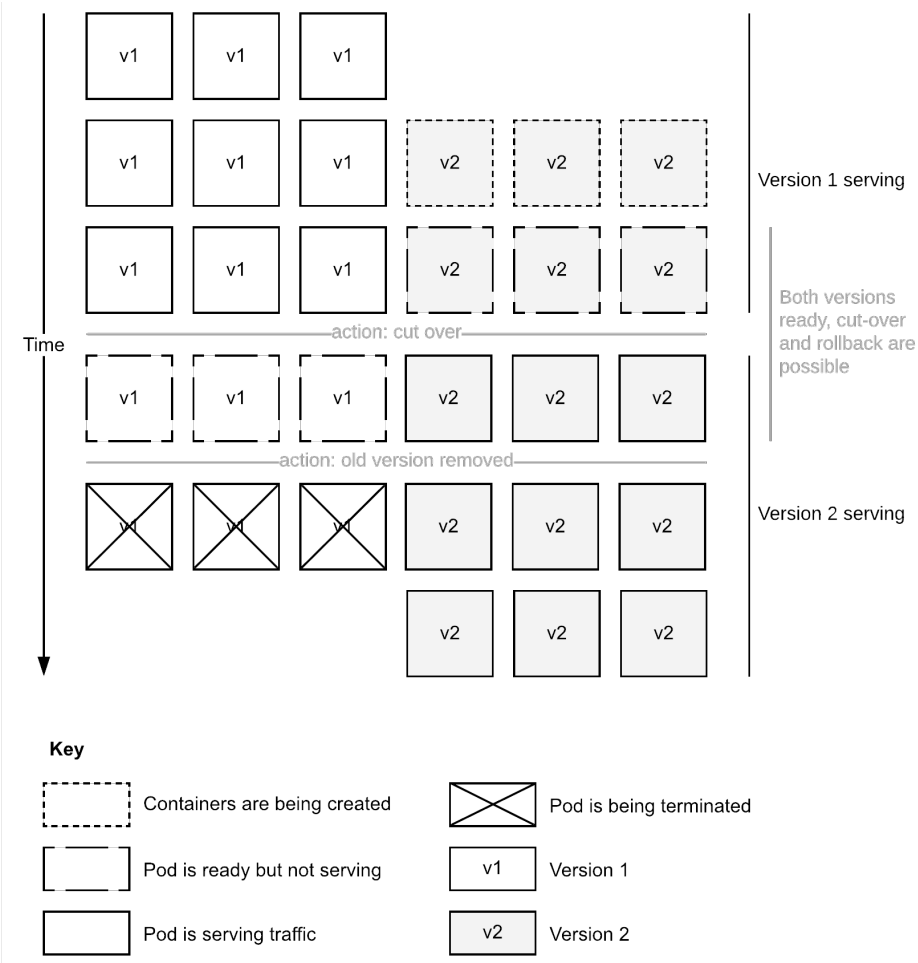


Figure 4.4: pod status during a blue / green rollout. Unlike the previous strategies, there are two action points where other systems, potentially including human actors make decisions.

The benefits of this strategy is:

a) Only one version of the app is running at a time, for a consistent user experience
b) The rollout is fast (within seconds)
c) Rollbacks are similarly fast

The drawbacks are:

a) Temporarily consumes double the compute resources
b) Not supported directly by Kubernetes Deployments.

This is an advanced rollout strategy, popular with large deployments. There are often several other processes included. For example, when the new version is ready – it can be tested first by a set of internal users, followed by a percentage of external traffic prior to the 100% cut-over – a process known as canary analysis. After the cut-over, there is often a period of time where the new version continues to be evaluated, prior to the old version being scaled down (this could last days). Of course, keeping both versions scaled up doubles the resource usage, with the trade off that near-instant rollbacks are possible during that window.

Unlike the prior two strategies - rolling update and replace – there is no native Kubernetes support for blue green. Typically users will use additional tooling to help with the complexities of such a rollout, native ones for Kubernetes include Istio for being able to split traffic at a fine-grained level, and Spinnaker to help automate the deployment pipeline with the canary analysis and decision points.

If you prefer to do a blue green style deployment without some of the fancier features like canary analysis, then you can perform a blue / green rollouts directly in Kubernetes using multiple deployments.

IMPLEMENTING BLUE / GREEN IN KUBERNETES

Despite the lack of native support, it is possible to perform a blue/green rollout in Kubernetes. Without the aforementioned tools to help with the pipeline and traffic splitting, it is a slightly manual process, and missing some benefits like being able to do canary analysis on a tiny percentage of production traffic, but that doesn't mean it's hard to implement.

Recall the Deployment and a Service we deployed in Chapter 3. Employing a blue green strategy for this application simply requires having one extra deployment. Duplicate the deployment, and suffix both deployment's *filename*, *metadata name*, and the Pod template's *labels* with "-blue", and "-green" respectively. You can then direct traffic from your Service by selecting either the "-blue", or the "-green" labels.

The update strategy you would specify in the Deployment configuration in this case is the `Recreate` strategy. Since only the Pods in the inactive deployment are updated, deleting all the old version and creating Pods with the new version won't result in downtime, and is faster than a rolling update.

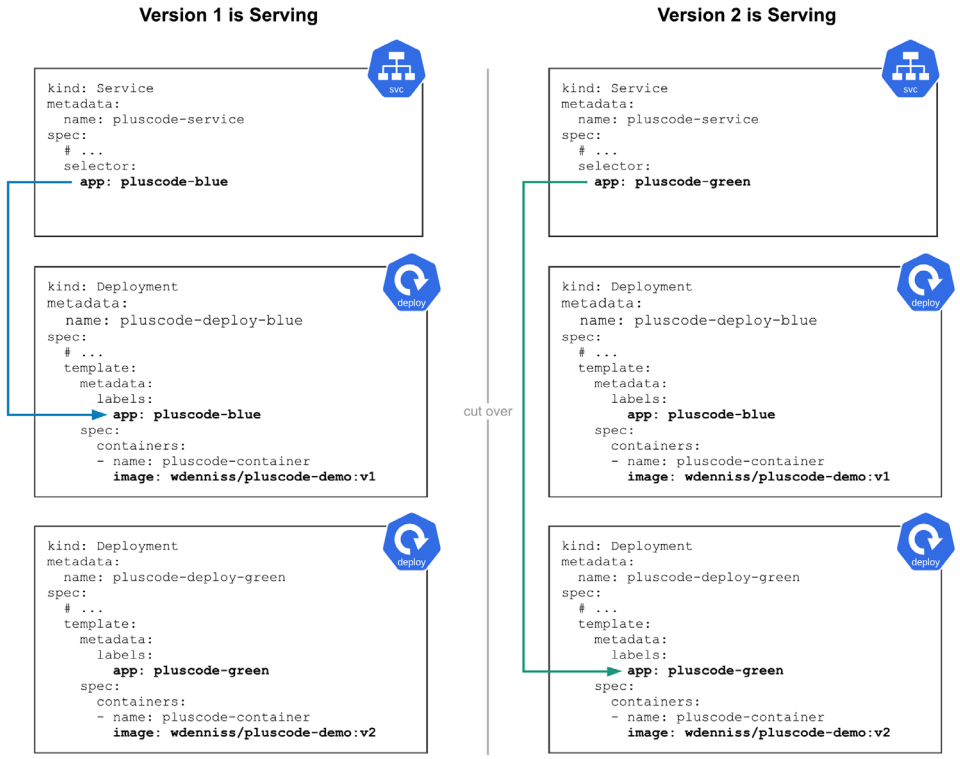


Figure 4.5: One service with a "blue" and "green" deployment with different versions of the same application. The service's selector is used to route traffic to the live version.

In this two-deployment system, one version is live, and one is non-live at any given time. The Service is selecting the live deployment with the label selector.

The steps to rollout a new version with blue green are the following:

1. Identify the non-live deployment (the one not selected by the Service)
2. Update the image path of the non-live deployment with the new container image version
3. Wait until the Deployment is fully rolled out (`kubectl get deploy`)
4. Update the Service's selector to point to the new version's Pod template's labels

The update steps are performed by modifying the YAML configuration for the resource in question, and applying the changes with `kubectl apply -f filename.yaml`. The example code that accompanies this book include a complete worked example for you to try.

The next time you want to rollout a change to this application, the steps are the same, but the colors are reversed (if blue was live for the last update, green will be live next time).

As mentioned, this strategy doubles the number of pods used by the deployment which will likely impact your resource usage. To minimize resource costs, you can scale the non-live

deployment to zero when you're not currently doing a rollout, scaling it back up to match the live version when you're about to do a rollout. You'll likely need to adjust the number of nodes in your cluster as well. See Chapter 5 for how to perform these steps.

4.2.4 Choosing a Rollout Strategy

For most deployments, the built-in rollout strategies (`RollingUpdate`, and `Replace`) are suitable.

Use `RollingUpdate` as an easy way to get zero-downtime updates on Kubernetes. To achieve the zero downtime or disruption, you will also need to have a readiness check implemented otherwise traffic can be sent to your container before it has fully booted. You need to consider that two versions of your application can be serving traffic simultaneously and design attributes like data formats with that in mind. As it happens, having your data store being able to support at least the current and previous version is good practice generally, as it also allows you to rollback to the previous version if something goes wrong.

`Replace` is a useful strategy when you really don't want two application versions running at the same time, and things like legacy single-instance services where only one copy can exist at a time.

Blue/green is an advance level strategy that requires additional tooling or processes, but with the advantage for near-instant cut-overs while offering the best of both worlds in that only one version is live at a time, but without the downtime of the `Replace` strategy. I recommend getting started with the in-built strategies but keep this one in mind for when you need something more.

4.3 Summary

As we saw in this chapter, Kubernetes provides many tools to help you keep your deployments running and updated. It's important to define health checks so that Kubernetes has the signals it needs to keep your application running by rebooting containers that have gotten stuck or are non-responsive.

- Health checks are used by Kubernetes to know when your application needs restarting
- Health checks are particularly during updates, as it's how Kubernetes knows when newly booted instances of your application are ready to serve traffic
- `RollingUpdate` is the default rollout strategy in Kubernetes, giving you a zero-downtime rollout with minimal additional resources
- `Recreate` is an alternative rollout strategy that does an in-place update with some downtime but no additional resource usage
- Blue/green is a rollout strategy that isn't directly supported by Kubernetes but can still be performed using native Kubernetes constructs.
- Blue/green offers some of the highest quality guarantees, but is more complex, and temporarily doubles the resources needed by the deployment.

5

Resource Management

This chapter covers

- How Kubernetes allocates the finite resources in your cluster
- Configuring your workload to request just the resources it needs
- Overcommitting resources to improve your performance-to-cost ratio
- Avoiding a single point of failure with a highly available deployment strategy
- Targeting and avoiding specific groups of nodes for deployments

In chapter 2, we talked about how Containers are the new level of isolation each with their own resources, and in Chapter 3 that the schedulable unit in Kubernetes is a Pod (basically just a collection of containers). In this chapter we go deeper into the "container orchestrator" that is the Kubernetes scheduler and look at how Pods are allocated to machines, as well as the information that you need to give the system to have things configured correctly.

Knowing how the scheduling of Pods to Nodes works helps you make better architectural decisions around allocations, bursting, overcommit, availability and reliability.

5.1 Pod Scheduling

The Kubernetes scheduler performs (at a basic level) a resource-based allocation of Pods to Nodes, and is really the brains of the whole system. When you submit your configuration to Kubernetes (as we did in Chapter 3 and 4), it's the scheduler that does the heavy lifting of finding a node in your cluster with enough resources, and tasks the node with booting and running the containers in your Pods.

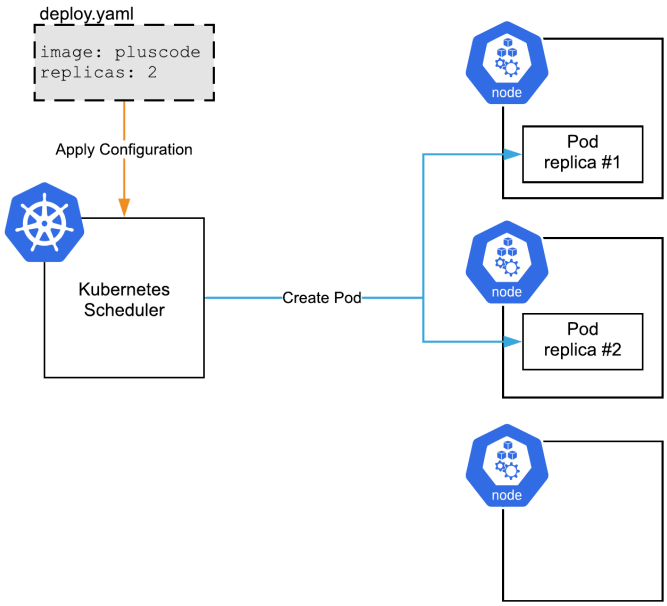


Figure 5.1: In response to the user applying configuration, the scheduler issues a Create Pod command to the node.

The scheduler's work doesn't stop there either. In the case of the Deployment object (what we've been using in the book so far) it actually continuously monitors the system with the goal to make the system state what you requested it to be. In other words, if your deployment requested 2 replicas of your Pod, the scheduler doesn't just create those replicas then forget about it, it will keep verifying that there are still 2 replicas running. If something were to happen (for example, say a node disappeared due to some failure), it would attempt to find a new place to schedule the Pod so that your desired state (2 replicas in this case) is still met.

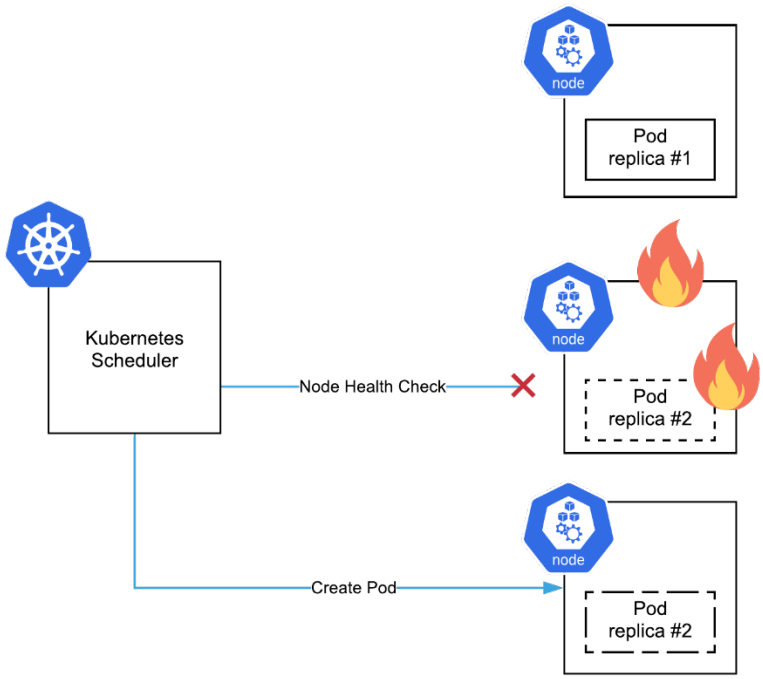


Figure 5.2: One of the nodes develops an issue. Health checks from the Kubernetes control plane fail, so the Scheduler issues a Create Pod command to a healthy node.

This recreation of Pods due to node failures by the scheduler is separate behavior to the Pod restarts we covered in the last chapter. Pod restarts due to liveness or readiness failures are handled locally on the node by the kubelet, whereas the Scheduler is responsible for monitoring the health of the nodes, and reallocating Pods when issues are detected.

Now, since each Node in the cluster is constrained by the resources that it has, and Pods may have differing resource requirements themselves, an important responsibility of the scheduler is finding the enough room to run your Pods. It considers multiple scheduling dimensions when considering where to place the containers of your Pod in the cluster whether for the first time they're deployed, or in response to disruption like the one illustrated in Figure 2.

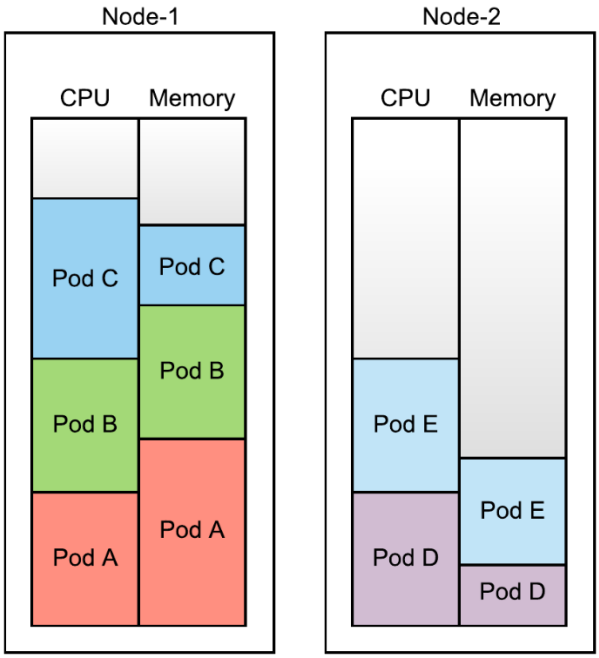


Figure 5.3: 5 containers allocated on 2 nodes based on their resource needs

It is the scheduler that has the task of finding the right place in your cluster to fit the Pod, based on its resource requirements and (as we'll cover later in this chapter) any other placement requirements. Any Pods that can't be placed on the cluster will have the status "Pending" (covered in Chapter 3, "Stuck in Pending").

5.1.1 Specifying Pod Resources

You give the scheduler the information it needs to make these decisions by specifying the resource requests in your deployment manifest (and other workload types that have an embedded Pod specification). So far, the examples in this book have not specified their resource requirements, but for the production grade deployment that we are working towards, that will need to change.

A Pod that needs 20% of a CPU core, and 200MiB of memory would be specified like so:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        resources:
            requests: #A
              cpu: 200m #A
              memory: 250Mi #A
```

#A The resource requests of this deployment

The "200m" in the example here represents 200 milli-cores, that is, 20% of 1 core. You can also use floating point numbers, e.g. "0.2", however it's very common among Kubernetes practitioners to use milli-cores so that's what we'll use. The "Mi" suffix for memory indicates Mebibytes, with "Gi" indicating Gibibyte (powers of 1024), while "M" and "G" indicate Megabyte and Gigabyte (powers of 1000).

These values are extremely important, as it gives Kubernetes the information it needs to match the Pod requirements to the node capacity. Say you have 3 Pods that have really high requirements, and 3 with low requirements, you would want Kubernetes to ensure each Pod has the resources it needs, and not place them randomly without regarding their needs (for example, by placing the 3 high requirement pods together on a node where they would each be starved of resources).

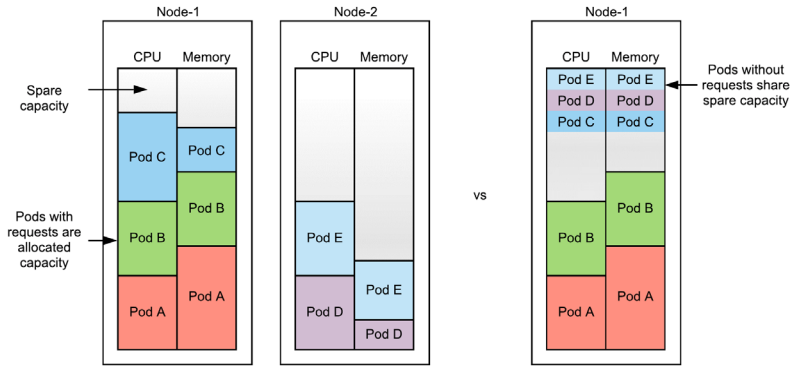


Figure 5.4: Comparison of Pod allocation when all Pods have resource requests, and when only some do. Pods without resource requests share the spare capacity on a best effort basis, without regards to their actual needs.

This may sound fairly simple so far – we're just pairing the requests with the resources. It would be simple, if it were not for the ability to *burst*, that is, consume more resources than you requested. Much of the time a process may not need all the resources it asked for, wouldn't it be good if the other Pods on the node could use that capacity on a temporary basis?

Kubernetes represents this burst capacity with limits. A Pod declares both the resources it requests which is used for scheduling, and the limits which is used for constraining the resources being used.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        resources:
            requests:
              cpu: 200m
              memory: 250Mi
            limits: #A
              cpu: 300m #A
              memory: 400Mi #A
```

#A The resource limits of this deployment, the pod can use up to 0.3 of a CPU core, and 400 MiB memory

The sample configuration above specifies both requests and limits. It is best practice to have both requests and limits set for all your deployments. But how do you determine what to set them at? Read on to understand how the requests and limits interact to form a quality of service class, and how you can measure your application's performance to determine what values to set.

5.1.2 Quality of Service

Having limits higher than requests, or not set at all, introduces a new problem, and that is what to do when all these Pods are consuming too many resources (most commonly, too much memory), and they need to be evicted to reclaim the resource. Kubernetes performs a stack rank of importance when choosing which pods to remove first.

Kubernetes traditionally classified Pods into 3 quality of service classes in order to rank their priority. These are actually no longer directly used in the eviction algorithm, but I'll present them here as there are a lot of people and documentation that use the terms, and it's still a reasonable way to consider the quality of service a Pod will receive.

GUARANTEED CLASS

Guaranteed class pods are where the limits are set equal to the requests. This is the most stable configuration as the pod is guaranteed the resources it requested, no more, no less. If your Pod has multiple containers, they all must meet this requirement for the Pod to be considered Guaranteed.

Guaranteed class Pods are always guaranteed to have the same resources available under varying conditions, and they won't be evicted from the node as it's not possible for them to use more resources than they were scheduled for.

BURSTABLE CLASS

Burstable class Pods on the other hand have limits set higher than requests, and are able to "burst" temporarily provided there are resources are available (i.e. from other Pods not using all of their requests, or unallocated space on the node).

You need to be careful with these Pods as there can be some unforeseen consequences such as accidently relying on the bursting. Say a Pod lands on an empty node and can burst to it's heart's content. Then sometime later, it gets rescheduled onto another node with less resources, the performance will now be different. So it's important to test burstable pods in a variety of conditions.

A Pod with multiple containers is considered Burstable if it doesn't meet the criteria for Guaranteed, and if any of the containers has a request set.

BEST EFFORT

Pods without any requests or limits set are considered "best effort" and are scheduled wherever Kubernetes wishes. This is the lowest of the classes, and I strongly recommend against using this pattern. You can achieve a similar result with the burstable class by setting really low requests, and that is more explicit than just closing your eyes and hoping for the best.

SUMMARY

In the next section we'll go more into the details of the eviction priority, but the long and short of it is, when thinking about the stability for your pods, it's always best to at least set the resource

requests to a high enough value that gives them enough resources to run, and avoid not setting any resource requests at all. High priority, critical workloads should always have limits set to their requests for guaranteed performance.

5.1.3 Evictions, Priority and Preemption

In times of resource contention (too many Pods trying to burst at once), Kubernetes will reclaim resource by removing (through a process known as evicting) pods that are using resources beyond their requested allocation. This is why it's so important to have a Pod's resources adequately specified.

EVICTION

Guaranteed class pods, as defined in the previous section are *never* evicted, so for a bulletproof deployment always set limits equal to requests. The rest of this section discusses how the non-guaranteed Pods are ranked when considering eviction, and how you can influence the ordering.

When looking for Pods to evict, Kubernetes considers those Pods which are using more resources than their requests, sorts them by their priority number, and finally by how many more resources (of the resource in contention) that the Pod us using beyond what it requested. By default, all Pods have the same priority number (zero), so the amount of usage above requests is what's used to rank, as shown in the following diagram.

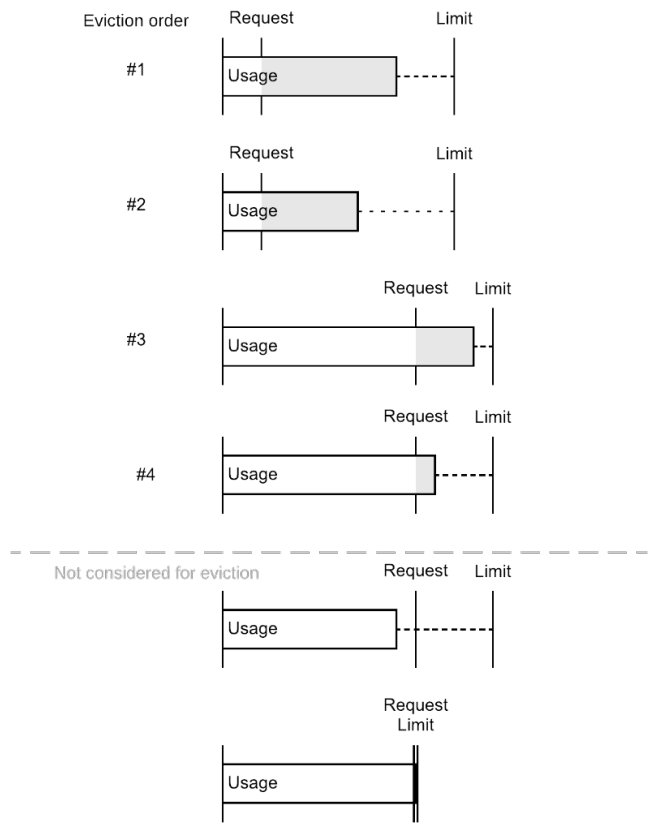


Figure 5.5: Eviction order for Pods of equal priority

"EVICTED" ERROR STATUS

If you query your Pods and you see a status of "Evicted" it indicates that the scheduler evicted your pod due to it using more resources than it requested. To resolve, increase the resources requested by your containers, and review whether your need to add more compute capacity to your cluster as a result.

PRIORITY

Priority is just an integer number (between 0 and 1,000,000,000) that you can assign to Pods (via a "priority class") to change the ranking. The following diagram shows the eviction order if priority numbers were assigned to Pods from the previous diagram. As you can see, the eviction is first sorted by the priority, then how much the usage is above requests. Pods that are not using more than their requests are not at risk of eviction, regardless of priority.

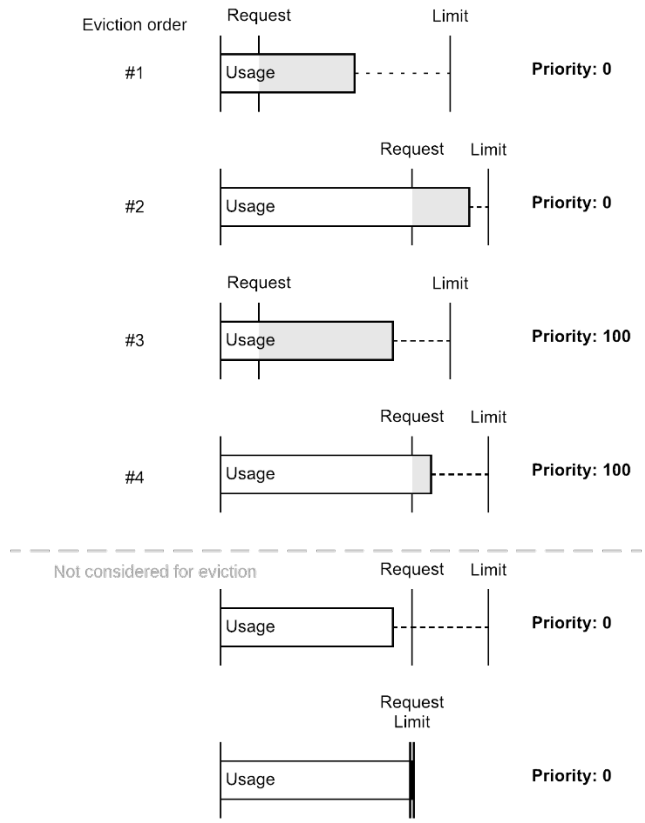


Figure 5.6: Eviction order of Pods with multiple priority values

To create your own priority level, you need to first create a `PriorityClass` object:

```
apiVersion: scheduling.k8s.io/v1
kind: PriorityClass
metadata:
  name: high-priority
value: 1000000 #A
preemptionPolicy: Never #B
globalDefault: false #C
description: "Critical services."
```

#A The priority integer
#B The 'Never' Preemption policy means that lower-priority Pods won't be booted if there's no space to schedule this Pod (see below for other options)
#C Whether this priority class should replace the default "0"

Then assign it to a Pod

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-high-priority
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode-high-priority
  template:
    metadata:
      labels:
        app: pluscode-high-priority
    spec:
      priorityClassName: high-priority #A
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        resources:
          requests:
            cpu: 200m
            memory: 250Mi
```

#A The priority class to use for this deployment

The priority number is also used during scheduling. If you have many Pods waiting to be scheduled, the scheduler will schedule the highest priority Pod first. Using priority to govern the scheduling order is particularly useful for ranking which batch jobs should execute first (batch jobs are covered in a later chapter).

PREEMPTION

When used by itself, priority is useful to rank workloads so that more important workloads are scheduled first and evicted last. There can be a situation however where the cluster does not have enough resources for a period of time and high-priority Pods are left stuck in Pending while low priority ones are running.

If you'd rather have higher priority workloads proactively bump lower priority ones rather than waiting for capacity to free up, you can add preemption behavior by changing the `preemptionPolicy` field in your `PriorityClass` as shown.

```
apiVersion: scheduling.k8s.io/v1
kind: PriorityClass
metadata:
  name: high-priority-preemption
value: 1000000
preemptionPolicy: PreemptLowerPriority
globalDefault: false
description: "Critical services."
```

Pods that belong to Deployments that are removed from the node due to eviction, or preemption are not forgotten about. These Pods are returned to the "Pending" state and will be re-scheduled on the cluster when there are enough rooms.

WHEN TO USE PRIORITY AND PREEMPTION

Priority and preemption are useful features of Kubernetes and are important to understand due to the impact on eviction and scheduling. Before spending too much time configuring all your Deployments with Priority, I would prioritize ensuring that your Pod requests and limits are appropriate as that is the most important configuration.

Priority and preemption really come into play when you're juggling many deployments and looking to save money by squeezing every ounce of compute out of your cluster by overcommitting where you need a way to signal which of your Pods are more important to resolve the resource contention. I wouldn't recommend starting with this design as you're just adding complexity. The simpler way to get started is to allocate enough resources to schedule all your workloads amply, and fine tune things later to squeeze some more efficiency out of your cluster.

Once again, the simplest way to guarantee the performance of your critical services is to set the resource requests appropriately, and have enough nodes in your cluster for them all to be scheduled.

5.2 Calculating Pod Resources

In the previous section we discussed why it's important to set appropriate resource requests and limits for pods for the most reliable operational experience. But how do you determine what the best values are? The key is to run and observe your Pods.

Kubernetes ships with a resource usage monitoring tool out of the box "kubectl top". You can use it to view the resources used by Pods and nodes. We'll be focusing on Pods as that's what we need to know to set the right resource request.

First, deploy your Pod with an excessively high resource request. This may even be a Pod that's already in production – after all, it's generally OK for performance (though not always for budget) to overestimate your resources needed. The goal of this exercise is to start high, observe the Pod's actual usage, then pair the requests back to provision the right resources and avoid wastage.

Until you have a good feel for how many resources the Pod needs, it may be best to leave the limits unset (allowing it to use all the spare resources on the node). This doesn't completely solve the need to set *some* requests, as you would prefer to be allocated dedicated capacity above what you need at first.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        resources: #A
            requests:
              cpu: 200m
              memory: 250Mi
```

#A The Pod under test. Resource limits are not set so we can analyze usage.

Run `kubectl top pods` (you may need to wait a minute or two for the data to be available), and note the startup resource usage, particularly memory. It's useful to have a snapshot of what resources the Pod needs to boot, as this is the lower bound if you choose to use Burstable quality of service.

Now, direct enough load at the Pod to simulate a real world usage. Performance tools like Apache bench (installed with Apache[1]) can help here. An example apache bench command that will generate 10k requests total using 20 threads is below. You typically want to run this test for a while (say, 5 minutes) to make it simpler to observe the high water mark.

```
ab -n 10000 -c 20 https://example.com
```

The ideal situation would be to observe a Pod receiving normal production load. To avoid impacting production, you can temporarily overprovision your capacity (by setting high resource requests) and adding extra nodes to your cluster. Once you have a good measure of the actual needs, you can later tune the requests and right-size the cluster.

With your Pod under load either generated or production, run `kubectl top pods` again (remembering that it can take a minute or two to reflect the latest values, so keep your load simulation running).

Now you should have values like so:

	Memory	CPU
Startup	200MiB	2%
Under Normal Load	400MiB	2%

It may be useful to repeat this process a couple more times and get values for your Pod under different loads (e.g. low, normal and high traffic), and timeframes. Multiple timeframes (e.g.

[1] http://httpd.apache.org/docs/2.4/install.html

directly after boot, 1 hour after boot, 1 day after boot) are useful to account for potential growth in usage (e.g. memory leaks).

So you might end up with something like:

	Memory	CPU
Startup	400MiB	2%
Under Normal Load	500MiB	20%
Under High Load	503MiB	25%
After 1 hour	505MiB	21%
After 1 day	600MiB	20%

5.2.1 Setting Memory Requests and Limits

With this data in hand, how should you set your resource requests? For starters, you now have an absolute lower bound for your memory: 400Mb. Since you're only ever guaranteed to get your resource request, and you know your Pod uses 400Mb under load, setting it any lower will likely cause your pod to be OOMKilled. You may not see it right away if you have a higher limit, but you don't want to rely on spare capacity when you know you'll need it.

Does that make 400Mb the right request? Probably not. Firstly, you definitely want to have a buffer, say 10%. Also, you can see that after an hour, 505Mb was used, so this might be a better starting lower bound (before accounting for the buffer). Does it need to be 600Mb though? We saw that after a day the Pod needed that much, possibly due to a leak somewhere. This depends. You certainly could set this higher limit, then you could have some confidence that your pod could run for a day, but also thanks to Kubernetes' automatic restarting of crashed containers, having the system reboot a leaky process after a day to reclaim memory may be OK, or even desirable.

When Memory Leaks are OK

Instagram famously[2] disabled the garbage collection in Python for a 10% CPU improvement. While this is probably not for everyone, it's an interesting pattern to consider. Does it really matter if a process gets bloated over time and is rebooted, if it all happens automatically, and there are thousands of replicas? Maybe not.

Kubernetes automatically restarts crashed containers (including when that crash is due to the system removing them due to an out of memory condition), making it fairly easy to implement such a pattern. I wouldn't recommend this without thorough investigation, but I do think it indicates that if your application has a slow leak that it may not be your highest priority bug to fix.

Importantly, you need to make sure you at least give the container enough resources to boot and run for a time, otherwise you could get caught in a OOMKill crashloop which is no fun for anyone. Having enough replicas (covered in the next section) is also important to avoid a user visible failure.

[2] https://instagram-engineering.com/dismissing-python-garbage-collection-at-instagram-4dca40b29172

Using the data you gathered, find the lower bound by looking at the memory usage of your Pod under load, and add a reasonable buffer (at least 10%). With this example data, would have picked 505MB * 1.1 = 484Mb. You know it's enough to run the Pod under load for at least an hour, with a bit to spare. Depending on your budget, and risk profile you can tune this number accordingly (the higher it is, the lower the risk, but higher the cost).

So, requests need to at least cover the stable state of the Pod. What about the memory **limit**? Assuming your data is solid and covered all use-cases (i.e. there's no high-memory code path that didn't execute while you were observing), I wouldn't set it too much higher than the 1-day value. Having an excessive limit (say, twice as high as the limit or greater) doesn't really help much since you already measured how much memory your Pods need over the course of a day, and if you do have a memory leak it may be better for the Pod to simply be restarted by the system when the limit is hit, than to be allowed to grow excessively.

An alternative is to simply set the limit equal to the request, for the guaranteed QoS class. This has the advantage of giving your Pod constant performance regardless of what else is running on the node. In this case, you should increase the buffer, since the Pod will be terminated the moment it exceeds it's request.

5.2.2 Setting CPU Requests and Limits

Unlike Memory, CPU is *compressible*. What this means is that if you don't get the CPU resources you need, the application just runs slower. Where as if it doesn't get the memory it needs, it will crash. You still likely want to give the application the CPU it needs, otherwise performance will decrease, but there's not as much need to have a buffer as there is with memory.

In the example data for our application, we can see that the stable state is about 20% of CPU. That would seem to be a good starting point for your CPU requests. If you want to save money and are OK with degrading performance, you could set it a little lower.

For the cpu **limit**, this is an area where Kubernetes can improve your resource efficiency as you can set a high limit where your application can consume the unused cycles on the node if it needs to burst. As with memory, Kubernetes only guarantees the requested CPU (e.g. 20%), but often it's nice too allow the pod to take advantage of unused capacity on the node to run a bit faster. For web applications that are spend a lot of time waiting on external dependencies (e.g. waiting for a database to respond), there is often spare CPU capacity on the node which the active request could take advantage of.

As with memory, the downside of setting limits to higher than requests (i.e. the Burstable QoS), is it means that your performance won't be constant. A burstable pod running on an empty node will have a lot more resources than on a dense node. While generally it's nice to be able to handle bursts in traffic by consuming the unused capacity on the node, if constant performance is important, setting limits equal to requests may be preferable.

5.2.3 Reducing Costs by Overcommitting CPU

One strategy to reduce costs is to use the property that CPU is compressible to overcommit the node. This is achieved by setting the CPU request to a low value (lower than what the Pod actually needs), and therefore cramming more Pods onto the node than you otherwise could if it was set to the actual usage.

This saves money but has the obvious performance drawback. However, in the case of workloads that are considered very "bursty" it can be a very desirable strategy. Let's say you are hosting hundreds of low-traffic applications. Each may only get a few requests an hour, only needing the CPU for that time. For such a deployment, each application could have a CPU request of 1% (allowing 100 to be scheduled on a single core), and limit of 25% (allowing it to temporarily burst up to a quarter of a core).

The key for making such an overcommit work is that you need to be intimately aware of what else is running on the machine. If you are confident that most of the websites will be idle most of the time this could work, but it may break down if all 100 suddenly need all the resources (unless 1% of a core is actually enough). This kind of violates one of the isolation properties of containers: now you need to be aware of and plan the make up of the node accordingly. However, it can be done.

The safest approach of course is not to overcommit at all. A sensible compromise is to not overcommit too much. Giving Pods a little extra CPU (through setting their limits higher) can help reduce latency in an opportunistic fashion, but set your CPU requests high enough to handle a reasonable base load so that this excess capacity isn't being relied on.

5.2.4 Balancing Pod Replicas and Internal Pod Concurrency

Now you have a handle on how the pod resource requests influence how your Pods are scheduled, and the resources they get. It's worth considering the how your concurrency within the Pod influences the resource size, and durability and the trade-off with concurrency achieved through multiple replicas of the Pod.

If you're coming from an environment where installations of your application were expensive, either in monetary cost for servers, or time to configure instances, your application will likely have a lot of internal concurrency through threads and/or forks, often described as the number of "workers" to handle incoming requests concurrently.

Concurrent workers still have advantages in the Kubernetes world due to their resource efficiency. I wouldn't take a Pod with 10 workers, and deploy 10 replicas with 1 worker each. The container's internal concurrency is very efficient memory wise, as forks share some of the memory used by the application binary, and threads share even more. CPU is also pooled between workers which is useful as a typical web application spends a lot of time waiting on external dependencies, meaning there is often spare capacity to handle many requests at once.

Balancing the benefits of workers is the fact that the more replicas of a Pod you have, the more durable it is. For example, if you have 2 replicas of a pod, with 18 workers each to handle a total of 36 concurrent connections, if one of those Pods were to crash (or be restarted because it failed the health check you setup in Ch.4), half your capacity would be offline before the Pod restarts. A better approach might be to have 6 Pods of 6 replicas each, still maintaining some inter-container concurrency while adding some redundancy.

To strike the right balance, a simple heuristic like the following can be used. Consider the total number of workers you need to serve your users, and of those how many can be offline at any given time without noticeable user impact. Once you've calculated how many can be offline—using our previous example, say 16% of the 36 workers could be offline before issues are noticed—then the most number of workers you can concentrate in a single Pod is 16%, or 6. If you find this

results in more replicas than you need, increase the total number of workers so you can have more per Pod.

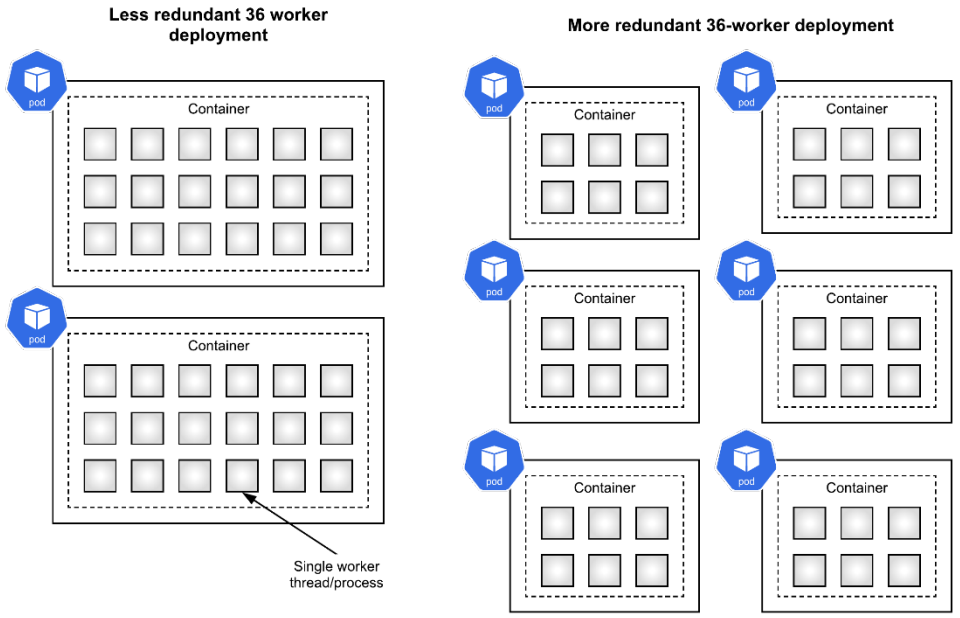


Figure 5.7: Comparison of two possible deployments for a total of 36 workers

In short, the more Pod replicas you have, the safer the design, but the less efficient in terms of resource usage, so it's worth considering this and balancing your own availability and resource requirements.

5.3 Placing Pods

In the previous section, we covered the balance between replicas and internal concurrency. While it's good having a bunch of Pod replicas for when one fails its health checks, or has a memory leak, and needs to be restarted, there are some other considerations and that is *where* those Pods are placed.

If you have 10 replicas of a Pod, but they're all on a single node then you would be impacted by the failure of that node. And expanding on this, using typical cloud topologies, if all your *nodes* are in a single availability zone, then you're at risk of a zone outage. How much time and money you should spend guarding against these conditions is a choice you need to make based on your own production guarantees and budget, since the sky is really the limit.

I will focus this section on some sensible and affordable strategies for spreading your Pods on the nodes you already have, as this is something you can do for free, and it gets you some additional availability.

5.3.1 Building Highly Available Deployments

So far we've talked about how resource requests are used to allocate pods to nodes. However, there are other dimensions to consider. To make your application highly available, it is desirable that the replicas don't all end up on the 1 node. Say you have a small Pod, 100mCPU, 100MiB, and 3 replicas. These 3 replicas could easily all fit on the same node. But then, if that node were to fail, the deployment would be offline

Better would be to have the scheduler spread these pods out across your cluster! Fortunately, Kubernetes has a built-in way to achieve this called a "topology spread constraint". A topology spread constraint aims to spread your nodes across a failure domain, such as the node, or even a whole zone, and multiple can be specified, so you can spread across both nodes and zones, or any other failure domains defined by your provider.

Figure 5.8: deployment pod placement with and without topology constraints

NOTE Many Kubernetes providers have some default topology spread for deployments—including GKE. If you trust the default settings to do the right thing in most cases, feel free to skip past this section. I've included this information it regardless, as I find it helps to know why things work the way they do, so I think it's important to understand why Pods get spread over nodes. It is also possible to use the techniques in this chapter to modify the default policies, such as to impose somethings stricter say for a mission-critical deployment, and to apply topology spreads to objects that don't get them by default like Jobs (covered in a later chapter).

To override the spread topology for a particular deployment, you can add the `topologySpreadConstraints` key, as I've done in the following example.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  strategy:
    type: Recreate
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      topologySpreadConstraints: #A
        - maxSkew: 1  #B
          topologyKey: kubernetes.io/hostname #C
          whenUnsatisfiable: ScheduleAnyway #D
          labelSelector: #E
            matchLabels: #E
              app: pluscode #E
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        resources:
          requests:
            cpu: 200m
            memory: 250Mi
          limits:
            cpu: 300m
            memory: 400Mi
```

#A the topology constraint added
#B the maximum number of replica imbalance
#C the node label to use for the topology
#D The behavior to use when it's not possible to satisfy the topology requirement
#E another label selector set to this template's metadata label

In this example we're targeting the `kubernetes.io/hostname` topology using the topologyKey setting, which really means that Kubernetes will consider all nodes labelled with the same value for the `kubernetes.io/hostname` key to be equal. Since no two nodes should be labelled with the same hostname, this yields a node-level spreading target.

For this configuration to work, and I cannot stress this enough, you must ensure that the nodes in your cluster actually have the label specified in topologyKey (`kubernetes.io/hostname` in my example). There are some well-known labels[3], like the one I'm using here, but there is no guarantee that your Kubernetes platform will use it. So, verify by running `kubectl describe node` and look at the Labels that your nodes have.

Going over the rest of the settings, in the example I've used a `maxSkew` of 1, the smallest possible skew, which means there can be at most 1 level of unbalance (which means any node can have at most 1 more pod than the other nodes).

`whenUnsatisfiable` governs what happens when the constraint can't be satisfied (say that a node is completely full with other pods). The choices are `ScheduleAnyway` and DoNotSchedule whose behavior is self explanatory. `DoNotSchedule` is helpful when testing as it makes it easier to see when the rule is working, but for production `ScheduleAnyway` is going to be safer. While `ScheduleAnyway` makes the rule a "soft" rule, Kubernetes will still do it's best to meet your requirements, which think is better than leaving the replica unscheduled altogether, especially when our goal is higher availability of our replicas!

The last field is a labelSelector with our friend `matchLabels` (covered in section 3.X). It's frustrating that Kubernetes doesn't have a simple self-reference here (i.e. why do you even need this at all since it's already embedded in the Pod's specification?), but basically this `matchLabels`, the earlier `matchLabels` and the metadata label (`app: pluscode`) that they both refer to must match, and be unique for this deployment.

With that, let's go ahead and deploy this example, and verify that the topology is what we expected! To demo this, we'll need a cluster with a few nodes, and one without any default spreading behavior. GKE comes with default node and zonal spreading, so this setting isn't needed on that platform (but in any case it's good to understand that this is what's happening behind the scenes, or if you need to fine-tune the behavior). To try this out and see the differences between various topologies, I suggest minikube configured with 3 nodes.

```
minikube start --nodes 3
kubectl create -f deploy_topology.yaml
kubectl get pods -o wide
```

Looking at the NODE column, you should see 3 separate nodes (assuming you have 3 nodes in the cluster).

```
> kubectl get pods -o wide
NAME                         READY   STATUS    RESTARTS   AGE   IP            NODE
pluscode-754665f45f-6n6bc    1/1     Running   0          39s   10.244.2.46   minikube-m03
pluscode-754665f45f-dkvvp    1/1     Running   0          39s   10.244.0.27   minikube
pluscode-754665f45f-dmqpq    1/1     Running   0          39s   10.244.1.47   minikube-m02
```

Figure 5.9: Deployment with topologySpreadConstraints, with the unique nodes highlighted

[3] https://kubernetes.io/docs/reference/kubernetes-api/labels-annotations-taints/

NOTE Topology spread is a scheduling-time constraint, in other words it's considered only when Pods are placed onto nodes. Once all replicas are running, if the topology changes (e.g. a node is added), the running Pods will not be moved. If needed, you can redeploy the Pods by making a change to the deployment, which will apply the scheduling rules again, so any topology changes would then be considered.

To compare, deploy the same deployment but without the `topologySpreadConstraints`, you'll notice that pods can be grouped up. Of course, due to chance they may be spread out anyway, in which case try deleting the deployment and redeploying. If you observe that the Pods are following a topology without one being explicitly set, then there's likely a default on the cluster, as in the case with GKE.

SPREADING ACROSS ZONES

`topologySpreadConstraints` can be used with any node label, so another common strategy is to spread across zones (if you have a multi zone cluster). For this you can repeat the earlier example, but using a zone-based key with `topology.kubernetes.io/zone` being the standardized "well known" key (but again, do check that your nodes actually have this label otherwise it will have no effect). Multiple topologies can be specified in the array provided to `topologySpreadConstraints`, so you can have both a node and zonal spread.

5.3.2 Collocating Interdependent Pods

In some cases, you may have tightly coupled Pods where it's desirable to have them be present on the same physical machine. Services that are particularly "chatty" (i.e. they make a lot of inter-service procedure calls) are often candidates for this type of architecture. Say that you have a front end, and a backend and they communicate a lot between each other. You may wish to pair them on nodes together to reduce network latency and traffic.

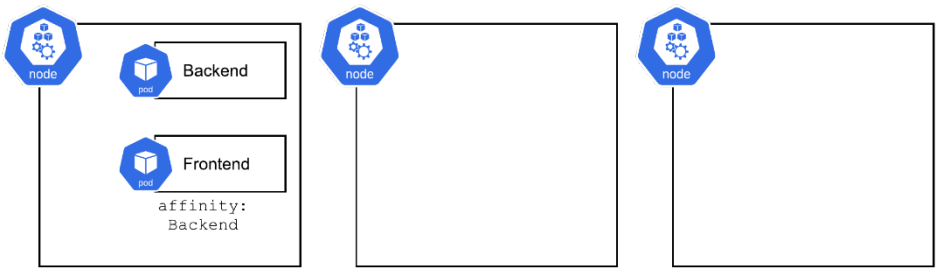


Figure 5.10: 3 frontend pods scheduled on the same node as the backend pod using pod affinity

This deployment construct can be achieved through Pod affinity rules. Essentially one of the deployments, using the above example perhaps the frontend, gets a rule that tells the scheduler "only place this Pod on nodes which have a backend Pod".

Let's say we have the following "backend" deployment:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: mariadb-deploy
spec:
  replicas: 1
  selector:
    matchLabels:
      app: mariadb
  template:
    metadata:
      labels:
        app: mariadb
    spec:
      containers:
      - name: mariadb-container
        image: mariadb
        env:
          - name: MARIADB_RANDOM_ROOT_PASSWORD
            value: "1"
```

There is nothing special about this deployment at all, it follows the same pattern we've been using. This Pod will be placed on any available space in the cluster.

Now, for the "frontend" deployment where we want to require it to be placed on nodes with instances of a Pod from the backend deployment, we can use the following configuration.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-deploy
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
      affinity: #a
        podAffinity:
          requiredDuringSchedulingIgnoredDuringExecution:
          - labelSelector:
              matchExpressions:
              - key: app
                operator: In
                values:
                - mariadb
            topologyKey: "kubernetes.io/hostname"
```

#A Pod affinity rule

This specification requires that the scheduler locate this Pod on a node within the specified topology that has an existing pod with the label "app: mariadb". As the topology in the example is a node

topology (using the well-known label for hostname), this means that the app will only be scheduled onto a node that has the target Pod. If a zonal topology was used (using the well-known label for zone, as discussed in 5.3.1), then the Pod would be placed on any node in the zone that has an existing pod with the target label.

To make this co-location a "soft" (or best-effort) requirement so that your Pods will still be scheduled, even if the requirement can't be satisfied, the `preferredDuringSchedulingIgnoredDuringExecution` can be used instead of `requiredDuringSchedulingIgnoredDuringExecution`.

As you can see, Kubernetes is really flexible allowing you to make scheduling rules binding or just guidelines, and specify your preferred topology in a myriad of ways (with node and zonal being two common choices). It's easy to get bamboozled with the choice. For most deployments, I would advise **not** using Pod affinities at the outset, but rather keep these techniques in your back pocket, and applying them when you have specific issues you wish to resolve (e.g. like wanting to co-locate Pods on a single node to reduce inter-service latency).

5.3.3 Avoiding Related Pods

In the earlier section "Building Highly Available Deployments", I covered how you can use topology spread to spread out Pods from the same deployment to avoid single points of failure. What about Pods that are related (so you want them spread out) but are deployed separately? An example might be say you have a deployment for a backend service, and a separate deployment for a caching service, and would prefer they be spread out.

For this, you can use pod anti-affinity. This is simply throwing the pod affinity rule from the previous section into reverse so that the Pods will be scheduled on other nodes (or the topology of your choice).

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-deploy
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
      affinity:
        podAntiAffinity: #A
          requiredDuringSchedulingIgnoredDuringExecution:
          - labelSelector:
              matchExpressions:
              - key: app
                operator: In
                values:
                - mariadb
```

```
            topologyKey: "kubernetes.io/hostname"
```

#A the pod affinity rule from the previous example is reversed, so now this Pod will explicitly avoid nodes that have a pod with the "`app: mariadb`" label.

All these things can act together too, so you can have a topology spread that seeks to keep pods apart, just be careful that your rules *can* actually be satisfied, otherwise you'll end up with unscheduled Pods. As with affinities in the previous section, you can also use "soft" rules by specifying `preferredDuringSchedulingIgnoredDuringExecution` instead of `requiredDuringSchedulingIgnoredDuringExecution`. When doing this, you might want to test it first with the required rule to ensure you have your `labelSelector` setup correctly, before relaxing the rule. Section 5.3.5 has some more debugging tips for setting these rules.

5.3.4 Avoiding or Targeting Groups of Nodes

Another common Pod placement requirement is to explicitly target, or avoid certain groups of nodes. For example, say you have a super expensive node type with GPU hardware, you wouldn't want your "normal" Pods to use it. Similarly, you will have Pods that explicitly need to land on those nodes (and not the others).

The first half of this requirement—to have Pods avoid certain groups of nodes by default—is achieved with a design known as taints. The special nodes, whether they are more limited than normal (e.g. preemptible VMs – ones that may only run for a short period of time), or more capable than normal (e.g. with an expensive GPU attached), or for any other reason are "tainted". Only workloads that are marked as specifically "tolerating" the taint will then be scheduled on these nodes. So you don't have to worry about a batch job being scheduled on your expensive nodes, or a critical piece of serving infrastructure landing on a preemptible VM, when those nodes have been tainted.

To taint your nodes, you can taint them directly with kubectl like so:

```
kubectl taint nodes NODE_NAME preemptible=true:NoSchedule
```

And remove it like so:

```
kubectl taint nodes NODE_NAME preemptible-
```

In this example, `preemptible=true` is the name we gave to the taint, and is used later when marking Pods as able to tolerate this taint. The NoSchedule which follows indicates the desired behavior of the effect of this taint (that Pods without the toleration should not be scheduled). There are alternatives to the `NoSchedule` behavior, but I do not recommend them. `PreferNoSchedule` is an option that creates a soft rule which may sound useful, but if your primary goal is to avoid scheduling pods on classes of nodes, a soft rule would not achieve that and may make it harder to debug. Sometimes it's better to have an unscheduled Pod that you need to allocate resources for, than having it scheduled on your special tainted machines and cause other unspecified issues.

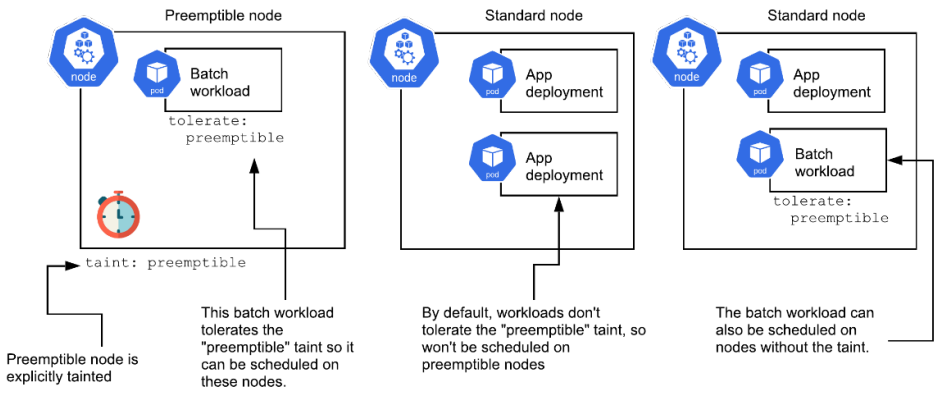


Figure 5.11: This cluster has a lower-quality preemptible VM, and 2 standard nodes.

The preemptible node is tainted to prevent Pods landing on it by default. Only Pods specifically marked as tolerating the taint, which the Batch workload does, can be scheduled on this tainted node. The batch workload is still eligible to be scheduled on untainted nodes.

The above command tainted an existing node, however generally speaking you'll want to taint *groups of nodes* that share a certain characteristic, and have this taint persist during upgrades and scaling. As node creation and updates are in the domain of your platform provider, the API you'll use to taint these groups of pods will vary by provider. In the case of GKE, node pool taints are applied at node pool creation time, like so:

```
gcloud container node-pools create NODE_POOL_NAME --cluster CLUSTER_NAME \
  --node-taints preemptible=true:NoSchedule
```

Then for those Pods which are OK with the taint (preemptible=true in this example), they can be marked as so:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-deploy
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
      tolerations:
      - key: "preemptible"
        value: "true"
```

So, taints are how you prevent Pods landing on certain nodes (like lower grade preemptible ones), and tolerations are how Pods can are marked as being compatible with these tainted nodes. Tolerations alone though don't force the Pod to *only* be scheduled on tainted nodes, they just make it possible. In cases where you both want to exclude other Pods *and* require that all of a given Pod are scheduled on these nodes, you need one more piece of config. This is a common pattern when you want to reserve a group of nodes for some Pods exclusively, for example in the case of expensive nodes with GPUs attached, you'll want your GPU workloads to land on these nodes but not Pods that don't need a GPU.

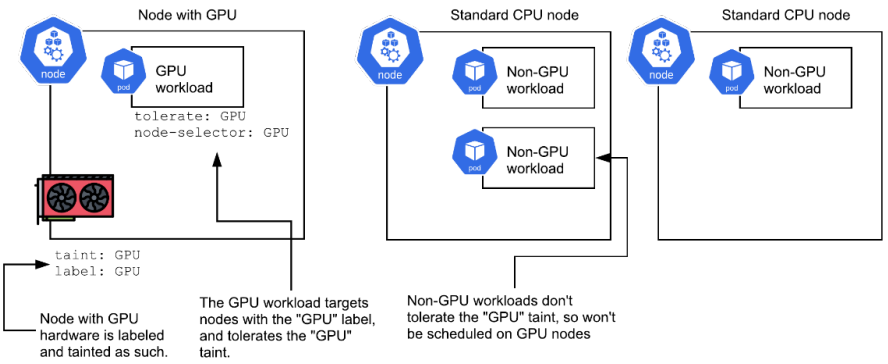


Figure 5.12: This cluster has a special node with a GPU, and 2 standard nodes.

The GPU node is tainted to prevent standard workloads from being scheduled on it. The GPU workload tolerates the taint, so can be scheduled on the GPU node, and uses a nodeSelector to ensure it is *only* scheduled on this node.

Once the taint is applied as above to prevent Pods being scheduled on your expensive node by default, you'll then need to use a node selector to target the property of the node to force the Pods to be scheduled only on that type of node. The simplest way to do this is with a nodeSelector. Node selectors target node labels, so first take a look at the labels on your node. You can use kubectl to describe the nodes and view labels:

```
kubectl describe nodes
```

Here's some example output from GKE

```
Name:               gke-cluster-1-pool-1-c7d036dd-hmvt
Roles:              <none>
Labels:             beta.kubernetes.io/arch=amd64
                    beta.kubernetes.io/instance-type=e2-standard-8
                    beta.kubernetes.io/os=linux
                    cloud.google.com/gke-nodepool=pool-1
                    cloud.google.com/gke-os-distribution=cos
                    failure-domain.beta.kubernetes.io/region=us-central1
                    failure-domain.beta.kubernetes.io/zone=us-central1-c
                    kubernetes.io/arch=amd64
                    kubernetes.io/hostname=gke-cluster-1-pool-1-c7d036dd-hmvt
                    kubernetes.io/os=linux
Annotations:        container.googleapis.com/instance_id: 7069679921314020139
                    node.alpha.kubernetes.io/ttl: 0
                    volumes.kubernetes.io/controller-managed-attach-detach: true
CreationTimestamp:  Wed, 15 Jul 2020 15:41:18 -0700
```

As you can see one of the labels is the node's node pool (`cloud.google.com/gke-nodepool`). Other providers will have a different label, but the concept is the same. We can target this label with our Pods using a **node selector** which will mean that they will only be scheduled on to this node pool

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-deploy
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      nodeSelector:
        cloud.google.com/gke-nodepool: pool-1 #A
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
```

#A Any node label can be used for the selector. Here we're using a GKE-specific one that targets a particular node pool

5.3.5 Debugging Placement Issues

Pod placement is a pretty complex topic, so don't be surprised if you run into problems. Here are the two most common:

PLACEMENT RULES DON'T APPEAR TO WORK

If your placement rules don't appear to work in testing, the first thing I'd suggest is ensure you are not using any "soft" placement rules. These rules mean that the scheduler basically ignores your rule when it can't be satisfied, which isn't so great for testing. It's better to verify that all your rules are working before relaxing them by changing them to soft rules.

Use a small cluster with only a couple of nodes, no soft rules, and you should be able to observe the affect of the placement features. Verify that the rules are enforced by intentionally attempting to schedule Pods that would violate the rules, their status should be "Pending" the constraints can't be satisfied.

PODS ARE PENDING

Pods that display as the "Pending" state mean that the scheduler can't find a suitable place for them. In Chapter 3, we discussed this error in the context of the cluster not having enough resources to place the Pod. Once you configure your placement rules, it's possible the Pod can't be scheduled because the rules can't be satisfied. To find out what the reason is (i.e. which rule couldn't be satisfied), *describe* the pod. Note, that you need to do this at a Pod level – the deployment itself won't show any error messages (although it will indicate that the desired number of replicas isn't met).

```
kubectl get pods
kubectl describe pod POD_NAME
```

Example abridged output:

```
Events:
  Type     Reason            Age   From               Message
  ----     ------            ----  ----               -------
Warning  FailedScheduling  4s    default-scheduler  0/1 nodes are available: 1 node(s) had taints
       that the pod didn't tolerate. #A
```

#A There are no nodes available without taints. Either add a tolleration to this pod, or add more untained nodes

```
Warning  FailedScheduling  17s (x3 over 90s)     default-scheduler  0/1 nodes are available: 1
       node(s) didn't match pod affinity/anti-affinity, 1 node(s) didn't match pod anti-affinity
       rules. #A
```

#A The Pod's affinity or anti-affinity rules could not be satisfied. Review and revise the rules.

5.3.6 Other Placement Policies

I chose to cover several of the most common situations for pod placement: spreading pods to achieve higher availability, bunching "chatty" pods together, and setting up groups of nodes that can be avoided, or targeted by Pods with specific requirements.

There are many other policies you can use, and the ones I showed can be configured to achieve completely different objectives than the ones I focused on. Examples include using node affinity and anti-affinity instead of `nodeSelector` for more expressive constraints that the option for "soft"

preferences (where the Pod can still be scheduled even if the preference is not met), as well as pod affinity (covered in Section 5.3.2) and anti-affinity, requiring that pods be placed, or not be placed on the same node as other pods.

5.4 Summary

The Kubernetes scheduler lies at the core of the system and does the heavy lifting of finding the right home for your deployment's Pods on your infrastructure.

- The scheduler will try to fit as many containers as it can on a given node, provided Pods have resource requests set appropriately
- Kubernetes uses the Pod's resource requests and limits to govern how resources are allocated, overcommitted, and reclaimed
- Overcommitting resources using bursting can save resources but introduces performance variability
- The specification of requests and limits by your workloads sets the quality of service they receive, but also the resources consumed yielding a trade-off between performance and price
- When designing your workloads, there is an availability/resource-usage trade-off between the replica count and the Pod's internal thread/process worker count
- You have many tools to guide the layout of your Pods to suite your needs
- Topology spread policy can be used to spread your Pod replicas out, and many platforms will have a default spread policy
- Pods that benefit from being in proximity to each other can be co-located with pod affinity
- To spread related but different Pods, anti-affinity rules can be applied
- Taints can be used to prevent workloads landing on certain types of nodes by default
- Tolerations and node selectors can be used to target specific workloads at tainted nodes

6

Scaling Up

This chapter covers

- Scaling Pods and Nodes manually
- How Kubernetes platforms can be configured to add and remove nodes automatically based on the resources your Pods require
- Using request-based metrics to dynamically scale Pod replicas
- Using low priority "balloon" pods to provision burst capacity
- Architecting apps so that they can be scaled

Now that we have the application deployed and have health checks in place to keep it running without intervention, it's a good time to look at how you're going to scale up. I've named this chapter "scaling up", as I think everyone cares deeply about whether their system architecture can handle being scaled up when your application becomes wildly successful and you need to serve all your new users, but don't worry I'll also cover scaling down so you can save money during the quiet periods.

Our goal is ultimately to operationalize our deployment using automatic scaling, that way we can be fast asleep, or relaxing on a beach in Australia, and our application can be responding to traffic spikes dynamically. To get there, we'll need to ensure that the application is capable of scaling, understand the scaling interactions of Pods and Nodes in the Kubernetes cluster, and the right metrics to configure an autoscaler to do it all for us.

6.1 Scaling Pods and Nodes

Getting your application containerized and deployed on Kubernetes is a great step towards building an application deployment that is capable of scaling and supporting your growth. Let's now go over how to actually scale things up when that moment of success arrives, and the traffic increases (and scale things down to save some money in the quiet periods).

In Kubernetes, there are essentially two resources that you need to scale: your application (Pods), and the compute resources they run on (Nodes). What can make life a bit complicated is that the way you scale these resources is separate, even though the requirements (e.g. more application capacity) are somewhat correlated. It's not enough to just scale Pods as they'll run out of compute resources to run on, nor is it enough to scale up your Nodes, as that just adds empty capacity. Scaling both in unison and at the correct ratio is what's needed. Fortunately there are some tools to make your life easier which I'll cover below.

To handle more traffic to your application, you'll need to increase the number of Pod replicas. Starting with the manual approach, you can achieve this by updating your deployment configuration with the desired number of replicas.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 6 #A
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
```

#A The replicas field specifies how many duplicate copies of your Pod that you wish to be running

As usual, you can apply changes you make to config with `kubectl apply -f deploy.yaml`.

Kubectl also offers a convenient imperative command that can achieve the same result:

```
kubectl scale deployment YOUR_DEPLOYMENT –replicas=6
```

Where the nodes come in, is that if you try to add too many Pod replicas, you'll run out of space on your cluster for those Pods to be scheduled. You'll know when you've run out of room when you run `kubectl get pods`, and a bunch are listed as "Pending".

Pods can be in "Pending" for a number of reasons, the most common of which is a lack of resources. Essentially the lack of resources is an unsatisfied condition, and the Pod remains "Pending" until the condition can be satisfied. There can be other unsatisfied conditions as well if the Pod has dependencies (like requiring to be deployed on a node with another Pod that hasn't been created). To disambiguate, descript the pod with `kubectl describe pod POD_NAME`, and look at the events. If you see an event such as "FailedScheduling" with a message like "Insufficient cpu", you likely need to add more nodes.

Nodeless Kubernetes

I'd like to take a moment to cover nodeless Kubernetes platforms. It is my opinion that the ideal cloud Kubernetes platform is one where the operator doesn't really need to care a whole lot about nodes. After all, if you're using the Cloud, why not have a platform that provisions the node resources that are needed based on the pod's requirements so you can focus more on creating great applications?

In my day job, as a Product Manager at Google Cloud, this is exactly the product that I created with my team, and we called it *GKE Autopilot*. The design of *Autopilot* is my take on a "nodeless" Kubernetes platform, one where the nodes are outside the developer's concern. Create your Pods using the Deployment object (Chapter 3), set your resource requests (Chapter 5) and replica count (above section), and *Autopilot* will provision the compute your Pods need.

One thing that sets *Autopilot* apart from the pack is that the Kubernetes node concept retains relevance. Much of the node-related scheduling logic (e.g. spread topologies, affinity, and anti-affinity covered in Chapter 5) is relevant and can still be used. *Autopilot* is "nodeless" in the sense that you no longer need to worry about how nodes are provisioned or managed, but it doesn't completely abstract away or hide nodes. After all, there *is* a machine somewhere running your code, and this can have physical relevance around things like failure domains or wishing to co-locate pods for reduced latency.

I believe *Autopilot* has a best-of-both worlds design that gives you the node level controls that you need, while still removing the burden of operating and administering those nodes. No need to care any more about how many nodes you have, their size and shape, whether they are healthy, and whether they are sitting idle or underused.

If you are using GKE Autopilot or a platform like it, you can basically ignore everything in this chapter that talks about scaling *Node*s, and focus purely on scaling *Pod*s. Scaling pods manually, or automatically with a `HorizontalPodAutoscaler` works in *Autopilot* to also provision the necessary node resources, without the need to pair it with another system that scales nodes.

To scale the nodes, you'll need to consult your Kubernetes provider's platform documentation, as Kubernetes itself doesn't orchestrate nodes. In the case of GKE, if you use Autopilot nodes are provisioned automatically, and you can skip right ahead to Section 6.2. For GKE's Standard mode of operation, the command looks like this:

```
gcloud container clusters resize cluster-name --node-pool pool-name \
--num-nodes 10
```

Scaling down is performed with the same commands. When you scale down the nodes, depending on your provider, you should be able to run the same command as to scale up, and the cluster will first cordon and drain the nodes (to prevent new Pods being scheduled on them, and give running Pods' time to shutdown gracefully and be re-created on other nodes). Alternatively, you can manually cordon, drain, and remove nodes with the following commands:

```
kubectl get nodes # get a list of node names
kubectl cordon node NODE_NAME # prevent scheduling on the node
kubectl drain node NODE_NAME # remove running pods from the node
kubectl delete node NODE_NAME
```

These manual steps are also useful if you have a node that you found was not behaving correctly, and you want it gone.

So, this is how you scale Pods and Nodes by hand. Read on to learn how you can automate both these operations with Horizontal Pod Autoscaling to scale pods, and Cluster Autoscaling to scale Nodes (for Cloud providers that offer it).

6.2 Horizontal Pod Autoscaling

Scaling the number of Pod replicas of your application in Kubernetes is referred to as horizontal pod autoscaling. It's "horizontal" as you're increasing the number of replicas in order to serve increased traffic, rather than "vertical" which implies increasing the resources available to each replica instead. Generally, to scale up a system, it's horizontal scaling that you want.

Kubernetes includes a feature called the Horizontal Pod Autoscaler (HPA), a system whereby you specify a Pod *metric* like CPU usage to observe and target, along with some scaling limits (minimum and maximum replicas). The HPA will then aim to satisfy your metric by creating and removing Pods. In the case of CPU, say your target is 20% CPU utilization, this means that the HPA will add replicas when your utilization goes above 20%, and remove them when it goes below 20%. These actions are subject to a minimum and maximum limit you provide, as well as cooldown periods to avoid too much churn.

We can create a HPA for our deployment like so:

```
apiVersion: autoscaling/v1
kind: HorizontalPodAutoscaler
metadata:
  name: pluscode-autoscaler
spec:
  minReplicas: 1 #A
  maxReplicas: 10 #B
  targetCPUUtilizationPercentage: 20 #C
scaleTargetRef: #D
    apiVersion: apps/v1 #D
    kind: Deployment #D
    name: pluscode-demo #D
```

#A minimum number of replicas
#B maximum number of replicas
#C The CPU utilization target (will create more replicas when the Pod CPU utilization is higher than this value)
#D The deployment that will be scaled

You can also create it imperatively. As always, I prefer the config approach as it makes it easier to edit things later. But here is the equivalent imperative command for completeness:

```
kubectl autoscale deployment pluscode-demo --cpu-percent=20 --min=1 --max=10
```

To test this, we'll need to make the CPU really busy. Fortunately, I added an endpoint (`/pi`) to the sample app that performs a really CPU-intensive operation by using an inefficient algorithm to calculate Pi.

Create the HPA definition above with the deployment and service YAML files we've been using so far. You can deploy all 3 from the samples repo like so:

```
cd 06/6_5
kubectl create -f .
kubectl get svc -w # wait for the external IP
```

While you're waiting for the external IP to be provisioned you can start watching the CPU utilization of your Pods with the following command (I'd suggest putting it in a new window):

```
kubectl top pods
```

Once you have the external IP, generate some load on the endpoint (again, I'd create a new window for this so you can watch everything together). I like Apache Bench for this, which you can install for most systems. The following command will send 50 requests simultaneously to our endpoint, until 10k have been sent—that should do it!

```
ab -n 10000 -c 50 http://$EXTERNAL_IP/pi
```

Back in the first window, you can watch the status of the deployment with

```
kubectl get pods -w
```

Or, if you have the `watch` command installed (see Section 3.2.5), I like the following command. Kubernetes' inbuilt watch switch doesn't handle multiple objects, but `watch` does so let's take advantage of it and show the deployment, HPA and pods all at once!

```
watch -d kubectl get deploy,hpa,pods
```

If all goes correctly, you should observe the CPU utilization increase in the window with `top`, and more replicas being created in the `watch` window. Once you stop sending load to the endpoint (e.g. by cancelling the `ab` command), you should observe these replicas gradually being removed. Generally the removal of replicas is slower than the addition, so that the system quickly scales up to meet demand, and cautiously scales down so that there's a bit of spare capacity in case the demand is spikey.

The HPA autoscaler shown here worked pretty well using the CPU metric, but there's a catch—your workload may not be CPU bound. Unlike the CPU-intensive request used in the demo, many HTTP services spend a lot of time waiting on external services like databases. These deployments may need to scale using other metrics like the number of requests per second hitting the service, rather than the CPU utilization. Kubernetes offers two built in metrics: CPU (demonstrated above), and memory. It doesn't directly support metrics like requests per second, but it can be configured by using custom and external metrics exposed by your monitoring service. The next section covers this situation.

What about *Vertical* Pod Autoscaling?

Vertical Pod Autoscaling (VPA) is a concept whereby Pods are scaled vertically by adjusting their CPU and memory resources. Implementations of VPA in Kubernetes achieve this by observing the Pods resource usage, and dynamically changing the Pod's resource requests over time. Kubernetes doesn't offer a VPA implementation out of the box, although an open source implementation is available[1], and cloud providers including GKE offer their own versions.

As a VPA can determine a Pod's resource requests automatically, it could save you some effort and provide some resource efficiency. It's also the right tool for the job if you need the Pod's resource requests to be adjusted dynamically over time (for Pods who have resource requirements that fluctuate widely).

Using a VPA adds its own complexity and may not always play nice with the HPA. I would focus first on setting appropriate pod resource requests, and the horizontal scaling of replicas, which is what this chapter covers before looking at VPA.

6.2.1 External Metrics

One popular scaling metric is Requests per Second (RPS). The basis of using RPS metrics for scaling is that you measure how many requests an instance of your application can serve every second (the replica's capacity). Then, you divide the current number of requests by this amount, and voila, you have the number of replicas needed.

```
replica_count = RPS ÷ replica_capacity
```

The benefit of the RPS metric is that if you are confident of your application to handle the RPS that you tested it for, then you can be confident that it should be able to scale under load as it's the auto-scaler's job to provision enough capacity.

In fact, even if you're not doing *auto* scaling, this is still a really good way to plan your capacity. You can measure the capacity of your replicas, project your traffic and increase your replicas accordingly. But since this is Kubernetes, we can set this up as an auto scaler.

Now in this case, we'll be using the "external metric" property of the HPA. One issue with this is that the metric, as its name suggests, it is sourced from outside the cluster. So, if you're using a different monitoring solution than the one I'm demoing you'll need to look up what the relevant RPS metric is. Fortunately, this is a pretty common metric, and any monitoring solution worth its salt will offer it.

In prior chapters we discussed a few different ways to get traffic into your cluster, via a so-called L3 LoadBalancer which operates at a TCP/IP level, and a so-called L7 ingress which operates at the HTTP level. As "requests" are a HTTP concept, you'll need to be using an Ingress to get this metric.

Let's use our deployment from Ch.3

[1] https://github.com/kubernetes/autoscaler/tree/master/vertical-pod-autoscaler

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-demo
spec:
  replicas: 1
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        resources:
            requests:
              cpu: 200m
              memory: 250Mi
```

Exposed with the following Service and Ingress.

```
apiVersion: v1
kind: Service
metadata:
  name: pluscode-service
spec:
  selector:
    app: pluscode
  ports:
  - port: 80
    targetPort: 80
    protocol: TCP
  type: NodePort

   ---

apiVersion: networking.k8s.io/v1beta1
kind: Ingress
metadata:
  name: pluscode-ingress
spec:
  rules:
  - http:
      paths:
      - path: /
        pathType: Prefix
        backend:
          serviceName: pluscode-service
          servicePort: 80
```

Now if you're using Google Cloud, the following HPA definition can pick up the RPS metric from the L7 ingress, once you replace the forwarding rule name with your own.

Listing 6.1 A horizontal pod autoscaler using an external metric: this one, a RPS metric sourced from Google Cloud Monitoring

```
apiVersion: autoscaling/v2beta1
kind: HorizontalPodAutoscaler
metadata:
  name: pluscode-autoscaler
spec:
  minReplicas: 1
  maxReplicas: 6
  scaleTargetRef:
    apiVersion: apps/v1
    kind: Deployment
    name: pluscode-demo
  metrics:
  - type: External
    external:
      metricName: loadbalancing.googleapis.com|https|request_count
      metricSelector:
        matchLabels:
          resource.labels.forwarding_rule_name: k8s2-fr-pqqby6yf-default-pluscode-ingress-
       hrsjzvkf
      targetAverageValue: 5
```

The `forwarding_rule_name` is how the metric server knows which ingress object you're talking about. You can omit the `metricSelector` completely, but then it will match on *all* ingress objects, probably not what you want.

Unfortuantely this forwarding rule name is a platform resource name, and not the Kubernetes object name (and in this example, that name is set automatically by GKE). To discover the platform resource name, you can describe your ingress object like so:

```
kubectl describe ingress

Name:             pluscode-ingress
Namespace:        default
Address:          34.120.223.5
Default backend:  default-http-backend:80 (10.60.2.5:8080)
Rules:
  Host        Path  Backends
  ----        ----  --------
  *
              /*     pluscode-service:80 (10.60.0.16:80,10.60.1.22:80,10.60.1.26:80 + 1 more...)
Annotations:  ingress.kubernetes.io/backends: {"k8s-be-30870--8c5585a7e32845e3":"HEALTHY","k8s-
       be-31212--8c5585a7e32845e3":"HEALTHY"}
              ingress.kubernetes.io/forwarding-rule: k8s2-fr-pqqby6yf-default-pluscode-ingress-
       hrsjzvkf
              ingress.kubernetes.io/target-proxy: k8s2-tp-pqqby6yf-default-pluscode-ingress-
       hrsjzvkf
              ingress.kubernetes.io/url-map: k8s2-um-pqqby6yf-default-pluscode-ingress-hrsjzvkf
Events:       <none>
```

There's another way to do this too, which is particularly useful for automation. kubectl supports jsonPath lookups (essentially a query on the returned data). We can look up the right annotation like so:

```
# kubectl get ingress -
       o=jsonpath="{.items[0].metadata.annotations['ingress\.kubernetes\.io\/forwarding-rule']}"

k8s2-fr-pqqby6yf-default-pluscode-ingress-hrsjzvk
```

Now there's one last step which is to install some glue that gives the HPA access to the metrics. You may want to check the latest instructions[2], at the time of writing it's a one-liner:

```
kubectl apply -f https://raw.githubusercontent.com/GoogleCloudPlatform/k8s-
       stackdriver/master/custom-metrics-stackdriver-
       adapter/deploy/production/adapter_new_resource_model.yaml
```

With our Deployment, (internal NodePort) Service, Ingress, HPA and metric adapter all configured, we can now try it out!

Generate some requests to the ingress IP with:

```
ab -n 10000 -c 100 -s 300 IP_ADDRESS
```

And observe the HPA with

```
kubectl get hpa,pods
```

One thing you may notice already is that it's already easier to validate that the system is performing more as expected. Apache Bench allows you to specify concurrent requests, you can see how long they take (and therefore calculate the RPS) and look at the number of replicas to see if it's right. This was a bit harder with the CPU metric where to test you might have just tried to make the pod as busy as possible. This property of scaling based on *user requests* is one reason why this is a popular metric to use.

OBSERVING AND DEBUGGING

To see what the HPA is doing, you can run `kubectl describe hpa`. Pay particular attention to the "ScalingActive" condition. If it is `False`, then it likely means that your metric is not active which can be for a number of reasons: a) the metric adapter wasn't installed (or isn't authenticated), b) your metric name or selector is wrong, or c) there just isn't any metrics available yet. Note that even with the correct configuration, you will see 'False' when there is no data (for example there are no requests), so be sure to send some requests to the endpoint and wait a minute or two for the data to come through before investigating further.

AVERAGEVALUE VS VALUE

In the example above, we used `targetAverageValue`. `targetAverageValue` is the target *per pod* value of the metric. `targetValue` is an alternative, which is the target absolute value. As the RPS capacity is calculated at a per-pod level, it's `targetAverageValue` we want.

OTHER METRICS

Another popular external metric when dealing with Batch Jobs (covered in a later chapter) is the PubSub queue length. PubSub is a queuing system that allows you to have a queue of work that needs to be performed, and you can set up a workload in Kubernetes to process that queue. For such a setup, you may wish to react to the queue size by adding and removing Pod replicas

[2] https://github.com/GoogleCloudPlatform/k8s-stackdriver/tree/master/custom-metrics-stackdriver-adapter

(workers that can process the queue). You can find a fully worked example on the GKE docs[3] for this, essentially it boils down to a HPA that looks like the one above, just with a different metric:

```
      metricName: pubsub.googleapis.com|subscription|num_undelivered_messages #A
      metricSelector:
        matchLabels:
          resource.labels.subscription_id: your-subscription #B
```

#A the metric name
#B the resource for the metric, in this case the PubSub's GCP resource name

OTHER MONITORING SOLUTIONS

External metrics is something you should be able to configure for *any* Kubernetes monitoring system. While the worked example given above was using Cloud Monitoring on GCP, the same principles should apply if you're using Prometheus, or another cloud. To get things going, you'll need to determine a) how to install the metric adapter for your monitoring solution b) what the metric name is in that system, and c) the right way to select the metric resource.

6.3 Node Autoscaling & Capacity Planning

6.3.1 Cluster Autoscaling

Cluster autoscaling obviates the need to scale your nodes manually, allowing you to focus just on your application and how many replicas it has. This is a platform-specific feature so the exact implementation will vary (and not all providers will offer it). Search for "*product name* Cluster Autoscaler" to find the relevant docs.

In the case of GKE for example, if you use the Autopilot mode of operation then all clusters created (e.g. with `gcloud container clusters create-auto CLUSTER_NAME`) have autoscaling. For the Standard mode of operation, you can configure autoscaling on an existing node pool like so:

```
gcloud container node-pools update NODE_POOL_NAME --cluster CLUSTER_NAME --enable-autoscaling --
       min-nodes=1 --max-nodes=10
```

This can also be setup during creation (the `enable-autoscaling`, `min-nodes`, and `max-nodes` params can also be passed during node pool, or cluster creation). Note that this will only add nodes of the same type as defined in the node pool, so if your Pod can't fit on *any* node, it may be stuck in pending. That's where Node Auto Provisioning comes in (or, you can just use GKE Autopilot).

When using cluster autoscaling, you can focus on scaling your own workloads, having the cluster respond automatically. This is really convenient, as it can solve the "Pending" pods problem, both when scaling existing workloads and deploying new ones. Do read the specific implementation details of your provider though to understand what cases are not covered (like how pods that are too big to fit on current node configurations are handled).

[3] https://cloud.google.com/kubernetes-engine/docs/tutorials/autoscaling-metrics#pubsub_8

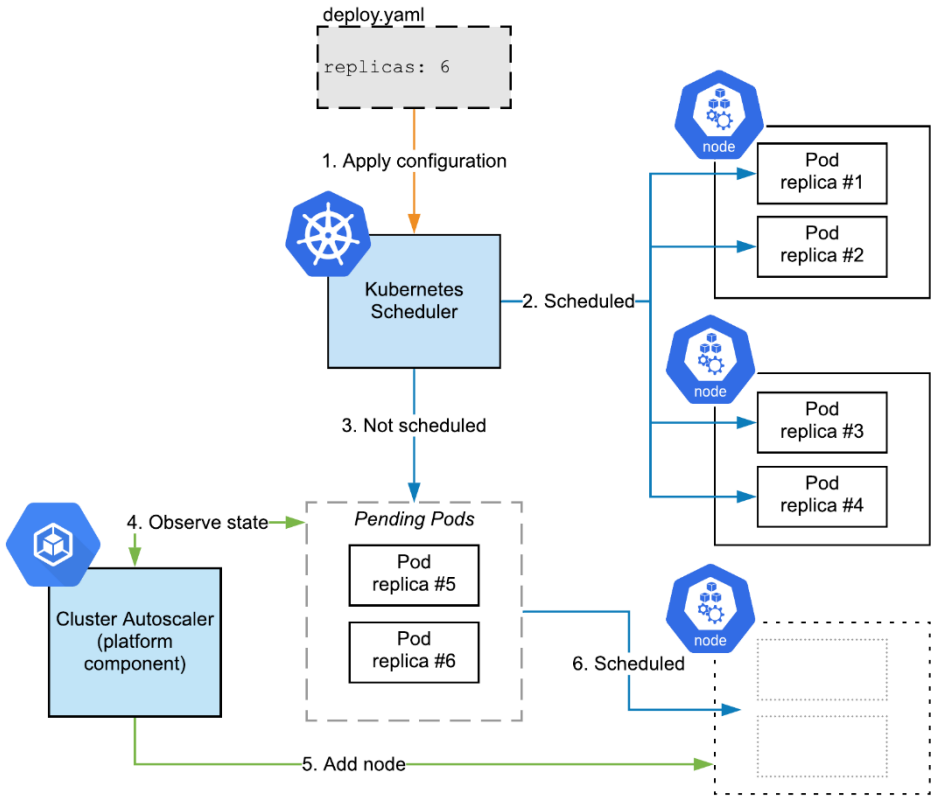


Figure6.1: The Cluster Autoscaler watches for Pending pods, and creates new nodes if needed

A common limitation of cluster autoscaling is that it may only add nodes of an existing configuration. This is very implementation dependent. In the case of GKE which defines nodes configuration in groups known as "node pools", when the Cluster Autoscaler adds a node (step 5 in the above figure), it only adds them to an existing node pool that's already been defined. Fortunately, this can be used in conjunction with a separate feature, Node Auto Provisioning (NAP) to also create the right sized machines.

The ideal way to interact with a Kubernetes platform is actually not to have to worry about nodes at all! What if your provider took care of that for you, and provisioned nodes behind the scenes (perhaps using cluster autoscaling, and node auto provisioning) to fit your workloads. This is exactly what GKE's *Autopilot* mode of operation does.

Cluster Autoscaling, advanced modes of operation like GKE's *Autopilot*, and other provider tools that can add and remove nodes automatically make your life easier by allowing you to mostly ignore nodes, and focus purely on your own Pods. Can we also make our life easier and scale the Pods too? It's Kubernetes, so of course there's a solution to this. Read on!

6.3.2 Capacity Planning with Cluster Autoscaling

One of the drawbacks of autoscaling nodes when compared to manually adding nodes to your cluster is that sometimes it can tune things a little *too* well. Let's say you run an eCommerce store, and it's the day before a major shopping event like Black Friday. Your traffic may be light at this time, and your autoscaling has provisioned your capacity appropriately, but you know you're going to need a lot of capacity tomorrow—something your automation may not be able to predict. It's risky to just wait till the next day and let the scaling do its thing because everyone else in your situation will be scaling at the same time, increasing the risk of a stock out situation (where the cloud provider has no capacity available).

Another issue with autoscaling is that adding new nodes is slower than adding new pods. Nodes have to be provisioned and booted, while Pods that get scheduled onto existing nodes just have to pull the container and boot (and if the container is already in the cache, they can even start booting right away). As shown in the figure below, the newly scheduled Pod must wait for capacity to be provisioned before it can begin booting.

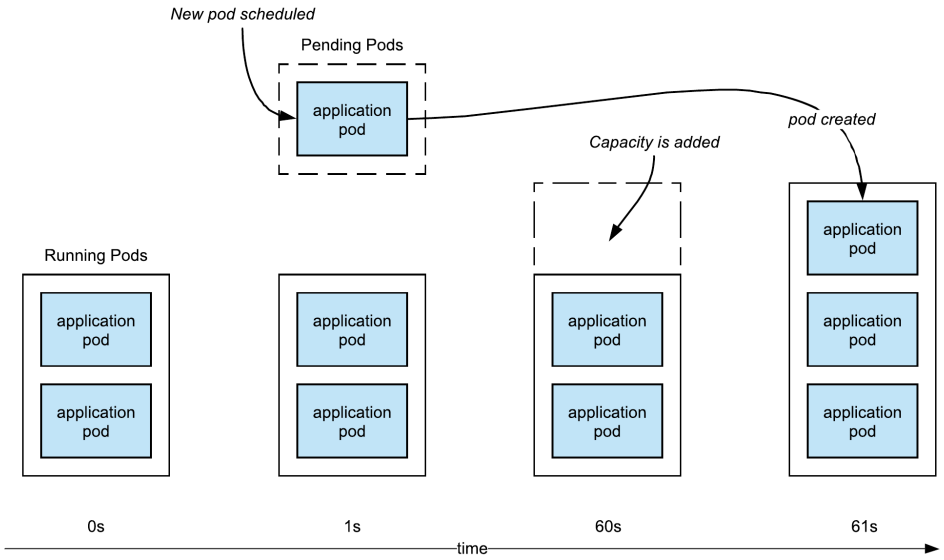


Figure 6.2: Dynamically adding capacity with autoscaling to accommodate newly scheduled pods

One way to solve both these problems, while still keeping your autoscaler is to use a low priority balloon pod. This is a Pod that does nothing itself, other than to reserve capacity (keeping additional nodes up and running on standby). This Pod's priority is low so that when your own workloads scale up, they can preempt this pod and use the node capacity.

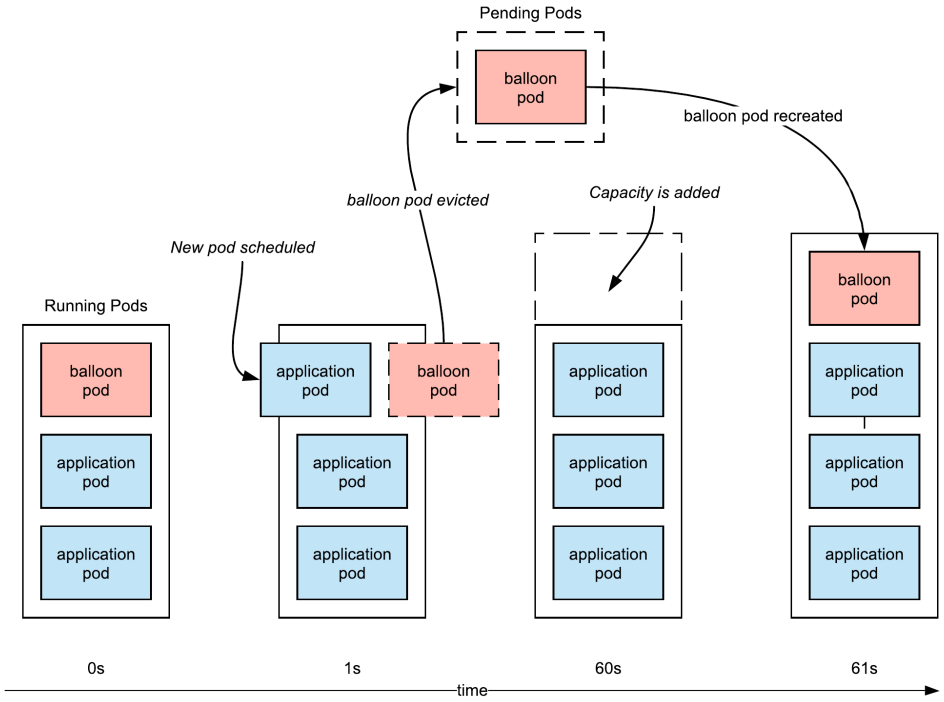


Figure 6.3: Autoscaling with a balloon pod allowing for rapid booting of new pods using spare capacity

To create our "balloon" pod deployment, first we'll need a `PriorityClass`. This priority class should have the lowest possible priority (we want every other priority class to preempt it).

```
apiVersion: scheduling.k8s.io/v1
kind: PriorityClass
metadata:
  name: balloon-priority
value: -2147483648
preemptionPolicy: Never
globalDefault: false
description: "Balloon pod priority."
```

Now we can create our "do nothing" container deployment like so:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: balloon-deploy
spec:
  replicas: 10 #A
  selector:
    matchLabels:
      app: balloon
  template:
    metadata:
      labels:
        app: balloon
    spec:
      priorityClassName: balloon-priority #B
      terminationGracePeriodSeconds: 0 #C
      containers:
      - name: ubuntu
        image: ubuntu
        command: ["sleep"] #D
        args: ["infinity"] #D
        resources:
            requests:
              cpu: 200m #E
              memory: 250Mi #E
```

#A how many replicas do you want? This, with the cpu and memory requests determines the size of the headroom capacity provided by the balloon pod
#B Use the priority we just created
#C We want this Pod to shutdown immediately with no grace period
#D This is our "do nothing" command
#E The resources that will be reserved by the balloon pod. This should be equal to the largest Pod you wish to replace this Pod

When creating this yourself, consider the number of replicas you need, the size (memory and CPU requests) of each replica. The size should be at least the size of your largest regular pod (otherwise, your workload may not fit in the space when the balloon pod is preempted). At the same time, don't increase the size too much – it would be better to use more replicas, than replicas that are much larger than your standard workloads pods if you wish to reserve extra capacity.

For these balloon pods to be preempted by other pods that you schedule, those pods will need to have a priority class that both has a higher value, and not have a `preemptionPolicy` of `Never`. Fortunately, the default priority class has a `value` of 0, and a `preemptionPolicy` of `PreemptLowerPriority`, so by default all other Pods will displace our balloon pod.

To represent the Kubernetes default as its own priority class, it would look like the following. As you don't actually need to change the default, I wouldn't bother configuring this. But if you're creating your own priority classes, you can use this as the reference (just don't set `globalDefault` to `true`, unless that's what you really intend). Once again: for the balloon pod preemption to work, be sure not to set `preemptionPolicy` to `Never`.

```
apiVersion: scheduling.k8s.io/v1
kind: PriorityClass
metadata:
  name: default-priority
value: 0
preemptionPolicy: PreemptLowerPriority
globalDefault: true
description: "The global default priority. Will preempt the balloon pods."
```

When you are running at maximum capacity, you may not need the extra headroom. So you can still configure your cluster autoscaler to have an upper bound. Once the upper bound is hit, the balloon pod will just sit in a Pending state, not adding to your bill. But when you're below that bound, the balloon pod will be scheduled, to retain the headroom.

6.4 Building Your App to Scale

Scaling your application up is only part of the equation. The application itself needs to build with scaling in mind. Even though you may not be at the point of your growth where you need to worry about these issues, I always like to say that **the time when you need to scale, is not the time to design how you're going to scale**.

When your application is one with unpredictable growth (for example, a startup with potentially unlimited users), I believe you really want to plan ahead to avoid the "success failure" scenario. This is where, in a breakout moment of your success, the app fails because it couldn't handle the scale. Since you don't know when this breakout moment will be, you need to have designed for this ahead of time. Not every startup will have a breakout moment, but if yours does, you want to be ready to capitalize on the opportunity otherwise it could all be for naught.

Fortunately, by choosing Kubernetes to orchestrate your containers, you are starting with a really solid foundation for a scalable app. This section has a few scaling basics to get you started. This process is largely independent to Kubernetes: most scalable design principles apply to both Kubernetes and non-Kubernetes environments.

Keeping some simple principles in mind as you develop your application could turn out to be hugely beneficial in the future when your breakout moment arrives, and you need the thing to go to the moon.

6.4.1 Avoiding State

One of the most important aspects to being able to scale, is avoiding local state in your applications. When each replica (instance) of your application that's running can serve any incoming request, without reference to any local state – that is files stored on the instance itself. Local data may be used as a temporary case, but the assumption it isn't shared between replicas, and there's no assumption that the data will be available in the next request. Applications designed in this way are typically called "stateless".

The most important of the twelve factors

This property of the application being stateless is, I believe, the most important factor in the popular "The Twelve-Factor App" design methodology (https://12factor.net/processes). Stateless apps are easier to scale and maintain as each instance can independently serve any request.

Unlike a classical web host deployment, in Kubernetes all data written to disk by the container is ephemeral (deleted when the container is terminated or restarted). It is possible to create stateful applications using Persistent Volumes, and the StatefulSet construct (see Chapter 9), but by default containers are treated as stateless, and you generally want to keep it that way so that you can scale.

Rather than storing state on disks that you manage in Kubernetes, use external data stores to store data instead, like SQL and NoSQL databases for structured data, object storage for files, and memory databases like Redis for session state. To support your ability to scale, choose managed services (rather than self-hosting), and ensure the services you choose can handle your potential growth.

This is not to say that state is evil. After all, you need *somewhere* to store your state, and sometimes this needs to be a self-hosted application. When you do create such an application, be sure to choose highly scalable solutions, like a popular open source solution with a track record of success (for example, Redis).

Relational Database Gotchas

If you use a relational database like MySQL and PostgreSQL to store data, then there are more than a few potential pitfalls worth paying attention to.

Taming your queries

It goes without saying that inefficient queries will give you inefficient scaling, slowing down as the amount of data increases and the number of requests increase. To keep things under control, I recommend logging and analyzing your queries, and starting early in the development process (you don't want to wait until your app is a hit to look at the queries!).

You can't improve what you don't measure, so logging the queries a request performs and their run time is the most important first step. Look for requests that generate a lot of queries, or slow queries, and start there.

Both MYSQL and PostgreSQL support the `EXPLAIN` command which can help analyze specific queries for performance. Common tactics to improve performance include adding indices for commonly searched columns, and reducing the number of JOINs you need to perform. MySQL's documentation *Optimizing SELECT Statements*[4] goes into great detail on many different optimization tactics.

Avoid N+1 queries

[4] https://dev.mysql.com/doc/refman/8.0/en/select-optimization.html

Even if your queries are super-efficient, each individual query you make to the database has overhead. Ideally each request your application processes should perform a constant number of queries, regardless of how much data is displayed.

If you have a request that renders a list of objects, you ideally want to serve this without generating a separate query for each of those objects. This is commonly referred to as the N+1 query problem (as when the problem occurs, there is often 1 query to get the list, and then one for each item – N items – in the list).

This anti-pattern is particularly common with systems that use object-rational mapping (ORM), and feature lazy loading between parent and child objects. Rendering the child objects of a one-to-many relationship with lazy loading typically results in N+1 queries (1 query for the parent, N queries for the N child objects), which will show up in your logs. Fortunately there is normally a way with such systems to indicate upfront that you plan to access the child objects so that the queries can be batched.

Such N+1 query situations can normally be optimized into a constant number of queries, either with a JOIN to return the child objects in the list query, or two queries: one to get the record set, then a second to get the details for the child objects in that set. Remember: the goal is to have a small constant number of queries per request, and in particular, the number of queries shouldn't scale linearly with the number of records being presented.

Use read replicas for SELECT queries

One of the best ways to reduce the strain on your primary DB, is to create a read replica. In cloud environments, this is often really trivial to setup. Send all your read queries to your read replica (or replicas!) to keep the load off the primary "read/write" instance.

To design your application with this pattern in mind before you actually need a read replica, you could have two database connections in your application to the same database, using the second to simulate the read replica. Setup the "read only" connection with its own user that only has read permissions. Later when you need to deploy an actual read replica, you can simply update the instance address of your second connection, and you're good to go!

Incrementing primary keys

If you really hit it big, you may end up regretting using incrementing primary keys. They're a problem for scaling, as they assume a single writable database instance (inhibiting horizontal scaling) and require a lock when inserting which impacts performance (i.e. you can't insert two records at once).

This is really only a problem at very large scale, but worth keeping in mind as it's harder to rearchitecting things when you suddenly need to scale up. The common solution to this is global UUIDs (e.g. `8fe05a6e-e65d-11ea-b0da-00155d51dc33`), a 128bit number commonly displayed as a hexadecimal string, which can be uniquely generated by any client (including code running on the user's device).

When Twitter needed to scale up, they opted instead to create their own global incrementing ids to retain the property that they are sortable (i.e. that newer tweets had a higher id), which you can read about in their post *Announcing Snowflake*[5].

On the other hand, might prefer to keep incrementing primary keys for aesthetic reasons, like when the record id is exposed to the user (as in the case of a tweet id), or for simplicity. Even if you plan to keep your incrementing primary keys for

[5] https://blog.twitter.com/engineering/en_us/a/2010/announcing-snowflake.html

a while, one step you can still take early on is not using auto incrementing primary keys in places where they wouldn't add any value, like say a user session object—maybe not *every* table needs an incrementing primary key.

6.4.2 Microservice Architectures

One way to build up your application is by splitting services into multiple services, often described as using a microservice architecture. This is basically just creating several internal services to perform separate tasks, and using remote procedure calls (a HTTP request, essentially) to call those functions from other services. This contrasts to the "monolith" service design approach, of having the complete program logic in a single container.

While there are some benefits to splitting up a monolith into multiple smaller services, there are some drawbacks as well, so I don't advocate using a microservice architecture just for the sake of it. Benefits including being able to use different programming languages for each service, being able to develop them independently (for example, by separate teams), and independent scaling. Drawbacks include more complex debugging and integration testing, as you now have more components, and need a way to trace requests through the system.

Microservice vs Monolith

For the sake of this debate, which I'm not going to litigate in this book, let me share two views on the topic and let you judge for yourself.

David Heinemeier Hansson (DHH) writes in his post *The Majestic Monolith* (https://m.signalvnoise.com/the-majestic-monolith/) that microservices is for large tech companies, and most smaller teams are better served by a "Magestic Monolith". His argument is that while microservices can have advantages in certain situations, it's not always clear cut, and the overhead—particularly for smaller teams—is not worth it.

James Lewis and Martin Fowler in their essay on *Microservices* (http://martinfowler.com/articles/microservices.html) lay out a well thought and balanced view on microservices. Benefits highlighted include a product mentality where internal teams focus on building and managing their own components, a decentralized approach that allows teams to make their own architectural decisions.

Whether you go all in on microservices or not, the key point I want to focus on here is that if you have multiple services, you can scale them separately. This is true of course even if you have just 1 internal service in addition to your main application – no need to make *every* endpoint its own service to benefit from this. For example, say you have a web application that mostly serves HTML and JSON requests, but has one endpoint that does some real-time graphics work that typically uses a lot more memory than your average request. It might be worth splitting off that graphics endpoint into its own Deployment, so you can scale it separately, and also isolate it a bit.

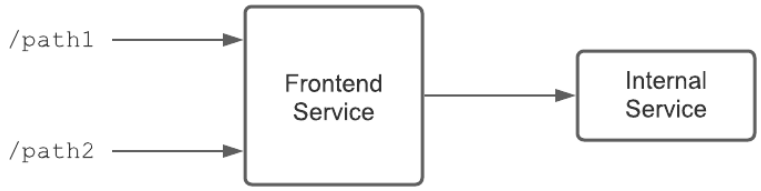


Figure 6.4: Two HTTP paths being served by the same frontend that communicates with an internal service.

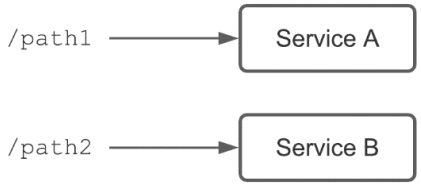


Figure 6.5: Two paths being served by separate services

Whether you are going all-in on microservices, splitting off a single service to be handled by its own scalable deployment, using multiple programming languages, or running internally developed and open-source software to provide your application, you will end up creating *internal services* in Kubernetes. Internal services are Kubernetes Services that are provisioned with a private cluster IP address, and are called by other services in the cluster in order to deliver this architecture. The next chapter covers how to configure internal services.

6.5 Summary

Kubernetes is well suited to help you scale, and proof of this is that some of the largest applications out there run on Kubernetes. To make the most of this architecture:

- Design your application at the get-go so that it can scale horizontally
- Considering splitting your application into microservices, or simply hosting multiple deployments of the same application to allow for separate scaling groups
- The Cluster Autoscaler technique (if supported by your provider) can be used to provision new nodes as needed
- The `HorizontalPodAutoscaler` can be used to provision new Pods as needed, working together with the Cluster Autoscaler for a complete auto-scaling solution
- You're not just confined to CPU metrics, but can scale your Pods based on any metric exported by your monitoring solution
- Balloon pods can be used to add capacity headroom even while autoscaling

7

Internal Services and Load Balancing

This chapter covers

- Creating internal services
- How packets are routed in Kubernetes between virtual IP addresses of pods and services
- Discovering the IP address of internal services
- Configuring HTTP Load Balancers with Ingress
- Provisioning TLS certificates to create HTTPS endpoints

Internal services are a way to scale how you develop and service your application by splitting your application into multiple smaller services. These individual services can be on different development cycles (possibly by different teams) and use completely different languages and technology from each other. After all, as long as you can containerize it, you can run it in Kubernetes. No longer do you need to worry whether your application deployment platform can run what you need it to run.

In this chapter, we'll look at how to configure and discover internal services in the cluster, as well as how Kubernetes gives each of these a cluster-local IP address and implements internal network routing to make them accessible from each other. We'll also look at how you can expose multiple services on a single external IP using Ingress, and how it can handle TLS termination so you can offer https endpoints for your application, without needing to configure TLS certificates in your applications.

This chapter covers how to configure and discover internal services in your cluster, and how to expose multiple services on a single external IP using Ingress.

7.1 Internal Services

There are many reasons to create services that are completely internal to your cluster. Perhaps you've adopted a microservice architecture, or you're integrating an open source service, or you just want to connect two applications together that are written in different languages.

In Chapter 3, I introduced Services of the type LoadBalancer as the way to get external traffic on a public IP. Services are also be used to connect internal services, but using private IP addresses. Kubernetes supports a few different Service types, the two used for internal services are `ClusterIP`, and `NodePort`.

Cluster IP gives you a virtual IP address in the Kubernetes cluster. This IP is addressable from any Pod within your cluster (like in this example, your main application). NodePort on the other hand reserves a high-level port number on each node in the cluster, allowing you to access it from any Pod using localhost, and the service IP. In both cases, Kubernetes provides the networking setup to proxy requests to the Pods that back the service.

7.1.1 Kubernetes Cluster Networking

Now might be a good time for a quick primer on Kubernetes networking. In Kubernetes, each Node, Pod and Service gets its own internal IP (on a private network). In the case of the Node, these IPs are directly routable on the private network, being assigned to a NIC (Network Interface Card). Nodes may also have a public IP routable on the public internet, but that isn't used for cluster-internal traffic.

In the case of Pods and Services, their internal IPs are virtual (there is no NIC, unlike for the nodes), and networking glue (provided by Kubernetes using either iptables or ipvs) is installed on each node to seamlessly route traffic via the node's NIC. This topic alone could fill several chapters; what you primarily need to know for deploying applications and consuming internal services is that **Pods and Services have virtual IPs that are usable within the cluster**. This means that each Pod has it's own port ranges to allocate too: you don't have to worry about port conflicts between Pods, in the same way you may normally when running several applications or containers on a host.

When a request is made from a Pod to a service over the `ClusterIP` or `NodePort`, that request is first handled by the networking glue on the node, which has an updated list from the Kubernetes control plane of every Pod that belongs to that service (and which nodes those Pods are on). It will pick one of the Pod IPs at random and route the request to that Pod via its node. Fortunately, all this happens quite seamlessly, your app can simply make a request such like HTTP GET using the IP of the service, and everything behaves as you'd expect.

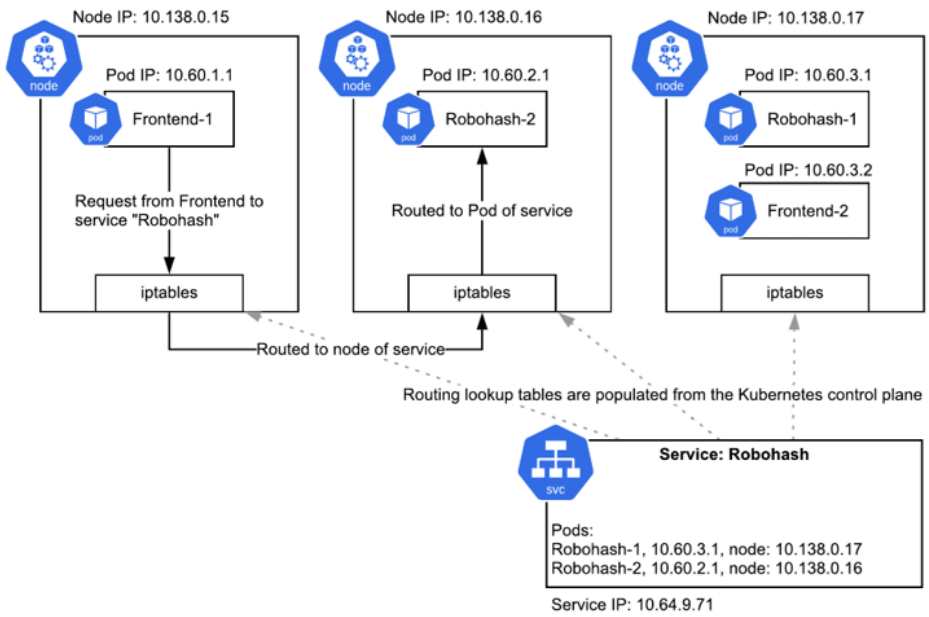


Figure 7.1: IP routing for an internal service named "Robohash". Frontend-1 Pod is makes an internal request to the service. The iptables routing glue on the node has a list of Pods for the service which is supplied by the Kubernetes control plane, and selects the Pod named "Robohash-2" at random. The request is then routed to that Pod.

What this all means is that when it's time for you to deploy an internal service, you can achieve this by creating a Service, of type `ClusterIP` thereby obtaining an IP address that the other services in your cluster (like your app's frontend) can communicate to seamlessly. This IP address will automatically balance the load between all Pod replicas of the internal service. You don't need to worry about all the networking glue that makes this possible, but hopefully this section has given you at least a superficial understanding on how it's glued together.

7.1.2 Creating an Internal Service

Now that you hopefully understand a bit about how Kubernetes networking works under the hood, let's build an internal service that can be used by other Pods in the cluster.

As an example, let's deploy a new internal service to our app. For this I'm going to use a neat open source library called "Robohash" that can generate cute robot avatars for users based on a hash (like a hash of their IP). For your own deployments, internal services can be things as simple as avatar generators, other parts of your application, or even entire database deployments.

The deployment looks like so, same as previously – just with a new container image:

```
metadata:
  name: robohash
spec:
  replicas: 2
  selector:
    matchLabels:
      app: robohash
  template:
    metadata:
      labels:
        app: robohash
    spec:
      containers:
      - name: robohash-container
        image: wdenniss/robohash:latest
        resources:
            requests:
              cpu: 100m
              memory: 50Mi
```

This time, instead of exposing this service to the world with a Service of type `LoadBalancer`, we'll keep it internal with a `NodePort` service. Why node port and cluster IP? Well, it turns out each NodePort service also gets a Cluster IP, so it's the best of both worlds. Plus, NodePort services can be used with Ingress (covered in the next section), while Cluster IP only ones cannot, so that's another advantage of choosing NodePort as the default. I setup my internal services typically with type NodePort, but will still often reference them via their assigned cluster IP as I find it a closer analogy to how you would host multiple services outside of Kubernetes.

Here's the internal service definition for our robohash deployment:

```
apiVersion: v1
kind: Service
metadata:
  name: robohash-internal
spec:
  selector:
    app: robohash
  ports:
  - port: 80
    targetPort: 80
    protocol: TCP
  type: NodePort
```

Since this isn't a LoadBalancer type service like we used in Chapter 3, it doesn't have an external IP. If you want to test it, you can use kubectl port forwarding like so:

```
kubectl port-forward service/robohash-internal 8080:80
```

Now you can browse to http://localhost:8080 on your local machine and check out the service. To generate a test avatar, try something like http://localhost:8080/example. You'll get an auto-generated robot avatar like:

Figure 7.2: Example robot avatar (attribution: Robohash.org)

Next, let's use this internal service from another service—our front end—and build out our microservice architecture!

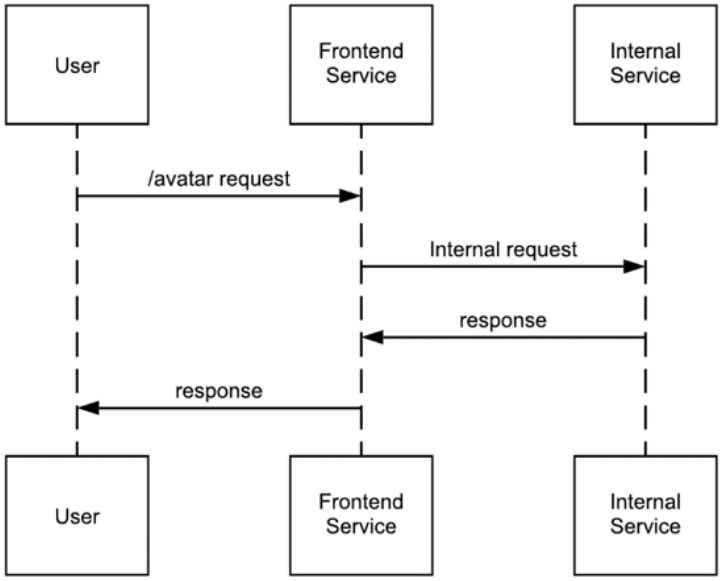


Figure 7.3: UML sequence diagram of a simple microservice configuration

To access this internal service from other Pods, you can reference its Cluster IP. As the type is `NodePort`, you can also access it over localhost on the assigned port. To view the Cluster IP and Node Port details, query the service like so:

```
$ kubectl get service
NAME              TYPE       CLUSTER-IP      EXTERNAL-IP   PORT(S)
robohash-service  NodePort   10.63.254.218   <none>        80:32473/TCP
```

In this case, you can query the service from other pods on the given Cluster IP (seen as `10.63.254.218` in the output above), such as by making a HTTP GET request to `http://10.63.254.218/example`. Or, using the node port of the service (seen as `32473` in the output above) you can also call `http://localhost:32473/example` from any node in the cluster. These paths only work from other Pods inside the cluster. There's no difference in the outcome if you use Cluster IP or the Node Port to call the service from other Pods, but from here on I'll use the cluster IP. I personally prefer to think about services mapping to IPs, as traditionally "localhost" meant the service was running on the same host, but it really doesn't matter which you choose.

7.1.3 Service Discovery

In the previous example we used `kubectl get service` to look up the internal Cluster IP address assigned to our service. While you could simply take that IP address and hardcode it into your application, doing this isn't great for portability. You may wish to deploy the same application in a few different places, like locally on your development machine, in a staging environment and in production (how to set up these different environments is covered in the next chapter), and this approach will mean you need to update your code every time.

Better is to discover the IP address dynamically in from the Pod that needs to call the service, much like we discovered the IP address using kubectl. Kubernetes offers Pods two ways to perform service discovery, using a DNS lookup, or an environment variable. The DNS lookup works cluster-wide, while the environment variable is only for Pods within the same namespace.

SERVICE DISCOVERY USING ENVIRONMENT VARIABLES

Kubernetes automatically creates an environment variable for each service and populates it with the Cluster IP, and makes this available in every Pod that is created after the service is created. The variable follows a naming conversion whereby our example `robohash-internal` service gets the environment variable `ROBOHASH_INTERNAL_SERVICE_HOST`.

Rather than figuring out the correct conversion, you can view a list of all such environment variables available to your Pod by running the `env` command on you Pod with `exec`, like so (with truncated output):

```
$ kubectl get pods
NAME                          READY   STATUS    RESTARTS   AGE
robohash-6c96c64448-7fn24   1/1     Running   0          2d23h

$ kubectl exec robohash-6c96c64448-7fn24 -- env

ROBOHASH_INTERNAL_PORT_80_TCP_ADDR=10.63.243.43
ROBOHASH_INTERNAL_PORT_80_TCP=tcp://10.63.243.43:80
ROBOHASH_INTERNAL_PORT_80_TCP_PROTO=tcp
ROBOHASH_INTERNAL_SERVICE_PORT=80
ROBOHASH_INTERNAL_PORT=tcp://10.63.243.43:80
ROBOHASH_INTERNAL_PORT_80_TCP_PORT=80
ROBOHASH_INTERNAL_SERVICE_HOST=10.63.243.43
```

The benefit of this approach is that it's extremely fast. Environment variables are just string constants, with no dependencies external to the pod itself. It also frees you to specify any DNS server you like to serve the other requests of the pod (e.g. 8.8.8.8).

The downside is that only those services in the same namespace of the Pod are populated in environment variables, and that ordering matters: the service must be created before the Pod, for the Pod to get the service's environment variable.

If you find yourself in a situation where you need to restart your Pods to pick up changes to the service, you can do this with the following command (no change to the Pod needed):

```
kubectl rollout restart deployment DEPLOYMENT_NAME
```

One common way to use these variables is to provide the complete service HTTP endpoint of the internal service in its own environment variable. This allows your container even more portable, and be run outside of Kubernetes. Here's how you can embed the value of the automatically generated environment variable (ROBOHASH_INTERNAL_SERVICE_HOST) in your own custom environment variable (AVATAR_ENDPOINT) which your application will ultimately consume:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        env:
        - name: AVATAR_ENDPOINT
          value: http://$(ROBOHASH_INTERNAL_SERVICE_HOST)
```

Using this additional layer of indirection, where our custom environment variable references the Kubernetes one is useful as now we can run this container standalone in docker (just populate AVATAR_ENDPOINT with the endpoint of the internal service wherever it's running), or switch to DNS-based lookups.

In summary, environment variable discovery has a few advantages:

- Super fast (they are string constants)
- No dependency on other the DNS Kubernetes component

And some disadvantages:

- Only available to pods in the same namespace
- Pods must be created after the service is created

SERVICE DISCOVERY USING DNS

The other way to discover services is via the cluster's internal DNS service. For services running in a different namespace to the pod, this is the only option for discovery. The service name is exposed as a DNS host, so you can simply do a DNS lookup on `robohash-internal` (or use `http://robohash-internal`) as your http path and it will resolve. When calling the service from other namespaces, append the namespace, e.g. `robohash-internal.default` to call the the service `robohash-internal` in the `default` namespace.

The only downside to this approach is that it's a little slower to resolve that IP address, as a network request is needed. In many Kubernetes clusters, this network service will be running on the same node so it's pretty fast, in others it may require a hop to the DNS service running on a different node.

To provide the endpoint URL of our internal service to our application in an environment variable (as we did using environment variable discovery) is just a matter of providing the previously constructed URL using the service name (`http://robohash-internal`). The complete deployment will look like so:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode
spec:
  replicas: 3
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: wdenniss/pluscode-demo:latest
        env:
        - name: AVATAR_ENDPOINT
          value: http://robohash-internal
```

In summary, DNS-based service discovery has a few advantages:

- Can be called from any namespace in the cluster
- No ordering dependencies

And some disadvantages:

- Slightly slower than using an environment variable (which is a constant)
- Dependency on the internal DNS service

So that is two ways how our front-end service can discover the internal service's internal Pod IP, rather than having that IP address hardcoded. We could add this to our application, safe in the knowledge we can deploy it in multiple Kubernetes environments without change. But these discovery methods are Kubernetes-specific, is there a way to avoid hardcoding the discovery logic `ROBOHASH_INTERNAL_SERVICE_HOST` or `http://robohash-internal`? Yes.

I like to provide the discovered service path *itself* as an environment variable to the container. This makes it easier to run the container *outside* of Kubernetes (for example, with Docker Compose), by setting the service path for that system. In other words, you can use `http://robohash-internal` in the Kubernetes deployment, and set it to something else when using the container standalone with Docker (using Docker's service discovery techniques).

PUTTING IT ALL TOGETHER

To try out everything we've learned here, if you have the robohash internal service deployed, and then updated or deployed the example pluscode app deployment using either environment variable or DNS based discovery, we can deploy a service of type `LoadBalancer` to get an external IP and for the demo and query the `/avatar` path from our browser. All this path does in the sample is make a HTTP request to the URL given as `AVATAR_ENDPOINT`, and return the result to the user. This is just a toy example of course, but hopefully you can imagine the internal service performing any number of complex operations.

To expose, can re-use our load balancer from Chapter 3:

```
apiVersion: v1
kind: Service
metadata:
  name: pluscode-service
spec:
  selector:
    app: pluscode
  ports:
  - port: 80
    targetPort: 80
    protocol: TCP
  type: LoadBalancer
```

Query the IP with `kubectl get service`, and view the results by browsing to the external IP, at the following path: `http://EXTERNAL_IP/avatar`.

We are now using microservice architecture for the demo! Using this technique, you can have multiple internal services that can be deployed and managed separately (perhaps by different teams). You can add in separate services using open source tooling, or simply bring together different components of your application written in different languages.

7.2 Ingress: HTTP(S) Load Balancing

So far in the book we've been using Services of type LoadBalancer. This provides you a so-called level 3 (L3) load balancer, which load balances requests at a network level, and can work with a variety of protocols (TCP, UDP, SCTP). You configure the Service with your desired protocol and port, and you get an IP that will balance traffic over your Pods. If you expose a HTTP service over a LoadBalancer, you need to implement your own TLS termination handling (configuring certificates, and running a HTTPS endpoint), and all traffic to that endpoint will get routed to one set of Pods (based on the matchLabels rules). There is no option for exposing two or more separate services directly on the same load balancer (though one can proxy requests to the other internally).

When you are publishing a HTTP app specifically, you may get more utility from a so-called level 7 (L7) load balancer, which load balances at a HTTP request level and can do more fancy things like terminate HTTPS connections (meaning it will handle the HTTPS details for you), and perform path-based routing, so you can serve a single domain host with multiple services. In Kubernetes, a HTTP load balancer is created with an Ingress object.

Ingress lets you place multiple internal services behind a single external IP with load balancing. You can direct HTTP requests to different backend services based on their URI path (/foo, /bar), hostname (foo.example.com, bar.example.com), or both. The ability to have multiple services hosting one host is unique to Ingress, because if you'd exposed them with individual load balancers as in the earlier chapter, the services would separate IP addresses, necessitating separate hosts (e.g. service 1 hosted on foo.example.com, and service 2 under bar.example.com).

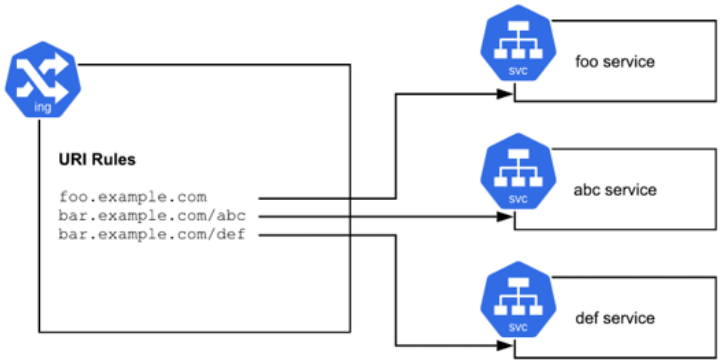


Figure 7.4: the ingress' rule list, or "URL Map" allows one HTTP load balancer to handle the traffic for multiple services.

The property of Ingress being able to place multiple services under one host is useful when scaling up your application. When you need to break up your services into multiple services for developer efficiency (teams wanting to manage their own deployment lifecycle), or scaling (being able to scale aspects of the application separately), you can use Ingress to route the requests while not altering any public-facing URL paths. For example, let's say that your application has a path that is a particularly CPU-intensive request. You might wish to move it to its own service to allow it to be scaled separately. Ingress allows you to make such changes seamlessly to end users.

Here's an example Ingress where the routes are served by different backends. In this example, we'll service the "pluscode" service on the root path (`/`), and we'll expose the internal Robohash service from the previous section on `/robohash`.

Listing 7.1 Ingress/ingress_path.yaml

```
apiVersion: networking.k8s.io/v1
kind: Ingress
metadata:
  name: pluscode-ingress
spec:
  rules:
  - http:
      paths:
      - path: /
        pathType: Prefix
        backend:
          service:
            name: pluscode-service
            port:
              number: 80
      - path: /robohash
        pathType: Prefix
        backend:
          service:
            name: pluscode-service
            port:
              number: 80
```

And here's one with different hosts. Each of these hosts can also have multiple paths using the format above.

Listing 7.2 Ingress/ingress_host.yaml

```
apiVersion: networking.k8s.io/v1
kind: Ingress
metadata:
  name: pluscode-ingress
spec:
  rules:
  - host: foo.example.com
    http:
      paths:
      - path: /
        pathType: Prefix
        backend:
          service:
            name: pluscode-service
            port:
              number: 80
  - host: bar.example.com
    http:
      paths:
      - path: /
        pathType: Prefix
        backend:
          service:
            name: pluscode-service
            port:
              number: 80
```

The Services referenced in the Ingress object are the same Services discussed in Ch. 03, and in the prior section with one important consideration, they are all of type `NodePort`.

Listing 7.3 One of the internal services referenced by the ingress

```
apiVersion: v1
kind: Service
metadata:
  name: pluscode-service
spec:
  selector:
    app: pluscode
  ports:
  - port: 80
    targetPort: 80
    protocol: TCP
  type: NodePort
```

For the `pathType` property in the Ingress object, you can use exact matching (only requests exactly matching the path given will be routed to that service), or prefix matching (all requests matching the path prefix will be routed). I'm not going to go into a lot of detail here, as the official docs do a great job. One item worth reproducing though is the rule on multiple matches:

> ***In some cases, multiple paths within an Ingress will match a request. In those cases precedence will be given first to the longest matching path. If two paths are still equally matched, precedence will be given to paths with an exact path type over prefix path type.***
>
> **Ingress – The Kubernetes Authors[1]**

As you may have seen in the first example I presented, there was a path for `/`, and a second one for `/foo`. A request to `/foo` will be routed to the second service, even though it also matched the first path. If you've used other routing mechanisms in the past (like Apache URL rewriting), often the preference would go to the *first* rule matched. Not so in Kubernetes, where the longer matched rule gets preference. This design in Kubernetes is convenient, as it matches well with developer intent.

[1] https://kubernetes.io/docs/concepts/services-networking/ingress/#multiple-matches

Cost Saving Tip: Saving IPs with Ingress

A benefit of Ingress is that by using host-based routing, you can host several services all with the same external IP address. The ingress inspects the `Host` header in the HTTP request, and routes traffic accordingly. This contrast with Services of type LoadBalancer which each get their own IP address assigned and perform no packet inspection or routing.

Cloud providers often charge based on "load balancing rules", which roughly translates into how many load balancing external IP addresses are assigned. By using an ingress to combine several services into one, rather than each being exposed with it's own IP, you can likely save money.

If your cloud provider groups HTTP Loadbalancers (Ingress) and Network Load Balancers (service of type LoadBalancer) separately, and has a minimum rule fee (like Google Cloud does as the time of writing), you may want exclusively use one or the other until you need more than the minimums.

Another trick, but one I don't recommend, is running your own ingress *controller*. This technique (not covered in this book), means deploying an open source component as a LoadBalancer to implement the Kubernetes ingress functionality, overriding the default implementation of your cloud provider. This approach means that the Ingress objects and LoadBalancer objects get treated as the same, rule types for billing which can save money if you need both, but there's a sacrifice which is that you now need to manage this component yourself. Are you an expert at debugging Kubernetes ingress controllers? Better to go all-in using standard Ingress objects, or stick with pure LoadBalancers if you need to save money, in my experience.

7.2.1 TLS

Another useful property of Ingress is that it will perform the TLS encryption for you. Modern web applications are typically hosted as secure HTTPS applications with TLS which is important for security, but comes with some overheads for the application server. Depending on the server middleware you are using, you may see performance gains by letting the Ingress load balancer handle the TLS connection (a so-called TLS terminator), and communicate on to your backend only over HTTP (via a secure network like that of your cloud provider, of course). If you prefer, the Ingress can re-encrypt traffic and connect to your services over HTTPS, but with Ingress there is no option to pass the traffic directly through (for that, you'd use a Service of type LoadBalancer, like we did in Chapter 3).

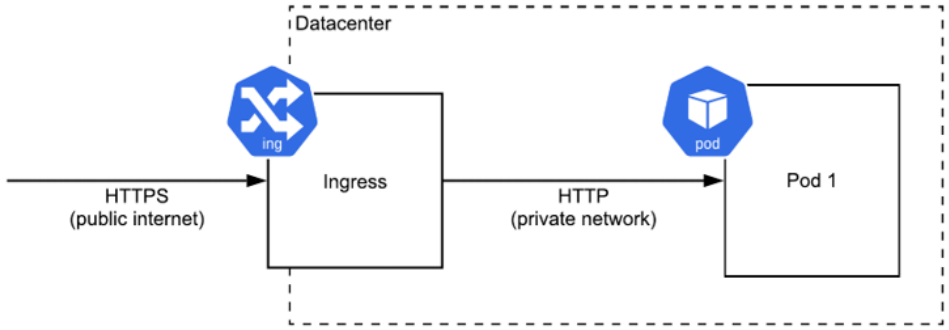


Figure 7.5: The Ingress terminates HTTPS (TLS) traffic, and can forward it to the serving Pods over plain-HTTP or HTTPS connections.

Now that the Ingress is terminating your TLS connections, you'll need to set it up with certificates. If like me you've done this a few times on different systems, you might be dreading this step. Fortunately, Kubernetes makes it a breeze!

You just need to import your certificate and key as a Kubernetes Secret, then reference that secret in your Ingress configuration. A Kubernetes Secret is simply a data object in your cluster to contain things like TLS keys.

To do this, normally you would follow the instructions of your certificate authority. The end product of which would include the two files we need: the private key that you created, and the certificate issued by the certificate authority.

For demonstration purposes we can create our own self-signed certificate in lieu of the trusted certificate. Note that while this will provide the same encryption for the connection, there is no identity verification, and you'll see scary messages in your browser. The following commands will create such a certificate.

```
# create a private key
openssl genrsa -out example.key 2048

# create a certificate request for 'example.com'
openssl req -new -key example.key -out example.csr \
    -subj "/CN=example.com"

# self-issue an untrusted certificate
openssl x509 -req -days 365 -in example.csr -signkey \
    example.key -out example.crt
```

Once you have your private key and certificate (whether your created them with the above instructions, or by following the instructions of your certificate authority), you can now create the Kubernetes secret like so:

```
kubectl create secret tls my-tls-cert \
  --cert example.crt --key example.key
```

You may notice the imperative `kubectl create` command here. This is one of the few times I recommend using an imperative command rather than defining the configuration in a file because it's simpler than creating the object manually and base64 encoding all the data. If you want to see the config that got created with this command, you can easily view it with `kubectl get -o yaml secret my-tls-cert`.

The final step is to reference this secret in our ingress.

Listing 7.4 TLS/ingress_tls.yaml

```
apiVersion: networking.k8s.io/v1
kind: Ingress
metadata:
  name: pluscode-ingress
spec:
  tls:
    - secretName: my-tls-cert
  rules:
  - host: example.com
    http:
      paths:
      - path: /
        pathType: Prefix
        backend:
          service:
            name: pluscode-service
            port:
              number: 80
      - path: /pc2
        pathType: Prefix
        backend:
          service:
            name: pluscode-service
            port:
              number: 80
```

To actually browse to this host you'll need to configure the DNS for the domain you've used with the IP of the ingress. To test locally, you can also edit your local hosts file and add the IP and domain name (to find instructions on how to do that, a Google search for "update hosts file in <your operating system version>" should do the trick!). The IP of the ingress can be found with `kubectl get ingress`.

Here's what my ingress object looks like, and the entry I added to my local hosts file:

```
$ kubectl get ingress
NAME               CLASS    HOSTS         ADDRESS        PORTS     AGE
pluscode-ingress   <none>   example.com   203.0.113.2    80, 443   82m

$ cat /etc/hosts
# ...
203.0.113.2 example.com
```

Now, provided that you've configured your host you can browse to https://example.com. If you generated a self-signed certificate, you'll get a scary browser error which in this case it's fine to click through. To actually publish your service to the world, you'll want to go back

and request a certificate from an actual certificate authority, and use that to create the TLS secret instead.

Once again, the nice thing about Kubernetes is that all this configuration is in the form of Kubernetes objects (rather than random files on a host VM), making it straight forward to reproduce the environment elsewhere.

Using GKE? Try Managed Certificates

The above are the instructions for adding a tried-and-true CA certificate to your Kubernetes Ingress object. If you're using GKE, and want an even simpler approach you can use a managed certificate instead.

With a managed certificate, you skip the CA signing step, and the copying of your private key and certificate into Kubernetes as a Secret. Instead, you need to first prove ownership of the domain to Google (this is done in the GCP console, outside of GKE), create a GKE-specific `ManagedCertificate` object listing the (sub)domains you wish to provision certificates for, then reference that object in your ingress. Google will then provision and manage the certificates automatically. It's all pretty straight forward, so I'll let the official docs[2] be your guide for this one.

7.3 Summary

Kubernetes offers several tools to create, discover, connect and expose multiple services, for when your requirements exceed what can be hosted in a single container.

- Internal services are a way to connect together a wide range of workloads that can be written in a different language, be on a different release schedule or simply need to scale independently
- Internal services can be exposed on a private Cluster IP that allows them to be called from other services in the cluster
- Kubernetes offers two forms of Service Discovery to find these internal service IPs: environment variables and DNS
- Ingress can be used to expose multiple internal services to the internet using a single IP, with routing performed by path and/or host name
- Ingress is a "L7" HTTP load balancer that can also handle your HTTPS connections and TLS termination
- By performing TLS termination at the load balancer layer, you can save configuration effort in your application and reduce CPU overhead

[2] https://cloud.google.com/kubernetes-engine/docs/how-to/managed-certs

8

GitOps: Configuration as Code

This chapter covers

- Using namespaces and configuration to replicate environments
- Benefits of treating Kubernetes deployment configuration like source code
- Using git pull (merge) requests to drive operations
- Handling secrets without storing them in plain text in version control

You may have noticed in this book so far that we've been writing a lot of YAML configuration. It is possible to interact with most Kubernetes objects without writing configuration files (using imperative `kubectl` commands), and these are arguably easier to learn. So why did I exclusively use the declarative configuration-based approach? One reason is so that now as we take the app to production, we can treat our configuration like we do our code.

Another reason is it allows us to easily spin up multiple environments with the same configuration. Let's say you want a staging and a production environment that are close to identical. With your deployment represented in configuration files it's possible to replicate the environments easily. Kubernetes has a namespaces feature which makes this possible without needing to worry about name collisions.

8.1 Production and Staging Environments using Namespaces

As you prepare your application for production, you'll likely want to create a staging environment where changes can be tested before the live production application is updated. Kubernetes makes this easy with namespaces.

Namespaces as their name suggests provide name uniqueness within a single logical space. So you can setup a "production" namespace and a "staging" namespace, and have the deployment object "foo-deployment" and "foo-service" in each of them. This avoids the need to excessively modify your configuration for the different environments, like creating "foo-staging-deployment"

and “foo-staging-service”, and provides some protection against accidental changes as by default, kubectl commands only apply to the namespace that’s currently active.

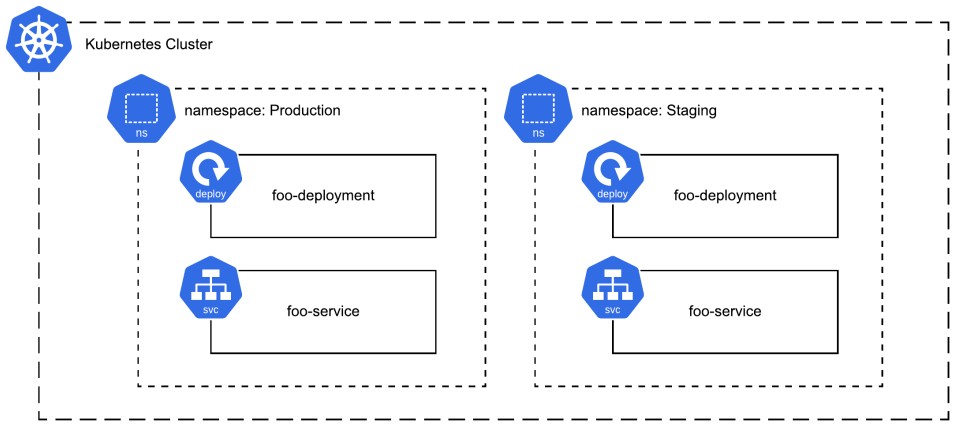


Figure 8.1: A Kubernetes cluster with two namespaces. Note that the deployment and service objects in these namespaces have the same name (and potentially, same configuration).

The main configuration differences between your production and staging are typically things like the scale (number of replicas), and any external service credentials as these external services are not included in the namespace.

To create a namespace you can run:

```
$ create the namespace “staging”
kubectl create namespace staging
```

To interact with this namespace, you can either add `--namespace staging` (or `-n staging` for short) to every `kubectl` command you run, or change the `kubectl` context so that all commands will run in this new namespace. I highly recommend the latter, as you don’t want to forget the `-n` flag and accidentally run a command in the wrong namespace. Better to switch contexts each time.

```
$ list the available namespaces
kubectl get namespace

$ set the context to the staging namespace
kubectl config set-context --current --namespace=staging
```

You may notice with the first command, that Kubernetes has a few namespaces out of the box. `kube-system` is where the system pods go, best not to touch this one unless you know what you’re doing. `default` is the default user namespace, but I recommend creating your own dedicated ones, one for each application environment.

I find the context setting command above tedious, and highly recommend setting up your shell with a utility to make it simpler to switch. The one I use is `kubectx + kubens`, written by my

colleague Ahmet Alp Balkan, available at https://github.com/ahmetb/kubectx. With `kubens` installed, you can instead run:

```
$ list namespaces
kubens

$ switch to the staging namespace
kubens staging
```

The other included utility, `kubectx`, can be used to quickly switch between different clusters entirely. These scripts are just shorthand for the longer `kubectl config set-context` commands, so you can go back to using `kubectl` as normal once the context is set.

8.1.1 Deploying to our new namespace

Once you have the namespace created, you can deploy your application easily from configuration. This is why the book has been using configuration files in every case. Instead of needing to re-run a bunch of imperative commands to recreate your deployment, can simply run the following command from the folder with your configuration:

```
$ deploy/update all configuration in this folder
kubectl apply -f .
```

And if you make any changes (or create another namespaced environment), you can just re-run that command to roll out your changes.

In fact, creating new environments with namespaces in Kubernetes is so trivial to configure, that if you were sharing a single staging environment in the past with other platforms, you may see some benefit to having a lot of different environments (e.g., one per developer, one for staging, another for integration testing, etc). The namespaces are free, although the compute resources used by your pods are not.

8.1.2 Syncing Mutations from the Cluster

But what about any changes that were made imperatively, outside of configuration? Perhaps you scaled a deployment with `kubectl scale`, or changed the image with `kubectl set-image`, or created a deployment with `kubectl run`. It happens, I won't judge.

Kubernetes lets you view, and export configuration with the `--output` parameter (`-o` for short) on any `get` request.

For example, to get the latest YAML configuration for a deployment:

```
$ View the deployment as YAML
kubectl get deploy your-deployment -o yaml

$ Pipe the deployment YAML config to a file
kubectl get deploy your-deployment -o yaml > your-deployment.yaml
```

The catch is that Kubernetes adds a lot of extra fields that you don't really want in your on-disk configuration, like status messages, etc. There used to be a handy `--export` option which would strip these, but sadly it's deprecated (depending on when you read this, it may still work). So it's a bit of an art to figure out which lines you can delete, and which you need to keep. But you can

compare the YAML files you get in this way to the ones in this book to see which lines are important.

If you plan to use the configuration in multiple namespaces (which is common), you will definitely want to delete the `metadata -> namespace` field. Removing this will allow you to deploy the configuration in the current namespace (while keeping it will mean any changes will update the object in whatever namespace was specified). The danger I see in keeping the namespace is you might accidently have some configuration in your staging folder set to the production namespace. Section 7.3 below discusses some tactics on safety around rollouts to different namespaces, but it relies on *not* specifying the namespace in resource objects directly.

Other fields to consider for removal for cleanliness are from the `metadata` section, the fields `uid`, `resourceVersion`, `selfLink`, `creationTimestamp`, and the entire `status` section. These fields won't prevent you from reusing the configuration in other namespaces or clusters, but don't really have meaning outside their deployed context, so best keep it out of version control to avoid confusion.

8.2 Configuration as Code the Kubernetes Way

When you have a bug in your code, you may inspect the version history to see when the code was changed and might even roll back a commit to get back to the previously working state. When you treat your configuration as code (by committing it to your version control system), you can perform similar actions, but with your production systems.

If you have a peer review process for code that's submitted, the same process should apply to configuration. After all, the configuration impacts the running system just as much as the code does. Peer review on configuration repositories can help to catch errors before they are rolled out. If you fat-finger the wrong number of replicas, hopefully your colleague might notice.

You'll find this pattern used at all major internet companies. Most Google services for example are developed and deployed out of a single code repository[1], so the service configuration sits right beside the code. The exact same code review practices are followed for code, and for services, although the list of owners (the engineers can approve the changes for merging) will differ.

There's no obligation to store the configuration in the same repository as the code like Google though, this is mostly a matter of taste (and endless technical debate). The model I'll present here for storing Kubernetes configuration in Git is just an example which I've found works for me, but you should adapt it to your own engineering practices.

I use a single Git repository to represent all the Kubernetes objects deployed in a single cluster. In this repo is a folder for each Kubernetes namespace, and in those folders are the YAML files for the objects in the namespace. An alternative is to use a separate branch for each namespace, which has some nice properties like being able to merge changes as they go from staging to production, but as there are likely some changes you *don't* want to merge, it can get messy (you wouldn't want to accidently merge your staging-only changes to production).

[1] https://research.google/pubs/pub45424/

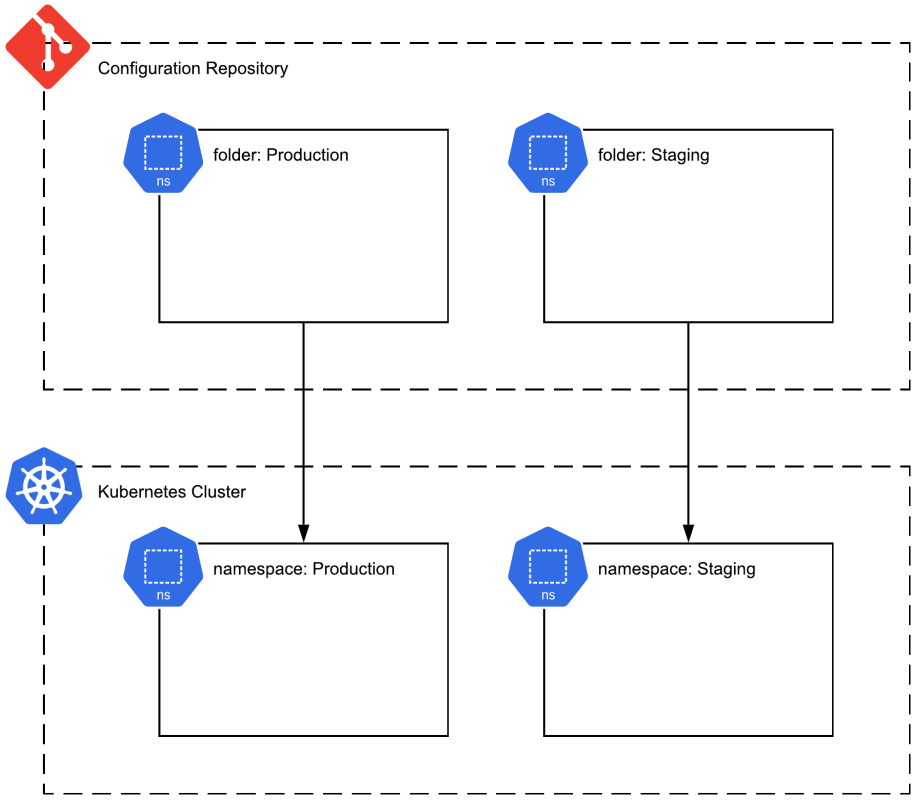


Figure 8.2: Git repository folder structure and the relationship to Kubernetes namespaces

Here's an example directory layout:

```
/_debug #A
/_cluster #B
/staging #C
/production #C
```

#A A directory for any debug scripts you wish to store for all developers
#B The cluster configuration, for example the namespace configuration files. These are only used during cluster creation
#C The environment configuration folders

Each directory in this repository is mapped to a Kubernetes namespace. The beauty of such a 1:1 mapping is that it allows you to confidently execute a `kubectl apply -f .` command to rollout all changes in the directory to the active namespace. Cloning the environment is as simple as duplicating the entire folder (and then deploying it to its own namespace).

It's common—particularly for smaller scale deployments—to share a cluster with multiple environment namespaces for cost reasons. This avoids extra charges for the control plane, and allows workloads to pool compute resources on the nodes. As the deployments get larger, it may be desirable to separate environments into their own clusters to provide an extra level of access control and resource isolation. The good news is that the configuration repository doesn't care where these namespaces are, it's totally fine for them to exist in different clusters.

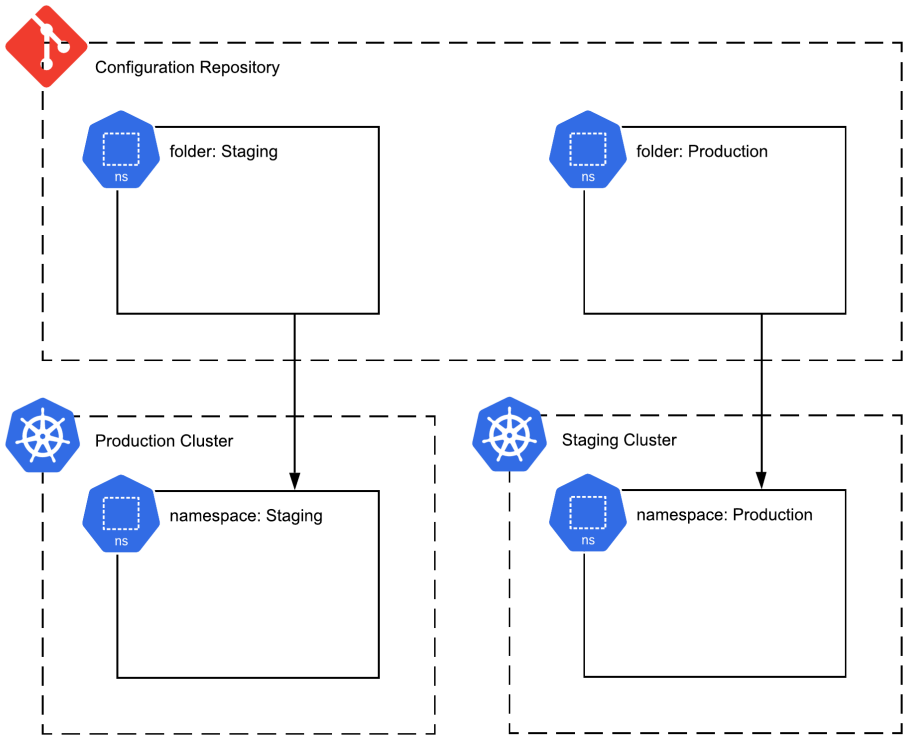


Figure 8.3: configuration repository with environments in multiple clusters

Now that your resource repository is setup, the work process looks like this: make changes to the deployed environment to your configuration, commit those changes, then update the live state by setting the current namespace with kubectl, then running `kubectl apply -f .` on the matching directory.

With this, you're following a "Configuration as Code" pattern, but there is more you can do. One danger with the setup as described so far is that you can accidently rollout the configuration from one folder to the wrong namespace. The next sections cover how to roll out safely and avoid this

problem, and how to up level to a full "GitOps" style process where the `git push` on the configuration repository triggers the rollout automatically.

8.3 Rolling Out Safely

With your configuration as code repository setup, there is now a question of how best to roll out the changes in the repo.

Sure, you can simply checkout the repository and run `kubectl apply -f .` as we did earlier, but this can be dangerous. You could accidently deploy the wrong configuration into the wrong namespace. Since we're reusing object names in multiple environments, this could be quite bad indeed. Also, there's nothing to stop you running any other commands that don't require the configuration to be committed to the repository.

To tackle the "wrong namespace" issue, what I recommend is to have some guardrails in place to avoid accidently deploying the wrong configuration to the wrong namespace. Instead of simply running `kubectl apply -f .` as we did earlier, wrap it up in a script that performs a check to ensure you're deploying into the right namespace. If we name our folders the same as the namespace, then the check is simple: if current namespace is equal to the folder name, deploy.

Here's an example script that compares the current directory name to the current namespace, and exits with an error status if they mismatch.

gitops_check.sh

```
#! /bin/bash

CURRENT_DIR=`echo "${PWD##*/}"`
CURRENT_NAMESPACE=`kubectl config view --minify -o=jsonpath='{.contexts[0].context.namespace}'`

if [ "$CURRENT_DIR" != "$CURRENT_NAMESPACE" ]; then
    >&2 echo "Wrong namespace (currently $CURRENT_NAMESPACE but $CURRENT_DIR expected)"
    exit 1
fi

exit 0
```

You can then use this in any other scripts, like the following rollout script:

rollout.sh

```
#! /bin/sh

if [ $(../gitops_check.sh; echo $?) != 0 ]; then exit 1; fi

kubectl apply -f .
```

A full "git ops" folder structure including these scripts is provided in the samples in `Chapter08/gitops`

This isn't the only option of course. Another approach would be to set the desired namespace in your rollout script and then deploy (just be sure if the "set namespace" step fails, the whole thing will bail out).

For these scripts to work though, you'll need to ensure that none of your configuration files specify a `metadata -> namespace` field directly. If they have a namespace set, it will ignore the current context, so the above script won't prevent updates in that case.

To really do GitOps properly though, you'll want to solve the other issue and that is to guarantee that the configuration deployed is what is in the repository. The best way to solve that is to remove the human from the loop completely, and configure a *deployment pipeline*, or a *gitops operator*.

8.3.1 Deployment Pipelines

A deployment pipeline is simply a set of functions that run based on a code repository trigger. For example: "when a code is pushed to the configuration repository, deploy the configuration to a Kubernetes cluster".

Using pipelines guarantees that the configuration being deployed matches what was committed. If the operator needs to make additional changes after the deployment (for example to correct an error), they make them in the configuration code repository like normal, push the code and trigger the pipeline rollout once again.

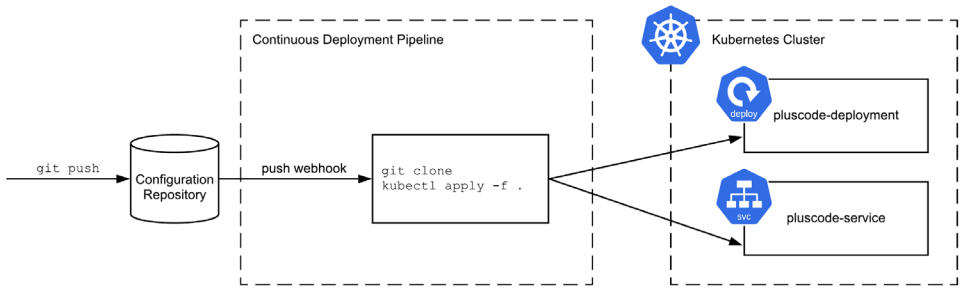


Figure 8.4: A continuous deployment pipeline to Kubernetes

Now that your pipeline is configured, you can push to producing by merging a code on your git repo, i.e. git-driven operations, or "GitOps". The key is to not make any changes on the cluster directly; all changes go through the configuration repository and the continuous deployment pipeline.

CONTINUOUS DEPLOYMENT WITH CLOUD BUILD

To implement such a deployment pipeline in practice, there are many products on the market. For GKE users, one option is Cloud Build. You can set up a trigger so that when your configuration repository is pushed, it will run "`kubectl apply -f .`".

Here's how to set it up: 1) configure IAM permissions[2] for the Cloud Build service account (to give it permission to act on your GKE cluster), 2) create a new trigger (set to fire when your configuration repository is pushed), and 3) add a Cloud Build configuration file to your repository, and reference it in the trigger.

[2] https://cloud.google.com/build/docs/securing-builds/configure-access-for-cloud-build-service-account

cloudbuild-deploy.yaml

```
steps:
- name: 'gcr.io/cloud-builders/kubectl'
  id: Deploy
  args:
  - 'apply'
  - '-f'
  - '$FOLDER'
  env:
  - 'CLOUDSDK_COMPUTE_ZONE=us-west1-a'
  - 'CLOUDSDK_CONTAINER_CLUSTER=my-cluster'
```

This is just scratching the service of continuous delivery, if you're using Cloud Build, then you could consult the excellent guide *GitOps-style continuous delivery with Cloud Build*[3], which goes further and sets up a complete end to end CI/CD flow.

CONTINUOUS RECONCILIATION

The method described here can be further improved by using a GitOps operator. This is a code loop that runs in the cluster and constantly reconciles what is running in the cluster to what is present in the configuration repository. The end result is similar to the event-driven pipeline described above, with the advantage that it can perform additional reconciliation if there is ever a divergence, while the pipeline relies on the push event to trigger. Flux[4] is one such GitOps operator.

8.4 Secrets

A git repo is a great place to store your Kubernetes configuration, but there is some data that probably shouldn't be stored there: secret values like database passwords and API Keys. If such secrets are embedded in the code itself, or in environment variables, it means that anyone with access to your source code will have the secret. An improvement would be that only those who can access your production system would have access to this data. You can go further of course, but in the context of this chapter on GitOps, I'll focus on how to separate your secrets from your code and config repositories.

Kubernetes actually has an object for storing secrets, aptly named Secrets. These objects are a way to provide information such as credentials and keys to workloads, in a way that separates them from the configuration of the workload itself.

8.4.1 String-based (Password) Secrets

If you've been embedding secrets like passwords in plain environment variables in the deployment configuration, now would be a good time to migrate them to Secrets. Let's say we have a secret with a value of `secret_value` (in reality, this might be a key obtained from your cloud provider).

We can encapsulate our `secret_value` into a Kubernetes Secret object like so:

[3] https://cloud.google.com/kubernetes-engine/docs/tutorials/gitops-cloud-build
[4] https://fluxcd.io/

```
apiVersion: v1
kind: Secret
metadata:
  name: secrets-production
type: Opaque
stringData:
  SECRET_KEY: secret_value
```

Secrets can be provided to Pods in two ways: as a file, and as an environment variable. You would use the file method for secret data that your application will access as a file (such as a private SSL key), and the environment variable for items like database passwords. Since our secret above is a simple string, we'll use the environment variable method here:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-demo
spec:
  replicas: 1
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: docker.io/wdenniss/pluscode-demo:latest
        env:
        - name: AVATAR_ENDPOINT #A
          value: http://robohash-internal #A
        - name: DATABASE_PASSWORD #B
          valueFrom: #B
            secretKeyRef: #B
              name: secrets-production #B
              key: SECRET_KEY #B
```

#A A normal (non-secret) environment variable
#B An environment variable populated with the value of the secret

To verify that everything worked correctly, create the deployment and secret. Run `kubectl get pods`, grab one of the pod names, and run:

```
$ kubectl exec POD_NAME exec -- env
SECRET_KEY=secret_value
```

You should see the secret in the list. Our application now has access to our SECRET_KEY environment variable.

8.4.2 Base64 Encoded Secrets

At the time of writing, the Kubernetes docs and many other materials demonstrate secrets where the value is base64 encoded (using the `data` key, rather than `stringData`). This isn't done for

security (base64 is an encoding, not encryption), but rather so that you can represent data that wouldn't be compatible YAML.

I find that this mostly serves to obfuscate the data without adding much value. However, if you have a string that you can't represent in YAML, or are storing a file, then you would want to base64 encode the data. Here's an equivalent representation of the secret shown earlier:

```
apiVersion: v1
kind: Secret
metadata:
  name: secrets-production
type: Opaque
stringData:
  SECRET_KEY: c2VjcmV0X3ZhbHVlCg==
```

To do the encoding, on any *nix system you can do the following:

```
$ echo "secret_value" | base64
c2VjcmV0X3ZhbHVlCg==

$ echo "c2VjcmV0X3ZhbHVlCg==" | base64 -D
secret_value
```

You can include both `data` and `stringData` in the same configuration file, if you have some values that need base64 encoding, and others that don't. You can also store multiple secrets in each Kubernetes Secret object (one per line). Here's an example that defines 3 secrets, 2 using plain text, and a third using base64.

```
apiVersion: v1
kind: Secret
metadata:
  name: secrets-production
type: Opaque
stringData:
  SECRET_KEY: secret_value
  ANOTHER_KEY: another_value
data:
  ENCODED_KEY: VGhpcyBzdHJpbmcKaXMgaGFyZGVyIHRvIGVuY29kZSBpbiBZQU1MIPCfmIUK
```

If you are retrieving secrets from the server, those are stored in base64, so you will need to decode to get the plain-text values.

I personally have one secret object for each of my namespaces, e.g. `myapp-secrets-production`, `myapp-secrets-staging`, each with multiple secrets, but I store them in a separate repo to the rest of my config (in Section 8.4.4 below, I'll discuss some options for how to store secrets apart from your main configuration repository, while still using a Gitops).

8.4.3 File-based Secrets

Sometimes you'll be dealing with secrets that you want to access from your application as files, rather than strings from environment variables.

Kubernetes has you covered here as well. Creating the secret is actually the same, but I'll provide a fresh example of a multi-line text file, since how such data is represented in YAML has some nuance.

Say we have a private key to store. Here's one I generated using `openssl genrsa -out example.key 256` (normally you'd use a 2048 bit key or higher, but for brevity, I'll use 256).

```
-----BEGIN RSA PRIVATE KEY-----
MIGsAgEAAiEA4TneQFg/UMsVGrAvsm1wkonC/5jX+ykJAMeNffnlPQkCAwEAAQIh
ANgcs+MgClkXFQAP0SSvmJRmnRze3+zgUbN+u+rrYNRlAhEA+K0ghKRgKlzVnOxw
qltgTwIRAOfb8LCVNf6FAdD+bJGwHycCED6YzfO1sONZBQiAWAf6Am8CEQDIEXI8
fVSNHmp108UNZcNLAhEA3hHFV5jZppEHHHLy4F9Dnw==
-----END RSA PRIVATE KEY-----
```

This can be represented in YAML, the following way. Note the all-important pipe character which will preserve the line endings (the config itself cannot have line breaks, this representation preserves the linebreaks in the value itself).

```
apiVersion: v1
kind: Secret
metadata:
  name: secret-files
type: Opaque
stringData:
  example.key: |
    -----BEGIN RSA PRIVATE KEY-----
    MIGsAgEAAiEA4TneQFg/UMsVGrAvsm1wkonC/5jX+ykJAMeNffnlPQkCAwEAAQIh
    ANgcs+MgClkXFQAP0SSvmJRmnRze3+zgUbN+u+rrYNRlAhEA+K0ghKRgKlzVnOxw
    qltgTwIRAOfb8LCVNf6FAdD+bJGwHycCED6YzfO1sONZBQiAWAf6Am8CEQDIEXI8
    fVSNHmp108UNZcNLAhEA3hHFV5jZppEHHHLy4F9Dnw==
    -----END RSA PRIVATE KEY-----
```

If you're tired of wrestling with YAML syntax by now, you can base64 encode the file data instead using `cat example.key | base64`, and represent it like so (with the data truncated for readability). Note that the entire base64 string is placed on one line (no line breaks!).

```
apiVersion: v1
kind: Secret
metadata:
  name: secret-files
type: Opaque
data:
  example.key: LS0tLS1CRUdJTiBSU0EgU...SBLRVktLS0tLQo=
```

It's a bit tedious creating these configuration files for secrets by hand. A more automated approach is to use to use `kubectl` to create the files for you. The following command will create the same functional output (note that the base64 string is truncated for readability).

```
$ kubectl create secret generic secret-files --from-file=example.key=./example.key --dry-
      run=client -o yaml

apiVersion: v1
data:
  example.key: LS0tLS1CRUdJTiBSU0EgU...SBLRVktLS0tLQo=
kind: Secret
metadata:
  creationTimestamp: null
  name: secret-files
```

The `--dry-run=client -o yaml` part means that you won't actually create the secret on the server, and instead will output it as YAML (for you to place in a configuration file, to be later applied to the server with `kubectl apply -f filename.yaml`). Omitting the dry-run, would create the secret directly on the cluster (the imperative style of creating Kubernetes objects). In fact, every example given in this section could have been written as an imperative `kubectl` command, but as I hopefully convinced you in section 7.2, there are durable benefits to a declarative, configuration-driven approach to operating your cluster.

Once created, you can mount all the secrets in the Secret into a folder of your choice. The below example mounts our `secret-files` secret into the folder `/etc/config`. Each of the data keys is mounted as its own file. In our case, there was only one: `example.key`.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pluscode-demo
spec:
  replicas: 1
  selector:
    matchLabels:
      app: pluscode
  template:
    metadata:
      labels:
        app: pluscode
    spec:
      containers:
      - name: pluscode-container
        image: docker.io/wdenniss/pluscode-demo:latest
        volumeMounts:
        - name: secret-volume
          mountPath: "/etc/config"
          readOnly: true
      volumes:
      - name: secret-volume
        secret:
          secretName: secret-files
```

To verify that everything worked correctly, create the deployment and secret. Run `kubectl get pods`, grab one of the pod names, and use exec to list the directory. You should see our file "example.key":

```
$ kubectl exec POD_NAME -- ls /etc/config
example.key
```

Now you can point your code to this file, just like any other file on the system.

8.4.4 Secrets and GitOps

Using Secrets is only part of the equation. Now you'll need to figure out how to store them. If you place them in the same configuration repository, you may as well have just used plain environment variables and skipped the step in the previous section.

There's no silver bullet to this problem, but here are a few ideas, presented in increasing order of complexity.

SEPARATE REPOSITORY

A simple option is to have a separate configuration repository for your secrets with fewer users granted access than your regular repos. You still have all the benefits of configuration as code (code reviews, rollback, etc), but can limit the audience. If you operate a repository with granular access control, you could place the secrets in an access-controlled folder of that repo.

One logical place for this repository to be located would be together with your production resources at your cloud provider, with the same access control as your production environment. Since anyone with access to your production environment has the secrets anyway, this model doesn't provide any additional access if someone compromises the account.

SEALED SECRETS

The Sealed Secrets[5] project has an interesting approach; it encodes all of your secrets with a master secret. While you still end up with the same problem of where to store the master secret, it means that the encoded secrets can be included in the main configuration repository with all the benefits that this entails, like rollback.

SECRETS SERVICE

Another option is to run a separate service that can inject secrets into your cluster. Vault by HashiCorp[6] is a very popular implementation of this concept, and is available as open source if you wish to run it yourself.

8.5 Summary

Aside from being able to express a wide range of deployment constructs, one of the big advantages of Kubernetes is the declarative design, how you can *declare* what you want in configuration files, and have Kubernetes take care of the rest. To take full advantage of this ability:

- Use Namespaces to separate different environments like production and staging, and different applications
- Always update your configuration first, then apply it to the cluster—don't operate directly on the cluster
- Store this configuration in a code repository, and treat it like code (with peer reviews if you do them, etc)
- Optionally, configure a continuous deployment pipeline driven by git pushes of the config repo (so-called "Gitops").
- Get secrets out of your application config, and into Kubernetes Secret objects. Store them in a way that limits access.

[5] https://github.com/bitnami-labs/sealed-secrets
[6] https://www.vaultproject.io/

9

Stateful Applications

This chapter covers

- How to attach persistent disk storage to Pods
- How the Kubernetes concepts of volumes, PersistentVolumes, PersistentVolumeClaims and StorageClasses interact to give you stateful capabilities
- Creating a simple single-Pod deployment with persistent state
- Deploying a complex multiple-Pod stateful application with multiple roles
- Migrating and recovering data by re-linking Kubernetes objects to the underlying disk resources

Stateful applications, ones that have attached storage, finally have a home with Kubernetes. While stateless applications are lauded for their high scalability, and not needing to manage attached storage helps with that, they are not the only way to deploy software. Whether you're deploying a sophisticated database or are migrating an old stateful application from a VM, Kubernetes has you covered.

Using Persistent Volumes, you can attach stateful storage to any Kubernetes Pod. When it comes to multi-replica deployments, just as Kubernetes offers Deployment as a high-level construct for managing a stateless application, StatefulSet exists to provide high-level management of stateful applications.

9.1 Volumes, Persistent Volumes, Claims and Storage Classes

To get started with storing state in Kubernetes, there are a few concepts around volume (disk) management to cover before moving on to the higher level StatefulSet construct. Just like nodes are the Kubernetes representation of a virtual machine, Kubernetes has its own representation of disks as well.

In this section we will deploy a MariaDB database, and attach an external disk mounted at `/var/lib/mysql`, which is where MariaDB stores its data. You can replace this MariaDB container with your own single-pod deployment that requires a persistent disk.

9.1.1 Volumes

Kubernetes offers functionality to Pods that allows them to mount a volume. What's a *volume*? The docs describe it like so:

> ***At its core, a volume is just a directory, possibly with some data in it, which is accessible to the containers in a pod. How that directory comes to be, the medium that backs it, and the contents of it are determined by the particular volume type used.***
>
> **Volumes, the Kubernetes Authors**

Kubernetes ships with some built in volume types, and others can be added by your platform administrator via storage drivers. Some types you may encounter frequently are emptyDir an ephemeral volume tied to the lifecycle of the node, ConfigMap which allows you specify files in Kubernetes manifests and present them to your application as file on disk, and cloud provider disks for persistent storage.

EMPTYDIR VOLUMES

The built-in volume type `emptyDir` is an ephemeral volume that is allocated on space from the node's boot disk. If the Pod is deleted, or moved to another node, or the node itself becomes unhealthy, all data is lost. So what's the benefit?

Pods can have multiple containers, and `emptyDir` mounts can be shared between them. So when you need to share data between containers, you would define an `emptyDir` volume, and mount it in each container in the Pod. The data is also persisted between container *restarts,* just not all the other events I mentioned earlier. This is useful for ephemeral data such as that of an on-disk cache where it is beneficial if the data was preserved between Pod restarts, but where long term storage isn't necessary.

```
apiVersion: v1
kind: Pod
metadata:
  name: pluscode-demo
  labels:
    app: pluscode
spec:
  containers:
    - name: pluscode-container
      image: wdenniss/pluscode-demo:latest
      volumeMounts:
      - name: cache-volume #A
        mountPath: /app/cache/ #A
  volumes:
  - name: cache-volume #B
    emptyDir: {} #B
```

#A The mount path

#B The volume definition

Why on earth is this called `emptyDir`? Because the data is stored in an initially empty directory on the node. It's a misnomer in my opinion, but what can you do.

As a practical example, see section 9.2.2 where `emptyDir` is used to share data between two containers in the same Pod, where one of them is an "init container" that runs first and can perform setup steps for the main container.

CONFIGMAP VOLUME

ConfigMap is a useful Kubernetes object. You can define key/value pairs and reference them in other object declarations. You can also use them to store entire files! Typically these files would be configuration files like `my.cnf` for MariaDB, `httpd.conf` for Apache, `redis.conf` for Redis and so on. You can mount the ConfigMap as a volume, which allows the files it defines to be read from the container. ConfigMap volumes are read-only.

This technique is particularly useful for defining a configuration file for use by a public container image, as it allows you to provide configuration without needing to extend the image itself. For example, to run Redis you can reference the official Redis image, and just mount your config file using ConfigMap wherever Redis expects it, no need to build your own image just to provide this one file.

See section 9.2.1 and 9.2.2 for examples of configuring Redis with a custom configuration file specified via a ConfigMap volume.

CLOUD PROVIDER VOLUMES

More applicable for building *stateful* applications (where you don't typically want to use ephemeral or read-only volumes), is mounting disks from your cloud provider as volumes. Wherever you are running Kubernetes, your provider should have supplied drivers into the cluster that allow you to mount persistent storage, whether that's NFS or block-based (often, both).

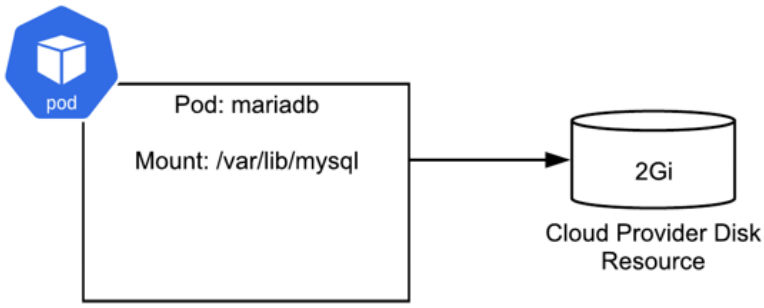


Figure 9.1: Pod with a mounted cloud provider volume

By way of example, here is the specification for a MariaDB Pod running in GKE mounting a GCE persistent disk for its storage.

```
apiVersion: v1
kind: Pod
metadata:
  name: mariadb-demo
  labels:
    app: mariadb
spec:
  affinity:
    nodeAffinity: #A
      requiredDuringSchedulingIgnoredDuringExecution: #A
        nodeSelectorTerms: #A
        - matchExpressions: #A
          - key: topology.kubernetes.io/zone #A
            operator: In #A
            values: #A
            - us-west1-a #A
  containers:
  - name: mariadb-container
    image: mariadb:latest
    volumeMounts: #B
    - mountPath: /var/lib/mysql #B
      name: mariadb-volume #B
    env:
      - name: MYSQL_ROOT_PASSWORD
        value: "your database password"
  volumes:
  - name: mariadb-volume
    gcePersistentDisk:
      pdName: mariadb-disk #C
      fsType: ext4
```

#A Node affinity targeting the zone where our disk exists, so that the Pod will be created in the same zone.
#B The directory where we want to mount the disk in our container.
#C The name of the persistent disk GCP resource.

Unlike the more automated and cloud agnostic approaches we'll cover next, this method is tied to your cloud provider, and requires manual creation of the disk. You need to ensure a that a disk with the name specified exists (which you need to create out-of-band, i.e. using your cloud provider's tools), and that both the disk and the pod are in the same zone. In this example, I use `nodeAffinity` to target the zone of the disk, which is important for any Kubernetes cluster that exists in multiple zones (otherwise your Pod could be scheduled on a different zone to that of the disk).

Creating the disk used by this example out-of-band can be achieved using the following command.

```
gcloud compute disks create --size=10GB --zone=us-west1-a mariadb-disk
```

Since we're creating this disk manually, pay close attention to the location where the resource is being created. The zone in the previous command, and the zone set via the `nodeAffinity` configuration needs to match. If you see your Pod stuck in "Container

Creating", inspect your event log for the answer. Here's a case where I hadn't created the disk in the right project:

```
$ kubectl get events -w
0s          Warning   FailedAttachVolume
       pod/mariadb-demo                                        AttachVolume.Attach failed
       for volume "mariadb-volume" : GCE persistent disk not found: diskName="mariadb-disk"
       zone="us-west1-a"
```

The downside to mounting volumes directly is that the disks need to be created outside of Kubernetes, which means:

a) The user creating the Pod must have permissions to create the disk (which is not always the case)
b) Steps exist outside of Kubernetes configuration that need to be remembered and ran manually
c) The volume descriptors are platform-dependent, so this Kubernetes YAML is not portable and won't work on another provider.

Naturally, Kubernetes has a solution to this lack of portability. By using the volume abstraction provided by Kubernetes, you can simply request the disk resources you need, and have them provisioned for you with no need to perform any out-of-band steps. Read on.

9.1.2 Persistent Volumes and Claims

To provide a way to manage persistent volumes in a more platform-agnostic way, Kubernetes offers higher level primitives around volumes, known as persistent volumes and persistent volume claims.

Instead of linking to the volume directly, the pod references a `PersistentVolumeClaim` object which defines the disk resources that the Pod requires in platform-agnostic terms (for example: "1 gigabyte of storage"). The disk resources themselves are represented in Kubernetes using a `PersistentVolume` object, much like how Nodes in Kubernetes represent the virtual machine resource. When the `PersistentVolumeClaim` is created, Kubernetes will seek to provide the resources requested in the claim by creating or matching it with a `PersistentVolume` and binding the two objects together. Once bound, the persistent volume and claim which now reference each other, typically remain linked until the underlying disk is to be deleted.

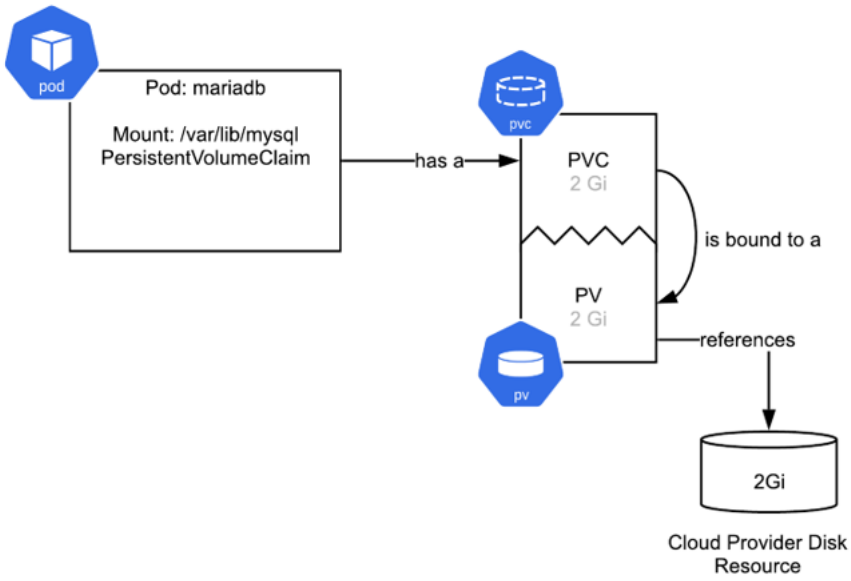


Figure 9.2: Pod that references a PersistentVolumeClaim that gets bound to a PersistentVolume which references a disk

This behavior of having the claim which requests resources, and a representation of those resources is similar to how a pod requests compute resources like CPU and memory, and the cluster finds a Node that has these resources to schedule the pod on. And like with a Pods CPU and memory capacity requests, it now means that the storage requests are defined in a platform independent manner. Unlike using the cloud provider disk directly, when using the PersistentVolumeClaim, your Pods can be deployed anywhere, provided the platform supports persistent storage.

Let's rewrite our Pod from the previous section to use an `PersistentVolumeClaim` to request a new persistent volume for our pod.

Listing 9.1 pvc-mariadb.yaml: Pod with a PersistentVolumeClaim

```
apiVersion: v1
kind: Pod
metadata:
  name: mariadb-demo2
  labels:
    app: mariadb
spec:
  containers:
  - name: mariadb-container
    image: mariadb:latest
    volumeMounts:
    - mountPath: /var/lib/mysql
      name: mariadb-volume
    resources: #A
        requests: #A
          cpu: 1 #A
          memory: 4Gi #A
    env:
      - name: MYSQL_ROOT_PASSWORD
        value: "your database password"
  volumes:
  - name: mariadb-volume
    persistentVolumeClaim:
      claimName: mariadb-pv-claim
---
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: mariadb-pv-claim
spec:
  accessModes:
    - ReadWriteOnce
  resources: #B
    requests: #B
      storage: 2Gi #B
```

#A the compute resources that the pod is requesting (see Chapter 5)
#B the disk resources that the pod is requesting

In the `PersistentVolumeClaim` definition, we're making a request for 2Gi of storage, and specifying the desired `accessMode`. The `ReadWriteOnce` access mode is for a volume that behaves like a traditional hard drive where your storage is mounted to a single pod for read write access and is the most common. The other choices for `accessMode` are `ReadOnlyMany` which can be used to mount a volume of existing data that's shared across many pods, and `ReadWriteMany` for mounting file storage (like NFS) where multiple pods can read/write at the same time (a fairly special mode, only supported by a few storage drivers). In this chapter the goal is stateful applications backed by traditional block-based volumes, so `ReadWriteOnce` is used throughout.

If your provider supports dynamic provisioning, a `PersistentVolume` backed by a disk resource will be created to fulfil the storage requested by the `PersistentVolumeClaim`, after which the `PersistentVolumeClaim` and `PersistentVolume` will be bound together. The dynamic provisioning behavior of the `PersisentVolume` is defined through the `StorageClass`

(which we cover in the next section). GKE and almost every provider supports dynamic provisioning, and will have a default storage class, so the above Pod can be deployed pretty much anywhere.

In the rare event that your provider *doesn't* have dynamic provisioning, you (or the cluster operator/admin) will need to manually create a `PersistentVolume` yourself with enough resources to satisfy the `PersistentVolumeClaim` request. Kubernetes still does the matchmaking of linking the claim to the volume.

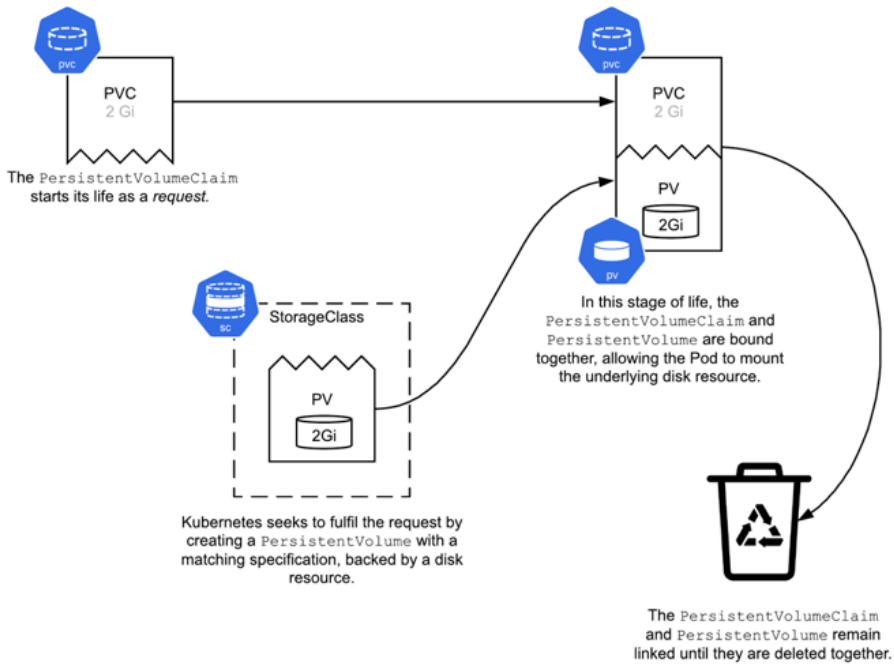


Figure 9.3: The lifecycle of a PersistentVolumeClaim and PersistentVolume in a dynamically provisioned system.

The `PersistentVolumeClaim` as defined in the above example can be thought of as a *request* for resources. The claim part really happens later, when it is matched with, and bound to a `PersistentVolume` resource (and both resources are linked to each other). Essentially the `PersistentVolumeClaim` has a lifecycle that starts as a request, and becomes a claim when bound.

We could leave it there, but since your precious data will be stored on these disks, let's dig in to see just how this binding works. If we query the YAML of the above `PersistentVolumeClaim` *after* it's bound, you'll see that it's been updated with a

`volumeName`. This `volumeName` is the name of the `PersistentVolume` that it was linked to, and now claims. Here's what it looks like (with some superfluous information omitted for readability):

```
$ kubectl get -o yaml pvc/mariadb-pv-claim
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: mariadb-pv-claim
spec:
  accessModes:
  - ReadWriteOnce
  resources:
    requests:
      storage: 2Gi
  storageClassName: standard-rwo
  volumeMode: Filesystem
  volumeName: pvc-ecb0c9ed-9aee-44b2-a1e5-ff70d9d3823a #A
status:
  accessModes:
  - ReadWriteOnce
  capacity:
    storage: 2Gi
  phase: Bound
```

#A the PersistentVolume which this object is now bound to

We can query the `PersistentVolume` named in this configuration with `kubectl get -o yaml pv NAME`, and we'll see that it links right back to the PVC. Here is what mine looked like.

```
$ kubectl get -o yaml pv pvc-ecb0c9ed-9aee-44b2-a1e5-ff70d9d3823a
apiVersion: v1
kind: PersistentVolume
metadata:
  name: pvc-ecb0c9ed-9aee-44b2-a1e5-ff70d9d3823a
spec:
  accessModes:
  - ReadWriteOnce
  capacity:
    storage: 2Gi
  claimRef:
    apiVersion: v1
    kind: PersistentVolumeClaim
    name: example-pv-claim #A
    namespace: default #A
  csi:
    driver: pd.csi.storage.gke.io
    fsType: ext4
    volumeAttributes:
      storage.kubernetes.io/csiProvisionerIdentity: 1615534731524-8081-
       pd.csi.storage.gke.io
    volumeHandle: projects/gke-autopilot-test/zones/us-west1-b/disks/pvc-ecb0c9ed-9aee-
       44b2-a1e5-ff70d9d3823a #B
  persistentVolumeReclaimPolicy: Delete
  storageClassName: standard-rwo
  volumeMode: Filesystem
status:
  phase: Bound #C
```

#A The PersistentVolumeClaim that this PersistentVolume is bound to
#B The pointer to the underlying disk resources
#C The status is now "bound"

It helps to visualize this side by side, so here it is:

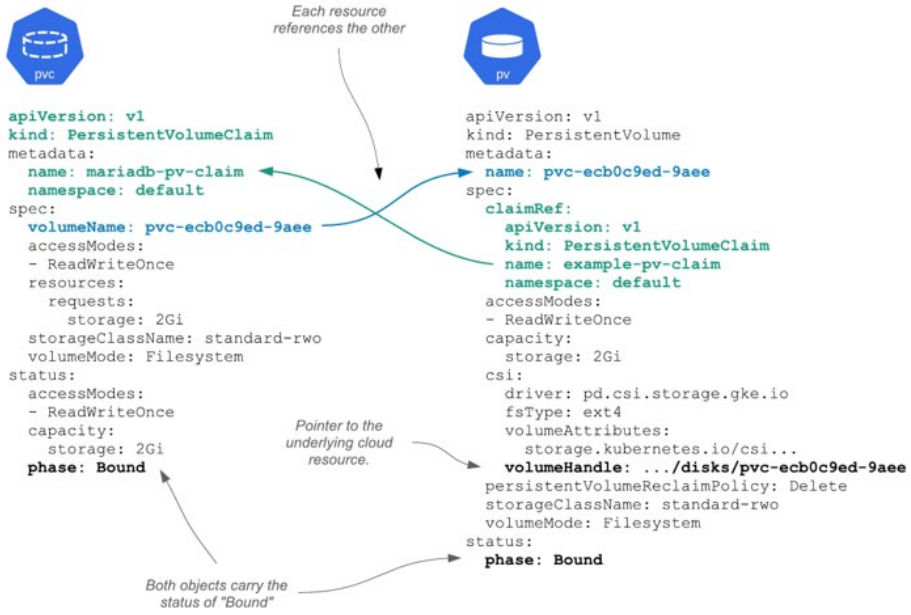


Figure 9.4: The PersistentVolumeClaim and PersistentVolume after the latter was provisioned, and they were bound together

The `PersistentVolumeClaim` has really undergone a metamorphosis here, going from a request for resources, to being a claim for a specific disk resource that exists (and will contain your data). This is not really like any other Kubernetes object I can think of. While it's common to have Kubernetes add fields and perform actions on the object, few change like these do, starting as a generic request for and representation of storage, and end up as a bound stateful object.

There is one exception to this typical lifecycle of a `PersistentVolumeClaim`, which is when you have *existing* data that you wish to mount into a Pod. In that case, you create the `PersistentVolumeClaim` and the `PersistentVolume` objects already pointing at each other, so they are bound immediately at birth. This scenario is discussed in section 9.3 on migrating and recovering disks, including a fully worked data recovery scenario.

9.1.3 Storage Classes

So far, we've relied on the default dynamic provisioning behavior of the platform provider. But what about if we want to change what type of disks we get during the binding process, or what happens to the data if the `PersistentVolumeClaim` is deleted? That's where storage classes come in.

Storage classes are way to describe the different types of *dynamic* storage that are available to be requested from `PersistentVolumeClaim`s, and how the volumes that are requested in this way should be configured.

Your Kubernetes cluster probably has a few defined already, let's view them (some columns have been stripped for readability):

```
$ kubectl get storageclass
NAME                    PROVISIONER             RECLAIMPOLICY
premium-rwo             pd.csi.storage.gke.io   Delete
standard                kubernetes.io/gce-pd    Delete
standard-rwo (default)  pd.csi.storage.gke.io   Delete
```

When we created the pod in the previous section with a `PersistentVolumeClaim`, the default storage class (`standard-rwo` in this case) was used. If you go back and look at the bound `PersistentVolumeClaim` object, you'll see this storage class in the configuration.

This is a pretty good start, and you may not need to do much here. There is one thing that I do suggest you consider customizing. You may notice if you read the "reclaim policy" column above and that it says `Delete`. What this means is that if the persistent volume claim is deleted the bound persistent volume and the disk resource that backs it will also be deleted. If your stateful workloads are mostly just caching services this might be fine, but if instead your workloads store unique and precious data this default behavior is probably not ideal.

Kubernetes also offers a `Retain` reclaim policy which means that the underlying disk resource will not be deleted on the deletion of the persistent volume claim allowing you to bind it to a new persistent volume and persistent volume claim potentially even one that you create in a completely separate cluster.

To build our own storage class, it's simplest to start with the system one. We can export it as follows. If your list is different to mine, replace `standard-rwo` with your default or preferred storage class:

```
kubectl get -o yaml storageclass standard-rwo > storageclass.yaml
```

Now we can customize and set the all-important `Retain` reclaim policy. Since we want to create a new policy it's also important to give it a new name, and strip the `uid` and `selfLink` metadata fields. After performing those steps, this is what I get:

Listing 9.2 storageclass.yaml: A default storage class with the Reclaim policy set

```
apiVersion: storage.k8s.io/v1
kind: StorageClass
metadata:
  annotations:
    storageclass.kubernetes.io/is-default-class: "true"
  name: example-default-rwo
parameters:
  type: pd-balanced
provisioner: pd.csi.storage.gke.io
reclaimPolicy: Retain #A
volumeBindingMode: WaitForFirstConsumer
allowVolumeExpansion: true
```

#A The reclaim policy is set to Retain

Before we can apply this config, we need to mark the current default as non-default. You can edit with `kubectl edit storageclass standard-rwo`, or patch it with the following one-liner. Again, replace `standard-rwo` with whatever the name of your default class is.

```
kubectl patch storageclass standard-rwo -p '{"metadata":
       {"annotations":{"storageclass.kubernetes.io/is-default-class":"false"}}}'
```

Then create our new storage class, with `kubectl create -f storageclass.yaml`.

If you have different types of persistent data in your cluster, say precious data and also caching data that can be re-created, you could have two storage classes configured to represent each "class" of storage (precious data, and cache data). You can then reference them manually using the `storageClassName` field in your `PersistentVolumeClaim` objects. The examples in this chapter however will all use the default `StorageClass`, whatever you (or your cloud provider) set that to be.

9.1.4 Single-pod Stateful Workload Deployments

Combining these concepts, we can provision a 1-replica stateful workload by simply enclosing our Pod into a Deployment. The benefit of using a Deployment even for a single-replica pod is that if the pod is terminated it will be recreated.

Listing 9.3 mariadb-deploy.yaml: A single-pod deployment with a PersistentVolumeClaim.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: mariadb-demo
spec:
  replicas: 1
  selector:
    matchLabels:
      app: mariadb
  template: #A
    metadata:
      labels:
        app: mariadb
    spec:
      containers:
      - name: mariadb-container
        image: mariadb:latest
        volumeMounts:
        - mountPath: /var/lib/mysql
          name: mariadb-volume
        resources:
            requests:
              cpu: 1
              memory: 4Gi
        env:
          - name: MYSQL_ROOT_PASSWORD
            value: "your database password"
      volumes:
      - name: mariadb-volume
        persistentVolumeClaim:
          claimName: mariadb-pvc
---
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: mariadb-pvc
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 2Gi
```

#A Our pod template spec is identical to the one shown in Section 9.1.2

So there we have it this is a single pod deployment of a MariaDB database with an attached disk that won't be deleted even if this entire Kubernetes cluster is deleted, thanks to the `Retain` policy in the storage class we created in the prior section.

If you want to give this database a spin, create a service for it (see the `service.yaml` file in the same directory). Once the service is created, you can connect to the database from a local client, or you can try out the containerized phpMyAdmin (see Bonus/phpMyAdmin in the code repository that accompanies the book for a sample configuration of that).

Running Databases in Kubernetes

Before you take the plunge to manage your own like MariaDB in Kubernetes like this, you probably want to look for managed solution with your cloud provider. I know it's tempting just to deploy in Kubernetes because it's fairly easy to create such a database, as I demonstrated, but the operational cost comes later when you have to secure, update and manage it. Generally, I recommend reserving the stateful workload functionality of Kubernetes for customized or bespoke services, or services that your cloud provider doesn't offer as a managed offering.

As demonstrated in this section, we can make our workloads stateful by attaching volumes, using `PersistentVolumeClaims`. Using Pod and Deployment objects for this however, constrains us to single replica stateful workloads. This might be enough for some, but what if you have a sophisticated stateful workload like Elasticsearch or Redis with multiple replicas? You could try and stitch together a bunch of deployments, but fortunately Kubernetes has a high-level construct that is designed to represent exactly this type of deployment called the stateful set.

9.2 StatefulSet

We've seen how persistent storage can be added to a pod in Kubernetes—a useful feature because Pods are the basic building block in Kubernetes, and they are used in many different deployment constructs like Deployments (Chapter 3) and Jobs (Chapter 10). Now you can add persistent storage to any of them and build stateful pods wherever you need, provided that the volume specification is the same for all instances.

The limitation of the deployment constructs like Deployment that all pods share the same specification is an issue for ReadWriteOnce volumes. These traditional block storage volumes can only be mounted by a single instance. This is OK when there is only one replica in your Deployment, but it means that if you create a second replica, that Pod will fail to be created as the volume is already mounted.

Fortunately, Kubernetes has a high-level construct that makes our lives easier when we need multiple Pods where they each get their own disk (a highly common pattern). Just like Deployment is a high-level construct for managing (normally stateless) continuously running services, StatefulSet is a high-level construct for managing stateful services.

StatefulSet has a few helpful properties for building such services. You can define a volume template instead of a referencing a single volume in the pod spec and Kubernetes will create a new persistent volume claim for each pod which solves the issue when using Deployment, where each instance shared the same persistent volume claim. StatefulSet assigns each pod a stable identifier which is linked to a particular persistent volume claim and provides ordering guarantees for deployment, scaling and updates. Now you can create multiple Pods and coordinate them by using this stable identifier to assign each a different role.

9.2.1 Deploying StatefulSet

Putting this into practice, let’s look at two popular stateful workloads: MariaDB and Redis, and how to deploy them as a StatefulSet. At first we'll stay with a single-pod StatefulSet

which is the simplest to demonstrate as there are not multiple roles to worry about. The next section will add additional replicas with different roles to fully use the power of StatefulSet.

MariaDB

First, let's convert the single pod MariaDB deployment we created in the previous section to one using StatefulSet and take advantage of the persistent volume claim template to avoid the need to create a separate PersistantVolumeClaim object ourselves.

Listing 9.4 mariadb-statefulset.yaml

```
apiVersion: apps/v1
kind: StatefulSet
metadata:
  name: mariadb
spec:
  selector: #A
    matchLabels: #A
      app: mariadb-sts #A
  serviceName: mariadb-service #B
  replicas: 1
  template:
    metadata:
      labels:
        app: mariadb-sts
    spec:
      terminationGracePeriodSeconds: 10 #C
      containers:
      - name: mariadb-container
        image: mariadb:latest
        volumeMounts:
        - name: mariadb-pvc #D
          mountPath: /var/lib/mysql #D
        resources:
            requests:
              cpu: 1
              memory: 4Gi
        env:
          - name: MYSQL_ROOT_PASSWORD
            value: "your database password"
  volumeClaimTemplates: #E
  - metadata: #E
      name: mariadb-pvc #E
    spec: #E
      accessModes: #E
        - ReadWriteOnce #E
      resources: #E
        requests: #E
          storage: 1Gi #E
---
apiVersion: v1 #F
kind: Service #F
metadata: #F
  name: mariadb-service #F
spec:
  ports:
  - port: 3306
```

```
  clusterIP: None
  selector:
    app: mariadb-sts
```

#A StatefulSet uses the match labels pattern as Deployments, which discussed in Chapter 3
#B This is a link to the headless service which is defined at the bottom of the file.
#C StatefulSet requires that a graceful termination period be set. This is the number of seconds that the Pod has to exit on its own before being terminated.
#D The volume claim matching this name is defined in the volumeClaimTemplates section
#E Unique to Statefulset, we can define a template of a PersisantVolumeClaim just like we define the template of the pod replicas. This template is used to create the PersistentVolumeClaims, associating one to each of the pod replicas.
#F The headless services for this StatefulSet (required)

So what changed compared to the Deployment of a MariaDB pod with an attached persistant volume in 9.1.4? Other than the usual metadata differences, there are two key changes.

The first difference is how the `PersistentVolumeClaim` is configured. In 9.1.4 when used with a Pod in a deployment, this was a standalone object. With StatefulSet, this is rolled into the definition itself. Much like how a Deployment has a Pod template. What this means is that each `PersistentVolume` claim will use this template. You end up with the same result, but don't have to define a separate object (which is useful with this example, and essential when creating one with more than 1 replica). Here they are side by side:

Table 9.1 PersistentVolumeClaim vs volumeClaimTemplates

```
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: mariadb-pvc
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 2Gi
```

```
...
  volumeClaimTemplates:
  - metadata:
      name: mariadb-pvc
    spec:
      accessModes:
        - ReadWriteOnce
      resources:
        requests:
          storage: 2Gi
```

If you query the persistent volume claims after creating the StatefulSet, you'll see this claim (with some columns removed for readability):

```
$ kubectl get pvc
NAME                    STATUS   VOLUME     CAPACITY   ACCESS MODES
mariadb-pvc-mariadb-0   Bound    pvc-71b1e  2Gi        RWO
```

The only difference is that the one created with the template has the pod name (`mariadb-0` in the case of the first pod) appended to it, so instead of being `mariadb-pvc` (the name of the claim template), it's `mariadb-pvc-mariadb-0` (the claim template name, and pod name combined).

The second difference is a service that is referenced in the StatefulSet with the `serviceName: mariadb-service` line, and defined as so:

```
apiVersion: v1 #F
kind: Service #F
metadata: #F
  name: mariadb-service
spec:
  ports:
  - port: 3306
  clusterIP: None
  selector:
    app: mariadb-sts
```

This Service is a bit different to the ones presented in the book so far, as it's what's known as a headless service (thanks to the clusterIP: None specification). That means, that unlike every other Service we created so far there is no service endpoint with load balancing. The service has no IP, external or internal. It exists so that the pods in the StatefulSet can get their own network identities so that *they* can be addressed. Remember that each pod in the stateful set is unique (unlike with Deployments), so it's common to address them individually.

Pods can be addressed at `STATEFULSET_NAME-POD_ORDINAL.SERVICE_NAME`

In this example, our single pod can be referenced using the DNS address: `mariadb-0.mariadb-service`. From outside the namespace, you can append the namespace e.g.:

```
mariadb-0-mariadb-service.production.svc
```

REDIS

Here's another example, this time Redis. Redis is a very popular deployment in Kubernetes, and has many different possible uses, often for caching and other real-time data storage and retrieval needs.

For this example, let's imagine the caching use-case where the data isn't super precious. You still want to persist the data to disk (to avoid rebuilding the cache in the event of a restart), but there's no need back it up. What follows is a perfectly usable single-pod Redis deployment for Kubernetes for such applications.

To configure Redis, let's first define our config file which we can mount as a volume in the container:

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: redis-config
data:
  redis.conf: |
    bind 0.0.0.0 #A
    port 6379 #B
    protected-mode no #C
    appendonly yes #D
    dir /redis/data #E
```

#A bind to all interfaces so that other Pods can connect
#B the port to use
#C disable protected mode so that other Pods in the cluster can connect without a password
#D enable the append log to persist data to disk
#E specify the directory

See the code annotation for what each of the configuration options do. The important thing is that we're persisting the Redis state to the `/redis/data` directory, so it can be reloaded if the Pod is re-created.

This example does not configure authentication for Redis, which means that every Pod in the cluster will have read/write access. If you take this example and use it for in a production cluster, please consider how you wish to configure the cluster.

Now let's go ahead and create a StatefulSet that will reference this config, and mount the `/redis/data` directory as a PersistentVolume:

```
apiVersion: apps/v1
kind: StatefulSet
metadata:
  name: redis
spec:
  selector:
    matchLabels:
      app: redis-sts
  serviceName: redis-service
  replicas: 1
  template:
    metadata:
      labels:
        app: redis-sts
    spec:
      terminationGracePeriodSeconds: 10
      containers:
      - name: redis-container
        image: redis:latest
        command: ["redis-server"]
        args: ["/redis/conf/redis.conf"]
        volumeMounts:
        - name: redis-configmap-volume
          mountPath: /redis/conf/
        - name: redis-pvc
          mountPath: /redis/data
        resources:
            requests:
              cpu: 1
              memory: 4Gi
      volumes:
      - name: redis-configmap-volume
        configMap:
          name: redis-config
  volumeClaimTemplates:
  - metadata:
      name: redis-pvc
    spec:
      accessModes: [ "ReadWriteOnce" ]
      resources:
        requests:
          storage: 1Gi
---
apiVersion: v1
kind: Service
metadata:
  name: redis-service
```

```
spec:
  ports:
  - port: 6379
  clusterIP: None
  selector:
    app: redis-sts
```

Compared to the MariaDB StatefulSet, it's a similar setup, other than the application specific differences, like the different ports used, the container image of course and the mounting of the config map into `/redis/conf`.

So that's a 1-replica StatefulSet. It's a bit more convenient than using a Deployment for such a workload, as Kubernetes can take care of creating the PersistentVolumeClaim automatically.

If you delete the StatefulSet object, the PersistentVolumeClaim object will remain. If you then re-create the StatefulSet, it will re-attach to the same PersistentVolumeClaim, so no data is lost. Deleting the PersistentVolumeClaim object itself *can* delete the underlying data though, depending on how the storage class is configured. If you care about the data being stored (e.g. it's more precious than a cache that can be re-created), be sure to follow the steps in Section 9.1.3 to setup a StorageClass that will retain the underlying cloud resources if the PersistentVolumeClaim object is deleted for whatever reason.

As previously, we can scale this StatefulSet but that would simply duplicate the Pods. In some cases this may be desirable, but for the MariaDB deployment defined here, it would just give us more MariaDB instances. The next section goes into detail about how to setup a multiple pod architecture within a single StatefulSet with different configuration based on the ordinal of the pod.

9.2.2 Deploying a Multi-Role StatefulSet

The real power of stateful set comes into play when you need to have multiple pods. When designing an application that will use stateful set, pod replicas within the stateful set need to know about each other and communicate to each other as part of the stateful application design. This is the benefit though of using stateful set because each of the pods gets a unique identifier in a set known as the ordinal. You can use this uniqueness and guaranteed ordering to assign different roles to the different unique Pods in the set and associate the same persistent disk through updates and even deletion and recreate.

For this example we'll take the single pod Redis StatefulSet from the previous section and convert it to a three-pod setup with two separate roles. In Redis parlance, one will be assigned the role of "master", the remaining as "replicas" (not to be confused with replicas in Kubernetes parlance used in Deployment and StatefulSet to mean pod instances).

Building on the example in the previous section, we'll add a second file to our configuration directory for the replica role. I've chosen Redis for the demo here as it is one of the most popular stateful applications to run on Kubernetes.

Listing 9.5 redis-configmap.yaml: ConfigMap contianing two Redis Configuration files, one for each role

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: redis-config
data:
  master.conf: |
    bind 0.0.0.0
    port 6379
    protected-mode no
    appendonly yes
    dir /redis/data
  replica.conf: |
    replicaof redis-0.redis-service 6379
    bind 0.0.0.0
    port 6379
    protected-mode no
    appendonly yes
    dir /redis/data
```

ConfigMaps are simply a convenient way for us to define two configuration files (one for each of the two roles). We could equally build our own container using the Redis base image, and put these two files in there. But since this is the only customization we need, it's simpler to just define them here, and mount them into our container.

Next, we'll update the StatefulSet deployment to use an init container (a container that runs during the initialization of the Pod) to set the role of each pod replica. The script that runs in this init container looks up the ordinal of the pod being initialized to determine its role, copies the relevant configuration for that role (recall that a special feature of StatefulSets is that each pod is assigned a unique ordinal). We can arbiturarily use the ordinal 0 to designate the master Redis pod, while assigning the remaining pods the replica role.

This technique can be applied to a variety of different statful workloads where you have multiple roles. If you're looking for MariaDB, there's a great guide[1] provided with the Kubernetes docs.

[1] https://kubernetes.io/docs/tasks/run-application/run-replicated-stateful-application/

Listing 9.6 redis-statefulset.yaml: Multi-role Redis StatefulSet

```
apiVersion: apps/v1
kind: StatefulSet
metadata:
  name: redis
spec:
  selector:
    matchLabels:
      app: redis-sts
  serviceName: redis-service
  replicas: 3
  template:
    metadata:
      labels:
        app: redis-sts
    spec:
      terminationGracePeriodSeconds: 10
      initContainers:
      - name: init-redis
        image: redis:latest
        command:
        - bash
        - "-c"
        - |
          set -ex
          # Generate server-id from pod ordinal index.re
          [[ `hostname` =~ -([0-9]+)$ ]] || exit 1
          ordinal=${BASH_REMATCH[1]}
          echo "ordinal ${ordinal}"
          # Copy appropriate config files from config-map to emptyDir.
          mkdir -p /redis/conf/
          if [[ $ordinal -eq 0 ]]; then
            cp /mnt/redis-configmap/master.conf /redis/conf/redis.conf
          else
            cp /mnt/redis-configmap/replica.conf /redis/conf/redis.conf
          fi
          cat /redis/conf/redis.conf
        volumeMounts:
        - name: redis-config-volume
          mountPath: /redis/conf/
        - name: redis-configmap-volume
          mountPath: /mnt/redis-configmap
      containers:
      - name: redis-container
        image: redis:latest
        command: ["redis-server"]
        args: ["/redis/conf/redis.conf"]
        volumeMounts:
        - name: redis-config-volume
          mountPath: /redis/conf/
        - name: redis-pvc
          mountPath: /redis/data
        resources:
            requests:
              cpu: 1
              memory: 4Gi
      volumes:
      - name: redis-configmap-volume
```

```
        configMap:
          name: redis-config
      - name: redis-config-volume
        emptyDir: {}
  volumeClaimTemplates:
  - metadata:
      name: redis-pvc
    spec:
      accessModes: [ "ReadWriteOnce" ]
      resources:
        requests:
          storage: 1Gi
---
apiVersion: v1
kind: Service
metadata:
  name: redis-service
spec:
  ports:
  - port: 6379
  clusterIP: None
  selector:
    app: redis-sts
```

There's a bit to unpack here. The main difference to our single-instance Redis StatefulSet is the presence of an init container. This init container, as its name suggests, runs during the initialization phase of the Pod. It mounts two volumes, the ConfigMap, and a new volume "redis-config-volume".

```
        volumeMounts:
        - name: redis-config-volume
          mountPath: /redis/conf/
        - name: redis-configmap-volume
          mountPath: /mnt/redis-configmap
```

The `redis-config-volume` is of type `emptyDir`, which allows data to be shared between containers, but does not persist data if the pod is rescheduled (unlike `PersistentVolume`). All we're using this `emptyDir` volume is to store the config, and this is ideal for that.

```
        command:
        - bash
        - "-c"
        - |
          set -ex
          # Generate server-id from pod ordinal index.
          [[ `hostname` =~ -([0-9]+)$ ]] || exit 1
          ordinal=${BASH_REMATCH[1]}
          # Copy appropriate config files from config-map to emptyDir.
          mkdir -p /redis/conf/
          if [[ $ordinal -eq 0 ]]; then
            cp /mnt/redis-configmap/master.conf /redis/conf/redis.conf
          else
            cp /mnt/redis-configmap/replica.conf /redis/conf/redis.conf
          fi
```

The bash command that the container runs copies the master, or replica config from the configmap volume (mounted at `/mnt/redis-configmap`) to this shared `emptyDir` volume (mounted at `/redis/conf`), depending on the ordinal number of the pod. That is, if the pod is "redis-0" the `mater.conf` file is copied, for the rest, `replica.conf` is copied.

The main container then mounts the same "redis-config-voulme" at `/redis/conf`, and the redis process is started and told to use whatever configuration resides at `/redis/conf/redis.conf`.

9.3 Migrating/Recovering Disks

Now I know what you're thinking: can I really trust Kubernetes with my precious data? There's a bit too much magic going on here, how can I be confident that my data is safe, and recoverable if the Kubernetes cluster goes away?

Time to build some confidence. Let's create a stateful workload in Kubernetes. Then completely delete every Kubernetes object associated with it and try to recreate that workload from scratch, relinking it to the underlying cloud disk resources.

One thing to be very aware of is that commonly by default, volumes that Kubernetes creates are deleted if you delete the associated bound `PersistentVolumeClaim`. Due to them being configured with the Delete retainPolicy. With this policy set in the StorageClass, deleting the StatefulSet doesn't itself delete the PersistentVolumeClaim, which is good (forcing admins to manually clean up the StatefulSet's PersistentVolumeClaims if they do wish to delete them, but avoiding accidental delete). But, deleting the PersistantVolumeClaim objects *will* delete the underlying disk resources and it's not that hard to do (e.g. by passing `--all` to the relevant `kubectl delete` command).

So if you value your data, the first thing is to make sure the StorageClass that's used when creating the disks for your precious data has its `reclaimPolicy` set to `Retain`, not `Delete`. This will preserve the underlying cloud disk when the Kubernetes objects are deleted allowing you to manually re-create the PersistentVolumeClaim / PersistentVolume pairing in the same, or a different cluster (which I will demonstrate). To run this experiment using the configuration provided, follow the steps in 9.1.3 to set a default `StorageClass` to be configured as `Retain`, so that the underlying cloud disk resource won't be deleted. Note that changes to the reclaimPolicy only apply for disks created *after* the change. For any existing PersistentVolumes, you'll need to update them manually.

With our reclaimPolicy set correctly we can now deploy Redis, and add some data to our newly created data volumes. First, deploy the example from 9.2.2 . Once it's running, let's add some data which we can use to validate our ability to recover our Kubernetes StatefulSet after we delete it. To add data, exec into the master pod and run the `redis-cli`, tool. You can do both with the following command:

```
kubectl exec -it redis-0 -- redis-cli
```

Next, we'll add some data to Redis. If you've not used Redis before, don't worry about this—we're just adding some trivial data so as to prove that we can recover it.

```
127.0.0.1:6379> SET capital:australia "Canberra"
OK
127.0.0.1:6379> SET capital:usa "Washington"
OK
```

If you like, at this point you can delete the StatefulSet, and re-create it, then exec back into the CLI and test the data. Here's how:

```
$ kubectl delete -f redis-statefulset.yaml; kubectl create -f redis-statefulset.yaml
service "redis-service" deleted
statefulset.apps "redis" deleted
service/redis-service created
statefulset.apps/redis created


$ kubectl exec -it redis-0 -- redis-cli
127.0.0.1:6379> GET capital:usa
"Washington"
```

This works (the data is persisted) because when the StatefulSet is re-created, it references the same PersistentVolumeClaim which has our data for Redis to load when it boots, and so Redis picks off right where it left off.

Good so far. Now let's take a more drastic step and delete the PVC and the Volume, and attempt to re-create. The re-creation can optionally be done in a completely new cluster if you like, to simulate the entire cluster being deleted (just be sure to use the same cloud region so the disk can be accessed).

Before we delete those objects though, let's save their configuration. This isn't strictly necessary, you certainly *can* re-create them from scratch if needed, but it will help save some time.

```
$ kubectl get pvc,pv
$ kubectl get -o yaml persistentvolumeclaim/redis-pvc-redis-0 > pvc.yaml
$ kubectl get -o persistentvolume/PV_NAME > pv.yaml
```

Now, the nuclear option: delete the stateful set and the pvc.

```
$ kubectl delete pvc,pv --all
```

Due to the `Retain` policy on the `StorageClass` (I hope you did use a storage class with `Retain` as instructed, otherwise that data is gone!), the cloud disk resource will still exist. Now it's just a matter of manually creating a PV to link to that disk, and a PVC to link to that.

Here's what we know:

- We know (or can find out) the name of the underlying disk resource in our cloud provider
- We know the name of the PVC that the StatefulSet will consume (redis-pvc-redis-0)

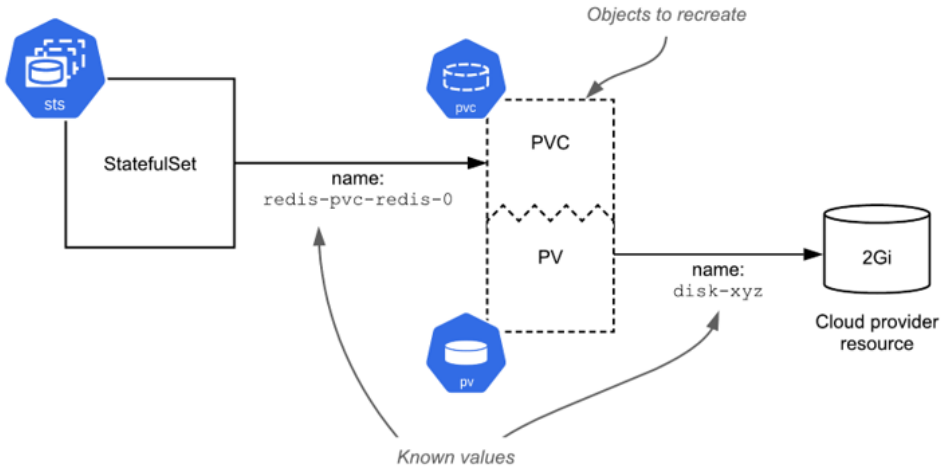


Figure 9.4: the known values, and the objects we need to recreate|

So what we need to do is create a PVC with the name `redis-pvc-redis-0` that is bound with a PV that references the disk. Importantly, the PVC needs to name the PV, and the PV needs to define the bound PVC, otherwise the PVC could bind a different PV, and the PV could be bound by a different PVC.

Creating the objects from our saved config with `kubectl create -f pv.yaml` and `kubectl create -f pvc.yaml` unfortunately won't work. This is because that configuration also exported the *state* of the binding, and unique identifiers that don't carry over when you delete and create the object from config. If you try this, you'll see that the PVC `Status` is `Lost`, and the PV status is `Released`. Not what we want.

To fix this, we just need to remove the binding status and the `uid`s:

Edit the PersistentVolume (the configuration we exported to `pv.yaml`) and make two changes:

a) Remove the `uid` field from the `claimRef` (the `claimRef` is the pointer to the PVC, the issue is that the PVC's `uid` has changed)
b) Set the `storageClassName` to the empty string `""` (we're manually provisioning and don't want to use a `storageClass`).

Edit to the PVC (pvc.yaml exported config) and make 2 changes there:

a) Delete the annotations such as `pv.kubernetes.io/bind-completed: "yes"` (this PVC needs to be re-bound and this annotation will prevent that)
b) Set the `storageClassName` to the empty string `""` (same reason as above)

Alternatively, if you're re-creating this config from scratch, the key is that the `volumeName` of the PVC needs to be set to that of the PV, the `claimRef` of the PV needs to reference the PVC's name and namespace, and both have the `storageClassName` of `""`.

Again, it's easier to visualze side by side. This figure is based on the configuration I exported when I ran this test, and removed the fields as documented above.

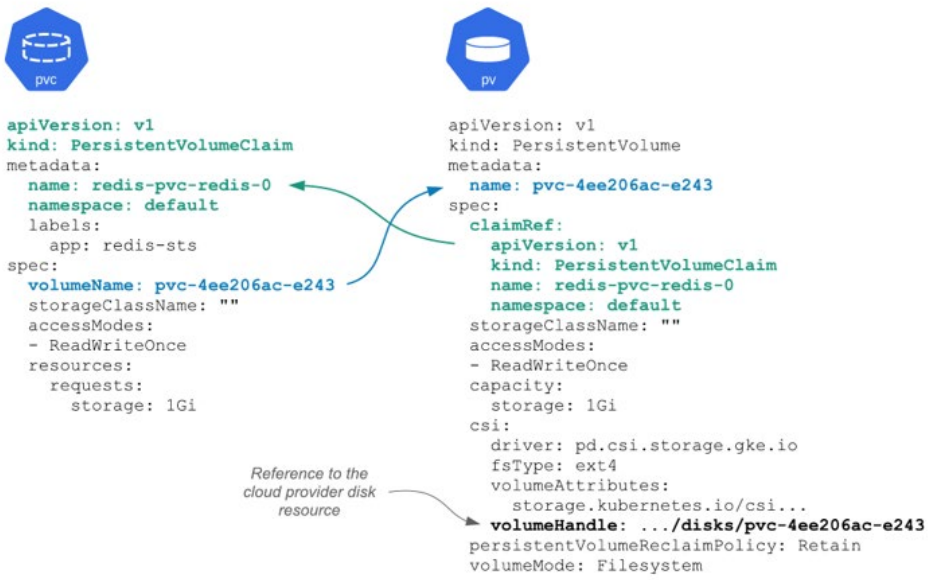


Figure 9.5: Pre-linked PVC and PV objects

Once prepared, you can create both configuration files in the cluster then inspect their status with `kubectl get pvc,pv`.

If it goes correctly, the status for both objects should read "Bound". If instead one or both are listed as Pending or Released, go back and check that they are linked correctly with all the information needed, and without any extra information. Yes, unfortunately, this is a bit of a pain, but it is possible to rebind these objects, provided that the underlying cloud resource is still there (which it will be, since you used the Retain policy on your StorageClass didn't you).

This is what success looks like (with some columns removed for readability):

```
$ kubectl get pvc
NAME                STATUS   VOLUME
redis-pvc-redis-0   Bound    pvc-f0fea6ae-e229

$ kubectl get pv
NAME                RECLAIM POLICY   STATUS   CLAIM
pvc-f0fea6ae-e229   Retain           Bound    default/redis-pvc-redis-0
```

Once you have your manually created PVC and PV objects, it's time to re-create the StatefulSet. As we tested earlier when we deleted and re-created the StatefulSet, as long as the PVC exists with the expected name, it will be re-attached to the Pods of the StatefulSet. The name of the PVCs that the StatefulSet is deterministic, so when we recreate the StatefulSet, it will see the existing PVC objects and reference them, rather than creating new ones. Basically, everything should just work as we re-create these objects using the same names as before.

Notice in this example, that despite the fact the StatefulSet has 3 PVCs and therefore 3 associated disks, we only manually recovered 1 disk, that of the master. This is because the replicas will automatically be recreated.

Once the StatefulSet is deployed, let's exec into one of those replicas and see if our data is still there:

```
$ kubectl create -f redis-statefulset.yaml
service "redis-service" deleted
statefulset.apps "redis" deleted
service/redis-service created
statefulset.apps/redis created

$ kubectl exec -it redis-1 -- redis-cli
127.0.0.1:6379> GET capital:australia
"Canberra"
```

If you can read back the data we wrote to Redis earlier, the congratulations! You've recovered the StatefulSet from scratch.

I hope this has given you some confidence about the persistence of the data when the `Retain` policy is used. As demonstrated, you can completely delete all the objects (heck, even the entire cluster), and re-create all the links from scratch. It's a bit laborsome, but it's possible. To reduce the toil, it's advisable (but not essential) to export the config for our PVC and PV objects and store them in our configuration repository, to make it faster to recreate these objects in the future.

9.4 Summary

One of the strengths of Kubernetes is that it can deftly handle deployments of stateful applications. It's not confined only to stateless applications, as some other application platforms are. There are several tools at your disposal to confidently host stateful applications, including:

- The ability to mount disks from your cloud provider directly into Pods
- Creating simple 1-Pod stateful deployments
- The complex lifecycle of the `PersistentVolume`, and `PersistentVolumeClaim` objects, including the metamorphosis they go through as they are bound together into a single logical object
- Configuring `StorageClasse`s to enable dynamic storage with your preferred configuration options (most importantly, the option to retain the cloud provider disk resources should the Kubernetes objects be deleted)
- Deploying simple 1-Pod stateless applications using `StatefulSet` or even just as a Deployment
- The benefit that the Kubernetes `StatefulSet` offers stateful deployments, being that each pod and their associated disks are assigned a specific number (ordinal) so that when pods are re-created, the disk is re-mounted to the pod with the same ordinal.
- Using the properties of `StatefulSet` to deploy more complex multi-pod stateful applications that employ different roles (such as a master copy and replicas) using the ordinal number of the Pod
- How to re-create bound `PersistentVolume` and `PersistentVolumeClaim` object pairs to reference existing disks (for example, when recovering a deployment or migrating between two clusters)

10

Background Processing

This chapter covers

- How to process background tasks in Kubernetes
- The Kubernetes Job and CronJob objects
- When to use (and not use) Job objects for your own batch processing workloads
- Creating a custom task queue with Redis
- Implementing a background processing task queue with Kubernetes

In the prior chapters we looked at developing services that are exposed on an IP address, whether it's an providing an external service on a public address, or an internal service on a cluster local IP. But what about all the other computation that you may need to do that isn't directly part of a request-response chain, like resizing a bunch of images, sending out device notifications, processing financial data, or rendering a movie one frame at a time? Background tasks are all the compute processes that take an input and produce an output without being part of the synchronous processing of requests in the way services are.

You can process background tasks using Deployment, or the Kubernetes Job object. Deployment is ideal for a continuously running task queue like the one most web applications run for tasks like image resizing. The Kubernetes Job construct is great for running one-off maintenance tasks, periodic tasks (via CronJob), and processing a batch workload when there is a set amount of work to complete.

Terminology: task or job

Practitioners routinely uses the terms "task" and "job" interchangeably when referring to a background computation for example "job queue" and "task queue", "background job", and "background task". Since Kubernetes has an object named Job, to reduce ambiguity I will always sentence-case "Job" when referring to the object itself, and will use the word "task" (like "background task" and "task queue") when referring to the general concept of background processing, however it is implemented.

This chapter covers using both Deployment and Job for background task processing. By the end, you'll be able to configure a continuous background task processing queue for your web application, defined batch workloads with an end-state, as well as period and one-off tasks, all in Kubernetes.

10.1 Background Processing Queues

Most web applications deployed in the wild have a major background task processing component in order to handle processing tasks that can't be completed in the short HTTP request/response time window. User research conducted by Google observes that the longer the page load is, the higher the chance the user will "bounce" (i.e. leave the page and go somewhere else), so it's generally a mistake to try and do any heavy lifting while the user is waiting, and instead put that task on a background queue, and keep the user apprised of the progress. Page load speeds need to be on everyone's mind, from the front end developers to the backend; it's a collective responsibility.

> The probability of bounce increases 32% as page load time goes from 1 second to 3 seconds.
>
> Google/SOASTA Research, 2017.[1]

There's a lot that goes into the time it takes to load the page, and many aspects like image sizes and JavaScript are out of scope for Kubernetes. A relevant metric to consider when looking at your workload deployments in Kubernetes is "time to first byte" or TTFB. This is the time it takes for your web server to complete its processing of the request and the client to start downloading the response. To achieve a low overall page loading time, it's critical to reduce the TTFB time and respond in sub-second times. That pretty much rules out any kind of data processing that happens "inline" as part of the request. Need to create a ZIP file to serve to a user, or shrink an image they just uploaded? Best not to do it in the request itself.

As a result of this, the common pattern is to run a continuous background processing queue. The web application hands off tasks it can't do inline like process data, which gets picked up by the background queue. The web application might show a spinner or some other UI affordance while it waits for the background queue to do its thing, or may email the user when the results are ready, or simply prompt the user to come back later. How you architect your user interaction is up to you. What we'll cover here is how to deploy this kind of background processing task queue in Kubernetes.

[1] https://www.thinkwithgoogle.com/marketing-strategies/app-and-mobile/page-load-time-statistics/

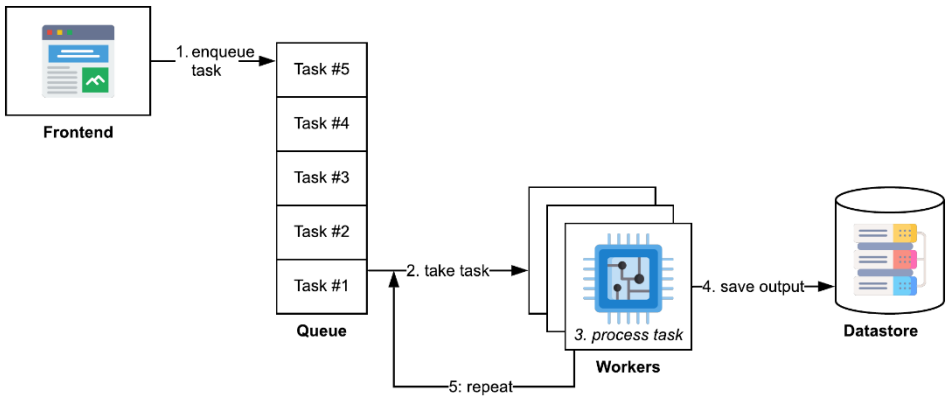


Figure 10.1: Front-end web server with a background task queue

Recall that a Deployment (as covered in chapter 3) is a workload construct in Kubernetes thats purpose is to maintain a set of continuously running Pods. For background task processing queues, what you need is a set of continuously running Pods being your task workers. So that's a match! It doesn't matter that the Pods in the Deployment won't be exposed with a Service, the key is that you want at least one worker to be continuously running. You'll be updating this Deployment with new container versions and scaling it up and down just like with a deployment that serves your frontend requests, so everything we've learnt so far can be applied equally to a Deployment of background task workers.

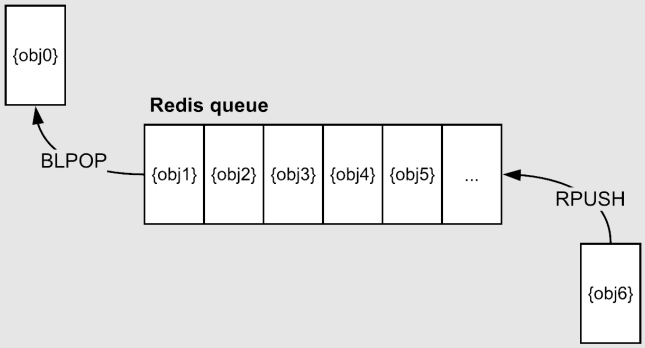
10.1.1 Creating a custom task queue

The worker Pods that you deploy in your deployment have a simple role: take an input and produce an output. But where do they get the input from? For that, you'll need a queue on which other components of the application can add tasks. This queue will store the list of pending tasks, which the worker Pods will process. There are a bunch of off-the-shelf solutions for background queues (some which I mention in section 10.1.2), but to best understand how these work, let's create our own!

For the queue data store, we'll be using the same Redis deployment we created in the previous chapter. Redis includes built-in support for queues, making it perfect for this task (and many off-the-shelf solutions also use Redis). The design of our work system is pretty straightforward: the web application role enqueues tasks to Redis (we can emulate this role by manually adding tasks), and worker Pods from our Deployment pop pop the tasks, perform the work and waits for the next one.

Queues in Redis

Redis has several convenient data structures out of the box. The one we're using today is a queue. There are two functions we'll be using with this queue structure to get FIFO (first-in, first-out) ordering which is typical of a background queue (processing items in the order they are added): `RPUSH` to add items to the back of the queue, and `BLPOP` to pop items from the front of the queue and block if none are available.



If you think of the queue going from right to left, where the rightmost item is at the back of the queue, and the leftmost item is the front, then the "L" and "R" function prefixes will make sense (`RPUSH` to push an object on the right, and `BLPOP` to blocking pop the leftmost item). The further "B" prefix refers to the blocking form of the function (in this case the blocking version of `LPOP`), which will cause it to wait for an item in the event the queue is empty rather than returning right away with nil. We could simply use `LPOP` in our own retry loop, but it's useful to block on the response to avoid a "busy wait" which would consume more resources. This way we can leave that task to Redis as well.

As a concrete but trivial example, our task will take as input an integer *n*, and calculate Pi using the Leibniz series formula[2] with *n* iterations (the more iterations when calculating Pi in this way, the more accurate the end result). In practice your task will likely be a lot more complex and complete whatever arbitrary processing you need it to do, and will take as input a URL, or dictionary of key/value parameters. The concept is the same.

CREATING A WORKER CONTAINER

Before we get to the Kubernetes deployment, we'll need to create our worker container. I'll use Python again for this sample, as we can implement a complete task queue in a few lines of Python. The complete code for this container can be found in the `Chapter10/worker` folder in the source code that accompanies this book. It consists of 3 python files, presented as follows:

[2] https://en.wikipedia.org/wiki/Leibniz_formula_for_pi

`pi.py` containers our work function. This is where the actual computation happens. It has no concept of being in a queue, it just does the processing. In your own case, you'd replace this with whatever computation you need to do, e.g. creating a ZIP file, or compressing an image.

Listing 10.1 Chapter10/pi_worker/pi.py

```
from decimal import *

# Calculate pi using the Gregory-Leibniz infinity series
def leibniz_pi(iterations):

  precision = 20
  getcontext().prec = 20
  piDiv4 = Decimal(1)
  odd = Decimal(3)

  for i in range(0, iterations):
    piDiv4 = piDiv4 - 1/odd
    odd = odd + 2
    piDiv4 = piDiv4 + 1/odd
    odd = odd + 2

  return piDiv4 * 4
```

Then, we have our worker implementation that will take the object at the head of the queue with the parameters of the work needed to be done, and perform the work by calling the `leibniz_pi` function above. For your own implementation, the object that you queue just needs to contain the relevant function parameters for the task, like the details of the ZIP file to create, or image to process.

Listing 10.2 Chapter10/pi_worker/pi_worker.py

```
import os
import redis
from pi import *

redis_host = os.environ.get('REDIS_HOST')
assert redis_host != None
r = redis.Redis(host=redis_host, port='6379', decode_responses=True)

print("starting")
while True:
  task = r.blpop('queue:task') #A
  iterations = int(task[1])
  print("got task: " + str(iterations))
  pi = leibniz_pi(iterations) #B
print (pi)
```

#A Pop the next task (and block if there are none in the queue)
#B Perform the work

To pop our Redis-based queue, we use the Redis `BLPOP` command which will get the first element in the list, and block if the queue is empty (thus, wait for more tasks to be added).

There is more we would need to do to make this production-grade, such as add signal handling for when the Pod is terminated, but this is enough for now.

Lastly, we have a little script to add some work to this queue. In the real world, you will queue tasks as needed (by calling RPUSH with the task parameters), such as in response to user actions (e.g. queuing the task to resize an image in response to the user uploading an image). For our demonstration, we can seed our task queue with some random values. The following code will create 100 sample tasks using a random value for our task input integer (with a value in the range 1 to 10 million). Here's some python code to add some tasks to our queue.

Listing 10.3 Chapter10/pi_worker/add_tasks.py

```
import os
import redis
import random

redis = redis.Redis(host=os.environ.get('REDIS_HOST'), port= '6379', decode_responses=True)
       #A

random.seed()
for i in range (0, 100):
  iterations = random.randint(1000000,10000000)
  redis.rpush('queue:task', iterations) #B
```

#A Connect to our Redis service
#B Add the task with the "iterations" value to our 'queue:task' list

The `rpush` python command used above maps to the `RPUSH` command[3] which adds the given value (in our case, an integer) to the list specified with the key (in our case the key is "queue:task"). If you've not used Redis before, you might be expecting something more complex, but this is all that's needed to create a queue there's no pre-configuration or schemas needed.

Bundling these python scripts into a container is pretty simple. We can use the official python base image, and add the Redis dependency (see chapter 2 if you need a refresher on how to build such containers). For the default container entry point, we'll start our worker loop with `python3 pi_worker.py`.

Listing 10.4 Chapter10/pi_worker/Dockerfile

```
FROM python:3
RUN pip install redis
COPY . /app
WORKDIR /app
CMD python3 pi_worker.py
```

With our Python worker container created, we can now get to the fun part of deploying it to Kubernetes!

[3] https://redis.io/commands/rpush

DEPLOYING TO KUBERNETES

Here's what the Kubernetes architecture looks like, we have the StatefulSet that runs Redis, and the Deployment which runs the worker pods. There is also the web application role which adds the tasks, but we'll just do that manually for this example.

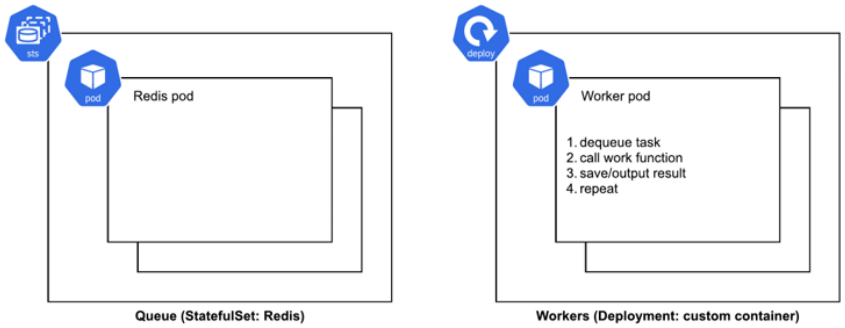


Figure 10.2: Kubernetes architecture of the background processing task queue

Our worker pods will be deployed in a hopefully now-familiar Deployment configuration (see chapter 3). We'll pass in the location of our Redis host using an environment variable, that references the internal service host (as per section 7.1.3):

Listing 10.5 Chapter10/10.1.1_TaskQueue/deploy_worker.yaml

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pi-worker
spec:
  replicas: 2
  selector:
    matchLabels:
      app: pi
  template:
    metadata:
      labels:
        app: pi
    spec:
      containers:
      - name: pi-container
        image: docker.io/wdenniss/pi_worker:v1
        env:
        - name: REDIS_HOST #A
          value: redis-0.redis-service #A
        - name: PYTHONUNBUFFERED #B
          value: "1" #B
```

#A The Kubernetes service host name of the master Redis pod
#B Env variable to instruct Python to output all print statements immediately

Notice how there's nothing special at all about this deployment when compared to the deployments we've seen so far that are exposed with services. It's just a bunch of Pods that we happen to have given the role of task workers.

Our worker pods are expecting a Redis instance, so let's deploy that first. We can use the one from chapter 9, the solutions in the `9.2.1_StatefulSet_Redis_SinglePod` and `9.2.2_StatefulSet_Redis_Replicated` folders both work for our purposes here. From the code sample root folder, simply run:

```
$ kubectl create -f Chapter09/9.2.2_StatefulSet_Redis_Replicated
$ kubectl get pods
NAME      READY   STATUS     RESTARTS   AGE
redis-0   1/1     Running    0          20s
redis-1   1/1     Running    0          13s
redis-2   0/1     Init:0/1   0          7s
```

Now create our worker deployment.

```
kubectl create -f Chapter10/10.1.1_TaskQueue/deploy_worker.yaml
```

Finally, verify everything is working correctly: you should see 5 running Pods.

```
$ kubectl get pods
NAME                         READY   STATUS    RESTARTS   AGE
pi-worker-55477bdf7b-7rmhp   1/1     Running   0          2m5s
pi-worker-55477bdf7b-ltcsd   1/1     Running   0          2m5s
redis-0                      1/1     Running   0          3m41s
redis-1                      1/1     Running   0          3m34s
redis-2                      1/1     Running   0          3m28s
```

Watching Rollout Progress

The `get` commands I show here like `kubectl get pods` give you a point-in-time status. Recall from chapter 3 that there are 2 great options for watching your rollout, you can append `-w` to kubectl commands which is Kubernetes' in-built watching option, for example `kubectl get pods -w`, or you can use my favorite, the Linux `watch` command. I use it like so: `watch -d kubectl get pods` which will refresh the status every 2 seconds, and highlight changes. You can also customize the refresh rate. To keep things simple in the book, I won't add watches to every command I share, but remember that they are available for use.

Now that our app is deployed, we can look at the logs to see what it's doing. Unfortunately, there's no built-in way in Kubernetes to stream logs from multiple pods like our 2 workers at the same time, but we can randomly pick one and follow its logs like so:

```
$ kubectl logs -f deployment/pi-worker
Found 2 pods, using pod/pi-worker-55477bdf7b-7rmhp
Starting
```

If you want to view the logs for all pods in the deployment (but not stream them), that can also be done by referencing the labels from the deployment, in our case the app=pi label, like so:

```
$ kubectl logs --selector app=pi
starting
starting
```

However you view the logs, we can see that the Pod has printed "starting", and nothing else, which is because our Pod is waiting on tasks to be added to the queue. Let's add some tasks for it to work on.

ADDING WORK TO THE QUEUE

Normally, it will be the web application or another process that will be adding work for the background queue to process. All that the web application need do is call `redis.rpush('queue:task', object)` **with the object that represents the tasks.**

For this example, we can run the `add_tasks.py` script that we included in our container (documented above) for scheduling some tasks. We can execute a one-off command on the container in one of our pods like so:

```
$ kubectl exec -it deploy/pi-worker -- python3 add_tasks.py
added task: 9500000
added task: 3800000
added task: 1900000
added task: 3600000
added task: 1200000
added task: 8600000
added task: 7800000
added task: 7100000
added task: 1400000
added task: 5600000
queue depth 8
done
```

Note that when we pass in `deploy/pi-worker` here, exec will pick one of our Pods randomly to run the actual command on (this can even be a Pod in the Terminating state, so be careful!). You can also run the command directly on the pod of your choice with `kubectl exec -it POD_NAME python3 add_tasks.py`.

VIEWING THE WORK

With tasks added to the queue, we can observe the logs of our worker pods to see how they're doing.

```
$ kubectl logs -f deployment/pi-worker
Found 2 pods, using pod/pi-worker-54dd47b44c-bjccg
starting
got task: 9500000
3.1415927062213693620
got task: 8600000
3.1415927117293246813
got task: 7100000
3.1415927240123234505
```

This worker is getting the task (calculate Pi with *n* iterations of the Gregory-Leibniz infinity series algorithm) and performing the work.

10.1.2 Signal Handling in Worker Pods

One thing to note is that the above worker implementation has no SIGTERM handling, which means it won't shutdown gracefully when the Pod needs to be replaced. There are a lot of reasons why a Pod might be terminated, including if you update the deployment, or the Kubernetes node is upgraded, so this is a very important signal to handle.

In Python we can fix this with a SIGTERM handler that will instruct our worker to terminate once it finishes its current task. We'll also add a timeout to our queue-pop call so the worker can check the status more frequently. For your own work, look up how to implement SIGTERM signal handling in your language of choice.

Let's add termination handling to shut down the worker when SIGTERM is received:

Listing 10.6 Chapter10/pi_worker2/pi_worker.py

```
import os
import signal
import redis
from pi import *

redis_host = os.environ.get('REDIS_HOST')
assert redis_host != None
r = redis.Redis(host=redis_host, port= '6379', decode_responses=True)

running = True #A

def signal_handler(signum, frame): #B
    print("got signal") #B
    running = False #B

signal.signal(signal.SIGTERM, signal_handler) #B

print("starting")
while running:
  task = r.blpop('queue:task', 5) #A
  if task != None:
    iterations = int(task[1])
    print("got task: " + str(iterations))
    pi = leibniz_pi(iterations)
    print (pi)
```

#A Add a running state variable instead of looping indefinitely
#B Register a signal handler to set the running state to false when SIGTERM receieved
#C Pop the next task, but only wait for 5 seconds so the loop can terminate. Returns "None" if there are no tasks in the queue after 5 seconds.

And deploy this revision in an updated Deployment, specifying the new image along with `terminationGracePeriodSeconds` to request 2 minutes to handle that SIGTERM by wrapping up the current work and exiting.

Listing 10.7 Chapter10/10.1.2_TaskQueue2/deploy_worker.yaml

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pi-worker
spec:
  replicas: 2
  selector:
    matchLabels:
      app: pi
  template:
    metadata:
      labels:
        app: pi
    spec:
      containers:
      - name: pi-container
        image: docker.io/wdenniss/pi_worker:v2
        imagePullPolicy: Always
        env:
        - name: REDIS_HOST
          value: redis-0.redis-service
        - name: PYTHONUNBUFFERED
          value: "1"
        resources:
            requests:
              cpu: 250m
              memory: 250Mi
      terminationGracePeriodSeconds: 120
```

Together, the signal handling in the pod, and the termination grace period means that this Pod will stop accepting new jobs once it receives the SIGTERM, and will have 120s to wrap up any current work. Adjust the terminationGracePeriodSeconds as needed for your own workloads.

There's a few more things we didn't consider here. For example. If the worker were to crash while processing a task, then that task would be lost (as it was removed from the queue, but not completed). Also there's only minimal observability and other functions. The goal of the above sample is not to provide a complete queue system, but rather to demonstrate conceptually how they work. You could continue to implement fault tolerance and other functionality or adopt an open source background task queue and have it do that for you. That choice is yours.

10.1.3 Scaling Worker Pods

Scaling the worker pods is the same technique for any Deployment, as covered in Chapter 6. You can set the replica count manually, or with a Horizontal Pod Autoscaler (HPA). Since our example workload is CPU-intensive, the CPU metric works well for scaling using a HPA, so let's set one up now.

Listing 10.8 Chapter10/10.1.3_HPA/hpa.yaml

```
apiVersion: autoscaling/v1
kind: HorizontalPodAutoscaler
metadata:
  name: pi-worker-autoscaler
spec:
  minReplicas: 2
  maxReplicas: 10
  targetCPUUtilizationPercentage: 20
scaleTargetRef:
    apiVersion: apps/v1
    kind: Deployment
    name: pi-worker
```

This will scale our deployment to between 2 and 10 Pods, aiming for each Pod to be using less than 20% of a CPU.

HPA uses Absolute CPU utilization numbers

Note that this utilization target isn't expressed as a percentage of the Pod's total requested CPU, but rather an absolute number in CPU units. Since our Pod deployment (as revised in 10.1.2) requests 250mCPU (i.e. 25% of a core), a 20% target in the HPA means that a scale up will occur when the average Pod is consuming greater than 20% of a core (200mCPU). In relative terms, this works out to 80% of its total requested capacity—being 20% of a core actual usage divided by 25% of a core requested, but don't make the mistake of specifying that relative percentage as your `targetCPUUtilizationPercentage`.

Create the HPA like so:

```
kubectl create -f kubectl create -f Chapter10/10.1.3_HPA
```

With the HPA in place, you can repeat the add tasks command from above, and watch the HPA do its thing. The kubectl get command supports multiple resource types, so you can run `kubectl get pods,hpa` (which I prefix with the linux `watch` command, naturally) in order to observe all the components interacting.

```
$ kubectl exec -it deploy/pi-worker -- python3 add_tasks.py
$ kubectl get pods,hpa
NAME                             READY   STATUS    RESTARTS   AGE
pod/pi-worker-54dd47b44c-22x9b   1/1     Running   0          2m42s
pod/pi-worker-54dd47b44c-9wppc   1/1     Running   0          2m27s
pod/pi-worker-54dd47b44c-bjccg   1/1     Running   0          13m
pod/pi-worker-54dd47b44c-f79hx   1/1     Running   0          2m42s
pod/pi-worker-54dd47b44c-fptj9   1/1     Running   0          2m27s
pod/pi-worker-54dd47b44c-hgbqd   1/1     Running   0          2m27s
pod/pi-worker-54dd47b44c-lj2bk   1/1     Running   0          2m27s
pod/pi-worker-54dd47b44c-wc267   1/1     Running   0          2m10s
pod/pi-worker-54dd47b44c-wk4dg   1/1     Running   0          2m10s
pod/pi-worker-54dd47b44c-x2s4m   1/1     Running   0          13m
pod/redis-0                      1/1     Running   0          56m
pod/redis-1                      1/1     Running   0          56m
pod/redis-2                      1/1     Running   0          56m

NAME                                                          REFERENCE               TARGETS
       MINPODS   MAXPODS   REPLICAS   AGE
horizontalpodautoscaler.autoscaling/pi-worker-autoscaler   Deployment/pi-worker   66%/20%
       2         10        10         3m46s
```

10.1.4 Open Source Task Queues

So far, we've been building our own task queue. I find it best to get hands on to understand how things work. However, you likely don't need to implement a task queue yourself from scratch, since others have done the work for you.

For Python, RQ (https://python-rq.org/) is a popular choice that allows you to basically enqueue a function call with a bunch of parameters. No need to even wrap this function in an object that implements a particular abstract method.

Ruby developers can look to Resque (https://github.com/resque/resque), created by the team at GitHub is a popular choice. Tasks in Resque are simply ruby classes that implement a `perform` method. The Ruby on Rails framework makes Resque particularly easy to use with its *Active Job* framework that allows Resque (among other task queue implementations) to be used as the queuing backend.

Before going out and building your own queue, I'd recommend looking at these options and more. If you have to build something yourself, or the off-the-shelf options just don't cut it, then I hope you saw through the earlier examples that it's at least pretty straightforward to get started.

10.2 Jobs

Kubernetes offers a way to define a finite set of work to process with the *Job construct*. Both Job and Deployment can be used for handling "batch jobs" and background processing in in Kubernetes in general. The key difference is that Job is designed to process a finite set of work, and can potentially be used without needing a queue data structure like Redis, while Deployment (as described in section 10.1) is for a continuously running background queue that will need some kind of queue structure for coordination. You can also use Jobs to run

one-off and periodic tasks like maintenance operations, which wouldn't make sense in a Deployment (which would restart the Pod once it finishes).

You may be wondering why a separate construct is needed in Kubernetes to run something once, since stand-alone Pods could do that as well. While it's true that you can schedule a Pod to perform a task and shutdown once its complete, there is no controller to ensure that the tasks actually completes. For example if the Pod was evicted due to a maintenance event before it had a chance to complete. Job adds some useful constructs around the Pod to ensure that the task will complete (by rescheduling it if it failed or was evicted), as well as the potential to track multiple completions and parallelism.

At the end of the day, Job is just another higher-order controller in Kubernetes for managing pods, like Deployment and StatefulSet. All three create Pods to run your actual code, just with different logic around scheduling and management provided by the controller. Deployments are for creating a set of continuously running Pods, StatefulSet for pods that have a unique ordinal and can attach disks through persistent volume templates, and Jobs for Pods that should run to completion (potentially multiple times).

10.2.1 Running one-off tasks with Jobs

Jobs are great for running one-off tasks. Let's say you want to perform a maintenance task like clearing a cache, or anything else that is essentially just running a command in your container. Instead of using `kubectl exec` on an existing Pod, you can schedule a Job to run the task as a separate process with its own resources, ensure that the action will complete as requested (or report a failure status), and make it easily repeatable.

Exec should really only be used for debugging running Pods. If you use exec to perform maintenance tasks, then your task is sharing the resources with the Pod which isn't great—the pod may not have enough resources to handle both, and you are impacting the performance. By moving tasks to a Job, they get their own Pod, with their own resource allocation.

Configuration as code for maintenance tasks

Throughout this book, I've been espousing how important it is to capture everything in configuration. By capturing routine maintenance tasks as Jobs, rather than having a list of shell commands to copy/paste, you're building repeatable configuration. If you follow the GitOps approach whereby production changes go through git (as covered in chapter 8), then your maintenance tasks can go through your usual code review process in order to be rolled out into production.

In the previous section we needed to execute a task in the container to add some work to our queue, and we used `kubectl exec` on an existing pod to run `python3 add_tasks.py`. Let's upgrade that to be a proper Job with its own Pod. The following Job definition can be used to perform the `python3 add_tasks.py` task on our container named `pi`.

Listing 10.9 Chapter10/10.2.1_Job/job_addwork.yaml

```
apiVersion: batch/v1
kind: Job
metadata:
  name: addwork
spec:
  backoffLimit: 2
  template:
    spec:
      containers:
      - name: pi
        image: docker.io/wdenniss/pi_worker:v2
        command: ["python3",  "add_tasks.py"]
        env:
        - name: REDIS_HOST
          value: redis-0.redis-service
        - name: PYTHONUNBUFFERED
          value: "1"
      restartPolicy: Never
```

The `spec` within the `template` within the `spec` pattern may look familiar, and that's because this object embeds a Pod template just as Deployment and StatefulSet do. All the parameters of the Pod can be used here like resource requests and environment variables, with only a couple of exceptions for parameter combinations that don't make sense in the Job context.

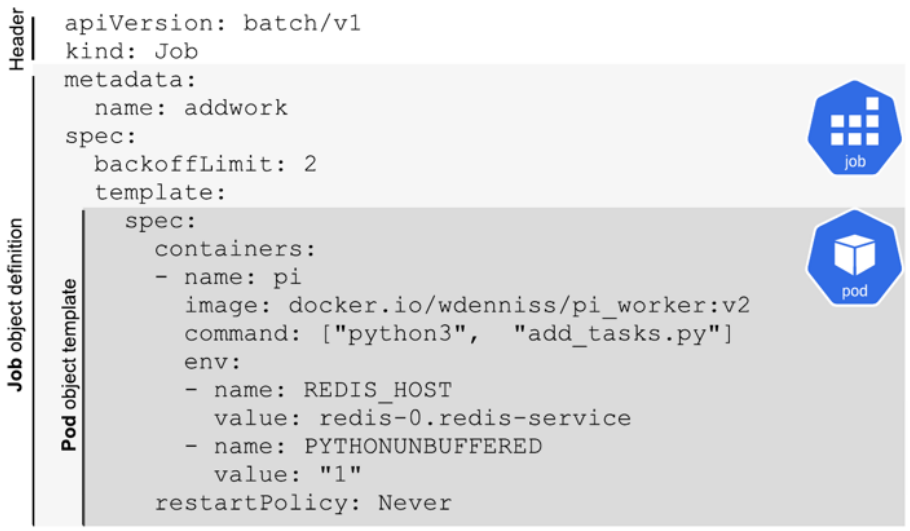


Figure 10.3: Object composition of Job

Our Podspec for the Job has the same environment variables as our Podspec from the deployment. That's the great thing about Kubernetes object composition, the specification is the same wherever the Pod is embedded. The other changes are the `restartPolicy`, and the `backoffLimit`.

The Pod restart property, actually a property of the Podspec and not the Job governs whether or not kubelet on the node will try to restart a container that existed with a non-success result in-place. For Jobs, this can be set to `OnFailure` to restart failed containers, or `Never`, which won't. The Always option doesn't make sense for Jobs, as this would restart a succeeded Pod, which is not what Jobs are designed to do (that's more in the domain of Deployment).

The backoff limit is part of the Job, and determines how many times to try and run the Job. This encompasses both crashes, but also node failures. For example, if you set this value to 6, and the Job crashes twice on a node, then that node is removed, the Job controller will reschedule the Pod elsewhere and try it 4 more times. Some practitioners like to use Never when debugging as it's easier to see all the failed Pods and query their logs.

Create the Job like any other Kubernetes object, and then observe the progress like so:

```
$ kubectl create -f Chapter10/10.2.1_Job/job_addwork.yaml
$ kubectl get job,pods
NAME                COMPLETIONS   DURATION   AGE
job.batch/addwork   1/1           3s         9s

NAME                              READY   STATUS      RESTARTS   AGE
pod/addwork-99q5k                 0/1     Completed   0          9s
pod/pi-worker-6f6dfdb548-7krpm    1/1     Running     0          7m2s
pod/pi-worker-6f6dfdb548-pzxq2    1/1     Running     0          7m2s
pod/redis-0                       1/1     Running     0          8m3s
pod/redis-1                       1/1     Running     0          7m30s
pod/redis-2                       1/1     Running     0          6m25s
```

If the Job succeeds, we can watch our worker pods which should become busy with newly added work. If you deployed the HPA earlier, then you'll soon see new containers created, as I did here:

```
$ kubectl get pods,hpa
NAME                              READY   STATUS              RESTARTS   AGE
pod/addwork-99q5k                 0/1     Completed           0          58s
pod/pi-worker-6f6dfdb548-7krpm    1/1     Running             0          7m51s
pod/pi-worker-6f6dfdb548-h6pld    0/1     ContainerCreating   0          8s
pod/pi-worker-6f6dfdb548-pzxq2    1/1     Running             0          7m51s
pod/pi-worker-6f6dfdb548-qpgxp    1/1     Running             0          8s
pod/redis-0                       1/1     Running             0          8m52s
pod/redis-1                       1/1     Running             0          8m19s
pod/redis-2                       1/1     Running             0          7m14s

NAME                                                          REFERENCE              TARGETS
       MINPODS   MAXPODS   REPLICAS   AGE
horizontalpodautoscaler.autoscaling/pi-worker-autoscaler   Deployment/pi-worker   100%/20%
       2         10        2          2d4h
```

One thing to note about Jobs is that whether it has completed or not, you won't be able to schedule it again with the same name (i.e. to repeat the action) without deleting it first. That's because, even though the work is now finished, the Job object still exists in Kubernetes. You can delete like any object:

```
$ kubectl delete -f Chapter10/10.2.1_Job/job_addwork.yaml
```

To recap, Job is for when you have some task or work to complete. Our example was to execute a simple command, however this could equally have been a long and complex computational task. If you have need to run a one-off background process, simply containerize it, define it in the Job and schedule. When the Job reports itself as "Complete", the work is done.

Two parameters which we didn't use to run a one-off task are `completions`, and `parallelism`. These parameters allow you to process a batch of tasks using a single Job object description, which is covered in 10.3. Before we get to that, let's look how to schedule Jobs at regular intervals.

10.2.2 Scheduling Tasks with Cron Jobs

In the previous section, we took a command that we had executed manually on the cluster and created a proper Kubernetes object to encapsulate it. Now any developer on the team can run perform that task by creating the Job object rather than needing to remember a complex exec command.

What about tasks that you need to run repeatedly on a set interval? Kubernetes has you covered with CronJob. CronJob encapsulates a Job object and adds a frequency parameter allowing you to set a daily or hourly (or any interval you like) frequency to run the Job. This is a popular way to schedule tasks like a daily cache cleanup and the like.

Listing 10.10 Chapter10/10.2.2_CronJob/cronjob_addwork.yaml

```
apiVersion: batch/v1
kind: CronJob
metadata:
  name: addwork
spec:
  schedule: "*/5 * * * *"
  jobTemplate:
    spec:
      backoffLimit: 2
      template:
        spec:
          containers:
          - name: pi
            image: docker.io/wdenniss/pi_worker:v2
            command: ["python3",  "add_tasks.py"]
            env:
            - name: REDIS_HOST
              value: redis-0.redis-service
            - name: PYTHONUNBUFFERED
              value: "1"
          restartPolicy: Never
```

You might notice that we just copied the entire specification of the Job (i.e. the `spec` dictionary) in the previous section under this CronJob's `spec` dictionary as the `jobTemplate` key, and added an extra spec-level field named `schedule`. Recall that the Job has it's own template for the Pods that will be created (which also have their own spec).

So, the CronJob embeds a Job object, which in turn embeds a Pod. I find it helpful to visualize this through object composition, so take a look at the following figure.

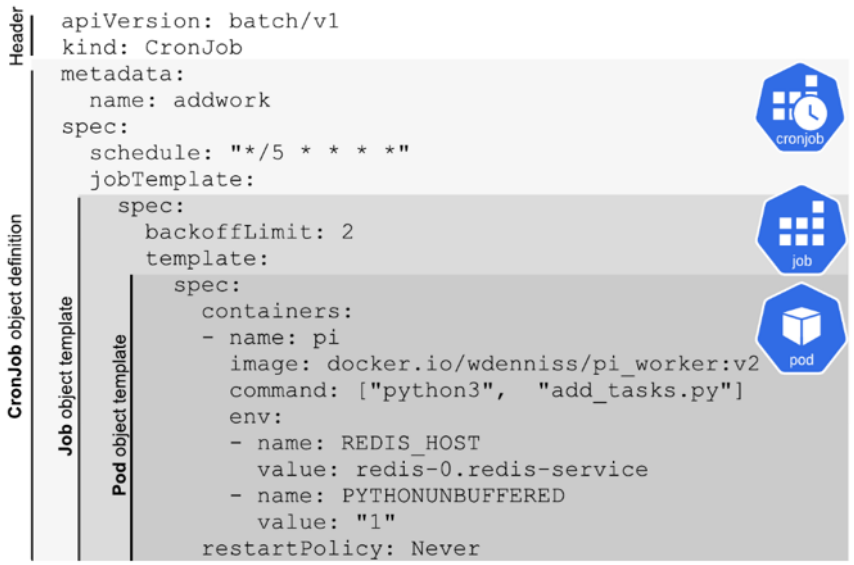


Figure 10.4: Object composition of CronJob

Object Composition in Kubernetes

With all the specs and templates embedding other templates and specs, sometimes it feels like turtles all the way down in Kubernetes. Here we have a CronJob whose spec contains the template for the Job that gets run (on the schedule), which itself containers the template of a Pod with its own spec. This may seem confusing, and repetitive, or both, but there is a huge benefit to this approach: when looking at the API docs, you can use any field of Job in the jobTemplate, just as you can use any field of Pod in the spec. Kubernetes objects are built from the composition of other objects.

Some nomenclature worth learning: when a Pod is embedded in another object, we refer to the specification of the embedded Pod as a Podspec (e.g., "a Deployment contains a Podspec"). When the controller for that higher-level object then creates the Pod in the cluster, that Pod is a Pod equal to any other, including ones that were created directly with their own specification. The only difference is that the Pods created by a controller (like Job or Deployment) continue to be observed by that controller (i.e. recreating them if they fail, etc).

So that's how it's composed, what about the `schedule` field which is CronJob's contribution to the specification? `schedule` is where we define the frequency in the age-old Unix cron format. The cron format is extremely expressive. In the example above, `0 0 * * *` translates to "run at 12:00am every day". You can configure schedules like "run every 30 minutes" (`*/30 * * * *`), run Mondays at 4:00pm (`0 16 * * 1`), and many, many more. I recommend using a visual cron editor (a Google search for "cron editor" should do the trick) to validate your preferred expression, rather than waiting a week to verify that the Job you wanted to run weekly actually ran.

```
$ kubectl create -f Chapter10/10.2.2_CronJob/cronjob_addwork.yaml
# kubectl get cronjob,job
NAME                    SCHEDULE      SUSPEND   ACTIVE   LAST SCHEDULE   AGE
cronjob.batch/addwork   */5 * * * *   False     0        <none>          58s
```

Wait a couple of minutes (for this example, the Job is created every 5 minutes, i.e. :00, :05, etc), then you can see the Job, and the Pod that it spawned.

```
$ kubectl get cronjob,job,pods
NAME                    SCHEDULE      SUSPEND   ACTIVE   LAST SCHEDULE   AGE
cronjob.batch/addwork   */5 * * * *   False     0        2m38s           3m11s

NAME                           COMPLETIONS   DURATION   AGE
job.batch/addwork-27237815   1/1           107s       2m38s

NAME                              READY   STATUS      RESTARTS   AGE
pod/addwork-27237815-b44ws        0/1     Completed   0          2m38s
pod/pi-worker-6f6dfdb548-5czkc    1/1     Running     5          14m
pod/pi-worker-6f6dfdb548-gfkcq    1/1     Running     0          7s
pod/pi-worker-6f6dfdb548-pl584    1/1     Running     0          7s
pod/pi-worker-6f6dfdb548-qpgxp    1/1     Running     5          25m
pod/redis-0                       1/1     Running     0          14m
pod/redis-1                       1/1     Running     0          33m
pod/redis-2                       1/1     Running     0          32m
```

CronJob will spawn a new Job on a schedule (which in turn, spawns a new Pod). You can inspect these historic jobs, as they remain with the "Complete" status. The `successfulJobsHistoryLimit` and `failedJobsHistoryLimit` options in the CronJobSpec[4] can be can be used to govern how many of those historic Jobs will be kept.

[4] https://kubernetes.io/docs/reference/kubernetes-api/workload-resources/cron-job-v1/#CronJobSpec

Timezones

Be aware that the cron job will run on the timezone of your cluster, which for many platforms like GKE will be UTC . The timezone used is that of the system Kubernetes controller component, which runs on the master. If you're on a managed platform, it may not be possible to query the master node directly, but it is possible to check nodes which likely are the same. Here's how to create a one-off Pod to run the Linux `date` command and then exit.

```
$ kubectl run date --restart=Never -it --rm --image ubuntu date +%Z
UTC
pod "date" deleted
```

There exists a prefix that can be added `CRON_TZ=<timezone>` (like `CRON_TZ=UTC 0 16 * * 1`), however as of Kubernetes 1.21 it doesn't form part of the official Kubernetes API contract, and thus isn't recommended.

10.3 Batch task processing with Jobs

What if you have a batch set of work that you want to process as a regular, or one-off event? As covered in section 10.1, if a *continuously running* task queue is what you want, then actually Deployment is the right Kubernetes object. But, if you have a finite batch of work to process, then Job is the ideal object to use.

If you have a dynamic work queue database like we did in section 10.1, but want your workers to shutdown completely when the queue is empty, that's something that Job can do. With a Deployment, you need a separate system (like a HorizontalPodAutoscaler) to scale the worker Pods up and down, for example when there is no more work in the queue. When using Job, the worker Pods themselves can signal to the Job controller when the work is complete and they should be shutdown, and the resources reclaimed.

Another way to use Job is to run it on a static work queue in such a way where a database is not needed at all. Let's say you know you need to process 100 tasks in a queue, you could run the Job 100 times. The catch of course is that each Pod instantiation in the Job series needs to know which of those 100 tasks to run on, which is where the indexed job comes in.

In this section, I'll cover both the dynamic and static approach to task processing.

10.3.1 Dynamic Queue Processing with Jobs

Let's redesign the dynamic queue from section 10.1 to use Job instead of Deployment. Both Kubernetes objects allow the creation of multiple Pod workers, and both will recreate Pods in the event of failure. The key difference is that when a Pod managed by a Job exits with a "success" code (`exit 0` in Unix terms), it indicates that the work is complete, and no new Pod workers will be created (while the running ones can wrap up their work).

It's this property of Job that allows the individual workers to signal when the work is finished that is the useful property of Job. If you're using a dynamic Kubernetes environment such as one with autoscaling (including my own product GKE Autopilot), then Job allows you to "set

and forget" the work, where you schedule it and once it's done the resource consumption goes to zero (which on a dynamic platform like Autopilot, means zero cost).

To work correctly in a Job, we need to adapt our task worker from the previous section to signal success (by terminating with the success status) when the queue becomes empty. Here's what our revised worker code looks like:

Listing 10.11 Chapter10/pi_worker3/pi_worker.py

```
import os
import signal
import redis
from pi import *

redis_host = os.environ.get('REDIS_HOST')
assert redis_host != None
r = redis.Redis(host=redis_host, port= '6379', decode_responses=True)

running = True

def signal_handler(signum, frame):
    print("got signal")
    running = False

signal.signal(signal.SIGTERM, signal_handler)

print("starting")
while running:
  job = r.blpop('queue:task', 5)
  if job != None:
    iterations = int(job[1])
    print("got job: " + str(iterations))
    pi = leibniz_pi(iterations)
    print (pi)
  else: #A
    if os.getenv('COMPLETE_WHEN_EMPTY', '0') != '0': #A
      print ("no more work") #A
      running = False #A
```

#A When configured with COMPLETE_WHEN_EMPTY, exit with success when there are no jobs

With our worker container setup to behave correctly in the Job context, we can now create a Kubernetes Job to run it. Whereas in the deployment we use the `replica` field to govern the number of pods that are running at once, with Job it's the `parallelism` parameter, which basically governs the same thing.

Listing 10.12 Chapter10/ 10.2.4_JobWorker/job_worker.yaml

```
apiVersion: batch/v1
kind: Job
metadata:
  name: jobworker
spec:
  backoffLimit: 2
  parallelism: 2
  template:
    spec:
      containers:
      - name: pi
        image: docker.io/wdenniss/pi_worker:v3
        imagePullPolicy: Always
        env:
        - name: REDIS_HOST
          value: redis-0.redis-service
        - name: PYTHONUNBUFFERED
          value: “1”
        - name: COMPLETE_WHEN_EMPTY
          value: “1”
      restartPolicy: Never
```

If you compare this to the code listing in 10.1 for Chapter10/10.1.1_TaskQueue/deploy_worker.yaml, you’ll notice that the PodSpec is identical other than the addition of the COMPLETE_WHEN_EMPTY flag.

Clean up

If you are running the previous samples, clean them by deleting the deployment and the CronJob if one was used.

```
$ kubectl delete -f 10.1.2_TaskQueue2
deployment.apps "pi-worker" deleted
$ kubectl delete -f 10.2.1_Job
job.batch "addwork" deleted
$ kubectl delete -f 10.2.2_CronJob
cronjob.batch "addwork" deleted
```

Since our Redis-based queue may have some existing jobs, you can reset it as well using the LTRIM Redis command.

```
kubectl exec -it pod/redis-0 -- redis-cli ltrim queue:task 0 0
```

You can also run the redis-cli interactively if you prefer

```
$ kubectl exec -it pod/redis-0 -- redis-cli
127.0.0.1:6379> LTRIM queue:task 0 0
OK
```

Lets take this Job for a spin. First, we can add some work to our Redis queue, like before.

```
# kubectl create -f 10.2.1_Job
job.batch/addwork created
# kubectl get job,pod
NAME                COMPLETIONS   DURATION   AGE
job.batch/addwork   0/1           19s        19s

NAME                 READY   STATUS              RESTARTS   AGE
pod/addwork-l9fgg    0/1     ContainerCreating   0          19s
pod/redis-0          1/1     Running             0          19h
pod/redis-1          1/1     Running             0          19h
pod/redis-2          1/1     Running             0          19h
```

Once this "addwork" Job has completed, we can run our new Job queue to process the work. Unlike previously, the order matters here since the Job workers will exit if there is no work in the queue, so make sure that "addwork" completed before you run the Job queue. Observe the status like so:

```
# kubectl get job,pod
NAME                COMPLETIONS   DURATION   AGE
job.batch/addwork   1/1           22s        36s

NAME                 READY   STATUS      RESTARTS   AGE
pod/addwork-l9fgg    0/1     Completed   0          37s
pod/redis-0          1/1     Running     0          19h
pod/redis-1          1/1     Running     0          19h
pod/redis-2          1/1     Running     0          19h
```

Once we see "Completed" on our addwork task, we can go ahead and schedule the Job queue.

```
$ kubectl create -f 10.2.4_JobWorker
job.batch/jobworker created
$ kubectl get job,pod
NAME                  COMPLETIONS   DURATION   AGE
job.batch/addwork     1/1           22s        3m45s
job.batch/jobworker   0/1 of 2      2m16s      2m16s

NAME                  READY   STATUS      RESTARTS   AGE
pod/addwork-l9fgg     0/1     Completed   0          3m45s
pod/jobworker-swb6k   1/1     Running     0          2m16s
pod/jobworker-tn6cd   1/1     Running     0          2m16s
pod/redis-0           1/1     Running     0          19h
pod/redis-1           1/1     Running     0          19h
pod/redis-2           1/1     Running     0          19h
```

What should happen next is that when the queue is empty, the workers will process 1 more task, then exit. If you want to monitor the queue depth, so as to know when the work should wrap up, you can run LLEN on the Redis queue to get the current length.

```
$ kubectl exec -it pod/redis-0 -- redis-cli llen queue:task
(integer) 0
```

When it's zero, you should observe the Pods entering the "Completed" state. Note that they won't enter this state right away, but rather after they wrap up the last task they are processing.

```
$ kubectl get job,pod
NAME                  COMPLETIONS   DURATION   AGE
job.batch/addwork     1/1           22s        3m45s
job.batch/jobworker   0/1 of 2      2m16s      2m16s

NAME                  READY   STATUS      RESTARTS   AGE
pod/addwork-l9fgg     0/1     Completed   0          10m09s
pod/jobworker-swb6k   1/1     Completed   0          8m40s
pod/jobworker-tn6cd   1/1     Completed   0          8m40s
pod/redis-0           1/1     Running     0          19h
pod/redis-1           1/1     Running     0          19h
pod/redis-2           1/1     Running     0          19h
```

10.3.2 Static Queue Processing with Jobs

Instead of using a dynamic queue like Redis above for the task list, there are a number of ways to run Jobs with a static queue. When using a static queue, the queue length is known ahead of time and is configured as part of the Job itself, and a new Pod is created for each task. Instead of having task workers running until the queue is empty, you are defining upfront how many Pods to create.

The main reason for doing this is to avoid modification of the container to pull tasks from the dynamic queue. The drawback is that there is generally additional configuration on the Kubernetes side. It essentially shifts the configuration burden from the worker container to Kubernetes objects.

Note that even if you have the requirement that you can't modify the container which performs the work, this doesn't mean you have to use a static queue. You have multiple containers in a Pod, and have one container that performs the dequeing, passing the parameters on to the other container.

So how do you represent this queue in Kubernetes configuration exactly? There are a few different options, three of which I'll outline here.

Static queue using an index

Indexed jobs are the most interesting static queue option in my opinion. Usable when you know ahead of time how many tasks to process, and the task list is one that is easily indexed. One example that comes to mind is rendering a movie. You know the number of frames (queue length), and can easily pass each instantiation the frame number (i.e. index into the queue) of the frame to render.

Kubernetes will run the Job the total number of times (completions) you specify, creating a Pod for each task. Each time it runs, it will give the Job the next index (supplied in the environment variable `$JOB_COMPLETION_INDEX`). If your work is naturally indexed, for example rendering frames in an animated movie, this works great! You can easily instruct Kubernetes to run the job 30,000 times (render 30,000 frames), and it will give each pod the frame number. Another obvious approach is to give each job the full list of work using some

data structure (e.g. an array of tasks encoded in YAML or just plain text, one per line), and Kubernetes supplies the index. The Job can then lookup the task in the list using the index.

At the time of writing, this option is still in beta, and so may or may not exist in the future in the form presented here.

Alpha and Beta Features

Alpha features in Kubernetes are ones in active development, and can be changed and removed at any time. Cloud providers generally don't offer them in production clusters. I will probably regret including this Alpha status workload pattern in the book, and you'll notice I've not included any other alpha objects—I just think this one is too interesting not to mention.

Alpha features can be dropped or changed without notice (i.e. they can exist in one version, but not the next). Beta features are only a little better, and can be removed after 3 releases (which can happen quicker than you realize—time goes fast!). Stay far, far away from Alpha features until they graduate, it's not worth the tears. For beta features, I know it's irresistible to use them when they can solve your use-case perfectly, and given how "young" Kubernetes still is, it may be unavoidable, just follow the releases careful and watch for changes or removal.

Here's an example configuration that simply outputs the frame number. You can sub in the actual movie rendering logic yourself.

```
apiVersion: batch/v1
kind: Job
metadata:
  name: render-frames
spec:
  completions: 100 #A
  parallelism: 2 #B
  completionMode: Indexed #C
  template:
    spec:
      restartPolicy: Never
      containers:
      - name: 'worker'
        image: 'docker.io/library/busybox'
        command: ["echo", "render frame: $JOB_COMPLETION_INDEX"]
```

#A the number of times to run the job (upper bound of the index)
#B number of worker pods to run in parallel
#C Run in indexed mode, passing in JOB_COMPLETION_INDEX

Kubernetes supports the ability for you to essentially define your queue length and each Pod can get an index into that queue. For example, say you want to render a movie with 100,000 frames. You can set your "completions" (the number of times you want to run the job successfully) to 100,000. This will create (over time) 100,000 pods, and set the environment variable JOB_COMPLETION_INDEX in each pod with the index (0, 1, 2 and so on).

Your application can either use this environment variable directly, or you can use an initContainer to transform it as needed (e.g. building the script that will run).

Static queue with a message queue service

Another approach that doesn't require modification is to populate a message queue, and have each Pod pull the work from that. As they can be configured to get the required parameters via Kubernetes configuration, it's possible to build a job where the container is unaware of the queue. It's still "static" since you have to declare upfront how many tasks there are, and run one worker pod per task, but it also requires a data structure (the message queue).

The Kubernetes docs do a great job of demonstrating this approach using RabbitMQ for the message queue here: https://kubernetes.io/docs/tasks/job/coarse-parallel-processing-work-queue/

Static queue via scripting

Another option is to use scripting to simply crate a separate job for each task in the queue. Basically, if you have 100 tasks to complete, you'd setup a script to "expand" your task definition to create 100 Jobs giving each the input data it needs This is personally my least favorite option as it's a bit unwieldy to manage. Imagine you queue all this work up and then want to cancel it? Instead of just deleting a single Job as in all the other examples in this section, you'd have to delete 100, so you'd likely need more scripting to do that, and on it goes.

Again, the Kubernetes docs have a good demo of this, so if it interests you, check it out here: https://kubernetes.io/docs/tasks/job/parallel-processing-expansion/

10.4 Liveness Probes for Background Tasks

Just like containers that serve HTTP traffic, containers that perform tasks, whether configured in a Deployment or Job should have liveness probes. A liveness probe helps protect you from coding errors like the inability to recover from the failure of an external dependency that causes your process to hang. The kubelet will automatically restart crashed containers (subject to how you configure your restart policy), but it has no way of knowing if your process has hung, or is performing as expected without a liveness probe.

You may recall from Chapter 4 (Zero Downtime Operations) that Kubernetes uses the information from Liveness and Readiness probes to make restart decisions on workloads. This is still true for background tasks, but with a few differences. Readiness as a concept isn't generally relevant for batch jobs as they don't serve traffic (so they can't therefore be ready, or not ready to receive traffic), but liveness still applies. We can use the same liveness probe concept that we used to detect stuck serving containers, to detect stuck tasks.

Whereas for a HTTP service we can use an endpoint that returns a success response for the liveness, and a TCP service where liveness can be indicated by successfully opening a port, batch workloads generally have neither, which leaves us with the third option for liveness probes: a command. You can provide any command, and if it exits with success, it indicates the task is live.

But what command can you run that would verify that the process has not hung? One approach is for the task to write the current timestamp to a file periodically, and simply check the recency of that timestamp using the liveness command.

LIVENESS BASH SCRIPT FOR BACKGROUND TASKS

In the application code, we have a function that writes the current Unix-format timestamp to a file. In this example, the code is Ruby – but the same pattern could be implemented in any language with ease.

```
def self.log_process_date
  fileName = "process.date"
  aFile = File.new(::Rails.root.to_s + "/log/" + fileName, "w")
  contents = Time.now.to_i.to_s
  aFile.write(contents)
  aFile.close
end
```

During normal operation of the background task, the `log_process_date` method will be called at various points. This should happen pretty frequently.

For the readiness command, we can run a bash script that can read and check this file. The goal of this script is simply to return the success exit code (0) when the timestamp file exists and is not stale. And exit with a non-zero code on any errors. This script is included in the application's container. It takes the timestamp file as an input parameter.

script/process_liveness.sh:

```
#!/bin/bash

# Liveness probe for batch process
# The process writes a logfile every time it runs with the current Unix timestamp.

# Usage: process_liveness.sh <path_to_file>
# The file must contain only the latest date as a Unix timestamp and no newlines

if ! rundate=$(<$1); then #A
  echo >&2 failed #A
  echo "no logfile" #A
  exit 1 #A
fi #A

curdate=$(date +'%s') #B

diff=$((curdate-rundate)) #C

if [ $diff -gt 300 ] #D
then #D
  echo "too old" #D
  exit 100 #D
fi #D

exit 0 #E
```

#A Read the timestamp file from the input (parameter $1), and exit with an error if it doesn't exist
#B Get the current timestamp from the system

#C Compare the two timestamp
#D Return an error status code if the process timestamp is older than 300 seconds
#E Return a success status code

Finally, we write a liveness probe to call this script.

deploy.yaml

```
livenessProbe:
  initialDelaySeconds: 600 #A
  periodSeconds: 30
  exec: #B
    command: ["./script/process_liveness.sh", "log/process.date"] #B
  successThreshold: 1
  timeoutSeconds: 1
```

#A The initial delay is long, as we need time for the app to boot and write the first timestamp
#B The command to run

10.5 Summary

Kubernetes has a few different options for handling background queues and batch jobs.

- Deployments can be used to build a continuously running job queue, using a queue data structure like that offered by Redis for coordination.
- The background processing that many websites run to offload heavy requests would typically be run as a Deployment
- Kubernetes also has a dedicated Job object for running tasks
- Jobs can be used for one-off tasks, such as a manual maintenance task
- CronJob can be used to schedule Jobs to run, for example a daily cleanup task
- The Job object also supports batch jobs through the completions and parallel configuration
- Unlike a Deployment-based background queue, Job can also be used to schedule work on a static queue, avoiding the need for a queue datastructure
- Liveness checks are still relevant for Pods that process background tasks (to detect stuck/hung processes), and can be configured using an exec liveness check

11

Securing Kubernetes

This chapter covers

- Keeping your cluster up to date and patched against vulnerabilities
- Managing update-related disruptions with a PodDisruptionBudget
- Using DaemonSets to deploy an agent to every node
- The security configuration of Pods
- Building and running containers as the non-root user
- Using Admission controllers to modify and/or validate Kubernetes objects
- Using the built-in Pod Security Admission to enforce security standards in namespaces
- Controlling user access to namespaces with RBAC

So far, the book has focused on deploying various different types of software into Kubernetes clusters. In this last chapter, I'll cover some key topics when it comes to keeping everything secure. Security is a huge area in general, and Kubernetes is no exception. If you deploy code to a Kubernetes cluster managed by another team, then lucky you, you may not need to worry about some of these topics. For developers who are also responsible for operations, or for cluster operators themselves, securing and updating the cluster will be a key responsibility.

In addition to keeping your cluster up to date, handling disruption, deploying node agents and building non-root containers, this chapter walks you through the process of creating a dedicated namespace for a team of developers, and how access can be granted specifically to that namespace. This is a pretty common pattern I've observed in companies where several teams share clusters.

11.1 Staying up to date

Kubernetes has a large surface area. There's the Linux kernel, the Kubernetes software running on the control plane and user nodes, then there's your own containers and all their dependencies like a base image. All this means there's a lot to keep up to date and protected against vulnerabilities.

11.1.1 Cluster and Node Updates

One critical task for a Kubernetes operator is to ensure that your cluster and nodes are up to date. This helps mitigate against known vulnerabilities in Kubernetes, and the operating system of your nodes.

Unlike most of the topics discussed in this book so far, the updating of clusters and nodes is actually not part of the Kubernetes API. It sits at the platform level, so you'll need to consult the docs for your Kubernetes platform. Fortunately, if you're using a managed platform this should be straight forward. If you're running Kubernetes the hard way via a manual installation on VMs (which I don't recommend), these updates will be a significant burden, as you are now the one offering the Kubernetes platform.

UPDATING GKE

In the case of GKE, staying up to date is easy. Simply enroll in one of the three release channels: Stable, Regular or Rapid. Security patches are rolled out to all channels quickly, what differs is how soon you get other new features of both Kubernetes and the GKE platform.

When enrolled in a release channel, both the cluster version and nodes are automatically kept up to date. The older "static version" (available only for the Standard mode of operation) option is not recommended, as you need to keep on top of the updates manually.

11.1.2 Updating Containers

Keeping the Kubernetes cluster up to date isn't the only updating you'll need to do. Security vulnerabilities are often found in components of base images like ubuntu. As your containerized application is built on these base images, it can inherit vulnerabilities that exist in them.

The solution is to rebuild and update your containers regularly (and especially, if any vulnerabilities are found in the base images you use). Many developers and enterprises employ vulnerability scanners (often known as "CVE scanners" after the Common Vulnerabilities and Exposures system where known vulnerabilities are documented) to look through built containers to see if any reported vulnerabilities exist in them, in order to prioritize rebuilds and rollouts.

When updating your containers, be sure to specify the base image which contains the latest fixes. Typically this can be achieved by only specifying the minor version of the base image

you're using, rather than the specific patch version. You can use the "latest" tag to achieve this, but then you might get some unwanted feature changes.

For example, take the python base image[1]. For any given version of python (say 3.10.2), you have a bunch of different options: `3.10.2-bullseye`, `3.10-bullseye`, `3-bullseye`, `bullseye` (bullseye refers to the version of Debian it uses). You can also use `latest`. For projects that follow semantic versioning (semver) principles, I would typically recommend going with the `major.minor` version, in this example `3.10-bullseye`. This allows you to get patches to the 3.10 version automatically, while avoiding breaking changes. The downside is that you need to pay attention to when the support drops for 3.10, and migrate. Going with the major version instead, i.e. `3-bullseye` in this example, would give you longer support but with slightly more risk of breakages (in *theory* with semver you should be safe to use the major version as changes should be backwards compatible, but in practice I find it safer to go with the minor version). Using `latest` while great from a security perspective, is typically not recommended due to the extremely high risk of breakage.

However you configure your docker file, the key principle is to rebuild often, reference base images that are up to date and patched, rollout updates to your workloads frequently and employ CVE scanning to look for containers that are out of date.

REDUCING CONTAINER UPDATES

A further mitigation to reduce potential vulnerabilities in application containers is to build extremely lightweight containers that contain only the absolute minimum needed to run your application, being your application and its dependencies. Using a typical base image like ubuntu includes a package manager, and various software packages which make life easy, but also increase the attack surface area. The less code there is in your container from other sources, the less you'll need to update it due to vulnerabilities found in that code, and the less bugs you can potentially be exposed to.

The code sample in section 2.1.8 earlier in the book employed this principle by using one container to build your code, and another to run the code. To reduce the potential attack surface, the key is to pick the slimmest possible runtime base image for the second stage of the container build. Google has an open source project distroless[2] to assist with providing super-lightweight runtime containers.

Here is the distroless project's example of a building Java container, referencing the Google-provided distroless image in the second step:

[1] https://hub.docker.com/_/python
[2] https://github.com/GoogleContainerTools/distroless

https://github.com/GoogleContainerTools/distroless/tree/main/examples/java/Dockerfile

```
FROM openjdk:11-jdk-slim-bullseye AS build-env
COPY . /app/examples
WORKDIR /app
RUN javac examples/*.java
RUN jar cfe main.jar examples.HelloJava examples/*.class

FROM gcr.io/distroless/java11-debian11
COPY --from=build-env /app /app
WORKDIR /app
CMD ["main.jar"]
```

11.1.3 Handling Disruptions

With all this updating, you might be wondering: what happens to my running workloads!? It's inevitable that as you update Pods will be deleted and recreated. This can obviously be very disruptive to the workloads running in those Pods, but fortunately Kubernetes has a number of ways to reduce this disruption and potentially eliminate any ill-effects.

READINESS CHECKS

Firstly, if you've not setup Readiness checks, now is the time to go back and do that as it's absolutely critical. Kubernetes relies on your container reporting when it's ready, and if you don't do that it will assume it's ready the moment the process starts running which is likely *before* your application has finished initializing and is actually ready to serve production traffic. Chapter 4 covers this topic. The more your Pods are moved around such as during updates, the more requests will error out hitting Pods that are not ready, unless you implement proper readiness checks.

SIGNAL HANDLING AND GRACEFUL TERMINATION

Just as Readiness checks are used to determine when your application is ready to start, graceful termination is used by Kubernetes to know when your application is ready to stop. In the case of a Job which may have a process that takes a while to complete, you may not want to simply terminate that process if it can be avoided. Even web applications with short-lived requests can suffer from abrupt termination that causes requests to fail.

To prevent these issues, it's important to handle SIGTERM events in your application code to start the shutdown process, and set a graceful termination window (configured with `terminationGracePeriodSeconds`) long enough to complete the termination. Web applications should handle SIGTERM to shutdown the server once all current request are completed, and batch jobs would ideally wrap up any work they are doing, and not start any new tasks.

In some cases, you may have a Job performing a long running task that if interrupted would lose its progress. In these cases, you may set a very long graceful termination window, accept the SIGTERM but simply continue to attempt to finish the current task. Managed platforms may have a limit on how long the graceful termination window can be for system-originated disruption.

Section 10.1.2 in the previous chapter has examples of `SIGTERM` handling and `terminationGracePeriodSeconds` configuration in the context of Jobs. The same principles apply to other workload types.

ROLLING UPDATES

When you update the containers in a Deployment or a StatefulSet (for example to update the base image), the rollout is governed by your rollout strategy. Rolling update, covered in Chapter 4, is a recommended strategy here to minimize disruption when updating workloads by updating Pods in batches, while keeping the application available. For Deployments, be sure to configure your `maxSurge` parameters of the Deployment which will do a rollout by temporarily increasing the pod replica count (safer for availability than reducing it).

POD DISRUPTION BUDGETS

When nodes are updated, this process does *not* go through the same Deployment rollout process. Here's how it works: firstly, the node is cordoned to prevent new Pods being deployed on it. Then the node is drained, whereby Pods are deleted from this node, and recreated on another node. By default, Kubernetes will delete all Pods at once from the node and schedule them to be created elsewhere. Note that it does *not* first schedule them to be created elsewhere, then delete them (although this is a feature I think we should add to Kubernetes). If multiple replicas of a single Deployment are running on the same node, this can cause unavailability.

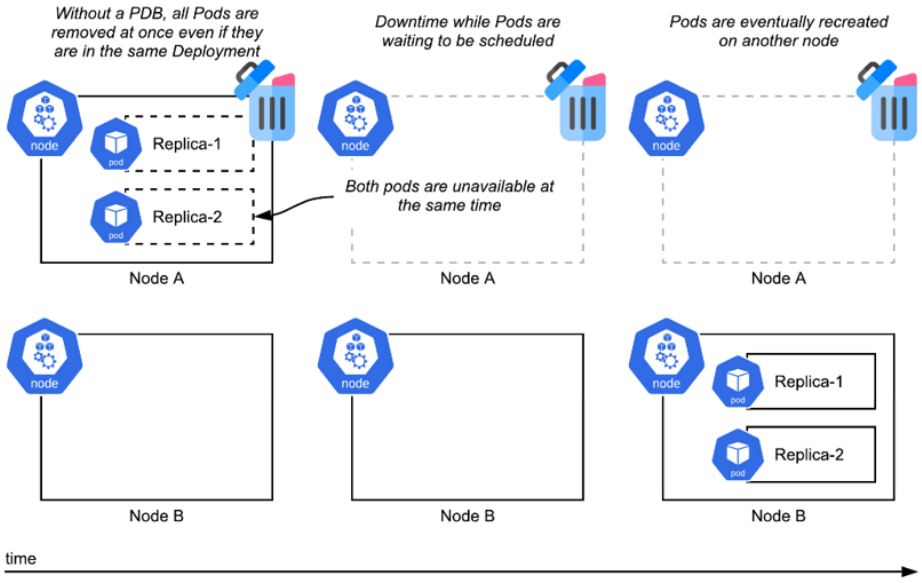


Figure 11.1: node deletion without pod disruption budgets. All the Pods on the node will become unavailable at once.

To solve the problem where draining a node may reduce the availability (meaning running replicas) of your deployments, should multiple pods from the same deployment be on that node, Kubernetes has a feature called Pod Disruption Budgets (PDBs). PDBs allow you to inform Kubernetes how many pods, or what percentage of your pods you are willing to have unavailable, for your workload to still function as you designed it.

11.1 PDB/pdb.yaml

```
apiVersion: policy/v1
kind: PodDisruptionBudget
metadata:
  name: pluscode-pdb
spec:
  maxUnavailable: 1
  selector:
    matchLabels:
      app: pluscode
```

Deploying this into your cluster will ensure that at no time during disruptions will more than 1 of your Pods be unavailable. An alternative configuration uses `minAvailable` to set how many replicas you need. I prefer `maxUnavailable`, as it works better with scaling (if you use `minAvailable`, you may need to scale that value along with your replica count to retain the desired minimum availability, which is just extra work).

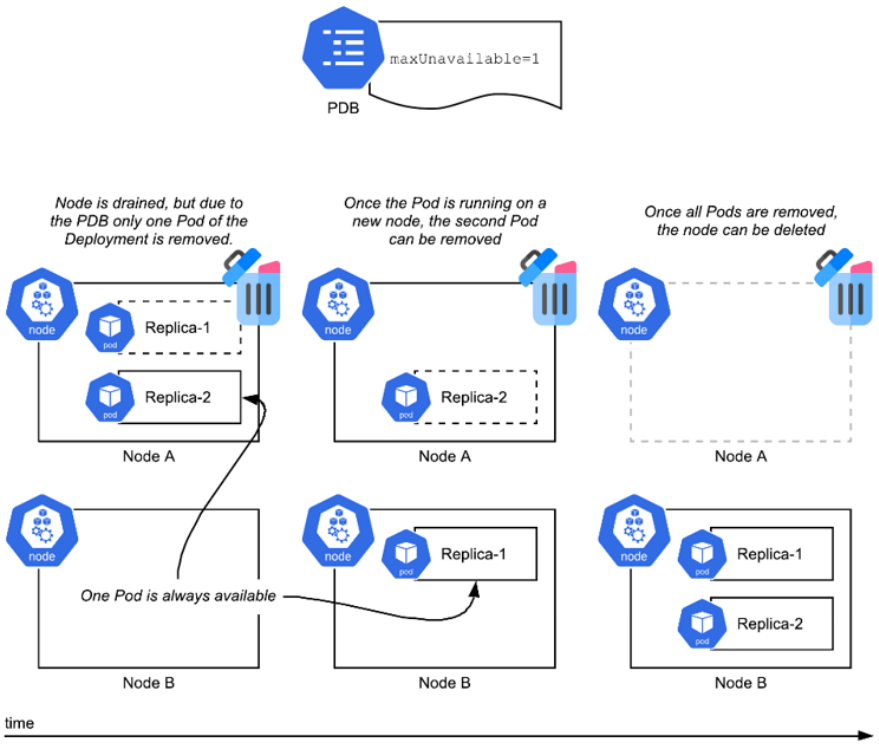


Figure 11.2: with a PDB, Kubernetes will wait for the required number of pods in a Deployment to be available before deleting others, reducing the disruption

The process of handling disruptions with a PDB is somewhat similar to how a rolling update avoids taking out too many pods at the same time. To ensure your application stays available during deployment updates that you initiate, and disruptions initiated by cluster updates, you'll need to have both the rolling update, and the PDB configured.

11.2 Deploying Node Agents with DaemonSet

This book has covered a bunch of high-order workload constructs that encapsulate Pods with particular objectives, like Deployment for application deployments, StatefulSet for database deployments, and CronJob for period tasks. DaemonSet is another workload type that allows you to run a Pod on every node.

When would you need that? It's almost entirely for cluster operational reasons, like logging, monitoring, and security. As an application developer, DaemonSet is generally not your go-to deployment construct. Due to the ability to expose services internally on a cluster IP, any Pod in your cluster can talk to any service you create, you don't need to run services on every node to make them available. And if you need to be able to connect to a service on

localhost, you can do that virtually with NodePort. DaemonSets are generally for when you need to perform operations at a node level, like reading load logs, or observing performance, putting them squarely in the administrative domain.

DaemonSets are typically how logging, monitoring and security vendors deploy their software. This software performs actions like reading logs off the node and uploading it to a central logging solution, querying the kubelet API for performance metrics (like how many pods are running, their boot times, etc.), and for security, such as monitoring container and host behaviors. These are all examples of Pods that need to be on every node to gather the data they need to provide their solution.

The typical cluster will have a few DaemonSets running in kube-system, such as this abridged list from a GKE Autopilot cluster that provides functionality like logging, monitoring and cluster DNS.

```
$ kubectl get daemonset -n kube-system
NAMESPACE     NAME
kube-system   filestore-node
kube-system   fluentbit-gke
kube-system   gke-metadata-server
kube-system   gke-metrics-agent
kube-system   kube-proxy
kube-system   metadata-proxy-v0.1
kube-system   netd
kube-system   node-local-dns
kube-system   pdcsi-node
```

Typically, application developers will not be creating DaemonSets directly, but rather be using off the shelf ones from vendors. By way of example though, here is a simple DaemonSet that reads logs from the node into standard output (stdout).

11.2 DaemonSet/logreaderds.yaml

```
apiVersion: apps/v1
kind: DaemonSet
metadata:
  name: logreader
spec:
  selector:
    matchLabels:
      ds: logreaderpod
  template:
    metadata:
      labels:
        ds: logreaderpod
    spec:
      containers:
      - image: ubuntu
        command: ["tail", "-f", "/var/log/kube-proxy.log"]
        name: logreadercontainer
        resources:
          requests:
            cpu: 50m
            memory: 100Mi
            ephemeral-storage: 100Mi
        volumeMounts:
        - name: logpath
          mountPath: /var/log
          readOnly: true
      volumes:
      - hostPath:
          path: /var/log
        name: logpath
```

To create the DaemonSet:

```
$ kubectl create -f 11.2_DaemonSet/logreader.yaml
daemonset.apps/logreader created
```

Once the Pods are ready, we can tail the output and we'll see the output from the node's kube-proxy.log file

```
$ kubectl get pods
NAME              READY   STATUS    RESTARTS   AGE
logreader-2nbt4   1/1     Running   0          4m14s
$ kubectl logs -f logreader-2nbt4
I0125 01:39:28.576504       1 proxier.go:845] "Syncing iptables rules"
I0125 01:39:28.615108       1 proxier.go:812] "SyncProxyRules complete"
       elapsed="38.697941ms"
```

This is just a trivial example. In practice, you will likely encounter DaemonSets when deploying logging, monitoring and security solutions from vendors.

11.3 Pod Security Context

The PodSpec has a `securityContext` property where the security attributes of the Pod, and its containers are defined. If your Pod needs to perform some kind of administrative function (for example, perhaps it's part of a DaemonSet which is doing a node-level

operation), it's here where you would define the various privileges it needs. For example, here is a Pod in a DaemonSet that requests privilege (root access) on the node:

```
apiVersion: apps/v1
kind: DaemonSet
metadata:
  name: admin-workload
spec:
  selector:
    matchLabels:
      name: admin-app
  template:
    metadata:
      labels:
        name: admin-app
    spec:
      containers:
      - name: admin-container
        image: ubuntu
        securityContext:
          privileged: true
```

As a developer of a non-administrative application that run on Kubernetes, you will more likely be using these properties to *limit* what functions your Pod can use in order to reduce risk. Contrasting the above example, here is the PodSpec for a Pod with locked-down privileges that runs as the non-root user and cannot elevate privileges.

```
apiVersion: v1
kind: Pod
metadata:
  name: timeserver-demo
  labels:
    app: timeserver
spec:
  containers:
  - name: timeserver-container
    image: wdenniss/timeserver2:latest
    securityContext:
      runAsNonRoot: true
      runAsUser: 1001
      allowPrivilegeEscalation: false
      capabilities:
        drop:
          - ALL
```

By default, any Pod is free to request whatever capabilities it wants, even root access (unless your Kubernetes platform restricts this, as some nodeless platforms do). As the cluster operator, this may be something you want to restrict as it basically means that anyone with kubectl access to the cluster has root privileges. Furthermore, there are some other recommended principles for hardening clusters, like not running containers as the root user (which is distinct from having root on the node), something that is enforced by the `runAsNonRoot: true` configuration in the prior example.

The remainder of this chapter will cover these topics, starting with how to build containers so they don't need to run as the root user, and how as a cluster administrator you can force users of the cluster to adopt this and other desired security settings.

11.4 Non-Root Containers

One common security recommendation when deploying containers is to not run them as the root user. The reason for this is that despite all the fancy packaging, Linux containers are basically just processes that run on the host with sandboxing technology applied (like Linux cgroups and namespaces). If your container is built to run using the root user (which is the default), then it actually runs as root on the node, just sandboxed. The container sandboxing means that the process doesn't have the power of root, but it's still running under the root user. The issue with this configuration is that while the sandboxing prevents the process from having root access, if there is ever a "container escape" vulnerability due to bugs in the underlying Linux containerization technology, the sandboxed container process can gain the same privileges as the user it's running, meaning if the container is running as root a container escape would give full root access on the node, which is not so good.

Since Docker runs all processes as root by default, this means that any container escape vulnerabilities can present an issue. While such vulnerabilities are fairly rare, they do occur, and for the security principle known as "defense in depth", it's best to protect against it. Defense in depth means that even though container isolation offers protection of the host in the event your application is breached, ideally you would have further layers of defense in case *that* protection is breached. In this case, defense in depth means running your containers as the non-root user, so in the event an attacker can breach your container and take advantage of a container escape vulnerability in Linux, they still wouldn't end up with elevated privileges on the node, and would need to string together a yet another vulnerability to elevate their privileges making for 3 layers of defense (your application, Linux containerization, and Linux user privileges).

> **WHY DOCKER DEFAULTS TO THE ROOT USER** You may be wondering, if it's the best practice to not run container processes as root, why then Docker defaults to the root user when building containers. The answer is developer convenience. It's convenient to act as the root user in a container, as you can use privileged ports (those with numbers below 1024, like the default HTTP port 80), and don't have to deal with any folder permission issue. As you'll see below, building and running containers with the non-root user can introduce some errors that need to be worked through. If you adopt this principle from the start however, you may not find it so difficult to fix these issues as they arise, and the payoff is adding one more layer of defense into your system.

Preventing containers from running as the root user is simple in Kubernetes, although the problem (as we'll see below) is that not all containers are designed to run this way and may fail.

You can annotate your Pods in Kubernetes to prevent them running as a root user. So, to achieve the goal of "not running as root", the first step is to simply add this annotation! If you're configuring a Kubernetes cluster for a wider team (or if you're a member of that team

using such a configured cluster), a Kubernetes admission controller can be used to automatically add this annotation to every pod. The end result is the same, so for this demo we'll just add it manually. The following deployment enforces the best practice to prevent containers running as root.

Listing 11.3 Chapter11/ 11.4_NonRootContainers/deploy_1.yaml

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: timeserver-demo
spec:
  replicas: 1
  selector:
    matchLabels:
      app: timeserver
  template:
    metadata:
      labels:
        app: timeserver
    spec:
      containers:
      - name: timeserver-container
        image: docker.io/wdenniss/timeserver:latest
        securityContext:
          runAsNonRoot: true
```

Unfortunately, we're not done because the container itself doesn't configure a non-root user to run as. If you try and create this deployment, Kubernetes will enforce the securityContext and won't let the container run as root. Below is the truncated output you'll see if you try and run this deployment.

```
$ kubectl get pods
NAME                              READY   STATUS                       RESTARTS   AGE
timeserver-demo-fd574695c-5t92p   0/1     CreateContainerConfigError   0          34s
$ kubectl describe pod timeserver-demo-fd574695c-5t92p
Name:         timeserver-demo-fd574695c-5t92p
Events:
  Type     Reason     Age                From                                Message
  ----     ------     ----               ----                                -------
  Warning  Failed     10s (x3 over 23s)  kubelet                             Error:
       container has runAsNonRoot and image will run as root (pod: "timeserver-demo-
       fd574695c-5t92p_default(8cfaf4a9-c2e6-4dde-b506-14ab04444f50)", container:
       timeserver-container)
```

To resolve, you need to configure the user that the Pod will be run under. Root is always user 0, so we just need to set any other user number, I'm going to pick user 1001. This can either be declared in the Dockerfile with `USER 1001`, or in the Kubernetes configuration with `runAsUser: 1001`. When both are present, the Kubernetes configuration takes priority, similar to how the `command` parameter in a Kubernetes deployment overrides `CMD` if present in the Dockerfile.

Here's the Dockerfile option:

```
FROM python:3
COPY . /app
WORKDIR /app
RUN mkdir logs
CMD python3 server.py
USER 1001
```

Or, in the Deployment:

Listing 11.4 Chapter11/ 11.4_NonRootContainers/deploy_2.yaml

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: timeserver-demo
spec:
  replicas: 1
  selector:
    matchLabels:
      app: timeserver
  template:
    metadata:
      labels:
        app: timeserver
    spec:
      containers:
      - name: timeserver-container
        image: docker.io/wdenniss/timeserver:latest
        securityContext:
          runAsNonRoot: true
          runAsUser: 1001
```

Both approaches work, but what I recommend is to configure it on the Kubernetes side as this is better for keeping your development and production environments separate. If you specify the run-as user in the Dockerfile and want to run your container locally outside of Kubernetes and try to mount a volume, you'll hit a snag like Docker issue #2259 which prevents you from mounting a volume as a user other than root[3], a 7+ year old issue. Since the original security concern to not run containers as root is only related to production, why not relegate this whole "run as non-root" concern to production as well! Fortunately, it's easy to let your container that runs as root in Docker for maximum convenience, and non-root in production in Kubernetes for better defense in depth.

The above configuration is enough to run our container as non-root. Provided that the container is capable of running as non-root then your job is done. Most public, well-known containers should be designed to run as non-root, but this likely isn't the case for your own containers.

In the case of our example container it wasn't designed to run as non-root and will need to be fixed. Two major differences when running the container as non-root are that you can't listen on privileged ports, those between 1 and 1023, and you don't have write access by default to container writable layer (meaning, by default you can't write any files). This would

[3] https://github.com/moby/moby/issues/2259

be a problem for the Timeserver sample app (first introduced in Chapter 2, section 2.2), which listens on port 80, and writes a logfile to `/app/logs`.

UPDATING CONTAINERS TO RUN AS NON-ROOT

If you were to create the deployment above (listing X), you will see that there is no config error when deployed, but the container itself is crashing. When your container starts crashing after you change the user it runs as non-root, it's probably a permission error related to that. Before you start debugging the non-root user errors, be sure your container runs fine as root, otherwise the issue could be something completely unrelated.

The steps to debug permission issues for containers running as non-root will vary, but let's walk through how to find and fix these two common errors with our example app. The following is the output and truncated logs that I see for this crashing container.

```
$ kubectl get pods
NAME                                READY   STATUS             RESTARTS      AGE
timeserver-demo-774c7f5ff9-fq94k    0/1     CrashLoopBackOff   5 (47s ago)   4m4s
$ kubectl logs timeserver-demo-76ddf6d5c-7s9zc
Traceback (most recent call last):
  File "/app/server.py", line 23, in <module>
    startServer()
  File "/app/server.py", line 17, in startServer
    server = ThreadingHTTPServer(('',80), RequestHandler)
  File "/usr/local/lib/python3.9/socketserver.py", line 452, in __init__
    self.server_bind()
  File "/usr/local/lib/python3.9/http/server.py", line 138, in server_bind
    socketserver.TCPServer.server_bind(self)
  File "/usr/local/lib/python3.9/socketserver.py", line 466, in server_bind
    self.socket.bind(self.server_address)
PermissionError: [Errno 13] Permission denied
```

Fortunately, the port issue in Kubernetes is an easy fix without any end-user impact. We can change the port that the container uses, while keeping the standard port 80 for the load balancer. First let's update the port used by the container:

Listing 11.5 Chapter11/ 11.4_NonRootContainers/ timeserver2_nonroot/server.py

```
//...

def startServer():
    try:
        server = ThreadingHTTPServer(('',8080), RequestHandler)
        server.serve_forever()
    except KeyboardInterrupt:
        server.shutdown()

if __name__== "__main__":
    startServer()
```

If we're changing ports in the application, then we'll need to update our Kubernetes service configuration to match the new port by updating the `targetPort`. Note that we do **not** need to change the actual port of the Service. The Service glue is provided by Kubernetes, and doesn't run as a particular user so it can use ports below 1024.

Listing 11.6 Chapter11/ 11.4_NonRootContainers/ deployment2_nonroot/ svc_2.yaml

```
apiVersion: v1
kind: Service
metadata:
  name: timeserver-lb
spec:
  selector:
    app: timeserver
  ports:
  - port: 80
    targetPort: 8080
    protocol: TCP
  type: LoadBalancer
```

Once the socket issue is fixed, and we re-run the application, another error will be encountered when the app attempts to write to the log file on disk. This error doesn't stop the app starting, but is encountered when a request is made. Looking at those logs, we see:

```
$ kubectl logs timeserver-demo-5fd5f6c7f9-cxzrb
10.22.0.129 - - [24/Mar/2022 02:10:43] "GET / HTTP/1.1" 200 -
Exception occurred during processing of request from ('10.22.0.129', 41702)
Traceback (most recent call last):
  File "/usr/local/lib/python3.10/socketserver.py", line 683, in process_request_thread
    self.finish_request(request, client_address)
  File "/usr/local/lib/python3.10/socketserver.py", line 360, in finish_request
    self.RequestHandlerClass(request, client_address, self)
  File "/usr/local/lib/python3.10/socketserver.py", line 747, in __init__
    self.handle()
  File "/usr/local/lib/python3.10/http/server.py", line 425, in handle
    self.handle_one_request()
  File "/usr/local/lib/python3.10/http/server.py", line 413, in handle_one_request
    method()
  File "/app/server.py", line 11, in do_GET
    with open("logs/log.txt", "a") as myfile:
PermissionError: [Errno 13] Permission denied: 'logs/log.txt'
```

If you see a permission denied error when running as non-root when writing a file, it's a clear sign that your folder permissions have not been setup correctly for non-root users.

The simplest way to solve this is to set the group permissions on the folder in question. I like using the group permissions, as we can use the same group (being group 0) for running locally using Docker, and deploying in production to Kubernetes without environment-specific changes in the Dockerfile. Let's update the Dockerfile to give write access to group 0:

Listing 11.7 Chapter11/ 11.4_NonRootContainers/ timeserver2_nonroot/Dockerfile

```
FROM python:3
COPY . /app
WORKDIR /app
RUN mkdir logs
RUN chgrp -R 0 logs \
  && chmod -R g+rwX logs
CMD python3 server.py
```

If you want to run the container in Docker using a non-root user, you can also override this at runtime, like so: docker run --user 1001:0

So there we have it, our container now runs happily as the non-root user. If you want to see all the changes made, compare 11.4_NonRootContainers/timeserver1_root to 11.4_NonRootContainers/timeserver2_nonroot for the app changes, and 11.4_NonRootContainers/deployment1_root to 11.4_NonRootContainers/deployment2_nonroot for the configuration.

11.5 Admission Controllers

In the previous section we added `runAsNonRoot` to our Pod to prevent it from ever running as root, but we did it manually. If this is a setting we want for all Pods, ideally we'd be able to configure the cluster to reject any Pod without this configuration, or even just add it automatically.

This is where admission controllers come in. Admission controllers are bits of code that are executed via webhooks when you create an object (like with `kubectl create`). There are two types: validating, and mutating. Validating admission webhooks can accept or reject the Kubernetes object, for example, rejecting Pods without `runAsNonRoot`. Mutating admission webhooks can change the object as it comes in, for example setting `runAsNonRoot` to true.

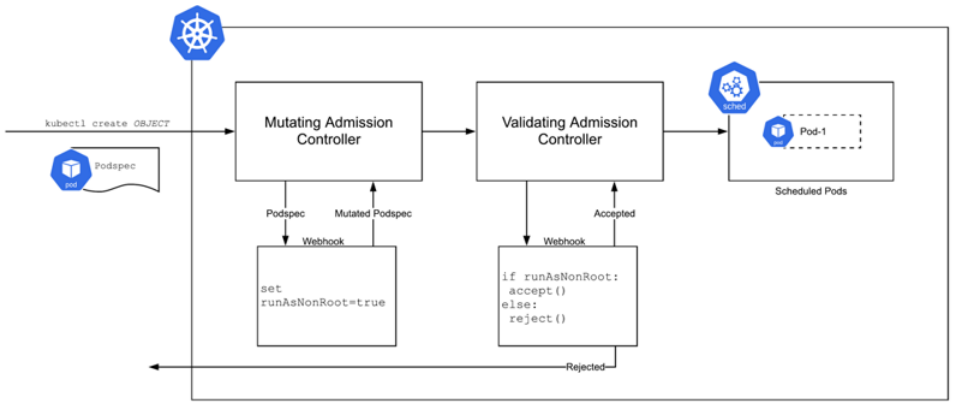


Figure 11.3: admission process of a pod that gets scheduled

You can write your own admission controllers to implement the behavior you desire, but depending on what you're hoping to achieve, you may not need to as Kubernetes ships with an admission controller out of the box, and others may be available as commercial or open source deployments.

11.5.1 Pod Security Admission

Writing admission controllers is no walk in the park. You need to configure certificates, build an application that can be setup as webhook which conforms to the request/response

API of Kubernetes, and you need to have a development process to keep it up to date as Kubernetes changes (which it does fairly frequently). The good news is that the typical end-developer running on Kubernetes would not need to write their own admission controllers. You'll typically use those from third party security vendors, and those included in Kubernetes.

Kubernetes has offered several included admission controllers for enforcing security policies like `runAsNonRoot`. The PodSecurityPolicy[4] feature originally served this purpose but never left beta and is slated for removal in Kubernetes 1.25. Pod Security Admission is the current recommended way to enforce security policies via an admission controller. It will be enabled by default from Kubernetes 1.23 (starting as a beta feature), but fortunately you can deploy it manually[5] into clusters running older version of Kubernetes, or where the feature wasn't enabled by the platform operator.

Pod Security Admission Beta

I've avoided discussing beta features as much as possible in the book, due to potential churn, and at the time of writing Pod Security Admission is beta in Kubernetes 1.23. Given its availability as a stand-alone deployment (which has its own lifecycle outside of Kubernetes), I hope that this section will have a bit of longevity. Even if this feature never makes it to GA as a built-in admission controller, you could always install the admission webhook directly, and the content here will apply. I'm also hoping that since this is the second bite at the apple when it comes to security admission controllers, this one might actually make it to GA.

INSTALLING POD SECURITY ADMISSION

First, verify if the pod-security-webhook is installed on your cluster. If it shows up in the list of `ValidatingWebhookConfiguration`s, then you don't need to install it.

```
$ kubectl get ValidatingWebhookConfiguration | grep pod-security-webhook.kubernetes.io
pod-security-webhook.kubernetes.io                  2          26h
```

If you need to install it, then you can in the following way:

```
$ git clone https://github.com/kubernetes/pod-security-admission.git
$ cd pod-security-admission/webhook
$ make certs
$ kubectl apply -k .
```

POD SECURITY POLICIES

Pod Security defines[6] three security policy levels that apply at a namespace level. These are:

- **Privileged** – Pods have unrestricted administrative access, and can gain root access to nodes
- **Baseline** – Pods cannot elevate privileges to gain administrative access, while still retaining most functionality.

[4] https://kubernetes.io/docs/concepts/policy/pod-security-policy/
[5] https://kubernetes.io/docs/concepts/security/pod-security-admission/#webhook
[6] https://kubernetes.io/docs/concepts/security/pod-security-standards/

- **Restricted** – Implements current best practices for hardening (i.e. defense in depth), adding additional layers of protection over the baseline profile, including restricting running as the root user.

Basically: privileged should be used only for system workloads. Baseline offers a good balance of security, and compatibility, while restricted offers additional defense in depth at a cost of some compatibility (such as needing to ensure all containers can run as non-root, per section X above).

CREATING A NAMESPACE WITH POD SECURITY

In keeping with the running example of this chapter, and to implement the most secure profile, let's create a namespace with the *restricted* policy. This will require pods to not run as the root user (per the docs[7] with the restricted policy "containers must be required to run as non-root users"), and will enforce several other security best practices as well.

To start, create a new namespace with the restricted policy. We'll call this namespace "team1", as it can be the place for a theoretical "team1" to deploy their code to.

11.8 PodSecurityAdmission/namespace.yaml

```
apiVersion: v1
kind: Namespace
metadata:
  name: team1
  labels:
    pod-security.kubernetes.io/enforce: restricted
    pod-security.kubernetes.io/enforce-version: v1.23
```

These two labels set the policy we want to enforce, and the version of the policy that will be enforced. While you can skip the version label, there is a good reason not to as the definition of what the policy actually enforces may evolve as new security risks are uncovered. If we don't reference the version, then we'll get whatever the current policy is, which could break existing workloads as that policy is updated. Ideally you would test the newer policy versions in a staging namespace or cluster to validate them first, before updating the enforce-version in your production environment.

Let's create this namespace:

```
kubectl create -f 11.3.1_PodSecurityAdmission/namespace.yaml
kubectl config set-context --current --namespace=team1
```

Now if we try to deploy a Pod from chapter 3 that doesn't set `runAsNonRoot` the pods will be rejected.

[7] https://kubernetes.io/docs/concepts/security/pod-security-standards/#restricted

```
$ kubectl create -f Chapter03/3.2.3_DeployingToKubernetes/pod.yaml
Error from server (Forbidden): error when creating "pod.yaml": admission webhook "pod-
       security-webhook.kubernetes.io" denied the request: pods "pluscode-demo" is
       forbidden: violates PodSecurity "restricted:v1.23": allowPrivilegeEscalation !=
       false (container "pluscode-container" must set
       securityContext.allowPrivilegeEscalation=false), unrestricted capabilities
       (container "pluscode-container" must set securityContext.capabilities.drop=["ALL"]),
       runAsNonRoot != true (pod or container "pluscode-container" must set
       securityContext.runAsNonRoot=true)
```

If we add the appropriate `securityContext` to satisfy the Pod Security admission policy, and use the updated container that is designed to run as root from the previous section, then our pod will be admitted.

11.9 PodSecurityAdmission/nonroot_pod.yaml

```
apiVersion: v1
kind: Pod
metadata:
  name: timeserver-demo
  labels:
    app: timeserver
spec:
  containers:
  - name: timeserver-container
    image: wdenniss/timeserver2:latest
    securityContext:
      runAsNonRoot: true
      allowPrivilegeEscalation: false
      runAsUser: 1001
      capabilities:
        drop:
          - ALL
```

Debugging Pod Admission Rejects for Deployments

The two examples in this section used Pods, rather than Deployments. The reason I did that is it's easier to debug when the Pod admission is rejected. Once you confirm it's working as expected, you can always embed the PodSpec in the Deployment of your choice.

Unfortunately, if you create a Deployment that violates these constraints, you won't see a error printed on the console like for my example when I tried to create the Pod directly. This is an unfortunate fact of Kubernetes' implementation of Deployment. Creating the Deployment object itself succeeds, so you don't see an error on the console. However, when the Deployment then goes to create it's Pods, they will fail. Also, since the Deployment actually creates an object called a ReplicaSet under the hood to manage Pods of a particular version of the deployment, you won't even find this error if you describe the Deployment object, but rather need to inspect its ReplicaSet.

I've not mentioned ReplicaSet yet in the book as it's basically implementation detail. Basically a ReplicaSet is a workload construct that manages a set of Pods. Deployment uses them by creating a new replicaset for each version you deploy. So when you're doing a rolling update, the deployment will actually have 2 replica sets, one for the old version, one for the new, and these are scaled gradually to achieve the rolling update. Normally this implementation

detail doesn't matter—which is why I didn't spend any time on it in the book–but here is one of the few times it does, since the replicaset is where this particular error is hidden.

So this is... not exactly an ideal UX, but here's how to debug this type of issue. Normally when you create a Deployment, it will create Pods. If you type kubectl get pods, you should see a bunch of Pods. Now, those pods may not always be Ready—there are a bunch of reasons why they might be pending (and in some cases, may get stuck in Pending forever), but there would still normally at least be the pod objects there in some state. If when you call kubectl get pods, you don't see any Pod objects at all for your Deployment, it could mean that those pods were rejected during admission, which is why there are no objects.

Since it's the ReplicaSet owned by the Deployment that actually creates the pods, you need to describe the ReplicaSet to see the error with kubectl describe replicaset (kubectl describe rs for short). Here's an example, with the output truncated to show the error message of interest:

```
$ kubectl create -f Chapter03/3.2.3_DeployingToKubernetes/deploy.yaml
$ kubectl get deploy
NAME          READY   UP-TO-DATE   AVAILABLE   AGE
pluscode-demo   0/3     0          0          14m
$ kubectl get pods
No resources found in myapp namespace.
$ kubectl get rs
NAME                  DESIRED   CURRENT   READY   AGE
pluscode-demo-8fb5db8bf   3       0       0      14m
$ kubectl describe rs
Events:
  Type     Reason       Age              From               Message
  ----     ------       ----             ----               -------
  Warning  FailedCreate  2m26s             replicaset-controller  Error creating: admission webhook "pod-security-
webhook.kubernetes.io" denied the request: pods "pluscode-demo-8fb5db8bf-8drr9" is forbidden: violates PodSecurity
"restricted:v1.23": allowPrivilegeEscalation != false (container "pluscode-container" must set
securityContext.allowPrivilegeEscalation=false), unrestricted capabilities (container "pluscode-container" must set
securityContext.capabilities.drop=["ALL"]), runAsNonRoot != true (pod or container "pluscode-container" must set
securityContext.runAsNonRoot=true)
```

BALANCING SECURITY WITH COMPATIBILITY In this section we used the example of the restricted pod security profile, and configured our container to be able to run as the non-root user. Hopefully this has given you the confidence to be able to run containers in a highly secure manner. While this is the best practice, and may be required in situations like regulated industries, there is a clear tradeoff with ease of development and it may not always be practical. Ultimately it's up to you, your security team (and maybe, your regulators) to determine what security profile you're happy with. I'm not necessarily recommending every single Kubernetes deployment should be into a namespace with the "restricted" profile. I would suggest that you should be using "baseline" for every non-administrative workload you deploy in your cluster, as it helps protect your cluster in the event that one of your containers is compromised, and shouldn't cause any incompatibility with the average app. Administrative workloads that need the "privileged" profile should be run in their own namespaces, separate to common workloads.

11.6 Role-based Access Control (RBAC)

Let's say that you have a requirement for Pods to runAsNonRoot (section 11.4), and setup an admission controller to force this using Pod Security Admission (section 11.5). This sounds great, provided you trust all the users of your cluster not to mess anything up and remove those restrictions whether accidently or on purpose. To actually enforce the requirements of your admission controller, and create a tiered user permission setup with roles like "platform operator" (who can configure namespaces and controller), and "developer" (who can deploy to namespaces, but not remove admission controllers), you use role-based access control (RBAC).

RBAC is a way to control what access users of the cluster have. One common setup is to give developers in a team access to a particular namespace in the cluster, with all the desired Pod Security configured. This gives them the freedom to deploy whatever they like within the namespace, provided it conforms to the security requirements that's been set. This way it's still DevOps, developers are the ones doing the deployments, just with some guardrails in place.

RBAC is configured through two configuration types at a namespace level: Role, and RoleBinding. Role is where you define a particular role for a namespace, like the "developer" role. RoleBinding is where you assign this role to subjects in your cluster, i.e. your developer identities. There are also cluster-level versions of these being ClusterRole and ClusterRoleBinding which behave identically to their namespace level counterparts, except that they grant access at a cluster level.

NAMESPACE ROLE

In the Role, you specify the API group(s), the resource(s) within that group, and the verb(s) which you are granting access to. Access is additive, there is no subtractive option, so everything you define grants access. Since our goal is to create a Role which gives the developer access to do pretty much everything within their namespace, *except* to modify the namespace itself and remove the Pod Security annotation, the following is a Role that can achieve that:

11.10 RBAC/role.yaml

```
apiVersion: rbac.authorization.k8s.io/v1
kind: Role
metadata:
  name: developer-access
  namespace: team1
rules:
  - apiGroups:
    - "" #A
    resources:
    - namespaces #B
    verbs: ["get"] #B
  - apiGroups: #C
    - ""  #C
    resources: #C
    - events #C
    - pods #C
    - pods/log #C
    - services #C
    - secrets #C
    - configmaps #C
    - persistentvolumeclaims #C
    verbs: ["*"] #C
  - apiGroups:
    - apps #D
    - autoscaling #E
    - batch #F
    - networking.k8s.io #G
    - policy #H
    resources: ["*"]
    verbs: ["*"]
```

#A The empty string here indicates the core API group
#B Allow developers to view the namespace resource, but not edit it
#C Grant developers full access on core workload types
#D 'apps' includes resources like Deployment
#E 'autoscaling' includes resources like the HorizontalPodAutoscaler
#F 'batch' includes the Job workloads
#G 'networking.k8s.io' is needed so developers can configure Ingress
#H 'policy' is required for configuring PodDisruptionBudgets

This Role grants access to the team1 namespace, and allows the user to modify Pods, Services, Secrets and ConfigMaps within the core API grouping, and all resources in the apps, autoscaling, batch, networking.k8s.io and policy groupings. This particular set of permissions will let the developer deploy nearly every YAML file in this book, including Deployments, StatefulSets Services, Ingress, HPA Autoscaling, Jobs and more. Importantly, the "namespaces" resource is not listed in the core API group (the empty string group), so the user won't be able to modify the namespace.

To grant this role to our developer, we can use a RoleBinding where the subject is our user.

11.11 RBAC/rolebinding.yaml

```
kind: RoleBinding
apiVersion: rbac.authorization.k8s.io/v1
metadata:
  name: developerA
  namespace: team1
roleRef:
  kind: Role
  name: developer-access
  apiGroup: rbac.authorization.k8s.io
subjects:
- kind: User
  name: example@gmail.com #A
```

#A Set this to be the identity of your developer. For GKE, this is a Google User who has "Kubernetes Engine Cluster Viewer" IAM role access to the project

Note that the acceptable values within the User subject are governed by your Kubernetes platform, and any identity systems you have configured. With Google Cloud, the name here can be any Google user. RBAC authorizes the user to the actions specified in the Role, however in order to authenticate the user, they need the `clusters.get` permission which is configured outside of Kubernetes (the "Kubernetes Engine Cluster Viewer" role allows users to authenticate to the cluster, without granting any further permission, after which RBAC can be used). The exact steps here will vary depending on your platform provider.

> **AUTHENTICATION VS AUTHORIZATION** Authentication (AuthN) is the means with which the user presents their identity credentials to the system. In this case, being able to authenticate to the cluster means that the user can retrieve credentials to access the cluster via kubectl. Authorization (AuthZ) is the process to grant users access within the cluster. Depending on your platform's IAM system, it should be possible to allow users to authenticate to the cluster (e.g. get kubectl credentials) but then not actually be able to perform any action (no authorization). You can then use RBAC to grant the precise authorization you want. In the case of GKE, granting users the "Kubernetes Engine Cluster Viewer" role in the IAM permissions (outside of Kubernetes) will allow them to Authenticate, after which you can authorize them to access specific resources using RBAC, and the examples shown here. Again, depending on your particular Kubernetes platform, it's possible (as is the case with GKE) that some IAM roles will also grant the user authorization to some resources in addition to whatever RBAC rules you have here (the project-wide "Viewer" role is one such example in GKE, that will allow users to view most of the resources in the cluster without needing specific RBAC rules to do so).

As the cluster administrator, create the namespace, and these two objects:

```
$ kubectl create ns team1
namespace/team1 created
$ kubectl create -f role3.yaml
krole.rbac.authorization.k8s.io/developer-access created
$ kubectl create -f binding.yaml
rolebinding.rbac.authorization.k8s.io/developerA created
```

With this role and binding deployed in the cluster, our developer user should be able to deploy most of the code in this book in the "team1" namespace, but specifically not be able

to change any other namespaces, nor edit the team1 namespace itself. For a meaningful experiment, you'll need to set as the User subject in the RoleBinding an actual user, for example a test developer account.

Switch to the test developer account, by authenticating to the cluster as the user specified in the Subject. Once authenticated as our developer user, and try to deploy something into the default namespace, it should fail:

```
$ kubectl config set-context --current --namespace=default
$ kubectl create -f Chapter03/3.2.3_DeployingToKubernetes/deploy.yaml
Error from server (Forbidden): error when creating
       "Chapter03/3.2.3_DeployingToKubernetes/deploy.yaml": deployments.apps is forbidden:
       User "example@gmail.com" cannot create resource "deployments" in API group "apps" in
       the namespace "default": requires one of ["container.deployments.create"]
       permission(s).
```

Switching the context to the team1 namespace, for which we configured with the Role above, we should now be able to create the deployment.

```
$ kubectl config set-context --current --namespace=team1
Context "gke_project-name_us-west1_cluster-name" modified.
$ kubectl create -f Chapter03/3.2.3_DeployingToKubernetes/deploy.yaml
deployment.apps/pluscode-demo created
```

While this developer can now deploy things in the namespace, if they try to edit the namespace to gain the privileged Pod Security level, it will be restricted to the lack of edit permission on the namespace resource

```
$ kubectl label --overwrite ns team1 pod-security.kubernetes.io/enforce=privileged
Error from server (Forbidden): namespaces "team1" is forbidden: User "example@gmail.com"
       cannot patch resource "namespaces" in API group "" in the namespace "team1":
       requires one of ["container.namespaces.update"] permission(s).
```

CLUSTER ROLE

So far, we've setup a Role and RoleBinding to give a developer access to a particular namespace. With this Role, they can deploy most of the configuration in this book. There are however a couple of things they won't be able to do, and that is create a PriorityClass (chapter 6), create a StorageClass (chapter 9), or list the PersistentVolumes in the cluster (chapter 9). Those resources are considered cluster-wide objects, so we can't amend the namespace-specific Role we created earlier. Instead, we'll need a separate ClusterRole and ClusterRole binding to grant this additional access.

Figuring out what permissions to grant

I've done the leg work here to provide a Role that cover all the needed permissions to deploy the code in the book, but this may be missing permission that you need to grant developers. To figure out which groups, resources and verbs you need to grant you can consult the API docs. When debugging permission errors, say a developer is complaining that they don't' have access they need you can simply inspect the error message, for example the following:

```
$ kubectl create -f balloon-priority.yaml
Error from server (Forbidden): error when creating "balloon-priority.yaml": priorityclasses.scheduling.k8s.io is forbidden:
User "example@gmail.com" cannot create resource "priorityclasses" in API group "scheduling.k8s.io" at the cluster scope:
RBAC: clusterrole.rbac.authorization.k8s.io "developer-cluster-access" not found
requires one of ["container.priorityClasses.create"] permission(s).
```

To add this to the Role, we can see that the group is scheduling.k8s.io, the resource is "priorityClasses", and the verb is "create", and thus form our Role based on that.

Here is a ClusterRole to provide the additional permissions needed to create StorageClass and PriorityClass objects:

11.12 RBAC/clusterrole.yaml

```
apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRole
metadata:
  name: developer-cluster-access
rules:
- apiGroups: #A
  - scheduling.k8s.io #A
  resources: #A
  - priorityclasses #A
  verbs: ["*"] #A
- apiGroups: #B
  - storage.k8s.io #B
  resources: #B
  - storageclasses #B
  verbs: ["*"] #B
- apiGroups: #C
  - "" #C
  resources: #C
  - persistentvolumes #C
  - namespaces #C
  verbs: ["get", "list"] #C
```

#A Grant developer access to modify all PriorityClasses in the cluster
#B Grant developer access to modify all StorageClasses in the cluster
#C Grant developer read-only access to view and list PersistentVolumes and Namespaces

And the ClusterRoleBinding which looks very similar to the RoleBinding used earlier:

11.13 RBAC/clusterrolebinding.yaml

```
kind: ClusterRoleBinding
apiVersion: rbac.authorization.k8s.io/v1
metadata:
  name: wdenniss-cluster
roleRef:
  kind: ClusterRole
  name: developer-cluster-access
  apiGroup: rbac.authorization.k8s.io
subjects:
- kind: User
  name: example@gmail.com #A
```

#A Set this to be the identity of your developer. For GKE, this is a Google User who has "Kubernetes Engine Cluster Viewer" IAM role access to the project

With these additional cluster roles and bindings, our developer should be able to perform every action in this book.

Identity Federation

For RBAC to be able to reference your developer identities as Users and Groups, your cluster needs to understand the concept of your developer's identities. In the case of GKE, it natively understands Google users in the User field, and also Google groups, when Google Groups for RBAC (a proprietary feature) is enabled. Depending on your platform and your corporate identity provider you may have this access already, or you may need to set it up. This setup is outside the scope of this book, what you probably want to do is configure OpenID Connect (OIDC) integration so that RBAC can reference identities provided by OIDC.

When using an identity system plugin that can offer Groups support, instead of needing to list every "User" as a subject of our role bindings, we can specify a single Group instead.

APPLYING THE POD SECURITY

Previously, we created the namespace without using Pod Security. If we go back and configure the namespace with the Pod Security labels from the previous section, it would have the effect of locking down this namespace to the "restricted" profile, and thanks to RBAC, our developer would not be able to modify that restriction. Mission accomplished.

RBAC FOR SERVICEACCOUNTS

In the examples in this section, we used RBAC with the "User" subject, that's because our developers are actual human users of our cluster. Another common use-case for RBAC is to grant access to services, that is, the code that runs in the cluster.

Let's say you have a Pod that belongs to a Deployment in the cluster which needs to access the Kubernetes API, like perhaps it's monitoring the pod status of another deployment. To give this machine user access, you can create a Kubernetes "ServiceAccount", and then reference this in the subject of your RBAC binding instead of a user.

You may see some documentation that sets up "ServiceAccounts" for human users, where the user then downloads the certs of the service account to interact with Kubernetes. While this is one way to configure your developers and bypasses the need to setup identify federation, it is not recommended as it sits outside of your identity system. For example, if say the developer resigned and their account was suspended in the identity system, the tokens they downloaded for the ServiceAccount would continue to be valid. It's better to properly configure identity federation and only use "User" subjects for human users, so that if the user is suspended their Kubernetes access will also be revoked. Once again, managed platforms like Google Cloud make this integration easy, for other platforms you may need to do a bit of setup to get it working.

Kubernetes ServiceAccounts are utilized when you have a Pod inside the cluster that needs its own access to the Kubernetes API. For example, say you want to create a Pod to monitor another Deployment, you can create a ServiceAccount to use as the subject of the RoleBinding, and assign that service account to the Pod. The Pod can then utilize that credential when making API calls, including with kubectl.

11.7 Summary

One of the most important things you can do as a developer using Kubernetes is to keep your cluster, and your code up to date. This can be time consuming, but is aided by choosing a well managed platform, and using a CI/CD system to build your code frequently. Additionally, Kubernetes offers several security-focused configuration options to help lock down your cluster, particularly when dealing with large teams of developers with the separation of the cluster operator, and developer roles.

- Kubernetes is a large and complex system with a huge surface area
- It's important to keep your cluster and its nodes up to date to mitigate against security vulnerabilities
- Docker base images also introduce their own attack surface area, requiring monitoring and updating of deployed containers
- Using the smallest possible base image can help to reduce this surface area, decreasing the frequency of application updates to mitigate security vulnerabilities
- DaemonSets are another workload type, along with Deployment, StatefulSet and Job, commonly used to configure logging, monitoring, and security software in the cluster
- The Pod Security Context is how Pods are configured to have elevated, or restricted permissions
- Admission Controllers can be used to make changes to Kubernetes objects as they are created, and also enforce requirements including around the Pod Security Context
- Kubernetes ships with an Admission Controller named Pod Security Admission to enable to you to enforce security profiles like baseline, for mitigating most known attacks and restricted to enforce security best practices on pods
- RBAC is a role-based permission system that allows users with the cluster administrator role to grant fine-grained access to developers in the system, for example restricting them to a given namespace, and preventing them from altering admission controller rules (like Pod Security)