Kubernetes Concepts

Jun 22, 2020

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CHAPTER 1

Prologue

I have been working on Kubernetes for almost a year now and started using Docker many years before that. I really think that containers and Kubernetes are transformative technologies in the same way that Virtualization has been a decade before.

The idea to write a guide about Kubernetes concepts came up when I started preparing for a technical talk at Catalogic Software (where I work). Instead of preparing usual slides and notes, I thought that writing a guide beforehand and then giving the talk would be better.

There are many Kubernetes tutorials available on the web and the Concepts section on Kubernetes website is quite brilliant. However, I haven't found any systematic presentations where concepts are introduced in an incremental fashion, starting all the way from containers and then gradually moving onto Kubernetes features. Hence, this guide. I hope developers find it useful.

If you have any comments or corrections, please send email to "draghuram at gmail.com" or open an issue (or PR) at the github repo.

CHAPTER 2

Introduction

Kubernetes is very much getting lots of love and mind share these days. Here is how kubernetes.io defines the technology:

> Kubernetes (K8s) is an open-source system for automating deployment, scaling, and management of containerized applications.

But what does it exactly mean? It is certainly not an easy technology to pick up and it really helps to understand the concepts behind its design and implementation.

This guide is an attempt to explain the concepts in an easy to understand and incremental fashion. I do assume that the reader is reasonably familiar with Docker and container concepts though I give a high level overview in the first two chapters.

Also, all the examples and descriptions in the guide use *Linux* as that is the operating system I am most comfortable with.

CHAPTER 3

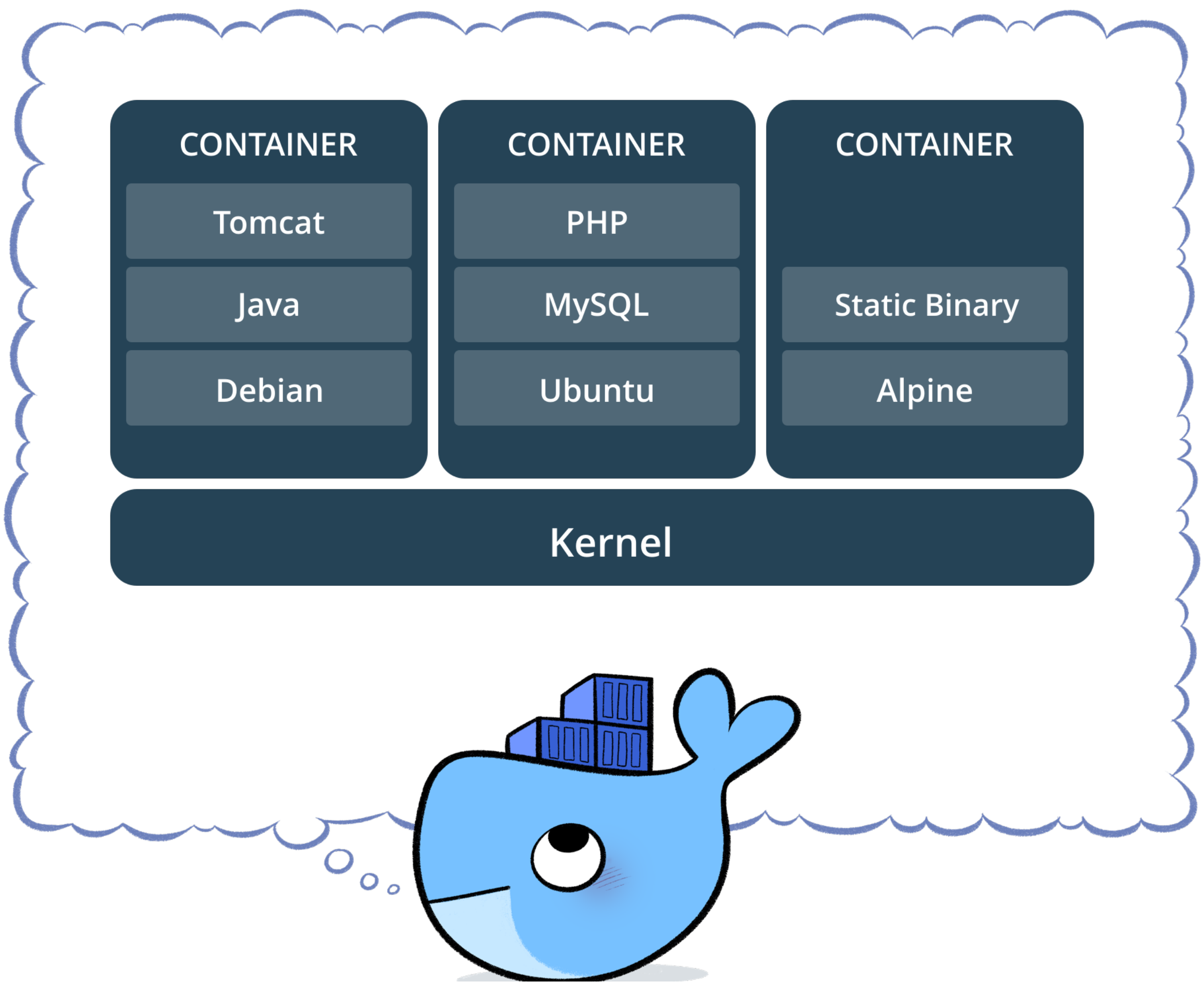
Containers

Kubernetes is a *container orchestration platform* so containers are at the heart of the technology.

3.1 Overview

Containers are *isolated* groups of processes running on a single host. They run directly on a host without any intermediate layer as opposed to Virtual Machines which require a Hypervisor to be present. This is also the reason why containers are referred to as a “light-weight” solution to deploy applications.

The most important point to note is the fact that container processes run directly on the host. As can be seen in the following picture (*source: docker.com*), there is no intermediate layer between kernel and applications, as is the case with virtualization such as vmware and VirtualBox.



So if the container processes run directly on the host, what stops them from seeing each other or even affecting each other? That is where the isolation aspects of the kernel comes in. Kernel has mechanisms to isolate or sandbox a process (or a group of processes) to the point that the processes behave as though they are running on a dedicated host. This is despite the fact that they are just normal processes on the host and they can be seen from the host just like any other processes (given sufficient permissions).

So Containerization is essentially creating an isolated environment around a process or group of processes, limiting them in terms of what they can see and what they can do.

Finally, it is important to understand that all containers share same running kernel. There is no isolation there and that is another big difference between Virtual Machines and containers. A side effect of sharing the kernel is that if the container uses a kernel module or does something with a kernel module, there is no way to isolate it from other containers (with some exceptions, see Kata Containers).

3.2 Container building blocks

There are three kernel features - *namespaces*, *cgroups*, and *chroot*, that work together to make containers possible. Docker and other container tools mainly use these features to build container solutions.

3.2.1 chroot

chroot is a system call that changes the root directory of a process. Once that happens, the process will only be able to access files that are reachable from the new root directory.

3.2.2 Namespaces

Namespaces allow partitioning of virtual system resources such as PIDs and mounted file systems.

Here are some examples:

PID Isolates process ID ranges so that processes in different namespaces can have same PID.

User Isolates UID and GID numbers. Especially useful to run as root inside the container.

UTS Provides isolation for host name and domain name.

3.2.3 Control groups (cgroups)

Control groups allow partitioning of physical system resources such as CPU and memory.

They also allow limiting physical resources to a group of processes. For example, if you want to limit a process to 100MB of main memory even though the host has much larger memory, you can easily do that using cgroups.

3.3 Docker

Containers existed in one form or another for very long time. E.g. Solaris Zones, lxc. But Docker brought the technology to mainstream due to following reasons:

- Defined a simple and portable image format
- Made it easy to build new images
- Made sharing images a breeze (Docker Hub)

Google has been using containers for long time. In fact, the initial code for cgroups has been donated by Google. Since then, namespaces were added to the mix and then "lxc" came along as a container solution.

But the real popularity in the wide developer world started after Docker came into the picture. The main reasons are the portable image format and APIs.

For a good understanding of Docker, please see Docker Concepts.

In the next chapter, we will see a simple example of how to work with Docker containers.

CHAPTER 4

Containers - Practical

This section will continue the discussion of containers by focusing on practical aspects of how to build images and run them.

We will start with a simple HTTP server and use it to demonstrate Container and Kubernetes concepts throughout the guide.

Here is a very basic example taken from Flask Quickstart:

```
from flask import Flask

app = Flask(__name__)

@app.route('/')
def hello_world():
    return 'Hello, World!'

if __name__ == '__main__':
    app.run(host="0.0.0.0")
```

As can be seen, the server is very simple and implements a single end point. Save the code in the file basicserver.py and you can then run the server as follows (command output is not shown):

```
$ python3 -m venv ~/venv/flask
$ export PATH=~/venv/flask/bin:$PATH
$ pip install flask
$ python basicserver.py
```

The end point can be verified with *curl*.

```
$ curl http://localhost:5000
Hello, World!
```

So our little HTTP server is up and responding to requests. Note that the server is running directly on the host.

As a next step, we will build a Docker image and run the server in a container (instead of directly running on the host). Create a file called Dockerfile in the same directory as basicserver.py with the following contents:

```
FROM python:3

RUN mkdir /opt/app && \
    python3 -m venv /opt/venv && \
    /opt/venv/bin/pip install flask

COPY basicserver.py /opt/app

EXPOSE 5000/tcp

CMD ["/opt/venv/bin/python", "/opt/app/basicserver.py"]
```

You usually build images from existing images as we are doing here. We are using `python:3` as the base image on top of which we install our application and configure some options. In this case, we are installing Flask and copying our application code. The "EXPOSE" directive indicates that the process in the container listens on port 5000. Finally, we specify the command to execute when some one "runs" the container.

Once we have a Dockerfile, we can build the container image and then "run" it.

```
# Build the container with name "basicserver" and tag "0.42"
# This command must be run in the same directory that contains
# "Dockerfile".
$ docker build -t basicserver:0.42 .
```

We are now ready to "run" the container.

```
$ docker run -p 5000:5000 --rm -it basicserver:0.42
```

"-p" option is to map the container port 5000 on to the host (so that we can access it directly on "localhost"). You can map to any available port, not just 5000. For information about other options, check Docker Run reference.

At this point, the HTTP server is running and we can access it using "curl" just like before.

```
$ curl http://localhost:5000
Hello, World!
```

Note that the way we access the server hasn't changed but we are now running it in a "container" instead of directly on a host. Imagine you have a machine that has no Python or Flask installed. You can still run the container using Docker and use the application. This is possible because all the required components of the server (e.g. Python and Flask) are packaged in the container image.

It is interesting to note that a container image is comparable to an "executable" file such as ELF binary while the "container" can be compared to a running process. Just like running a process involves taking an executable file and creating a "process", running a container takes an image and creates a "container".

You don't need to build images yourself in order to use containers. In many cases, you will be able to use images that are already available at Docker Hub.

4.1 Use Cases

There are many different scenarios where you can use containers. Here are few interesting ones:

Microservices Microservices are services that implement a small and well defined interface. They are typically accessed using REST. Containers are a perfect fit run microservices.

Tools If you want to run a tool but don't want to install it on your machine, containers are the way to go. For example, I usually run Jekyll locally as follows, to check that my blog looks ok (my blog is built using Jekyll).

```
$ docker run -it --rm --volume=$(pwd):/srv/jekyll -it -p 4000:4000
      jekyll/jekyll jekyll s
```

Exploring Say you are running Ubuntu and you want to check something out on a Fedora machine. You can simply run a container with Fedora image, like so:

```
$ docker run -it --rm fedora bash
```

4.2 Conclusion

This concludes the discussion about containers in general and Docker in particular. If you want to explore further, here are some useful resources:

- Container image spec
- Container runtime spec
- Docker Concepts

At this point, we have a Docker image for a simple and basic HTTP server and we have seen how it can be run as a Docker container. In the next chapter, we will see how we can deploy the same server in Kubernetes.

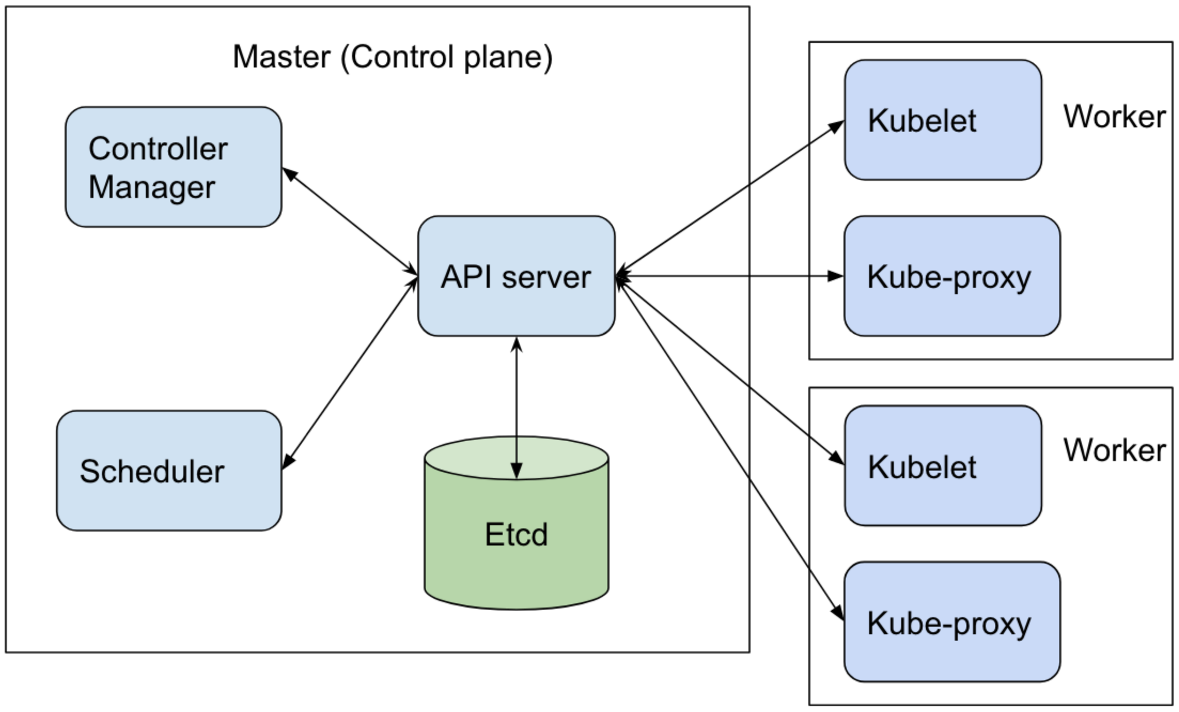
CHAPTER 5

Kubernetes Overview

In the last chapter, we built a Docker image of a simple HTTP server and ran it as a container. We are now ready to enter the world of Kubernetes and see how we can run the same server inside Kubernetes.

In a Kubernetes cluster, a "Pod" is the smallest unit that can be deployed and run. It is essentially a container or a group of containers. We will learn more about Pods and why they support group of containers in later sections but for now, it is sufficient to understand that a container is wrapped in a "Pod" to be run in a Kubernetes cluster.

Before we take a deep dive into Kubernetes concepts, let us try to understand what exactly is a "Kubernetes cluster". The following diagram shows Kubernetes components at a very high level.



A very concise overview of the architecture:

- Kubernetes is a cluster solution in that it manages multiple nodes and can seamlessly run pods on any node.
- There is a master node that runs the components that “manage” the cluster. These components are typically referred to as “control plane” of the cluster. Note that it is possible to have more than one master if you want to create highly available clusters but for our discussion, we will assume there is a single master node.
- The remaining nodes are ‘worker” nodes that run pods. The cluster components that run on the worker nodes are referred to as “Node components”.

Typically, master node is dedicated to running control plane components and workloads are not run there. But you can easily change that and if you are using a one node cluster, you obviously need to do that.

Here is a brief description of each component in a Kubernetes cluster. We will learn more details about them in the coming chapters.

API server API server is the front end to the cluster. It implements the Kubernetes REST API. An important point is that the APIs are used not only by external components but internal components as well (though they may use a slightly different format of the API).

Etcd Etcd is a distributed key-value store and is used by API server to persist all resources.

Scheduler Decides which node should run a newly created pod.

Controller Manager Comprises of several different “controllers” that manage Kubernetes resources such as nodes, pods, service accounts etc.

Kubelet Runs on each node and makes sure that pods are running containers as per the spec.

kube-proxy Runs on each node. It implements the network semantics for the cluster by forwarding traffic from one node to the other.

Now that we have a high level understanding of what Kubernetes is, we need a test environment where you can run the commands and see the cluster in action. There are many options when it comes to setting up a test Kubernetes cluster. The easiest perhaps is to use Katacoda but my personal preference is to install minikube locally.

5.1 Minikube

Minikube creates a one node cluster that is very handy to test things locally. It can install cluster components in several different ways.

- Directly on the host itself
- Using Docker
- Using VirtualBox VM

The recommended way is to use “Docker”, like so:

```
$ minikube start --vm-driver docker
```

5.2 Kubectl

To access the cluster we just created, we need kubectl which is a command line tool to manage and control Kubernetes clusters. If you work with Kubernetes actively, you will be spending lot of time running this command so it is very important and useful to master it.

Using `kubectl`, you can perform CRUD actions on all Kubernetes resources. After installing minikube and kubectl, run the following command to verify that the test setup is working:

```
$ kubectl -n kube-system get pod

NAME                             READY   STATUS    RESTARTS    AGE
coredns-66bff467f8-mdr29         1/1     Running   0           5d19h
coredns-66bff467f8-rrxxd         1/1     Running   0           5d19h
etcd-test                        1/1     Running   0           5d19h
kindnet-lnmg9                    1/1     Running   0           5d19h
kube-apiserver-test              1/1     Running   0           5d19h
kube-controller-manager-test     1/1     Running   0           5d19h
kube-proxy-wp5pm                 1/1     Running   0           5d19h
kube-scheduler-test              1/1     Running   0           5d19h
storage-provisioner              1/1     Running   0           5d19h
```

The command shows all the running pods in the namespace “kube-system” (more about namespaces later). You can see some of the components we discussed earlier such as *etcd* and *apiserver* in the listing above.

5.3 Running the HTTP Server

We are now ready to run our basic HTTP server in a Kubernetes cluster.

First, we need to add the Docker image of our basic server (which we built in the last chapter) to minikube cluster we just created:

```
$ minikube cache add basicserver:0.42
```

This step is only necessary for local images. If the image is available in Docker Hub or in some other Docker registry, we don’t need to explicitly add the image to the cache.

Let us now run the server:

```
$ kubectl run --image basicserver:0.42 testpod
pod/testpod created

$ kubectl get pod
NAME      READY   STATUS    RESTARTS   AGE
testpod   1/1     Running   0          4s
```

We can see that the HTTP server pod is running. However, even though the server is running, it is not reachable from outside the cluster yet. One simple way to fix this is to have “kubectl” forward traffic from a port on the localhost to the server inside the cluster, like so:

```
$ kubectl port-forward testpod 5000:5000
Forwarding from 127.0.0.1:5000 -> 5000
Forwarding from [::1]:5000 -> 5000
```

Once this forwarding is set up, we can reach the HTTP server from localhost. We can easily verify that using the same curl command we used in the previous chapter.

```
$ curl http://localhost:5000
Hello, World!
```

That’s it! We now managed to run our server in three different environments - on the host directly, as a Docker container, and finally in a Kubernetes cluster. But do note that the above commands were only meant to get a pod up and running for some quick testing. They are not the recommended way to create resources in a Kubernetes cluster.

In the next chapter, we will learn all about pods and some other abstractions that work with pods. In the process, we will also learn some general concepts about Kubernetes resources and the recommended way of creating and otherwise managing such resources.

More content is coming soon. Stay tuned!

CHAPTER 6

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