This section of the Kubernetes documentation contains tutorials. A tutorial shows how to accomplish a goal that is larger than a single task. Typically a tutorial has several sections, each of which has a sequence of steps. Before walking through each tutorial, you may want to bookmark the Standardized Glossary page for later references.

Basics

- Kubernetes Basics is an in-depth interactive tutorial that helps you understand the Kubernetes system and try out some basic Kubernetes features.
- Introduction to Kubernetes (edX)
- Hello Minikube

Configuration

- Example: Configuring a Java Microservice
- Configuring Redis Using a ConfigMap

Stateless Applications

- Exposing an External IP Address to Access an Application in a Cluster
- Example: Deploying PHP Guestbook application with Redis

Stateful Applications

- StatefulSet Basics
- Example: WordPress and MySQL with Persistent Volumes
- Example: Deploying Cassandra with Stateful Sets
- Running ZooKeeper, A CP Distributed System

Services

- Connecting Applications with Services
- Using Source IP

Security

- Apply Pod Security Standards at Cluster level
- Apply Pod Security Standards at Namespace level
- AppArmor
- Seccomp

What's next

If you would like to write a tutorial, see Content Page Types for information about the tutorial page type.

Hello Minikube

This tutorial shows you how to run a sample app on Kubernetes using minikube. The tutorial provides a container image that uses NGINX to echo back all the requests.

Objectives

- Deploy a sample application to minikube.
- Run the app.
- View application logs.

Before you begin

This tutorial assumes that you have already set up `minikube`. See minikube start for installation instructions.

You also need to install `kubectl`. See Install tools for installation instructions.

Create a minikube cluster

```
minikube start
```

Open the Dashboard

Open the Kubernetes dashboard. You can do this two different ways:

- Launch a browser
- URL copy and paste

Open a **new** terminal, and run:

```
# Start a new terminal, and leave this running.
minikube dashboard
```

Now, switch back to the terminal where you ran `minikube start`.

Note:

The `dashboard` command enables the dashboard add-on and opens the proxy in the default web browser. You can create Kubernetes resources on the dashboard such as Deployment and Service.

If you are running in an environment as root, see Open Dashboard with URL.

By default, the dashboard is only accessible from within the internal Kubernetes virtual network. The `dashboard` command creates a temporary proxy to make the dashboard accessible from outside the Kubernetes virtual network.

To stop the proxy, run `Ctrl+C` to exit the process. After the command exits, the dashboard remains running in the Kubernetes cluster. You can run the `dashboard` command again to create another proxy to access the dashboard.

If you don't want minikube to open a web browser for you, run the dashboard command with the `--url` flag. `minikube` outputs a URL that you can open in the browser you prefer.

Open a **new** terminal, and run:

```
# Start a new terminal, and leave this running.
minikube dashboard --url
```

Now, switch back to the terminal where you ran `minikube start`.

Create a Deployment

A Kubernetes *Pod* is a group of one or more Containers, tied together for the purposes of administration and networking. The Pod in this tutorial has only one Container. A Kubernetes *Deployment* checks on the health of your Pod and restarts the Pod's Container if it terminates. Deployments are the recommended way to manage the creation and scaling of Pods.

1. Use the `kubectl create` command to create a Deployment that manages a Pod. The Pod runs a Container based on the provided Docker image.

   ```
   # Run a test container image that includes a webserver
   kubectl create deployment hello-node --image=registry.k8s.io/e2e-test-images/agnhost:2.39 -- /agnhost netexec --http-port=8080
   ```

2. View the Deployment:

   ```
   kubectl get deployments
   ```

   The output is similar to:

   ```
   NAME         READY   UP-TO-DATE   AVAILABLE   AGE
   hello-node   1/1     1            1           1m
   ```

3. View the Pod:

   ```
   kubectl get pods
   ```

   The output is similar to:

   ```
   NAME                          READY     STATUS    RESTARTS   AGE
   hello-node-5f76cf6ccf-br9b5   1/1       Running   0          1m
   ```

4. View cluster events:

   ```
   kubectl get events
   ```

5. View the `kubectl` configuration:

   ```
   kubectl config view
   ```

6. View application logs for a container in a pod.

```
kubectl logs hello-node-5f76cf6ccf-br9b5
```

The output is similar to:

```
I0911 09:19:26.677397       1 log.go:195] Started HTTP server on port 8080
I0911 09:19:26.677586       1 log.go:195] Started UDP server on port  8081
```

Note: For more information about `kubectl` commands, see the [kubectl overview](#).

Create a Service

By default, the Pod is only accessible by its internal IP address within the Kubernetes cluster. To make the `hello-node` Container accessible from outside the Kubernetes virtual network, you have to expose the Pod as a Kubernetes *Service*.

1. Expose the Pod to the public internet using the `kubectl expose` command:

   ```
   kubectl expose deployment hello-node --type=LoadBalancer --port=8080
   ```

   The `--type=LoadBalancer` flag indicates that you want to expose your Service outside of the cluster.

   The application code inside the test image only listens on TCP port 8080. If you used `kubectl expose` to expose a different port, clients could not connect to that other port.

2. View the Service you created:

   ```
   kubectl get services
   ```

   The output is similar to:

   ```
   NAME         TYPE           CLUSTER-IP      EXTERNAL-IP   PORT(S)          AGE
   hello-node   LoadBalancer   10.108.144.78   <pending>     8080:30369/TCP   21s
   kubernetes   ClusterIP      10.96.0.1       <none>        443/TCP          23m
   ```

   On cloud providers that support load balancers, an external IP address would be provisioned to access the Service. On minikube, the `LoadBalancer` type makes the Service accessible through the `minikube service` command.

3. Run the following command:

   ```
   minikube service hello-node
   ```

   This opens up a browser window that serves your app and shows the app's response.

Enable addons

The minikube tool includes a set of built-in [addons](#) that can be enabled, disabled and opened in the local Kubernetes environment.

1. List the currently supported addons:

```
minikube addons list
```

The output is similar to:

```
addon-manager: enabled
dashboard: enabled
default-storageclass: enabled
efk: disabled
freshpod: disabled
gvisor: disabled
helm-tiller: disabled
ingress: disabled
ingress-dns: disabled
logviewer: disabled
metrics-server: disabled
nvidia-driver-installer: disabled
nvidia-gpu-device-plugin: disabled
registry: disabled
registry-creds: disabled
storage-provisioner: enabled
storage-provisioner-gluster: disabled
```

2. Enable an addon, for example, `metrics-server`:

```
minikube addons enable metrics-server
```

The output is similar to:

```
The 'metrics-server' addon is enabled
```

3. View the Pod and Service you created by installing that addon:

```
kubectl get pod,svc -n kube-system
```

The output is similar to:

```
NAME                                        READY     STATUS    RESTARTS   AGE
pod/coredns-5644d7b6d9-mh9ll                1/1       Running   0          34m
pod/coredns-5644d7b6d9-pqd2t                1/1       Running   0          34m
pod/metrics-server-67fb648c5                1/1       Running   0          26s
pod/etcd-minikube                           1/1       Running   0          34m
pod/influxdb-grafana-b29w8                  2/2       Running   0          26s
pod/kube-addon-manager-minikube             1/1       Running   0          34m
pod/kube-apiserver-minikube                 1/1       Running   0          34m
pod/kube-controller-manager-minikube        1/1       Running   0          34m
pod/kube-proxy-rnlps                        1/1       Running   0          34m
pod/kube-scheduler-minikube                 1/1       Running   0          34m
pod/storage-provisioner                     1/1       Running   0          34m

NAME                           TYPE        CLUSTER-IP      EXTERNAL-IP   PORT(S)             AGE
service/metrics-server         ClusterIP   10.96.241.45    <none>        80/TCP              26s
service/kube-dns               ClusterIP   10.96.0.10      <none>        53/UDP,53/TCP       34m
service/monitoring-grafana     NodePort    10.99.24.54     <none>        80:30002/TCP
26s
```

```
service/monitoring-influxdb   ClusterIP   10.111.169.94   <none>       8083/TCP,8086/
TCP   26s
```

4. Disable `metrics-server`:

```
minikube addons disable metrics-server
```

The output is similar to:

```
metrics-server was successfully disabled
```

Clean up

Now you can clean up the resources you created in your cluster:

```
kubectl delete service hello-node
kubectl delete deployment hello-node
```

Stop the Minikube cluster

```
minikube stop
```

Optionally, delete the Minikube VM:

```
# Optional
minikube delete
```

If you want to use minikube again to learn more about Kubernetes, you don't need to delete it.

What's next

- Tutorial to *deploy your first app on Kubernetes with kubectl*.
- Learn more about Deployment objects.
- Learn more about Deploying applications.
- Learn more about Service objects.

Learn Kubernetes Basics

html

Kubernetes Basics

This tutorial provides a walkthrough of the basics of the Kubernetes cluster orchestration system. Each module contains some background information on major Kubernetes features and concepts, and a tutorial for you to follow along.

Using the tutorials, you can learn to:

- Deploy a containerized application on a cluster.
- Scale the deployment.
- Update the containerized application with a new software version.

- Debug the containerized application.

What can Kubernetes do for you?

With modern web services, users expect applications to be available 24/7, and developers expect to deploy new versions of those applications several times a day. Containerization helps package software to serve these goals, enabling applications to be released and updated without downtime. Kubernetes helps you make sure those containerized applications run where and when you want, and helps them find the resources and tools they need to work. Kubernetes is a production-ready, open source platform designed with Google's accumulated experience in container orchestration, combined with best-of-breed ideas from the community.

Kubernetes Basics Modules

1. Create a Kubernetes cluster

2. Deploy an app

3. Explore your app

4. Expose your app publicly

5. Scale up your app

6. Update your app

Create a Cluster

Learn about Kubernetes cluster and create a simple cluster using Minikube.

Using Minikube to Create a Cluster

Learn what a Kubernetes cluster is. Learn what Minikube is. Start a Kubernetes cluster.

Using Minikube to Create a Cluster

Learn what a Kubernetes cluster is. Learn what Minikube is. Start a Kubernetes cluster.
html

Objectives

- Learn what a Kubernetes cluster is.
- Learn what Minikube is.
- Start a Kubernetes cluster on your computer.

Kubernetes Clusters

Kubernetes coordinates a highly available cluster of computers that are connected to work as a single unit. The abstractions in Kubernetes allow you to deploy containerized applications to a cluster without tying them specifically to individual machines. To make use of this new model of deployment, applications need to be packaged in a way that decouples them from individual hosts: they need to be containerized. Containerized applications are more flexible and available than in past deployment models, where applications were installed directly onto specific machines as packages deeply integrated into the host. **Kubernetes automates the distribution and scheduling of application containers across a cluster in a more efficient way.** Kubernetes is an open-source platform and is production-ready.

A Kubernetes cluster consists of two types of resources:

- The **Control Plane** coordinates the cluster
- **Nodes** are the workers that run applications

Summary:

- Kubernetes cluster
- Minikube

Kubernetes is a production-grade, open-source platform that orchestrates the placement (scheduling) and execution of application containers within and across computer clusters.

Cluster Diagram

The Control Plane is responsible for managing the cluster. The Control Plane coordinates all activities in your cluster, such as scheduling applications, maintaining applications' desired state, scaling applications, and rolling out new updates.

A node is a VM or a physical computer that serves as a worker machine in a Kubernetes cluster. Each node has a Kubelet, which is an agent for managing the node and communicating with the Kubernetes control plane. The node should also have tools for handling container operations, such as [containerd]() or [CRI-O](). A Kubernetes cluster that handles production traffic should have a minimum of three nodes because if one node goes down, both an etcd member and a control plane instance are lost, and redundancy is compromised. You can mitigate this risk by adding more control plane nodes.

Control Planes manage the cluster and the nodes that are used to host the running applications.

When you deploy applications on Kubernetes, you tell the control plane to start the application containers. The control plane schedules the containers to run on the cluster's nodes. **Node-level components, such as the kubelet, communicate with the control plane using the Kubernetes API**, which the control plane exposes. End users can also use the Kubernetes API directly to interact with the cluster.

A Kubernetes cluster can be deployed on either physical or virtual machines. To get started with Kubernetes development, you can use Minikube. Minikube is a lightweight Kubernetes implementation that creates a VM on your local machine and deploys a simple cluster containing only one node. Minikube is available for Linux, macOS, and Windows systems. The Minikube CLI provides basic bootstrapping operations for working with your cluster, including start, stop, status, and delete.

Now that you know more about what Kubernetes is, visit Hello Minikube to try this out on your computer.

Once you've done that, move on to Using kubectl to create a Deployment.

Deploy an App

Using kubectl to Create a Deployment

Learn about application Deployments. Deploy your first app on Kubernetes with kubectl.

Using kubectl to Create a Deployment

Learn about application Deployments. Deploy your first app on Kubernetes with kubectl.
html

Objectives

- Learn about application Deployments.
- Deploy your first app on Kubernetes with kubectl.

Kubernetes Deployments

Once you have a running Kubernetes cluster, you can deploy your containerized applications on top of it. To do so, you create a Kubernetes **Deployment**. The Deployment instructs Kubernetes how to create and update instances of your application. Once you've created a Deployment, the Kubernetes control plane schedules the application instances included in that Deployment to run on individual Nodes in the cluster.

Once the application instances are created, a Kubernetes Deployment controller continuously monitors those instances. If the Node hosting an instance goes down or is deleted, the Deployment controller replaces the instance with an instance on another Node in the cluster. **This provides a self-healing mechanism to address machine failure or maintenance.**

In a pre-orchestration world, installation scripts would often be used to start applications, but they did not allow recovery from machine failure. By both creating your application instances and keeping them running across Nodes, Kubernetes Deployments provide a fundamentally different approach to application management.

Summary:

- Deployments
- Kubectl

A Deployment is responsible for creating and updating instances of your application

Deploying your first app on Kubernetes

You can create and manage a Deployment by using the Kubernetes command line interface, **kubectl**. Kubectl uses the Kubernetes API to interact with the cluster. In this module, you'll learn the most common kubectl commands needed to create Deployments that run your applications on a Kubernetes cluster.

When you create a Deployment, you'll need to specify the container image for your application and the number of replicas that you want to run. You can change that information later by updating your Deployment; Modules 5 and 6 of the bootcamp discuss how you can scale and update your Deployments.

Applications need to be packaged into one of the supported container formats in order to be deployed on Kubernetes

For your first Deployment, you'll use a hello-node application packaged in a Docker container that uses NGINX to echo back all the requests. (If you didn't already try creating a hello-node application and deploying it using a container, you can do that first by following the instructions from the Hello Minikube tutorial).

You will need to have installed kubectl as well. If you need to install it, visit install tools.

Now that you know what Deployments are, let's deploy our first app!

kubectl basics

The common format of a kubectl command is: `kubectl` *`action resource`*

This performs the specified *action* (like create, describe or delete) on the specified *resource* (like node or deployment). You can use --help after the subcommand to get additional info about possible parameters (for example: kubectl get nodes --help).

Check that kubectl is configured to talk to your cluster, by running the **kubectl version** command.

Check that kubectl is installed and you can see both the client and the server versions.

To view the nodes in the cluster, run the **kubectl get nodes** command.

You see the available nodes. Later, Kubernetes will choose where to deploy our application based on Node available resources.

Deploy an app

Let's deploy our first app on Kubernetes with the kubectl create deployment command. We need to provide the deployment name and app image location (include the full repository url for images hosted outside Docker Hub).

kubectl create deployment kubernetes-bootcamp --image=gcr.io/google-samples/kubernetes-bootcamp:v1

Great! You just deployed your first application by creating a deployment. This performed a few things for you:

- searched for a suitable node where an instance of the application could be run (we have only 1 available node)
- scheduled the application to run on that Node
- configured the cluster to reschedule the instance on a new Node when needed

To list your deployments use the kubectl get deployments command:

kubectl get deployments

We see that there is 1 deployment running a single instance of your app. The instance is running inside a container on your node.

View the app

Pods that are running inside Kubernetes are running on a private, isolated network. By default they are visible from other pods and services within the same Kubernetes cluster, but not outside that network. When we use kubectl, we're interacting through an API endpoint to communicate with our application.

We will cover other options on how to expose your application outside the Kubernetes cluster later, in Module 4.

The kubectl proxy command can create a proxy that will forward communications into the cluster-wide, private network. The proxy can be terminated by pressing control-C and won't show any output while its running.

You need to open a second terminal window to run the proxy.

kubectl proxy

We now have a connection between our host (the terminal) and the Kubernetes cluster. The proxy enables direct access to the API from these terminals.

You can see all those APIs hosted through the proxy endpoint. For example, we can query the version directly through the API using the curl command:

curl http://localhost:8001/version

Note: If port 8001 is not accessible, ensure that the kubectl proxy that you started above is running in the second terminal.

The API server will automatically create an endpoint for each pod, based on the pod name, that is also accessible through the proxy.

First we need to get the Pod name, and we'll store in the environment variable POD_NAME:

export POD_NAME=$(kubectl get pods -o go-template --template '{{range .items}}{{.metadata.name}}{{"\n"}}{{end}}')
echo Name of the Pod: $POD_NAME

You can access the Pod through the proxied API, by running:

curl http://localhost:8001/api/v1/namespaces/default/pods/$POD_NAME/

In order for the new Deployment to be accessible without using the proxy, a Service is required which will be explained in Module 4.

Once you're ready, move on to Viewing Pods and Nodes.

Explore Your App

Viewing Pods and Nodes

Learn how to troubleshoot Kubernetes applications using kubectl get, kubectl describe, kubectl logs and kubectl exec.

Viewing Pods and Nodes

Learn how to troubleshoot Kubernetes applications using kubectl get, kubectl describe, kubectl logs and kubectl exec.
html

Objectives

- Learn about Kubernetes Pods.
- Learn about Kubernetes Nodes.
- Troubleshoot deployed applications.

Kubernetes Pods

When you created a Deployment in Module 2, Kubernetes created a **Pod** to host your application instance. A Pod is a Kubernetes abstraction that represents a group of one or more application containers (such as Docker), and some shared resources for those containers. Those resources include:

- Shared storage, as Volumes
- Networking, as a unique cluster IP address
- Information about how to run each container, such as the container image version or specific ports to use

A Pod models an application-specific "logical host" and can contain different application containers which are relatively tightly coupled. For example, a Pod might include both the container with your Node.js app as well as a different container that feeds the data to be published by the Node.js webserver. The containers in a Pod share an IP Address and port space, are always co-located and co-scheduled, and run in a shared context on the same Node.

Pods are the atomic unit on the Kubernetes platform. When we create a Deployment on Kubernetes, that Deployment creates Pods with containers inside them (as opposed to creating containers directly). Each Pod is tied to the Node where it is scheduled, and remains there until termination (according to restart policy) or deletion. In case of a Node failure, identical Pods are scheduled on other available Nodes in the cluster.

Summary:

- Pods
- Nodes
- Kubectl main commands

A Pod is a group of one or more application containers (such as Docker) and includes shared storage (volumes), IP address and information about how to run them.

Pods overview

Nodes

A Pod always runs on a **Node**. A Node is a worker machine in Kubernetes and may be either a virtual or a physical machine, depending on the cluster. Each Node is managed by the control plane. A Node can have multiple pods, and the Kubernetes control plane automatically handles scheduling the pods across the Nodes in the cluster. The control plane's automatic scheduling takes into account the available resources on each Node.

Every Kubernetes Node runs at least:

- Kubelet, a process responsible for communication between the Kubernetes control plane and the Node; it manages the Pods and the containers running on a machine.
- A container runtime (like Docker) responsible for pulling the container image from a registry, unpacking the container, and running the application.

Containers should only be scheduled together in a single Pod if they are tightly coupled and need to share resources such as disk.

Node overview

Troubleshooting with kubectl

In Module 2, you used the kubectl command-line interface. You'll continue to use it in Module 3 to get information about deployed applications and their environments. The most common operations can be done with the following kubectl subcommands:

- **kubectl get** - list resources
- **kubectl describe** - show detailed information about a resource
- **kubectl logs** - print the logs from a container in a pod
- **kubectl exec** - execute a command on a container in a pod

You can use these commands to see when applications were deployed, what their current statuses are, where they are running and what their configurations are.

Now that we know more about our cluster components and the command line, let's explore our application.

A node is a worker machine in Kubernetes and may be a VM or physical machine, depending on the cluster. Multiple Pods can run on one Node.

Check application configuration

Let's verify that the application we deployed in the previous scenario is running. We'll use the `kubectl get` command and look for existing Pods:

`kubectl get pods`

If no pods are running, please wait a couple of seconds and list the Pods again. You can continue once you see one Pod running.

Next, to view what containers are inside that Pod and what images are used to build those containers we run the `kubectl describe pods` command:

`kubectl describe pods`

We see here details about the Pod's container: IP address, the ports used and a list of events related to the lifecycle of the Pod.

The output of the describe subcommand is extensive and covers some concepts that we didn't explain yet, but don't worry, they will become familiar by the end of this bootcamp.

Note: *the describe subcommand can be used to get detailed information about most of the Kubernetes primitives, including Nodes, Pods, and Deployments. The describe output is designed to be human readable, not to be scripted against.*

Show the app in the terminal

Recall that Pods are running in an isolated, private network - so we need to proxy access to them so we can debug and interact with them. To do this, we'll use the `kubectl proxy` command to run a proxy in a **second terminal**. Open a new terminal window, and in that new terminal, run:

`kubectl proxy`

Now again, we'll get the Pod name and query that pod directly through the proxy. To get the Pod name and store it in the POD_NAME environment variable:

```
export POD_NAME="$(kubectl get pods -o go-template --template '{{range .items}}{{.metadata.name}}{{"\n"}}{{end}}')"
echo Name of the Pod: $POD_NAME
```

To see the output of our application, run a `curl` request:

`curl http://localhost:8001/api/v1/namespaces/default/pods/$POD_NAME:8080/proxy/`

The URL is the route to the API of the Pod.

View the container logs

Anything that the application would normally send to standard output becomes logs for the container within the Pod. We can retrieve these logs using the `kubectl logs` command:

`kubectl logs "$POD_NAME"`

Note: *We don't need to specify the container name, because we only have one container inside the pod.*

Executing command on the container

We can execute commands directly on the container once the Pod is up and running. For this, we use the `exec` subcommand and use the name of the Pod as a parameter. Let's list the environment variables:

`kubectl exec "$POD_NAME" -- env`

Again, it's worth mentioning that the name of the container itself can be omitted since we only have a single container in the Pod.

Next let's start a bash session in the Pod's container:

kubectl exec -ti $POD_NAME -- bash

We have now an open console on the container where we run our NodeJS application. The source code of the app is in the server.js file:

cat server.js

You can check that the application is up by running a curl command:

curl http://localhost:8080

Note: *here we used localhost because we executed the command inside the NodeJS Pod. If you cannot connect to localhost:8080, check to make sure you have run the kubectl exec command and are launching the command from within the Pod*

To close your container connection, type **exit**.

Once you're ready, move on to [Using A Service To Expose Your App](#).

Expose Your App Publicly

[Using a Service to Expose Your App](#)

Learn about a Service in Kubernetes. Understand how labels and selectors relate to a Service. Expose an application outside a Kubernetes cluster.

Using a Service to Expose Your App

Learn about a Service in Kubernetes. Understand how labels and selectors relate to a Service. Expose an application outside a Kubernetes cluster.
html

Objectives

- Learn about a Service in Kubernetes
- Understand how labels and selectors relate to a Service
- Expose an application outside a Kubernetes cluster using a Service

Overview of Kubernetes Services

Kubernetes [Pods](#) are mortal. Pods have a [lifecycle](#). When a worker node dies, the Pods running on the Node are also lost. A [ReplicaSet](#) might then dynamically drive the cluster back to the desired state via the creation of new Pods to keep your application running. As another example, consider an image-processing backend with 3 replicas. Those replicas are exchangeable; the front-end system should not care about backend replicas or even if a Pod is lost and recreated. That said, each Pod in a Kubernetes cluster has a unique IP address, even Pods on the same Node, so there needs to be a way of automatically reconciling changes among Pods so that your applications continue to function.

A Service in Kubernetes is an abstraction which defines a logical set of Pods and a policy by which to access them. Services enable a loose coupling between dependent Pods. A Service is defined using YAML or JSON, like all Kubernetes object manifests. The set of Pods targeted by a Service is usually determined by a *label selector* (see below for why you might want a Service without including a `selector` in the spec).

Although each Pod has a unique IP address, those IPs are not exposed outside the cluster without a Service. Services allow your applications to receive traffic. Services can be exposed in different ways by specifying a `type` in the spec of the Service:

- *ClusterIP* (default) - Exposes the Service on an internal IP in the cluster. This type makes the Service only reachable from within the cluster.
- *NodePort* - Exposes the Service on the same port of each selected Node in the cluster using NAT. Makes a Service accessible from outside the cluster using `<NodeIP>:<NodePort>`. Superset of ClusterIP.
- *LoadBalancer* - Creates an external load balancer in the current cloud (if supported) and assigns a fixed, external IP to the Service. Superset of NodePort.
- *ExternalName* - Maps the Service to the contents of the `externalName` field (e.g. `foo.bar.example.com`), by returning a `CNAME` record with its value. No proxying of any kind is set up. This type requires v1.7 or higher of `kube-dns`, or CoreDNS version 0.0.8 or higher.

More information about the different types of Services can be found in the [Using Source IP](#) tutorial. Also see [Connecting Applications with Services](#).

Additionally, note that there are some use cases with Services that involve not defining a `selector` in the spec. A Service created without `selector` will also not create the corresponding Endpoints object. This allows users to manually map a Service to specific endpoints. Another possibility why there may be no selector is you are strictly using `type: ExternalName`.

Summary

- Exposing Pods to external traffic
- Load balancing traffic across multiple Pods
- Using labels

A Kubernetes Service is an abstraction layer which defines a logical set of Pods and enables external traffic exposure, load balancing and service discovery for those Pods.

Services and Labels

A Service routes traffic across a set of Pods. Services are the abstraction that allows pods to die and replicate in Kubernetes without impacting your application. Discovery and routing among dependent Pods (such as the frontend and backend components in an application) are handled by Kubernetes Services.

Services match a set of Pods using [labels and selectors](#), a grouping primitive that allows logical operation on objects in Kubernetes. Labels are key/value pairs attached to objects and can be used in any number of ways:

- Designate objects for development, test, and production

- Embed version tags
- Classify an object using tags

Labels can be attached to objects at creation time or later on. They can be modified at any time. Let's expose our application now using a Service and apply some labels.

Create a new Service

Let’s verify that our application is running. We’ll use the `kubectl get` command and look for existing Pods:

kubectl get pods

If no Pods are running then it means the objects from the previous tutorials were cleaned up. In this case, go back and recreate the deployment from the [Using kubectl to create a Deployment]() tutorial. Please wait a couple of seconds and list the Pods again. You can continue once you see the one Pod running.

Next, let’s list the current Services from our cluster:

kubectl get services

We have a Service called kubernetes that is created by default when minikube starts the cluster. To create a new service and expose it to external traffic we'll use the expose command with NodePort as parameter.

kubectl expose deployment/kubernetes-bootcamp --type="NodePort" --port 8080

Let's run again the `get services` subcommand:

kubectl get services

We have now a running Service called kubernetes-bootcamp. Here we see that the Service received a unique cluster-IP, an internal port and an external-IP (the IP of the Node).

To find out what port was opened externally (for the type: NodePort Service) we’ll run the `describe service` subcommand:

kubectl describe services/kubernetes-bootcamp

Create an environment variable called NODE_PORT that has the value of the Node port assigned:

export NODE_PORT="$(kubectl get services/kubernetes-bootcamp -o go-template='{{(index .spec.ports 0).nodePort}}')"
echo "NODE_PORT=$NODE_PORT"

Now we can test that the app is exposed outside of the cluster using `curl`, the IP address of the Node and the externally exposed port:

curl http://"$(minikube ip):$NODE_PORT"

Note:

If you're running minikube with Docker Desktop as the container driver, a minikube tunnel is needed. This is because containers inside Docker Desktop are isolated from your host computer.

In a separate terminal window, execute:
minikube service kubernetes-bootcamp --url

The output looks like this:

```
http://127.0.0.1:51082
!  Because you are using a Docker driver on darwin, the terminal needs to be open to run it.
```

Then use the given URL to access the app:
curl 127.0.0.1:51082

And we get a response from the server. The Service is exposed.

Step 2: Using labels

The Deployment created automatically a label for our Pod. With the describe deployment subcommand you can see the name (the *key*) of that label:

kubectl describe deployment

Let's use this label to query our list of Pods. We'll use the kubectl get pods command with -l as a parameter, followed by the label values:

kubectl get pods -l app=kubernetes-bootcamp

You can do the same to list the existing Services:

kubectl get services -l app=kubernetes-bootcamp

Get the name of the Pod and store it in the POD_NAME environment variable:

```
export POD_NAME="$(kubectl get pods -o go-template --template '{{range .items}}{{.metadata.name}}{{"\n"}}{{end}}')"
echo "Name of the Pod: $POD_NAME"
```

To apply a new label we use the label subcommand followed by the object type, object name and the new label:

kubectl label pods "$POD_NAME" version=v1

This will apply a new label to our Pod (we pinned the application version to the Pod), and we can check it with the describe pod command:

kubectl describe pods "$POD_NAME"

We see here that the label is attached now to our Pod. And we can query now the list of pods using the new label:

kubectl get pods -l version=v1

And we see the Pod.

Deleting a service

To delete Services you can use the `delete service` subcommand. Labels can be used also here:

kubectl delete service -l app=kubernetes-bootcamp

Confirm that the Service is gone:

kubectl get services

This confirms that our Service was removed. To confirm that route is not exposed anymore you can curl the previously exposed IP and port:

curl http://"$(minikube ip):$NODE_PORT"

This proves that the application is not reachable anymore from outside of the cluster. You can confirm that the app is still running with a curl from inside the pod:

kubectl exec -ti $POD_NAME -- curl http://localhost:8080

We see here that the application is up. This is because the Deployment is managing the application. To shut down the application, you would need to delete the Deployment as well.

Once you're ready, move on to [Running Multiple Instances of Your App](#).

Scale Your App

[Running Multiple Instances of Your App](#)

Scale an existing app manually using kubectl.

Running Multiple Instances of Your App

Scale an existing app manually using kubectl.
html

Objectives

- Scale an app using kubectl.

Scaling an application

Previously we created a [Deployment](#), and then exposed it publicly via a [Service](#). The Deployment created only one Pod for running our application. When traffic increases, we will need to scale the application to keep up with user demand.

If you haven't worked through the earlier sections, start from Using minikube to create a cluster.

Scaling is accomplished by changing the number of replicas in a Deployment

NOTE If you are trying this after the previous section , you may need to start from creating a cluster as the services may have been deleted

Summary:

- Scaling a Deployment

You can create from the start a Deployment with multiple instances using the --replicas parameter for the kubectl create deployment command

Scaling overview

1.
2.

Previous Next

Scaling out a Deployment will ensure new Pods are created and scheduled to Nodes with available resources. Scaling will increase the number of Pods to the new desired state. Kubernetes also supports autoscaling of Pods, but it is outside of the scope of this tutorial. Scaling to zero is also possible, and it will terminate all Pods of the specified Deployment.

Running multiple instances of an application will require a way to distribute the traffic to all of them. Services have an integrated load-balancer that will distribute network traffic to all Pods of an exposed Deployment. Services will monitor continuously the running Pods using endpoints, to ensure the traffic is sent only to available Pods.

Scaling is accomplished by changing the number of replicas in a Deployment.

Once you have multiple instances of an application running, you would be able to do Rolling updates without downtime. We'll cover that in the next section of the tutorial. Now, let's go to the terminal and scale our application.

Scaling a Deployment

To list your Deployments, use the `get deployments` subcommand:

`kubectl get deployments`

The output should be similar to:

```
NAME                READY   UP-TO-DATE   AVAILABLE   AGE
kubernetes-bootcamp   1/1     1            1           11m
```

We should have 1 Pod. If not, run the command again. This shows:

- *NAME* lists the names of the Deployments in the cluster.
- *READY* shows the ratio of CURRENT/DESIRED replicas
- *UP-TO-DATE* displays the number of replicas that have been updated to achieve the desired state.
- *AVAILABLE* displays how many replicas of the application are available to your users.
- *AGE* displays the amount of time that the application has been running.

To see the ReplicaSet created by the Deployment, run:

kubectl get rs

Notice that the name of the ReplicaSet is always formatted as [DEPLOYMENT-NAME]-[RANDOM-STRING]. The random string is randomly generated and uses the *pod-template-hash* as a seed.

Two important columns of this output are:

- *DESIRED* displays the desired number of replicas of the application, which you define when you create the Deployment. This is the desired state.
- *CURRENT* displays how many replicas are currently running.

Next, let's scale the Deployment to 4 replicas. We'll use the `kubectl scale` command, followed by the Deployment type, name and desired number of instances:

kubectl scale deployments/kubernetes-bootcamp --replicas=4

To list your Deployments once again, use `get deployments`:

kubectl get deployments

The change was applied, and we have 4 instances of the application available. Next, let's check if the number of Pods changed:

kubectl get pods -o wide

There are 4 Pods now, with different IP addresses. The change was registered in the Deployment events log. To check that, use the describe subcommand:

kubectl describe deployments/kubernetes-bootcamp

You can also view in the output of this command that there are 4 replicas now.

Load Balancing

Let's check that the Service is load-balancing the traffic. To find out the exposed IP and Port we can use the describe service as we learned in the previous part of the tutorial:

kubectl describe services/kubernetes-bootcamp

Create an environment variable called NODE_PORT that has a value as the Node port:

export NODE_PORT="$(kubectl get services/kubernetes-bootcamp -o go-template='{{(index .spec.ports 0).nodePort}}')"

echo NODE_PORT=$NODE_PORT

Next, we'll do a curl to the exposed IP address and port. Execute the command multiple times:

curl http://"$(minikube ip):$NODE_PORT"

We hit a different Pod with every request. This demonstrates that the load-balancing is working.

Scale Down

To scale down the Deployment to 2 replicas, run again the scale subcommand:

kubectl scale deployments/kubernetes-bootcamp --replicas=2

List the Deployments to check if the change was applied with the get deployments subcommand:

kubectl get deployments

The number of replicas decreased to 2. List the number of Pods, with get pods:

kubectl get pods -o wide

This confirms that 2 Pods were terminated.

Once you're ready, move on to Performing a Rolling Update.

Update Your App

Performing a Rolling Update

Perform a rolling update using kubectl.

Performing a Rolling Update

Perform a rolling update using kubectl.
html

Objectives

- Perform a rolling update using kubectl.

Updating an application

Users expect applications to be available all the time and developers are expected to deploy new versions of them several times a day. In Kubernetes this is done with rolling updates. **Rolling updates** allow Deployments' update to take place with zero downtime by incrementally updating Pods instances with new ones. The new Pods will be scheduled on Nodes with available resources.

In the previous module we scaled our application to run multiple instances. This is a requirement for performing updates without affecting application availability. By default, the maximum number of Pods that can be unavailable during the update and the maximum number of new Pods that can be created, is one. Both options can be configured to either numbers or percentages (of Pods). In Kubernetes, updates are versioned and any Deployment update can be reverted to a previous (stable) version.

Summary:

- Updating an app

Rolling updates allow Deployments' update to take place with zero downtime by incrementally updating Pods instances with new ones.

Rolling updates overview

1.
2.
3.
4.

Previous Next

Similar to application Scaling, if a Deployment is exposed publicly, the Service will load-balance the traffic only to available Pods during the update. An available Pod is an instance that is available to the users of the application.

Rolling updates allow the following actions:

- Promote an application from one environment to another (via container image updates)
- Rollback to previous versions
- Continuous Integration and Continuous Delivery of applications with zero downtime

If a Deployment is exposed publicly, the Service will load-balance the traffic only to available Pods during the update.

In the following interactive tutorial, we'll update our application to a new version, and also perform a rollback.

Update the version of the app

To list your Deployments, run the get deployments subcommand: **kubectl get deployments**

To list the running Pods, run the get pods subcommand:

kubectl get pods

To view the current image version of the app, run the describe pods subcommand and look for the Image field:

kubectl describe pods

To update the image of the application to version 2, use the set image subcommand, followed by the deployment name and the new image version:

kubectl set image deployments/kubernetes-bootcamp kubernetes-bootcamp=jocatalin/kubernetes-bootcamp:v2

The command notified the Deployment to use a different image for your app and initiated a rolling update. Check the status of the new Pods, and view the old one terminating with the get pods subcommand:

kubectl get pods

Step 2: Verify an update

First, check that the app is running. To find the exposed IP address and port, run the describe service command:

kubectl describe services/kubernetes-bootcamp

Create an environment variable called NODE_PORT that has the value of the Node port assigned:

export NODE_PORT="$(kubectl get services/kubernetes-bootcamp -o go-template='{{(index .spec.ports 0).nodePort}}')"
echo "NODE_PORT=$NODE_PORT"

Next, do a curl to the exposed IP and port:

curl http://"$(minikube ip):$NODE_PORT"

Every time you run the curl command, you will hit a different Pod. Notice that all Pods are now running the latest version (v2).

You can also confirm the update by running the rollout status subcommand:

kubectl rollout status deployments/kubernetes-bootcamp

To view the current image version of the app, run the describe pods subcommand:

kubectl describe pods

In the Image field of the output, verify that you are running the latest image version (v2).

Roll back an update

Let’s perform another update, and try to deploy an image tagged with v10:

kubectl set image deployments/kubernetes-bootcamp kubernetes-bootcamp=gcr.io/google-samples/kubernetes-bootcamp:v10

Use get deployments to see the status of the deployment:

kubectl get deployments

Notice that the output doesn't list the desired number of available Pods. Run the get pods subcommand to list all Pods:

kubectl get pods

Notice that some of the Pods have a status of ImagePullBackOff.

To get more insight into the problem, run the describe pods subcommand:

kubectl describe pods

In the Events section of the output for the affected Pods, notice that the v10 image version did not exist in the repository.

To roll back the deployment to your last working version, use the rollout undo subcommand:

kubectl rollout undo deployments/kubernetes-bootcamp

The rollout undo command reverts the deployment to the previous known state (v2 of the image). Updates are versioned and you can revert to any previously known state of a Deployment.

Use the get pods subcommand to list the Pods again:

kubectl get pods

Four Pods are running. To check the image deployed on these Pods, use the describe pods subcommand:

kubectl describe pods

The Deployment is once again using a stable version of the app (v2). The rollback was successful.

Remember to clean up your local cluster

kubectl delete deployments/kubernetes-bootcamp services/kubernetes-bootcamp

Configuration

[Example: Configuring a Java Microservice]

[Configuring Redis using a ConfigMap]

Example: Configuring a Java Microservice

[Externalizing config using MicroProfile, ConfigMaps and Secrets]

Externalizing config using MicroProfile, ConfigMaps and Secrets

In this tutorial you will learn how and why to externalize your microservice's configuration. Specifically, you will learn how to use Kubernetes ConfigMaps and Secrets to set environment variables and then consume them using MicroProfile Config.

Before you begin

Creating Kubernetes ConfigMaps & Secrets

There are several ways to set environment variables for a Docker container in Kubernetes, including: Dockerfile, kubernetes.yml, Kubernetes ConfigMaps, and Kubernetes Secrets. In the tutorial, you will learn how to use the latter two for setting your environment variables whose values will be injected into your microservices. One of the benefits for using ConfigMaps and Secrets is that they can be re-used across multiple containers, including being assigned to different environment variables for the different containers.

ConfigMaps are API Objects that store non-confidential key-value pairs. In the Interactive Tutorial you will learn how to use a ConfigMap to store the application's name. For more information regarding ConfigMaps, you can find the documentation [here].

Although Secrets are also used to store key-value pairs, they differ from ConfigMaps in that they're intended for confidential/sensitive information and are stored using Base64 encoding. This makes secrets the appropriate choice for storing such things as credentials, keys, and tokens, the former of which you'll do in the Interactive Tutorial. For more information on Secrets, you can find the documentation [here].

Externalizing Config from Code

Externalized application configuration is useful because configuration usually changes depending on your environment. In order to accomplish this, we'll use Java's Contexts and Dependency Injection (CDI) and MicroProfile Config. MicroProfile Config is a feature of MicroProfile, a set of open Java technologies for developing and deploying cloud-native microservices.

CDI provides a standard dependency injection capability enabling an application to be assembled from collaborating, loosely-coupled beans. MicroProfile Config provides apps and microservices a standard way to obtain config properties from various sources, including the application, runtime, and environment. Based on the source's defined priority, the properties are automatically combined into a single set of properties that the application can access via an API. Together, CDI & MicroProfile will be used in the Interactive Tutorial to retrieve the externally provided properties from the Kubernetes ConfigMaps and Secrets and get injected into your application code.

Many open source frameworks and runtimes implement and support MicroProfile Config. Throughout the interactive tutorial, you'll be using Open Liberty, a flexible open-source Java runtime for building and running cloud-native apps and microservices. However, any MicroProfile compatible runtime could be used instead.

Objectives

- Create a Kubernetes ConfigMap and Secret
- Inject microservice configuration using MicroProfile Config

Example: Externalizing config using MicroProfile, ConfigMaps and Secrets

Start Interactive Tutorial

Configuring Redis using a ConfigMap

This page provides a real world example of how to configure Redis using a ConfigMap and builds upon the Configure a Pod to Use a ConfigMap task.

Objectives

- Create a ConfigMap with Redis configuration values
- Create a Redis Pod that mounts and uses the created ConfigMap
- Verify that the configuration was correctly applied.

Before you begin

You need to have a Kubernetes cluster, and the kubectl command-line tool must be configured to communicate with your cluster. It is recommended to run this tutorial on a cluster with at least two nodes that are not acting as control plane hosts. If you do not already have a cluster, you can create one by using minikube or you can use one of these Kubernetes playgrounds:

- Killercoda
- Play with Kubernetes

To check the version, enter `kubectl version`.

- The example shown on this page works with `kubectl` 1.14 and above.
- Understand Configure a Pod to Use a ConfigMap.

Real World Example: Configuring Redis using a ConfigMap

Follow the steps below to configure a Redis cache using data stored in a ConfigMap.

First create a ConfigMap with an empty configuration block:

```
cat <<EOF >./example-redis-config.yaml
apiVersion: v1
kind: ConfigMap
metadata:
  name: example-redis-config
data:
  redis-config: ""
EOF
```

Apply the ConfigMap created above, along with a Redis pod manifest:

```
kubectl apply -f example-redis-config.yaml
kubectl apply -f https://raw.githubusercontent.com/kubernetes/website/main/content/en/
examples/pods/config/redis-pod.yaml
```

Examine the contents of the Redis pod manifest and note the following:

- A volume named `config` is created by `spec.volumes[1]`
- The `key` and `path` under `spec.volumes[1].items[0]` exposes the `redis-config` key from the `example-redis-config` ConfigMap as a file named `redis.conf` on the `config` volume.
- The `config` volume is then mounted at `/redis-master` by `spec.containers[0].volumeMounts[1]`.

This has the net effect of exposing the data in `data.redis-config` from the `example-redis-config` ConfigMap above as `/redis-master/redis.conf` inside the Pod.

[pods/config/redis-pod.yaml]

```
apiVersion: v1
kind: Pod
metadata:
  name: redis
spec:
  containers:
  - name: redis
    image: redis:5.0.4
    command:
      - redis-server
      - "/redis-master/redis.conf"
    env:
    - name: MASTER
      value: "true"
    ports:
    - containerPort: 6379
    resources:
      limits:
```

```
      cpu: "0.1"
    volumeMounts:
    - mountPath: /redis-master-data
      name: data
    - mountPath: /redis-master
      name: config
  volumes:
    - name: data
      emptyDir: {}
    - name: config
      configMap:
        name: example-redis-config
        items:
        - key: redis-config
          path: redis.conf
```

Examine the created objects:

```
kubectl get pod/redis configmap/example-redis-config
```

You should see the following output:

```
NAME        READY   STATUS    RESTARTS   AGE
pod/redis   1/1     Running   0          8s

NAME                             DATA   AGE
configmap/example-redis-config   1      14s
```

Recall that we left `redis-config` key in the `example-redis-config` ConfigMap blank:

```
kubectl describe configmap/example-redis-config
```

You should see an empty `redis-config` key:

```
Name:         example-redis-config
Namespace:    default
Labels:       <none>
Annotations:  <none>

Data
====
redis-config:
```

Use `kubectl exec` to enter the pod and run the `redis-cli` tool to check the current configuration:

```
kubectl exec -it redis -- redis-cli
```

Check `maxmemory`:

```
127.0.0.1:6379> CONFIG GET maxmemory
```

It should show the default value of 0:

```
1) "maxmemory"
2) "0"
```

Similarly, check maxmemory-policy:

```
127.0.0.1:6379> CONFIG GET maxmemory-policy
```

Which should also yield its default value of noeviction:

```
1) "maxmemory-policy"
2) "noeviction"
```

Now let's add some configuration values to the example-redis-config ConfigMap:

pods/config/example-redis-config.yaml

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: example-redis-config
data:
  redis-config: |
    maxmemory 2mb
    maxmemory-policy allkeys-lru
```

Apply the updated ConfigMap:

```
kubectl apply -f example-redis-config.yaml
```

Confirm that the ConfigMap was updated:

```
kubectl describe configmap/example-redis-config
```

You should see the configuration values we just added:

```
Name:         example-redis-config
Namespace:    default
Labels:       <none>
Annotations:  <none>

Data
====
redis-config:
----
maxmemory 2mb
maxmemory-policy allkeys-lru
```

Check the Redis Pod again using redis-cli via kubectl exec to see if the configuration was applied:

```
kubectl exec -it redis -- redis-cli
```

Check maxmemory:

```
127.0.0.1:6379> CONFIG GET maxmemory
```

It remains at the default value of 0:

```
1) "maxmemory"
2) "0"
```

Similarly, `maxmemory-policy` remains at the `noeviction` default setting:

```
127.0.0.1:6379> CONFIG GET maxmemory-policy
```

Returns:

```
1) "maxmemory-policy"
2) "noeviction"
```

The configuration values have not changed because the Pod needs to be restarted to grab updated values from associated ConfigMaps. Let's delete and recreate the Pod:

```
kubectl delete pod redis
kubectl apply -f https://raw.githubusercontent.com/kubernetes/website/main/content/en/
examples/pods/config/redis-pod.yaml
```

Now re-check the configuration values one last time:

```
kubectl exec -it redis -- redis-cli
```

Check `maxmemory`:

```
127.0.0.1:6379> CONFIG GET maxmemory
```

It should now return the updated value of 2097152:

```
1) "maxmemory"
2) "2097152"
```

Similarly, `maxmemory-policy` has also been updated:

```
127.0.0.1:6379> CONFIG GET maxmemory-policy
```

It now reflects the desired value of `allkeys-lru`:

```
1) "maxmemory-policy"
2) "allkeys-lru"
```

Clean up your work by deleting the created resources:

```
kubectl delete pod/redis configmap/example-redis-config
```

What's next

- Learn more about ConfigMaps.

Security

Security is an important concern for most organizations and people who run Kubernetes clusters. You can find a basic security checklist elsewhere in the Kubernetes documentation.

To learn how to deploy and manage security aspects of Kubernetes, you can follow the tutorials in this section.

Apply Pod Security Standards at the Cluster Level

Note

This tutorial applies only for new clusters.

Pod Security is an admission controller that carries out checks against the Kubernetes Pod Security Standards when new pods are created. It is a feature GA'ed in v1.25. This tutorial shows you how to enforce the `baseline` Pod Security Standard at the cluster level which applies a standard configuration to all namespaces in a cluster.

To apply Pod Security Standards to specific namespaces, refer to Apply Pod Security Standards at the namespace level.

If you are running a version of Kubernetes other than v1.28, check the documentation for that version.

Before you begin

Install the following on your workstation:

- kind
- kubectl

This tutorial demonstrates what you can configure for a Kubernetes cluster that you fully control. If you are learning how to configure Pod Security Admission for a managed cluster where you are not able to configure the control plane, read Apply Pod Security Standards at the namespace level.

Choose the right Pod Security Standard to apply

Pod Security Admission lets you apply built-in Pod Security Standards with the following modes: `enforce`, `audit`, and `warn`.

To gather information that helps you to choose the Pod Security Standards that are most appropriate for your configuration, do the following:

1. Create a cluster with no Pod Security Standards applied:

   ```
   kind create cluster --name psa-wo-cluster-pss
   ```

   The output is similar to:

   ```
   Creating cluster "psa-wo-cluster-pss" ...
    Ensuring node image (kindest/node:v1.28.4)
    Preparing nodes
    Writing configuration
    Starting control-plane
    Installing CNI
    Installing StorageClass
   Set kubectl context to "kind-psa-wo-cluster-pss"
   You can now use your cluster with:

   kubectl cluster-info --context kind-psa-wo-cluster-pss

   Thanks for using kind!
   ```

2. Set the kubectl context to the new cluster:

   ```
   kubectl cluster-info --context kind-psa-wo-cluster-pss
   ```

   The output is similar to this:

   ```
   Kubernetes control plane is running at https://127.0.0.1:61350

   CoreDNS is running at https://127.0.0.1:61350/api/v1/namespaces/kube-system/services/
   kube-dns:dns/proxy

   To further debug and diagnose cluster problems, use 'kubectl cluster-info dump'.
   ```

3. Get a list of namespaces in the cluster:

   ```
   kubectl get ns
   ```

   The output is similar to this:

   ```
   NAME                 STATUS   AGE
   default              Active   9m30s
   kube-node-lease      Active   9m32s
   kube-public          Active   9m32s
   kube-system          Active   9m32s
   local-path-storage   Active   9m26s
   ```

4. Use `--dry-run=server` to understand what happens when different Pod Security Standards are applied:

   1. Privileged

```
kubectl label --dry-run=server --overwrite ns --all \
pod-security.kubernetes.io/enforce=privileged
```

The output is similar to:

```
namespace/default labeled
namespace/kube-node-lease labeled
namespace/kube-public labeled
namespace/kube-system labeled
namespace/local-path-storage labeled
```

2. Baseline

```
kubectl label --dry-run=server --overwrite ns --all \
pod-security.kubernetes.io/enforce=baseline
```

The output is similar to:

```
namespace/default labeled
namespace/kube-node-lease labeled
namespace/kube-public labeled
Warning: existing pods in namespace "kube-system" violate the new PodSecurity
enforce level "baseline:latest"
Warning: etcd-psa-wo-cluster-pss-control-plane (and 3 other pods): host
namespaces, hostPath volumes
Warning: kindnet-vzj42: non-default capabilities, host namespaces, hostPath
volumes
Warning: kube-proxy-m6hwf: host namespaces, hostPath volumes, privileged
namespace/kube-system labeled
namespace/local-path-storage labeled
```

3. Restricted

```
kubectl label --dry-run=server --overwrite ns --all \
pod-security.kubernetes.io/enforce=restricted
```

The output is similar to:

```
namespace/default labeled
namespace/kube-node-lease labeled
namespace/kube-public labeled
Warning: existing pods in namespace "kube-system" violate the new PodSecurity
enforce level "restricted:latest"
Warning: coredns-7bb9c7b568-hsptc (and 1 other pod): unrestricted capabilities,
runAsNonRoot != true, seccompProfile
Warning: etcd-psa-wo-cluster-pss-control-plane (and 3 other pods): host
namespaces, hostPath volumes, allowPrivilegeEscalation != false, unrestricted
capabilities, restricted volume types, runAsNonRoot != true
Warning: kindnet-vzj42: non-default capabilities, host namespaces, hostPath
volumes, allowPrivilegeEscalation != false, unrestricted capabilities, restricted
volume types, runAsNonRoot != true, seccompProfile
Warning: kube-proxy-m6hwf: host namespaces, hostPath volumes, privileged,
allowPrivilegeEscalation != false, unrestricted capabilities, restricted volume types,
runAsNonRoot != true, seccompProfile
```

```
namespace/kube-system labeled
Warning: existing pods in namespace "local-path-storage" violate the new PodSecurity enforce level "restricted:latest"
Warning: local-path-provisioner-d6d9f7ffc-lw9lh: allowPrivilegeEscalation != false, unrestricted capabilities, runAsNonRoot != true, seccompProfile
namespace/local-path-storage labeled
```

From the previous output, you'll notice that applying the `privileged` Pod Security Standard shows no warnings for any namespaces. However, `baseline` and `restricted` standards both have warnings, specifically in the `kube-system` namespace.

Set modes, versions and standards

In this section, you apply the following Pod Security Standards to the `latest` version:

- `baseline` standard in `enforce` mode.
- `restricted` standard in `warn` and `audit` mode.

The `baseline` Pod Security Standard provides a convenient middle ground that allows keeping the exemption list short and prevents known privilege escalations.

Additionally, to prevent pods from failing in `kube-system`, you'll exempt the namespace from having Pod Security Standards applied.

When you implement Pod Security Admission in your own environment, consider the following:

1. Based on the risk posture applied to a cluster, a stricter Pod Security Standard like `restricted` might be a better choice.

2. Exempting the `kube-system` namespace allows pods to run as `privileged` in this namespace. For real world use, the Kubernetes project strongly recommends that you apply strict RBAC policies that limit access to `kube-system`, following the principle of least privilege. To implement the preceding standards, do the following:

3. Create a configuration file that can be consumed by the Pod Security Admission Controller to implement these Pod Security Standards:

   ```
   mkdir -p /tmp/pss
   cat <<EOF > /tmp/pss/cluster-level-pss.yaml
   apiVersion: apiserver.config.k8s.io/v1
   kind: AdmissionConfiguration
   plugins:
   - name: PodSecurity
     configuration:
       apiVersion: pod-security.admission.config.k8s.io/v1
       kind: PodSecurityConfiguration
       defaults:
         enforce: "baseline"
         enforce-version: "latest"
         audit: "restricted"
         audit-version: "latest"
         warn: "restricted"
   ```

```
    warn-version: "latest"
  exemptions:
    usernames: []
    runtimeClasses: []
    namespaces: [kube-system]
EOF
```

Note: `pod-security.admission.config.k8s.io/v1` configuration requires v1.25+. For v1.23 and v1.24, use v1beta1. For v1.22, use v1alpha1.

4. Configure the API server to consume this file during cluster creation:

```
cat <<EOF > /tmp/pss/cluster-config.yaml
kind: Cluster
apiVersion: kind.x-k8s.io/v1alpha4
nodes:
- role: control-plane
  kubeadmConfigPatches:
  - |
    kind: ClusterConfiguration
    apiServer:
        extraArgs:
          admission-control-config-file: /etc/config/cluster-level-pss.yaml
        extraVolumes:
          - name: accf
            hostPath: /etc/config
            mountPath: /etc/config
            readOnly: false
            pathType: "DirectoryOrCreate"
  extraMounts:
  - hostPath: /tmp/pss
    containerPath: /etc/config
    # optional: if set, the mount is read-only.
    # default false
    readOnly: false
    # optional: if set, the mount needs SELinux relabeling.
    # default false
    selinuxRelabel: false
    # optional: set propagation mode (None, HostToContainer or Bidirectional)
    # see https://kubernetes.io/docs/concepts/storage/volumes/#mount-propagation
    # default None
    propagation: None
EOF
```

Note: If you use Docker Desktop with *kind* on macOS, you can add `/tmp` as a Shared Directory under the menu item **Preferences > Resources > File Sharing**.

5. Create a cluster that uses Pod Security Admission to apply these Pod Security Standards:

```
kind create cluster --name psa-with-cluster-pss --config /tmp/pss/cluster-config.yaml
```

The output is similar to this:

```
Creating cluster "psa-with-cluster-pss" ...
   Ensuring node image (kindest/node:v1.28.4)
   Preparing nodes
   Writing configuration
   Starting control-plane
   Installing CNI
   Installing StorageClass
Set kubectl context to "kind-psa-with-cluster-pss"
You can now use your cluster with:

kubectl cluster-info --context kind-psa-with-cluster-pss

Have a question, bug, or feature request? Let us know! https://kind.sigs.k8s.io/
#community
```

6. Point kubectl to the cluster:

   ```
   kubectl cluster-info --context kind-psa-with-cluster-pss
   ```

   The output is similar to this:

   ```
   Kubernetes control plane is running at https://127.0.0.1:63855
   CoreDNS is running at https://127.0.0.1:63855/api/v1/namespaces/kube-system/services/
   kube-dns:dns/proxy

   To further debug and diagnose cluster problems, use 'kubectl cluster-info dump'.
   ```

7. Create a Pod in the default namespace:

   ```
   kubectl apply -f https://k8s.io/examples/security/example-baseline-pod.yaml
   ```

   The pod is started normally, but the output includes a warning:

   ```
   Warning: would violate PodSecurity "restricted:latest": allowPrivilegeEscalation != false
   (container "nginx" must set securityContext.allowPrivilegeEscalation=false), unrestricted
   capabilities (container "nginx" must set securityContext.capabilities.drop=["ALL"]),
   runAsNonRoot != true (pod or container "nginx" must set
   securityContext.runAsNonRoot=true), seccompProfile (pod or container "nginx" must set
   securityContext.seccompProfile.type to "RuntimeDefault" or "Localhost")
   pod/nginx created
   ```

Clean up

Now delete the clusters which you created above by running the following command:

```
kind delete cluster --name psa-with-cluster-pss
```

```
kind delete cluster --name psa-wo-cluster-pss
```

What's next

- Run a shell script to perform all the preceding steps at once:
  1. Create a Pod Security Standards based cluster level Configuration

2. Create a file to let API server consume this configuration
3. Creates a cluster that creates an API server with this configuration
4. Set kubectl context to this new cluster
5. Create a minimal pod yaml file
6. Apply this file to create a Pod in the new cluster

- Pod Security Admission
- Pod Security Standards
- Apply Pod Security Standards at the namespace level

Apply Pod Security Standards at the Namespace Level

Note

This tutorial applies only for new clusters.

Pod Security Admission is an admission controller that applies Pod Security Standards when pods are created. It is a feature GA'ed in v1.25. In this tutorial, you will enforce the `baseline` Pod Security Standard, one namespace at a time.

You can also apply Pod Security Standards to multiple namespaces at once at the cluster level. For instructions, refer to Apply Pod Security Standards at the cluster level.

Before you begin

Install the following on your workstation:

- kind
- kubectl

Create cluster

1. Create a `kind` cluster as follows:

```
kind create cluster --name psa-ns-level
```

The output is similar to this:

```
Creating cluster "psa-ns-level" ...
  Ensuring node image (kindest/node:v1.28.4)
  Preparing nodes
  Writing configuration
  Starting control-plane
  Installing CNI
  Installing StorageClass
Set kubectl context to "kind-psa-ns-level"
You can now use your cluster with:

kubectl cluster-info --context kind-psa-ns-level
```

```
Not sure what to do next?  Check out https://kind.sigs.k8s.io/docs/user/quick-start/
```

2. Set the kubectl context to the new cluster:

   ```
   kubectl cluster-info --context kind-psa-ns-level
   ```

   The output is similar to this:

   ```
   Kubernetes control plane is running at https://127.0.0.1:50996
   CoreDNS is running at https://127.0.0.1:50996/api/v1/namespaces/kube-system/services/kube-dns:dns/proxy

   To further debug and diagnose cluster problems, use 'kubectl cluster-info dump'.
   ```

Create a namespace

Create a new namespace called `example`:

```
kubectl create ns example
```

The output is similar to this:

```
namespace/example created
```

Enable Pod Security Standards checking for that namespace

1. Enable Pod Security Standards on this namespace using labels supported by built-in Pod Security Admission. In this step you will configure a check to warn on Pods that don't meet the latest version of the *baseline* pod security standard.

   ```
   kubectl label --overwrite ns example \
     pod-security.kubernetes.io/warn=baseline \
     pod-security.kubernetes.io/warn-version=latest
   ```

2. You can configure multiple pod security standard checks on any namespace, using labels. The following command will `enforce` the `baseline` Pod Security Standard, but `warn` and `audit` for `restricted` Pod Security Standards as per the latest version (default value)

   ```
   kubectl label --overwrite ns example \
     pod-security.kubernetes.io/enforce=baseline \
     pod-security.kubernetes.io/enforce-version=latest \
     pod-security.kubernetes.io/warn=restricted \
     pod-security.kubernetes.io/warn-version=latest \
     pod-security.kubernetes.io/audit=restricted \
     pod-security.kubernetes.io/audit-version=latest
   ```

Verify the Pod Security Standard enforcement

1. Create a baseline Pod in the `example` namespace:

```
kubectl apply -n example -f https://k8s.io/examples/security/example-baseline-pod.yaml
```

The Pod does start OK; the output includes a warning. For example:

```
Warning: would violate PodSecurity "restricted:latest": allowPrivilegeEscalation != false
(container "nginx" must set securityContext.allowPrivilegeEscalation=false), unrestricted
capabilities (container "nginx" must set securityContext.capabilities.drop=["ALL"]),
runAsNonRoot != true (pod or container "nginx" must set
securityContext.runAsNonRoot=true), seccompProfile (pod or container "nginx" must set
securityContext.seccompProfile.type to "RuntimeDefault" or "Localhost")
pod/nginx created
```

2. Create a baseline Pod in the `default` namespace:

   ```
   kubectl apply -n default -f https://k8s.io/examples/security/example-baseline-pod.yaml
   ```

   Output is similar to this:

   ```
   pod/nginx created
   ```

The Pod Security Standards enforcement and warning settings were applied only to the `example` namespace. You could create the same Pod in the `default` namespace with no warnings.

Clean up

Now delete the cluster which you created above by running the following command:

```
kind delete cluster --name psa-ns-level
```

What's next

- Run a [shell script] to perform all the preceding steps all at once.
  1. Create kind cluster
  2. Create new namespace
  3. Apply `baseline` Pod Security Standard in `enforce` mode while applying `restricted` Pod Security Standard also in `warn` and `audit` mode.
  4. Create a new pod with the following pod security standards applied
- Pod Security Admission
- Pod Security Standards
- Apply Pod Security Standards at the cluster level

Restrict a Container's Access to Resources with AppArmor

FEATURE STATE: `Kubernetes v1.4 [beta]`

AppArmor is a Linux kernel security module that supplements the standard Linux user and group based permissions to confine programs to a limited set of resources. AppArmor can be configured for any application to reduce its potential attack surface and provide greater in-depth defense. It is configured through profiles tuned to allow the access needed by a specific program or container, such as Linux capabilities, network access, file permissions, etc. Each profile can be run in either *enforcing* mode, which blocks access to disallowed resources, or *complain* mode, which only reports violations.

AppArmor can help you to run a more secure deployment by restricting what containers are allowed to do, and/or provide better auditing through system logs. However, it is important to keep in mind that AppArmor is not a silver bullet and can only do so much to protect against exploits in your application code. It is important to provide good, restrictive profiles, and harden your applications and cluster from other angles as well.

Objectives

- See an example of how to load a profile on a node
- Learn how to enforce the profile on a Pod
- Learn how to check that the profile is loaded
- See what happens when a profile is violated
- See what happens when a profile cannot be loaded

Before you begin

Make sure:

1. Kubernetes version is at least v1.4 -- Kubernetes support for AppArmor was added in v1.4. Kubernetes components older than v1.4 are not aware of the new AppArmor annotations, and will **silently ignore** any AppArmor settings that are provided. To ensure that your Pods are receiving the expected protections, it is important to verify the Kubelet version of your nodes:

   ```
   kubectl get nodes -o=jsonpath=$'{range .items[*]}{@.metadata.name}:
   {@.status.nodeInfo.kubeletVersion}\n{end}'
   ```

   ```
   gke-test-default-pool-239f5d02-gyn2: v1.4.0
   gke-test-default-pool-239f5d02-x1kf: v1.4.0
   gke-test-default-pool-239f5d02-xwux: v1.4.0
   ```

2. AppArmor kernel module is enabled -- For the Linux kernel to enforce an AppArmor profile, the AppArmor kernel module must be installed and enabled. Several distributions enable the module by default, such as Ubuntu and SUSE, and many others provide optional support. To check whether the module is enabled, check the /sys/module/apparmor/parameters/enabled file:

   ```
   cat /sys/module/apparmor/parameters/enabled
   Y
   ```

   If the Kubelet contains AppArmor support (>= v1.4), it will refuse to run a Pod with AppArmor options if the kernel module is not enabled.

Note: Ubuntu carries many AppArmor patches that have not been merged into the upstream Linux kernel, including patches that add additional hooks and features. Kubernetes has only been tested with the upstream version, and does not promise support for other features.

1. Container runtime supports AppArmor -- Currently all common Kubernetes-supported container runtimes should support AppArmor, like [Docker](), [CRI-O]() or [containerd](). Please refer to the corresponding runtime documentation and verify that the cluster fulfills the requirements to use AppArmor.

2. Profile is loaded -- AppArmor is applied to a Pod by specifying an AppArmor profile that each container should be run with. If any of the specified profiles is not already loaded in the kernel, the Kubelet (>= v1.4) will reject the Pod. You can view which profiles are loaded on a node by checking the `/sys/kernel/security/apparmor/profiles` file. For example:

   ```
   ssh gke-test-default-pool-239f5d02-gyn2 "sudo cat /sys/kernel/security/apparmor/profiles | sort"
   ```

   ```
   apparmor-test-deny-write (enforce)
   apparmor-test-audit-write (enforce)
   docker-default (enforce)
   k8s-nginx (enforce)
   ```

   For more details on loading profiles on nodes, see [Setting up nodes with profiles]().

As long as the Kubelet version includes AppArmor support (>= v1.4), the Kubelet will reject a Pod with AppArmor options if any of the prerequisites are not met. You can also verify AppArmor support on nodes by checking the node ready condition message (though this is likely to be removed in a later release):

```
kubectl get nodes -o=jsonpath='{range .items[*]}{@.metadata.name}: {.status.conditions[?(@.reason=="KubeletReady")].message}{"\n"}{end}'
```

```
gke-test-default-pool-239f5d02-gyn2: kubelet is posting ready status. AppArmor enabled
gke-test-default-pool-239f5d02-x1kf: kubelet is posting ready status. AppArmor enabled
gke-test-default-pool-239f5d02-xwux: kubelet is posting ready status. AppArmor enabled
```

Securing a Pod

Note: AppArmor is currently in beta, so options are specified as annotations. Once support graduates to general availability, the annotations will be replaced with first-class fields.

AppArmor profiles are specified *per-container*. To specify the AppArmor profile to run a Pod container with, add an annotation to the Pod's metadata:

```
container.apparmor.security.beta.kubernetes.io/<container_name>: <profile_ref>
```

Where <container_name> is the name of the container to apply the profile to, and <profile_ref> specifies the profile to apply. The `profile_ref` can be one of:

- `runtime/default` to apply the runtime's default profile
- localhost/<profile_name> to apply the profile loaded on the host with the name <profile_name>
- `unconfined` to indicate that no profiles will be loaded

See the [API Reference](#) for the full details on the annotation and profile name formats.

Kubernetes AppArmor enforcement works by first checking that all the prerequisites have been met, and then forwarding the profile selection to the container runtime for enforcement. If the prerequisites have not been met, the Pod will be rejected, and will not run.

To verify that the profile was applied, you can look for the AppArmor security option listed in the container created event:

```
kubectl get events | grep Created
```

```
22s        22s         1         hello-apparmor     Pod       spec.containers{hello}   Normal    Created
{kubelet e2e-test-stclair-node-pool-31nt}   Created container with docker id 269a53b202d3;
Security:[seccomp=unconfined apparmor=k8s-apparmor-example-deny-write]
```

You can also verify directly that the container's root process is running with the correct profile by checking its proc attr:

```
kubectl exec <pod_name> -- cat /proc/1/attr/current
```

```
k8s-apparmor-example-deny-write (enforce)
```

Example

This example assumes you have already set up a cluster with AppArmor support.

First, we need to load the profile we want to use onto our nodes. This profile denies all file writes:

```
#include <tunables/global>

profile k8s-apparmor-example-deny-write flags=(attach_disconnected) {
  #include <abstractions/base>

  file,

  # Deny all file writes.
  deny /** w,
}
```

Since we don't know where the Pod will be scheduled, we'll need to load the profile on all our nodes. For this example we'll use SSH to install the profiles, but other approaches are discussed in [Setting up nodes with profiles](#).

```
NODES=(
    # The SSH-accessible domain names of your nodes
    gke-test-default-pool-239f5d02-gyn2.us-central1-a.my-k8s
    gke-test-default-pool-239f5d02-x1kf.us-central1-a.my-k8s
    gke-test-default-pool-239f5d02-xwux.us-central1-a.my-k8s)
for NODE in ${NODES[*]}; do ssh $NODE 'sudo apparmor_parser -q <<EOF
#include <tunables/global>

profile k8s-apparmor-example-deny-write flags=(attach_disconnected) {
```

```
  #include <abstractions/base>

  file,

  # Deny all file writes.
  deny /** w,
}
EOF'
done
```

Next, we'll run a simple "Hello AppArmor" pod with the deny-write profile:

pods/security/hello-apparmor.yaml

```
apiVersion: v1
kind: Pod
metadata:
  name: hello-apparmor
  annotations:
    # Tell Kubernetes to apply the AppArmor profile "k8s-apparmor-example-deny-write".
    # Note that this is ignored if the Kubernetes node is not running version 1.4 or greater.
    container.apparmor.security.beta.kubernetes.io/hello: localhost/k8s-apparmor-example-deny-
write
spec:
  containers:
  - name: hello
    image: busybox:1.28
    command: [ "sh", "-c", "echo 'Hello AppArmor!' && sleep 1h" ]
```

```
kubectl create -f ./hello-apparmor.yaml
```

If we look at the pod events, we can see that the Pod container was created with the AppArmor profile "k8s-apparmor-example-deny-write":

```
kubectl get events | grep hello-apparmor
```

```
14s        14s        1        hello-apparmor   Pod                              Normal    Scheduled   {default-
scheduler }                   Successfully assigned hello-apparmor to gke-test-default-
pool-239f5d02-gyn2
14s        14s        1        hello-apparmor   Pod       spec.containers{hello}   Normal    Pulling
{kubelet gke-test-default-pool-239f5d02-gyn2}   pulling image "busybox"
13s        13s        1        hello-apparmor   Pod       spec.containers{hello}   Normal    Pulled
{kubelet gke-test-default-pool-239f5d02-gyn2}   Successfully pulled image "busybox"
13s        13s        1        hello-apparmor   Pod       spec.containers{hello}   Normal    Created
{kubelet gke-test-default-pool-239f5d02-gyn2}   Created container with docker id 06b6cd1c0989;
Security:[seccomp=unconfined apparmor=k8s-apparmor-example-deny-write]
13s        13s        1        hello-apparmor   Pod       spec.containers{hello}   Normal    Started
{kubelet gke-test-default-pool-239f5d02-gyn2}   Started container with docker id 06b6cd1c0989
```

We can verify that the container is actually running with that profile by checking its proc attr:

```
kubectl exec hello-apparmor -- cat /proc/1/attr/current
```

```
k8s-apparmor-example-deny-write (enforce)
```

Finally, we can see what happens if we try to violate the profile by writing to a file:

```
kubectl exec hello-apparmor -- touch /tmp/test
```

```
touch: /tmp/test: Permission denied
error: error executing remote command: command terminated with non-zero exit code: Error executing in Docker Container: 1
```

To wrap up, let's look at what happens if we try to specify a profile that hasn't been loaded:

```
kubectl create -f /dev/stdin <<EOF
```

```
apiVersion: v1
kind: Pod
metadata:
  name: hello-apparmor-2
  annotations:
    container.apparmor.security.beta.kubernetes.io/hello: localhost/k8s-apparmor-example-allow-write
spec:
  containers:
  - name: hello
    image: busybox:1.28
    command: [ "sh", "-c", "echo 'Hello AppArmor!' && sleep 1h" ]
EOF
pod/hello-apparmor-2 created
```

```
kubectl describe pod hello-apparmor-2
```

```
Name:          hello-apparmor-2
Namespace:     default
Node:          gke-test-default-pool-239f5d02-x1kf/
Start Time:    Tue, 30 Aug 2016 17:58:56 -0700
Labels:        <none>
Annotations:   container.apparmor.security.beta.kubernetes.io/hello=localhost/k8s-apparmor-example-allow-write
Status:        Pending
Reason:        AppArmor
Message:       Pod Cannot enforce AppArmor: profile "k8s-apparmor-example-allow-write" is not loaded
IP:
Controllers:   <none>
Containers:
  hello:
    Container ID:
    Image:     busybox
    Image ID:
    Port:
    Command:
      sh
      -c
      echo 'Hello AppArmor!' && sleep 1h
    State:              Waiting
      Reason:           Blocked
```

```
    Ready:          False
    Restart Count:     0
    Environment:       <none>
    Mounts:
      /var/run/secrets/kubernetes.io/serviceaccount from default-token-dnz7v (ro)
Conditions:
  Type          Status
  Initialized   True
  Ready         False
  PodScheduled  True
Volumes:
  default-token-dnz7v:
    Type:    Secret (a volume populated by a Secret)
    SecretName:    default-token-dnz7v
    Optional:   false
QoS Class:      BestEffort
Node-Selectors: <none>
Tolerations:    <none>
Events:
  FirstSeen    LastSeen    Count    From                        SubobjectPath    Type        Reason
Message
  ---------    --------    -----    ----                        -------------    --------    ------        -------
  23s          23s         1        {default-scheduler }                         Normal      Scheduled
Successfully assigned hello-apparmor-2 to e2e-test-stclair-node-pool-t1f5
  23s          23s         1        {kubelet e2e-test-stclair-node-pool-t1f5}             Warning
AppArmor    Cannot enforce AppArmor: profile "k8s-apparmor-example-allow-write" is not
loaded
```

Note the pod status is Pending, with a helpful error message: `Pod Cannot enforce AppArmor: profile "k8s-apparmor-example-allow-write" is not loaded`. An event was also recorded with the same message.

Administration

Setting up nodes with profiles

Kubernetes does not currently provide any native mechanisms for loading AppArmor profiles onto nodes. There are lots of ways to set up the profiles though, such as:

- Through a DaemonSet that runs a Pod on each node to ensure the correct profiles are loaded. An example implementation can be found here.
- At node initialization time, using your node initialization scripts (e.g. Salt, Ansible, etc.) or image.
- By copying the profiles to each node and loading them through SSH, as demonstrated in the Example.

The scheduler is not aware of which profiles are loaded onto which node, so the full set of profiles must be loaded onto every node. An alternative approach is to add a node label for each profile (or class of profiles) on the node, and use a node selector to ensure the Pod is run on a node with the required profile.

Disabling AppArmor

If you do not want AppArmor to be available on your cluster, it can be disabled by a command-line flag:

```
--feature-gates=AppArmor=false
```

When disabled, any Pod that includes an AppArmor profile will fail validation with a "Forbidden" error.

Note: Even if the Kubernetes feature is disabled, runtimes may still enforce the default profile. The option to disable the AppArmor feature will be removed when AppArmor graduates to general availability (GA).

Authoring Profiles

Getting AppArmor profiles specified correctly can be a tricky business. Fortunately there are some tools to help with that:

- `aa-genprof` and `aa-logprof` generate profile rules by monitoring an application's activity and logs, and admitting the actions it takes. Further instructions are provided by the AppArmor documentation.
- bane is an AppArmor profile generator for Docker that uses a simplified profile language.

To debug problems with AppArmor, you can check the system logs to see what, specifically, was denied. AppArmor logs verbose messages to `dmesg`, and errors can usually be found in the system logs or through `journalctl`. More information is provided in AppArmor failures.

API Reference

Pod Annotation

Specifying the profile a container will run with:

- **key**: `container.apparmor.security.beta.kubernetes.io/<container_name>` Where `<container_name>` matches the name of a container in the Pod. A separate profile can be specified for each container in the Pod.
- **value**: a profile reference, described below

Profile Reference

- `runtime/default`: Refers to the default runtime profile.
    - Equivalent to not specifying a profile, except it still requires AppArmor to be enabled.
    - In practice, many container runtimes use the same OCI default profile, defined here: https://github.com/containers/common/blob/main/pkg/apparmor/apparmor_linux_template.go
- `localhost/<profile_name>`: Refers to a profile loaded on the node (localhost) by name.
    - The possible profile names are detailed in the core policy reference.
- `unconfined`: This effectively disables AppArmor on the container.

Any other profile reference format is invalid.

What's next

Additional resources:

- Quick guide to the AppArmor profile language
- AppArmor core policy reference

Restrict a Container's Syscalls with seccomp

FEATURE STATE: Kubernetes v1.19 [stable]

Seccomp stands for secure computing mode and has been a feature of the Linux kernel since version 2.6.12. It can be used to sandbox the privileges of a process, restricting the calls it is able to make from userspace into the kernel. Kubernetes lets you automatically apply seccomp profiles loaded onto a node to your Pods and containers.

Identifying the privileges required for your workloads can be difficult. In this tutorial, you will go through how to load seccomp profiles into a local Kubernetes cluster, how to apply them to a Pod, and how you can begin to craft profiles that give only the necessary privileges to your container processes.

Objectives

- Learn how to load seccomp profiles on a node
- Learn how to apply a seccomp profile to a container
- Observe auditing of syscalls made by a container process
- Observe behavior when a missing profile is specified
- Observe a violation of a seccomp profile
- Learn how to create fine-grained seccomp profiles
- Learn how to apply a container runtime default seccomp profile

Before you begin

In order to complete all steps in this tutorial, you must install kind and kubectl.

The commands used in the tutorial assume that you are using Docker as your container runtime. (The cluster that `kind` creates may use a different container runtime internally). You could also use Podman but in that case, you would have to follow specific instructions in order to complete the tasks successfully.

This tutorial shows some examples that are still beta (since v1.25) and others that use only generally available seccomp functionality. You should make sure that your cluster is configured correctly for the version you are using.

The tutorial also uses the `curl` tool for downloading examples to your computer. You can adapt the steps to use a different tool if you prefer.

Note: It is not possible to apply a seccomp profile to a container running with `privileged: true` set in the container's `securityContext`. Privileged containers always run as `Unconfined`.

Download example seccomp profiles

The contents of these profiles will be explored later on, but for now go ahead and download them into a directory named `profiles/` so that they can be loaded into the cluster.

- audit.json
- violation.json
- fine-grained.json

pods/security/seccomp/profiles/audit.json

```
{
    "defaultAction": "SCMP_ACT_LOG"
}
```

pods/security/seccomp/profiles/violation.json

```
{
    "defaultAction": "SCMP_ACT_ERRNO"
}
```

pods/security/seccomp/profiles/fine-grained.json

```
{
    "defaultAction": "SCMP_ACT_ERRNO",
    "architectures": [
        "SCMP_ARCH_X86_64",
        "SCMP_ARCH_X86",
        "SCMP_ARCH_X32"
    ],
    "syscalls": [
        {
            "names": [
                "accept4",
                "epoll_wait",
                "pselect6",
                "futex",
                "madvise",
                "epoll_ctl",
                "getsockname",
                "setsockopt",
                "vfork",
                "mmap",
                "read",
                "write",
                "close",
                "arch_prctl",
                "sched_getaffinity",
                "munmap",
                "brk",
```

```
                "rt_sigaction",
                "rt_sigprocmask",
                "sigaltstack",
                "gettid",
                "clone",
                "bind",
                "socket",
                "openat",
                "readlinkat",
                "exit_group",
                "epoll_create1",
                "listen",
                "rt_sigreturn",
                "sched_yield",
                "clock_gettime",
                "connect",
                "dup2",
                "epoll_pwait",
                "execve",
                "exit",
                "fcntl",
                "getpid",
                "getuid",
                "ioctl",
                "mprotect",
                "nanosleep",
                "open",
                "poll",
                "recvfrom",
                "sendto",
                "set_tid_address",
                "setitimer",
                "writev"
            ],
            "action": "SCMP_ACT_ALLOW"
        }
    ]
}
```

Run these commands:

```
mkdir ./profiles
curl -L -o profiles/audit.json https://k8s.io/examples/pods/security/seccomp/profiles/audit.json
curl -L -o profiles/violation.json https://k8s.io/examples/pods/security/seccomp/profiles/violation.json
curl -L -o profiles/fine-grained.json https://k8s.io/examples/pods/security/seccomp/profiles/fine-grained.json
ls profiles
```

You should see three profiles listed at the end of the final step:

```
audit.json  fine-grained.json  violation.json
```

Create a local Kubernetes cluster with kind

For simplicity, kind can be used to create a single node cluster with the seccomp profiles loaded. Kind runs Kubernetes in Docker, so each node of the cluster is a container. This allows for files to be mounted in the filesystem of each container similar to loading files onto a node.

pods/security/seccomp/kind.yaml

```
apiVersion: kind.x-k8s.io/v1alpha4
kind: Cluster
nodes:
- role: control-plane
  extraMounts:
  - hostPath: "./profiles"
    containerPath: "/var/lib/kubelet/seccomp/profiles"
```

Download that example kind configuration, and save it to a file named kind.yaml:

```
curl -L -O https://k8s.io/examples/pods/security/seccomp/kind.yaml
```

You can set a specific Kubernetes version by setting the node's container image. See Nodes within the kind documentation about configuration for more details on this. This tutorial assumes you are using Kubernetes v1.28.

As a beta feature, you can configure Kubernetes to use the profile that the container runtime prefers by default, rather than falling back to Unconfined. If you want to try that, see enable the use of RuntimeDefault as the default seccomp profile for all workloads before you continue.

Once you have a kind configuration in place, create the kind cluster with that configuration:

```
kind create cluster --config=kind.yaml
```

After the new Kubernetes cluster is ready, identify the Docker container running as the single node cluster:

```
docker ps
```

You should see output indicating that a container is running with name kind-control-plane. The output is similar to:

```
CONTAINER ID        IMAGE                  COMMAND                  CREATED
STATUS              PORTS                       NAMES
6a96207fed4b        kindest/node:v1.18.2   "/usr/local/bin/entr…"   27 seconds ago      Up 24
seconds       127.0.0.1:42223->6443/tcp   kind-control-plane
```

If observing the filesystem of that container, you should see that the profiles/ directory has been successfully loaded into the default seccomp path of the kubelet. Use docker exec to run a command in the Pod:

```
# Change 6a96207fed4b to the container ID you saw from "docker ps"
docker exec -it 6a96207fed4b ls /var/lib/kubelet/seccomp/profiles
```

```
audit.json  fine-grained.json  violation.json
```

You have verified that these seccomp profiles are available to the kubelet running within kind.

Create a Pod that uses the container runtime default seccomp profile

Most container runtimes provide a sane set of default syscalls that are allowed or not. You can adopt these defaults for your workload by setting the seccomp type in the security context of a pod or container to `RuntimeDefault`.

Note: If you have the `seccompDefault` [configuration](#) enabled, then Pods use the `RuntimeDefault` seccomp profile whenever no other seccomp profile is specified. Otherwise, the default is `Unconfined`.

Here's a manifest for a Pod that requests the `RuntimeDefault` seccomp profile for all its containers:

[pods/security/seccomp/ga/default-pod.yaml](#)

```yaml
apiVersion: v1
kind: Pod
metadata:
  name: default-pod
  labels:
    app: default-pod
spec:
  securityContext:
    seccompProfile:
      type: RuntimeDefault
  containers:
  - name: test-container
    image: hashicorp/http-echo:1.0
    args:
    - "-text=just made some more syscalls!"
    securityContext:
      allowPrivilegeEscalation: false
```

Create that Pod:

```
kubectl apply -f https://k8s.io/examples/pods/security/seccomp/ga/default-pod.yaml
```

```
kubectl get pod default-pod
```

The Pod should be showing as having started successfully:

```
NAME        READY   STATUS    RESTARTS   AGE
default-pod 1/1     Running   0          20s
```

Delete the Pod before moving to the next section:

```
kubectl delete pod default-pod --wait --now
```

Create a Pod with a seccomp profile for syscall auditing

To start off, apply the `audit.json` profile, which will log all syscalls of the process, to a new Pod.

Here's a manifest for that Pod:

pods/security/seccomp/ga/audit-pod.yaml

```
apiVersion: v1
kind: Pod
metadata:
  name: audit-pod
  labels:
    app: audit-pod
spec:
  securityContext:
    seccompProfile:
      type: Localhost
      localhostProfile: profiles/audit.json
  containers:
  - name: test-container
    image: hashicorp/http-echo:1.0
    args:
    - "-text=just made some syscalls!"
    securityContext:
      allowPrivilegeEscalation: false
```

Note: Older versions of Kubernetes allowed you to configure seccomp behavior using annotations. Kubernetes 1.28 only supports using fields within `.spec.securityContext` to configure seccomp, and this tutorial explains that approach.

Create the Pod in the cluster:

```
kubectl apply -f https://k8s.io/examples/pods/security/seccomp/ga/audit-pod.yaml
```

This profile does not restrict any syscalls, so the Pod should start successfully.

```
kubectl get pod audit-pod
```

```
NAME        READY   STATUS    RESTARTS   AGE
audit-pod   1/1     Running   0          30s
```

In order to be able to interact with this endpoint exposed by this container, create a NodePort Service that allows access to the endpoint from inside the kind control plane container.

```
kubectl expose pod audit-pod --type NodePort --port 5678
```

Check what port the Service has been assigned on the node.

```
kubectl get service audit-pod
```

The output is similar to:

```
NAME        TYPE       CLUSTER-IP      EXTERNAL-IP   PORT(S)          AGE
audit-pod   NodePort   10.111.36.142   <none>        5678:32373/TCP   72s
```

Now you can use curl to access that endpoint from inside the kind control plane container, at the port exposed by this Service. Use docker exec to run the curl command within the container belonging to that control plane container:

```
# Change 6a96207fed4b to the control plane container ID and 32373 to the port number you saw from "docker ps"
docker exec -it 6a96207fed4b curl localhost:32373
```

```
just made some syscalls!
```

You can see that the process is running, but what syscalls did it actually make? Because this Pod is running in a local cluster, you should be able to see those in /var/log/syslog on your local system. Open up a new terminal window and tail the output for calls from http-echo:

```
# The log path on your computer might be different from "/var/log/syslog"
tail -f /var/log/syslog | grep 'http-echo'
```

You should already see some logs of syscalls made by http-echo, and if you run curl again inside the control plane container you will see more output written to the log.

For example:

```
Jul  6 15:37:40 my-machine kernel: [369128.669452] audit: type=1326
audit(1594067860.484:14536): auid=4294967295 uid=0 gid=0 ses=4294967295 pid=29064
comm="http-echo" exe="/http-echo" sig=0 arch=c000003e syscall=51 compat=0 ip=0x46fe1f
code=0x7ffc0000
Jul  6 15:37:40 my-machine kernel: [369128.669453] audit: type=1326
audit(1594067860.484:14537): auid=4294967295 uid=0 gid=0 ses=4294967295 pid=29064
comm="http-echo" exe="/http-echo" sig=0 arch=c000003e syscall=54 compat=0 ip=0x46fdba
code=0x7ffc0000
Jul  6 15:37:40 my-machine kernel: [369128.669455] audit: type=1326
audit(1594067860.484:14538): auid=4294967295 uid=0 gid=0 ses=4294967295 pid=29064
comm="http-echo" exe="/http-echo" sig=0 arch=c000003e syscall=202 compat=0 ip=0x455e53
code=0x7ffc0000
Jul  6 15:37:40 my-machine kernel: [369128.669456] audit: type=1326
audit(1594067860.484:14539): auid=4294967295 uid=0 gid=0 ses=4294967295 pid=29064
comm="http-echo" exe="/http-echo" sig=0 arch=c000003e syscall=288 compat=0 ip=0x46fdba
code=0x7ffc0000
Jul  6 15:37:40 my-machine kernel: [369128.669517] audit: type=1326
audit(1594067860.484:14540): auid=4294967295 uid=0 gid=0 ses=4294967295 pid=29064
comm="http-echo" exe="/http-echo" sig=0 arch=c000003e syscall=0 compat=0 ip=0x46fd44
code=0x7ffc0000
Jul  6 15:37:40 my-machine kernel: [369128.669519] audit: type=1326
audit(1594067860.484:14541): auid=4294967295 uid=0 gid=0 ses=4294967295 pid=29064
comm="http-echo" exe="/http-echo" sig=0 arch=c000003e syscall=270 compat=0 ip=0x4559b1
code=0x7ffc0000
Jul  6 15:38:40 my-machine kernel: [369188.671648] audit: type=1326
audit(1594067920.488:14559): auid=4294967295 uid=0 gid=0 ses=4294967295 pid=29064
comm="http-echo" exe="/http-echo" sig=0 arch=c000003e syscall=270 compat=0 ip=0x4559b1
code=0x7ffc0000
Jul  6 15:38:40 my-machine kernel: [369188.671726] audit: type=1326
```

```
audit(1594067920.488:14560): auid=4294967295 uid=0 gid=0 ses=4294967295 pid=29064
comm="http-echo" exe="/http-echo" sig=0 arch=c000003e syscall=202 compat=0 ip=0x455e53
code=0x7ffc0000
```

You can begin to understand the syscalls required by the `http-echo` process by looking at the `syscall=` entry on each line. While these are unlikely to encompass all syscalls it uses, it can serve as a basis for a seccomp profile for this container.

Delete the Service and the Pod before moving to the next section:

```
kubectl delete service audit-pod --wait
kubectl delete pod audit-pod --wait --now
```

Create a Pod with a seccomp profile that causes violation

For demonstration, apply a profile to the Pod that does not allow for any syscalls.

The manifest for this demonstration is:

[pods/security/seccomp/ga/violation-pod.yaml]()

```yaml
apiVersion: v1
kind: Pod
metadata:
  name: violation-pod
  labels:
    app: violation-pod
spec:
  securityContext:
    seccompProfile:
      type: Localhost
      localhostProfile: profiles/violation.json
  containers:
  - name: test-container
    image: hashicorp/http-echo:1.0
    args:
    - "-text=just made some syscalls!"
    securityContext:
      allowPrivilegeEscalation: false
```

Attempt to create the Pod in the cluster:

```
kubectl apply -f https://k8s.io/examples/pods/security/seccomp/ga/violation-pod.yaml
```

The Pod creates, but there is an issue. If you check the status of the Pod, you should see that it failed to start.

```
kubectl get pod violation-pod
```

```
NAME            READY   STATUS             RESTARTS   AGE
violation-pod   0/1     CrashLoopBackOff   1          6s
```

As seen in the previous example, the `http-echo` process requires quite a few syscalls. Here seccomp has been instructed to error on any syscall by setting `"defaultAction":`

"SCMP_ACT_ERRNO". This is extremely secure, but removes the ability to do anything meaningful. What you really want is to give workloads only the privileges they need.

Delete the Pod before moving to the next section:

```
kubectl delete pod violation-pod --wait --now
```

Create a Pod with a seccomp profile that only allows necessary syscalls

If you take a look at the fine-grained.json profile, you will notice some of the syscalls seen in syslog of the first example where the profile set "defaultAction": "SCMP_ACT_LOG". Now the profile is setting "defaultAction": "SCMP_ACT_ERRNO", but explicitly allowing a set of syscalls in the "action": "SCMP_ACT_ALLOW" block. Ideally, the container will run successfully and you will see no messages sent to syslog.

The manifest for this example is:

pods/security/seccomp/ga/fine-pod.yaml

```
apiVersion: v1
kind: Pod
metadata:
  name: fine-pod
  labels:
    app: fine-pod
spec:
  securityContext:
    seccompProfile:
      type: Localhost
      localhostProfile: profiles/fine-grained.json
  containers:
  - name: test-container
    image: hashicorp/http-echo:1.0
    args:
    - "-text=just made some syscalls!"
    securityContext:
      allowPrivilegeEscalation: false
```

Create the Pod in your cluster:

```
kubectl apply -f https://k8s.io/examples/pods/security/seccomp/ga/fine-pod.yaml
```

```
kubectl get pod fine-pod
```

The Pod should be showing as having started successfully:

```
NAME       READY   STATUS    RESTARTS   AGE
fine-pod   1/1     Running   0          30s
```

Open up a new terminal window and use tail to monitor for log entries that mention calls from http-echo:

```
# The log path on your computer might be different from "/var/log/syslog"
tail -f /var/log/syslog | grep 'http-echo'
```

Next, expose the Pod with a NodePort Service:

```
kubectl expose pod fine-pod --type NodePort --port 5678
```

Check what port the Service has been assigned on the node:

```
kubectl get service fine-pod
```

The output is similar to:

```
NAME        TYPE       CLUSTER-IP      EXTERNAL-IP   PORT(S)          AGE
fine-pod    NodePort   10.111.36.142   <none>        5678:32373/TCP   72s
```

Use curl to access that endpoint from inside the kind control plane container:

```
# Change 6a96207fed4b to the control plane container ID and 32373 to the port number you saw from "docker ps"
docker exec -it 6a96207fed4b curl localhost:32373
```

```
just made some syscalls!
```

You should see no output in the syslog. This is because the profile allowed all necessary syscalls and specified that an error should occur if one outside of the list is invoked. This is an ideal situation from a security perspective, but required some effort in analyzing the program. It would be nice if there was a simple way to get closer to this security without requiring as much effort.

Delete the Service and the Pod before moving to the next section:

```
kubectl delete service fine-pod --wait
kubectl delete pod fine-pod --wait --now
```

Enable the use of RuntimeDefault as the default seccomp profile for all workloads

FEATURE STATE: Kubernetes v1.27 [stable]

To use seccomp profile defaulting, you must run the kubelet with the --seccomp-default command line flag enabled for each node where you want to use it.

If enabled, the kubelet will use the RuntimeDefault seccomp profile by default, which is defined by the container runtime, instead of using the Unconfined (seccomp disabled) mode. The default profiles aim to provide a strong set of security defaults while preserving the functionality of the workload. It is possible that the default profiles differ between container runtimes and their release versions, for example when comparing those from CRI-O and containerd.

Note: Enabling the feature will neither change the Kubernetes securityContext.seccompProfile API field nor add the deprecated annotations of the workload. This provides users the possibility to rollback anytime without actually changing the workload configuration. Tools like crictl inspect can be used to verify which seccomp profile is being used by a container.

Some workloads may require a lower amount of syscall restrictions than others. This means that they can fail during runtime even with the RuntimeDefault profile. To mitigate such a failure, you can:

- Run the workload explicitly as Unconfined.
- Disable the SeccompDefault feature for the nodes. Also making sure that workloads get scheduled on nodes where the feature is disabled.
- Create a custom seccomp profile for the workload.

If you were introducing this feature into production-like cluster, the Kubernetes project recommends that you enable this feature gate on a subset of your nodes and then test workload execution before rolling the change out cluster-wide.

You can find more detailed information about a possible upgrade and downgrade strategy in the related Kubernetes Enhancement Proposal (KEP): [Enable seccomp by default](https://github.com/kubernetes/enhancements/tree/9a124fd29d1f9ddf2ff455c49a630e3181992c25/keps/sig-node/2413-seccomp-by-default#upgrade--downgrade-strategy).

Kubernetes 1.28 lets you configure the seccomp profile that applies when the spec for a Pod doesn't define a specific seccomp profile. However, you still need to enable this defaulting for each node where you would like to use it.

If you are running a Kubernetes 1.28 cluster and want to enable the feature, either run the kubelet with the --seccomp-default command line flag, or enable it through the kubelet configuration file. To enable the feature gate in kind, ensure that kind provides the minimum required Kubernetes version and enables the SeccompDefault feature in the kind configuration:

```
kind: Cluster
apiVersion: kind.x-k8s.io/v1alpha4
nodes:
  - role: control-plane
    image: kindest/
node:v1.28.0@sha256:9f3ff58f19dcf1a0611d11e8ac989fdb30a28f40f236f59f0bea31fb956ccf5c
    kubeadmConfigPatches:
      - |
        kind: JoinConfiguration
        nodeRegistration:
          kubeletExtraArgs:
            seccomp-default: "true"
  - role: worker
    image: kindest/
node:v1.28.0@sha256:9f3ff58f19dcf1a0611d11e8ac989fdb30a28f40f236f59f0bea31fb956ccf5c
    kubeadmConfigPatches:
      - |
        kind: JoinConfiguration
        nodeRegistration:
          kubeletExtraArgs:
            seccomp-default: "true"
```

If the cluster is ready, then running a pod:

```
kubectl run --rm -it --restart=Never --image=alpine alpine -- sh
```

Should now have the default seccomp profile attached. This can be verified by using docker exec to run crictl inspect for the container on the kind worker:

```
docker exec -it kind-worker bash -c \
    'crictl inspect $(crictl ps --name=alpine -q) | jq .info.runtimeSpec.linux.seccomp'
```

```
{
  "defaultAction": "SCMP_ACT_ERRNO",
  "architectures": ["SCMP_ARCH_X86_64", "SCMP_ARCH_X86", "SCMP_ARCH_X32"],
  "syscalls": [
    {
      "names": ["..."]
    }
  ]
}
```

What's next

You can learn more about Linux seccomp:

- A seccomp Overview
- Seccomp Security Profiles for Docker

Stateless Applications

Exposing an External IP Address to Access an Application in a Cluster

Example: Deploying PHP Guestbook application with Redis

Exposing an External IP Address to Access an Application in a Cluster

This page shows how to create a Kubernetes Service object that exposes an external IP address.

Before you begin

- Install kubectl.
- Use a cloud provider like Google Kubernetes Engine or Amazon Web Services to create a Kubernetes cluster. This tutorial creates an external load balancer, which requires a cloud provider.
- Configure `kubectl` to communicate with your Kubernetes API server. For instructions, see the documentation for your cloud provider.

Objectives

- Run five instances of a Hello World application.
- Create a Service object that exposes an external IP address.
- Use the Service object to access the running application.

Creating a service for an application running in five pods

1. Run a Hello World application in your cluster:

   service/load-balancer-example.yaml

   ```
   apiVersion: apps/v1
   kind: Deployment
   metadata:
     labels:
       app.kubernetes.io/name: load-balancer-example
     name: hello-world
   spec:
     replicas: 5
     selector:
       matchLabels:
         app.kubernetes.io/name: load-balancer-example
     template:
       metadata:
         labels:
           app.kubernetes.io/name: load-balancer-example
       spec:
         containers:
         - image: gcr.io/google-samples/node-hello:1.0
           name: hello-world
           ports:
           - containerPort: 8080
   ```

   ```
   kubectl apply -f https://k8s.io/examples/service/load-balancer-example.yaml
   ```

   The preceding command creates a Deployment and an associated ReplicaSet. The ReplicaSet has five Pods each of which runs the Hello World application.

2. Display information about the Deployment:

   ```
   kubectl get deployments hello-world
   kubectl describe deployments hello-world
   ```

3. Display information about your ReplicaSet objects:

   ```
   kubectl get replicasets
   kubectl describe replicasets
   ```

4. Create a Service object that exposes the deployment:

   ```
   kubectl expose deployment hello-world --type=LoadBalancer --name=my-service
   ```

5. Display information about the Service:

   ```
   kubectl get services my-service
   ```

   The output is similar to:

```
NAME       TYPE         CLUSTER-IP    EXTERNAL-IP     PORT(S)   AGE
my-service  LoadBalancer  10.3.245.137  104.198.205.71  8080/TCP  54s
```

Note: The type=LoadBalancer service is backed by external cloud providers, which is not covered in this example, please refer to this page for the details.
Note: If the external IP address is shown as <pending>, wait for a minute and enter the same command again.

6. Display detailed information about the Service:

```
kubectl describe services my-service
```

The output is similar to:

```
Name:           my-service
Namespace:      default
Labels:         app.kubernetes.io/name=load-balancer-example
Annotations:    <none>
Selector:       app.kubernetes.io/name=load-balancer-example
Type:           LoadBalancer
IP:             10.3.245.137
LoadBalancer Ingress:   104.198.205.71
Port:           <unset> 8080/TCP
NodePort:       <unset> 32377/TCP
Endpoints:      10.0.0.6:8080,10.0.1.6:8080,10.0.1.7:8080 + 2 more...
Session Affinity:   None
Events:         <none>
```

Make a note of the external IP address (`LoadBalancer Ingress`) exposed by your service. In this example, the external IP address is 104.198.205.71. Also note the value of `Port` and `NodePort`. In this example, the `Port` is 8080 and the `NodePort` is 32377.

7. In the preceding output, you can see that the service has several endpoints: 10.0.0.6:8080,10.0.1.6:8080,10.0.1.7:8080 + 2 more. These are internal addresses of the pods that are running the Hello World application. To verify these are pod addresses, enter this command:

```
kubectl get pods --output=wide
```

The output is similar to:

```
NAME                         ...  IP         NODE
hello-world-2895499144-1jaz9 ...  10.0.1.6   gke-cluster-1-default-pool-e0b8d269-1afc
hello-world-2895499144-2e5uh ...  10.0.1.8   gke-cluster-1-default-pool-e0b8d269-1afc
hello-world-2895499144-9m4h1 ...  10.0.0.6   gke-cluster-1-default-pool-e0b8d269-5v7a
hello-world-2895499144-o4z13 ...  10.0.1.7   gke-cluster-1-default-pool-e0b8d269-1afc
hello-world-2895499144-segjf ...  10.0.2.5   gke-cluster-1-default-pool-e0b8d269-cpuc
```

8. Use the external IP address (`LoadBalancer Ingress`) to access the Hello World application:

```
curl http://<external-ip>:<port>
```

where `<external-ip>` is the external IP address (`LoadBalancer Ingress`) of your Service, and `<port>` is the value of `Port` in your Service description. If you are using minikube, typing `minikube service my-service` will automatically open the Hello World application in a browser.

The response to a successful request is a hello message:

```
Hello Kubernetes!
```

Cleaning up

To delete the Service, enter this command:

```
kubectl delete services my-service
```

To delete the Deployment, the ReplicaSet, and the Pods that are running the Hello World application, enter this command:

```
kubectl delete deployment hello-world
```

What's next

Learn more about [connecting applications with services](#).

Example: Deploying PHP Guestbook application with Redis

This tutorial shows you how to build and deploy a simple *(not production ready)*, multi-tier web application using Kubernetes and [Docker](#). This example consists of the following components:

- A single-instance [Redis](#) to store guestbook entries
- Multiple web frontend instances

Objectives

- Start up a Redis leader.
- Start up two Redis followers.
- Start up the guestbook frontend.
- Expose and view the Frontend Service.
- Clean up.

Before you begin

You need to have a Kubernetes cluster, and the kubectl command-line tool must be configured to communicate with your cluster. It is recommended to run this tutorial on a cluster with at least two nodes that are not acting as control plane hosts. If you do not already have a cluster, you can create one by using [minikube](#) or you can use one of these Kubernetes playgrounds:

- [Killercoda](#)
- [Play with Kubernetes](#)

Your Kubernetes server must be at or later than version v1.14. To check the version, enter `kubectl version`.

Start up the Redis Database

The guestbook application uses Redis to store its data.

Creating the Redis Deployment

The manifest file, included below, specifies a Deployment controller that runs a single replica Redis Pod.

[application/guestbook/redis-leader-deployment.yaml]()

```yaml
# SOURCE: https://cloud.google.com/kubernetes-engine/docs/tutorials/guestbook
apiVersion: apps/v1
kind: Deployment
metadata:
  name: redis-leader
  labels:
    app: redis
    role: leader
    tier: backend
spec:
  replicas: 1
  selector:
    matchLabels:
      app: redis
  template:
    metadata:
      labels:
        app: redis
        role: leader
        tier: backend
    spec:
      containers:
      - name: leader
        image: "docker.io/redis:6.0.5"
        resources:
          requests:
            cpu: 100m
            memory: 100Mi
        ports:
        - containerPort: 6379
```

1. Launch a terminal window in the directory you downloaded the manifest files.

2. Apply the Redis Deployment from the `redis-leader-deployment.yaml` file:

   ```
   kubectl apply -f https://k8s.io/examples/application/guestbook/redis-leader-deployment.yaml
   ```

3. Query the list of Pods to verify that the Redis Pod is running:

```
kubectl get pods
```

The response should be similar to this:

```
NAME                           READY   STATUS    RESTARTS   AGE
redis-leader-fb76b4755-xjr2n   1/1     Running   0          13s
```

4. Run the following command to view the logs from the Redis leader Pod:

```
kubectl logs -f deployment/redis-leader
```

Creating the Redis leader Service

The guestbook application needs to communicate to the Redis to write its data. You need to apply a Service to proxy the traffic to the Redis Pod. A Service defines a policy to access the Pods.

application/guestbook/redis-leader-service.yaml

```
# SOURCE: https://cloud.google.com/kubernetes-engine/docs/tutorials/guestbook
apiVersion: v1
kind: Service
metadata:
  name: redis-leader
  labels:
    app: redis
    role: leader
    tier: backend
spec:
  ports:
  - port: 6379
    targetPort: 6379
  selector:
    app: redis
    role: leader
    tier: backend
```

1. Apply the Redis Service from the following `redis-leader-service.yaml` file:

```
kubectl apply -f https://k8s.io/examples/application/guestbook/redis-leader-service.yaml
```

2. Query the list of Services to verify that the Redis Service is running:

```
kubectl get service
```

The response should be similar to this:

```
NAME           TYPE        CLUSTER-IP     EXTERNAL-IP   PORT(S)    AGE
kubernetes     ClusterIP   10.0.0.1       <none>        443/TCP    1m
redis-leader   ClusterIP   10.103.78.24   <none>        6379/TCP   16s
```

Note: This manifest file creates a Service named `redis-leader` with a set of labels that match the labels previously defined, so the Service routes network traffic to the Redis Pod.

Set up Redis followers

Although the Redis leader is a single Pod, you can make it highly available and meet traffic demands by adding a few Redis followers, or replicas.

application/guestbook/redis-follower-deployment.yaml

```
# SOURCE: https://cloud.google.com/kubernetes-engine/docs/tutorials/guestbook
apiVersion: apps/v1
kind: Deployment
metadata:
  name: redis-follower
  labels:
    app: redis
    role: follower
    tier: backend
spec:
  replicas: 2
  selector:
    matchLabels:
      app: redis
  template:
    metadata:
      labels:
        app: redis
        role: follower
        tier: backend
    spec:
      containers:
      - name: follower
        image: gcr.io/google_samples/gb-redis-follower:v2
        resources:
          requests:
            cpu: 100m
            memory: 100Mi
        ports:
        - containerPort: 6379
```

1. Apply the Redis Deployment from the following `redis-follower-deployment.yaml` file:

   ```
   kubectl apply -f https://k8s.io/examples/application/guestbook/redis-follower-deployment.yaml
   ```

2. Verify that the two Redis follower replicas are running by querying the list of Pods:

   ```
   kubectl get pods
   ```

   The response should be similar to this:

   ```
   NAME                             READY   STATUS    RESTARTS   AGE
   redis-follower-dddfbdcc9-82sfr   1/1     Running   0          37s
   redis-follower-dddfbdcc9-qrt5k   1/1     Running   0          38s
   redis-leader-fb76b4755-xjr2n     1/1     Running   0          11m
   ```

Creating the Redis follower service

The guestbook application needs to communicate with the Redis followers to read data. To make the Redis followers discoverable, you must set up another Service.

application/guestbook/redis-follower-service.yaml

```
# SOURCE: https://cloud.google.com/kubernetes-engine/docs/tutorials/guestbook
apiVersion: v1
kind: Service
metadata:
  name: redis-follower
  labels:
    app: redis
    role: follower
    tier: backend
spec:
  ports:
    # the port that this service should serve on
  - port: 6379
  selector:
    app: redis
    role: follower
    tier: backend
```

1. Apply the Redis Service from the following `redis-follower-service.yaml` file:

   ```
   kubectl apply -f https://k8s.io/examples/application/guestbook/redis-follower-service.yaml
   ```

2. Query the list of Services to verify that the Redis Service is running:

   ```
   kubectl get service
   ```

   The response should be similar to this:

   ```
   NAME             TYPE        CLUSTER-IP       EXTERNAL-IP   PORT(S)    AGE
   kubernetes       ClusterIP   10.96.0.1        <none>        443/TCP    3d19h
   redis-follower   ClusterIP   10.110.162.42    <none>        6379/TCP   9s
   redis-leader     ClusterIP   10.103.78.24     <none>        6379/TCP   6m10s
   ```

Note: This manifest file creates a Service named `redis-follower` with a set of labels that match the labels previously defined, so the Service routes network traffic to the Redis Pod.

Set up and Expose the Guestbook Frontend

Now that you have the Redis storage of your guestbook up and running, start the guestbook web servers. Like the Redis followers, the frontend is deployed using a Kubernetes Deployment.

The guestbook app uses a PHP frontend. It is configured to communicate with either the Redis follower or leader Services, depending on whether the request is a read or a write. The frontend exposes a JSON interface, and serves a jQuery-Ajax-based UX.

Creating the Guestbook Frontend Deployment

[application/guestbook/frontend-deployment.yaml]

```yaml
# SOURCE: https://cloud.google.com/kubernetes-engine/docs/tutorials/guestbook
apiVersion: apps/v1
kind: Deployment
metadata:
  name: frontend
spec:
  replicas: 3
  selector:
    matchLabels:
        app: guestbook
        tier: frontend
  template:
    metadata:
      labels:
        app: guestbook
        tier: frontend
    spec:
      containers:
      - name: php-redis
        image: gcr.io/google_samples/gb-frontend:v5
        env:
        - name: GET_HOSTS_FROM
          value: "dns"
        resources:
          requests:
            cpu: 100m
            memory: 100Mi
        ports:
        - containerPort: 80
```

1. Apply the frontend Deployment from the frontend-deployment.yaml file:

   ```
   kubectl apply -f https://k8s.io/examples/application/guestbook/frontend-deployment.yaml
   ```

2. Query the list of Pods to verify that the three frontend replicas are running:

   ```
   kubectl get pods -l app=guestbook -l tier=frontend
   ```

   The response should be similar to this:

   ```
   NAME                        READY   STATUS    RESTARTS   AGE
   frontend-85595f5bf9-5tqhb   1/1     Running   0          47s
   frontend-85595f5bf9-qbzwm   1/1     Running   0          47s
   frontend-85595f5bf9-zchwc   1/1     Running   0          47s
   ```

Creating the Frontend Service

The Redis Services you applied is only accessible within the Kubernetes cluster because the default type for a Service is [ClusterIP](). ClusterIP provides a single IP address for the set of Pods the Service is pointing to. This IP address is accessible only within the cluster.

If you want guests to be able to access your guestbook, you must configure the frontend Service to be externally visible, so a client can request the Service from outside the Kubernetes cluster. However a Kubernetes user can use kubectl port-forward to access the service even though it uses a ClusterIP.

Note: Some cloud providers, like Google Compute Engine or Google Kubernetes Engine, support external load balancers. If your cloud provider supports load balancers and you want to use it, uncomment type: LoadBalancer.
[application/guestbook/frontend-service.yaml]()

```
# SOURCE: https://cloud.google.com/kubernetes-engine/docs/tutorials/guestbook
apiVersion: v1
kind: Service
metadata:
  name: frontend
  labels:
    app: guestbook
    tier: frontend
spec:
  # if your cluster supports it, uncomment the following to automatically create
  # an external load-balanced IP for the frontend service.
  # type: LoadBalancer
  #type: LoadBalancer
  ports:
    # the port that this service should serve on
  - port: 80
  selector:
    app: guestbook
    tier: frontend
```

1. Apply the frontend Service from the frontend-service.yaml file:

   ```
   kubectl apply -f https://k8s.io/examples/application/guestbook/frontend-service.yaml
   ```

2. Query the list of Services to verify that the frontend Service is running:

   ```
   kubectl get services
   ```

   The response should be similar to this:

   ```
   NAME             TYPE        CLUSTER-IP       EXTERNAL-IP   PORT(S)    AGE
   frontend         ClusterIP   10.97.28.230     <none>        80/TCP     19s
   kubernetes       ClusterIP   10.96.0.1        <none>        443/TCP    3d19h
   redis-follower   ClusterIP   10.110.162.42    <none>        6379/TCP   5m48s
   redis-leader     ClusterIP   10.103.78.24     <none>        6379/TCP   11m
   ```

Viewing the Frontend Service via `kubectl port-forward`

1. Run the following command to forward port `8080` on your local machine to port `80` on the service.

   ```
   kubectl port-forward svc/frontend 8080:80
   ```

   The response should be similar to this:

   ```
   Forwarding from 127.0.0.1:8080 -> 80
   Forwarding from [::1]:8080 -> 80
   ```

2. load the page http://localhost:8080 in your browser to view your guestbook.

Viewing the Frontend Service via `LoadBalancer`

If you deployed the `frontend-service.yaml` manifest with `type: LoadBalancer` you need to find the IP address to view your Guestbook.

1. Run the following command to get the IP address for the frontend Service.

   ```
   kubectl get service frontend
   ```

   The response should be similar to this:

   ```
   NAME       TYPE           CLUSTER-IP      EXTERNAL-IP        PORT(S)        AGE
   frontend   LoadBalancer   10.51.242.136   109.197.92.229     80:32372/TCP   1m
   ```

2. Copy the external IP address, and load the page in your browser to view your guestbook.

Note: Try adding some guestbook entries by typing in a message, and clicking Submit. The message you typed appears in the frontend. This message indicates that data is successfully added to Redis through the Services you created earlier.

Scale the Web Frontend

You can scale up or down as needed because your servers are defined as a Service that uses a Deployment controller.

1. Run the following command to scale up the number of frontend Pods:

   ```
   kubectl scale deployment frontend --replicas=5
   ```

2. Query the list of Pods to verify the number of frontend Pods running:

   ```
   kubectl get pods
   ```

   The response should look similar to this:

   ```
   NAME                             READY   STATUS    RESTARTS   AGE
   frontend-85595f5bf9-5df5m        1/1     Running   0          83s
   frontend-85595f5bf9-7zmg5        1/1     Running   0          83s
   frontend-85595f5bf9-cpskg        1/1     Running   0          15m
   frontend-85595f5bf9-l2l54        1/1     Running   0          14m
   ```

```
frontend-85595f5bf9-l9c8z       1/1     Running   0          14m
redis-follower-dddfbdcc9-82sfr   1/1     Running   0          97m
redis-follower-dddfbdcc9-qrt5k   1/1     Running   0          97m
redis-leader-fb76b4755-xjr2n     1/1     Running   0          108m
```

3. Run the following command to scale down the number of frontend Pods:

```
kubectl scale deployment frontend --replicas=2
```

4. Query the list of Pods to verify the number of frontend Pods running:

```
kubectl get pods
```

The response should look similar to this:

```
NAME                             READY   STATUS    RESTARTS   AGE
frontend-85595f5bf9-cpskg        1/1     Running   0          16m
frontend-85595f5bf9-l9c8z        1/1     Running   0          15m
redis-follower-dddfbdcc9-82sfr   1/1     Running   0          98m
redis-follower-dddfbdcc9-qrt5k   1/1     Running   0          98m
redis-leader-fb76b4755-xjr2n     1/1     Running   0          109m
```

Cleaning up

Deleting the Deployments and Services also deletes any running Pods. Use labels to delete multiple resources with one command.

1. Run the following commands to delete all Pods, Deployments, and Services.

```
kubectl delete deployment -l app=redis
kubectl delete service -l app=redis
kubectl delete deployment frontend
kubectl delete service frontend
```

The response should look similar to this:

```
deployment.apps "redis-follower" deleted
deployment.apps "redis-leader" deleted
deployment.apps "frontend" deleted
service "frontend" deleted
```

2. Query the list of Pods to verify that no Pods are running:

```
kubectl get pods
```

The response should look similar to this:

```
No resources found in default namespace.
```

What's next

- Complete the Kubernetes Basics Interactive Tutorials
- Use Kubernetes to create a blog using Persistent Volumes for MySQL and Wordpress

- Read more about connecting applications with services
- Read more about using labels effectively

Stateful Applications

StatefulSet Basics

This tutorial provides an introduction to managing applications with StatefulSets. It demonstrates how to create, delete, scale, and update the Pods of StatefulSets.

Before you begin

Before you begin this tutorial, you should familiarize yourself with the following Kubernetes concepts:

- Pods
- Cluster DNS
- Headless Services
- PersistentVolumes
- PersistentVolume Provisioning
- The kubectl command line tool

You need to have a Kubernetes cluster, and the kubectl command-line tool must be configured to communicate with your cluster. It is recommended to run this tutorial on a cluster with at least two nodes that are not acting as control plane hosts. If you do not already have a cluster, you can create one by using minikube or you can use one of these Kubernetes playgrounds:

- Killercoda
- Play with Kubernetes

You should configure `kubectl` to use a context that uses the `default` namespace. If you are using an existing cluster, make sure that it's OK to use that cluster's default namespace to practice. Ideally, practice in a cluster that doesn't run any real workloads.

It's also useful to read the concept page about StatefulSets.

Note: This tutorial assumes that your cluster is configured to dynamically provision PersistentVolumes. You'll also need to have a default StorageClass. If your cluster is not configured to provision storage dynamically, you will have to manually provision two 1 GiB volumes prior to starting this tutorial and set up your cluster so that those PersistentVolumes map to the PersistentVolumeClaim templates that the StatefulSet defines.

Objectives

StatefulSets are intended to be used with stateful applications and distributed systems. However, the administration of stateful applications and distributed systems on Kubernetes is a broad, complex topic. In order to demonstrate the basic features of a StatefulSet, and not to conflate the former topic with the latter, you will deploy a simple web application using a StatefulSet.

After this tutorial, you will be familiar with the following.

- How to create a StatefulSet
- How a StatefulSet manages its Pods
- How to delete a StatefulSet
- How to scale a StatefulSet
- How to update a StatefulSet's Pods

Creating a StatefulSet

Begin by creating a StatefulSet using the example below. It is similar to the example presented in the StatefulSets concept. It creates a headless Service, `nginx`, to publish the IP addresses of Pods in the StatefulSet, `web`.

application/web/web.yaml

```
apiVersion: v1
kind: Service
metadata:
  name: nginx
  labels:
    app: nginx
spec:
  ports:
  - port: 80
    name: web
  clusterIP: None
  selector:
    app: nginx
---
apiVersion: apps/v1
kind: StatefulSet
metadata:
  name: web
spec:
  serviceName: "nginx"
  replicas: 2
  selector:
    matchLabels:
      app: nginx
  template:
    metadata:
      labels:
        app: nginx
```

```
  spec:
    containers:
    - name: nginx
      image: registry.k8s.io/nginx-slim:0.8
      ports:
      - containerPort: 80
        name: web
      volumeMounts:
      - name: www
        mountPath: /usr/share/nginx/html
volumeClaimTemplates:
- metadata:
    name: www
  spec:
    accessModes: [ "ReadWriteOnce" ]
    resources:
      requests:
        storage: 1Gi
```

Download the example above, and save it to a file named `web.yaml`

You will need to use two terminal windows. In the first terminal, use [kubectl get](#) to watch the creation of the StatefulSet's Pods.

```
kubectl get pods -w -l app=nginx
```

In the second terminal, use [kubectl apply](#) to create the headless Service and StatefulSet defined in `web.yaml`.

```
kubectl apply -f web.yaml
```

```
service/nginx created
statefulset.apps/web created
```

The command above creates two Pods, each running an [NGINX](#) webserver. Get the `nginx` Service...

```
kubectl get service nginx
```

```
NAME      TYPE        CLUSTER-IP   EXTERNAL-IP   PORT(S)   AGE
nginx     ClusterIP   None         <none>        80/TCP    12s
```

...then get the `web` StatefulSet, to verify that both were created successfully:

```
kubectl get statefulset web
```

```
NAME      DESIRED   CURRENT   AGE
web       2         1         20s
```

Ordered Pod Creation

For a StatefulSet with *n* replicas, when Pods are being deployed, they are created sequentially, ordered from *{0..n-1}*. Examine the output of the `kubectl get` command in the first terminal. Eventually, the output will look like the example below.

```
kubectl get pods -w -l app=nginx
```

```
NAME      READY     STATUS    RESTARTS   AGE
web-0     0/1       Pending   0          0s
web-0     0/1       Pending   0         0s
web-0     0/1       ContainerCreating   0         0s
web-0     1/1       Running   0         19s
web-1     0/1       Pending   0         0s
web-1     0/1       Pending   0         0s
web-1     0/1       ContainerCreating   0         0s
web-1     1/1       Running   0         18s
```

Notice that the `web-1` Pod is not launched until the `web-0` Pod is *Running* (see Pod Phase) and *Ready* (see `type` in Pod Conditions).

Note: To configure the integer ordinal assigned to each Pod in a StatefulSet, see Start ordinal.

Pods in a StatefulSet

Pods in a StatefulSet have a unique ordinal index and a stable network identity.

Examining the Pod's ordinal index

Get the StatefulSet's Pods:

```
kubectl get pods -l app=nginx
```

```
NAME      READY     STATUS    RESTARTS   AGE
web-0     1/1       Running   0          1m
web-1     1/1       Running   0          1m
```

As mentioned in the StatefulSets concept, the Pods in a StatefulSet have a sticky, unique identity. This identity is based on a unique ordinal index that is assigned to each Pod by the StatefulSet controller.
The Pods' names take the form `<statefulset name>-<ordinal index>`. Since the `web` StatefulSet has two replicas, it creates two Pods, `web-0` and `web-1`.

Using stable network identities

Each Pod has a stable hostname based on its ordinal index. Use kubectl exec to execute the `hostname` command in each Pod:

```
for i in 0 1; do kubectl exec "web-$i" -- sh -c 'hostname'; done
```

```
web-0
web-1
```

Use kubectl run to execute a container that provides the nslookup command from the dnsutils package. Using nslookup on the Pods' hostnames, you can examine their in-cluster DNS addresses:

```
kubectl run -i --tty --image busybox:1.28 dns-test --restart=Never --rm
```

which starts a new shell. In that new shell, run:

```
# Run this in the dns-test container shell
nslookup web-0.nginx
```

The output is similar to:

```
Server:    10.0.0.10
Address 1: 10.0.0.10 kube-dns.kube-system.svc.cluster.local

Name:      web-0.nginx
Address 1: 10.244.1.6

nslookup web-1.nginx
Server:    10.0.0.10
Address 1: 10.0.0.10 kube-dns.kube-system.svc.cluster.local

Name:      web-1.nginx
Address 1: 10.244.2.6
```

(and now exit the container shell: exit)

The CNAME of the headless service points to SRV records (one for each Pod that is Running and Ready). The SRV records point to A record entries that contain the Pods' IP addresses.

In one terminal, watch the StatefulSet's Pods:

```
kubectl get pod -w -l app=nginx
```

In a second terminal, use kubectl delete to delete all the Pods in the StatefulSet:

```
kubectl delete pod -l app=nginx
```

```
pod "web-0" deleted
pod "web-1" deleted
```

Wait for the StatefulSet to restart them, and for both Pods to transition to Running and Ready:

```
kubectl get pod -w -l app=nginx
```

```
NAME      READY     STATUS              RESTARTS   AGE
web-0     0/1       ContainerCreating   0          0s
NAME      READY     STATUS    RESTARTS   AGE
web-0     1/1       Running   0          2s
web-1     0/1       Pending   0         0s
web-1     0/1       Pending   0         0s
web-1     0/1       ContainerCreating   0         0s
web-1     1/1       Running   0         34s
```

Use kubectl exec and kubectl run to view the Pods' hostnames and in-cluster DNS entries. First, view the Pods' hostnames:

```
for i in 0 1; do kubectl exec web-$i -- sh -c 'hostname'; done
```

```
web-0
web-1
```

then, run:

```
kubectl run -i --tty --image busybox:1.28 dns-test --restart=Never --rm
```

which starts a new shell.
In that new shell, run:

```
# Run this in the dns-test container shell
nslookup web-0.nginx
```

The output is similar to:

```
Server:    10.0.0.10
Address 1: 10.0.0.10 kube-dns.kube-system.svc.cluster.local

Name:      web-0.nginx
Address 1: 10.244.1.7

nslookup web-1.nginx
Server:    10.0.0.10
Address 1: 10.0.0.10 kube-dns.kube-system.svc.cluster.local

Name:      web-1.nginx
Address 1: 10.244.2.8
```

(and now exit the container shell: exit)

The Pods' ordinals, hostnames, SRV records, and A record names have not changed, but the IP addresses associated with the Pods may have changed. In the cluster used for this tutorial, they have. This is why it is important not to configure other applications to connect to Pods in a StatefulSet by IP address.

Discovery for specific Pods in a StatefulSet

If you need to find and connect to the active members of a StatefulSet, you should query the CNAME of the headless Service (nginx.default.svc.cluster.local). The SRV records associated with the CNAME will contain only the Pods in the StatefulSet that are Running and Ready.

If your application already implements connection logic that tests for liveness and readiness, you can use the SRV records of the Pods (web-0.nginx.default.svc.cluster.local, web-1.nginx.default.svc.cluster.local), as they are stable, and your application will be able to discover the Pods' addresses when they transition to Running and Ready.

Writing to stable storage

Get the PersistentVolumeClaims for web-0 and web-1:

```
kubectl get pvc -l app=nginx
```

The output is similar to:

```
NAME        STATUS    VOLUME                                     CAPACITY   ACCESSMODES   AGE
www-web-0   Bound     pvc-15c268c7-b507-11e6-932f-42010a800002   1Gi        RWO           48s
www-web-1   Bound     pvc-15c79307-b507-11e6-932f-42010a800002   1Gi        RWO           48s
```

The StatefulSet controller created two [PersistentVolumeClaims] that are bound to two [PersistentVolumes].

As the cluster used in this tutorial is configured to dynamically provision PersistentVolumes, the PersistentVolumes were created and bound automatically.

The NGINX webserver, by default, serves an index file from `/usr/share/nginx/html/index.html`. The `volumeMounts` field in the StatefulSet's `spec` ensures that the `/usr/share/nginx/html` directory is backed by a PersistentVolume.

Write the Pods' hostnames to their `index.html` files and verify that the NGINX webservers serve the hostnames:

```
for i in 0 1; do kubectl exec "web-$i" -- sh -c 'echo "$(hostname)" > /usr/share/nginx/html/index.html'; done

for i in 0 1; do kubectl exec -i -t "web-$i" -- curl http://localhost/; done
```

```
web-0
web-1
```

Note:

If you instead see **403 Forbidden** responses for the above curl command, you will need to fix the permissions of the directory mounted by the `volumeMounts` (due to a [bug when using hostPath volumes]), by running:

`for i in 0 1; do kubectl exec web-$i -- chmod 755 /usr/share/nginx/html; done`

before retrying the `curl` command above.

In one terminal, watch the StatefulSet's Pods:

```
kubectl get pod -w -l app=nginx
```

In a second terminal, delete all of the StatefulSet's Pods:

```
kubectl delete pod -l app=nginx
```

```
pod "web-0" deleted
pod "web-1" deleted
```

Examine the output of the `kubectl get` command in the first terminal, and wait for all of the Pods to transition to Running and Ready.

```
kubectl get pod -w -l app=nginx
```

```
NAME    READY   STATUS              RESTARTS   AGE
web-0   0/1     ContainerCreating   0          0s
NAME    READY   STATUS    RESTARTS   AGE
web-0   1/1     Running   0          2s
web-1   0/1     Pending   0          0s
web-1   0/1     Pending   0          0s
web-1   0/1     ContainerCreating   0          0s
web-1   1/1     Running   0          34s
```

Verify the web servers continue to serve their hostnames:

```
for i in 0 1; do kubectl exec -i -t "web-$i" -- curl http://localhost/; done
```

```
web-0
web-1
```

Even though web-0 and web-1 were rescheduled, they continue to serve their hostnames because the PersistentVolumes associated with their PersistentVolumeClaims are remounted to their volumeMounts. No matter what node web-0and web-1 are scheduled on, their PersistentVolumes will be mounted to the appropriate mount points.

Scaling a StatefulSet

Scaling a StatefulSet refers to increasing or decreasing the number of replicas. This is accomplished by updating the replicas field. You can use either [kubectl scale] or [kubectl patch] to scale a StatefulSet.

Scaling up

In one terminal window, watch the Pods in the StatefulSet:

```
kubectl get pods -w -l app=nginx
```

In another terminal window, use kubectl scale to scale the number of replicas to 5:

```
kubectl scale sts web --replicas=5
```

```
statefulset.apps/web scaled
```

Examine the output of the kubectl get command in the first terminal, and wait for the three additional Pods to transition to Running and Ready.

```
kubectl get pods -w -l app=nginx
```

```
NAME    READY   STATUS    RESTARTS   AGE
web-0   1/1     Running   0          2h
web-1   1/1     Running   0          2h
NAME    READY   STATUS    RESTARTS   AGE
web-2   0/1     Pending   0          0s
web-2   0/1     Pending   0          0s
web-2   0/1     ContainerCreating   0          0s
web-2   1/1     Running   0          19s
web-3   0/1     Pending   0          0s
```

```
web-3     0/1       Pending   0         0s
web-3     0/1       ContainerCreating   0         0s
web-3     1/1       Running   0         18s
web-4     0/1       Pending   0         0s
web-4     0/1       Pending   0         0s
web-4     0/1       ContainerCreating   0         0s
web-4     1/1       Running   0         19s
```

The StatefulSet controller scaled the number of replicas. As with [StatefulSet creation](), the StatefulSet controller created each Pod sequentially with respect to its ordinal index, and it waited for each Pod's predecessor to be Running and Ready before launching the subsequent Pod.

Scaling Down

In one terminal, watch the StatefulSet's Pods:

```
kubectl get pods -w -l app=nginx
```

In another terminal, use `kubectl patch` to scale the StatefulSet back down to three replicas:

```
kubectl patch sts web -p '{"spec":{"replicas":3}}'
```

```
statefulset.apps/web patched
```

Wait for `web-4` and `web-3` to transition to Terminating.

```
kubectl get pods -w -l app=nginx
```

```
NAME      READY     STATUS              RESTARTS   AGE
web-0     1/1       Running             0          3h
web-1     1/1       Running             0          3h
web-2     1/1       Running             0          55s
web-3     1/1       Running             0          36s
web-4     0/1       ContainerCreating   0          18s
NAME      READY     STATUS    RESTARTS   AGE
web-4     1/1       Running   0          19s
web-4     1/1       Terminating   0         24s
web-4     1/1       Terminating   0         24s
web-3     1/1       Terminating   0         42s
web-3     1/1       Terminating   0         42s
```

Ordered Pod termination

The controller deleted one Pod at a time, in reverse order with respect to its ordinal index, and it waited for each to be completely shutdown before deleting the next.

Get the StatefulSet's PersistentVolumeClaims:

```
kubectl get pvc -l app=nginx
```

```
NAME        STATUS    VOLUME                                     CAPACITY   ACCESSMODES   AGE
www-web-0   Bound     pvc-15c268c7-b507-11e6-932f-42010a800002   1Gi        RWO           13h
www-web-1   Bound     pvc-15c79307-b507-11e6-932f-42010a800002   1Gi        RWO           13h
```

```
www-web-2   Bound    pvc-e1125b27-b508-11e6-932f-42010a800002   1Gi        RWO           13h
www-web-3   Bound    pvc-e1176df6-b508-11e6-932f-42010a800002   1Gi        RWO           13h
www-web-4   Bound    pvc-e11bb5f8-b508-11e6-932f-42010a800002   1Gi        RWO           13h
```

There are still five PersistentVolumeClaims and five PersistentVolumes. When exploring a Pod's stable storage, we saw that the PersistentVolumes mounted to the Pods of a StatefulSet are not deleted when the StatefulSet's Pods are deleted. This is still true when Pod deletion is caused by scaling the StatefulSet down.

Updating StatefulSets

In Kubernetes 1.7 and later, the StatefulSet controller supports automated updates. The strategy used is determined by the `spec.updateStrategy` field of the StatefulSet API Object. This feature can be used to upgrade the container images, resource requests and/or limits, labels, and annotations of the Pods in a StatefulSet. There are two valid update strategies, `RollingUpdate` and `OnDelete`.

`RollingUpdate` update strategy is the default for StatefulSets.

RollingUpdate

The `RollingUpdate` update strategy will update all Pods in a StatefulSet, in reverse ordinal order, while respecting the StatefulSet guarantees.

Patch the `web` StatefulSet to apply the `RollingUpdate` update strategy:

```
kubectl patch statefulset web -p '{"spec":{"updateStrategy":{"type":"RollingUpdate"}}}'
```

```
statefulset.apps/web patched
```

In one terminal window, patch the `web` StatefulSet to change the container image again:

```
kubectl patch statefulset web --type='json' -p='[{"op": "replace", "path": "/spec/template/spec/containers/0/image", "value":"gcr.io/google_containers/nginx-slim:0.8"}]'
```

```
statefulset.apps/web patched
```

In another terminal, watch the Pods in the StatefulSet:

```
kubectl get pod -l app=nginx -w
```

The output is similar to:

```
NAME      READY     STATUS    RESTARTS   AGE
web-0     1/1       Running   0          7m
web-1     1/1       Running   0          7m
web-2     1/1       Running   0          8m
web-2     1/1       Terminating   0         8m
web-2     1/1       Terminating   0         8m
web-2     0/1       Terminating   0         8m
web-2     0/1       Terminating   0         8m
web-2     0/1       Terminating   0         8m
web-2     0/1       Terminating   0         8m
```

```
web-2    0/1      Pending   0        0s
web-2    0/1      Pending   0        0s
web-2    0/1      ContainerCreating   0        0s
web-2    1/1      Running   0        19s
web-1    1/1      Terminating   0        8m
web-1    0/1      Terminating   0        8m
web-1    0/1      Terminating   0        8m
web-1    0/1      Terminating   0        8m
web-1    0/1      Pending   0        0s
web-1    0/1      Pending   0        0s
web-1    0/1      ContainerCreating   0        0s
web-1    1/1      Running   0        6s
web-0    1/1      Terminating   0        7m
web-0    1/1      Terminating   0        7m
web-0    0/1      Terminating   0        7m
web-0    0/1      Terminating   0        7m
web-0    0/1      Terminating   0        7m
web-0    0/1      Terminating   0        7m
web-0    0/1      Pending   0        0s
web-0    0/1      Pending   0        0s
web-0    0/1      ContainerCreating   0        0s
web-0    1/1      Running   0        10s
```

The Pods in the StatefulSet are updated in reverse ordinal order. The StatefulSet controller terminates each Pod, and waits for it to transition to Running and Ready prior to updating the next Pod. Note that, even though the StatefulSet controller will not proceed to update the next Pod until its ordinal successor is Running and Ready, it will restore any Pod that fails during the update to its current version.

Pods that have already received the update will be restored to the updated version, and Pods that have not yet received the update will be restored to the previous version. In this way, the controller attempts to continue to keep the application healthy and the update consistent in the presence of intermittent failures.

Get the Pods to view their container images:

```
for p in 0 1 2; do kubectl get pod "web-$p" --template '{{range $i, $c := .spec.containers}}{{$c.image}}{{end}}'; echo; done
```

```
registry.k8s.io/nginx-slim:0.8
registry.k8s.io/nginx-slim:0.8
registry.k8s.io/nginx-slim:0.8
```

All the Pods in the StatefulSet are now running the previous container image.

Note: You can also use `kubectl rollout status sts/<name>` to view the status of a rolling update to a StatefulSet

Staging an update

You can stage an update to a StatefulSet by using the `partition` parameter of the `RollingUpdate` update strategy. A staged update will keep all of the Pods in the StatefulSet at the current version while allowing mutations to the StatefulSet's `.spec.template`.

Patch the web StatefulSet to add a partition to the updateStrategy field:

```
kubectl patch statefulset web -p '{"spec":{"updateStrategy":
{"type":"RollingUpdate","rollingUpdate":{"partition":3}}}}'
```

```
statefulset.apps/web patched
```

Patch the StatefulSet again to change the container's image:

```
kubectl patch statefulset web --type='json' -p='[{"op": "replace", "path": "/spec/template/spec/
containers/0/image", "value":"registry.k8s.io/nginx-slim:0.7"}]'
```

```
statefulset.apps/web patched
```

Delete a Pod in the StatefulSet:

```
kubectl delete pod web-2
```

```
pod "web-2" deleted
```

Wait for the Pod to be Running and Ready.

```
kubectl get pod -l app=nginx -w
```

```
NAME      READY     STATUS              RESTARTS   AGE
web-0     1/1       Running             0          4m
web-1     1/1       Running             0          4m
web-2     0/1       ContainerCreating   0          11s
web-2     1/1       Running   0         18s
```

Get the Pod's container image:

```
kubectl get pod web-2 --template '{{range $i, $c := .spec.containers}}{{$c.image}}{{end}}'
```

```
registry.k8s.io/nginx-slim:0.8
```

Notice that, even though the update strategy is RollingUpdate the StatefulSet restored the Pod with its original container. This is because the ordinal of the Pod is less than the partition specified by the updateStrategy.

Rolling out a canary

You can roll out a canary to test a modification by decrementing the partition you specified above.

Patch the StatefulSet to decrement the partition:

```
kubectl patch statefulset web -p '{"spec":{"updateStrategy":
{"type":"RollingUpdate","rollingUpdate":{"partition":2}}}}'
```

```
statefulset.apps/web patched
```

Wait for web-2 to be Running and Ready.

```
kubectl get pod -l app=nginx -w
```

```
NAME      READY     STATUS              RESTARTS   AGE
web-0     1/1       Running             0          4m
web-1     1/1       Running             0          4m
web-2     0/1       ContainerCreating   0          11s
web-2     1/1       Running   0         18s
```

Get the Pod's container:

```
kubectl get pod web-2 --template '{{range $i, $c := .spec.containers}}{{$c.image}}{{end}}'
```

```
registry.k8s.io/nginx-slim:0.7
```

When you changed the `partition`, the StatefulSet controller automatically updated the `web-2` Pod because the Pod's ordinal was greater than or equal to the `partition`.

Delete the `web-1` Pod:

```
kubectl delete pod web-1
```

```
pod "web-1" deleted
```

Wait for the `web-1` Pod to be Running and Ready.

```
kubectl get pod -l app=nginx -w
```

The output is similar to:

```
NAME      READY     STATUS        RESTARTS   AGE
web-0     1/1       Running       0          6m
web-1     0/1       Terminating   0          6m
web-2     1/1       Running       0          2m
web-1     0/1       Terminating   0         6m
web-1     0/1       Terminating   0         6m
web-1     0/1       Terminating   0         6m
web-1     0/1       Pending   0         0s
web-1     0/1       Pending   0         0s
web-1     0/1       ContainerCreating   0         0s
web-1     1/1       Running   0         18s
```

Get the `web-1` Pod's container image:

```
kubectl get pod web-1 --template '{{range $i, $c := .spec.containers}}{{$c.image}}{{end}}'
```

```
registry.k8s.io/nginx-slim:0.8
```

`web-1` was restored to its original configuration because the Pod's ordinal was less than the partition. When a partition is specified, all Pods with an ordinal that is greater than or equal to the partition will be updated when the StatefulSet's `.spec.template` is updated. If a Pod that has an ordinal less than the partition is deleted or otherwise terminated, it will be restored to its original configuration.

Phased roll outs

You can perform a phased roll out (e.g. a linear, geometric, or exponential roll out) using a partitioned rolling update in a similar manner to how you rolled out a [canary](). To perform a phased roll out, set the `partition` to the ordinal at which you want the controller to pause the update.

The partition is currently set to `2`. Set the partition to `0`:

```
kubectl patch statefulset web -p '{"spec":{"updateStrategy":{"type":"RollingUpdate","rollingUpdate":{"partition":0}}}}'
```

```
statefulset.apps/web patched
```

Wait for all of the Pods in the StatefulSet to become Running and Ready.

```
kubectl get pod -l app=nginx -w
```

The output is similar to:

```
NAME    READY   STATUS              RESTARTS   AGE
web-0   1/1     Running             0          3m
web-1   0/1     ContainerCreating   0          11s
web-2   1/1     Running             0          2m
web-1   1/1     Running   0         18s
web-0   1/1     Terminating   0         3m
web-0   1/1     Terminating   0         3m
web-0   0/1     Terminating   0         3m
web-0   0/1     Terminating   0         3m
web-0   0/1     Terminating   0         3m
web-0   0/1     Terminating   0         3m
web-0   0/1     Pending   0         0s
web-0   0/1     Pending   0         0s
web-0   0/1     ContainerCreating   0         0s
web-0   1/1     Running   0         3s
```

Get the container image details for the Pods in the StatefulSet:

```
for p in 0 1 2; do kubectl get pod "web-$p" --template '{{range $i, $c := .spec.containers}}{{$c.image}}{{end}}'; echo; done
```

```
registry.k8s.io/nginx-slim:0.7
registry.k8s.io/nginx-slim:0.7
registry.k8s.io/nginx-slim:0.7
```

By moving the `partition` to `0`, you allowed the StatefulSet to continue the update process.

OnDelete

The `OnDelete` update strategy implements the legacy (1.6 and prior) behavior, When you select this update strategy, the StatefulSet controller will not automatically update Pods when a modification is made to the StatefulSet's `.spec.template` field. This strategy can be selected by setting the `.spec.template.updateStrategy.type` to `OnDelete`.

Deleting StatefulSets

StatefulSet supports both Non-Cascading and Cascading deletion. In a Non-Cascading Delete, the StatefulSet's Pods are not deleted when the StatefulSet is deleted. In a Cascading Delete, both the StatefulSet and its Pods are deleted.

Non-cascading delete

In one terminal window, watch the Pods in the StatefulSet.

```
kubectl get pods -w -l app=nginx
```

Use [kubectl delete](https://kubernetes.io/docs/reference/generated/kubectl/kubectl-commands/#delete) to delete the StatefulSet. Make sure to supply the `--cascade=orphan` parameter to the command. This parameter tells Kubernetes to only delete the StatefulSet, and to not delete any of its Pods.

```
kubectl delete statefulset web --cascade=orphan
```

```
statefulset.apps "web" deleted
```

Get the Pods, to examine their status:

```
kubectl get pods -l app=nginx
```

```
NAME      READY     STATUS    RESTARTS   AGE
web-0     1/1       Running   0          6m
web-1     1/1       Running   0          7m
web-2     1/1       Running   0          5m
```

Even though `web` has been deleted, all of the Pods are still Running and Ready. Delete `web-0`:

```
kubectl delete pod web-0
```

```
pod "web-0" deleted
```

Get the StatefulSet's Pods:

```
kubectl get pods -l app=nginx
```

```
NAME      READY     STATUS    RESTARTS   AGE
web-1     1/1       Running   0          10m
web-2     1/1       Running   0          7m
```

As the `web` StatefulSet has been deleted, `web-0` has not been relaunched.

In one terminal, watch the StatefulSet's Pods.

```
kubectl get pods -w -l app=nginx
```

In a second terminal, recreate the StatefulSet. Note that, unless you deleted the `nginx` Service (which you should not have), you will see an error indicating that the Service already exists.

```
kubectl apply -f web.yaml
```

```
statefulset.apps/web created
service/nginx unchanged
```

Ignore the error. It only indicates that an attempt was made to create the *nginx* headless Service even though that Service already exists.

Examine the output of the `kubectl get` command running in the first terminal.

```
kubectl get pods -w -l app=nginx
```

```
NAME      READY     STATUS    RESTARTS   AGE
web-1     1/1       Running   0          16m
web-2     1/1       Running   0          2m
NAME      READY     STATUS    RESTARTS   AGE
web-0     0/1       Pending   0          0s
web-0     0/1       Pending   0         0s
web-0     0/1       ContainerCreating   0         0s
web-0     1/1       Running   0         18s
web-2     1/1       Terminating   0         3m
web-2     0/1       Terminating   0         3m
web-2     0/1       Terminating   0         3m
web-2     0/1       Terminating   0         3m
```

When the `web` StatefulSet was recreated, it first relaunched `web-0`. Since `web-1` was already Running and Ready, when `web-0` transitioned to Running and Ready, it adopted this Pod. Since you recreated the StatefulSet with `replicas` equal to 2, once `web-0` had been recreated, and once `web-1` had been determined to already be Running and Ready, `web-2` was terminated.

Let's take another look at the contents of the `index.html` file served by the Pods' webservers:

```
for i in 0 1; do kubectl exec -i -t "web-$i" -- curl http://localhost/; done
```

```
web-0
web-1
```

Even though you deleted both the StatefulSet and the `web-0` Pod, it still serves the hostname originally entered into its `index.html` file. This is because the StatefulSet never deletes the PersistentVolumes associated with a Pod. When you recreated the StatefulSet and it relaunched `web-0`, its original PersistentVolume was remounted.

Cascading delete

In one terminal window, watch the Pods in the StatefulSet.

```
kubectl get pods -w -l app=nginx
```

In another terminal, delete the StatefulSet again. This time, omit the `--cascade=orphan` parameter.

```
kubectl delete statefulset web
```

```
statefulset.apps "web" deleted
```

Examine the output of the kubectl get command running in the first terminal, and wait for all of the Pods to transition to Terminating.

```
kubectl get pods -w -l app=nginx
```

```
NAME      READY     STATUS    RESTARTS   AGE
web-0     1/1       Running   0          11m
web-1     1/1       Running   0          27m
NAME      READY     STATUS        RESTARTS   AGE
web-0     1/1       Terminating   0          12m
web-1     1/1       Terminating   0         29m
web-0     0/1       Terminating   0         12m
web-0     0/1       Terminating   0         12m
web-0     0/1       Terminating   0         12m
web-1     0/1       Terminating   0         29m
web-1     0/1       Terminating   0         29m
web-1     0/1       Terminating   0         29m
```

As you saw in the [Scaling Down] section, the Pods are terminated one at a time, with respect to the reverse order of their ordinal indices. Before terminating a Pod, the StatefulSet controller waits for the Pod's successor to be completely terminated.

Note: Although a cascading delete removes a StatefulSet together with its Pods, the cascade does not delete the headless Service associated with the StatefulSet. You must delete the nginx Service manually.

```
kubectl delete service nginx
```

```
service "nginx" deleted
```

Recreate the StatefulSet and headless Service one more time:

```
kubectl apply -f web.yaml
```

```
service/nginx created
statefulset.apps/web created
```

When all of the StatefulSet's Pods transition to Running and Ready, retrieve the contents of their index.html files:

```
for i in 0 1; do kubectl exec -i -t "web-$i" -- curl http://localhost/; done
```

```
web-0
web-1
```

Even though you completely deleted the StatefulSet, and all of its Pods, the Pods are recreated with their PersistentVolumes mounted, and web-0 and web-1 continue to serve their hostnames.

Finally, delete the nginx Service...

```
kubectl delete service nginx
```

```
service "nginx" deleted
```

…and the `web` StatefulSet:

```
kubectl delete statefulset web
```

```
statefulset "web" deleted
```

Pod management policy

For some distributed systems, the StatefulSet ordering guarantees are unnecessary and/or undesirable. These systems require only uniqueness and identity. To address this, in Kubernetes 1.7, we introduced `.spec.podManagementPolicy` to the StatefulSet API Object.

OrderedReady Pod management

`OrderedReady` pod management is the default for StatefulSets. It tells the StatefulSet controller to respect the ordering guarantees demonstrated above.

Parallel Pod management

`Parallel` pod management tells the StatefulSet controller to launch or terminate all Pods in parallel, and not to wait for Pods to become Running and Ready or completely terminated prior to launching or terminating another Pod. This option only affects the behavior for scaling operations. Updates are not affected.

[application/web/web-parallel.yaml]

```
apiVersion: v1
kind: Service
metadata:
  name: nginx
  labels:
    app: nginx
spec:
  ports:
  - port: 80
    name: web
  clusterIP: None
  selector:
    app: nginx
---
apiVersion: apps/v1
kind: StatefulSet
metadata:
  name: web
spec:
  serviceName: "nginx"
  podManagementPolicy: "Parallel"
  replicas: 2
  selector:
    matchLabels:
      app: nginx
  template:
```

```
    metadata:
      labels:
        app: nginx
    spec:
      containers:
      - name: nginx
        image: registry.k8s.io/nginx-slim:0.8
        ports:
        - containerPort: 80
          name: web
        volumeMounts:
        - name: www
          mountPath: /usr/share/nginx/html
  volumeClaimTemplates:
  - metadata:
      name: www
    spec:
      accessModes: [ "ReadWriteOnce" ]
      resources:
        requests:
          storage: 1Gi
```

Download the example above, and save it to a file named `web-parallel.yaml`

This manifest is identical to the one you downloaded above except that the `.spec.podManagementPolicy` of the `web` StatefulSet is set to `Parallel`.

In one terminal, watch the Pods in the StatefulSet.

```
kubectl get pod -l app=nginx -w
```

In another terminal, create the StatefulSet and Service in the manifest:

```
kubectl apply -f web-parallel.yaml
```

```
service/nginx created
statefulset.apps/web created
```

Examine the output of the `kubectl get` command that you executed in the first terminal.

```
kubectl get pod -l app=nginx -w
```

```
NAME      READY     STATUS    RESTARTS   AGE
web-0     0/1       Pending   0          0s
web-0     0/1       Pending   0         0s
web-1     0/1       Pending   0         0s
web-1     0/1       Pending   0         0s
web-0     0/1       ContainerCreating   0         0s
web-1     0/1       ContainerCreating   0         0s
web-0     1/1       Running   0         10s
web-1     1/1       Running   0         10s
```

The StatefulSet controller launched both `web-0` and `web-1` at the same time.

Keep the second terminal open, and, in another terminal window scale the StatefulSet:

```
kubectl scale statefulset/web --replicas=4
```

```
statefulset.apps/web scaled
```

Examine the output of the terminal where the `kubectl get` command is running.

```
web-3     0/1       Pending   0         0s
web-3     0/1       Pending   0         0s
web-3     0/1       Pending   0         7s
web-3     0/1       ContainerCreating   0         7s
web-2     1/1       Running   0         10s
web-3     1/1       Running   0         26s
```

The StatefulSet launched two new Pods, and it did not wait for the first to become Running and Ready prior to launching the second.

Cleaning up

You should have two terminals open, ready for you to run `kubectl` commands as part of cleanup.

```
kubectl delete sts web
# sts is an abbreviation for statefulset
```

You can watch `kubectl get` to see those Pods being deleted.

```
kubectl get pod -l app=nginx -w
```

```
web-3     1/1       Terminating   0         9m
web-2     1/1       Terminating   0         9m
web-3     1/1       Terminating   0         9m
web-2     1/1       Terminating   0         9m
web-1     1/1       Terminating   0         44m
web-0     1/1       Terminating   0         44m
web-0     0/1       Terminating   0         44m
web-3     0/1       Terminating   0         9m
web-2     0/1       Terminating   0         9m
web-1     0/1       Terminating   0         44m
web-0     0/1       Terminating   0         44m
web-2     0/1       Terminating   0         9m
web-2     0/1       Terminating   0         9m
web-2     0/1       Terminating   0         9m
web-1     0/1       Terminating   0         44m
web-1     0/1       Terminating   0         44m
web-1     0/1       Terminating   0         44m
web-0     0/1       Terminating   0         44m
web-0     0/1       Terminating   0         44m
web-0     0/1       Terminating   0         44m
web-3     0/1       Terminating   0         9m
web-3     0/1       Terminating   0         9m
web-3     0/1       Terminating   0         9m
```

During deletion, a StatefulSet removes all Pods concurrently; it does not wait for a Pod's ordinal successor to terminate prior to deleting that Pod.

Close the terminal where the kubectl get command is running and delete the nginx Service:

```
kubectl delete svc nginx
```

Delete the persistent storage media for the PersistentVolumes used in this tutorial.

```
kubectl get pvc
```

```
NAME        STATUS    VOLUME                                     CAPACITY   ACCESS MODES   STORAGECLASS   AGE
www-web-0   Bound     pvc-2bf00408-d366-4a12-bad0-1869c65d0bee   1Gi        RWO            standard       25m
www-web-1   Bound     pvc-ba3bfe9c-413e-4b95-a2c0-3ea8a54dbab4   1Gi        RWO            standard       24m
www-web-2   Bound     pvc-cba6cfa6-3a47-486b-a138-db5930207eaf   1Gi        RWO            standard       15m
www-web-3   Bound     pvc-0c04d7f0-787a-4977-8da3-d9d3a6d8d752   1Gi        RWO            standard       15m
www-web-4   Bound     pvc-b2c73489-e70b-4a4e-9ec1-9eab439aa43e   1Gi        RWO            standard       14m
```

```
kubectl get pv
```

```
NAME                                       CAPACITY   ACCESS MODES   RECLAIM POLICY   STATUS   CLAIM               STORAGECLASS   REASON   AGE
pvc-0c04d7f0-787a-4977-8da3-d9d3a6d8d752   1Gi        RWO            Delete           Bound    default/www-web-3   standard                15m
pvc-2bf00408-d366-4a12-bad0-1869c65d0bee   1Gi        RWO            Delete           Bound    default/www-web-0   standard                25m
pvc-b2c73489-e70b-4a4e-9ec1-9eab439aa43e   1Gi        RWO            Delete           Bound    default/www-web-4   standard                14m
pvc-ba3bfe9c-413e-4b95-a2c0-3ea8a54dbab4   1Gi        RWO            Delete           Bound    default/www-web-1   standard                24m
pvc-cba6cfa6-3a47-486b-a138-db5930207eaf   1Gi        RWO            Delete           Bound    default/www-web-2   standard                15m
```

```
kubectl delete pvc www-web-0 www-web-1 www-web-2 www-web-3 www-web-4
```

```
persistentvolumeclaim "www-web-0" deleted
persistentvolumeclaim "www-web-1" deleted
persistentvolumeclaim "www-web-2" deleted
persistentvolumeclaim "www-web-3" deleted
persistentvolumeclaim "www-web-4" deleted
```

```
kubectl get pvc
```

```
No resources found in default namespace.
```

Note: You also need to delete the persistent storage media for the PersistentVolumes used in this tutorial. Follow the necessary steps, based on your environment, storage configuration, and provisioning method, to ensure that all storage is reclaimed.

Example: Deploying WordPress and MySQL with Persistent Volumes

This tutorial shows you how to deploy a WordPress site and a MySQL database using Minikube. Both applications use PersistentVolumes and PersistentVolumeClaims to store data.

A PersistentVolume (PV) is a piece of storage in the cluster that has been manually provisioned by an administrator, or dynamically provisioned by Kubernetes using a StorageClass. A PersistentVolumeClaim (PVC) is a request for storage by a user that can be fulfilled by a PV. PersistentVolumes and PersistentVolumeClaims are independent from Pod lifecycles and preserve data through restarting, rescheduling, and even deleting Pods.

Warning: This deployment is not suitable for production use cases, as it uses single instance WordPress and MySQL Pods. Consider using WordPress Helm Chart to deploy WordPress in production.
Note: The files provided in this tutorial are using GA Deployment APIs and are specific to kubernetes version 1.9 and later. If you wish to use this tutorial with an earlier version of Kubernetes, please update the API version appropriately, or reference earlier versions of this tutorial.

Objectives

- Create PersistentVolumeClaims and PersistentVolumes
- Create a `kustomization.yaml` with
    - a Secret generator
    - MySQL resource configs
    - WordPress resource configs
- Apply the kustomization directory by `kubectl apply -k ./`
- Clean up

Before you begin

You need to have a Kubernetes cluster, and the kubectl command-line tool must be configured to communicate with your cluster. It is recommended to run this tutorial on a cluster with at least two nodes that are not acting as control plane hosts. If you do not already have a cluster, you can create one by using minikube or you can use one of these Kubernetes playgrounds:

- Killercoda
- Play with Kubernetes

To check the version, enter `kubectl version`.

The example shown on this page works with `kubectl` 1.27 and above.

Download the following configuration files:

1. mysql-deployment.yaml

2. wordpress-deployment.yaml

Create PersistentVolumeClaims and PersistentVolumes

MySQL and Wordpress each require a PersistentVolume to store data. Their PersistentVolumeClaims will be created at the deployment step.

Many cluster environments have a default StorageClass installed. When a StorageClass is not specified in the PersistentVolumeClaim, the cluster's default StorageClass is used instead.

When a PersistentVolumeClaim is created, a PersistentVolume is dynamically provisioned based on the StorageClass configuration.

Warning: In local clusters, the default StorageClass uses the `hostPath` provisioner. `hostPath` volumes are only suitable for development and testing. With `hostPath` volumes, your data lives in `/tmp` on the node the Pod is scheduled onto and does not move between nodes. If a Pod dies and gets scheduled to another node in the cluster, or the node is rebooted, the data is lost.
Note: If you are bringing up a cluster that needs to use the `hostPath` provisioner, the `--enable-hostpath-provisioner` flag must be set in the `controller-manager` component.
Note: If you have a Kubernetes cluster running on Google Kubernetes Engine, please follow this guide.

Create a kustomization.yaml

Add a Secret generator

A Secret is an object that stores a piece of sensitive data like a password or key. Since 1.14, `kubectl` supports the management of Kubernetes objects using a kustomization file. You can create a Secret by generators in `kustomization.yaml`.

Add a Secret generator in `kustomization.yaml` from the following command. You will need to replace `YOUR_PASSWORD` with the password you want to use.

```
cat <<EOF >./kustomization.yaml
secretGenerator:
- name: mysql-pass
  literals:
  - password=YOUR_PASSWORD
EOF
```

Add resource configs for MySQL and WordPress

The following manifest describes a single-instance MySQL Deployment. The MySQL container mounts the PersistentVolume at /var/lib/mysql. The `MYSQL_ROOT_PASSWORD` environment variable sets the database password from the Secret.

application/wordpress/mysql-deployment.yaml

```
apiVersion: v1
kind: Service
metadata:
  name: wordpress-mysql
  labels:
    app: wordpress
```

```yaml
spec:
  ports:
    - port: 3306
  selector:
    app: wordpress
    tier: mysql
  clusterIP: None
---
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: mysql-pv-claim
  labels:
    app: wordpress
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 20Gi
---
apiVersion: apps/v1
kind: Deployment
metadata:
  name: wordpress-mysql
  labels:
    app: wordpress
spec:
  selector:
    matchLabels:
      app: wordpress
      tier: mysql
  strategy:
    type: Recreate
  template:
    metadata:
      labels:
        app: wordpress
        tier: mysql
    spec:
      containers:
      - image: mysql:8.0
        name: mysql
        env:
        - name: MYSQL_ROOT_PASSWORD
          valueFrom:
            secretKeyRef:
              name: mysql-pass
              key: password
        - name: MYSQL_DATABASE
          value: wordpress
        - name: MYSQL_USER
          value: wordpress
```

```
    - name: MYSQL_PASSWORD
      valueFrom:
        secretKeyRef:
          name: mysql-pass
          key: password
    ports:
    - containerPort: 3306
      name: mysql
    volumeMounts:
    - name: mysql-persistent-storage
      mountPath: /var/lib/mysql
  volumes:
  - name: mysql-persistent-storage
    persistentVolumeClaim:
      claimName: mysql-pv-claim
```

The following manifest describes a single-instance WordPress Deployment. The WordPress container mounts the PersistentVolume at `/var/www/html` for website data files. The `WORDPRESS_DB_HOST` environment variable sets the name of the MySQL Service defined above, and WordPress will access the database by Service. The `WORDPRESS_DB_PASSWORD` environment variable sets the database password from the Secret kustomize generated.

application/wordpress/wordpress-deployment.yaml

```
apiVersion: v1
kind: Service
metadata:
  name: wordpress
  labels:
    app: wordpress
spec:
  ports:
    - port: 80
  selector:
    app: wordpress
    tier: frontend
  type: LoadBalancer
---
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: wp-pv-claim
  labels:
    app: wordpress
spec:
  accessModes:
    - ReadWriteOnce
  resources:
    requests:
      storage: 20Gi
---
apiVersion: apps/v1
kind: Deployment
```

```yaml
metadata:
  name: wordpress
  labels:
    app: wordpress
spec:
  selector:
    matchLabels:
      app: wordpress
      tier: frontend
  strategy:
    type: Recreate
  template:
    metadata:
      labels:
        app: wordpress
        tier: frontend
    spec:
      containers:
      - image: wordpress:6.2.1-apache
        name: wordpress
        env:
        - name: WORDPRESS_DB_HOST
          value: wordpress-mysql
        - name: WORDPRESS_DB_PASSWORD
          valueFrom:
            secretKeyRef:
              name: mysql-pass
              key: password
        - name: WORDPRESS_DB_USER
          value: wordpress
        ports:
        - containerPort: 80
          name: wordpress
        volumeMounts:
        - name: wordpress-persistent-storage
          mountPath: /var/www/html
      volumes:
      - name: wordpress-persistent-storage
        persistentVolumeClaim:
          claimName: wp-pv-claim
```

1. Download the MySQL deployment configuration file.

   ```
   curl -LO https://k8s.io/examples/application/wordpress/mysql-deployment.yaml
   ```

2. Download the WordPress configuration file.

   ```
   curl -LO https://k8s.io/examples/application/wordpress/wordpress-deployment.yaml
   ```

3. Add them to `kustomization.yaml` file.

   ```
   cat <<EOF >>./kustomization.yaml
   resources:
     - mysql-deployment.yaml
   ```

```
  - wordpress-deployment.yaml
EOF
```

Apply and Verify

The kustomization.yaml contains all the resources for deploying a WordPress site and a MySQL database. You can apply the directory by

```
kubectl apply -k ./
```

Now you can verify that all objects exist.

1. Verify that the Secret exists by running the following command:

   ```
   kubectl get secrets
   ```

   The response should be like this:

   ```
   NAME                  TYPE                    DATA   AGE
   mysql-pass-c57bb4t7mf   Opaque                  1      9s
   ```

2. Verify that a PersistentVolume got dynamically provisioned.

   ```
   kubectl get pvc
   ```

   Note: It can take up to a few minutes for the PVs to be provisioned and bound.

   The response should be like this:

   ```
   NAME             STATUS    VOLUME                                     CAPACITY   ACCESS MODES
   STORAGECLASS       AGE
   mysql-pv-claim   Bound     pvc-8cbd7b2e-4044-11e9-b2bb-42010a800002   20Gi
   RWO            standard           77s
   wp-pv-claim      Bound     pvc-8cd0df54-4044-11e9-b2bb-42010a800002   20Gi
   RWO            standard           77s
   ```

3. Verify that the Pod is running by running the following command:

   ```
   kubectl get pods
   ```

   Note: It can take up to a few minutes for the Pod's Status to be RUNNING.

   The response should be like this:

   ```
   NAME                               READY     STATUS    RESTARTS   AGE
   wordpress-mysql-1894417608-x5dzt   1/1       Running   0          40s
   ```

4. Verify that the Service is running by running the following command:

   ```
   kubectl get services wordpress
   ```

   The response should be like this:

   ```
   NAME        TYPE            CLUSTER-IP   EXTERNAL-IP   PORT(S)        AGE
   wordpress   LoadBalancer    10.0.0.89    <pending>     80:32406/TCP   4m
   ```

Note: Minikube can only expose Services through `NodePort`. The EXTERNAL-IP is always pending.

5. Run the following command to get the IP Address for the WordPress Service:

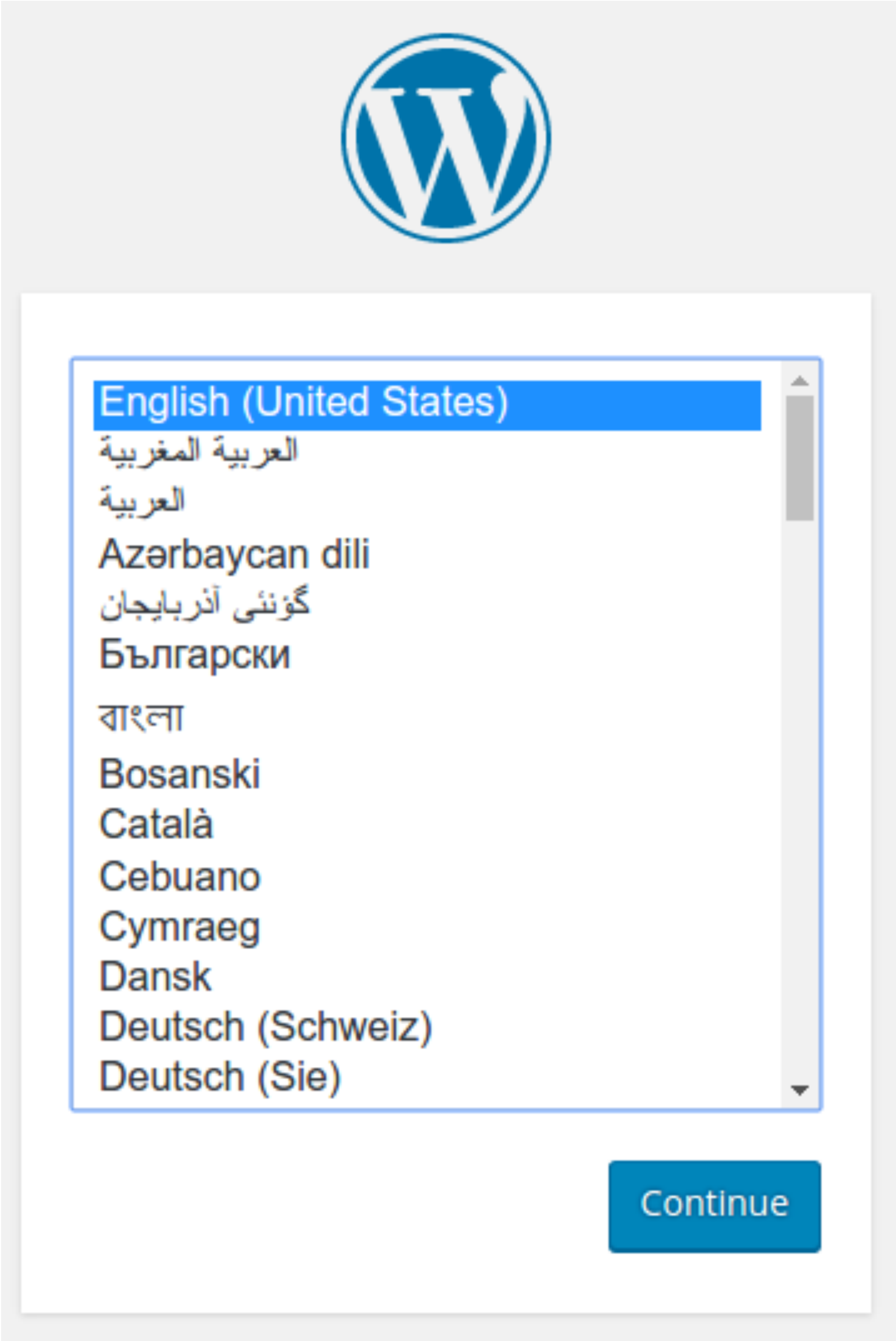
   ```
   minikube service wordpress --url
   ```

   The response should be like this:

   ```
   http://1.2.3.4:32406
   ```

6. Copy the IP address, and load the page in your browser to view your site.

   You should see the WordPress set up page similar to the following screenshot.



Warning: Do not leave your WordPress installation on this page. If another user finds it, they can set up a website on your instance and use it to serve malicious content.

Either install WordPress by creating a username and password or delete your instance.

Cleaning up

1. Run the following command to delete your Secret, Deployments, Services and PersistentVolumeClaims:

   ```
   kubectl delete -k ./
   ```

What's next

- Learn more about Introspection and Debugging
- Learn more about Jobs
- Learn more about Port Forwarding
- Learn how to Get a Shell to a Container

Example: Deploying Cassandra with a StatefulSet

This tutorial shows you how to run Apache Cassandra on Kubernetes. Cassandra, a database, needs persistent storage to provide data durability (application *state*). In this example, a custom Cassandra seed provider lets the database discover new Cassandra instances as they join the Cassandra cluster.

StatefulSets make it easier to deploy stateful applications into your Kubernetes cluster. For more information on the features used in this tutorial, see StatefulSet.

Note:

Cassandra and Kubernetes both use the term *node* to mean a member of a cluster. In this tutorial, the Pods that belong to the StatefulSet are Cassandra nodes and are members of the Cassandra cluster (called a *ring*). When those Pods run in your Kubernetes cluster, the Kubernetes control plane schedules those Pods onto Kubernetes Nodes.

When a Cassandra node starts, it uses a *seed list* to bootstrap discovery of other nodes in the ring. This tutorial deploys a custom Cassandra seed provider that lets the database discover new Cassandra Pods as they appear inside your Kubernetes cluster.

Objectives

- Create and validate a Cassandra headless Service.
- Use a StatefulSet to create a Cassandra ring.
- Validate the StatefulSet.
- Modify the StatefulSet.
- Delete the StatefulSet and its Pods.

Before you begin

You need to have a Kubernetes cluster, and the kubectl command-line tool must be configured to communicate with your cluster. It is recommended to run this tutorial on a cluster with at least two nodes that are not acting as control plane hosts. If you do not already have a cluster, you can create one by using minikube or you can use one of these Kubernetes playgrounds:

- Killercoda
- Play with Kubernetes

To complete this tutorial, you should already have a basic familiarity with Pods, Services, and StatefulSets.

Additional Minikube setup instructions

Caution:

Minikube defaults to 2048MB of memory and 2 CPU. Running Minikube with the default resource configuration results in insufficient resource errors during this tutorial. To avoid these errors, start Minikube with the following settings:

```
minikube start --memory 5120 --cpus=4
```

Creating a headless Service for Cassandra

In Kubernetes, a Service describes a set of Pods that perform the same task.

The following Service is used for DNS lookups between Cassandra Pods and clients within your cluster:

application/cassandra/cassandra-service.yaml

```
apiVersion: v1
kind: Service
metadata:
  labels:
    app: cassandra
  name: cassandra
spec:
  clusterIP: None
  ports:
  - port: 9042
  selector:
    app: cassandra
```

Create a Service to track all Cassandra StatefulSet members from the `cassandra-service.yaml` file:

```
kubectl apply -f https://k8s.io/examples/application/cassandra/cassandra-service.yaml
```

Validating (optional)

Get the Cassandra Service.

```
kubectl get svc cassandra
```

The response is

```
NAME        TYPE        CLUSTER-IP   EXTERNAL-IP   PORT(S)    AGE
cassandra   ClusterIP   None         <none>        9042/TCP   45s
```

If you don't see a Service named `cassandra`, that means creation failed. Read [Debug Services]() for help troubleshooting common issues.

Using a StatefulSet to create a Cassandra ring

The StatefulSet manifest, included below, creates a Cassandra ring that consists of three Pods.

Note: This example uses the default provisioner for Minikube. Please update the following StatefulSet for the cloud you are working with.
[application/cassandra/cassandra-statefulset.yaml]()

```yaml
apiVersion: apps/v1
kind: StatefulSet
metadata:
  name: cassandra
  labels:
    app: cassandra
spec:
  serviceName: cassandra
  replicas: 3
  selector:
    matchLabels:
      app: cassandra
  template:
    metadata:
      labels:
        app: cassandra
    spec:
      terminationGracePeriodSeconds: 1800
      containers:
      - name: cassandra
        image: gcr.io/google-samples/cassandra:v13
        imagePullPolicy: Always
        ports:
        - containerPort: 7000
          name: intra-node
        - containerPort: 7001
          name: tls-intra-node
        - containerPort: 7199
          name: jmx
        - containerPort: 9042
          name: cql
```

```
    resources:
      limits:
        cpu: "500m"
        memory: 1Gi
      requests:
        cpu: "500m"
        memory: 1Gi
    securityContext:
      capabilities:
        add:
          - IPC_LOCK
    lifecycle:
      preStop:
        exec:
          command:
          - /bin/sh
          - -c
          - nodetool drain
    env:
      - name: MAX_HEAP_SIZE
        value: 512M
      - name: HEAP_NEWSIZE
        value: 100M
      - name: CASSANDRA_SEEDS
        value: "cassandra-0.cassandra.default.svc.cluster.local"
      - name: CASSANDRA_CLUSTER_NAME
        value: "K8Demo"
      - name: CASSANDRA_DC
        value: "DC1-K8Demo"
      - name: CASSANDRA_RACK
        value: "Rack1-K8Demo"
      - name: POD_IP
        valueFrom:
          fieldRef:
            fieldPath: status.podIP
    readinessProbe:
      exec:
        command:
        - /bin/bash
        - -c
        - /ready-probe.sh
      initialDelaySeconds: 15
      timeoutSeconds: 5
    # These volume mounts are persistent. They are like inline claims,
    # but not exactly because the names need to match exactly one of
    # the stateful pod volumes.
    volumeMounts:
    - name: cassandra-data
      mountPath: /cassandra_data
# These are converted to volume claims by the controller
# and mounted at the paths mentioned above.
# do not use these in production until ssd GCEPersistentDisk or other ssd pd
volumeClaimTemplates:
```

```
  - metadata:
      name: cassandra-data
    spec:
      accessModes: [ "ReadWriteOnce" ]
      storageClassName: fast
      resources:
        requests:
          storage: 1Gi
---
kind: StorageClass
apiVersion: storage.k8s.io/v1
metadata:
  name: fast
provisioner: k8s.io/minikube-hostpath
parameters:
  type: pd-ssd
```

Create the Cassandra StatefulSet from the `cassandra-statefulset.yaml` file:

```
# Use this if you are able to apply cassandra-statefulset.yaml unmodified
kubectl apply -f https://k8s.io/examples/application/cassandra/cassandra-statefulset.yaml
```

If you need to modify `cassandra-statefulset.yaml` to suit your cluster, download https://k8s.io/examples/application/cassandra/cassandra-statefulset.yaml and then apply that manifest, from the folder you saved the modified version into:

```
# Use this if you needed to modify cassandra-statefulset.yaml locally
kubectl apply -f cassandra-statefulset.yaml
```

Validating the Cassandra StatefulSet

1. Get the Cassandra StatefulSet:

   ```
   kubectl get statefulset cassandra
   ```

   The response should be similar to:

   ```
   NAME        DESIRED   CURRENT   AGE
   cassandra   3         0         13s
   ```

   The `StatefulSet` resource deploys Pods sequentially.

2. Get the Pods to see the ordered creation status:

   ```
   kubectl get pods -l="app=cassandra"
   ```

   The response should be similar to:

   ```
   NAME          READY     STATUS              RESTARTS   AGE
   cassandra-0   1/1       Running             0          1m
   cassandra-1   0/1       ContainerCreating   0          8s
   ```

   It can take several minutes for all three Pods to deploy. Once they are deployed, the same command returns output similar to:

```
NAME          READY     STATUS    RESTARTS   AGE
cassandra-0   1/1       Running   0          10m
cassandra-1   1/1       Running   0          9m
cassandra-2   1/1       Running   0          8m
```

3. Run the Cassandra [nodetool](https://cwiki.apache.org/confluence/display/CASSANDRA2/NodeTool) inside the first Pod, to display the status of the ring.

   ```
   kubectl exec -it cassandra-0 -- nodetool status
   ```

   The response should look something like:

   ```
   Datacenter: DC1-K8Demo
   ======================
   Status=Up/Down
   |/ State=Normal/Leaving/Joining/Moving
   --  Address     Load       Tokens       Owns (effective)  Host ID                               Rack
   UN  172.17.0.5  83.57 KiB  32           74.0%             e2dd09e6-d9d3-477e-96c5-45094c08db0f  Rack1-K8Demo
   UN  172.17.0.4  101.04 KiB  32           58.8%             f89d6835-3a42-4419-92b3-0e62cae1479c  Rack1-K8Demo
   UN  172.17.0.6  84.74 KiB  32           67.1%             a6a1e8c2-3dc5-4417-b1a0-26507af2aaad  Rack1-K8Demo
   ```

Modifying the Cassandra StatefulSet

Use `kubectl edit` to modify the size of a Cassandra StatefulSet.

1. Run the following command:

   ```
   kubectl edit statefulset cassandra
   ```

   This command opens an editor in your terminal. The line you need to change is the `replicas` field. The following sample is an excerpt of the StatefulSet file:

   ```
   # Please edit the object below. Lines beginning with a '#' will be ignored,
   # and an empty file will abort the edit. If an error occurs while saving this file will be
   # reopened with the relevant failures.
   #
   apiVersion: apps/v1
   kind: StatefulSet
   metadata:
     creationTimestamp: 2016-08-13T18:40:58Z
     generation: 1
     labels:
     app: cassandra
     name: cassandra
     namespace: default
     resourceVersion: "323"
     uid: 7a219483-6185-11e6-a910-42010a8a0fc0
   spec:
     replicas: 3
   ```

2. Change the number of replicas to 4, and then save the manifest.

The StatefulSet now scales to run with 4 Pods.

3. Get the Cassandra StatefulSet to verify your change:

```
kubectl get statefulset cassandra
```

The response should be similar to:

```
NAME        DESIRED   CURRENT   AGE
cassandra   4         4         36m
```

Cleaning up

Deleting or scaling a StatefulSet down does not delete the volumes associated with the StatefulSet. This setting is for your safety because your data is more valuable than automatically purging all related StatefulSet resources.

Warning: Depending on the storage class and reclaim policy, deleting the *PersistentVolumeClaims* may cause the associated volumes to also be deleted. Never assume you'll be able to access data if its volume claims are deleted.

1. Run the following commands (chained together into a single command) to delete everything in the Cassandra StatefulSet:

```
grace=$(kubectl get pod cassandra-0 -o=jsonpath='{.spec.terminationGracePeriodSeconds}') \
  && kubectl delete statefulset -l app=cassandra \
  && echo "Sleeping ${grace} seconds" 1>&2 \
  && sleep $grace \
  && kubectl delete persistentvolumeclaim -l app=cassandra
```

2. Run the following command to delete the Service you set up for Cassandra:

```
kubectl delete service -l app=cassandra
```

Cassandra container environment variables

The Pods in this tutorial use the gcr.io/google-samples/cassandra:v13 image from Google's container registry. The Docker image above is based on debian-base and includes OpenJDK 8.

This image includes a standard Cassandra installation from the Apache Debian repo. By using environment variables you can change values that are inserted into cassandra.yaml.

Environment variable	Default value
CASSANDRA_CLUSTER_NAME	'Test Cluster'
CASSANDRA_NUM_TOKENS	32
CASSANDRA_RPC_ADDRESS	0.0.0.0

What's next

- Learn how to Scale a StatefulSet.

- Learn more about the *KubernetesSeedProvider*
- See more custom Seed Provider Configurations

Running ZooKeeper, A Distributed System Coordinator

This tutorial demonstrates running Apache Zookeeper on Kubernetes using StatefulSets, PodDisruptionBudgets, and PodAntiAffinity.

Before you begin

Before starting this tutorial, you should be familiar with the following Kubernetes concepts:

- Pods
- Cluster DNS
- Headless Services
- PersistentVolumes
- PersistentVolume Provisioning
- StatefulSets
- PodDisruptionBudgets
- PodAntiAffinity
- kubectl CLI

You must have a cluster with at least four nodes, and each node requires at least 2 CPUs and 4 GiB of memory. In this tutorial you will cordon and drain the cluster's nodes. **This means that the cluster will terminate and evict all Pods on its nodes, and the nodes will temporarily become unschedulable.** You should use a dedicated cluster for this tutorial, or you should ensure that the disruption you cause will not interfere with other tenants.

This tutorial assumes that you have configured your cluster to dynamically provision PersistentVolumes. If your cluster is not configured to do so, you will have to manually provision three 20 GiB volumes before starting this tutorial.

Objectives

After this tutorial, you will know the following.

- How to deploy a ZooKeeper ensemble using StatefulSet.
- How to consistently configure the ensemble.
- How to spread the deployment of ZooKeeper servers in the ensemble.
- How to use PodDisruptionBudgets to ensure service availability during planned maintenance.

ZooKeeper

Apache ZooKeeper is a distributed, open-source coordination service for distributed applications. ZooKeeper allows you to read, write, and observe updates to data. Data are organized in a file system like hierarchy and replicated to all ZooKeeper servers in the ensemble (a set of ZooKeeper servers). All operations on data are atomic and sequentially consistent. ZooKeeper ensures this by using the Zab consensus protocol to replicate a state machine across all servers in the ensemble.

The ensemble uses the Zab protocol to elect a leader, and the ensemble cannot write data until that election is complete. Once complete, the ensemble uses Zab to ensure that it replicates all writes to a quorum before it acknowledges and makes them visible to clients. Without respect to weighted quorums, a quorum is a majority component of the ensemble containing the current leader. For instance, if the ensemble has three servers, a component that contains the leader and one other server constitutes a quorum. If the ensemble can not achieve a quorum, the ensemble cannot write data.

ZooKeeper servers keep their entire state machine in memory, and write every mutation to a durable WAL (Write Ahead Log) on storage media. When a server crashes, it can recover its previous state by replaying the WAL. To prevent the WAL from growing without bound, ZooKeeper servers will periodically snapshot them in memory state to storage media. These snapshots can be loaded directly into memory, and all WAL entries that preceded the snapshot may be discarded.

Creating a ZooKeeper ensemble

The manifest below contains a Headless Service, a Service, a PodDisruptionBudget, and a StatefulSet.

application/zookeeper/zookeeper.yaml

```
apiVersion: v1
kind: Service
metadata:
  name: zk-hs
  labels:
    app: zk
spec:
  ports:
  - port: 2888
    name: server
  - port: 3888
    name: leader-election
  clusterIP: None
  selector:
    app: zk
---
apiVersion: v1
kind: Service
metadata:
  name: zk-cs
  labels:
    app: zk
spec:
  ports:
  - port: 2181
    name: client
  selector:
    app: zk
```

```yaml
---
apiVersion: policy/v1
kind: PodDisruptionBudget
metadata:
  name: zk-pdb
spec:
  selector:
    matchLabels:
      app: zk
  maxUnavailable: 1
---
apiVersion: apps/v1
kind: StatefulSet
metadata:
  name: zk
spec:
  selector:
    matchLabels:
      app: zk
  serviceName: zk-hs
  replicas: 3
  updateStrategy:
    type: RollingUpdate
  podManagementPolicy: OrderedReady
  template:
    metadata:
      labels:
        app: zk
    spec:
      affinity:
        podAntiAffinity:
          requiredDuringSchedulingIgnoredDuringExecution:
            - labelSelector:
                matchExpressions:
                  - key: "app"
                    operator: In
                    values:
                    - zk
              topologyKey: "kubernetes.io/hostname"
      containers:
      - name: kubernetes-zookeeper
        imagePullPolicy: Always
        image: "registry.k8s.io/kubernetes-zookeeper:1.0-3.4.10"
        resources:
          requests:
            memory: "1Gi"
            cpu: "0.5"
        ports:
        - containerPort: 2181
          name: client
        - containerPort: 2888
          name: server
        - containerPort: 3888
```

```
      name: leader-election
    command:
    - sh
    - -c
    - "start-zookeeper \
      --servers=3 \
      --data_dir=/var/lib/zookeeper/data \
      --data_log_dir=/var/lib/zookeeper/data/log \
      --conf_dir=/opt/zookeeper/conf \
      --client_port=2181 \
      --election_port=3888 \
      --server_port=2888 \
      --tick_time=2000 \
      --init_limit=10 \
      --sync_limit=5 \
      --heap=512M \
      --max_client_cnxns=60 \
      --snap_retain_count=3 \
      --purge_interval=12 \
      --max_session_timeout=40000 \
      --min_session_timeout=4000 \
      --log_level=INFO"
    readinessProbe:
      exec:
        command:
        - sh
        - -c
        - "zookeeper-ready 2181"
      initialDelaySeconds: 10
      timeoutSeconds: 5
    livenessProbe:
      exec:
        command:
        - sh
        - -c
        - "zookeeper-ready 2181"
      initialDelaySeconds: 10
      timeoutSeconds: 5
    volumeMounts:
    - name: datadir
      mountPath: /var/lib/zookeeper
  securityContext:
    runAsUser: 1000
    fsGroup: 1000
volumeClaimTemplates:
- metadata:
    name: datadir
  spec:
    accessModes: [ "ReadWriteOnce" ]
    resources:
      requests:
        storage: 10Gi
```

Open a terminal, and use the kubectl apply command to create the manifest.

```
kubectl apply -f https://k8s.io/examples/application/zookeeper/zookeeper.yaml
```

This creates the zk-hs Headless Service, the zk-cs Service, the zk-pdb PodDisruptionBudget, and the zk StatefulSet.

```
service/zk-hs created
service/zk-cs created
poddisruptionbudget.policy/zk-pdb created
statefulset.apps/zk created
```

Use kubectl get to watch the StatefulSet controller create the StatefulSet's Pods.

```
kubectl get pods -w -l app=zk
```

Once the zk-2 Pod is Running and Ready, use CTRL-C to terminate kubectl.

```
NAME      READY     STATUS    RESTARTS   AGE
zk-0      0/1       Pending   0          0s
zk-0      0/1       Pending   0         0s
zk-0      0/1       ContainerCreating   0         0s
zk-0      0/1       Running   0         19s
zk-0      1/1       Running   0         40s
zk-1      0/1       Pending   0         0s
zk-1      0/1       Pending   0         0s
zk-1      0/1       ContainerCreating   0         0s
zk-1      0/1       Running   0         18s
zk-1      1/1       Running   0         40s
zk-2      0/1       Pending   0         0s
zk-2      0/1       Pending   0         0s
zk-2      0/1       ContainerCreating   0         0s
zk-2      0/1       Running   0         19s
zk-2      1/1       Running   0         40s
```

The StatefulSet controller creates three Pods, and each Pod has a container with a ZooKeeper server.

Facilitating leader election

Because there is no terminating algorithm for electing a leader in an anonymous network, Zab requires explicit membership configuration to perform leader election. Each server in the ensemble needs to have a unique identifier, all servers need to know the global set of identifiers, and each identifier needs to be associated with a network address.

Use kubectl exec to get the hostnames of the Pods in the zk StatefulSet.

```
for i in 0 1 2; do kubectl exec zk-$i -- hostname; done
```

The StatefulSet controller provides each Pod with a unique hostname based on its ordinal index. The hostnames take the form of <statefulset name>-<ordinal index>. Because the replicas field of the zk StatefulSet is set to 3, the Set's controller creates three Pods with their hostnames set to zk-0, zk-1, and zk-2.

```
zk-0
zk-1
zk-2
```

The servers in a ZooKeeper ensemble use natural numbers as unique identifiers, and store each server's identifier in a file called `myid` in the server's data directory.

To examine the contents of the `myid` file for each server use the following command.

```
for i in 0 1 2; do echo "myid zk-$i";kubectl exec zk-$i -- cat /var/lib/zookeeper/data/myid; done
```

Because the identifiers are natural numbers and the ordinal indices are non-negative integers, you can generate an identifier by adding 1 to the ordinal.

```
myid zk-0
1
myid zk-1
2
myid zk-2
3
```

To get the Fully Qualified Domain Name (FQDN) of each Pod in the `zk` StatefulSet use the following command.

```
for i in 0 1 2; do kubectl exec zk-$i -- hostname -f; done
```

The `zk-hs` Service creates a domain for all of the Pods, `zk-hs.default.svc.cluster.local`.

```
zk-0.zk-hs.default.svc.cluster.local
zk-1.zk-hs.default.svc.cluster.local
zk-2.zk-hs.default.svc.cluster.local
```

The A records in [Kubernetes DNS] resolve the FQDNs to the Pods' IP addresses. If Kubernetes reschedules the Pods, it will update the A records with the Pods' new IP addresses, but the A records names will not change.

ZooKeeper stores its application configuration in a file named `zoo.cfg`. Use `kubectl exec` to view the contents of the `zoo.cfg` file in the `zk-0` Pod.

```
kubectl exec zk-0 -- cat /opt/zookeeper/conf/zoo.cfg
```

In the `server.1`, `server.2`, and `server.3` properties at the bottom of the file, the `1`, `2`, and `3` correspond to the identifiers in the ZooKeeper servers' `myid` files. They are set to the FQDNs for the Pods in the `zk` StatefulSet.

```
clientPort=2181
dataDir=/var/lib/zookeeper/data
dataLogDir=/var/lib/zookeeper/log
tickTime=2000
initLimit=10
syncLimit=2000
maxClientCnxns=60
minSessionTimeout= 4000
maxSessionTimeout= 40000
autopurge.snapRetainCount=3
```

```
autopurge.purgeInterval=0
server.1=zk-0.zk-hs.default.svc.cluster.local:2888:3888
server.2=zk-1.zk-hs.default.svc.cluster.local:2888:3888
server.3=zk-2.zk-hs.default.svc.cluster.local:2888:3888
```

Achieving consensus

Consensus protocols require that the identifiers of each participant be unique. No two participants in the Zab protocol should claim the same unique identifier. This is necessary to allow the processes in the system to agree on which processes have committed which data. If two Pods are launched with the same ordinal, two ZooKeeper servers would both identify themselves as the same server.

```
kubectl get pods -w -l app=zk
```

```
NAME      READY     STATUS    RESTARTS   AGE
zk-0      0/1       Pending   0          0s
zk-0      0/1       Pending   0         0s
zk-0      0/1       ContainerCreating   0         0s
zk-0      0/1       Running   0         19s
zk-0      1/1       Running   0         40s
zk-1      0/1       Pending   0         0s
zk-1      0/1       Pending   0         0s
zk-1      0/1       ContainerCreating   0         0s
zk-1      0/1       Running   0         18s
zk-1      1/1       Running   0         40s
zk-2      0/1       Pending   0         0s
zk-2      0/1       Pending   0         0s
zk-2      0/1       ContainerCreating   0         0s
zk-2      0/1       Running   0         19s
zk-2      1/1       Running   0         40s
```

The A records for each Pod are entered when the Pod becomes Ready. Therefore, the FQDNs of the ZooKeeper servers will resolve to a single endpoint, and that endpoint will be the unique ZooKeeper server claiming the identity configured in its `myid` file.

```
zk-0.zk-hs.default.svc.cluster.local
zk-1.zk-hs.default.svc.cluster.local
zk-2.zk-hs.default.svc.cluster.local
```

This ensures that the `servers` properties in the ZooKeepers' `zoo.cfg` files represents a correctly configured ensemble.

```
server.1=zk-0.zk-hs.default.svc.cluster.local:2888:3888
server.2=zk-1.zk-hs.default.svc.cluster.local:2888:3888
server.3=zk-2.zk-hs.default.svc.cluster.local:2888:3888
```

When the servers use the Zab protocol to attempt to commit a value, they will either achieve consensus and commit the value (if leader election has succeeded and at least two of the Pods are Running and Ready), or they will fail to do so (if either of the conditions are not met). No state will arise where one server acknowledges a write on behalf of another.

Sanity testing the ensemble

The most basic sanity test is to write data to one ZooKeeper server and to read the data from another.

The command below executes the `zkCli.sh` script to write `world` to the path `/hello` on the `zk-0` Pod in the ensemble.

```
kubectl exec zk-0 -- zkCli.sh create /hello world
```

```
WATCHER::

WatchedEvent state:SyncConnected type:None path:null
Created /hello
```

To get the data from the `zk-1` Pod use the following command.

```
kubectl exec zk-1 -- zkCli.sh get /hello
```

The data that you created on `zk-0` is available on all the servers in the ensemble.

```
WATCHER::

WatchedEvent state:SyncConnected type:None path:null
world
cZxid = 0x100000002
ctime = Thu Dec 08 15:13:30 UTC 2016
mZxid = 0x100000002
mtime = Thu Dec 08 15:13:30 UTC 2016
pZxid = 0x100000002
cversion = 0
dataVersion = 0
aclVersion = 0
ephemeralOwner = 0x0
dataLength = 5
numChildren = 0
```

Providing durable storage

As mentioned in the [ZooKeeper Basics] section, ZooKeeper commits all entries to a durable WAL, and periodically writes snapshots in memory state, to storage media. Using WALs to provide durability is a common technique for applications that use consensus protocols to achieve a replicated state machine.

Use the [kubectl delete] command to delete the `zk` StatefulSet.

```
kubectl delete statefulset zk
```

```
statefulset.apps "zk" deleted
```

Watch the termination of the Pods in the StatefulSet.

```
kubectl get pods -w -l app=zk
```

When zk-0 if fully terminated, use CTRL-C to terminate kubectl.

```
zk-2      1/1       Terminating   0         9m
zk-0      1/1       Terminating   0         11m
zk-1      1/1       Terminating   0         10m
zk-2      0/1       Terminating   0         9m
zk-2      0/1       Terminating   0         9m
zk-2      0/1       Terminating   0         9m
zk-1      0/1       Terminating   0         10m
zk-1      0/1       Terminating   0         10m
zk-1      0/1       Terminating   0         10m
zk-0      0/1       Terminating   0         11m
zk-0      0/1       Terminating   0         11m
zk-0      0/1       Terminating   0         11m
```

Reapply the manifest in zookeeper.yaml.

```
kubectl apply -f https://k8s.io/examples/application/zookeeper/zookeeper.yaml
```

This creates the zk StatefulSet object, but the other API objects in the manifest are not modified because they already exist.

Watch the StatefulSet controller recreate the StatefulSet's Pods.

```
kubectl get pods -w -l app=zk
```

Once the zk-2 Pod is Running and Ready, use CTRL-C to terminate kubectl.

```
NAME      READY     STATUS    RESTARTS   AGE
zk-0      0/1       Pending   0          0s
zk-0      0/1       Pending   0         0s
zk-0      0/1       ContainerCreating   0         0s
zk-0      0/1       Running   0         19s
zk-0      1/1       Running   0         40s
zk-1      0/1       Pending   0         0s
zk-1      0/1       Pending   0         0s
zk-1      0/1       ContainerCreating   0         0s
zk-1      0/1       Running   0         18s
zk-1      1/1       Running   0         40s
zk-2      0/1       Pending   0         0s
zk-2      0/1       Pending   0         0s
zk-2      0/1       ContainerCreating   0         0s
zk-2      0/1       Running   0         19s
zk-2      1/1       Running   0         40s
```

Use the command below to get the value you entered during the sanity test, from the zk-2 Pod.

```
kubectl exec zk-2 zkCli.sh get /hello
```

Even though you terminated and recreated all of the Pods in the zk StatefulSet, the ensemble still serves the original value.

```
WATCHER::
```

```
WatchedEvent state:SyncConnected type:None path:null
world
cZxid = 0x100000002
ctime = Thu Dec 08 15:13:30 UTC 2016
mZxid = 0x100000002
mtime = Thu Dec 08 15:13:30 UTC 2016
pZxid = 0x100000002
cversion = 0
dataVersion = 0
aclVersion = 0
ephemeralOwner = 0x0
dataLength = 5
numChildren = 0
```

The `volumeClaimTemplates` field of the `zk` StatefulSet's `spec` specifies a PersistentVolume provisioned for each Pod.

```
volumeClaimTemplates:
  - metadata:
      name: datadir
      annotations:
        volume.alpha.kubernetes.io/storage-class: anything
    spec:
      accessModes: [ "ReadWriteOnce" ]
      resources:
        requests:
          storage: 20Gi
```

The `StatefulSet` controller generates a `PersistentVolumeClaim` for each Pod in the `StatefulSet`.

Use the following command to get the `StatefulSet`'s `PersistentVolumeClaims`.

```
kubectl get pvc -l app=zk
```

When the `StatefulSet` recreated its Pods, it remounts the Pods' PersistentVolumes.

```
NAME           STATUS    VOLUME                                     CAPACITY   ACCESSMODES   AGE
datadir-zk-0   Bound     pvc-bed742cd-bcb1-11e6-994f-42010a800002   20Gi       RWO           1h
datadir-zk-1   Bound     pvc-bedd27d2-bcb1-11e6-994f-42010a800002   20Gi       RWO           1h
datadir-zk-2   Bound     pvc-bee0817e-bcb1-11e6-994f-42010a800002   20Gi       RWO           1h
```

The `volumeMounts` section of the `StatefulSet`'s container `template` mounts the PersistentVolumes in the ZooKeeper servers' data directories.

```
volumeMounts:
- name: datadir
  mountPath: /var/lib/zookeeper
```

When a Pod in the `zk` `StatefulSet` is (re)scheduled, it will always have the same `PersistentVolume` mounted to the ZooKeeper server's data directory. Even when the Pods are rescheduled, all the writes made to the ZooKeeper servers' WALs, and all their snapshots, remain durable.

Ensuring consistent configuration

As noted in the Facilitating Leader Election and Achieving Consensus sections, the servers in a ZooKeeper ensemble require consistent configuration to elect a leader and form a quorum. They also require consistent configuration of the Zab protocol in order for the protocol to work correctly over a network. In our example we achieve consistent configuration by embedding the configuration directly into the manifest.

Get the `zk` StatefulSet.

```
kubectl get sts zk -o yaml
```

```
...
command:
    - sh
    - -c
    - "start-zookeeper \
      --servers=3 \
      --data_dir=/var/lib/zookeeper/data \
      --data_log_dir=/var/lib/zookeeper/data/log \
      --conf_dir=/opt/zookeeper/conf \
      --client_port=2181 \
      --election_port=3888 \
      --server_port=2888 \
      --tick_time=2000 \
      --init_limit=10 \
      --sync_limit=5 \
      --heap=512M \
      --max_client_cnxns=60 \
      --snap_retain_count=3 \
      --purge_interval=12 \
      --max_session_timeout=40000 \
      --min_session_timeout=4000 \
      --log_level=INFO"
...
```

The command used to start the ZooKeeper servers passed the configuration as command line parameter. You can also use environment variables to pass configuration to the ensemble.

Configuring logging

One of the files generated by the `zkGenConfig.sh` script controls ZooKeeper's logging. ZooKeeper uses Log4j, and, by default, it uses a time and size based rolling file appender for its logging configuration.

Use the command below to get the logging configuration from one of Pods in the `zk` StatefulSet.

```
kubectl exec zk-0 cat /usr/etc/zookeeper/log4j.properties
```

The logging configuration below will cause the ZooKeeper process to write all of its logs to the standard output file stream.

```
zookeeper.root.logger=CONSOLE
zookeeper.console.threshold=INFO
log4j.rootLogger=${zookeeper.root.logger}
log4j.appender.CONSOLE=org.apache.log4j.ConsoleAppender
log4j.appender.CONSOLE.Threshold=${zookeeper.console.threshold}
log4j.appender.CONSOLE.layout=org.apache.log4j.PatternLayout
log4j.appender.CONSOLE.layout.ConversionPattern=%d{ISO8601} [myid:%X{myid}] - %-5p [%t:%C{1}@%L] - %m%n
```

This is the simplest possible way to safely log inside the container. Because the applications write logs to standard out, Kubernetes will handle log rotation for you. Kubernetes also implements a sane retention policy that ensures application logs written to standard out and standard error do not exhaust local storage media.

Use [kubectl logs] to retrieve the last 20 log lines from one of the Pods.

```
kubectl logs zk-0 --tail 20
```

You can view application logs written to standard out or standard error using `kubectl logs` and from the Kubernetes Dashboard.

```
2016-12-06 19:34:16,236 [myid:1] - INFO  [NIOServerCxn.Factory:0.0.0.0/0.0.0.0:2181:NIOServerCnxn@827] - Processing ruok command from /127.0.0.1:52740
2016-12-06 19:34:16,237 [myid:1] - INFO  [Thread-1136:NIOServerCnxn@1008] - Closed socket connection for client /127.0.0.1:52740 (no session established for client)
2016-12-06 19:34:26,155 [myid:1] - INFO  [NIOServerCxn.Factory:0.0.0.0/0.0.0.0:2181:NIOServerCnxnFactory@192] - Accepted socket connection from /127.0.0.1:52749
2016-12-06 19:34:26,155 [myid:1] - INFO  [NIOServerCxn.Factory:0.0.0.0/0.0.0.0:2181:NIOServerCnxn@827] - Processing ruok command from /127.0.0.1:52749
2016-12-06 19:34:26,156 [myid:1] - INFO  [Thread-1137:NIOServerCnxn@1008] - Closed socket connection for client /127.0.0.1:52749 (no session established for client)
2016-12-06 19:34:26,222 [myid:1] - INFO  [NIOServerCxn.Factory:0.0.0.0/0.0.0.0:2181:NIOServerCnxnFactory@192] - Accepted socket connection from /127.0.0.1:52750
2016-12-06 19:34:26,222 [myid:1] - INFO  [NIOServerCxn.Factory:0.0.0.0/0.0.0.0:2181:NIOServerCnxn@827] - Processing ruok command from /127.0.0.1:52750
2016-12-06 19:34:26,226 [myid:1] - INFO  [Thread-1138:NIOServerCnxn@1008] - Closed socket connection for client /127.0.0.1:52750 (no session established for client)
2016-12-06 19:34:36,151 [myid:1] - INFO  [NIOServerCxn.Factory:0.0.0.0/0.0.0.0:2181:NIOServerCnxnFactory@192] - Accepted socket connection from /127.0.0.1:52760
2016-12-06 19:34:36,152 [myid:1] - INFO  [NIOServerCxn.Factory:0.0.0.0/0.0.0.0:2181:NIOServerCnxn@827] - Processing ruok command from /127.0.0.1:52760
2016-12-06 19:34:36,152 [myid:1] - INFO  [Thread-1139:NIOServerCnxn@1008] - Closed socket connection for client /127.0.0.1:52760 (no session established for client)
2016-12-06 19:34:36,230 [myid:1] - INFO  [NIOServerCxn.Factory:0.0.0.0/0.0.0.0:2181:NIOServerCnxnFactory@192] - Accepted socket connection from /127.0.0.1:52761
2016-12-06 19:34:36,231 [myid:1] - INFO  [NIOServerCxn.Factory:0.0.0.0/0.0.0.0:2181:NIOServerCnxn@827] - Processing ruok command from /127.0.0.1:52761
2016-12-06 19:34:36,231 [myid:1] - INFO  [Thread-1140:NIOServerCnxn@1008] - Closed socket connection for client /127.0.0.1:52761 (no session established for client)
```

```
2016-12-06 19:34:46,149 [myid:1] - INFO  [NIOServerCxn.Factory:
0.0.0.0/0.0.0.0:2181:NIOServerCnxnFactory@192] - Accepted socket connection from /
127.0.0.1:52767
2016-12-06 19:34:46,149 [myid:1] - INFO  [NIOServerCxn.Factory:
0.0.0.0/0.0.0.0:2181:NIOServerCnxn@827] - Processing ruok command from /127.0.0.1:52767
2016-12-06 19:34:46,149 [myid:1] - INFO  [Thread-1141:NIOServerCnxn@1008] - Closed socket
connection for client /127.0.0.1:52767 (no session established for client)
2016-12-06 19:34:46,230 [myid:1] - INFO  [NIOServerCxn.Factory:
0.0.0.0/0.0.0.0:2181:NIOServerCnxnFactory@192] - Accepted socket connection from /
127.0.0.1:52768
2016-12-06 19:34:46,230 [myid:1] - INFO  [NIOServerCxn.Factory:
0.0.0.0/0.0.0.0:2181:NIOServerCnxn@827] - Processing ruok command from /127.0.0.1:52768
2016-12-06 19:34:46,230 [myid:1] - INFO  [Thread-1142:NIOServerCnxn@1008] - Closed socket
connection for client /127.0.0.1:52768 (no session established for client)
```

Kubernetes integrates with many logging solutions. You can choose a logging solution that best fits your cluster and applications. For cluster-level logging and aggregation, consider deploying a [sidecar container](#) to rotate and ship your logs.

Configuring a non-privileged user

The best practices to allow an application to run as a privileged user inside of a container are a matter of debate. If your organization requires that applications run as a non-privileged user you can use a [SecurityContext](#) to control the user that the entry point runs as.

The `zk` `StatefulSet`'s Pod `template` contains a `SecurityContext`.

```
securityContext:
  runAsUser: 1000
  fsGroup: 1000
```

In the Pods' containers, UID 1000 corresponds to the zookeeper user and GID 1000 corresponds to the zookeeper group.

Get the ZooKeeper process information from the `zk-0` Pod.

```
kubectl exec zk-0 -- ps -elf
```

As the `runAsUser` field of the `securityContext` object is set to 1000, instead of running as root, the ZooKeeper process runs as the zookeeper user.

```
F S UID        PID  PPID  C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
4 S zookeep+     1     0  0  80   0 -  1127 -      20:46 ?        00:00:00 sh -c zkGenConfig.sh &&
zkServer.sh start-foreground
0 S zookeep+    27     1  0  80   0 - 1155556 -    20:46 ?        00:00:19 /usr/lib/jvm/java-8-openjdk-
amd64/bin/java -Dzookeeper.log.dir=/var/log/zookeeper -
Dzookeeper.root.logger=INFO,CONSOLE -cp /usr/bin/../build/classes:/usr/bin/../build/lib/*.jar:/
usr/bin/../share/zookeeper/zookeeper-3.4.9.jar:/usr/bin/../share/zookeeper/slf4j-
log4j12-1.6.1.jar:/usr/bin/../share/zookeeper/slf4j-api-1.6.1.jar:/usr/bin/../share/zookeeper/
netty-3.10.5.Final.jar:/usr/bin/../share/zookeeper/log4j-1.2.16.jar:/usr/bin/../share/zookeeper/
jline-0.9.94.jar:/usr/bin/../src/java/lib/*.jar:/usr/bin/../etc/zookeeper: -Xmx2G -Xms2G -
Dcom.sun.management.jmxremote -Dcom.sun.management.jmxremote.local.only=false
org.apache.zookeeper.server.quorum.QuorumPeerMain /usr/bin/../etc/zookeeper/zoo.cfg
```

By default, when the Pod's PersistentVolumes is mounted to the ZooKeeper server's data directory, it is only accessible by the root user. This configuration prevents the ZooKeeper process from writing to its WAL and storing its snapshots.

Use the command below to get the file permissions of the ZooKeeper data directory on the `zk-0` Pod.

```
kubectl exec -ti zk-0 -- ls -ld /var/lib/zookeeper/data
```

Because the `fsGroup` field of the `securityContext` object is set to 1000, the ownership of the Pods' PersistentVolumes is set to the zookeeper group, and the ZooKeeper process is able to read and write its data.

```
drwxr-sr-x 3 zookeeper zookeeper 4096 Dec  5 20:45 /var/lib/zookeeper/data
```

Managing the ZooKeeper process

The [ZooKeeper documentation] mentions that "You will want to have a supervisory process that manages each of your ZooKeeper server processes (JVM)." Utilizing a watchdog (supervisory process) to restart failed processes in a distributed system is a common pattern. When deploying an application in Kubernetes, rather than using an external utility as a supervisory process, you should use Kubernetes as the watchdog for your application.

Updating the ensemble

The `zk` `StatefulSet` is configured to use the `RollingUpdate` update strategy.

You can use `kubectl patch` to update the number of `cpus` allocated to the servers.

```
kubectl patch sts zk --type='json' -p='[{"op": "replace", "path": "/spec/template/spec/containers/0/resources/requests/cpu", "value":"0.3"}]'
```

```
statefulset.apps/zk patched
```

Use `kubectl rollout status` to watch the status of the update.

```
kubectl rollout status sts/zk
```

```
waiting for statefulset rolling update to complete 0 pods at revision zk-5db4499664...
Waiting for 1 pods to be ready...
Waiting for 1 pods to be ready...
waiting for statefulset rolling update to complete 1 pods at revision zk-5db4499664...
Waiting for 1 pods to be ready...
Waiting for 1 pods to be ready...
waiting for statefulset rolling update to complete 2 pods at revision zk-5db4499664...
Waiting for 1 pods to be ready...
Waiting for 1 pods to be ready...
statefulset rolling update complete 3 pods at revision zk-5db4499664...
```

This terminates the Pods, one at a time, in reverse ordinal order, and recreates them with the new configuration. This ensures that quorum is maintained during a rolling update.

Use the `kubectl rollout history` command to view a history or previous configurations.

```
kubectl rollout history sts/zk
```

The output is similar to this:

```
statefulsets "zk"
REVISION
1
2
```

Use the `kubectl rollout undo` command to roll back the modification.

```
kubectl rollout undo sts/zk
```

The output is similar to this:

```
statefulset.apps/zk rolled back
```

Handling process failure

[Restart Policies](#) control how Kubernetes handles process failures for the entry point of the container in a Pod. For Pods in a `StatefulSet`, the only appropriate `RestartPolicy` is Always, and this is the default value. For stateful applications you should **never** override the default policy.

Use the following command to examine the process tree for the ZooKeeper server running in the `zk-0` Pod.

```
kubectl exec zk-0 -- ps -ef
```

The command used as the container's entry point has PID 1, and the ZooKeeper process, a child of the entry point, has PID 27.

```
UID        PID  PPID  C STIME TTY          TIME CMD
zookeep+     1     0  0 15:03 ?        00:00:00 sh -c zkGenConfig.sh && zkServer.sh start-foreground
zookeep+    27     1  0 15:03 ?        00:00:03 /usr/lib/jvm/java-8-openjdk-amd64/bin/java -
Dzookeeper.log.dir=/var/log/zookeeper -Dzookeeper.root.logger=INFO,CONSOLE -cp /usr/
bin/../build/classes:/usr/bin/../build/lib/*.jar:/usr/bin/../share/zookeeper/zookeeper-3.4.9.jar:/usr/
bin/../share/zookeeper/slf4j-log4j12-1.6.1.jar:/usr/bin/../share/zookeeper/slf4j-api-1.6.1.jar:/usr/
bin/../share/zookeeper/netty-3.10.5.Final.jar:/usr/bin/../share/zookeeper/log4j-1.2.16.jar:/usr/
bin/../share/zookeeper/jline-0.9.94.jar:/usr/bin/../src/java/lib/*.jar:/usr/bin/../etc/zookeeper: -
Xmx2G -Xms2G -Dcom.sun.management.jmxremote -
Dcom.sun.management.jmxremote.local.only=false
org.apache.zookeeper.server.quorum.QuorumPeerMain /usr/bin/../etc/zookeeper/zoo.cfg
```

In another terminal watch the Pods in the `zk` `StatefulSet` with the following command.

```
kubectl get pod -w -l app=zk
```

In another terminal, terminate the ZooKeeper process in Pod `zk-0` with the following command.

```
kubectl exec zk-0 -- pkill java
```

The termination of the ZooKeeper process caused its parent process to terminate. Because the `RestartPolicy` of the container is Always, it restarted the parent process.

```
NAME      READY     STATUS    RESTARTS   AGE
zk-0      1/1       Running   0          21m
zk-1      1/1       Running   0          20m
zk-2      1/1       Running   0          19m
NAME      READY     STATUS    RESTARTS   AGE
zk-0      0/1       Error     0          29m
zk-0      0/1       Running   1          29m
zk-0      1/1       Running   1          29m
```

If your application uses a script (such as zkServer.sh) to launch the process that implements the application's business logic, the script must terminate with the child process. This ensures that Kubernetes will restart the application's container when the process implementing the application's business logic fails.

Testing for liveness

Configuring your application to restart failed processes is not enough to keep a distributed system healthy. There are scenarios where a system's processes can be both alive and unresponsive, or otherwise unhealthy. You should use liveness probes to notify Kubernetes that your application's processes are unhealthy and it should restart them.

The Pod template for the zk StatefulSet specifies a liveness probe.

```
 livenessProbe:
   exec:
     command:
     - sh
     - -c
     - "zookeeper-ready 2181"
   initialDelaySeconds: 15
   timeoutSeconds: 5
```

The probe calls a bash script that uses the ZooKeeper ruok four letter word to test the server's health.

```
OK=$(echo ruok | nc 127.0.0.1 $1)
if [ "$OK" == "imok" ]; then
    exit 0
else
    exit 1
fi
```

In one terminal window, use the following command to watch the Pods in the zk StatefulSet.

```
kubectl get pod -w -l app=zk
```

In another window, using the following command to delete the zookeeper-ready script from the file system of Pod zk-0.

```
kubectl exec zk-0 -- rm /opt/zookeeper/bin/zookeeper-ready
```

When the liveness probe for the ZooKeeper process fails, Kubernetes will automatically restart the process for you, ensuring that unhealthy processes in the ensemble are restarted.

```
kubectl get pod -w -l app=zk
```

```
NAME      READY     STATUS    RESTARTS   AGE
zk-0      1/1       Running   0          1h
zk-1      1/1       Running   0          1h
zk-2      1/1       Running   0          1h
NAME      READY     STATUS    RESTARTS   AGE
zk-0      0/1       Running   0          1h
zk-0      0/1       Running   1         1h
zk-0      1/1       Running   1         1h
```

Testing for readiness

Readiness is not the same as liveness. If a process is alive, it is scheduled and healthy. If a process is ready, it is able to process input. Liveness is a necessary, but not sufficient, condition for readiness. There are cases, particularly during initialization and termination, when a process can be alive but not ready.

If you specify a readiness probe, Kubernetes will ensure that your application's processes will not receive network traffic until their readiness checks pass.

For a ZooKeeper server, liveness implies readiness. Therefore, the readiness probe from the `zookeeper.yaml` manifest is identical to the liveness probe.

```
 readinessProbe:
   exec:
     command:
     - sh
     - -c
     - "zookeeper-ready 2181"
   initialDelaySeconds: 15
   timeoutSeconds: 5
```

Even though the liveness and readiness probes are identical, it is important to specify both. This ensures that only healthy servers in the ZooKeeper ensemble receive network traffic.

Tolerating Node failure

ZooKeeper needs a quorum of servers to successfully commit mutations to data. For a three server ensemble, two servers must be healthy for writes to succeed. In quorum based systems, members are deployed across failure domains to ensure availability. To avoid an outage, due to the loss of an individual machine, best practices preclude co-locating multiple instances of the application on the same machine.

By default, Kubernetes may co-locate Pods in a `StatefulSet` on the same node. For the three server ensemble you created, if two servers are on the same node, and that node fails, the clients of your ZooKeeper service will experience an outage until at least one of the Pods can be rescheduled.

You should always provision additional capacity to allow the processes of critical systems to be rescheduled in the event of node failures. If you do so, then the outage will only last until the Kubernetes scheduler reschedules one of the ZooKeeper servers. However, if you want your service to tolerate node failures with no downtime, you should set `podAntiAffinity`.

Use the command below to get the nodes for Pods in the zk StatefulSet.

```
for i in 0 1 2; do kubectl get pod zk-$i --template {{.spec.nodeName}}; echo ""; done
```

All of the Pods in the zk StatefulSet are deployed on different nodes.

```
kubernetes-node-cxpk
kubernetes-node-a5aq
kubernetes-node-2g2d
```

This is because the Pods in the zk StatefulSet have a PodAntiAffinity specified.

```
affinity:
  podAntiAffinity:
    requiredDuringSchedulingIgnoredDuringExecution:
      - labelSelector:
          matchExpressions:
            - key: "app"
              operator: In
              values:
                - zk
        topologyKey: "kubernetes.io/hostname"
```

The requiredDuringSchedulingIgnoredDuringExecution field tells the Kubernetes Scheduler that it should never co-locate two Pods which have app label as zk in the domain defined by the topologyKey. The topologyKey kubernetes.io/hostname indicates that the domain is an individual node. Using different rules, labels, and selectors, you can extend this technique to spread your ensemble across physical, network, and power failure domains.

Surviving maintenance

In this section you will cordon and drain nodes. If you are using this tutorial on a shared cluster, be sure that this will not adversely affect other tenants.

The previous section showed you how to spread your Pods across nodes to survive unplanned node failures, but you also need to plan for temporary node failures that occur due to planned maintenance.

Use this command to get the nodes in your cluster.

```
kubectl get nodes
```

This tutorial assumes a cluster with at least four nodes. If the cluster has more than four, use [kubectl cordon] to cordon all but four nodes. Constraining to four nodes will ensure Kubernetes encounters affinity and PodDisruptionBudget constraints when scheduling zookeeper Pods in the following maintenance simulation.

```
kubectl cordon <node-name>
```

Use this command to get the zk-pdb PodDisruptionBudget.

```
kubectl get pdb zk-pdb
```

The max-unavailable field indicates to Kubernetes that at most one Pod from zk StatefulSet can be unavailable at any time.

```
NAME     MIN-AVAILABLE   MAX-UNAVAILABLE   ALLOWED-DISRUPTIONS   AGE
zk-pdb   N/A             1                 1
```

In one terminal, use this command to watch the Pods in the zk StatefulSet.

```
kubectl get pods -w -l app=zk
```

In another terminal, use this command to get the nodes that the Pods are currently scheduled on.

```
for i in 0 1 2; do kubectl get pod zk-$i --template {{.spec.nodeName}}; echo ""; done
```

The output is similar to this:

```
kubernetes-node-pb41
kubernetes-node-ixsl
kubernetes-node-i4c4
```

Use [kubectl drain]() to cordon and drain the node on which the zk-0 Pod is scheduled.

```
kubectl drain $(kubectl get pod zk-0 --template {{.spec.nodeName}}) --ignore-daemonsets --force
--delete-emptydir-data
```

The output is similar to this:

```
node "kubernetes-node-pb41" cordoned

WARNING: Deleting pods not managed by ReplicationController, ReplicaSet, Job, or
DaemonSet: fluentd-cloud-logging-kubernetes-node-pb41, kube-proxy-kubernetes-node-pb41;
Ignoring DaemonSet-managed pods: node-problem-detector-v0.1-o5elz
pod "zk-0" deleted
node "kubernetes-node-pb41" drained
```

As there are four nodes in your cluster, kubectl drain, succeeds and the zk-0 is rescheduled to another node.

```
NAME     READY     STATUS    RESTARTS   AGE
zk-0     1/1       Running   2          1h
zk-1     1/1       Running   0          1h
zk-2     1/1       Running   0          1h
NAME     READY     STATUS        RESTARTS   AGE
zk-0     1/1       Terminating   2          2h
zk-0     0/1       Terminating   2         2h
zk-0     0/1       Terminating   2         2h
zk-0     0/1       Terminating   2         2h
zk-0     0/1       Pending   0         0s
zk-0     0/1       Pending   0         0s
zk-0     0/1       ContainerCreating   0         0s
zk-0     0/1       Running   0         51s
zk-0     1/1       Running   0         1m
```

Keep watching the StatefulSet's Pods in the first terminal and drain the node on which zk-1 is scheduled.

```
kubectl drain $(kubectl get pod zk-1 --template {{.spec.nodeName}}) --ignore-daemonsets --force --delete-emptydir-data
```

The output is similar to this:

```
"kubernetes-node-ixsl" cordoned
WARNING: Deleting pods not managed by ReplicationController, ReplicaSet, Job, or DaemonSet: fluentd-cloud-logging-kubernetes-node-ixsl, kube-proxy-kubernetes-node-ixsl;
Ignoring DaemonSet-managed pods: node-problem-detector-v0.1-voc74
pod "zk-1" deleted
node "kubernetes-node-ixsl" drained
```

The zk-1 Pod cannot be scheduled because the zk StatefulSet contains a PodAntiAffinity rule preventing co-location of the Pods, and as only two nodes are schedulable, the Pod will remain in a Pending state.

```
kubectl get pods -w -l app=zk
```

The output is similar to this:

```
NAME      READY     STATUS    RESTARTS   AGE
zk-0      1/1       Running   2          1h
zk-1      1/1       Running   0          1h
zk-2      1/1       Running   0          1h
NAME      READY     STATUS        RESTARTS   AGE
zk-0      1/1       Terminating   2          2h
zk-0      0/1       Terminating   2         2h
zk-0      0/1       Terminating   2         2h
zk-0      0/1       Terminating   2         2h
zk-0      0/1       Pending   0         0s
zk-0      0/1       Pending   0         0s
zk-0      0/1       ContainerCreating   0         0s
zk-0      0/1       Running   0         51s
zk-0      1/1       Running   0         1m
zk-1      1/1       Terminating   0         2h
zk-1      0/1       Terminating   0         2h
zk-1      0/1       Terminating   0         2h
zk-1      0/1       Terminating   0         2h
zk-1      0/1       Pending   0         0s
zk-1      0/1       Pending   0         0s
```

Continue to watch the Pods of the StatefulSet, and drain the node on which zk-2 is scheduled.

```
kubectl drain $(kubectl get pod zk-2 --template {{.spec.nodeName}}) --ignore-daemonsets --force --delete-emptydir-data
```

The output is similar to this:

```
node "kubernetes-node-i4c4" cordoned

WARNING: Deleting pods not managed by ReplicationController, ReplicaSet, Job, or
```

```
DaemonSet: fluentd-cloud-logging-kubernetes-node-i4c4, kube-proxy-kubernetes-node-i4c4;
Ignoring DaemonSet-managed pods: node-problem-detector-v0.1-dyrog
WARNING: Ignoring DaemonSet-managed pods: node-problem-detector-v0.1-dyrog; Deleting pods not managed by ReplicationController, ReplicaSet, Job, or DaemonSet: fluentd-cloud-logging-kubernetes-node-i4c4, kube-proxy-kubernetes-node-i4c4
There are pending pods when an error occurred: Cannot evict pod as it would violate the pod's disruption budget.
pod/zk-2
```

Use `CTRL-C` to terminate kubectl.

You cannot drain the third node because evicting `zk-2` would violate `zk-budget`. However, the node will remain cordoned.

Use `zkCli.sh` to retrieve the value you entered during the sanity test from `zk-0`.

```
kubectl exec zk-0 zkCli.sh get /hello
```

The service is still available because its `PodDisruptionBudget` is respected.

```
WatchedEvent state:SyncConnected type:None path:null
world
cZxid = 0x200000002
ctime = Wed Dec 07 00:08:59 UTC 2016
mZxid = 0x200000002
mtime = Wed Dec 07 00:08:59 UTC 2016
pZxid = 0x200000002
cversion = 0
dataVersion = 0
aclVersion = 0
ephemeralOwner = 0x0
dataLength = 5
numChildren = 0
```

Use kubectl uncordon to uncordon the first node.

```
kubectl uncordon kubernetes-node-pb41
```

The output is similar to this:

```
node "kubernetes-node-pb41" uncordoned
```

`zk-1` is rescheduled on this node. Wait until `zk-1` is Running and Ready.

```
kubectl get pods -w -l app=zk
```

The output is similar to this:

```
NAME      READY     STATUS    RESTARTS   AGE
zk-0      1/1       Running   2          1h
zk-1      1/1       Running   0          1h
zk-2      1/1       Running   0          1h
NAME      READY     STATUS        RESTARTS   AGE
zk-0      1/1       Terminating   2          2h
zk-0      0/1       Terminating   2          2h
```

```
zk-0    0/1    Terminating   2      2h
zk-0    0/1    Terminating   2      2h
zk-0    0/1    Pending   0      0s
zk-0    0/1    Pending   0      0s
zk-0    0/1    ContainerCreating   0      0s
zk-0    0/1    Running   0      51s
zk-0    1/1    Running   0      1m
zk-1    1/1    Terminating   0      2h
zk-1    0/1    Terminating   0      2h
zk-1    0/1    Terminating   0      2h
zk-1    0/1    Terminating   0      2h
zk-1    0/1    Pending   0      0s
zk-1    0/1    Pending   0      0s
zk-1    0/1    Pending   0      12m
zk-1    0/1    ContainerCreating   0      12m
zk-1    0/1    Running   0      13m
zk-1    1/1    Running   0      13m
```

Attempt to drain the node on which `zk-2` is scheduled.

```
kubectl drain $(kubectl get pod zk-2 --template {{.spec.nodeName}}) --ignore-daemonsets --force
--delete-emptydir-data
```

The output is similar to this:

```
node "kubernetes-node-i4c4" already cordoned
WARNING: Deleting pods not managed by ReplicationController, ReplicaSet, Job, or
DaemonSet: fluentd-cloud-logging-kubernetes-node-i4c4, kube-proxy-kubernetes-node-i4c4;
Ignoring DaemonSet-managed pods: node-problem-detector-v0.1-dyrog
pod "heapster-v1.2.0-2604621511-wht1r" deleted
pod "zk-2" deleted
node "kubernetes-node-i4c4" drained
```

This time `kubectl drain` succeeds.

Uncordon the second node to allow `zk-2` to be rescheduled.

```
kubectl uncordon kubernetes-node-ixsl
```

The output is similar to this:

```
node "kubernetes-node-ixsl" uncordoned
```

You can use `kubectl drain` in conjunction with `PodDisruptionBudgets` to ensure that your services remain available during maintenance. If drain is used to cordon nodes and evict pods prior to taking the node offline for maintenance, services that express a disruption budget will have that budget respected. You should always allocate additional capacity for critical services so that their Pods can be immediately rescheduled.

Cleaning up

- Use `kubectl uncordon` to uncordon all the nodes in your cluster.

- You must delete the persistent storage media for the PersistentVolumes used in this tutorial. Follow the necessary steps, based on your environment, storage configuration, and provisioning method, to ensure that all storage is reclaimed.

Services

Connecting Applications with Services

The Kubernetes model for connecting containers

Now that you have a continuously running, replicated application you can expose it on a network.

Kubernetes assumes that pods can communicate with other pods, regardless of which host they land on. Kubernetes gives every pod its own cluster-private IP address, so you do not need to explicitly create links between pods or map container ports to host ports. This means that containers within a Pod can all reach each other's ports on localhost, and all pods in a cluster can see each other without NAT. The rest of this document elaborates on how you can run reliable services on such a networking model.

This tutorial uses a simple nginx web server to demonstrate the concept.

Exposing pods to the cluster

We did this in a previous example, but let's do it once again and focus on the networking perspective. Create an nginx Pod, and note that it has a container port specification:

service/networking/run-my-nginx.yaml

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: my-nginx
spec:
  selector:
    matchLabels:
      run: my-nginx
  replicas: 2
  template:
    metadata:
      labels:
        run: my-nginx
```

```
  spec:
    containers:
    - name: my-nginx
      image: nginx
      ports:
      - containerPort: 80
```

This makes it accessible from any node in your cluster. Check the nodes the Pod is running on:

```
kubectl apply -f ./run-my-nginx.yaml
kubectl get pods -l run=my-nginx -o wide
```

```
NAME                        READY     STATUS    RESTARTS   AGE       IP            NODE
my-nginx-3800858182-jr4a2   1/1       Running   0          13s       10.244.3.4    kubernetes-minion-905m
my-nginx-3800858182-kna2y   1/1       Running   0          13s       10.244.2.5    kubernetes-minion-ljyd
```

Check your pods' IPs:

```
kubectl get pods -l run=my-nginx -o custom-columns=POD_IP:.status.podIPs
    POD_IP
    [map[ip:10.244.3.4]]
    [map[ip:10.244.2.5]]
```

You should be able to ssh into any node in your cluster and use a tool such as `curl` to make queries against both IPs. Note that the containers are *not* using port 80 on the node, nor are there any special NAT rules to route traffic to the pod. This means you can run multiple nginx pods on the same node all using the same `containerPort`, and access them from any other pod or node in your cluster using the assigned IP address for the pod. If you want to arrange for a specific port on the host Node to be forwarded to backing Pods, you can - but the networking model should mean that you do not need to do so.

You can read more about the [Kubernetes Networking Model] if you're curious.

Creating a Service

So we have pods running nginx in a flat, cluster wide, address space. In theory, you could talk to these pods directly, but what happens when a node dies? The pods die with it, and the ReplicaSet inside the Deployment will create new ones, with different IPs. This is the problem a Service solves.

A Kubernetes Service is an abstraction which defines a logical set of Pods running somewhere in your cluster, that all provide the same functionality. When created, each Service is assigned a unique IP address (also called clusterIP). This address is tied to the lifespan of the Service, and will not change while the Service is alive. Pods can be configured to talk to the Service, and know that communication to the Service will be automatically load-balanced out to some pod that is a member of the Service.

You can create a Service for your 2 nginx replicas with `kubectl expose`:

```
kubectl expose deployment/my-nginx
```

```
service/my-nginx exposed
```

This is equivalent to `kubectl apply -f` the following yaml:

service/networking/nginx-svc.yaml

```
apiVersion: v1
kind: Service
metadata:
  name: my-nginx
  labels:
    run: my-nginx
spec:
  ports:
  - port: 80
    protocol: TCP
  selector:
    run: my-nginx
```

This specification will create a Service which targets TCP port 80 on any Pod with the `run: my-nginx` label, and expose it on an abstracted Service port (`targetPort`: is the port the container accepts traffic on, `port`: is the abstracted Service port, which can be any port other pods use to access the Service). View Service API object to see the list of supported fields in service definition. Check your Service:

```
kubectl get svc my-nginx
```

```
NAME       TYPE        CLUSTER-IP     EXTERNAL-IP   PORT(S)   AGE
my-nginx   ClusterIP   10.0.162.149   <none>        80/TCP    21s
```

As mentioned previously, a Service is backed by a group of Pods. These Pods are exposed through EndpointSlices. The Service's selector will be evaluated continuously and the results will be POSTed to an EndpointSlice that is connected to the Service using a labels. When a Pod dies, it is automatically removed from the EndpointSlices that contain it as an endpoint. New Pods that match the Service's selector will automatically get added to an EndpointSlice for that Service. Check the endpoints, and note that the IPs are the same as the Pods created in the first step:

```
kubectl describe svc my-nginx
```

```
Name:                my-nginx
Namespace:           default
Labels:              run=my-nginx
Annotations:         <none>
Selector:            run=my-nginx
Type:                ClusterIP
IP Family Policy:    SingleStack
IP Families:         IPv4
IP:                  10.0.162.149
IPs:                 10.0.162.149
Port:                <unset> 80/TCP
TargetPort:          80/TCP
Endpoints:           10.244.2.5:80,10.244.3.4:80
```

```
Session Affinity:    None
Events:              <none>
```

```
kubectl get endpointslices -l kubernetes.io/service-name=my-nginx
```

```
NAME             ADDRESSTYPE   PORTS   ENDPOINTS               AGE
my-nginx-7vzhx   IPv4          80      10.244.2.5,10.244.3.4   21s
```

You should now be able to curl the nginx Service on `<CLUSTER-IP>:<PORT>` from any node in your cluster. Note that the Service IP is completely virtual, it never hits the wire. If you're curious about how this works you can read more about the [service proxy].

Accessing the Service

Kubernetes supports 2 primary modes of finding a Service - environment variables and DNS. The former works out of the box while the latter requires the [CoreDNS cluster addon].

Note: If the service environment variables are not desired (because possible clashing with expected program ones, too many variables to process, only using DNS, etc) you can disable this mode by setting the `enableServiceLinks` flag to `false` on the [pod spec].

Environment Variables

When a Pod runs on a Node, the kubelet adds a set of environment variables for each active Service. This introduces an ordering problem. To see why, inspect the environment of your running nginx Pods (your Pod name will be different):

```
kubectl exec my-nginx-3800858182-jr4a2 -- printenv | grep SERVICE
```

```
KUBERNETES_SERVICE_HOST=10.0.0.1
KUBERNETES_SERVICE_PORT=443
KUBERNETES_SERVICE_PORT_HTTPS=443
```

Note there's no mention of your Service. This is because you created the replicas before the Service. Another disadvantage of doing this is that the scheduler might put both Pods on the same machine, which will take your entire Service down if it dies. We can do this the right way by killing the 2 Pods and waiting for the Deployment to recreate them. This time the Service exists *before* the replicas. This will give you scheduler-level Service spreading of your Pods (provided all your nodes have equal capacity), as well as the right environment variables:

```
kubectl scale deployment my-nginx --replicas=0; kubectl scale deployment my-nginx --replicas=2;

kubectl get pods -l run=my-nginx -o wide
```

```
NAME                        READY     STATUS    RESTARTS   AGE     IP            NODE
my-nginx-3800858182-e9ihh   1/1       Running   0          5s      10.244.2.7    kubernetes-minion-ljyd
my-nginx-3800858182-j4rm4   1/1       Running   0          5s      10.244.3.8    kubernetes-minion-905m
```

You may notice that the pods have different names, since they are killed and recreated.

```
kubectl exec my-nginx-3800858182-e9ihh -- printenv | grep SERVICE
```

```
KUBERNETES_SERVICE_PORT=443
MY_NGINX_SERVICE_HOST=10.0.162.149
KUBERNETES_SERVICE_HOST=10.0.0.1
MY_NGINX_SERVICE_PORT=80
KUBERNETES_SERVICE_PORT_HTTPS=443
```

DNS

Kubernetes offers a DNS cluster addon Service that automatically assigns dns names to other Services. You can check if it's running on your cluster:

```
kubectl get services kube-dns --namespace=kube-system
```

```
NAME       TYPE        CLUSTER-IP   EXTERNAL-IP   PORT(S)         AGE
kube-dns   ClusterIP   10.0.0.10    <none>        53/UDP,53/TCP   8m
```

The rest of this section will assume you have a Service with a long lived IP (my-nginx), and a DNS server that has assigned a name to that IP. Here we use the CoreDNS cluster addon (application name kube-dns), so you can talk to the Service from any pod in your cluster using standard methods (e.g. gethostbyname()). If CoreDNS isn't running, you can enable it referring to the CoreDNS README or Installing CoreDNS. Let's run another curl application to test this:

```
kubectl run curl --image=radial/busyboxplus:curl -i --tty --rm
```

```
Waiting for pod default/curl-131556218-9fnch to be running, status is Pending, pod ready: false
Hit enter for command prompt
```

Then, hit enter and run nslookup my-nginx:

```
[ root@curl-131556218-9fnch:/ ]$ nslookup my-nginx
Server:    10.0.0.10
Address 1: 10.0.0.10

Name:      my-nginx
Address 1: 10.0.162.149
```

Securing the Service

Till now we have only accessed the nginx server from within the cluster. Before exposing the Service to the internet, you want to make sure the communication channel is secure. For this, you will need:

- Self signed certificates for https (unless you already have an identity certificate)
- An nginx server configured to use the certificates
- A secret that makes the certificates accessible to pods

You can acquire all these from the nginx https example. This requires having go and make tools installed. If you don't want to install those, then follow the manual steps later. In short:

```
make keys KEY=/tmp/nginx.key CERT=/tmp/nginx.crt
kubectl create secret tls nginxsecret --key /tmp/nginx.key --cert /tmp/nginx.crt
```

```
secret/nginxsecret created
```

```
kubectl get secrets
```

```
NAME                  TYPE                                  DATA      AGE
nginxsecret           kubernetes.io/tls                     2         1m
```

And also the configmap:

```
kubectl create configmap nginxconfigmap --from-file=default.conf
```

You can find an example for `default.conf` in [the Kubernetes examples project repo](#).

```
configmap/nginxconfigmap created
```

```
kubectl get configmaps
```

```
NAME             DATA   AGE
nginxconfigmap   1      114s
```

You can view the details of the `nginxconfigmap` ConfigMap using the following command:

```
kubectl describe configmap  nginxconfigmap
```

The output is similar to:

```
Name:         nginxconfigmap
Namespace:    default
Labels:       <none>
Annotations:  <none>

Data
====
default.conf:
----
server {
        listen 80 default_server;
        listen [::]:80 default_server ipv6only=on;

        listen 443 ssl;

        root /usr/share/nginx/html;
        index index.html;

        server_name localhost;
        ssl_certificate /etc/nginx/ssl/tls.crt;
        ssl_certificate_key /etc/nginx/ssl/tls.key;

        location / {
                try_files $uri $uri/ =404;
        }
}

BinaryData
```

```
====

Events:  <none>
```

Following are the manual steps to follow in case you run into problems running make (on windows for example):

```
# Create a public private key pair
openssl req -x509 -nodes -days 365 -newkey rsa:2048 -keyout /d/tmp/nginx.key -out /d/tmp/
nginx.crt -subj "/CN=my-nginx/O=my-nginx"
# Convert the keys to base64 encoding
cat /d/tmp/nginx.crt | base64
cat /d/tmp/nginx.key | base64
```

Use the output from the previous commands to create a yaml file as follows. The base64 encoded value should all be on a single line.


```
apiVersion: "v1"
kind: "Secret"
metadata:
  name: "nginxsecret"
  namespace: "default"
type: kubernetes.io/tls
data:
  tls.crt: "LS0tLS1CRUdJTiBDRVJUSUZJQ0FURS0tLS0tCk1JSURIekNDQWdlZ0F3SUJBZ0lKQUp5
M3lQK0pzMlpJTUEwR0NTcUdTSWIzRFFFQkJRVUFNQ1l4RVRBUEJnTlYKQkFNVENHNW5hV
zU0YzNaak1SRXdEd1lEVlFRS0V3aHVaMmx1ZUhOMll6QWVGdzB4TnpFd01qWXdOekEzTVRK
YQpGdzB4T0RFd01qWXdOekEzTVRKYU1DWXhFVEFQQmdOVkJBTVRDRzVuYVc1NGMzWm
pNUkV3RHdZRFZRUUtFd2h1CloybHVlSE4yWXpDQ0FTSXdEUVlKS29aSWh2Y05BUUVCQlFB
RGdnRVBBRENDQVFvQ2dnRUJBSjFxSU1SOVdWM0lKMlZIQlRMRmtobDRONXljMEJxYUhIQ
ktMSnJMcy8vdzZhU3hRS29GbHlJSU94NGUrMlN5ajBFcndCLzlYTnBwbQppeW1CL3JkRldkOXg
5UWhBQUxCZkVaTmNiV3NsTVFVcnhBZW50VWt1dk1vLzgvMHRpbGhjc3paenJEYVJ4NEo5C
i82UVRtVVI3a0ZTWUpOWTVQZkR3cGc3dlVvaDZmZ1Voam92VG42eHNVR0M2QURVODBp
NXFlZWhNeVI1N2lmU2YKNHZpaXdIY3hnL3lZR1JBRS9mRTRqakxCdmdON2c2SU90S01rZXV3
R0ljNDFhd05tNnNTZRqYUNGeGpYSnZaZQp2by9kTlEybHhHWCtKT2l3SEhXbXNhdGp4WTR
aNVk3R1ZoK0QrWnYvcW1mMFgvbVY0Rmo1NzV3ajFMWVBocWtsCmdhSXZYRyt4U1FVQ0F3
RUFBYU5RTUU0d0hRWURWUjBPQkJZRUZPNG9OWkI3YXc1OUlsYkROMzhIYkduYnhFVjcKT
UI4R0ExVWRJd1FZTUJhQUZPNG9OWkI3YXc1OUlsYkROMzhIYkduYnhFVjdNQXdHQTFVZE
V3UUZNQU1CQWY4dwpEUVlKS29aSWh2Y05BUUVGQlFBRGdnRUJBRVhhTW9FU0lFaXdyM
DhWcVA0K2NwTHI3TW5FMTducDBvMm14alFvCjRGb0RvRjdRZnZqeE04Tzd2TjB0clclxb2pGS
W0vWDE4ZnZaL3k4ZzVaWG40Vm8zc3hKVmRBcStNZC9jTStzUGEKNmJjTkUzNUekZqeFpUV0U
rKzE5NS9zb2dmOUZ3VDVDK3U2Q3B5N0M3MTZvUXRUakViV05VdEt4cXI0Nk1OZWNCMAp
wRFhWZmdWQTRadkR4NFo3S2RiZDY5eXM3OVFHYmg5ZW1PZ05ZFlsSUswSGt0ejF5WU4v
bVpmK3FqTkJqbWZjCkNnMnlwbGQ0Wi8rUUNQZjl3SkoybFIrY2FnT0R4elBWcGxNSEcybzgvT
HFDdnh6elZPUDUxeXdLZEtxaUMwSVEKQ0I5T2wwWW5scE9UNEh1b2hSUzBPStlMm9KdF
ZsNUIyczRpbDlhZ3RTVXFxUlU9Ci0tLS0tRU5EIENFUlRJRklDQVRFLS0tLS0K"
  tls.key: "LS0tLS1CRUdJTiBQUklWQVRFIEtFWS0tLS0tCk1JSUV2UUlCQURBTkJna3Foa2lHOXc
wQkFRRUZBQVNDQktjd2dnU2pBZ0VBQW9JQkFRQ2RhaURFZlZsZHdkbFIKd1V5eFpJWmVE
ZWNuTkFhbWh4d1NpeWF5N1AvOE9ta3NVQ3FCWmNpQ0RzZUh2dGtzbzlCSzhBZi9WemFh
Wm9zcApnZjYzZUluZmNmVUlRQUN3WHhHVFhHMXJKVEVGSzhRSHA3VkpMcnpLUC9QO
UxZcFlYTE0yYzZ3MmtjZUNmZitrCkU1bEVlNUJVbUNUV09UM3c4S1lPNzFLSWVuNEZJWTZ
MMDUrc2JGQmd1Z0ExUE5JdWFubm9UTWtlZTRuMG4rTDQKb3NCM0NM01ZUDhtQmtRQlAzeE9
JNHl3YjREZXUraURyU2pKSHJzQmlIT05Xc0RadXJJaXVJMmdoY1kxxeWIyWHI2UAozVFVOcG
```

```
NSbC9pVG9zQngxcHJHclk4V09HZVdPeGxZZmcvbWIvNnBuOUYvNWxlQlkrZStjSTlTMkQ0YX
BKWUdpCkwxeHZzVWtGQWdNQkFBRUNnZ0VBZFhCK0xkbk8ySElOTGo5bWRsb25IUGlHW
WVzZ294RGQwci9hQ1Zkank4dlEKTjIwL3FQWkUxek1yall6Ry9kVGhTMmMwc0QxaTBXSjdw
R1lGb0xtdXlWTjltY0FXUTM5SjM0VHZaU2FFSWZWNgo5TE1jUHhNTmFsNjRLMFRVbUFQZy
tGam9QSFlhUUxLOERLOUtnNXNrSE5pOWNzMlY5ckd6VWlVZWtBL0RBUlBTClI3L2ZjUFBac
DRuRWVBZmI3WTk1R1llb1p5V21SU3VKdlNyblBESGtUdW1vVlVWdkxMRHRzaG9reUxiTWV
tN3oKMmJzVmpwSW1GTHJqbGtmQXlpNHg0WjJrV3YyMFRrdWtsZU1jaVlMbjk4QWxiRi9DS
mRLM3QraTRoMTVlR2ZQegpoTnh3bk9QdlVTaDR2Q0o3c2Q5TmtEUGJvS2JneVVHOXBYamZ
hRGR2UVFLQmdRRFFLM01nUkhkQ1pKNVFqZWFKClFGdXF4cHdnNzhZTjQyL1NwenlUYmtG
cVFoQWtyczJxWGx1MDZBRzhrZzIzQkswaHkzaE9zSGgxcXRVK3NHZVAKOWRERHBsUWV0
ODZsY2FlR3hoc0V0L1R6cEdtNGFKSm5oNzVVaTVGZk9QTDhPTm1FZ3MxMVRhUldhNzZxelR
yMgphRlpjQ2pWV1g0YnRSTHVwSkgrMjZnY0FhUUtCZ1FEQmxVSUUzTnNVOFBBZEYvL25sQ
VB5VWs1T3lDdWc3dmVyClUycXlrdXFzYnBkSi9hODViT1JhM05IVmpVM25uRGpHVHBWaE9J
eXg5TEFrc2RwZEFjVmxvcG9HODhXYk9lMTAKMUdqbnkySmdDK3JVWUZiRGtpUGx1K09IYn
RnOXFYcGJMSHBzUVpsMGhucDBYSFNYVm9CMUliQndnMGEyOFVadApCbFBtWmc2d1BRS0
JnRHVIUVV2SDZHYTNDVUsxNFdmOFhIcFFnMU16M2VvWTBPQm5iSDRvZUZKZmcraEppS
XlnCm9RN3hqWldVR3BIc3AyblRtcHErQWlSNzdyRVhsdlhtOElVU2FsbkNiRGlKY01Pc29RdFBZ
NS9NczJMRm5LQTQKaENmL0pWb2FtZm1nZEN0ZGtFMXNINE9MR2lJVHdEbTRpb0dWZGIw
MllnbzFyb2htNUpLMUI3MkpBb0dBUW01UQpHNDhXOTVhL0w1eSt5dCsyZ3YvUHM2VnBvMj
ZlTzRNQ3lJazJVem9ZWE9IYnNkODJkaC8xT2sybGdHZlI2K3VuCnc1YytZUXRSTHlhQmd3MUt
pbGhFZDBKTWU3cGpUSVpnQWJ0LzVPbnlDak9OVXN2aDJjS2lrQ1Z2dTZsZlBjNkQKckliT2ZI
aHhxV0RZK2Q1TGN1YSt2NzJ0RkxhenJsSlBsRzlOZHhrQ2dZRUF5elIzT3UyMDNRVVV6bUlCR
kwzZAp4Wm5XZ0JLSEo3TnNxcGFWb2RjL0d5aGVycjFDZzE2MmJaSjJDV2RsZkI0VEdtUjZZdm
xTZEFOOFRwUWhFbUtKCnFBLzVzdHdxNWd0WGVLOVJmMWxXK29xNThRNTBxMmk1NVd
UTThoSDZhTjlaMTltZ0FGdE5VdGNqQUx2dFYxdEYKWSs4WFJkSHJaRnBIWll2NWkwVW1Vb
Gc9Ci0tLS0tRU5EIFBSSVZBVEUgS0VZLS0tLS0K"
```


Now create the secrets using the file:

```
kubectl apply -f nginxsecrets.yaml
kubectl get secrets
```

```
NAME            TYPE                  DATA   AGE
nginxsecret     kubernetes.io/tls     2      1m
```

Now modify your nginx replicas to start an https server using the certificate in the secret, and the Service, to expose both ports (80 and 443):

service/networking/nginx-secure-app.yaml

```
apiVersion: v1
kind: Service
metadata:
  name: my-nginx
  labels:
    run: my-nginx
spec:
  type: NodePort
  ports:
  - port: 8080
    targetPort: 80
    protocol: TCP
    name: http
  - port: 443
```

```
    protocol: TCP
    name: https
  selector:
    run: my-nginx
---
apiVersion: apps/v1
kind: Deployment
metadata:
  name: my-nginx
spec:
  selector:
    matchLabels:
      run: my-nginx
  replicas: 1
  template:
    metadata:
      labels:
        run: my-nginx
    spec:
      volumes:
      - name: secret-volume
        secret:
          secretName: nginxsecret
      - name: configmap-volume
        configMap:
          name: nginxconfigmap
      containers:
      - name: nginxhttps
        image: bprashanth/nginxhttps:1.0
        ports:
        - containerPort: 443
        - containerPort: 80
        volumeMounts:
        - mountPath: /etc/nginx/ssl
          name: secret-volume
        - mountPath: /etc/nginx/conf.d
          name: configmap-volume
```

Noteworthy points about the nginx-secure-app manifest:

- It contains both Deployment and Service specification in the same file.
- The nginx server serves HTTP traffic on port 80 and HTTPS traffic on 443, and nginx Service exposes both ports.
- Each container has access to the keys through a volume mounted at `/etc/nginx/ssl`. This is set up *before* the nginx server is started.

```
kubectl delete deployments,svc my-nginx; kubectl create -f ./nginx-secure-app.yaml
```

At this point you can reach the nginx server from any node.

```
kubectl get pods -l run=my-nginx -o custom-columns=POD_IP:.status.podIPs
    POD_IP
    [map[ip:10.244.3.5]]
```

```
node $ curl -k https://10.244.3.5
...
<h1>Welcome to nginx!</h1>
```

Note how we supplied the `-k` parameter to curl in the last step, this is because we don't know anything about the pods running nginx at certificate generation time, so we have to tell curl to ignore the CName mismatch. By creating a Service we linked the CName used in the certificate with the actual DNS name used by pods during Service lookup. Let's test this from a pod (the same secret is being reused for simplicity, the pod only needs nginx.crt to access the Service):

service/networking/curlpod.yaml

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: curl-deployment
spec:
  selector:
    matchLabels:
      app: curlpod
  replicas: 1
  template:
    metadata:
      labels:
        app: curlpod
    spec:
      volumes:
      - name: secret-volume
        secret:
          secretName: nginxsecret
      containers:
      - name: curlpod
        command:
        - sh
        - -c
        - while true; do sleep 1; done
        image: radial/busyboxplus:curl
        volumeMounts:
        - mountPath: /etc/nginx/ssl
          name: secret-volume
```

```
kubectl apply -f ./curlpod.yaml
kubectl get pods -l app=curlpod
```

```
NAME                               READY     STATUS    RESTARTS   AGE
curl-deployment-1515033274-1410r   1/1       Running   0          1m
```

```
kubectl exec curl-deployment-1515033274-1410r -- curl https://my-nginx --cacert /etc/nginx/ssl/tls.crt
...
<title>Welcome to nginx!</title>
...
```

Exposing the Service

For some parts of your applications you may want to expose a Service onto an external IP address. Kubernetes supports two ways of doing this: NodePorts and LoadBalancers. The Service created in the last section already used `NodePort`, so your nginx HTTPS replica is ready to serve traffic on the internet if your node has a public IP.

```
kubectl get svc my-nginx -o yaml | grep nodePort -C 5
  uid: 07191fb3-f61a-11e5-8ae5-42010af00002
spec:
  clusterIP: 10.0.162.149
  ports:
  - name: http
    nodePort: 31704
    port: 8080
    protocol: TCP
    targetPort: 80
  - name: https
    nodePort: 32453
    port: 443
    protocol: TCP
    targetPort: 443
  selector:
    run: my-nginx
```

```
kubectl get nodes -o yaml | grep ExternalIP -C 1
    - address: 104.197.41.11
      type: ExternalIP
    allocatable:
--
    - address: 23.251.152.56
      type: ExternalIP
    allocatable:
...

$ curl https://<EXTERNAL-IP>:<NODE-PORT> -k
...
<h1>Welcome to nginx!</h1>
```

Let's now recreate the Service to use a cloud load balancer. Change the `Type` of `my-nginx` Service from `NodePort` to `LoadBalancer`:

```
kubectl edit svc my-nginx
kubectl get svc my-nginx
```

```
NAME       TYPE           CLUSTER-IP     EXTERNAL-IP        PORT(S)               AGE
my-nginx   LoadBalancer   10.0.162.149     xx.xxx.xxx.xxx     8080:30163/TCP        21s
```

```
curl https://<EXTERNAL-IP> -k
...
<title>Welcome to nginx!</title>
```

The IP address in the EXTERNAL-IP column is the one that is available on the public internet. The CLUSTER-IP is only available inside your cluster/private cloud network.

Note that on AWS, type LoadBalancer creates an ELB, which uses a (long) hostname, not an IP. It's too long to fit in the standard kubectl get svc output, in fact, so you'll need to do kubectl describe service my-nginx to see it. You'll see something like this:

```
kubectl describe service my-nginx
...
LoadBalancer Ingress:   a320587ffd19711e5a37606cf4a74574-1142138393.us-east-1.elb.amazonaws.com
...
```

What's next

- Learn more about Using a Service to Access an Application in a Cluster
- Learn more about Connecting a Front End to a Back End Using a Service
- Learn more about Creating an External Load Balancer

Using Source IP

Applications running in a Kubernetes cluster find and communicate with each other, and the outside world, through the Service abstraction. This document explains what happens to the source IP of packets sent to different types of Services, and how you can toggle this behavior according to your needs.

Before you begin

Terminology

This document makes use of the following terms:

NAT
: network address translation

Source NAT
: replacing the source IP on a packet; in this page, that usually means replacing with the IP address of a node.

Destination NAT
: replacing the destination IP on a packet; in this page, that usually means replacing with the IP address of a Pod

VIP
: a virtual IP address, such as the one assigned to every Service in Kubernetes

kube-proxy
: a network daemon that orchestrates Service VIP management on every node

Prerequisites

You need to have a Kubernetes cluster, and the kubectl command-line tool must be configured to communicate with your cluster. It is recommended to run this tutorial on a cluster with at least two nodes that are not acting as control plane hosts. If you do not already have a cluster, you can create one by using minikube or you can use one of these Kubernetes playgrounds:

- Killercoda
- Play with Kubernetes

The examples use a small nginx webserver that echoes back the source IP of requests it receives through an HTTP header. You can create it as follows:

```
kubectl create deployment source-ip-app --image=registry.k8s.io/echoserver:1.4
```

The output is:

```
deployment.apps/source-ip-app created
```

Objectives

- Expose a simple application through various types of Services
- Understand how each Service type handles source IP NAT
- Understand the tradeoffs involved in preserving source IP

Source IP for Services with `Type=ClusterIP`

Packets sent to ClusterIP from within the cluster are never source NAT'd if you're running kube-proxy in iptables mode, (the default). You can query the kube-proxy mode by fetching `http://localhost:10249/proxyMode` on the node where kube-proxy is running.

```
kubectl get nodes
```

The output is similar to this:

```
NAME                     STATUS     ROLES    AGE     VERSION
kubernetes-node-6jst   Ready      <none>   2h      v1.13.0
kubernetes-node-cx31   Ready      <none>   2h      v1.13.0
kubernetes-node-jj1t   Ready      <none>   2h      v1.13.0
```

Get the proxy mode on one of the nodes (kube-proxy listens on port 10249):

```
# Run this in a shell on the node you want to query.
curl http://localhost:10249/proxyMode
```

The output is:

```
iptables
```

You can test source IP preservation by creating a Service over the source IP app:

```
kubectl expose deployment source-ip-app --name=clusterip --port=80 --target-port=8080
```

The output is:

```
service/clusterip exposed
```

```
kubectl get svc clusterip
```

The output is similar to:

```
NAME        TYPE        CLUSTER-IP    EXTERNAL-IP   PORT(S)    AGE
clusterip   ClusterIP   10.0.170.92   <none>        80/TCP     51s
```

And hitting the ClusterIP from a pod in the same cluster:

```
kubectl run busybox -it --image=busybox:1.28 --restart=Never --rm
```

The output is similar to this:

```
Waiting for pod default/busybox to be running, status is Pending, pod ready: false
If you don't see a command prompt, try pressing enter.
```

You can then run a command inside that Pod:

```
# Run this inside the terminal from "kubectl run"
ip addr
```

```
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
3: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1460 qdisc noqueue
    link/ether 0a:58:0a:f4:03:08 brd ff:ff:ff:ff:ff:ff
    inet 10.244.3.8/24 scope global eth0
       valid_lft forever preferred_lft forever
    inet6 fe80::188a:84ff:feb0:26a5/64 scope link
       valid_lft forever preferred_lft forever
```

…then use wget to query the local webserver

```
# Replace "10.0.170.92" with the IPv4 address of the Service named "clusterip"
wget -qO - 10.0.170.92
```

```
CLIENT VALUES:
client_address=10.244.3.8
command=GET
...
```

The client_address is always the client pod's IP address, whether the client pod and server pod are in the same node or in different nodes.

Source IP for Services with Type=NodePort

Packets sent to Services with Type=NodePort are source NAT'd by default. You can test this by creating a NodePort Service:

```
kubectl expose deployment source-ip-app --name=nodeport --port=80 --target-port=8080 --type=NodePort
```

The output is:

```
service/nodeport exposed
```

```
NODEPORT=$(kubectl get -o jsonpath="{.spec.ports[0].nodePort}" services nodeport)
NODES=$(kubectl get nodes -o jsonpath='{ $.items[*].status.addresses[?
(@.type=="InternalIP")].address }')
```

If you're running on a cloud provider, you may need to open up a firewall-rule for the `nodes:nodeport` reported above. Now you can try reaching the Service from outside the cluster through the node port allocated above.

```
for node in $NODES; do curl -s $node:$NODEPORT | grep -i client_address; done
```

The output is similar to:

```
client_address=10.180.1.1
client_address=10.240.0.5
client_address=10.240.0.3
```

Note that these are not the correct client IPs, they're cluster internal IPs. This is what happens:

- Client sends packet to `node2:nodePort`
- `node2` replaces the source IP address (SNAT) in the packet with its own IP address
- `node2` replaces the destination IP on the packet with the pod IP
- packet is routed to node 1, and then to the endpoint
- the pod's reply is routed back to node2
- the pod's reply is sent back to the client

Visually:

> [source IP nodeport figure 01]()
>
> Figure. Source IP Type=NodePort using SNAT

To avoid this, Kubernetes has a feature to [preserve the client source IP](). If you set `service.spec.externalTrafficPolicy` to the value Local, kube-proxy only proxies proxy requests to local endpoints, and does not forward traffic to other nodes. This approach preserves the original source IP address. If there are no local endpoints, packets sent to the node are dropped, so you can rely on the correct source-ip in any packet processing rules you might apply a packet that make it through to the endpoint.

Set the `service.spec.externalTrafficPolicy` field as follows:

```
kubectl patch svc nodeport -p '{"spec":{"externalTrafficPolicy":"Local"}}'
```

The output is:

```
service/nodeport patched
```

Now, re-run the test:

```
for node in $NODES; do curl --connect-timeout 1 -s $node:$NODEPORT | grep -i
client_address; done
```

The output is similar to:

```
client_address=198.51.100.79
```

Note that you only got one reply, with the *right* client IP, from the one node on which the endpoint pod is running.

This is what happens:

- client sends packet to `node2:nodePort`, which doesn't have any endpoints
- packet is dropped
- client sends packet to `node1:nodePort`, which *does* have endpoints
- node1 routes packet to endpoint with the correct source IP

Visually:

source IP nodeport figure 02

Figure. Source IP Type=NodePort preserves client source IP address

Source IP for Services with `Type=LoadBalancer`

Packets sent to Services with [`Type=LoadBalancer`] are source NAT'd by default, because all schedulable Kubernetes nodes in the `Ready` state are eligible for load-balanced traffic. So if packets arrive at a node without an endpoint, the system proxies it to a node *with* an endpoint, replacing the source IP on the packet with the IP of the node (as described in the previous section).

You can test this by exposing the source-ip-app through a load balancer:

```
kubectl expose deployment source-ip-app --name=loadbalancer --port=80 --target-port=8080 --type=LoadBalancer
```

The output is:

```
service/loadbalancer exposed
```

Print out the IP addresses of the Service:

```
kubectl get svc loadbalancer
```

The output is similar to this:

```
NAME           TYPE           CLUSTER-IP    EXTERNAL-IP       PORT(S)   AGE
loadbalancer   LoadBalancer   10.0.65.118   203.0.113.140     80/TCP    5m
```

Next, send a request to this Service's external-ip:

```
curl 203.0.113.140
```

The output is similar to this:

```
CLIENT VALUES:
client_address=10.240.0.5
...
```

However, if you're running on Google Kubernetes Engine/GCE, setting the same `service.spec.externalTrafficPolicy` field to `Local` forces nodes *without* Service endpoints to remove themselves from the list of nodes eligible for loadbalanced traffic by deliberately failing health checks.

Visually:

Source IP with externalTrafficPolicy

You can test this by setting the annotation:

```
kubectl patch svc loadbalancer -p '{"spec":{"externalTrafficPolicy":"Local"}}'
```

You should immediately see the `service.spec.healthCheckNodePort` field allocated by Kubernetes:

```
kubectl get svc loadbalancer -o yaml | grep -i healthCheckNodePort
```

The output is similar to this:

```
  healthCheckNodePort: 32122
```

The `service.spec.healthCheckNodePort` field points to a port on every node serving the health check at `/healthz`. You can test this:

```
kubectl get pod -o wide -l app=source-ip-app
```

The output is similar to this:

```
NAME                            READY     STATUS    RESTARTS   AGE       IP             NODE
source-ip-app-826191075-qehz4   1/1       Running   0          20h       10.180.1.136   kubernetes-node-6jst
```

Use `curl` to fetch the `/healthz` endpoint on various nodes:

```
# Run this locally on a node you choose
curl localhost:32122/healthz
```

```
1 Service Endpoints found
```

On a different node you might get a different result:

```
# Run this locally on a node you choose
curl localhost:32122/healthz
```

```
No Service Endpoints Found
```

A controller running on the [control plane](#) is responsible for allocating the cloud load balancer. The same controller also allocates HTTP health checks pointing to this port/path on each node. Wait about 10 seconds for the 2 nodes without endpoints to fail health checks, then use `curl` to query the IPv4 address of the load balancer:

```
curl 203.0.113.140
```

The output is similar to this:

```
CLIENT VALUES:
client_address=198.51.100.79
...
```

Cross-platform support

Only some cloud providers offer support for source IP preservation through Services with `Type=LoadBalancer`. The cloud provider you're running on might fulfill the request for a loadbalancer in a few different ways:

1. With a proxy that terminates the client connection and opens a new connection to your nodes/endpoints. In such cases the source IP will always be that of the cloud LB, not that of the client.

2. With a packet forwarder, such that requests from the client sent to the loadbalancer VIP end up at the node with the source IP of the client, not an intermediate proxy.

Load balancers in the first category must use an agreed upon protocol between the loadbalancer and backend to communicate the true client IP such as the HTTP Forwarded or X-FORWARDED-FOR headers, or the proxy protocol. Load balancers in the second category can leverage the feature described above by creating an HTTP health check pointing at the port stored in the `service.spec.healthCheckNodePort` field on the Service.

Cleaning up

Delete the Services:

```
kubectl delete svc -l app=source-ip-app
```

Delete the Deployment, ReplicaSet and Pod:

```
kubectl delete deployment source-ip-app
```

What's next

- Learn more about connecting applications via services
- Read how to Create an External Load Balancer

Explore Termination Behavior for Pods And Their Endpoints

Once you connected your Application with Service following steps like those outlined in Connecting Applications with Services, you have a continuously running, replicated application, that is exposed on a network. This tutorial helps you look at the termination flow for Pods and to explore ways to implement graceful connection draining.

Termination process for Pods and their endpoints

There are often cases when you need to terminate a Pod - be it for upgrade or scale down. In order to improve application availability, it may be important to implement a proper active connections draining.

This tutorial explains the flow of Pod termination in connection with the corresponding endpoint state and removal by using a simple nginx web server to demonstrate the concept.

Example flow with endpoint termination

The following is the example of the flow described in the Termination of Pods document.

Let's say you have a Deployment containing of a single `nginx` replica (just for demonstration purposes) and a Service:

service/pod-with-graceful-termination.yaml

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: nginx-deployment
  labels:
    app: nginx
spec:
  replicas: 1
  selector:
    matchLabels:
      app: nginx
  template:
    metadata:
      labels:
        app: nginx
    spec:
      terminationGracePeriodSeconds: 120 # extra long grace period
      containers:
      - name: nginx
        image: nginx:latest
        ports:
        - containerPort: 80
        lifecycle:
          preStop:
            exec:
              # Real life termination may take any time up to terminationGracePeriodSeconds.
              # In this example - just hang around for at least the duration of
terminationGracePeriodSeconds,
              # at 120 seconds container will be forcibly terminated.
              # Note, all this time nginx will keep processing requests.
              command: [
                "/bin/sh", "-c", "sleep 180"
              ]
```

service/explore-graceful-termination-nginx.yaml

```yaml
apiVersion: v1
kind: Service
metadata:
  name: nginx-service
spec:
  selector:
    app: nginx
  ports:
    - protocol: TCP
      port: 80
      targetPort: 80
```

Now create the Deployment Pod and Service using the above files:

```
kubectl apply -f pod-with-graceful-termination.yaml
kubectl apply -f explore-graceful-termination-nginx.yaml
```

Once the Pod and Service are running, you can get the name of any associated EndpointSlices:

```
kubectl get endpointslice
```

The output is similar to this:

```
NAME                  ADDRESSTYPE   PORTS   ENDPOINTS                 AGE
nginx-service-6tjbr   IPv4          80      10.12.1.199,10.12.1.201   22m
```

You can see its status, and validate that there is one endpoint registered:

```
kubectl get endpointslices -o json -l kubernetes.io/service-name=nginx-service
```

The output is similar to this:

```
{
    "addressType": "IPv4",
    "apiVersion": "discovery.k8s.io/v1",
    "endpoints": [
        {
            "addresses": [
                "10.12.1.201"
            ],
            "conditions": {
                "ready": true,
                "serving": true,
                "terminating": false
```

Now let's terminate the Pod and validate that the Pod is being terminated respecting the graceful termination period configuration:

```
kubectl delete pod nginx-deployment-7768647bf9-b4b9s
```

All pods:

```
kubectl get pods
```

The output is similar to this:

```
NAME                               READY   STATUS        RESTARTS      AGE
nginx-deployment-7768647bf9-b4b9s   1/1     Terminating   0             4m1s
nginx-deployment-7768647bf9-rkxlw   1/1     Running       0             8s
```

You can see that the new pod got scheduled.

While the new endpoint is being created for the new Pod, the old endpoint is still around in the terminating state:

```
kubectl get endpointslice -o json nginx-service-6tjbr
```

The output is similar to this:


```
{
    "addressType": "IPv4",
    "apiVersion": "discovery.k8s.io/v1",
    "endpoints": [
        {
            "addresses": [
                "10.12.1.201"
            ],
            "conditions": {
                "ready": false,
                "serving": true,
                "terminating": true
            },
            "nodeName": "gke-main-default-pool-dca1511c-d17b",
            "targetRef": {
                "kind": "Pod",
                "name": "nginx-deployment-7768647bf9-b4b9s",
                "namespace": "default",
                "uid": "66fa831c-7eb2-407f-bd2c-f96dfe841478"
            },
            "zone": "us-central1-c"
        },
        {
            "addresses": [
                "10.12.1.202"
            ],
            "conditions": {
                "ready": true,
                "serving": true,
                "terminating": false
            },
            "nodeName": "gke-main-default-pool-dca1511c-d17b",
            "targetRef": {
                "kind": "Pod",
                "name": "nginx-deployment-7768647bf9-rkxlw",
                "namespace": "default",
                "uid": "722b1cbe-dcd7-4ed4-8928-4a4d0e2bbe35"
            },
            "zone": "us-central1-c"
```

This allows applications to communicate their state during termination and clients (such as load balancers) to implement a connections draining functionality. These clients may detect terminating endpoints and implement a special logic for them.

In Kubernetes, endpoints that are terminating always have their `ready` status set as as `false`. This needs to happen for backward compatibility, so existing load balancers will not use it for regular traffic. If traffic draining on terminating pod is needed, the actual readiness can be checked as a condition `serving`.

When Pod is deleted, the old endpoint will also be deleted.

What's next

- Learn how to Connect Applications with Services
- Learn more about Using a Service to Access an Application in a Cluster
- Learn more about Connecting a Front End to a Back End Using a Service
- Learn more about Creating an External Load Balancer