Advanced Scheduling in Kubernetes

Overview

This chapter focuses on scheduling, which is the process by which Kubernetes selects a node for running a Pod. In this chapter, we will take a closer look at this process and the Kubernetes Scheduler, which is the default Kubernetes component responsible for this process.

By the end of this chapter, you will be able to use different ways to control the behavior of the Kubernetes Scheduler to suit the requirements of an application. The chapter will equip you to be able to choose appropriate Pod scheduling methods to control which nodes you want to run your Pods on based on your business needs. You will learn about the different ways to control the scheduling of Pods on the Kubernetes cluster.

Introduction

We have seen that we package our applications as containers and deploy them as a Pod in Kubernetes, which is the minimal unit of Deployment. With the help of the advanced scheduling capabilities provided by Kubernetes, we can optimize the deployment of these Pods with respect to our hardware infrastructure to meet our needs and get the most out of the available resources.

Kubernetes clusters generally have more than a few nodes (or machines or hosts) where the Pod can be executed. Consider that you are managing a few of the machines and you have been assigned to execute an application on these machines. What would you do to decide which machine is the best fit for the given application? Until now in this workshop, whenever you wanted to run a Pod on a Kubernetes cluster, have you mentioned which node(s) the Pod should run on?

That's right -- we don't need to; Kubernetes comes with a smart component that finds the best node to run your Pod. This component is the **Kubernetes Scheduler**. In this chapter, we will look a bit more deeply into how the Kubernetes Scheduler works, and how to adapt it to better control our cluster to suit different needs.

The Kubernetes Scheduler

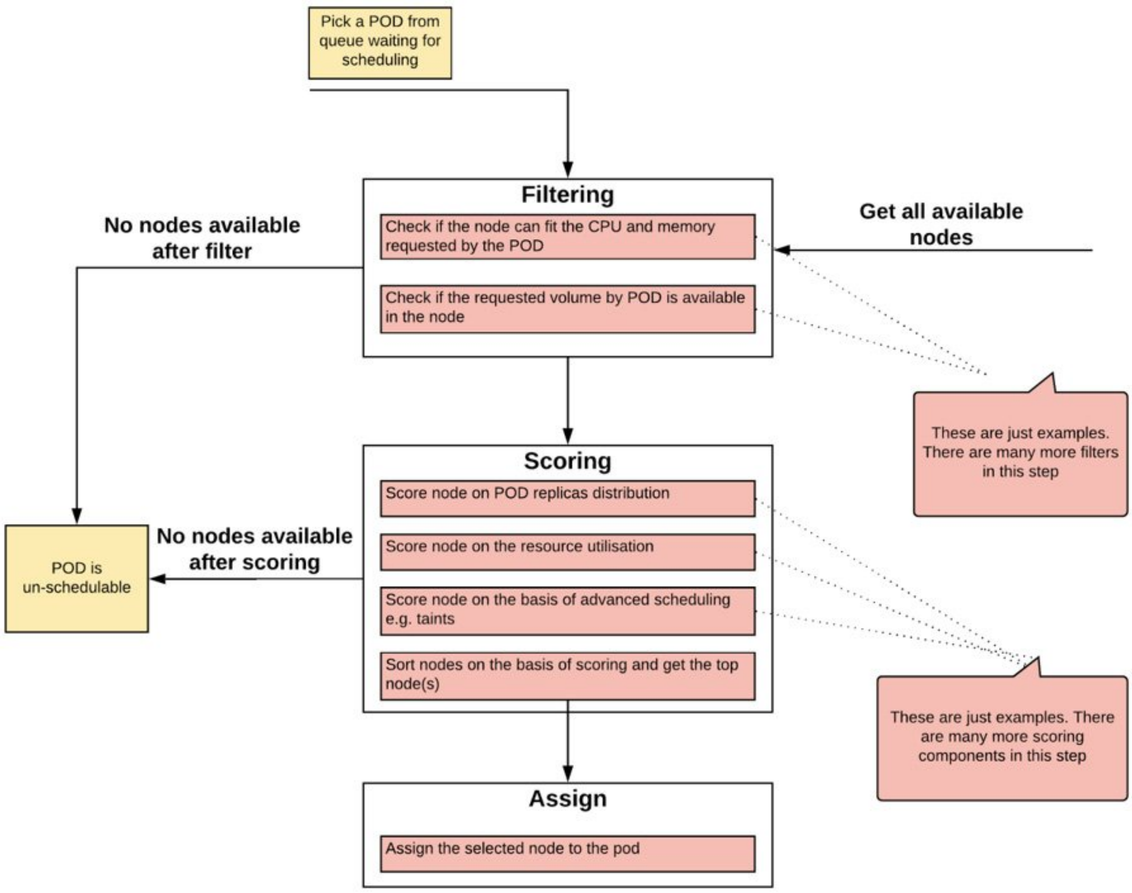
As mentioned in the introduction, a typical cluster has several nodes. When you create a Pod, Kubernetes has to choose a node and assign the Pod to it. This process is known as **Pod scheduling**.

The Kubernetes component that is responsible for deciding which node a Pod should be assigned to for execution is called a scheduler. Kubernetes comes with a default scheduler that suffices for most use cases. For example, the default Kubernetes Scheduler spreads the load evenly in the cluster.

Now, consider a scenario in which two different Pods are expected to communicate with each other very often. As a system architect, you may want them to be on the same node to reduce latency and free up some internal networking bandwidth. The Scheduler does not know the relationship between different types of Pods, but Kubernetes provides ways to inform the Scheduler about this relationship and influence the scheduling behavior so that these two different Pods can be hosted on the same node. But first, let's take a closer look at the Pod **scheduling process**.

The Pod Scheduling Process

The scheduler works in a three-step process: **filtering**, **scoring**, and **assigning**. Let's take a look at what happens during the execution of each of these steps. An overview of the process is described in the following diagram:



Kubermetes Scheduler - An overview of how it selects the node

Filtering

Filtering is a process in which the **Kubernetes Scheduler** runs a series of checks or filters to see which nodes are not suitable to run the target Pod. An example of a filter is to see if the node has enough CPU and memory to host the Pod, or if the storage volume requested by the Pod can be mounted on the host. If the cluster has no node that's suitable to meet the requirements of the Pod, then the Pod is deemed un-schedulable and is not executed on the cluster.

Scoring

Once the **Kubernetes Scheduler** has a list of feasible nodes, the second step is to score the nodes and find the best node(s) to host the target Pod. The node is passed through several priority functions and assigned a priority score. Each function assigns a score between 0 and 10, where 0 is the lowest and 10 is the highest.

To understand priority functions, let's take `SelectorSpreadPriority` as an example. This priority function uses label selectors to find the Pods that are associated together. Let's say, for example, that a bunch of Pods is created by the same Deployment. As the name SpreadPriority suggests, this function tries to spread the Pods across different nodes so that in case of a node failure, we will still have replicas running on other nodes. Under this priority function, the Kubernetes Scheduler selects the nodes that have the fewest Pods running using the same label selectors as the requested Pod. These nodes will be assigned the highest score and vice versa.

Another example of a priority function is `LeastRequestedPriority`. This tries to spread the workload on the nodes that have the most resources available. The scheduler gets the nodes that have the lowest amount of memory and CPU allocated to existing Pods. These nodes are assigned the highest scores. In other words, this priority function will assign a higher score for a larger amount of free resources.

Note

There are far too many priority functions to cover within the limited scope of this chapter. The full list of priority functions can be found at the following link: https://kubernetes.io/docs/concepts/scheduling/kube-scheduler/#scoring.

Assigning

Lastly, the Scheduler informs the API server about the node that has been selected based on the highest score. If there are multiple nodes with the same score, the Scheduler picks a random node and effectively applies a tiebreaker.

The default Kubernetes Scheduler runs as a Pod in the `kube-system` namespace. You can see it running by listing all the Pods in the `kube-system` namespace:

```
kubectl get pods -n kube-system
```

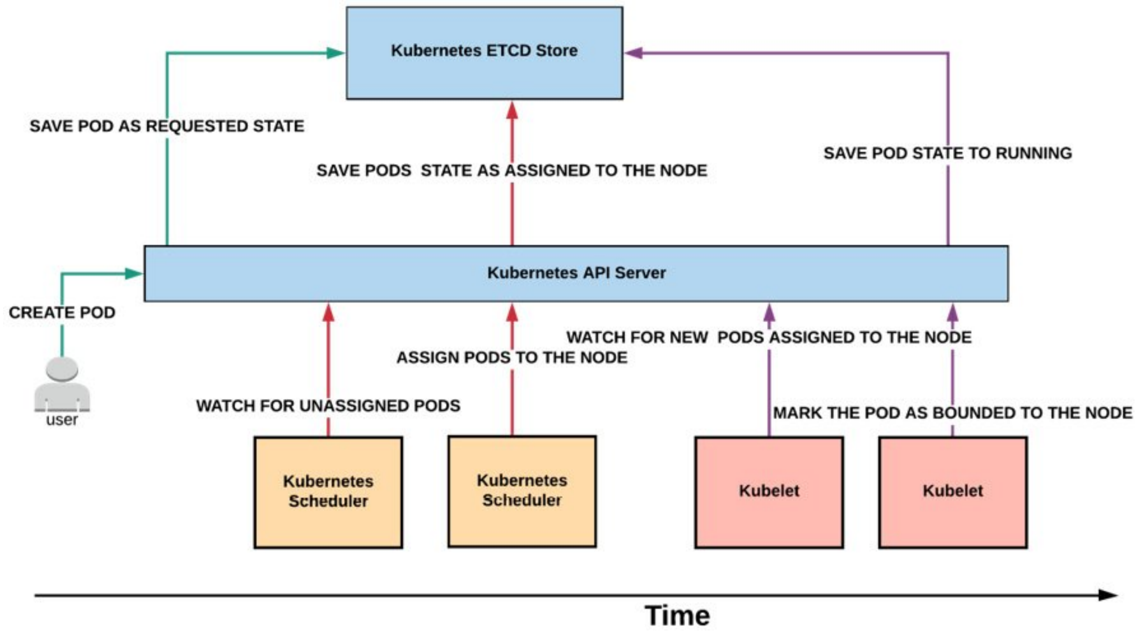
You should see the following list of Pods:

```
NAME                               READY   STATUS    RESTARTS   AGE
coredns-fb8b8dccf-6kf4g            1/1     Running   1          3m5s
coredns-fb8b8dccf-gfvmf            1/1     Running   1          3m5s
etcd-minikube                      1/1     Running   0          113s
kube-addon-manager-minikube        1/1     Running   0          112s
kube-apiserver-minikube            1/1     Running   0          2m11s
kube-controller-manager-minikube   1/1     Running   0          2m3s
kube-proxy-gqzxj                   1/1     Running   0          3m5s
kube-scheduler-minikube            1/1     Running   0          110s
storage-provisioner                1/1     Running   0          3m4s
```

In our Minikube environment, the Kubernetes Scheduler Pod is named `kube-scheduler-minikube`, as you can see in this screenshot.

Timeline of Pod Scheduling

Let's dig into the timeline of the **Pod scheduling** process. When you request a Pod to be created, different Kubernetes components get invoked to assign the Pod to the right node. There are three steps involved, from requesting a Pod to assigning a node. The following diagram gives an overview of this process, and we will elaborate and break down the process into more detailed steps after the diagram:



Step 1: When a request is raised for creating and running a Pod, for instance, through a kubectl command or by a Kubernetes Deployment, the API server responds to this request. It updates the Kubernetes internal database (etcd) with a Pod pending entry to be executed. Note that at this stage, there is no guarantee that Pod will be scheduled.

Step 2: The **Kubernetes Scheduler** constantly watches the Kubernetes data store through the API server. As soon as a Pod creation request is available (or a Pod is in the pending state), the Scheduler tries to schedule it. It is important to note that the Scheduler is not responsible for running the Pod. It simply calculates the best node for hosting the Pod and informs the Kubernetes API server, which then stores this information in etcd. In this step, the Pod is assigned to the optimal node, and the association is stored in etcd.

Step 3: The Kubernetes agent (kubelet) constantly watches the Kubernetes data store through the API server. As soon as a new Pod is assigned to a node, it tries to execute the Pod on the node. When the Pod is successfully up and running, it is marked as running in etcd through the API server, and now the process is complete.

Now that we have an idea of the scheduling process, let's see how we can tweak it to suit our needs in the following topic.

Managing the Kubernetes Scheduler

Kubernetes provides many parameters and objects through which we can manage the behavior of the **Kubernetes Scheduler**. We will look into the following ways of managing the scheduling process:

- Node affinity and anti-affinity
- Pod affinity and anti-affinity
- Pod priority and preemption
- Taints and tolerations

Node Affinity and Anti-Affinity

Using node affinity rules, a Kubernetes cluster administrator can control the placement of Pods on specific sets of nodes. Node affinity or anti-affinity allows you to constrain which nodes a Pod can run on based on the labels of the nodes.

Imagine that you are an administrator of the shared Kubernetes cluster in a bank. Multiple teams are running their applications on the same cluster. Your organization's security group has identified nodes that can run data-sensitive applications and would like you to make sure that no other applications run on those nodes. Node affinity or anti-affinity rules provide a solution to this requirement to only associate specific Pods to a set of nodes.

Node affinity rules are defined through two components. First, you assign a label to a set of nodes. The second part is to configure the Pods to associate them only with the nodes with certain labels. Another way to think about this is that the Pod defines where it should be placed, and the Scheduler matches the labels in this definition with the node labels.

There are two types of node affinity/anti-affinity rules:

- **Required rules** are hard rules. If these rules are not met, the Pod cannot be scheduled on a node. It is defined as the `requiredDuringSchedulingIgnoredDuringExecution` section in the Pod specification. Please see *Exercise 17.01*, *Running a Pod with Node Affinity* as an example of this.
- **Preferred rules** are soft rules. The Scheduler tries to enforce preferred rules whenever possible, but it goes ahead to ignore them when the rules cannot be enforced, that is, the Pod would be rendered unschedulable if these rules were followed as rigidly. Preferred rules are defined as the `preferredDuringSchedulingIgnoredDuringExecution` section in the Pod specification.

Preferred rules have weights associated with each criterion. The Scheduler will create a score based on these weights to schedule a Pod at the right node. The value of the weight field ranges from 1 to 100. The Scheduler calculates the priority score for all the suitable nodes to find the optimal one. Note that the score can be impacted by other priority functions, such as `LeastRequestedPriority`.

If you define a weight that is too low (compared to the other weights), then the overall score will be most affected by other priority functions, and our preferred rule may have little effect on the scheduling process. If you have multiple rules defined, then you can alter the weights of the rules that are the most important to you.

Affinity rules are defined in the Pod specification. Based on the labels of our desired/undesired nodes, we would provide the first part of the selection criteria in the Pod spec. It consists of the set of labels and, optionally, their values.

The other part of the criteria is to provide the way we want to match the labels. We define these matching criteria as the **operator** in the affinity definition. This operator can have the following values:

- The `In` operator instructs the Scheduler to schedule the Pods on the nodes that match the label and one of the specified values.
- The `NotIn` operator instructs the Scheduler to not schedule the Pods on the nodes that do not match the label and any of the specified values. This is a negative operator and denotes the anti-affinity configuration.
- The `Exists` operator instructs the Scheduler to schedule the Pods on the nodes that match the label. The value of the label does not matter in this case. Thus, this operator is satisfied even if the specified label exists and the value of the label does not match.
- The `DoesNotExist` operator instructs the Scheduler to not schedule the Pods on the nodes that do not match the label. The value of the label does not matter in this case. This is a negative operator and denotes the anti-affinity configuration.

Note that affinity and anti-affinity rules are defined based on the labels on the nodes. If the labels on a node are changed, it is possible that a node affinity rule may no longer be applied. In this case, the Pods that are running will continue to run on the node. If a Pod is restarted, or if it dies and a new Pod is created, Kubernetes considers this a new Pod. In this case, if the node labels have been modified, the Scheduler may not put the Pod on the same node. This is something that you would want to be mindful of when you modify node labels. Let's implement these rules for a Pod in the following exercise.

Exercise 17.01: Running a Pod with Node Affinity

In this exercise, we will configure a Pod to be scheduled on the node available in our Minikube environment. We will also see, if the labels do not match, the Pod will be in the `Pending` state. Think of this state in which the scheduler is unable to find the right node to assign to the Pod:

1. Create a new namespace called `schedulerdemo` using the following command:

   ```
   kubectl create ns schedulerdemo
   ```

   You should see the following response:

   ```
   namespace/schedulerdemo created
   ```

2. Now we need to create a Pod with node affinity defined. Create a file named `pod-with-node-affinity.yaml` with the following specification:

   ```
   apiVersion: v1
   kind: Pod
   metadata:
     name: pod-with-node-affinity
   spec:
     affinity:
      nodeAffinity:
        requiredDuringSchedulingIgnoredDuringExecution:
          nodeSelectorTerms:
          - matchExpressions:
            - key: data-center
              operator: In
              values:
              - sydney
     containers:
       - name: pod-with-node-affinity-container
         image: k8s.gcr.io/busybox
         command: [ "/bin/sh", "-c", "while :; do echo '.'; sleep         5 ;
   done" ]
   ```

   Note that in the Pod specification, we have added the new `affinity` section. This rule is configured as `requiredDuringSchedulingIgnoredDuringExecution`. This means if the node with a matching label does not exist, this Pod will not get scheduled. Also note that as per the `In` operator, the expressions mentioned here are to be matched with the node labels. In this example, a matching node would have the label `data-center=sydney`.

3. Try to create this Pod and see if it gets scheduled and executed:

   ```
   kubectl create -f pod-with-node-affinity.yaml -n schedulerdemo
   ```

   You should see the following response:

   ```
   pod/pod-with-node-affinity created
   ```

   Note that the response you see here does not necessarily imply that the Pod has successfully been executed on a node. Let's check that in the following step.

4. Check the status of the Pod using this command:

```
kubectl get pods -n schedulerdemo
```

You will see the following response:

```
NAME                     READY   STATUS    RESTARTS   AGE
pod-with-node-affinity   0/1     Pending   0          10s
```

From this output, you can see that the Pod is in the `Pending` state and it is not being executed.

5. Check the `events` to see why the Pod is not being executed:

```
kubectl get events -n schedulerdemo
```

You will see the following response:

```
LAST SEEN   TYPE      REASON             OBJECT                       MESSAGE
<unknown>   Warning   FailedScheduling   pod/pod-with-node-affinity   0/1 nodes are availabl
e: 1 node(s) didn't match node selector.
```

```
You can see that Kubernetes is saying that there is no node to match
the selector for this Pod.
```

6. Let's delete the Pod before proceeding further:

```
kubectl delete pod pod-with-node-affinity -n schedulerdemo
```

You should see the following response:

```
pod "pod-with-node-affinity" deleted
```

7. Now, let's see what nodes are available in our cluster:

```
kubectl get nodes
```

You will see the following response:

```
NAME       STATUS   ROLES    AGE    VERSION
minikube   Ready    master   105d   v1.14.3
```

Since we are using Minikube, there is only one node available called `minikube`.

8. Check the label for the `minikube` node. Use the `describe` command as shown here:

```
kubectl describe node minikube
```

You should see the following response:

```
Name:                 minikube
Roles:                master
Labels:               beta.kubernetes.io/arch=amd64
                      beta.kubernetes.io/os=linux
                      kubernetes.io/arch=amd64
                      kubernetes.io/hostname=minikube
                      kubernetes.io/os=linux
                      node-role.kubernetes.io/master=
Annotations:          kubeadm.alpha.kubernetes.io/cri-socket: /var/run/dockershim.sock
                      node.alpha.kubernetes.io/ttl: 0
                      volumes.kubernetes.io/controller-managed-attach-detach: true
```

```
As you can see, the label that we want,
`data-center=sydney`, does not exist.
```

9. Now, let's apply the desired label to our node using this command:

```
kubectl label node minikube data-center=sydney
```

You will see the following response indicating that the node was labeled:

```
node/minikube labeled
```

10. Verify whether the label is applied to the node using the `describe` command:

```
kubectl describe node minikube
```

You should see the following response:

```
Name:               minikube
Roles:              master
Labels:             beta.kubernetes.io/arch=amd64
                    beta.kubernetes.io/os=linux
                    data-center=sydney
                    kubernetes.io/arch=amd64
                    kubernetes.io/hostname=minikube
                    kubernetes.io/os=linux
                    node-role.kubernetes.io/master=
```

```
As you can see in this image, our label has now been applied.
```

11. Now try to run the Pod again and see if it can be executed:

```
kubectl create -f pod-with-node-affinity.yaml -n schedulerdemo
```

You should see the following response:

```
pod/pod-with-node-affinity created
```

12. Now, let's check whether the Pod is successfully running:

```
kubectl get pods -n schedulerdemo
```

You should see the following response:

```
NAME                        READY    STATUS     RESTARTS    AGE
pod-with-node-affinity      1/1      Running    0           5m22s
```

Thus, our Pod is successfully running.

13. Let's check out how Pod scheduling is displayed in `events`:

```
kubectl get events -n schedulerdemo
```

You will get the following response:

```
LAST SEEN   TYPE      REASON             OBJECT                       MESSAGE
<unknown>   Warning   FailedScheduling   pod/pod-with-node-affinity   0/1 nodes are availabl
e: 1 node(s) didn't match node selector.
<unknown>   Warning   FailedScheduling   pod/pod-with-node-affinity   0/1 nodes are availabl
e: 1 node(s) didn't match node selector.
<unknown>   Warning   FailedScheduling   pod/pod-with-node-affinity   skip schedule deleting
 pod: schedulerdemo/pod-with-node-affinity
<unknown>   Normal    Scheduled          pod/pod-with-node-affinity   Successfully assigned
schedulerdemo/pod-with-node-affinity to minikube
16s         Normal    Pulling            pod/pod-with-node-affinity   Pulling image "k8s.gcr
.io/busybox"
16s         Normal    Pulled             pod/pod-with-node-affinity   Successfully pulled im
age "k8s.gcr.io/busybox"
16s         Normal    Created            pod/pod-with-node-affinity   Created container pod-
with-node-affinity-container
15s         Normal    Started            pod/pod-with-node-affinity   Started container pod-
with-node-affinity-container
```

```
As you can see in the preceding output, the Pod has been
successfully scheduled.
```

14. Now, let's do some housekeeping to avoid conflicts with further exercises and activities. Delete the Pod using this command:

```
kubectl delete pod pod-with-node-affinity -n schedulerdemo
```

You should see the following response:

```
pod "pod-with-node-affinity" deleted
```

15. Remove the label from the node using the following command:

```
kubectl label node minikube data-center-
```

Note that the syntax for deleting the label from the Pod has an additional hyphen (`-`) after the label name. You should see the following response:

```
node/minikube labeled
```

In this exercise, we have seen how node affinity works by labeling a node and then scheduling a Pod on the labeled node. We have also seen how Kubernetes events can be used to see the status of Pod scheduling.

The `data-center=sydney` label that we used in this exercise also hints at an interesting use case. We can use node affinity and anti-affinity rules to target not just a specific Pod, but also specific server racks or data centers. We would simply assign specific labels to all nodes in a specific server rack, data center, availability zone, and so on. Then, we can simply pick and choose the desired targets for our Pods.

Pod Affinity and Anti-Affinity

Pod affinity and Pod anti-affinity allow your Pods to check what other Pods are running on a given node before they are scheduled on that node. Note that other Pods in this context do not mean a new copy of the same Pod, but Pods related to different workloads.

Pod affinity allows you to control on which node your Pod is eligible to be scheduled based on the labels of the other Pods that are already running on that node. The idea is to cater to the need to place two different types of containers relative to each other at the same place or to keep them apart.

Consider that your application has two components: a frontend part (for example, a GUI) and a backend (for example, an API). Let's assume that you want to run them on the same host because the communications between frontend and backend Pods would be faster if they are hosted on the same node. By default, on a multi-node cluster (not Minikube), the Scheduler will schedule such Pods on different nodes. Pod affinity provides a way to control the scheduling of Pods relative to each other so that we can ensure the optimal performance of our application.

There are two components that are required to define Pod affinity. The first component defines how the scheduler will relate the target Pod (in our previous example, the frontend Pod) to the already running Pods (the backend Pod). This is done through labels on the Pod. In the Pod affinity rules, we mention which labels of the other Pods should be used to relate to the new Pod. Label selectors have similar operators, as described in the Node Affinity and Anti-Affinity section, for matching the labels of the Pods.

The second component describes where you want to run the target Pods. Just as we have seen in the previous exercise, we can use Pod affinity rules to schedule a Pod on the same node as the other Pod (in our example, we are assuming that the backend Pod is the other Pod that is already running), any node on the same rack as the other Pod, any node on the same data center as the other Pod, and so on. This component defines the set of nodes where the Pods can be allocated. To achieve this, we label our group of nodes and define this label as `topologyKey` in the Pod specification. For example, if we use the hostname as the value for `topologyKey`, the Pods will be placed on the same node.

If we label our nodes with the rack name on which they are hosted and define the rack name as `topologyKey`, then the candidate Pods will be scheduled for one of the nodes with the same rack name label.

Similar to the node affinity rules defined in the previous section, there are hard and soft Pod affinity rules as well. Hard rules are defined with `requiredDuringSchedulingIgnoredDuringExecution` while soft rules are defined with `preferredDuringSchedulingIgnoredDuringExecution`. It is possible to have multiple combinations of hard and soft rules in the Pod affinity configuration.

Exercise 17.02: Running Pods with Pod Affinity

In this exercise, we will see how Pod affinity can help the Scheduler to see the relationships between different Pods and assign them to suitable nodes. We will place Pods using the `preferred` option. In a later part of this exercise, we will configure the Pod anti-affinity using the `required` option and see that that Pod will not be scheduled until all the criteria are met. We will use the same example of frontend and backend Pods that we mentioned earlier:

1. We need to create and run the backend Pod first. Create a file named `pod-with-pod-affinity-first.yaml` with the following contents:

   ```
   apiVersion: v1
   kind: Pod
   metadata:
     name: pod-with-pod-affinity
     labels:
        application-name: banking-app
   spec:
     containers:
       - name: pod-with-node-pod-container
         image: k8s.gcr.io/busybox
         command: [ "/bin/sh", "-c", "while :; do echo 'this is         backend
   pod'; sleep 5 ; done" ]
   ```

   This Pod is a simple Pod with just a loop printing a message. Notice that we have assigned a label to the Pod so that it can be related to the frontend pod.

2. Let's create the Pod defined in the previous step:

   ```
   kubectl create -f pod-with-pod-affinity-first.yaml -n schedulerdemo
   ```

   You should see the following response:

   ```
   pod/pod-with-pod-affinity created
   ```

3. Now, let's see if the Pod has been successfully created:

   ```
   kubectl get pods -n schedulerdemo
   ```

   You should see a response like this:

   ```
   NAME                     READY    STATUS     RESTARTS    AGE
   pod-with-pod-affinity    1/1      Running    0           22s
   ```

4. Now, let's check the labels on the `minikube` node:

   ```
   kubectl describe node minikube
   ```

   You should see the following response:

   ```
   Name:                 minikube
   Roles:                master
   Labels:               beta.kubernetes.io/arch=amd64
                         beta.kubernetes.io/os=linux
                         kubernetes.io/arch=amd64
                         kubernetes.io/hostname=minikube
                         kubernetes.io/os=linux
                         node-role.kubernetes.io/master=
   ```

```
Since we want to run both the Pods on the same host, we can use the
`kubernetes.io/hostname` label of the node.
```

5. Now, let's define the second Pod. Create a file named `pod-with-pod-affinity-second.yaml` with the following contents:

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-with-pod-affinity-fe
  labels:
     application-name: banking-app
spec:
  affinity:
   podAffinity:
     preferredDuringSchedulingIgnoredDuringExecution:
     - weight: 100
       podAffinityTerm:
         labelSelector:
           matchExpressions:
           - key: application-name
             operator: In
             values:
             - banking-app
         topologyKey: kubernetes.io/hostname
  containers:
    - name: pod-with-node-pod-container-fe
      image: k8s.gcr.io/busybox
      command: [ "/bin/sh", "-c", "while :; do echo 'this is         frontend
pod'; sleep 5 ; done" ]
```

Consider this Pod as the frontend application. Notice that we have defined a `preferredDuringSchedulingIgnoredDuringExecution` rule in the `podAffinity` section. We have also defined the `labels` and the `topologyKey` for the Pods and the nodes.

6. Let's create the Pod defined in the previous step:

```
kubectl create -f pod-with-pod-affinity-second.yaml -n schedulerdemo
```

You should see the following response:

```
pod/pod-with-pod-affinity-fe created
```

7. Verify the status of the Pods using the `get` command:

```
kubectl get pods -n schedulerdemo
```

You should see the following response:

```
NAME                         READY    STATUS    RESTARTS   AGE
pod-with-pod-affinity        1/1      Running   0          7m33s
pod-with-pod-affinity-fe     1/1      Running   0          21s
```

As you can see, the `pod-with-pod-affinity-fe` Pod is running. This is not much different than the normal Pod placement. This is because we have only one node in the Minikube environment and we have defined the Pod affinity using `preferredDuringSchedulingIgnoredDuringExecution`, which is the soft variation of the matching criteria.

The next steps of this exercise will talk about anti-affinity using `requiredDuringSchedulingIgnoredDuringExecution` or the hard variation of the matching criteria, and you will see that the Pod does not reach the `Running` state.

8. First, let's delete the `pod-with-pod-affinity-fe` Pod:

```
kubectl delete pod pod-with-pod-affinity-fe -n schedulerdemo
```

You should see the following response:

```
pod "pod-with-pod-affinity-fe" deleted
```

9. Confirm that the Pod has been deleted by listing all the Pods:

```
kubectl get pods -n schedulerdemo
```

You should see the following response:

```
NAME                     READY    STATUS     RESTARTS   AGE
pod-with-pod-affinity    1/1      Running    0          10m
```

10. Now create another Pod definition with the following contents and save it as `pod-with-pod-anti-affinity-second.yaml`:

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-with-pod-anti-affinity-fe
  labels:
     application-name: backing-app
spec:
  affinity:
   podAntiAffinity:
     requiredDuringSchedulingIgnoredDuringExecution:
     - labelSelector:
         matchExpressions:
         - key: application-name
           operator: In
           values:
           - banking-app
       topologyKey: kubernetes.io/hostname
  containers:
    - name: pod-with-node-pod-anti-container-fe
      image: k8s.gcr.io/busybox
      command: [ "/bin/sh", "-c", "while :; do echo 'this is         frontend
pod'; sleep 5 ; done" ]
```

As you can see, the configuration is for `podAntiAffinity` and it uses the `requiredDuringSchedulingIgnoredDuringExecution` option, which is the hard variation of Pod affinity rules. Here, the Scheduler will not schedule any Pod if the condition is not met. We are using the `In` operator so that our Pod will not run on the same host as any Pod with the parameters defined in the `labelSelector` component of the configuration.

11. Try creating the Pod with the preceding specification:

```
kubectl create -f pod-with-pod-anti-affinity-second.yaml -n schedulerdemo
```

You should see the following response:

```
pod/pod-with-pod-anti-affinity-fe created
```

12. Now, check the status of this Pod:

```
kubectl get pods -n schedulerdemo
```

You should see the following response:

```
NAME                             READY  STATUS    RESTARTS   AGE
pod-with-pod-affinity            1/1    Running   0          14m
pod-with-pod-anti-affinity-fe    1/1    Pending   0          3s
```

From this output, you can see the Pod is in the `Pending` state.

13. You can verify that the Pod is not being scheduled because of Pod anti-affinity by checking events:

```
kubectl get events -n schedulerdemo
```

You should see the following response:

```
<unknown>   Warning   FailedScheduling   pod/pod-with-pod-anti-affinity-fe   0/1 nodes are a
vailable: 1 node(s) didn't match pod affinity/anti-affinity, 1 node(s) didn't match pod anti
-affinity rules.
```

In this exercise, we have seen how Pod affinity can help place two different Pods on the same node. We have also seen how Pod anti-affinity options can help us schedule the Pods on different sets of hosts.

Pod Priority

Kubernetes allows you to associate a priority with a Pod. If there are resource constraints, if a new Pod with high priority is requested to be scheduled, the Kubernetes scheduler may evict the Pods with lower priority in order to make room for the new high-priority Pod.

Consider an example where you are a cluster administrator and you run both critical and non-critical workloads in the cluster. An example is a Kubernetes cluster for a bank. In this case, you would have a payment service as well as the bank's website. You may decide that processing payments are of higher importance than running the website. By configuring Pod priority, you can prevent lower-priority workloads from impacting critical workloads in your cluster, especially in cases where the cluster starts to reach its resource capacity. This technique of evicting lower-priority Pods to schedule more critical Pods could be faster than adding additional nodes and would help you better manage traffic spikes on the cluster.

The way we associate a priority with a Pod is to define an object known as `PriorityClass`. This object holds the priority, which is defined as a number between 1 and 1 billion. The higher the number, the higher the priority. Once we have defined our priority classes, we assign a priority to a Pod by associating a `PriorityClass` with the Pod. By default, if there is no priority class associated with the Pod, the Pod either gets assigned the default priority class if it is available, or it gets assigned the priority value of 0.

You can get the list of priority classes similarly to any other objects:

```
kubectl get priorityclasses
```

You should see a response like this:

```
NAME                      VALUE        GLOBAL-DEFAULT   AGE
system-cluster-critical   2000000000   false            9d
system-node-critical      2000001000   false            9d
```

Note that in Minikube, there are two priority classes predefined in the environment. Let's learn more about the `system-cluster-critical` class. Issue the following command to get the details about it:

```
kubectl get pc system-cluster-critical -o yaml
```

You should see the following response:

```
apiVersion: scheduling.k8s.io/v1
description: Used for system critical pods that must run in the cluster, but can be
  moved to another node if necessary.
kind: PriorityClass
metadata:
  creationTimestamp: "2019-10-01T07:46:47Z"
  generation: 1
  name: system-cluster-critical
  resourceVersion: "42"
  selfLink: /apis/scheduling.k8s.io/v1/priorityclasses/system-cluster-critical
  uid: 9f0701d3-e41f-11e9-b737-000c2917147b
value: 2000000000
```

The output here mentions that this class is reserved for the Pods that are absolutely critical for the cluster. etcd is one such Pod. Let's see if this priority class is associated with it.

Issue the following command to get details about the etcd Pod running in Minikube:

```
kubectl get pod etcd-minikube -n kube-system -o yaml
```

You should see the following response:

```
dnsPolicy: ClusterFirst
enableServiceLinks: true
hostNetwork: true
nodeName: minikube
priority: 2000000000
priorityClassName: system-cluster-critical
restartPolicy: Always
schedulerName: default-scheduler
securityContext: {}
terminationGracePeriodSeconds: 30
```

You can see from this output that the Pod has been associated with the `system-cluster-critical` priority.

In the following exercise, we will add a default priority class and a higher-priority class to better understand the behavior of the Kubernetes scheduler.

It is important to understand that Pod priority works in coordination with other rules, such as Pod affinity. If the Scheduler determines that a high-priority Pod cannot be scheduled even if lower-priority Pods are evicted, it will not evict lower-priority Pods.

Similarly, if high-priority and low-priority Pods are waiting to be scheduled and the scheduler determines that high-priority Pods cannot be scheduled due to affinity or anti-affinity rules, the scheduler will schedule the suitable low-priority Pods.

Exercise 17.03: Pod Priority and Preemption

In this exercise, we shall define two priority classes: default (low priority) and high priority. We will then create 10 Pods with default priority and allocate some CPU and memory to each Pod. After this, we will check how much capacity is being used from our local cluster. We will then create 10 more Pods with high priority and allocate resources to them. We will see that the Pods with the default priority will be terminated and the higher-priority Pods will be scheduled on the cluster. We will then reduce the number of high-priority Pods from 10 to 5 and then see that some of the low-priority Pods are being scheduled again. This is because reducing the number of high-priority Pods should free up some resources:

1. First, let's create the definition for the default priority class. Create a file named `priority-class-default.yaml` with the following contents:

   ```
   apiVersion: scheduling.k8s.io/v1
   kind: PriorityClass
   metadata:
     name: default-priority
   value: 1
   globalDefault: true
   description: "Default Priority class."
   ```

   Note that we have marked this priority class as default by setting the value of `globalDefault` as `true`. Also, the priority number, `1`, is very low.

2. Create this priority class using the following command:

   ```
   kubectl create -f priority-class-default.yaml
   ```

You should see the following response:

```
priorityclass.scheduling.k8s.io/default-priority
```

Note that we have not mentioned the namespace as this object is not a namespace-level object. A priority class is a cluster scope object in Kubernetes.

3. Let's check whether our priority class has been created:

```
kubectl get priorityclasses
```

You should see the following list:

```
NAME                      VALUE        GLOBAL-DEFAULT   AGE
default-priority          1            true             5m46s
system-cluster-critical   2000000000   false            105d
system-node-critical      2000001000   false            105d
```

In this output, you can see the priority class that we just created under the name `default-priority`, and it is the global default as you can see in the `GLOBAL-DEFAULT` column. Now create another priority class with higher priority.

4. Create a file named `priority-class-highest.yaml` with the following contents:

```
apiVersion: scheduling.k8s.io/v1
kind: PriorityClass
metadata:
  name: highest-priority
value: 100000
globalDefault: false
description: "This priority class should be used for pods with   the highest of
priority."
```

Note the very high value of the `value` field in this object.

5. Use the definition from the previous step to create a Pod priority class using the following command:

```
kubectl create -f priority-class-highest.yaml
```

You should see the following response:

```
priorityclass.scheduling.k8s.io/highest-priority created
```

6. Now let's create a definition for a Deployment with `10` Pods and a default priority. Create a file named `pod-with-default-priority.yaml` using the following contents to define our Deployment:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pod-default-priority-deployment
spec:
  replicas: 10
  selector:
    matchLabels:
```

```
      app: priority-test

  template:
    metadata:
      labels:
        app: priority-test
    spec:
      containers:
      - name: pod-default-priority-deployment-container
        image: k8s.gcr.io/busybox
        command: [ "/bin/sh", "-c", "while :; do echo 'this is
backend pod'; sleep 5 ; done" ]
      priorityClassName: default-priority
```

7. Let's create the Deployment that we defined in the previous step:

```
kubectl create -f pod-with-default-priority.yaml -n schedulerdemo
```

You should see this response:

```
deployment.apps/pod-default-priority-deployment created
```

8. Now, increase the memory and CPU allocated to each of them to 128 MiB and 1/10 of the CPU by using the following commands:

```
kubectl set resources deployment/pod-default-priority-deployment --
limits=cpu=100m,memory=128Mi -n schedulerdemo
```

You should see the following response:

```
deployment.extensions/pod-default-priority-deployment resource requirements
updated
```

Note

You may need to adjust this resource allocation as per the resources available on your computer. You can start with 1/10 CPU and verify the resources as mentioned in *step 10*.

9. Verify that the Pods are running using the following command:

```
kubectl get pods -n schedulerdemo
```

You should see the following list of Pods:

```
NAME                                                READY   STATUS    RESTAR
TS   AGE
pod-default-priority-deployment-57c965b8cd-4z944   1/1     Running   0
     3m9s
pod-default-priority-deployment-57c965b8cd-6k4gf   1/1     Running   0
     3m4s
pod-default-priority-deployment-57c965b8cd-c7tg4   1/1     Running   0
     3m34s
pod-default-priority-deployment-57c965b8cd-gk8kv   1/1     Running   0
     3m34s
pod-default-priority-deployment-57c965b8cd-gwm9k   1/1     Running   0
     3m34s
pod-default-priority-deployment-57c965b8cd-hsn9r   1/1     Running   0
     3m34s
pod-default-priority-deployment-57c965b8cd-j5jxm   1/1     Running   0
     3m34s
pod-default-priority-deployment-57c965b8cd-q2cnw   1/1     Running   0
     3m11s
pod-default-priority-deployment-57c965b8cd-qcjnv   1/1     Running   0
     3m6s
pod-default-priority-deployment-57c965b8cd-zjhjd   1/1     Running   0
     3m3s
```

10. Check the resource usage in our cluster. Note that we have only one node, and thus we can easily see the values by issuing the `describe` command:

    ```
    kubectl describe node minikube
    ```

    The following screenshot is truncated for a better presentation. Find the `Allocated resources` section in your output:

    ```
    Allocated resources:
      (Total limits may be over 100 percent, i.e., overcommitted.)
      Resource           Requests      Limits
      --------           --------      ------
      cpu                1555m (77%)   800m (40%)
      memory             1214Mi (64%)  1364Mi (72%)
      ephemeral-storage  0 (0%)        0 (0%)
    ```

    Note that CPU usage is at 77% and memory at 64% for the `minikube` host. Please note that the resource utilization is dependent on the hardware of your computer and the resources allocated to Minikube. If your CPU is too powerful or if you have a huge amount of memory (or even if you have a slower CPU and less memory), you may see resource utilization values vastly different from what we see here. Please adjust the CPU and memory resources as mentioned in *step 8* so that we get similar resource utilization as we see here. This will enable you to see a similar result to the one we have demonstrated in the following steps of this exercise.

11. Now let's schedule Pods with high priority. Create 10 Pods using the Kubernetes Deployment object. For this, create a file named `pod-with-high-priority.yaml` with the following contents:

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: pod-highest-priority-deployment
spec:
  replicas: 10
  selector:
    matchLabels:
      app: priority-test

  template:
    metadata:
      labels:
        app: priority-test
    spec:
      containers:
      - name: pod-highest-priority-deployment-container
        image: k8s.gcr.io/busybox
        command: [ "/bin/sh", "-c", "while :; do echo 'this is 
backend pod'; sleep 5 ; done" ]
      priorityClassName: highest-priority
```

Note that `priorityClassName` has been set to the `highest-priority` class in the preceding specification.

12. Now create the Deployment that we created in the previous step:

```
kubectl create -f pod-with-high-priority.yaml -n schedulerdemo
```

You should get the following output:

```
deployment.apps/pod-with-highest-priority-deployment created
```

13. Allocate a similar amount of CPU and memory to these Pods as you did for the Pods with default priority:

```
kubectl set resources deployment/pod-highest-priority-deployment --
limits=cpu=100m,memory=128Mi -n schedulerdemo
```

You should see the following response:

```
deployment.apps/pod-highest-priority-deployment resource requirements updated
```

14. After a minute or so, run the following command to see which Pods are running:

```
kubectl get pods -n schedulerdemo
```

You should see a response similar to this:

```
NAME                                              READY   STATUS    RESTARTS   AGE
pod-default-priority-deployment-57c965b8cd-2qlvp   0/1     Pending   0          2m30s
pod-default-priority-deployment-57c965b8cd-6f6f2   0/1     Pending   0          2m25s
pod-default-priority-deployment-57c965b8cd-bssnv   0/1     Pending   0          2m30s
pod-default-priority-deployment-57c965b8cd-bx85k   0/1     Pending   0          104s
pod-default-priority-deployment-57c965b8cd-dbsd8   0/1     Pending   0          2m30s
pod-default-priority-deployment-57c965b8cd-hz7qj   0/1     Pending   0          2m31s
pod-default-priority-deployment-57c965b8cd-ng22k   0/1     Pending   0          2m27s
pod-default-priority-deployment-57c965b8cd-qcjnv   1/1     Running   0          7m51s
pod-default-priority-deployment-57c965b8cd-tzqsq   0/1     Pending   0          102s
pod-default-priority-deployment-57c965b8cd-zjhjd   1/1     Running   0          7m48s
pod-highest-priority-deployment-6df898d4c4-2jk8p   1/1     Running   0          2m31s
pod-highest-priority-deployment-6df898d4c4-cjc8r   1/1     Running   0          102s
pod-highest-priority-deployment-6df898d4c4-gc4tr   1/1     Running   0          2m31s
pod-highest-priority-deployment-6df898d4c4-gmh2j   1/1     Running   0          2m31s
pod-highest-priority-deployment-6df898d4c4-hdpr4   1/1     Running   0          104s
pod-highest-priority-deployment-6df898d4c4-jmnjb   1/1     Running   0          2m31s
pod-highest-priority-deployment-6df898d4c4-l2nsz   1/1     Running   0          2m25s
pod-highest-priority-deployment-6df898d4c4-mhq2x   1/1     Running   0          2m27s
pod-highest-priority-deployment-6df898d4c4-qmj5w   1/1     Running   0          105s
pod-highest-priority-deployment-6df898d4c4-wm6rs   1/1     Running   0          2m31s
```

```
You can see that most of our high-priority Pods are in the
`Running` state and the Pods with low-priority Pods are
moved to the `Pending` state. This tells us the Kubernetes
Scheduler has actually terminated the lower-priority Pods, and it is
now waiting for the resources to be available to schedule them
again.
```

15. Try changing the number of high-priority Pods from 10 to 5 and see if additional low-priority Pods can be scheduled. Change the number of replicas using this command:

    ```
    kubectl scale deployment/pod-highest-priority-deployment --replicas=5 -n
    schedulerdemo
    ```

    You should see the following response:

    ```
    deployment.extensions/pod-highest-priority-deployment scaled
    ```

16. Verify that high-priority Pods are reduced from 10 to 5 using the following command:

    ```
    kubectl get pods -n schedulerdemo
    ```

```
NAME                                              READY   STATUS    RESTARTS   AGE
pod-default-priority-deployment-57c965b8cd-2qlvp  1/1     Running   0          8m23s
pod-default-priority-deployment-57c965b8cd-6f6f2  0/1     Pending   0          8m18s
pod-default-priority-deployment-57c965b8cd-bssnv  1/1     Running   0          8m23s
pod-default-priority-deployment-57c965b8cd-bx85k  0/1     Pending   0          7m37s
pod-default-priority-deployment-57c965b8cd-dbsd8  1/1     Running   0          8m23s
pod-default-priority-deployment-57c965b8cd-hz7qj  0/1     Pending   0          8m24s
pod-default-priority-deployment-57c965b8cd-ng22k  1/1     Running   0          8m20s
pod-default-priority-deployment-57c965b8cd-qcjnv  1/1     Running   0          13m
pod-default-priority-deployment-57c965b8cd-tzqsq  1/1     Running   0          7m35s
pod-default-priority-deployment-57c965b8cd-zjhjd  1/1     Running   0          13m
pod-highest-priority-deployment-6df898d4c4-gc4tr  1/1     Running   0          8m24s
pod-highest-priority-deployment-6df898d4c4-gmh2j  1/1     Running   0          8m24s
pod-highest-priority-deployment-6df898d4c4-jmnjb  1/1     Running   0          8m24s
pod-highest-priority-deployment-6df898d4c4-l2nsz  1/1     Running   0          8m18s
pod-highest-priority-deployment-6df898d4c4-wm6rs  1/1     Running   0          8m24s
```

As you can see in this screenshot, some more low-priority Pods changed from the `Pending` state to the `Running` state. Thus, we can see that the Scheduler is working to make optimal use of the available resources based on the priority of workloads.

In this exercise, we have used the Pod priority rules and seen how the Kubernetes Scheduler may choose to terminate the Pods with a lower priority if there are requests for a Pod with a higher priority to be fulfilled.

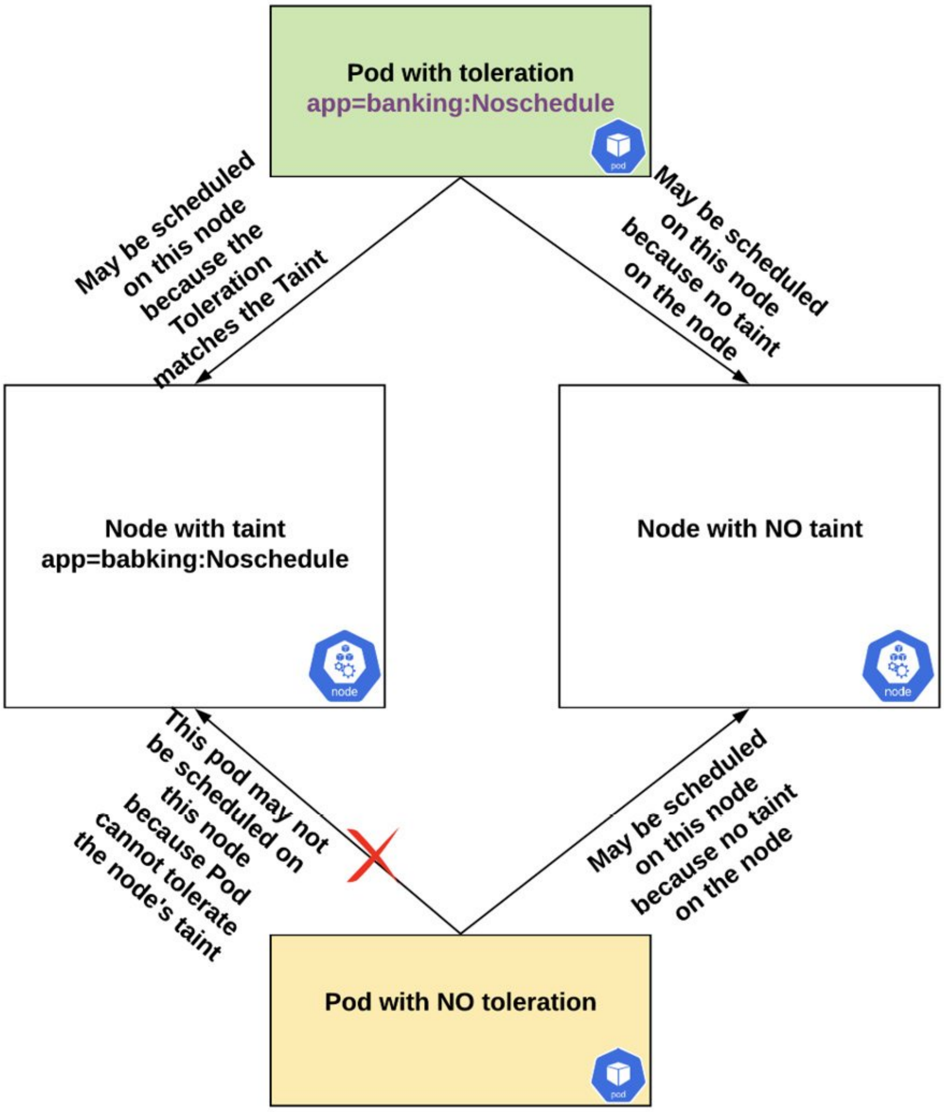
Taints and Tolerations

Previously, we have seen how Pods can be configured to control which node they run on. Now we will see how nodes can control which Pods can run on them using taints and tolerations.

A taint prevents the scheduling of a pod unless that Pod has a matching toleration for the Pod. Think of taint as an attribute of a node and a toleration is an attribute of a Pod. The Pod will get scheduled on the node only if the Pod's toleration matches the node's taint. The taints on a node tell the scheduler to check which Pods tolerate the taint and run only those Pods that match their toleration with the node's taint.

A taint definition contains the key, value, and effect. The key and value will match the Pod toleration definition in the Pod specification, while the effect instructs the scheduler what should be done once the node's taint matches the Pod's toleration.

The following diagram provides an overview of how the process of controlling scheduling based on taints and tolerations works. Notice that a Pod with toleration can also be scheduled on a node with no taint.



When we define a taint, we also need to specify the behavior of the taint. This can be specified by the following values:

- `NoSchedule` provides the ability to reject the scheduling of new Pods on the node. Existing Pods that were scheduled before the taint was defined will continue to run on the node.
- `NoExecute` taint provides the ability to resist new Pods that do not have a toleration that matches the taint. It further checks whether all the existing Pods running on the node match this taint, and removes the ones that don't.
- `PreferNoSchedule` instructs the scheduler to avoid scheduling Pods that do not tolerate the taint on the node. This is a soft rule, where the scheduler will try to find the right node but it will still schedule the Pods on the node if it cannot find any other node that is appropriate as per the defined taint and toleration rules.

In order to apply a taint to a node, we can use the `kubectl taint` command as follows:

```
kubectl taint nodes <NODE_NAME> <TAINT>:<TAINT_TYPE>
```

There can be many reasons why you would want certain Pods (applications) not to be run on specific nodes. An example use case could be the requirement of specialized hardware, such as a GPU for machine learning applications. Another case could be when a license restriction for software on the Pod dictates that it needs to run on specific nodes. For example, out of 10 worker nodes in your cluster, only 2 nodes are allowed to run particular software. Using the taints and tolerations combination, you can help the scheduler to schedule Pods on the right node.

Exercise 17.04: Taints and Tolerations

In this exercise, we will see how taints and tolerations can allow us to schedule Pods on the nodes we desire. We will define a taint and try to schedule a Pod on the node. We then showcase the `NoExecute` functionality in which a Pod can be removed from a node if that taint on the node changes:

1. Get the list of nodes using the following command:

   ```
   kubectl get nodes
   ```

   You should see the following list of nodes:

   ```
   NAME       STATUS   ROLES    AGE   VERSION
   minikube   Ready    master   44h   v1.14.3
   ```

   Recall that in our Minikube environment, we have only one node.

2. Create a taint for the `minikube` node using the following command:

   ```
   kubectl taint nodes minikube app=banking:NoSchedule
   ```

   You should see the following response:

   ```
   node/minikube tainted
   ```

3. Verify that the node has been tainted correctly. You can use the `describe` command to see what taints are applied to the node:

   ```
   kubectl describe node minikube
   ```

   You should see the following response:

   ```
   Name:               minikube
   Roles:              master
   Labels:             beta.kubernetes.io/arch=amd64
                       beta.kubernetes.io/os=linux
                       kubernetes.io/arch=amd64
                       kubernetes.io/hostname=minikube
                       kubernetes.io/os=linux
                       node-role.kubernetes.io/master=
   Annotations:        kubeadm.alpha.kubernetes.io/cri-socket: /var/run/dockershim.sock
                       node.alpha.kubernetes.io/ttl: 0
                       volumes.kubernetes.io/controller-managed-attach-detach: true
   CreationTimestamp:  Tue, 01 Oct 2019 17:46:46 +1000
   Taints:             app=banking:NoSchedule
   ```

4. Now we need to create a Pod with toleration defined as per the taint. Create a file named `pod-toleration-noschedule.yaml` with the following contents:

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-with-node-toleration-noschedule
spec:
  tolerations:
  - key: "app"
    operator: "Equal"
    value: "banking"
    effect: "NoSchedule"
  containers:
    - name: pod-with-node-toleration-noschedule-container
      image: k8s.gcr.io/busybox
      command: [ "/bin/sh", "-c", "while :; do echo '.'; sleep         5 ;
done" ]
```

   Notice that the toleration value is the same as the taint defined in *step 1*, that is, `app=banking`. The `effect` attribute controls the type of toleration behavior. Here, we have defined `effect` as `NoSchedule`.

5. Let's create the Pod as per the preceding specification:

```
kubectl create -f pod-toleration-noschedule.yaml -n schedulerdemo
```

   This should give the following response:

```
pod/pod-with-node-toleration-noschedule created
```

6. Verify that the Pod is running using the following command:

```
kubectl get pods -n schedulerdemo
```

   You should see the following response:

```
NAME                                  READY   STATUS    RESTARTS   AGE
pod-with-node-toleration-noschedule   1/1     Running   0          2m2s
```

7. Now let's define a different Pod with a toleration that does not match the taint on the node. Create a file named `pod-toleration-noschedule2.yaml` with the following contents:

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-with-node-toleration-noschedule2
spec:
  tolerations:
  - key: "app"
    operator: "Equal"
```

```
    value: "hr"
    effect: "NoSchedule"
  containers:
    - name: pod-with-node-toleration-noschedule-container2
      image: k8s.gcr.io/busybox
      command: [ "/bin/sh", "-c", "while :; do echo '.'; sleep         5 ;
done" ]
```

Notice that here we have the toleration set to `app=hr`. We need a Pod with the same taint to match this toleration. Since we have tainted our node with `app=banking`, this Pod should not be scheduled by the scheduler. Let's try this in the following steps.

8. Create the Pod using the definition from the previous step:

```
kubectl create -f pod-toleration-noschedule2.yaml -n schedulerdemo
```

This should give the following response:

```
pod/pod-with-node-toleration-noschedule2 created
```

9. Check the status of the Pod using the following command:

```
kubectl get pods -n schedulerdemo
```

You should see this response:

```
NAME                                   READY   STATUS    RESTARTS   AGE
pod-with-node-toleration-noschedule    1/1     Running   0          5m7s
pod-with-node-toleration-noschedule2   0/1     Pending   0          20s
```

```
You can see that Pod is in the `Pending` state and not in
the `Running` state.
```

10. In the remaining part of this exercise, we shall see how the `NoExecute` effect instructs the scheduler to even remove Pods after they have been scheduled to the node. Before that, we need to do some cleanup. Delete both Pods using the following command:

```
kubectl delete pod pod-with-node-toleration-noschedule pod-with-node-
toleration-noschedule2 -n schedulerdemo
```

You should see the following response:

```
pod "pod-with-node-toleration-noschedule" deleted
pod "pod-with-node-toleration-noschedule2" deleted
```

11. Let's remove the taint from the node using the following command:

```
kubectl taint nodes minikube app:NoSchedule-
```

Note the hyphen (`-`) at the end of the command, which tells Kubernetes to remove this label. You should see the following response:

```
node/minikube untainted
```

Our node is in the state where there is no taint defined. Now, we want to run a Pod first with the toleration as `app=banking` and allocate the Pod. Once the Pod is in the `Running` state, we will remove the taint from the node and see whether the Pod has been removed.

12. Now, taint the node again with the `NoExecute` type as follows:

```
kubectl taint nodes minikube app=banking:NoExecute
```

You should see the following response:

```
node/minikube tainted
```

13. Now, we need to define a Pod with matching toleration. Create a file called `pod-toleration-noexecute.yaml` with the following contents:

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-with-node-toleration-noexecute
spec:
  tolerations:
  - key: "app"
    operator: "Equal"
    value: "banking"
    effect: "NoExecute"
  containers:
    - name: pod-with-node-toleration-noexecute-container
      image: k8s.gcr.io/busybox
      command: [ "/bin/sh", "-c", "while :; do echo '.'; sleep         5 ;
done" ]
```

Note that the `tolerations` section defines the label as `app=banking` and the `effect` as `NoExecute`.

14. Create the Pod that we defined in the previous step using the following command:

```
kubectl create -f pod-toleration-noexecute.yaml -n schedulerdemo
```

You should see the following response:

```
pod/pod-with-node-toleration-noexecute created
```

15. Verify that the Pod is in the `Running` state using the following command:

```
kubectl get pods -n schedulerdemo
```

You should see the following response:

```
NAME                                  READY   STATUS    RESTARTS   AGE
pod-with-node-toleration-noexecute    1/1     Running   0          32s
```

16. Now remove the taint from the node using this command:

    ```
    kubectl taint nodes minikube app:NoExecute-
    ```

    Note the hyphen (`-`) at the end of this command, which tells Kubernetes to remove the taint. You will see the following response:

    ```
    node/minikube untainted
    ```

    As mentioned earlier, Pods with tolerations can be attached to nodes with no taints. After you remove the taint, the Pod will still be executed. Note that we have not deleted the Pod and it is still running.

17. Now, if we add a new taint with `NoExecute` to the node, the Pod should be removed from it. To see this in action, add a new taint that is different than the Pod toleration:

    ```
    kubectl taint nodes minikube app=hr:NoExecute
    ```

    As you can see, we have added the `app=hr` taint to the Pod. You should see the following response:

    ```
    node/minikube tainted
    ```

18. Now, let's check the status of the Pod:

    ```
    kubectl get pods -n schedulerdemo
    ```

    You will see the following response:

    ```
    NAME                                READY   STATUS        RESTARTS   AGE
    pod-with-node-toleration-noexecute  0/1     Terminating   0          2m41s
    ```

The Pod will either be removed or go into the `Terminating` (marked for removal) state. After a few seconds, Kubernetes will remove the Pod.

In this exercise, you have seen how we can configure taints on nodes so that they accept only specific Pods. You have also configured the taint to affect the running Pods.

Using a Custom Kubernetes Scheduler

Building your own fully featured scheduler is out of the scope of this workshop. However, it is important to understand that the Kubernetes platform allows you to write your own scheduler if your use case requires it, although it is not recommended to use a custom scheduler unless you have a very specialized use case.

A custom scheduler runs as a normal Pod. You can specify in the definition of the Pod running your application to use the custom scheduler. You can add a `schedulerName` field in the Pod specification with the name of the custom scheduler as shown in this sample definition:

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-with-custom-scheduler
spec:
```

```
  containers:
    - name: mutating-pod-example-container
      image: k8s.gcr.io/busybox
      command: [ "/bin/sh", "-c", "while :; do echo '.'; sleep 5 ;         done" ]
  schedulerName: "custom-scheduler"
```

For this configuration to work, it is assumed that a custom scheduler called `custom-scheduler` is available in the cluster.

Activity 17.01: Configuring a Kubernetes Scheduler to Schedule Pods

Consider you are the administrator of a Kubernetes cluster and you have the following scenario:

1. There is an API Pod that provides the current currency conversion rate.
2. There is a GUI Pod that displays the conversion rate on a website.
3. There is a Pod that provides services for stock exchanges to get the real-time currency conversion rate.

You have been tasked to make sure that the API and GUI Pods run on the same node. You have also been asked to give higher priority to the real-time currency converter Pod if the traffic spikes. In this activity, you will control the behavior of the Kubernetes Scheduler to complete the activity.

Each of the Pods in this activity should have 0.1 CPU and 100 MiB of memory allocated to it. Note that we have named the Pods API, GUI, and real-time to make things easier. The Pods in this activity are expected to be just printing expressions on the console. You can use the `k8s.gcr.io/busybox` image for all of them.

Note

Before starting this activity, make sure that the nodes are not tainted from the previous exercises. To see how to remove a taint, please see *step 15* of *Exercise 17.01*, *Running a Pod with Node Affinity* in this chapter.

Here are some guidelines for the activity:

1. Create a namespace called `scheduleractivity`.
2. Create the Pod priority for the API Pods.
3. Deploy and make sure that the API and GUI Pods are using Pod affinity to be on the same node. The GUI Pod should define the affinity to be on the same node as the API pod.
4. Scale the replicas of the API and GUI Pod to two each.
5. Create a Pod priority for the real-time currency converter Pod. Make sure that the API Pod priority, defined earlier, is less than the real-time Pod but greater than 0.
6. Deploy and run the real-time currency converter Pod with one replica.
7. Make sure that all Pods are in the `Running` state.
8. Now, increase the number of replicas for the real-time currency converter Pod from 1 to 10.
9. See whether the real-time currency converter Pods are being started and whether the GUI Pods are being evicted. If not, keep on increasing the real-time Pods by a factor of 5.
10. Depending on your resources and the number of Pods, the scheduler may start evicting API Pods.
11. Reduce the number of replicas of the real-time Pod from 10 to 1 and see that the API and GUI Pods are scheduled back on the cluster.

Once you have completed the activity, two Pods each of the API and GUI Pods are expected to be in the `Running` state, along with one real-time Pod as shown in the following screenshot:

```
NAME                            READY   STATUS    RESTARTS   AGE
api-pod-c644d44b8-f5xq2         1/1     Running   0          2m16s
api-pod-c644d44b8-wztg6         1/1     Running   0          2m16s
gui-pod-6c494b5888-54vxp        1/1     Running   0          5m22s
gui-pod-6c494b5888-lzcbh        1/1     Running   0          5m22s
realtime-pod-59d4c8b768-dgnvr   1/1     Running   0          12m
```

Note that your output will vary as per your system resources, and hence, you may not see exactly what you see in this screenshot.

Note

The solution to this activity can be found at the following address: `Activity_Solutions\Solution_Final.pdf`.

Summary

The Kubernetes Scheduler is a powerful software that abstracts the work of selecting the appropriate node for a Pod on a cluster. The Scheduler watches for unscheduled Pods and attempts to find suitable nodes for them. Once it finds a suitable node for a Pod, it updates etcd (via the API server) that the Pod has been bound to the node.

The scheduler has matured with every release of Kubernetes. The default behavior of the scheduler is sufficient for a variety of workloads, although you have also seen many ways to customize the way that the Scheduler associates resources with Pods. You have seen how node affinity can help you schedule Pods on your desired nodes. Pod affinity can help you schedule a Pod relative to another Pod, and it is a good tool for applications where multiple modules are targeted to be placed next to each other. Taints and tolerations can also help you assign specific workloads to specific nodes. You have also seen that Pod priority can help you schedule the workloads as per the total resources available in the cluster.